NAB ENGINEERING HANDBOOK

NAB
ENGINEERING HANDBOOK

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TO THE PROFESSIONAL BROADCAST ENGINEER

Whose adherence to sound engineering principles has created a superb broadcast system in the United States of America

"Its technical future is as limitless as space, its service potential is bounded only by the ingenuity of man, and its economic progress will keep step with that of the country itself."

HAROLD E. FELLOWS
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FOREWORD

Modern engineering has been expanding explosively. This has been evident in all fields, particularly in communication, including broadcast engineering. Cut and try experimentation, so productive in the early period of development, has now been replaced by designs of antennas, transmitters, associated equipment, and interconnections based upon a thorough understanding of the principles involved. During the past two decades, the usable spectrum has been expanded to include a portion of the needs for frequency modulation and television, but these needs have expanded even faster than the available bands. Whenever needs increase faster than resources, advanced engineering must be applied to insure the most adequate service available within the limitations imposed by nature (or man).

In order to serve the wide range of modern technology, engineers must be educated first in fundamentals common to many applications. This is the primary function of the engineering school. But as society demands ever more sophisticated and elaborate systems to meet its needs, each segment of our complex economy must develop means for continuing the education of practicing engineers into the more advanced principles and specialized applications peculiar to that section of industry. I want to congratulate the broadcasting industry on the fact that, through its organization, The National Association of Broadcasters, it is providing a most convenient means for keeping its own practicing engineers abreast of the latest developments by the publication of this new edition of the NAB Engineering Handbook. The several sections have been written by outstanding authoritative leaders in each appropriate field. It should go far toward insuring that the best engineering practices are put into effect throughout the industry.

I know of no other group where cooperation in the technical field has been more general. Note, for example, the series of cooperative studies through the National Television Standards Committees and the Television Allocation Study Organization. It is a record of which the industry should be proud. This handbook is another milestone in technical cooperation and in the literature of its field.

W. L. Everitt
Dean of Engineering
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PREFACE

The previous editions of the NAB Engineering Handbook highlighted various aspects of broadcast engineering which were of pressing need at the time without attempting to deal with the entire broadcast system. During the period subsequent to World War II, technical developments in broadcasting proceeded at a tremendous pace, particularly in television. While there is a wealth of broadcast technical information available, it is usually difficult for the average broadcast engineer to know where to find it when he needs it.

The fundamental purpose of this Handbook is to present in one volume a logical treatment of the broadcast system, both radio and television, stressing the practical aspect and the type of information that often is passed along from person to person with no concrete basis for evaluation. In addition, there is great need for authoritative information on the application of more recently developed methods and techniques. Much of the basis for the contents of this Handbook was provided by seven years of correspondence with broadcast engineers relative to their problems in the field. Although theory and mathematics have been included where necessary, the practical, operational aspects have received greatest attention. Theoretical treatment of the various subjects can be found in numerous textbooks readily available. Although this Handbook has been prepared primarily in the interests of the member stations of the National Association of Broadcasters, it will be available to everyone through the publisher. The many peculiar engineering problems encountered in foreign countries have been taken into account insofar as possible, without specifically delineating them.

To obtain maximum uniformity, emphasis, and coherence, the editor submitted an outline of the Handbook to the various contributing authors and suggested the type of treatment which was thought to be of most value to those who would use the material. The plan of the Handbook is based on providing the Rules, Regulations, and Standards applicable to broadcasting, and then dealing with the main parts of the broadcast system. It seems logical to treat with the system beginning with the Antenna, Wave Propagation, and Field-strength Measurements, then proceeding to the Tower Structure, Transmission Lines, Transmitters, Studio-Transmitter Links, Studios and Equipment, Remote Pickup Facilities, Networking Facilities, and Recent Techniques. Obviously, a complete

volume could be written on any one of these topics. Consequently, the treatment was designed to cover the type of problem and situation that is both fundamental in nature and unusual in circumstance. One of the more current mysteries to radio broadcast engineers concerns the directional antenna and its proper understanding, adjustment, and maintenance. This material, particularly, has been completely rewritten to correlate the theoretical aspects with practical operation. Color television has been sufficiently covered to provide an understanding of the system plus certain equipment considerations required in actual broadcast use. It has been paramount throughout this Handbook to avoid the type of information contained in equipment technical manuals.

Any attempt to deal with a broadcast system for both radio and television inevitably omits certain information that some engineers would like to have covered. This was considered and resulted in the conclusion that in order to keep the Handbook to a single volume, certain limitations had to be accepted. It was also impossible to include complete information on certain subjects because of the current status of development and standardization. To those who kindly offered information that could not be included, the editor tenders his regrets. There has been no vigorous scrutiny to avoid duplication, but very little occurs throughout the Handbook. In any manuscript of 3,000 pages and its processing into a Handbook, errors inevitably occur, although every attempt has been made to eliminate them. The editor will appreciate having them called to his attention when noticed.

To all the contributing authors and organizations, the editor extends his sincere thanks and at the same time apologies for often demanding a great deal in a short period of time. Their patience, cooperation, and willingness to prepare their material while performing their regular duties deserves high praise and appreciation.

The editor wishes particularly to express his appreciation and thanks to Mr. George W. Bartlett, Assistant Manager of Engineering, NAB, who has worked diligently during the 36 months of the preparation of this Handbook.

A. Prose Walker

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Section 1

RULES, REGULATIONS, AND STANDARDS

INTRODUCTION TO SECTION 1

The broadcast industry is founded upon certain technical rules, regulations, and standards which form the necessary guides to the establishment of a healthy and prosperous system of broadcasting. Some of these standards are the culmination of much effort on the part of both government and industry and are constantly in a state of modification or revision as the state of the art develops. As new techniques are introduced, standards are reappraised and rewritten to reflect new thinking.

Here are presented certain rules and regulations, government-industry reports, and various standards which have a bearing upon daily operation. The Federal Communications Commission's Rules and Regulations set forth herein are those necessary for the construction and operation of broadcast stations to meet the technical requirements and for operation in the public interest along technical lines not specifically enunciated in the regulations. These Rules are based on the best engineering data available from evidence supplied in formal and informal hearings and extensive surveys conducted in the field. Numerous informal conferences have been held with radio engineers, manufacturers of radio equipment and others for the guidance of the Commission in the formulation of these standards.

While these rules provide for flexibility and set forth the conditions under which they are applicable, it is not expected that material deviation therefrom as to fundamental principles will be recognized unless full information is submitted regarding the reasonableness of such departure and the need therefor.

These rules will necessarily change as progress is made in the art, and accordingly it will be necessary to make revisions from time to time. The Commission will accumulate and analyze engineering data available concerning the progress of the art so that its rules may be kept current with the developments.

Part 1

FCC ADMINISTRATIVE PROCEDURES FOR AM, FM, TV, AND RELATED SERVICES

Any qualified citizen, firm, or group may apply to the Federal Communications Commission for authority to construct a commercial standard (AM), frequency modulation (FM), or television (TV) broadcast station.

Licensing of these facilities is prescribed by the Communications Act of 1934, as amended, which sets up certain basic requirements. In general, applicants must satisfy the Commission that they are legally, technically, and financially qualified, and that operation of the proposed station would serve the public convenience, interest, or necessity. The Communications Act also recognizes broadcasting as a competitive industry and invests the Commission with the responsibility of allocating facilities so as to provide a fair, efficient, and equitable distribution of radio service.

The licensing procedure is detailed in Part 1 of the Commission's "Rules Relating to Practice and Procedure," while station operation is covered by Part 3, "Rules Governing Radio Broadcast Services."

Following is a summary of the consecutive steps required in applying for authorization to build and operate a commercial broadcast station. The application procedure is substantially the same whether the facility sought is for AM, FM, or TV broadcast.

SELECTING A FREQUENCY

Standard (AM) broadcast stations operate on "local," "regional," or "clear" channels. Local stations are of 100 to 1000 watts power and serve smaller communities; stations of 500 watts to 5 kilowatts power cover larger centers of population and surrounding areas; stations of 10 to 50 kilowatt maximum power are for large area coverage, particularly at night. There is no separate classification for AM operation by educational stations.

To determine whether an AM frequency is available for assignment in a particular area, it is necessary for the applicant to have a frequency search made by a competent engineer. The Commission's engineering personnel cannot undertake to make such studies for prospective applicants.

An applicant for a commercial FM station must specify a frequency available to the area to be served. The demand for FM stations has not yet exceeded the supply of available frequencies. (The Noncommercial Educational FM Broadcast Service is a separate category with its own rules.)

An applicant for a new television station must request a channel assigned in the Table of Assignments to the community involved. However, a channel assigned to any community listed in the table can be requested for operation in any unlisted community within 15 miles of the listed community. Commercial TV stations are authorized for unlimited hours of operation with minimum power determined by the size of the principal city and maximum power dependent on antenna height and allocation zone. Channels are reserved for noncommercial educational TV operation.

In addition, TV translator stations are authorized to operate on the top 13 channels of the UHF band (470–890 Mc).

APPLYING FOR A CONSTRUCTION PERMIT

Once a prospective licensee has decided upon the type of station he wishes to apply for, the next step is to make application for a construction permit. This application must be in writing on a form supplied by the Commission (Form 301, "Application for Authority to Construct a New Broadcast Station," which covers AM, FM, and TV broadcast). This form requires information about the citizenship and character of the applicant, as well as his financial, technical, and other qualifications to construct and operate a station, plus details about the transmitting apparatus to be used, and the proposed new service. Triplicate copies are required, one of which must be executed under oath or affirmation.

APPLICATION PROCESSING

Applications for new broadcast stations are twice reported by the Commission—when first tendered, and, again, when accepted for filing. Such an application is not acted upon until at least 30 days after public notice is given of its acceptance.

Applications are reviewed in their engineering, legal, and financial aspects by the Broadcast Bureau, which makes recommendations to the Commission.

Applications are, in general, processed in the order in which accepted for filing.

If, upon examination of an application, the Commission determines that there are no engineering conflicts, that the applicant is qualified, and that all other requirements are met, the application is granted without hearing and a construction permit is issued.

Any grant made by the Commission without a hearing is subject to protest within a period of 30 days, during which the protesting party may request a hearing. Within 15 days thereafter the Commission must determine whether the objection merits a hearing.

The law requires that, in general, final decision on noncontested applications be rendered within three months from the date of the original filing, and within six months from the conclusion of a hearing in those cases which go through a hearing.

HEARINGS

Where it appears that an application violates provisions of the Commission's rules and regulations, that interference would be caused to another AM or FM broadcast station, or that the minimum separation requirements for TV stations are not met, or if other serious questions of a technical, legal, or financial character are involved, a hearing usually is required before a final decision on the application can be made. Often a hearing is necessary because two or more applicants seek to use the same frequency or immediately adjacent frequencies with such a proximity of stations that excessive interference would result. In such instances, the Commission is compelled by law to accord a hearing to the competing applicants and to make a comparative judgment as to which, if either, should be granted.

If unable to grant an application, the Commission is required to notify the applicant and other known parties of interest as to the reason. The applicant usually is given 30 days in which to reply. After that, if the Commission is still unable to make a grant, a hearing is ordered.

In designating an application for hearing, the Commission gives public notice of the issues for the information of the applicant and other parties who may be concerned. The hearing notice generally allows the applicant a period of 60 days or more in which to prepare. Even after being designated for hearing, an applicant may sometimes find it possible to satisfy the issues by amending his application, especially if the apparent deficiencies are of an engineering nature.

Competing applications for the same facility are not considered if filed more than

10 days after public notice designating the prior application or applications for hearing.

Hearings are customarily conducted by an examiner. The hearing examiner has authority to administer oaths, examine witnesses and rule upon the admission of evidence.

Pre-hearing conferences are held both prior to and after an exchange of exhibits by the parties. The latter takes place at least 20 days in advance of the hearing date, the second pre-hearing conference is held at least 10 days before the hearing commences.

Within 20 days after the close of a record by the hearing examiner, each party and the Chief of the Broadcast Bureau of the Commission has the privilege of filing proposed findings of fact and conclusions in support of their contentions. After review of the evidence and statements, the hearing examiner issues an initial decision.

In the event he wishes to contest the initial decision, the applicant or any other interested party has 20 days from the date on which the initial decision was announced to file exceptions and to request oral arguments before the Commission. In all cases heard by the examiner, the Commission will hear oral argument on request of either party. After oral argument, the Commission may adopt, modify or reverse the hearing examiner's initial decision. Within 30 days thereafter, any party involved may petition for rehearing.

If no exceptions are filed, and the Commission does not initiate a review of the hearing examiner's initial decision, the latter becomes effective 40 days after the issuance of the initial decision, unless otherwise ordered by the Commission. Court appeals can be taken within 30 days following announcement of the Commission decision.

CONSTRUCTION PERMIT

When and if an application meets statutory and other requirements, it is granted and a construction permit is issued. A maximum of 60 days from date of grant is provided in which construction shall begin, and a maximum of 6 months thereafter as the time for completion (or 8 months in all). Application to modify a broadcast construction authorization, or to make changes in an existing station, or to modify a license, is made on the same form (301) used in seeking initial construction authorization. If the permittee is unable to build his station within the time specified he can apply for extension of time on Form 701 ("Application for Additional Time to Construct a Radio Station"), giving the reasons. Upon completion of construction the permittee can engage in equipment tests.

LICENSE

The final step is to apply for the actual license. All applicants for broadcast license are required to fill out Form 302 ("Application for New Broadcast Station License"). Applicants must show compliance with all terms, conditions, and obligations set forth in the original application and the construction permit. After applying for a license and receiving authority from the Commission, the holder of a construction permit can conduct program tests. A station license is then issued if no new cause or circumstance has come to the attention of the Commission that would make operation of the station contrary to public interest.

AM, FM, and TV broadcast stations are licensed for the statutory limit of three years. Applications for renewal of license are made on Form 303 ("Application for Renewal of Broadcast Station License").

FORMS FOR OTHER PURPOSES

If the holder of a construction permit or license desires to assign the same to someone else, he makes application on Form 314 ("Application for Consent to Assignment of Radio Broadcast Station Construction Permit or License").

Should the permittee or the licensee wish to transfer corporate control, he applies

on Form 315 ("Application for Consent to Transfer Control of Corporation Holding Radio Broadcast Station Construction Permit or License").

In certain cases a permittee or licensee can apply for a transfer of corporate control or an assignment of license by using Form 316 ("Application for Assignment or Transfer–Short Form"). This form may only be used when the transfer or assignment is pro forma or technical in nature, i.e., where no substantial changes in interest occur.

In the event the licensee desires to operate his transmitter by remote control, application for such authorization should be made using Form 301-A.

Application for Subsidiary Communications Authorization (FM multiplex) should be made using Form 318.

Part 2

FREQUENCIES USED BY THE BROADCAST SERVICE

STANDARD BROADCAST (AM) STATIONS

Classes and Power of Standard Broadcast Stations

(FCC Rules, Section 3.22)

Class I Station: A Class I station is a dominant station operating on a clear channel and designed to render primary and secondary service over an extended area and at relatively long distances. Its primary service area is free from objectionable interference from other stations on the same and adjacent channels and its secondary service area free from interference, except from stations on the adjacent channel, and from stations on the same channel in accordance with the channel designation in Section 3.25 or in accordance with the Engineering Standards of Allocation. The operating power shall be not less than 10 kilowatts nor more than 50 kilowatts.

Class II Station: A Class II station is a secondary station which operates on a clear channel and is designed to render service over a primary service area which is limited by and subject to such interference as may be received from Class I stations. A station of this class shall operate with power not less than 0.25 kilowatt nor more than 50 kilowatts. Whenever necessary, a Class II station shall use a directional antenna or other means to avoid interference with Class I stations and with other Class II stations, in accordance with the Engineering Standards of Allocation.

Class III Station: A Class III station is a station which operates on a regional channel and is designed to render service primarily to a metropolitan district, and the rural area contiguous thereto. Class III stations are subdivided into two classes:

1. **Class III-A Station:** A Class III-A station is a Class III station which operates with power not less than 1 kilowatt nor more than 5 kilowatts and the service area of which is subject to interference in accordance with the Engineering Standards of Allocation.
2. **Class III-B Station:** A Class III-B station is a Class III station which operates with a power not less than 0.5 kilowatt, and not more than 1 kilowatt night and 5 kilowatts daytime, and the service area of which is subject to interference in accordance with the Engineering Standards of Allocation.

Class IV Station: A Class IV station is a station operating on a local channel and designed to render service primarily to a city or town and the suburban and rural areas contiguous thereto. The power of a station of this class shall not be less than 0.1 kilowatt and not more than 0.25 kilowatt night time, and 1 kilowatt daytime, and its service area is subject to interference in accordance with Section 3.182.

NOTE: The power ceiling for Class IV stations under the North American Regional Broadcasting Agreement (NARBA) is 250 watts. The Agreement between the United States of America and the United Mexican States Concerning Radio Broadcasting in the Standard

Broadcast Band [1] would permit daytime operation of Class IV stations with a maximum power of 1 kilowatt in all areas of the United States more than 100 kilometers (62 miles) from the United States/Mexican border. Pursuant to the U.S./Mexican Agreement and informal coordination with the other NARBA [1] signatories, the Commission will consider applications proposing the use of daytime power in excess of 250 watts by a Class IV station providing such station is located more than 100 kilometers (62 miles) from the U.S./Mexican border, or, if located in the State of Florida, providing that such station is not located south of 28 degrees north latitude and between 80 and 82 degrees west longitude.

"10% Rule"

Except for certain circumstances, FCC requires Class II, III, and IV stations to serve at least 90% of the population within their normally protected contours. For a more detailed explanation of the exceptions, see FCC Rules, Section 3.28(c).

Time of Operation of Standard Broadcast Stations

(FCC Rules, Section 3.23)

Standard broadcast stations may be licensed to operate in accordance with the following:

(a) *Unlimited time* permits operation without a maximum limit as to time.

(b) Limited time is applicable to Class II (secondary) stations operating on a clear channel with facilities authorized before October 30, 1959. It permits operation of the secondary station during daytime, and until local sunset if located west of the dominant station on the channel, or if located east thereof, until sunset at the dominant station, and in addition during night hours, if any, not used by the dominant station or stations on the channel.

(c) Daytime permits operation during the hours between average monthly sunrise and average monthly local sunset. Daytime stations operating on local channels with a power of 0.1 kw or 0.25 kw may, upon notification to the Commission and to the Engineer in Charge of the radio district in which they are located, operate at hours beyond those specified in their license.[2]

(d) *Sharing time* permits operation during hours which are so restricted by the station license as to require a division of time with one or more other stations using the same channel.

(e) *Specified hours* means that the exact operating hours are specified in the license. Specified hours stations operating on local channels except those sharing time with other stations may, upon notification to the Commission and the Engineer in Charge of the radio district in which they are located, operate at hours beyond those specified in their license.

Minimum Operating Schedule

(FCC Rules, Section 3.71)

Except Sundays, the licensee of each standard broadcast station shall maintain a minimum operating schedule of two-thirds of the total hours that it is authorized to operate between 6 AM and 6 PM, local standard time, and two-thirds of the total hours it is authorized to operate between 6 PM and midnight, local standard time, except that in an emergency when, due to causes beyond the control of the licensee, it becomes impossible to continue operating, the station may cease operation for a period of not to exceed 10 days, provided that the Commission and the Engineer in Charge shall be notified in writing immediately after the emergency develops.

[1] Not yet ratified by the U.S. Senate. Various provisions of Part 3 of FCC Rules would be amended upon ratification.

[2] See footnotes 6 and 11 to Standard Broadcast Section.

Frequencies Used for Standard Broadcast Stations

The band 535–1605 Kc is used for standard broadcasting. It is divided into 107 channels of 10 Kc each. Following is a list of standard broadcast channels and the conditions under which each may be used in the United States. For further reference and additional information, see FCC Rules, Part 3, Subpart A, Radio Broadcast Service, and the 1950 North American Regional Broadcasting Agreement, as well as the U.S./Mexico Agreement.

Channel	*Classification*	*NARBA Class I Priority*	*Use Under FCC Rules*	*See Footnotes*
540	Clear	Canada (I-A) Mexico (I-A)	II	(1) (2) (3) (14) (21)
550	Regional	Cuba (I-C)	III-A, III-B	(4) (5) (6)
560	Regional		III-A, III-B	(4) (6)
570	Regional	Cuba (I-D)	III-A, III-B	(4) (6) (7)
580	Regional		III-A, III-B	(4) (6)
590	Regional	Cuba (I-D)	III-A, III-B	(4) (6) (7)
600	Regional		III-A, III-B	(4) (6)
610	Regional		III-A, III-B	(4) (6)
620	Regional	Dominican Republic (I-C)	III-A, III-B	(4) (5) (6)
630	Regional	Cuba (I-D)	III-A, III-B	(4) (6) (7)
640	Clear	USA (I-A) Canada (I-B) Cuba (I-C)	I, II	(5) (8) (9) (10) (11) (12) (19) (22)
650	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (22)
660	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (23)
670	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (24)
680	Clear	USA (I-B)	I, II	(10) (11) (13) (19)
690	Clear	Canada (I-A) Mexico (I-B) Cuba (I-C)	II	(1) (3) (5)
700	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (22)
710	Clear	USA (I-B)	I, II	(10) (11) (13) (19)
720	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (24)
730	Clear	Mexico (I-A)	II	(14) (21)
740	Clear	Canada (I-A) Cuba (I-D)	II	(1) (3) (7)
750	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19)
760	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (22)
770	Clear	USA (I-A)	I, II	(8) (9) (11) (20) (23)
780	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (24)
790	Regional		III-A, III-B	(4) (6)
800	Clear	Mexico (I-A)	II	(14) (21)
810	Clear	USA (I-B)	I, II	(10) (11) (13) (19)
820	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (22)
830	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (22)
840	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (22)
850	Clear	USA (I-B) Mexico (I-B)	I, II	(10) (11) (13) (19)
860	Clear	Canada (I-A) Cuba (I-C)	II	(1) (3) (5)
870	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (22)
880	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (23)
890	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (24)
900	Clear	Mexico (I-A)	II	(14) (21)
910	Regional		III-A, III-B	(4) (6)
920	Regional	Cuba (I-D)	III-A, III-B	(4) (6) (7)
930	Regional		III-A, III-B	(4) (6)
940	Clear	Canada & Mexico (I-B)	I, II	(11) (19)
950	Regional	Cuba (I-D)	III-A, III-B	(4) (6) (7)
960	Regional		III-A, III-B	(4) (6)
970	Regional		III-A, III-B	(4) (6)
980	Regional	Cuba (I-D)	III-A, III-B	(4) (6) (7)
990	Clear	Canada (I-A)	II	(1) (3)
1000	Clear	Mexico & USA (I-B)	I, II	(10) (11) (13) (19)
1010	Clear	Canada (I-A) Cuba (I-B)	II	(1) (3) (15)

Channel	*Classification*	*NARBA Class I Priority*	*Use Under FCC Rules*	*See Footnotes*
1020	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (24)
1030	Clear	USA (I-A)	I, II	(11) (13) (16) (20)
1040	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (22)
1050	Clear	Mexico (I-A)	II	(14) (17) (21)
1060	Clear	Mexico & USA (I-B)	I, II	(10) (11) (13) (19)
1070	Clear	Canada & USA (I-B)	I, II	(10) (11) (13) (19)
1080	Clear	USA (I-B)	I, II	(10) (11) (13) (19)
1090	Clear	Mexico & USA (I-B)	I, II	(10) (11) (13) (19)
1100	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (23)
1110	Clear	USA (I-B)	I, II	(10) (11) (13) (19)
1120	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (24)
1130	Clear	Canada & USA (I-B)	I, II	(10) (11) (13) (19)
1140	Clear	Mexico & USA (I-B)	I, II	(10) (11) (13) (19)
1150	Regional		III-A, III-B	(4) (6)
1160	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (22)
1170	Clear	USA (I-B)	I, II	(10) (11) (13) (19)
1180	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (23)
1190	Clear	Mexico & USA (I-B)	I, II	(10) (11) (13) (19)
1200	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (22)
1210	Clear	USA (I-A)	I, II	(8) (9) (10) (11) (19) (24)
1220	Clear	Mexico (I-A)	II	(14) (18) (21)
1230	Local		IV	
1240	Local		IV	(12)
1250	Regional		III-A, III-B	(4) (6)
1260	Regional		III-A, III-B	(4) (6)
1270	Regional		III-A, III-B	(4) (6)
1280	Regional		III-A, III-B	(4) (6)
1290	Regional		III-A, III-B	(4) (6)
1300	Regional		III-A, III-B	(4) (6)
1310	Regional		III-A, III-B	(4) (6)
1320	Regional		III-A, III-B	(4) (6)
1330	Regional		III-A, III-B	(4) (6)
1340	Local		IV	
1350	Regional		III-A, III-B	(4) (6)
1360	Regional		III-A, III-B	(4) (6)
1370	Regional		III-A, III-B	(4) (6)
1380	Regional		III-A, III-B	(4) (6)
1390	Regional		III-A, III-B	(4) (6)
1400	Local		IV	
1410	Regional		III-A, III-B	(4) (6)
1420	Regional		III-A, III-B	(4) (6)
1430	Regional		III-A, III-B	(4) (6)
1440	Regional		III-A, III-B	(4) (6)
1450	Local		IV	
1460	Regional		III-A, III-B	(4) (6)
1470	Regional		III-A, III-B	(4) (6)
1480	Regional		III-A, III-B	(4) (6)
1490	Local		IV	
1500	Clear	USA (I-B)	I, II	(11) (13) (19) (26)
1510	Clear	USA (I-B)	I, II	(11) (13) (19) (26)
1520	Clear	USA (I-B)	I, II	(11) (13) (19) (26)
1530	Clear	USA (I-B)	I, II	(11) (13) (19) (26)
1540	Clear	Bahamas (I-A) USA (I-B)	II	(13) (19) (25) (26)
1550	Clear	Canada & Mexico (I-B)	I, II	(11) (19)
1560	Clear	USA & Cuba (I-B)	I, II	(11) (13) (19) (26)
1570	Clear	Mexico (I-A)	II	(14) (21)
1580	Clear	Canada (I-A)	II	(1) (3)
1590	Regional		III-A, III-B	(4) (6)
1600	Regional		III-A, III-B	(4) (6)

Footnotes to Standard Broadcast Section

(1) For Class II stations which will not deliver over 5 microvolts per meter groundwave or 25 microvolts per meter 10% time skywave at any point on the Canadian border and provided that such stations operating nighttime (i.e., sunset to sunrise at the location of the Class II station) are located not less than 650 miles from the nearest Canadian border.

(2) Subject to the condition that no harmful interference be caused to services operating on 500 Kc and in the band 510–535 Kc.

(3) Proposed rule-making in Docket 10453 provides for certain assignments on this channel to be submitted to the Canadian government for comments, taking into account daytime skywave. No applications are being granted at this time which are not in conformity with the proposals contained in Docket 10453.

(4) Class IV stations presently operating on this channel are allowed to continue operation, but are not protected against interference from Class III stations. No new Class IV stations will be assigned to the channel.

(5) New assignments may not deliver over 25 microvolts per meter 10% time skywave at any point on the border of the country having priority for a Class I-C station on this channel. For definition of this class of station and requirements for daytime protection, see 1950 North American Regional Broadcasting Agreement.

(6) Class III-A and Class III-B stations on this channel may begin operations at 4:00 AM with their authorized daytime facilities. The FCC may order such operations to cease, however, if undue interference is caused to other stations on the same channel. (See FCC Rules, Section 3.87.)

(7) New assignments may not deliver over 50 microvolts per meter 10% time skywave at any point on the border of the country having priority for a Class I-D station on this channel. For definition of this class of station and requirements for daytime protection, see 1950 North American Regional Broadcasting Agreement.

(8) One Class I and one or more Class II stations may be assigned on this channel. Class II stations are restricted to limited time or daytime only operation in the continental limits of the United States. There may also be assigned to this frequency Class II stations operating unlimited time in Alaska, Hawaii, Virgin Islands, and Puerto Rico which will not deliver over 5 microvolts per meter groundwave day or night or 25 microvolts per meter 10 per cent time skywave at night at any point within the continental limits of the United States.

(9) Power shall not be less than 50 Kw for Class I stations on this channel.

(10) The Commission's decision in Docket 8333 pointed out that, as a general principle, the maintenance of the "freeze" on certain Class I channels was in accord with their decision of 1954 on Docket 6741, and still applies. That proceeding has been recently under more active consideration and study. Certain tentative judgments have been made which limit the classes of applications on which action must continue to be deferred. (See paragraph 34 of the 1954 decision, and Docket 6741 proposed rule making on April 15, 1958.) Developments enable certain changes in the scope of the "freeze" in two directions: (1) removing from the "freeze" those I-B frequencies which can have no relation to possible changes in the I-A structure, and (2) changing the classes of applications covered by the "freeze" so as to reflect the impingement of such applications on the possible "clear channel" assignments rather than merely the daytime skywave effects. Consequently, the "freeze" still applies, pending a decision in Docket 6741, except for the channels 1500, 1510, 1520, 1530, 1540, and 1560 Kc, and extends the "freeze" in the case of applications for changes in existing facilities to any proposal which would increase radiation or change station location.

(11) Class II stations on this channel may begin operations at 4:00 AM with their authorized daytime facilities provided no interference is caused within the 0.5 millivolt per meter 50% skywave of the Class I station(s) except

1. Where the Class I station is located east of the Class II station, in which case the Class II station may begin operations at local sunrise time of the Class I station; or
2. Where agreement has been reached with the Class I station to begin operations prior to local sunrise.

NOTE: FCC may order such operations to cease, however, if undue interference is caused to other stations on the same channel. (See FCC Rules, Section 3.87.)

(12) This is one of the two channels used for CONELRAD transmissions.

(13) One or more Class 1 stations may be assigned to this channel. Class II applications are subject to the same provisions as stated in Footnote 10.

(14) In continental U.S., for Class II stations which operate daytime only with power not in excess of 1 Kw and which will not deliver over 5 microvolts per meter groundwave at any point on the Mexican border, and in Alaska, Hawaii, Puerto Rico, and the Virgin Islands, for Class II stations which will not deliver over 5 microvolts per meter groundwave or 25 microvolts per meter 10% time skywave at any point on said border.

(15) A station on 1010 Kc shall also protect a Class I-B station at Havana, Cuba.

(16) Under terms of the 1950 North American Regional Broadcasting Agreement, Class I-A priority on this channel is assigned to USA, however FCC Rules continue to classify 1030 Kc as Class 1-B, pending ratification of the 1950 Agreement.

(17) The U.S. is permitted under the "Gentlemen's Agreement" to continue operation of one 50 Kw full-time Class II station with directional pattern that will direct the signal to the northeast and protect the Mexican station's signal in the U.S. as much as possible.

(18) The U.S. is permitted under the "Gentlemen's Agreement" to assign a station in in the Detroit, Michigan, area with a directional antenna that will direct the signal to the northward and protect the Mexican station's coverage in the U.S. as much as possible.

(19) All new assignments on this channel must be in accordance with Section 3.187.

(20) No applications will be processed on this channel until a decision is reached in Docket 6741. On the frequency of 770 Kc two Class I stations may be assigned.

(21) The United States may assign stations to operate with powers not in excess of 5 Kw daytime on this frequency. Stations with powers in excess of 1 Kw may not be assigned in areas within the following distances of the locations specified:

800 Kc 820 miles from Ciudad Juarez, Chihuahua
1050 Kc 620 miles from Monterrey, Nuevo Leon
1570 Kc 620 miles from Ciudad Acuna, Coahuila

Before the Commission will take final action with respect to an application proposing 5 Kw, appropriate coordination of the rules must be effected with other North American countries.

(22) Docket 6741 proposes no action at this time in regard to increased power for these channels.

(23) Docket 6741 proposes to assign a new Class I station in a designated state and require both the new and existing Class I stations to directionalize.

(24) Docket 6741 proposes to retain present maximum power of 50 Kw and assign unlimited time Class II stations in underserved areas.

(25) Class I and II stations on 1540 Kc shall deliver not over 5 microvolts per meter groundwave or 25 microvolts per meter 10 per cent time skywave at any point of land in the Bahama Islands, and such stations operating nighttime (i.e., sunset to sunrise at the location of the Class II station) shall be located not less than 650 miles from the nearest point of land in the Bahama Islands.

(26) In accordance with the Commission's decision in Docket 8333, these channels have been removed from the "freeze."

FM STATIONS

Classes and Power of FM Stations

Class A Station: A Class A station is a station which operates on a Class A channel and is designed to render service primarily to a community or to a city or town other than the principal city of an area, and the surrounding rural area. The coverage of a Class A station shall be not more than the equivalent of 1 kilowatt effective radiated power and antenna height of 250 feet above average terrain, as determined by the methods prescribed in the Standards of Good Engineering Practice Concerning FM Broadcast Stations. A Class A station will not be licensed with more than 1 kilowatt effective radiated power. The power rating of the transmitter used for a Class A station shall be not less than 250 watts nor more than 1 kilowatt. The signal intensity requirements of Section 2 of the Standards of Good Engineering Practice Concerning FM Broadcast Stations shall determine the minimum coverage of a Class A station. Class A stations will normally be protected to the 1 mv/m

contour; however, assignments will be made in a manner to insure, in so far as possible, a maximum of service to all listeners, whether urban or rural, giving consideration to the minimum signal capable of providing service. (FCC Rules, Section 3.203)

Class B Station: The coverage of a Class B station in Area II * shall normally be not more than the equivalent of 20 kilowatts effective radiated power and antenna height of 500 feet above average terrain. The use of greater power and antenna height will be encouraged in those portions of Area II where such use would not result in undue interference to stations already authorized or to probable assignments in so far as can be determined at the time of the grant. In such cases, the power, antenna height, and area will be determined on the merits of each application with particular attention being given to rural areas which would not otherwise receive service. (FCC Rules, Section 3.204)

Time of Operation

All FM broadcast stations are licensed for unlimited time operation. A minimum of 36 hours per week during the hours of 6 AM to midnight, consisting of not less than five hours in any one day, must be devoted to FM broadcast operation. Time devoted to operations conducted under a Subsidiary Communications Authorization is not included in meeting this requirement. In an emergency when, due to causes beyond the control of a licensee, it becomes impossible to continue operation, the station may cease operation for a period not to exceed 10 days, provided the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified in writing immediately after the emergency develops. (FCC Rules, Section 3.261)

Subsidiary Communications Authorizations (SCA)

FM broadcast stations may engage in "functional (background) music" operations in addition to their regular FM broadcast service. The SCA will run concurrently with the FM broadcast license, and may not be renewed unless the FM broadcast license is also renewed. (For further details, see FCC Rules, Sections 3.293, 3.294, 3.295 and 3.296, Subpart B—FM Broadcast stations.)

Frequencies Used for FM Broadcast Stations

The band 88–108 Mc is reserved for the FM Broadcast Service. These are 100 channels of 200 Kc each (80 for commercial broadcasting and 20 for educational broadcasting). Educational channels are in the 88–92 Mc portion of the FM band, and commercial broadcasting is allotted the remainder, 92–108 Mc.

For further reference, see FCC Rules, Part 3, Subpart B, and the Standards of Good Engineering Practice Concerning FM Broadcast Stations.

Channel No.	*Frequency*	*For Class*	*Channel No.*	*Frequency*	*For Class*
221	92.1 Mc	A	233	94.5 Mc	B
222	92.3 Mc	B	234	94.7 Mc	B
223	92.5 Mc	B	235	94.9 Mc	B
224	92.7 Mc	A	236	95.1 Mc	B
225	92.9 Mc	B	237	95.3 Mc	A
226	93.1 Mc	B	238	95.5 Mc	B
227	93.3 Mc	B	239	95.7 Mc	B
228	93.5 Mc	A	240	95.9 Mc	A
229	93.7 Mc	B	241	96.1 Mc	B
230	93.9 Mc	B	242	96.3 Mc	B
231	94.1 Mc	B	243	96.5 Mc	B
232	94.3 Mc	A	244	96.7 Mc	A

* See Footnote 1 at end of channel tabulation.

Channel No.	*Frequency*	*For Class*	*Channel No.*	*Frequency*	*For Class*
245	96.9 Mc	B	273*	102.5 Mc	B
246	97.1 Mc	B	274*	102.7 Mc	B
247	97.3 Mc	B	275*	102.9 Mc	B
248	97.5 Mc	B	276*	103.1 Mc	A
249	97.7 Mc	A	277*	103.3 Mc	B
250	97.9 Mc	B	278*	103.5 Mc	B
251*	98.1 Mc	B	279*	103.7 Mc	B
252*	98.3 Mc	A	280*	103.9 Mc	A
253*	98.5 Mc	B	281*	104.1 Mc	B
254*	98.7 Mc	B	282*	104.3 Mc	B
255*	98.9 Mc	B	283*	104.5 Mc	B
256*	99.1 Mc	B	284*	104.7 Mc	B
257*	99.3 Mc	A	285*	104.9 Mc	A
258*	99.5 Mc	B	286*	105.1 Mc	B
259*	99.7 Mc	B	287*	105.3 Mc	B
260*	99.9 Mc	B	288*	105.5 Mc	A
261*	100.1 Mc	A	289*	105.7 Mc	B
262*	100.3 Mc	B	290*	105.9 Mc	B
263*	100.5 Mc	B	291*	106.1 Mc	B
264*	100.7 Mc	B	292*	106.3 Mc	A
265*	100.9 Mc	A	293*	106.5 Mc	B
266*	101.1 Mc	B	294*	106.7 Mc	B
267*	101.3 Mc	B	295*	106.9 Mc	B
268*	101.5 Mc	B	296*	107.1 Mc	A
269*	101.7 Mc	A	297*	107.3 Mc	B
270*	101.9 Mc	B	298*	107.5 Mc	B
271*	102.1 Mc	B	299*	107.7 Mc	B
272*	102.3 Mc	A	300*	107.9 Mc	B

* See Footnote 2.

Footnotes to FM Broadcast Section

(1) Area I includes southern New Hampshire; all of Massachusetts, Rhode Island, and Connecticut; southeastern New York as far north as Albany-Troy-Schenectady; all of New Jersey, Delaware, and the District of Columbia; Maryland as far west as Hagerstown; and eastern Pennsylvania as far west as Harrisburg.
Area II comprehends the remainder of the United States not included in Area 1.

(2) In Hawaii, the band 98–108 Mc is allocated for non-broadcast use, and the frequencies 98.1–107.9 Mc will not be assigned in Hawaii for use by FM broadcast stations.

TELEVISION STATIONS

Minimum and Maximum Visual Effective Radiated Power (ERP)

Minimum

Applications will not be accepted for filing if they specify less than −10 dbk (100 watts) visual effective radiated power in any horizontal direction. No minimum antenna height above average terrain is specified.

Maximum

Channel Nos.	*Maximum Visual ERP*
2–6	20 dbk (100 Kw)
7–13	25 dbk (316 Kw)
14–83	37 dbk (5000 Kw)

NOTE: The maximum visual effective radiated power of television broadcast stations operating on Channels 14–83 within 250 miles of the Canadian-USA border may not be in excess of 30 dbk (1000 Kw).

Time of Operation

All television broadcast stations are licensed for unlimited time operation. Each station must maintain a regular program operating schedule as follows:

First 18 months of operation: Not less than 2 hours daily in any five broadcast days per week, and not less than a total of 12 hours per week.

Each successive 6-month period: Not less than 2 hours daily in any five broadcast days per week, and not less than a total of 16 hours, 20 hours, and 24 hours per week respectively. *Third year of operation and thereafter:* Not less than 2 hours in each of the seven days of the week, and not less than a total of 28 hours per week. See FCC Rules, Section 3.651.

Frequencies Used for Television Stations

There are 82 channels in the Television Broadcast Service, 12 for VHF television and 70 for UHF television. Each channel has a bandwidth of 6 Mc.

Assignment of a channel to an applicant is made in accordance with the Table of Assignments given in FCC Rules, Section 3.606(b).

For further reference, see FCC Rules, Part 3, Subpart E.

The channel numbers and frequency bands for television stations are as follows:

Channel No.	*Frequency Band*	*Channel No.*	*Frequency Band*
2	54–60 Mc	37	608–614 Mc
3	60–66 Mc	38	614–620 Mc
4	66–72 Mc *	39	620–626 Mc
5	76–82 Mc	40	626–632 Mc
6	82–88 Mc	41	632–638 Mc
7	174–180 Mc	42	638–644 Mc
8	180–186 Mc	43	644–650 Mc
9	186–192 Mc	44	650–656 Mc
10	192–198 Mc	45	656–662 Mc
11	198–204 Mc	46	662–668 Mc
12	204–210 Mc	47	668–674 Mc
13	210–216 Mc	48	674–680 Mc
14	470–476 Mc	49	680–686 Mc
15	476–482 Mc	50	686–692 Mc
16	482–488 Mc	51	692–698 Mc
17	488–494 Mc	52	698–704 Mc
18	494–500 Mc	53	704–710 Mc
19	500–506 Mc	54	710–716 Mc
20	506–512 Mc	55	716–722 Mc
21	512–518 Mc	56	722–728 Mc
22	518–524 Mc	57	728–734 Mc
23	524–530 Mc	58	734–740 Mc
24	530–536 Mc	59	740–746 Mc
25	536–542 Mc	60	746–752 Mc
26	542–548 Mc	61	752–758 Mc
27	548–554 Mc	62	758–764 Mc
28	554–560 Mc	63	764–770 Mc
29	560–566 Mc	64	770–776 Mc
30	566–572 Mc	65	776–782 Mc
31	572–578 Mc	66	782–788 Mc
32	578–584 Mc	67	788–794 Mc
33	584–590 Mc	68	794–800 Mc
34	590–596 Mc	69	800–806 Mc
35	596–602 Mc	70	806–812 Mc
36	602–608 Mc	71	812–818 Mc

* NOTE: 72–76 Mc is used for assignment of Fixed Radio (nonbroadcast) stations on the condition that no harmful interference be caused to TV channels 4 and 5.

Channel No.	*Frequency Band*	*Channel No.*	*Frequency Band*
72	818–824 Mc	78	854–860 Mc
73	824–830 Mc	79	860–866 Mc
74	830–836 Mc	80	866–872 Mc
75	836–842 Mc	81	872–878 Mc
76	842–848 Mc	82	878–884 Mc
77	848–854 Mc	83	884–890 Mc

FREQUENCY SELECTION

Service	*Choice*
Standard Broadcasting (AM)	Applicant must specify frequency. Search must be made for an available frequency by the applicant, or his consultant.
FM Broadcasting	Applicant must specify frequency.
Television Broadcasting	Applicant may select any unassigned channel from Section 3.606(b). Applications will not be accepted by FCC if they are not in accord with 3.606(b). Petition for rule-making to change the Table of Assignments (3.606b) may be filed, and if granted, then application may be filed for new channel so added. Petitions to change 3.606(b) should be considered in the light of the following: Sec. 3.607–Availability of channels. Sec. 3.608–International agreements. Sec. 3.610–Separations.

TRANSLATOR STATIONS

Definition

A television translator is a station in the broadcasting service operated solely for the purpose of retransmitting the signals of a television broadcast station or another television broadcast translator station, by means of direct frequency conversion and amplification of the incoming signals and without significantly altering any characteristic of the incoming signal other than its frequency and amplitude, for the purpose of providing television reception to the general public.

Power

A television broadcast translator station will not be authorized to operate with a transmitter power output in excess of the rated power output of the transmitter and in no event shall the rated peak visual power output of the transmitter be in excess of 100 watts.

Frequencies Used for Translator Stations

There are 14 channels in the translator service. Each channel has a bandwidth of 6 Mc. Assignment of a channel to an applicant is made in accordance with the Frequency Assignment given in FCC Rules, Section 4.702. The channel numbers and frequency band for translator stations are as follows:

Channel No.	*Frequency Band*
70	806–812 Mc
71	812–818 Mc
72	818–824 Mc
73	824–830 Mc
74	830–836 Mc
75	836–842 Mc
76	842–848 Mc
77	848–854 Mc
78	854–860 Mc
79	860–866 Mc
80	866–872 Mc
81	872–878 Mc
82	878–884 Mc
83	884–890 Mc

For further information on this subject see Part 4 of the FCC Rules-Experimental, Auxiliary and Special Broadcast Services—Subpart G. FCC proposed rule making in Docket 11331 would permit operation of VHF booster transmitters under certain conditions. See Docket 11331 for full details.

AUXILIARY BROADCAST SERVICES

Introduction

FCC Rules provide for the use of radio transmitting apparatus to supply certain auxiliary services in connection with broadcasting. These services fall into four general categories:

1. *Portable or mobile stations* which may be used to relay programs from places of origination other than a studio.
2. *Base stations*, usually located at the studio or transmitter of a broadcast station, and used to co-ordinate the activities of portable or mobile stations.
3. *Fixed stations* (*STL*) which may be used to provide a program circuit between the main or auxiliary studios to the transmitter of a broadcast station.
4. *Fixed stations* (*Inter-city Relay*) which may be used to relay programs from one broadcast station to other broadcast stations for network programming.

Category (1) includes two classes of stations, i.e., *Remote Pickup Broadcast Mobile Stations* which may be used for relaying aural broadcast program material or the aural portion of television programs and are available to AM, FM, and TV broadcast station licensees; and *Television Pickup Stations* which may be used for relaying television program material, either visual alone or the combined visual and aural program material by means of multiplexing. Television pickup stations are available only to television broadcast stations.

Category (2) contains a class of station called a *Remote Pickup Broadcast Base Station*. From the standpoint of equipment, frequency assignments, technical operation, and availability, they are identical with Remote Pickup Broadcast Mobile Stations. A differentiation is made because they are permanently installed at a fixed location and do not normally carry program material. The primary purpose of such base stations is to provide communication with remote mobile stations or television pickup stations, however, other uses are permitted under special circumstances.

Category (3) includes three classes of stations; *Standard Broadcast STL Stations, FM Broadcast STL Stations*, and *Television STL Stations*. STLs (studio-transmitter links) are used to provide a program circuit between the studio and the transmitter of a broadcast station. They are available to AM, FM and TV broadcast stations. AM, FM, and TV STLs which are used to carry only the aural portion of TV programs, operate in the same general portion of the spectrum and the same type of transmitting equipment is used in all three services. Television STLs which are used to carry the visual portion of television programs operate in the so-called "micro-

wave" portion of the spectrum. Some equipment is designed to simultaneously carry the aural portion of the program material on the same carrier by means of multiplexing and such use is permitted if it can be accomplished without degrading the visual and aural signal to a point where the overall performance of the television system cannot meet the minimum requirements of the Rules Governing Television Broadcast Stations. Television broadcasters contemplating the use of multiplexing in their STL circuit should assure themselves that the equipment proposed to be used has sufficient performance capability to enable them to meet the requirements of Sec. 3.687.

Category (4) includes two classes of stations; *FM Broadcast Inter-city Relay Stations* and *TV Inter-city Relay Stations*. (There is no AM Inter-city Relay Service.) Inter-city relay stations are used for the interexchange of programs between broadcast stations for network operation. Circuits for the interexchange of broadcast programs are normally operated by communications common carriers, however, in the case of FM broadcasting, where high-quality aural circuits are required and in the case of television, where special video circuits as well as high-quality aural circuits are required, the telephone company serving a certain area may not be able to supply the desired service due to lack of adequate facilities. Under such circumstances, inter-city relay stations are available to FM and TV broadcasters on *an interim basis* pending the availability of adequate common carrier circuits. No provision is made for inter-city relay stations to be used in conjunction with AM broadcast stations since telephone circuits of suitable broadcast quality are generally available or can be made available on short notice. FM inter-city relay stations and TV inter-city relay stations which carry only the aural portion of the television program operate in the same general portion of the spectrum as AM, FM, and TV STL stations. TV inter-city relay stations used for the visual portion of television programs operate in the microwave bands used by TV pickup and TV STL stations. As in the case of TV STLs, the aural portion of the TV program may be transmitted on the same carrier as the visual program material by means of multiplexing. Quality standards for inter-city relay stations are left to the discretion of the individual broadcaster.

Some broadcasters prefer to keep equipment running on a 24-hour basis, feeling this is a factor in economical and trouble-free operation. Radiation of an unmodulated carrier is not authorized for the auxiliary broadcast services except during brief test periods, but equipment may be kept operating when no program material is being transmitted by shunting the output into a dummy antenna or a similar non-radiating load.

Remote pickup broadcast stations are required to monitor for CONELRAD Radio Alerts and go off the air until the Radio All Clear. They may obtain the Radio Alert by monitoring any standard, FM, or TV station. Since the remote personnel would naturally be in communication with the mother station, and monitoring its transmissions in any case, no special receiver is required.

All of the material in this section is intended to be an explanation of the FCC Rules relating to the operation of auxiliary broadcast stations. It should not be understood to replace the need for reference to the full text of Part 4 of the FCC Rules which covers the services. The material in this article is arranged according to classes of broadcasting stations which may use auxiliary stations, and reference is made throughout to the pertinent sections of Part 4 for further study.

AM/FM SECTION

Remote Pickup Broadcast Stations

See page 1–17, categories (1) and (2) for definitions. Broadcasters may use remote pickup broadcast stations at their discretion, and the choice between radio and wire lines does not depend on whether or not wire lines are available.

Remote pickup broadcast stations may be used for:

1. Transmission of AM, FM or the aural portion of TV program material originating outside a regular studio. (Normally, only Mobile stations are used.)

2. Orders and related communications directly concerning such transmissions, but *may not be used* to provide private mobile telephone systems to station personnel. (Both Base and Mobile stations may be so used.)
3. Emergency program or order circuits from studios in the event of failure of regular wire circuits, but *may not be used* for such purposes on a regular basis. (Both Base and Mobile stations may be so used.)
4. In Alaska, Hawaii, Puerto Rico and Virgin Islands for inter-city relays and STL's, provided such transmissions are not intended to be received directly by the public. Such use is not authorized in the continental limits of the U.S. (Both Base and Mobile stations may be so used.)
5. Under STA for mobile communications in connection with adjustment and maintenance of antenna system, or in connection with field intensity surveys. (Both Base and Mobile stations may be so used.)
6. Coordination of the activities of portable or mobile stations.
7. Two-way communication between the studio and transmitter of a broadcast station which has a radio STL. (Base stations only.)

Wire lines may be used to complete remote pickup circuits, if necessary.

Remote pickup broadcast stations will not be granted exclusive frequency assignments, and the same frequency or frequencies may be assigned to other licensees in the same area. (In the television section, it will be noted that some exclusive assignments of auxiliary frequencies are made for television purposes.)

Applicants may request information about the existing remote pickup assignments in a particular area, and apply for unassigned frequencies to the extent permitted by the FCC rules. The Commission is unable to supply information regarding existing assignments to the Industrial Radio Stations in the band shared by remote pickup stations with the service.

Where a frequency is shared by two or more remote pickup stations and simultaneous operation is contemplated, the transmission of actual program material has first priority, the transmission of cues and orders including preparatory communications has second priority, and the use of the remote pickup station for other authorized communication has the lowest priority. An exception to this rule is made for the frequencies 26.07 Mc, 26.09 Mc, 26.11 Mc, 26.13 Mc, 26.45 Mc and 26.47 Mc as noted below.

The following groups of frequencies are allocated for assignment to remote pickup broadcast stations. A licensee may have one or more frequencies assigned for operation in the same area, but is limited within each "division" to assignments from a single "group."

Division	*Group*	*Frequencies*	*Type of Emission*	*Notes*
1	A	1606 Kc [1] 1622 Kc 1646 Kc	10-A-3	Not shared with other services.
2	D	25.87 Mc [2] 26.15 Mc 26.25 Mc 26.35 Mc		Finalization of Docket 11696 now enables the operation of wireless microphones and cueing circuits in the bands 26.10–26.48 Mc and 450–451 Mc.
2	E	25.91 Mc [2] 26.17 Mc 26.27 Mc 26.37 Mc	20-A-3 or 20-F-3	Not shared with other services.
2	F	25.95 Mc [2] 26.19 Mc 26.29 Mc 26.39 Mc		

Division	*Group*	*Frequencies*	*Type of Emission*	*Notes*
2	G	25.99 Mc [2] 26.21 Mc 26.31 Mc 26.41 Mc	20-A-3 or 20-F-3	
2	H	26.03 Mc [2] 26.23 Mc 26.33 Mc 26.43 Mc		
3	I	26.07 Mc [2] 26.11 Mc 26.45 Mc	20-A-3 or 20-F-3	Not shared with other services. When used for radio order circuits (see page 1–22), such use is secondary to all other permissible uses.
3	J	26.09 Mc [2] 26.13 Mc 26.47 Mc		
4	K	152.87 Mc 152.93 Mc 152.99 Mc 153.05 Mc 153.11 Mc 153.17 Mc 153.23 Mc 153.29 Mc 153.35 Mc	30-A-3 or 60-F-3	Shared with Industrial Services which have 1st priority of use. Such operation on basis of "split channel" provisions of Doc. 11959, which do not apply to Broadcast remote pickup stations. In Doc. 11997 NAB requested that such shared use with Industrial be continued.
		159.51 Mc 159.57 Mc 159.63 Mc 159.69 Mc 159.75 Mc 159.81 Mc 159.87 Mc 159.93 Mc 159.99 Mc	30-A-3 or 60-F-3	For assignment to remote pickup base and mobile stations in the Island of Puerto Rico only.
5	L	166.25 Mc	30-A-3 or	Use is subject to the condition that harmful interference will not be caused to present or future government stations in the band 162–174 Mc. Also, operation on these frequencies is not authorized in the TVA area, nor within 150 miles of New York City, nor outside the continental limits of the U.S.
5	M	170.15 Mc	60-F-3	
6	N	450.05 Mc 450.15 Mc 450.25 Mc 450.35 Mc 450.45 Mc 450.55 Mc 450.65 Mc 450.75 Mc 450.85 Mc 450.95 Mc 455.05 Mc 455.15 Mc	30-A-3 or 100-F-3	Not shared with other services. Docket 11959 proposes to reduce present 100 Kc bandwidths to 50 Kc. See Note Group D. Docket 11959 proposes six exclusive channels be assigned the Broadcast Service at 161.645–161.825 Mc with 30 Kc widths.

Division	Group	Frequencies	Type of Emission	Notes
		455.25 Mc		
		455.35 Mc		
		455.45 Mc		
		455.55 Mc		
		455.65 Mc		
		455.75 Mc		
		455.85 Mc		
		455.95 Mc		

[1] Use is subject to the condition that no harmful interference is caused to the reception of standard broadcast stations.

[2] Use is subject to the condition that no harmful interference is caused to the reception of high-frequency broadcast stations.

AM/FM Studio-transmitter Link Stations

STL stations are available to the licensees of both AM and FM broadcast stations and are used to relay programs from the studio to the transmitter of the station. Where the licensee of an AM station is also the licensee of an FM station, the same STL may be used for both stations. (See Section 4.532a.) The STL may also be used for the purpose of providing communication between studio and transmitter when no programs are being transmitted, or if multiplexing is employed, may be used for communication during program transmission.

Broadcasters may use radio STLs at their discretion, and the choice between radio STL and wire line (common carrier) STL does not depend on whether or not wire lines are available.

Any AM or FM station employing a radio STL may also use remote pickup base stations to provide an "order circuit" for communication of information concerning program service. Radio circuits may be used for this purpose *only* when the broadcast station uses a radio STL. See page 1–22.

Exclusive assignments will be made to STL stations providing the program circuit from the main studio to the transmitter of FM broadcast stations. In the case of AM STL stations, and FM STL stations at secondary studios, exclusive assignments will be made wherever practicable.

The following frequencies are available for broadcast STL stations including TV STL, TV Inter-city relays. Aural portion only.

Frequency	Type of Emission	Notes
942.5 Mc	430-F-3	Not shared with other services. May also be used for FM Inter-city Relay Stations. Licensed for unlimited time operation. Directional antenna is required. See FCC Rules, Section 4.536. May be operated by remote control in accordance with the provisions of FCC Rules, Sec. 4.533.
943.0 Mc		
943.5 Mc		
944.0 Mc		
944.5 Mc		
945.0 Mc		
945.5 Mc		
946.0 Mc		
946.5 Mc		
947.0 Mc		
947.5 Mc		
948.0 Mc		
948.5 Mc		
949.0 Mc		
949.5 Mc		
950.0 Mc		
950.5 Mc		
951.0 Mc		
951.5 Mc		

No new fixed stations, including tropospheric scatter stations in the international fixed service, will be authorized in the band 890–942 Mc, provided that all stations presently authorized to operate on frequencies in the band 890–942 Mc may continue to operate pursuant to the provisions of their existing authorizations until the termination of such authorizations. Renewal of authorizations for such stations will be issued only on the condition (1) that they accept any harmful interference that may be experienced from either ISM equipment in the band 890–940 Mc, or from the radio-positioning service in the band 890–942 Mc and (2) that they do not cause harmful interference to the radio-positioning service.

Radio Order Circuits

Remote pickup base stations may be authorized to provide two-way communication between the studio and transmitter of a broadcast station which has a radio STL.

The following frequencies may be assigned for radio order circuits. They are licensed for unlimited time operation, but their use is secondary to other need for the same frequency(s).

Group	*Frequency*	*Type of Emission*
I	26.07 Mc *	20-A-3
	26.09 Mc *	or
	26.11 Mc	20-F-3
	26.45 Mc	
J	26.13 Mc	20-A-3
	26.47 Mc	or
		20-F-3

* Use is subject to the condition that no harmful interference is caused to the reception of high frequency broadcast stations.

FM Inter-city Relay Stations

The operation of FM inter-city relay stations is subject to the condition that no harmful interference is caused to other radio stations, present or future, operating in accordance with the Table of Frequency Allocations.

Wire lines may be used to complete circuits for FM inter-city relays. Inter-city relay stations may be used for communication of program information when no programs are being transmitted, or if multiplexing is employed, may be used for communication during program transmission.

Relay stations will be authorized only when suitable common carrier facilities are not available. Each application for a new FM inter-city relay system, or for renewal of an existing system must be accompanied by verified statements showing:

1. Why the facilities are needed, including reasons why common carrier facilities are not available.
2. That the applicant has requested such facilities from the common carrier serving the area, and including copies of such request(s) and reply(s).

Frequencies available for FM inter-city relay stations are the same as those used for broadcast STLs (see listing on page 1–21).

As in the case of STLs, they are licensed for unlimited time operation, directional antennas are required, and they may be operated by remote control.

TELEVISION SECTION

Television Pickup Stations

Television pickup stations may be used for:

1. Transmission of program material originating outside a regular studio. These channels are primarily used for the transmission of the video portion of the

pickup, but the aural portion may be multiplexed on the same channel. Applications must clearly state the nature of any multiplexing proposed.

If only the video portion is transmitted on the television pickup channel, the aural portion may be transmitted by wire line, or on one of the frequencies designated for remote pickup broadcast stations. Listed on pages 1–19, 1–20, and 1–21.

2. To provide temporary studio-transmitter links (without further authority of the FCC provided the installation of the antenna does not increase the height of any existing structure by more than 20 feet. Authority for increase of more than 20 feet may be obtained from FCC if necessary).
3. Orders and related communications concerning such transmissions. They *may not be used* solely for this purpose.

No standards are specified in either the FCC Rules or in any existing proposed rule-making concerning the quality of television pickups.

Television STL Stations

The TV STL may be nsed for communications relating to program continuity during periods when no programs are being transmitted, or by multiplexing at any time.

The aural signal may be multiplexed on the STL, but broadcasters contemplating the use of multiplexing should assure themselves that the equipment proposed to be used has sufficient performance quality to enable them to meet the requirements of Section 3.687 of the FCC Rules.

The television broadcaster may elect to have a communications common carrier provide television pickup or television STL service, and in this case, the common carrier may use the same channels which would normally be assigned to the television station.

When the television station uses a television channel STL, it may also use remote pickup base stations to provide an "order circuit" for communication of information concerning program service. Radio circuits may be used for this purpose *only* when a television channel STL is used.

Television Inter-city Relay Stations

Television inter-city relay stations provide a means whereby television broadcast licenses may provide their own inter-city television transmission services in connection with the operation of their television broadcast stations.

The use of channels for television inter-city relay stations is on a secondary basis, and is subject to the condition that no harmful interference is caused to stations operating in accordance with the Table of Frequency Allocations.

No standards are specified in either FCC Rules or in any existing proposed rule-making concerning the quality of television inter-city relay stations. Inter-city relay stations may be used for communication of program information either by multiplexing, or by simplex during periods of non-use for program transmission.

Assignment of Channels for the Television Auxiliary Services

The television auxiliary frequencies are assigned interchangeably for television pickups, STLs, or inter-city relay stations.

Television stations may request the assignment of one channel in Band A or Band B, and one channel in Band D, or the following list of channels for use on an exclusive basis. In addition, they may request the assignment of additional channels which will be assigned, if available in the area, on a non-exclusive basis. The non-exclusive channels may be withdrawn any time they are needed to provide exclnsive channels for other television stations in the same area.

No exclusive assignments are made in Band C.*

* Channels in Band A marked with (**) and all channels in Band C are allocated to accommodate the incidental radiations of industrial, scientific, and medical equipment, and

If two television stations in the same area are so located that they may share a single STL, they may by mutual agreement request the same assignment of the exclusive channel and, in addition, may be granted a second exclusive channel for each station from either Band A or Band B and a third exclusive channel from Band D.

Where only one exclusive channel is assigned, it is normally assigned to the main studio STL (where the television station employs a television channel STL); additional STLs may be operated at the broadcaster's discretion. Operation of the STL on a non-exclusive channel is subject to the condition that no harmful interference is caused to the operation of television pickup stations.

Any suitable type of emission may be used for the frequencies above 1500 Mc. Identification of the emission may be by whatever means the emission is authorized for, except that a visual-only transmitter may be identified by means of a keyed signal, either interrupting the carrier or by means of modulation impressed on the carrier, giving the call sign of the station.

Directional antennas are not required, but are usually employed at these frequencies.

Band A	*Band B*	*Band C* **
1990–2008 Mc	6875–6900 Mc	10550–10575 Mc
2008–2025 Mc	6900–6925 Mc	10575–10600 Mc
2025–2042 Mc	6925–6950 Mc	10600–10625 Mc
2042–2059 Mc	6950–6975 Mc	10625–10650 Mc
2059–2076 Mc	6975–7000 Mc	10650–10675 Mc
2076–2093 Mc	7000–7025 Mc	10675–10700 Mc
2093–2110 Mc	7025–7050 Mc	
2450–2467 Mc **	7050–7075 Mc ***	
2467–2484 Mc **	7075–7100 Mc ***	
2484–2500 Mc **	7100–7125 Mc ***	

** See previous footnote.

*** Until further order by the Commission, these three channels will not be assigned to television broadcast stations in order that they may be used by communications common carriers to provide television pickup and STL services to television stations.

Band D		
12700–12725 Mc	12875–12900 Mc	13050–13075 Mc
12725–12750 Mc	12900–12925 Mc	13075–13100 Mc
12750–12775 Mc	12925–12950 Mc	13100–13125 Mc
12775–12800 Mc	12950–12975 Mc	13125–13150 Mc
12800–12825 Mc	12975–13000 Mc	13150–13175 Mc
12825–12850 Mc	13000–13025 Mc	13175–13200 Mc
12850–12875 Mc	13025–13050 Mc	13200–13225 Mc

Additional frequencies for the transmission of the aural portion of a television pickup may be selected from the remote pickup broadcast frequencies assigned by the FCC.°

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stations operating therein must accept any interference that may be caused by the operation of such equipment. These frequencies are also shared with other communications services and exclusive channel assignments will not be made, nor is the channeling shown in Bands A and C necessarily that which will be employed by such other services. By final Report and Order in Docket 11866, the Commission proposes to delete Band C for use by broadcast auxiliary services.

° Frequencies in the bands 16000–18000 Mc and 26000–30000 Mc are available for assignment on a case-by-case basis for television pickup, STL, and inter-city relay purposes. Channel widths and frequency tolerance will be specified in individual authorizations. The frequencies between 17850 and 18000 Mc must accept any interference that may be caused by incidental radiations of industrial, scientific, and medical (ISM) equipment.

Radio Order Circuits

Remote pickup base stations may be authorized to provide two-way communication between the studio and transmitter of a television station which has a television channel STL.

The following frequencies may be assigned for radio order circuits. They are licensed for unlimited time operation, but their use is secondary to other need for the same frequency(s).

Group	*Frequency*	*Type of Emission*
I	26.07 Mc ° 26.09 Mc ° 26.11 Mc 26.45 Mc	20-A-3 or 20-F-3
J	26.13 Mc 26.47 Mc	20-A-3 or 20-F-3

° Use is subject to the condition that no harmful interference is caused to the reception of high-frequency broadcast stations.

OTHER FREQUENCIES OF INTEREST TO BROADCASTERS

Motion Picture Radio Service

Rules and regulations governing the Motion Picture Radio Service are found in Part 11, Subpart I. Part 11 covers all of the Industrial Radio Services and was set up to prescribe the manner in which frequencies may be made available for radio communication and control facilities to various industrial enterprises which, for safety purposes or other necessity, require radio transmitting facilities in order to function efficiently.

Of all the types of industrial enterprises covered in Part 11, only the Motion Picture Radio Service seems to be applicable to use by broadcasters, and this service may only be used by broadcasters while they are engaged in the production or filming of motion pictures (newsreels, documentaries, features, etc.). Since other services are both more practicable and more economical for general use as auxiliary broadcast stations, the Motion Picture Radio Service should be considered only by television stations which employ full-time motion picture crews, or by companies engaged in the business of making motion pictures for use either by theatres or television stations.

The frequencies allocated to this service cannot be used for video transmissions, but would provide a mobile telephone service, or a radio telephone circuit for transmission of communications relating to the operation of a film crew, or to coordinate action during the filming of motion pictures.

Motion Picture Radio Service stations may communicate with other stations in the same service, and with Government stations where such communication is needed for cooperation and coordination of activities. They may not communicate with broadcast or auxiliary stations, or be used for direct transmission of program material to any broadcast or auxiliary station. For a more detailed explanation of permissible communications, see Sec. 11.151.

All communications in this service are to be limited to the minimum practicable transmission time, and some type of standard operating procedure must be employed by each licensee. Continuous radiation of an unmodulated carrier is prohibited, except when necessary for test purposes, or when specifically authorized in writing by the Commission.

The power which may be used by a station in the Motion Picture Radio Service is limited to the minimum required for satisfactory technical operation commensurate with the size of the area to be served and local conditions which affect radio trans-

mission and reception. In cases of harmful interference, the Commission may order a change in power, or antenna height, or both.

All transmitter adjustments or tests during or coincident with the installation, servicing, or maintenance of a Motion Picture Radio Station which may affect the proper operation of the station must be made by, or under the immediate supervision and responsibility of a first or second-class commercial radio operator licensee. If use of radio telegraphy is contemplated, either a first or second-class commercial radiotelegraph operator licensee is required.

Stations in the Motion Picture Radio Service which employ radiotelephony may be operated by persons holding a commercial radio license or permit of any class except the Aircraft Radiotelephone Operators Authorization. Under certain conditions, some of the stations may be operated by unlicensed persons, but in no case is the station licensee relieved of the responsibility for the station's proper operation, and as stated above all adjustments and tests require either a first- or second-class commercial radio operator. For a detailed discussion of operator requirements, see Sec. 11.154.

Motion Picture Radio Service stations may be remotely controlled if wire lines are used for the control.

Frequencies Used for Motion Picture Radio Service Stations

All assignments of frequencies to base and mobile stations in the Motion Picture Radio Service are on *a shared basis with other services.*

Certain other frequencies are available to the Motion Picture Radio Service for use in developmental operations for the service, but only the frequencies available for assignment without this limitation are shown below. For a complete listing of frequencies for this service see Secs. 11.402, 11.403 and 11.404 of Subpart I of Part 11 of the FCC Rules.

Base and Mobile Stations

Frequency	*Type of Emission*	*Notes*
1628 Kc	8-A-3 or 40-F-3	All shared with other services.
1652 Kc		
2292 Kc *		* Also subject to the conditions that harmful interference shall not be caused to the service of any station not in the Industrial Radio Service which, at the discretion of the Commission, may have priority on the frequency or frequencies used for the service to which interference is caused.
2398 Kc *		
4637.5 Kc *		
49.70 Mc		
49.74 Mc		** These frequencies are available for assignment to remote pickup stations and the same transmitting equipment may be cross-licensed as a remote pickup station under which license it could perform the services of a remote pickup station.
49.78 Mc		
49.82 Mc		
152.87 Mc **		
152.93 Mc **		
152.99 Mc **		
173.225 Mc		
173.275 Mc		
173.325 Mc		
173.375 Mc		

Operational Fixed Stations

Subject to the condition that no harmful interference will be caused to reception of television channel numbers 4 or 5, the following frequencies are available for assignment to operational fixed stations in the Motion Picture Radio Service *on a shared basis* with other services.

The type of emission employed for these stations is either 8-A-3 or 40-F-3.

72.02 Mc	72.82 Mc	73.66 Mc	74.50 Mc
72.06 Mc	72.86 Mc	73.70 Mc	74.54 Mc
72.10 Mc	72.90 Mc	73.74 Mc	74.58 Mc
72.14 Mc	72.94 Mc	73.78 Mc	75.42 Mc
72.18 Mc	73.02 Mc	73.82 Mc	75.46 Mc
72.22 Mc	73.06 Mc	73.90 Mc	75.50 Mc
72.26 Mc	73.10 Mc	73.94 Mc	75.54 Mc
72.30 Mc	73.14 Mc	73.98 Mc	75.58 Mc
72.34 Mc	73.18 Mc	74.02 Mc	75.62 Mc
72.38 Mc	73.22 Mc	74.06 Mc	75.66 Mc
72.42 Mc	73.26 Mc	74.10 Mc	75.70 Mc
72.46 Mc	73.30 Mc	74.14 Mc	75.74 Mc
72.50 Mc	73.34 Mc	74.18 Mc	75.78 Mc
72.54 Mc	73.38 Mc	74.22 Mc	75.82 Mc
72.58 Mc	73.42 Mc	74.26 Mc	75.86 Mc
72.62 Mc	73.46 Mc	74.30 Mc	75.90 Mc
72.66 Mc	73.50 Mc	74.34 Mc	75.94 Mc
72.70 Mc	73.54 Mc	74.38 Mc	75.98 Mc
72.74 Mc	73.58 Mc	74.42 Mc	
72.78 Mc	73.62 Mc	74.46 Mc	

Citizens Radio Service

Rules and regulations governing the Citizens Radio Service are found in Part 19, which begins with this statement of basis and purpose:

"The following rules and regulations are issued pursuant to the provisions of Title III of the Communications Act of 1934, as amended, which vests authority in the Federal Communications Commission to regulate radio transmissions and to issue licenses for radio stations. These rules are designed to provide for private short-distance radio communication, radio signaling, and control of objects or devices by radio, with minimum licensing requirements, and to provide procedures whereby manufacturers of radio and equipment to be used or operated in the Citizens Radio Service may obtain type approval of such equipment."

Possible Uses of the Citizens Radio Service by Broadcasters

Class A, B, and D Stations: Each station in the Citizens Radio Service is authorized to communicate *only with other stations in the same service.* Communications with stations licensed under other parts of the FCC rules, such as radio broadcast or auxiliary broadcast stations, are prohibited. Citizens Radio Service stations, where authorized by the FCC, may be used as a privately owned mobile radiotelephone, as a privately owned radiotelephone circuit for any combination of broadcast station offices/studios/transmitter/home of a staff member licensed in this service, or as a cue and order circuit when the radio or television station is ineligible for a cue and order circuit under Part 4 of the FCC Rules. They may also be used for communications purposes in connection with adjustment and maintenance of antenna systems or in connection with field intensity surveys.

Transmissions must, however, be confined to business or personal communications; they may not be used to carry program material of any kind, either directly or indirectly, for use in connection with radio broadcasting, or for direct transmission to the public through public address systems or any other means. The stations may not be used to carry communications for hire, or for any purpose contrary to federal, state or local law.

Citizens Radio Service transmissions may be made at any time during day or night, but must be limited to the minimum practicable transmission time. An unmodulated carrier wave may not be emitted except for brief tests or during adjustments to the transmitter.

Class C Stations: Class C stations may be used only for radio control of objects and devices. They would provide a means of radio controlled alarm devices, or could be used to open and shut doors for convenience in moving scenery in television stations, or other uses of a similar nature.

Eligibility for Use of the Citizens Radio Service

No hard and fast definitions of "eligibility" for the Citizens Radio Service may be laid down. In general, the Commission will not authorize the use of one service if the applicant is eligible for a like assignment in another service. This policy would preclude the use of a Citizens Radio Service station as a cue and order circuit where the station had a radio studio-transmitter link circuit in Part 4 of the Rules. Applications must clearly show (1) what use is intended to be made of the stations, and (2) why the applicant is not eligible to conduct the proposed operation under the rules governing some other service.

Any individual, partnership, association, trust, corporation, or duly authorized Civil Defense organization may apply for a Citizens Radio Service license, provided:

(a) Not more than one person shall be eligible as licensee of the same apparatus, and,

(b) The licensee of a Class A, B, or D station must be 18 or more years of age. The licensee of a Class C station must be 12 or more years of age.

(c) The licensee must be a United States citizen.

Citizens Radio Service stations, when employing radiotelephony, may be operated by any person designated by the licensee, but the licensee will be held responsible for the operation of the station in accordance with all applicable provisions of treaty, laws, and regulations. The operator need hold no special license, however, *all transmitter adjustments or tests during or coincident with the installation, servicing, or maintenance of a Citizens Radio Station which may affect the proper operation of the station must be made by or under the immediate supervision and responsibility of a first- or second-class radio-telephone operator licensee.* If use of radio telegraphy is contemplated, see Sec. 19.71 for operator requirements.

The license for a Citizens Radio Service station is issued for a term of five years from date of issuance.

Either amplitude, phase, or frequency modulation may be employed for radiotelephony on Class A and Class B Citizens Radio Service stations. Class C stations may be used only for remote control of objects and devices, and except when used to control model aircraft, may use only on-off unmodulated or amplitude tone modulated carrier. Class D stations are authorized to use amplitude voice modulation for radiotelephone communications only.

Frequencies Used for Citizens Radio Service Stations

Frequencies for use in this service are generally contained in the following blocks. For specific information regarding their usage see Subpart C, Part 19 of the FCC Rules.

26.965–27.255 Mc
460.05–460.95 Mc
462.55–466.45 Mc

FREQUENCY TOLERANCES

Standard Broadcast

The operating frequency of each station shall be maintained within ±20 cycles of the assigned frequency.

FM Broadcast

The center frequency of each FM broadcast station shall be maintained within ±2,000 cycles of the assigned center frequency.

TV Broadcast

(a) The carrier frequency of the visual transmitter shall be maintained within ±1,000 cycles of the authorized carrier frequency.

(b) The center frequency of the aural transmitter shall be maintained 4.5 megacycles, ±1,000 cycles, above the visual carrier frequency.

Non-commercial—FM

(a) The center of each noncommercial educational FM broadcast station licensed for transmitter power output of 10 watts or less shall be maintained within 3,000 cycles of the assigned center frequency.

(b) The center frequency of each non-commercial educational FM broadcast station licensed for transmitter power output above 10 watts shall be maintained within 2,000 cycles of the assigned center frequency.

Remote Pickup

The licensee of a remote pickup broadcast station shall maintain the operating frequency of its stations in accordance with the following: *

Frequency range	Tolerance (percent)	
	Base station	Mobile station
1606 to 2830 Kc:		
200 watts or less	0.01	0.02
Over 200 watts [1]	0.005	0.02
26.11 to 26.47 Mc:		
5 watts or less	0.005	0.02
Over 5 watts	0.005	0.005
152.87 to 153.35, 166.25 and 170.15 Mc:		
5 watts or less	0.005	0.01
Over 5 watts	0.005	0.005
450.05 to 451.95 Mc:		
All powers	0.01	0.01

[1] The listing of tolerance for power over 200 watts is in accordance with treaty values and shall not be construed as a finding that such power will be authorized.

AM/FM/TV (Aural Only) STL and FM Intercity Relay

The licensee of each broadcast STL or FM intercity relay station shall maintain the operating frequency of the station within ±0.005 percent of the assigned frequency.

TV STL Remote Pickup or TV Intercity Relay

(a) The licensee of a television auxiliary broadcast station shall maintain the operating frequency of its station so that the normal sideband energy shall fall within the assigned channel. If transmission is by asymmetrical sideband operation,

* Remote pickup broadcast stations now operating in the frequency range 30–40 Mc and on frequencies above 154 Mc will, during the period such operation continues pending frequency reassignment of these stations pursuant to the proceedings in Docket No. 6651, retain the frequency tolerance requirements of their present licenses.

suitable filters or other devices shall be employed to insure a minimum of radiated energy outside the assigned channel.

(b) Television STL stations operating on frequencies shown in Section 4.603(b) shall maintain their operating frequency within 0.005 percent of the assigned frequency.

TV Translators

The licensee of a television broadcast translator station shall maintain the visual carrier frequency and the aural center frequency at the output of the translator within 0.01 percent of its assigned frequencies when the primary station is not on its assigned frequencies, by more than the amount of the departure by the primary station.

Motion Picture Radio Service

(a) Except as provided in paragraph (b) of this section, a permittee or licensee in these services shall maintain the carrier frequency of each authorized transmitter within the following percentage of the assigned frequency:

Frequency range	All fixed and base stations, %	All mobile stations	
		Over 3 watts, %	3 watts or less, %
Below 25 Mc....	0.01	0.01	0.02
25 to 50 Mc.....	0.002	0.002	0.005
50 to 1000 Mc...	0.0005	0.005	0.005
Above 1000 Mc..	[1]	[1]	[1]

[1] To be specified in the station authorization.

(b) In lieu of meeting the requirements of paragraph (a) of this section for the frequency ranges shown below, transmitters authorized prior to November 1, 1958, and transmitters which are operationally integrated with existing radio systems authorized prior to November 1, 1958, may conform to the following frequency tolerances until not later than October 13, 1963:

Frequency range	Transmitter power	
	Over 3 watts, %	3 watts or less, %
25 to 50 Mc.....	0.01	0.02
50 to 220 Mc.....	0.005	0.01
220 to 1000 Mc.....	[1]	[1]

[1] To be specified in the authorization.

(c) For the purpose of determining the frequency tolerance applicable to a particular transmitter in accordance with the foregoing provisions of this section, the power of a transmitter shall he the maximum rated plate power input to its final radio frequency stage, as specified by the manufacturer.

Citizens Radio

The carrier frequency of a station in this service shall be maintained within the following percentage of the authorized frequency:

Class of station	Maximum authorized plate power input	Frequency tolerance	
		Fixed and base, %	Mobile, %
A	3 watts or less	0.001	0.005
A	Over 3 watts	0.001	0.001
B	3 watts or less	.....	0.5
B	Over 3 watts	.....	0.3
C	5 watts or less [1]	.....	0.005
C	Over 5 watts (25.255 Mc only)	.....	0.005
D	5 watts or less	.....	0.005

[1] Class C stations of 3 watts or less plate power input which are used solely for the remote control of objects or devices by radio (other than devices used solely as a means of attracting attention) are permitted a frequency tolerance of 0.01%.

SUMMARY OF FREQUENCIES ALLOCATED TO THE BROADCAST SERVICES

Frequency or Band	*Use*	*Exclusive to Broadcast Service*
535–1605 Kc	107 AM Channels	Yes
1606 Kc 1622 Kc	Remote Pickup Broadcast	Yes
1646 Kc	Remote Pickup Broadcast	Yes
25.87–26.47 Mc	26 Remote Pickup B/c Channels	Yes
54–72 Mc	TV Channels 2–4	Yes
72–76 Mc	78 Motion Picture Radio Serv. Operational and Fixed Channels	No
76–88 Mc	TV Channels 5 & 6	Yes
88–92	20 Non-commercial FM Channels	Yes
92–108 Mc	80 Commercial FM Channels	Yes—except in Hawaii where the 98–108 Mc portion is assigned to Fixed Services and is not used for FM Broadcast.
152.87–153.35 Mc	9 Remote Pickup B/c Channels	No—shared with Industrial Services which have first priority of use.
166.25 Mc 170.15 Mc	Remote Pickup Broadcast	No—Government stations operating on these two frequencies must be protected.
174–216 Mc	TV Channels 7–13	Yes
450–451 Mc 455–456 Mc	20 Remote Pickup B/c Channels	Yes
470–890 Mc	TV Channels 14–83	Yes—except 806–890 Mc which may be assigned for television broadcast translator station operation on a secondary basis. (Sec. 4.702)
942–952 Mc	19 STL Channels	Yes
1990–2110 Mc	7 TV Pickup/STL/Intercity Relay Channels	Yes

SUMMARY OF FREQUENCIES ALLOCATED TO THE BROADCAST SERVICES—(*Continued*)

Frequency or Band	*Use*	*Exclusive to Broadcast Service*
2450–2500 Mc	3 TV Pickup/STL/Intercity Relay Channels	No—must accept interference from I-S-M services. Also used by Fixed and Mobile Services.
6875–7050 Mc	7 TV Pickup/STL/Intercity Relay Channels	Yes
7050–7125 Mc	3 TV Pickup/STL Channels	Yes—bnt temporarily to be used by common carriers to provide service to broadcasters.
10550–10700 Mc	6 TV Pickup/STL/Intercity Relay Channels	No—must accept interference from I-S-M services. Also used by Fixed and Mobile Services.
12700–13225 Mc	21 TV Pickup/STL/Intercity Relay Channels	Yes
16000–18000 Mc	TV Pickup/STL/Intercity Relay Channels	Yes—except 17850–18000 Mc must accept interference from I-S-M services.
26000–30000 Mc	TV Pickup/STL/Intercity Relay Channels	Yes

Part 3

FEDERAL COMMUNICATIONS COMMISSION
PART 3 — RADIO BROADCAST SERVICES

TITLE 47—TELECOMMUNICATION

Chapter 1—Federal Communications Commission

Part 3—Radio Broadcast Services

SUBPART A—STANDARD BROADCAST STATIONS

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SUBPART A—STANDARD BROADCAST STATIONS

Definitions

§ 3.1 **Standard broadcast station.** The term "standard broadcast station" means a broadcasting station licensed for the transmission of radiotelephone emissions primarily intended to be received by the general public and operated on a channel in the band 535–1605 kilocycles.

§ 3.2 **Standard broadcast band.** The term "standard broadcast band" means the band of frequencies extending from 535 to 1605 kilocycles.

§3.3 **Standard broadcast channel.** The term "standard broadcast channel" means the band of frequencies occupied by the carrier and two side bands of a broadcast signal with the carrier frequency at the center. Channels shall be designated by their assigned carrier frequencies. The 107 carrier frequencies assigned to standard broadcast stations shall begin at 540 kilocycles and be in successive steps of 10 kilocycles.

§ 3.4 **Dominant station.** The term "dominant station" means a Class I station, as hereinafter defined, operating on a clear channel.

§ 3.5 **Secondary station.** The term "secondary station" means any station except a Class I station operating on a clear channel.

§ 3.6 **Daytime.** The term "daytime" means that period of time between local sunrise and local sunset.

§ 3.7 **Nighttime.** The term "nighttime" means that period of time between local sunset and 12 midnight local standard time.

§ 3.8 **Sunrise and sunset.** The terms "sunrise and sunset" mean, for each particular location and during any particular month, the time of sunrise and sunset as specified in the instrument of authorization.

§ 3.9 **Broadcast day.** The term "broadcast day" means that period of time between local sunrise and 12 midnight local standard time.

§ 3.10 **Experimental period.** The term "experimental period" means that time between 12 midnight and local sunrise. This period may be used for experimental purposes in testing and maintaining apparatus by the licensee of any standard broadcast station on its assigned frequency and with its authorized power, provided no interference is caused to other stations maintaining a regular operating schedule within such period. No station licensed for "daytime" or "specified hours" of operation may broadcast any regular or scheduled program during this period.

§ 3.11 **Service areas.** (a) The term "primary service area" of a broadcast station means the area in which the groundwave is not subject to objectionable interference or objectionable fading.

(b) The term "secondary service area" of a broadcast station means the area served by the skywave and not subject to objectionable interference. The signal is subject to intermittent variations in intensity.

(c) The term "intermittent service area" of a broadcast station means the area receiving service from the groundwave but beyond the primary service area and subject to some interference and fading.

§ 3.12 **Portable transmitter.** The term "portable transmitter" means a transmitter so constructed that it may be moved about conveniently from place to place, and is

in fact so moved about from time to time, but not ordinarily used while in motion. In the standard broadcast band, such a transmitter is used in making field intensity measurements for locating a transmitter site for a standard broadcast station. A portable broadcast station will not be licensed in the standard broadcast band for regular transmission of programs intended to be received by the public.

§ 3.13 **Auxiliary transmitter.** The term "auxiliary transmitter" means a transmitter maintained only for transmitting the regular programs of a station in case of failure of the main transmitter.

§ 3.14 **Technical definitions.** (a) *Combined audio harmonics.* The term "combined audio harmonics" means the arithmetical sum of the amplitudes of all the separate harmonic components. Root sum square harmonic readings may be accepted under conditions prescribed by the Commission.

(b) *Effective field.* The term "effective field" or "effective field intensity" is the root-mean-square (RMS) value of the inverse distance fields at a distance of 1 mile from the antenna in all directions in the horizontal plane.

(c) *Operating power.* "Operating power" is the power that is actually snpplied to the radio station antenna.

(d) *Maximum rated carrier power.* "Maximum rated carrier power" is the maximum power at which the transmitter can be operated satisfactorily and is determined by the design of the transmitter and the type and number of vacuum tubes used in the last radio stage.

(e) *Plate input power.* "Plate input power" means the product of the direct plate voltage applied to the tubes in the last radio stage and the total direct current flowing to the plates of these tubes, measured without modulation.

(f) *Antenna power.* "Antenna input power" or "antenna power" means the product of the square of the antenna current and the antenna resistance at the point where the current is measured.

(g) *Antenna current.* "Antenna current" means the radio-frequency current in the antenna with no modulation.

(h) *Antenna resistance.* "Antenna resistance" means the total resistance of the transmitting antenna system at the operating frequency and at the point at which the antenna current is measured.

(i) *Modulator stage.* "Modulator stage" means the last amplifier stage of the modulating wave which modulates a radio-frequency stage.

(j) *Modulated stage.* "Modulated stage" means the radio-frequency stage to which the modulator is coupled and in which the continuous wave (carrier wave) is modulated in accordance with the system of modulation and the characteristics of the modulating wave.

(k) *Last radio stage.* "Last radio stage" means the oscillator or radio-frequency-power amplifier stage which supplies power to the antenna.

(l) *Percentage modulation (amplitude).* "Percentage modulation" with respect to an amplitude modulated wave means the ratio of half the difference between the maximum and minimum amplitudes of the amplitude modulated wave to the average amplitude expressed in percentage.

(m) *Maximum percentage of modulation.* "Maximum percentage of modulation" means the greatest percentage of modulation that may be obtained by a transmitter without producing in its output harmonics of the modulating frequency in excess of those permitted by these regulations.

(n) *High level modulation.* "High level modulation" is modulation produced in the plate circuit of the last radio stage of the system.

(o) *Low level modulation.* "Low level modulation" is modulation produced in an earlier stage than the final.

(p) *Plate modulation.* "Plate modulation" is modulation produced by introduction of the modulating wave into the plate circuit of any tube in which the carrier frequency wave is present.

(q) *Grid modulation.* "Grid modulation" is modulation produced by introduction of the modulating wave into any of the grid circuits of any tube in which the carrier frequency wave is present.

(r) *Blanketing.* Blanketing is that form of interference which is caused by the presence of a broadcast signal of 1 v/m or greater intensity in the area adjacent to the antenna of the transmitting station. The 1 v/m contour is referred to as the blanket contour and the area within this contour is referred to as the blanket area.

Administrative Procedure

§ 3.17 **Cross reference.** See §§ 1.300 to 1.364, Subpart D of Part 1 of this chapter, for general requirements as to applications, filing of applications and description of application forms, other forms and information to be filed with the Commission, the manner in which applications are processed, and provisions applying to action on applications.

§ 3.18 **Notification of filing of applications.** In order to minimize harmful interference at the National Radio Astronomy Observatory site located at Green Bank, Pocahontas County, West Virginia, and at the Naval Radio Research Observatory at Sugar Grove, Pendleton County, West Virginia, an applicant for authority to construct a new standard broadcast station or for authority to make changes in the frequency, power, antenna height, or antenna directivity of an existing station within the area bounded by 39° 15′ N on the north, 78° 30′ W on the east, 37° 30′ N on the south, and 80° 30′ W on the west shall, at the time of filing such application with the Commission, simultaneously notify the Director, National Radio Astronomy Observatory, P.O. Box No. 2, Green Bank, West Virginia, in writing, of the technical particulars of the proposed station. Such notification shall include the geographical coordinates of the antenna, antenna height, antenna directivity if any, proposed frequency, type of emission, and power. In addition, the applicant shall indicate in his application to the Commission the date notification was made to the observatory. After receipt of such applications, the Commission will allow a period of twenty (20) days for comments or objections in response to the notifications indicated. If an objection to the proposed operation is received during the twenty-day period from the National Radio Astronomy Observatory for itself or on behalf of the Naval Radio Research Observatory, the Commission will consider all aspects of the problem and take whatever action is deemed appropriate.

Allocation of Facilities

§ 3.21 **Three classes of standard broadcast channels.** (a) *Clear channel.* A clear channel is one on which the dominant station or stations render service over wide areas and which are cleared of objectionable interference within their primary service areas and over all or a substantial portion of their secondary service areas.

(b) *Regional channel.* A regional channel is one on which several stations may operate with powers not in excess of 5 kilowatts. The primary service area of a station operating on any such channel may be limited as a consequence of interference to a given field intensity contour.

(c) *Local channel.* A local channel is one on which several stations operate with powers not in excess of 1 kilowatt daytime, and 250 watts nighttime. The primary service area of a station operating on any such channel may be limited as a consequence of interference to a given field intensity contour.

NOTE: The power ceiling for Class IV stations under the North American Regional Broadcasting Agreement (NARBA) is 250 watts. The Agreement between the United States of America and the United Mexican States Concerning Radio Broadcasting in the Standard Broadcast Band would permit daytime operation of Class IV stations with a maximum power of 1 kilowatt in all areas of the United States more than 100 kilometers (62 miles) from the United States-Mexican border. Accordingly, before the Commission will take final action with respect to an application proposing the use of daytime power in excess of 250 watts by a Class IV station, appropriate coordination of the rules providing for the use of such power must be effected with other North American countries. (See note under § 3.28(b).)

§ 3.22 **Classes and power of standard broadcast stations.** (a) *Class I station.* A Class 1 station is a dominant station operating on a clear channel and designed

to render primary and secondary service over an extended area and at relatively long distances. Its primary service area is free from objectionable interference from other stations on the same and adjacent channels, and its secondary service area free from interference except from stations on the adjacent channel, and from stations on the same channel in accordance with the channel designation in § 3.25 or § 3.182. The operating power shall be not less than 10 kilowatts nor more than 50 kilowatts. (Also see § 3.25(a) for further power limitation.)

(b) *Class II station.* A Class II station is a secondary station which operates on a clear channel (see § 3.25) and is designed to render service over a primary service area which is limited by and subject to such interference as may be received from Class I stations. A station of this class shall operate with power not less than 0.25 kilowatt nor more than 50 kilowatts. Whenever necessary a Class II station shall use a directional antenna or other means to avoid interference with Class I stations and with other Class II stations, in accordance with § 3.182.

(c) *Class III station.* A Class III station is a station which operates on a regional channel and is designed to render service primarily to a metropolitan district and the rural area contiguous thereto. Class III stations are subdivided into two classes. (The term "metropolitan district" as used in this paragraph is not limited in accordance with the definition given by the Bureau of the Census but includes any principal center of population in any area.)

(1) *Class III-A station.* A Class III-A station is a Class III station which operates with power not less than 1 kilowatt nor more than 5 kilowatts and the service area of which is subject to interference in accordance with § 3.182.

(2) *Class III-B station.* A Class III-B station is a Class III station which operates with a power not less than 0.5 kilowatt, and not more than 1 kilowatt nighttime and 5 kilowatts daytime, and the service area of which is subject to interference in accordance with § 3.182.

(d) *Class IV Station.* A Class IV station is a station operating on a local channel and designed to render service primarily to a city or town and the suburban and rural areas contiguous thereto. The power of a station of this class shall not be less than 0.1 kilowatt and not more than 0.25 kilowatt nighttime, and 1 kilowatt daytime, and its service area is subject to interference in accordance with § 3.182.

§ 3.23 Time of operation of the several classes of stations. The several classes of standard broadcast stations may be licensed to operate in accordance with the following:

(a) Unlimited time permits operation without a maximum limit as to time.

(b) Limited time is applicable to Class II (secondary stations) operating on a clear channel with facilities authorized before Oct. 30, 1959. It permits operation of the secondary station during daytime, and until local sunset if located west of the dominant station on the channel, or if located east thereof, until sunset at the dominant station, and in addition during night hours, if any, not used by the dominant station or stations on the channel.

(c) Daytime permits operation during the hours between average monthly local sunrise and average monthly local sunset. Daytime stations operating on local channels with a power of 0.1 kw or 0.25 kw may, upon notification to the Commission and to the Engineer in Charge of the radio district in which they are located, operate at hours beyond those specified in their license.

(d) Sharing time permits operation during hours which are so restricted by the station license as to require a division of time with one or more other stations using the same channel.

(e) Specified hours means that the exact operating hours are specified in the license. (The minimum hours that any station shall operate are specified in § 3.71.) Specified hours stations operating on local channels with a power of 0.1 kw or 0.25 kw, except those sharing time with other stations may, upon notification to the Commission and the Engineer in Charge of the radio district in which they are located, operate at hours beyond those specified in their license.

§ 3.24 Broadcast facilities; showing required. An authorization for a new standard broadcast station or increase in facilities of an existing station will be issued only

after a satisfactory showing has been made in regard to the following, among others:

(a) That the proposed assignment will tend to effect a fair, efficient, and equitable distribution of radio service among the several states and communities.

(b) That objectionable interference will not be caused to existing stations or that if interference will be caused the need for the proposed service outweighs the need for the service which will be lost by reason of such interference. That the proposed station will not suffer interference to such an extent that its service would be reduced to an unsatisfactory degree. (For determining objectionable interference, see §§ 3.182 and 3.186.)

(c) That the applicant is financially qualified to construct and operate the proposed station.

(d) That the applicant is legally qualified. That the applicant (or the person or persons in control of an applicant corporation or other organization) is of good character and possesses other qualifications sufficient to provide a satisfactory public service.

(e) That the technical equipment proposed, the location of the transmitter, and other technical phases of operation comply with the regulations governing the same, and the requirements of good engineering practice. (See technical regulations of this subpart and § 3.188.)

(f) That the facilities sought are subject to assignment as requested under existing international agreements and the rules and regulations of the Commission.

(g) That the population within the 1 v/m contour does not exceed 1.0 percent of the population within the 25 mv/m contour: *Provided, however,* That where the number of persons within the 1 v/m contour is 300 or less the provisions of this subparagraph are not applicable.

(h) That, in the case of an application for a Class II station, the proposed station would radiate, during two hours following local sunrise and two hours preceding local sunset, in any direction toward the 0.1 mv/m groundwave contour of a co-channel United States Class I station, no more than the maximum radiation values permitted under the provisions of 3.187.

(i) That the public interest, convenience, and necessity will be served through the operation under the proposed assignment.

Frequency Allocation by Classes of Stations

§ 3.25 Clear channels: Class I and II stations. The frequencies in the following tabulations are designated as clear channels and assigned for use by the Classes of stations given:

(a) To each of the channels below, except as provided in paragraph (e) of this section, there will be assigned one Class I station and there may be assigned one or more Class II stations within the continental limits of the United States operating limited time or daytime only: 640, 650, 660, 670, 700, 720, 750, 760, 770, 780, 820, 830, 840, 870, 880, 890, 1020, 1040, 1100, 1120, 1160, 1180, 1200, and 1210 kc. There also may be assigned to these frequencies Class II stations operating unlimited time in Alaska, Hawaii, Virgin Islands and Puerto Rico which will not deliver over 5 microvolts per meter groundwave day or night or 25 microvolts per meter 10 percent time skywave at night at any point within the continental limits of the United States. The power of the Class I stations on these channels shall not be less than 50 kw.

NOTE: On the frequency 770 kilocycles, two Class I stations may be assigned.

(b) To each of the channels below there may be assigned Class I and Class II stations: 680, 710, 810, 850, 940, 1000, 1030, 1060, 1070, 1080, 1090, 1110, 1130, 1140, 1170, 1190, 1500, 1510, 1520, 1530, 1540, 1550, and 1560 kilocycles.

NOTE: Class I and II stations on 1540 kc shall deliver not over 5 microvolts per meter groundwave or 25 microvolts per meter 10 percent time skywave at any point of land in the Bahama Islands, and such stations operating nighttime (i.e., sunset to sunrise at the

location of the Class II station) shall be located not less than 650 miles from the nearest point of land in the Bahama Islands.

(c) For Class II stations which will not deliver over 5 microvolts per meter groundwave or 25 microvolts per meter 10 percent time skywave at any point on the Canadian border and provided that such stations operating nighttime (i.e., sunset to sunrise at the location of the Class II station) are located not less than 650 miles from the nearest Canadian border, 540, 690, 740, 860, 990, 1010, and 1580 kilocycles.

NOTE 1: See § 2.104(a) of this chapter with respect to use of 540 kc.
NOTE 2: A station on 1010 kilocycles shall also protect a Class I-B station at Havana, Cuba.

(d) In continental United States, for Class II stations which operate daytime only with power not in excess of 1 kilowatt and which will not deliver over 5 microvolts per meter groundwave at any point on the Mexican border, and in Alaska, Hawaii, Puerto Rico, and the Virgin Islands, for Class II stations which will not deliver over 5 microvolts per meter groundwave or 25 microvolts per meter 10 percent time skywave at any point on the said border: 730, 800, 900, 1050, 1220 and 1570 kilocycles.

NOTE 1: See North American Regional Broadcasting Agreement, Havana, 1937 (Appendix I, Table IV), for use of 1050 kc by a station in New York.
NOTE 2: See agreement with Mexico for further use of 1220 kc.

§ 3.26 Regional channels: Classes III-A and III-B stations. The following frequencies are designated as regional channels and are assigned for use by Class III-A and III-B stations: 550, 560, 570, 580, 590, 600, 610, 620, 630, 790, 910, 920, 930, 950, 960, 970, 980, 1150, 1250, 1260, 1270, 1280, 1290, 1300, 1310, 1320, 1330, 1350, 1360, 1370, 1380, 1390, 1410, 1420, 1430, 1440, 1460, 1470, 1480, 1590, and 1600 kilocycles.

NOTE: See North American Regional Broadcasting Agreement for special provisions concerning the assigning of Class II stations in other countries of North America to 560, 570, 590, 630, and 1270 kcs. Such stations shall be protected from interference in accordance with appendix II, table 1, of said agreement.

§ 3.27 Local channels: Class IV stations. The following frequencies are designated as local channels and are assigned for use by Class IV stations: 1230, 1240, 1340, 1400, 1450, and 1490 kilocycles.

§ 3.28 Assignment of stations to channels. (a) The individual assignments of stations to channels which may cause interference to other United States stations only, shall be made in accordance with the provisions of this part for the respective classes of stations involved. (For determining objectionable interference, see §§ 3.182 and 3.186.)

(b) In all cases where an individual station assignment may cause interference with or may involve a channel assigned for priority of use by a station in another North American country, the classifications, allocation requirements and engineering standards set forth in the North American Regional Broadcasting Agreement shall be observed.

NOTE: Pending action with respect to ratification and entry into force of the North American Regional Broadcasting Agreement, Washington, 1950 (referred to herein as NARBA), and the Agreement between the United States of America and the United Mexican States Concerning Radio Broadcasting in Standard Broadcast Band (referred to herein as the U.S./Mexican Agreement) no assignment for a standard broadcast station will be made which would be inconsistent with the terms of these agreements.

On an interim basis while protection by countries not signatory to either of these agreements continues for assignments in the United States, no assignment for a standard broadcast station will be made which would cause objectionable interference to a duly notified station in a North American country which is not signatory to the NARBA or the U.S./Mexican Agreement (i.e., Haiti). For purposes of this paragraph, interference will, in general, be determined in accordance with the engineering standards set forth in the NARBA.

The Haitian stations considered to be duly notified will be those notified and accepted in

accordance with past agreements, and those subsequently notified in substantial accordance with the procedures and understandings that have pertained thus far.

Engineering standards now in force domestically differ in some respects from those specified for international purposes. For example, the engineering standards specified for international purposes will be used to determine (1) the extent to which interference might be caused by a proposed station in the United States to a station in another North American country and (2) whether the United States should register an objection to any new or changed assignment notified by another North American country. The domestic standards in effect in the United States will be used to determine the extent to which interference exists or would exist from a foreign station where the value of such interference enters into a calculation (1) of the service to be rendered by a proposed operation in the United States or (2) of the permissible interfering signal from one station in the United States towards another United States station.

In general, an application for standard broadcast station assignment, the grant of which would be consistent with provisions of the NARBA and the U.S./Mexican Agreement and would not cause objectionable interference to a duly notified station in a North American country not signatory to either agreement, will be considered and acted upon by the Commission in accordance with its rules and established procedure for action upon such applications, even though these agreements may not yet have entered into force. However, in particular cases such applications may also present considerations of an international nature which require that a different procedure be followed. In such cases the procedure to be followed will be determined by the Commission in the light of the special considerations involved.

Special provisions of a procedural nature respecting the consideration of applications for standard broadcast station assignments pending action with respect to ratification and entry into force of NARBA and the U.S./Mexican Agreement, and respecting the consideration of applications the grant of which would cause objectionable interference to duly notified station in countries not signatory to either of these agreements are set out in § 1.300 of this chapter.

(c) Upon showing that a need exists, a Class II, III, or IV station may be assigned to a channel available for such class, even though interference will be received within its normally protected contour; *Provided:* (1) No objectionable interference will be caused by the proposed station to existing stations or that if interference will be caused, the need for the proposed service outweighs the need for the service which will be lost by reason of such interference; and (2) primary service will be provided to the community in which the proposed station is to be located; and (3) the interference received does not affect more than 10 percent of the population in the proposed station's normally protected primary service area. However, in the event that the nighttime interference received by the proposed station would exceed this amount, then an assignment may be made if the proposed station would provide either a standard broadcast nighttime facility to a community not having such a facility or if 25 percent or more of the nighttime primary service area of the proposed station is without primary nighttime service.

§ 3.29 **Class IV stations on regional channels.** No license will be granted for the operation of a Class IV station on a regional channel: *Provided, however,* That Class IV stations presently authorized to operate on regional channels will not be required to change frequency, or power, but will not be protected against interference from Class III stations.

§ 3.30 **Station location and program origination.** (a) Except as provided in paragraph (b) of this section, each standard broadcast station will be licensed to serve primarily a particular city, town, or other political subdivision which will be specified in the station license and the station will be considered to be located in such place. Unless licensed as a synchronous amplifier transmitter, each station shall maintain a studio, which will be known as the main studio, in the place where the station is located provided that the main studio may be located at the transmitter site whether or not the transmitter site is in the place where the station is located. A majority (computed on the basis of duration and not number) of a station's programs or in the case of a station affiliated with a network, ⅔ of such station's non-network programs, whichever is smaller, shall originate from the main studio or from other studios or remote points situated in the place where the station is located.

(b) Stations will be licensed to serve more than one city, town, or other political

subdivision only where a satisfactory showing is made that each such place meets all the requirements of the rules and regulations of this subpart with respect to the location of main studios, that the station can and will originate a substantial number of local live programs from each such place; and that the requirements as to origination of programs contained in paragraph (a) of this section would place an unreasonable burden on the station if it were licensed to serve only one city, town, or other political sub-division. A station licensed to serve more than one place shall be considered to be located in and shall maintain main studios in each such place. With respect to such station the requirements as to origination of programs contained in paragraph (a) of this section shall be satisfied by the origination of programs from any or all of the main studios or from other studios and remote points situated in any or all of the places in which the main studios are located.

(c) The transmitter of each standard broadcast station shall be so located that primary service is delivered to the borough or city in which the main studio is located in accordance with the rules and regulations of this subpart.

§ 3.31 **Authority to move main studio.** The licensee of a station shall not move its main studio outside the borders of the borough or city, state, district, territory, or possession in which it is located, unless such move is to the location of the station's transmitter, without first securing a modification of construction permit or license. The licensee shall promptly notify the Commission of any other change in location of the main studio.

§ 3.32 **Special experimental authorizations.** (a) Special experimental authorization may be issued to the licensee of a standard broadcast station in addition to the regular license upon informal application therefor and upon a satisfactory showing in regard to the following, among others:

(1) That the applicant has a program of research and experimentation which indicates reasonable promise of contribution to the development and practical application of broadcasting, and will be in addition to and advancement of the work that can be accomplished under its regular license.

(2) That the experimental operation and experimentation will be under the direct supervision of a qualified engineer with an adequate staff of engineers qualified to carry on the program of research and experimentation.

(3) That the public interest, convenience, and necessity will be served by granting the authorization requested.

(b) In case a special experimental authorization permits additional hours of operation, no licensee shall transmit any commercial or sponsored program or make any commercial announcement during such time of operation. In case of other additional facilities, no additional charge shall be made by reason of transmission with such facilities.

(c) A special experimental authorization will not be extended after the actual experimentation is concluded.

(d) The program of research and experimentation as outlined in the application for a special experimental authorization shall be adhered to in the main unless the licensee is authorized to do otherwise by the Commission.

(e) The Commission may require from time to time a broadcast station holding such experimental authorization to conduct experiments that are deemed desirable and reasonable.

(f) A supplemental report shall be filed with and made a part of each application for an extension of a special experimental authorization and shall include statements of the following:

(1) Comprehensive summary of all research and experimentation conducted.

(2) Conclusions and outline of proposed program for further research and development.

(3) Comprehensive summary and conclusions as to the social and economic effects of its use.

§ 3.33 **Antenna systems; showing required.** (a) An application for authority to install a broadcast antenna shall specify a definite site and include full details of the antenna design and expected performance. (Site-to-be-determined applications

which were on file prior to October 28, 1953, may be granted conditioned upon the filing within 60 days of such grant of an application for modification of permit specifying a site conforming to Commission's rules and standards.)

(b) All data necessary to show compliance with the terms and conditions of the construction permit must be filed with the license application. If the station is using a directional antenna, a proof of performance must also be filed.

§ 3.34 **Normal license period.** All standard broadcast station licenses will be issued for a normal license period of three years. Licenses will be issued to expire at the hour of 3:00 a.m., e.s.t., in accordance with the following schedule and at three-year intervals thereafter.

(1) For stations located in Delaware and Pennsylvania, August 1, 1957.
(2) For stations located in Maryland, District of Columbia, Virginia, West Virginia, October 1, 1957.
(3) For stations located in North Carolina, South Carolina, December 1, 1957.
(4) For stations located in Florida, Puerto Rico and Virgin Islands, February 1, 1958.
(5) For stations located in Alabama and Georgia, April 1, 1958.
(6) For stations located in Arkansas, Louisiana and Mississippi, June 1, 1958.
(7) For stations located in Tennessee, Kentucky and Indiana, August 1, 1958.
(8) For stations located in Ohio and Michigan, October 1, 1958.
(9) For stations located in Illinois and Wisconsin, December 1, 1958.
(10) For stations located in Iowa and Missouri, February 1, 1956.
(11) For stations located in Minnesota, North Dakota, South Dakota, Montana and Colorado, April 1, 1956.
(12) For stations located in Kansas, Oklahoma, Nebraska, June 1, 1956.
(13) For stations located in Texas, August 1, 1956.
(14) For stations located in Wyoming, Nevada, Arizona, Utah, New Mexico and Idaho, October 1, 1956.
(15) For stations located in California, December 1, 1956.
(16) For stations located in Washington, Oregon, Alaska, Guam and Hawaii, February 1, 1957.
(17) For stations located in Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont, April 1, 1957.
(18) For stations located in New Jersey and New York, June 1, 1957.

§ 3.35 **Multiple ownership.** No license for a standard broadcast station shall be granted to any party (including all parties under common control) if:

(a) Such party directly or indirectly owns, operates or controls another standard broadcast station, a substantial portion of whose primary service area would receive primary service from the station in question, except npon a showing that public interest, convenience and necessity will be served through such multiple owuership situation; or

(b) Such party, or any stockholder, officer or director of such party, directly or indirectly owns, operates, controls, or has any interest in, or is an officer or director of any other standard broadcast station if the grant of such license would result in a concentration of control of standard broadcasting in a manner inconsistent with public interest, convenience, or necessity. In determining whether there is such a concentration of control, consideration will be given to the facts of each case with particular reference to such factors as the size, extent and location of areas served, the number of people served, classes of stations involved and the extent of other competitive service to the areas in question. The Commission, however, will in any event consider that there would be such a concentration of control contrary to the public interest, convenience or necessity for any party or any of its stockholders, officers or directors to have a direct or indirect interest in, or be stockholders, officers, or directors of, more than seven standard broadcast stations.

NOTE: 1. The word "control" as used herein is not limited to majority stock ownership, but includes actual working control in whatever manner exercised.

2. In applying the foregoing provisions to the stockholders of a corporation which has more than 50 voting stockholders, only those stockholders need be considered who are officers or directors or who directly or indirectly own 1 percent or more of the outstanding voting stock.

§ 3.36 **Special field test authorization.** (a) Upon a showing that a need exists, a special test authorization to operate a portable or regularly authorized transmitter may be issued to persons desiring to make field intensity surveys to determine values of soil conductivity, or other factors influencing radio wave propagation, in particular areas or paths for the period necessary to conduct the survey. Such authorizations may be granted upon the following conditions:

(1) No objectionable interference will result to the operation of other authorized radio services; in this connection, the power requested shall not exceed that necessary for the purposes of the test.

(2) The carrier will be unmodulated except for half-hourly voice identification.

(3) The plate power ($E_p \times I_p$) of the final stage of the transmitter shall not exceed authorized test power and the antenna current shall be maintained at a constant value for each phase of the test.

(4) The test equipment shall not be permanently installed, unless such installation has been separately authorized. Mobile units shall not be deemed permanent installations.

(5) The equipment must be operated by or under the personal direction of either a licensed radiotelephone first-class or second-class operator.

(6) A report, under oath, containing the measurements, their analysis and other results of the survey shall be filed with the Commission within sixty (60) days from the termination of the test authorization. The measurements taken shall be sufficiently complete, in accordance with § 3.186, so as to permit a determination of the inverse distance field at 1 mile in pertinent directions.

(7) The plate voltage (E_p) and plate current (I_p) of the final stage of the transmitter shall be logged at half-hour intervals and at any time that such power is changed. Certified copies of such log notations shall be submitted to the Commission with the required report.

(8) Operation shall conform to the requirements of Subpart G of this part.

(b) The test equipment, installation and operation thereof need not comply with the requirements of Commission rules and standards except as specified in this section: *Provided however,* That the equipment, installation and operation shall be consistent with good engineering principles and practices.

(c) No authorization shall be issued unless the applicant for such authorization is determined to be legally qualified. Requests for authorizations to operate a transmitter under this section shall be made in writing, signed by the applicant under oath or affirmation (with no special form provided, however), and shall set forth the following information:

(1) Purpose, duration and need for the survey.

(2) Frequency, plate power and time of operation.

(3) A brief description of the test antenna system and its estimated effective field and its proposed location.

(4) In the case of a directional test antenna, an estimate of the maximum fields expected to be radiated in the direction of pertinent broadcast stations.

(5) In the case of a person who is not a licensee or permittee of this Commission the information required by section II of FCC Form 301.

(d) The authorization may be modified or terminated by notification from the Commission if in its judgment such action will promote the public interest, convenience or necessity.

§ 3.37 **Minimum separation between stations.** A license will not be granted for a station on a frequency of ±30 kc from that of another station if the area enclosed by the 25 mv/m groundwave contours of the two stations overlap, nor will a license be granted for the operation of a station on a frequency ±20 kc or ±10 kc from the frequency of another station if the area enclosed by the 25 mv/m groundwave contour of either one overlaps the area enclosed by the 2 mv/m groundwave contour of the other.

§ 3.38 **Limited time authorizations.** No authorization for new Class II Limited Time facilities will be granted. No authorization for modification of existing Class II Limited Time facilities will be granted for a change in frequency, an increase in power, a change in antenna radiation pattern, or a change in station location.

Equipment

§ 3.39 **Indicating instruments—specifications.**

(a) Instruments indicating the plate current or plate voltage of the last radio stage (linear scale instruments) shall meet the following specifications:

(1) Length of scale shall be not less than $2\frac{3}{10}$ inches.

(2) Accuracy shall be at least 2 percent of the full scale reading.

(3) The maximum rating of the meter shall be such that it does not read off scale during modulation.

(4) Scale shall have at least 40 divisions.

(5) Full scale reading shall not be greater than five times the minimum normal indication.

(b) Instruments indicating antenna current, common point current, and base currents shall meet the following specifications:

(1) Instruments having logarithmic or square law scales.

(i) Shall meet same requirements as paragraph (a) (1), (2) and (3) of this section for linear scale instruments.

(ii) Full scale reading shall not be greater than three times the minimum normal indication.

(iii) No scale division above one-third full scale reading (in amperes) shall be greater than one-thirtieth of the full scale reading. (Example: An ammeter meeting requirement (i) having full scale reading of 6 amperes is acceptable for reading currents from 2 to 6 amperes, provided no scale division between 2 and 6 amperes is greater than one-thirtieth of 6 amperes, 0.2 ampere.)

(2) Radio frequency instruments having expanded scales.

(i) Shall meet same requirements as paragraph (a) (1), (2) and (3) of this section for linear scale instruments.

(ii) Full scale reading shall not be greater than five times the minimum normal indication.

(iii) No scale division above one-fifth full scale reading (in amperes) shall be greater than one-fiftieth of the full scale reading. (Example: An ammeter meeting the requirement (i) is acceptable for indicating currents from 1 to 5 amperes, provided no division between 1 and 5 amperes is greater than one-fiftieth of 5 amperes, 0.1 ampere.)

(iv) Manufacturers of instruments of the expanded scale type must submit data to the Commission showing that these instruments have acceptable expanded scales, and the type number of these instruments must include suitable designation.

(c) A thermocouple type ammeter meeting the requirements of paragraph (b) of this section shall be installed in the antenna circuit so as to indicate the antenna current. In the case of directional antennas the same type of ammeters shall be installed to indicate the common point current and the base current of each tower. (The ammeter may be so connected that it is short circuited or open circuited when not actually being read. If open circuited, a make-before-break switch must be employed.)

(d) Remote reading antenna ammeter(s) may be employed and the indications logged as the antenna current, or in the case of directional antenna, the common point current and base currents, in accordance with the following:

(1) Remote reading antenna, common point or base ammeters may be provided by:

(i) Inserting second thermocouple directly in the antenna circuit with remote leads to the indicating instrument.

(ii) Inductive coupling to thermocouple or other device for providing direct current to indicating instrument.

(iii) Capacity coupling to thermocouple or other device for providing direct current to indicating instrument.

(iv) Current transformer connected to second thermocouple or other device for providing direct current to indicating instrument.

(v) Using transmission line current meter at transmitter as remote reading ammeter. See subparagraph (7) of this paragraph.

(vi) Using indications of phase monitor for determining the antenna base currents or their ratio in the case of directional antennas, provided that the base current readings are read and logged in accordance with the provision of the station license, and provided further that the indicating instruments in the unit are connected directly in the current sampling circuits with no other shunt circuits of any nature. The meters in the phase monitor may utilize arbitrary scale divisions provided a calibration curve showing the relationship between the arbitrary scale and the scale of the base meters is maintained at the transmitter location.

(vii) Using indications of remote control equipment provided that the indicating instruments are capable of being connected directly into the antenna circuit at the same point as, but below (transmitter side), the antenna ammeter. The meter(s) in the remote control equipment may utilize an arbitrary scale division provided a calibration curve showing the relationship between the arbitrary scale and the scale of the antenna ammeter is maintained at the remote control point. The meter(s) in the remote control equipment must be calibrated once a week against the regular meter and the results thereof entered in the operating log.

(2) Remote ammeters shall be connected into the antenna circuit at the same point as, but below (transmitter side), the antenna ammeter(s), and shall be calibrated to indicate within 2 percent of the regular meter over the entire range above one-third or one-fifth full scale. See paragraphs (b) (1) (i) (iii) and (b) (2) (i), (iii) of this section.

(3) The regular antenna ammeter, common point ammeter, or base current ammeters shall be above (antenna side) the coupling to the remote meters in the antenna circuit so they do not read the current to ground through the remote meter(s).

(4) All remote meters shall meet the same requirements as the regular antenna ammeter with respect to scale accuracy, etc.

(5) Calibration shall be checked against the regular meter at least once a week.

(6) All remote meters shall be provided with shielding or filters as necessary to prevent any feed-back from the antenna to the transmitter.

(7) In the case of shunt excited antennas, the transmission line current meter at the transmitter may be considered as the remote antenna ammeter provided the transmission line is terminated directly into the excitation circuit feed line, which shall employ series tuning only (no shunt circuits of any type shall be employed) and insofar as practicable, the type and scale of the transmission line meter should be the same as those of the excitation circuit feed line meter (meter in slant wire feed line or equivalent).

(8) Remote reading antenna ammeters employing vacuum tube rectifiers or semiconductor devices are acceptable, provided:

(i) The indicating instruments shall meet all the above requirements for linear scale instruments.

(ii) Data are submitted under oath showing the unit has an over-all accuracy of at least 2 percent of the full scale reading.

(iii) The installation, calibration, and checking are in accordance with the requirements of this paragraph.

(9) In the event there is any question as to the method of providing or the accuracy of the remote meter, the burden of proof of satisfactory performance shall be upon the licensee and the manufacturer of the equipment.

(e) Stations determining power by the indirect method may log the transmission line current in lieu of the antenna current provided the instrument meets the above requirements for antenna ammeters, and further provided that the ratio between the transmission line current and the antenna current is entered each time in the log. In case the station is authorized for the same operating power for both day and nighttime operation, this ratio shall be checked at least once daily. Stations which are authorized to operate with nighttime power different from the daytime power shall check the ratio for each power at least once daily.

(f) No instrument, the seal of which has been broken, or the accuracy of which is questionable, shall be employed. Any instrument which was not originally sealed by the manufacturer that has been opened shall not be used until it has been re-

calibrated and sealed in accordance with the following: Repairs and recalibration of instruments shall be made by the manufacturer, by an authorized instrument repair service of the manufacturer or by some other properly qualified and equipped instrument repair service. In either case the instrument must be resealed with the symbol or trade-mark of the repair service and a certificate of calibration supplied therewith.

(g) Since it is usually impractical to measure the actual antenna current of a shunt excited antenna system, the current measured at the input of the excitation circuit feed line is accepted as the antenna current.

(h) Recording instruments may be employed in addition to the indicating instruments to record the antenna current and the direct plate current and direct plate voltage of the last radio stage provided that they do not affect the operation of the circuits or accuracy of the indicating instruments. If the records are to be used in any proceedings before the Commission as representation of operation with respect to plate or antenna current and plate voltage only, the accuracy must be the equivalent of the indicating instruments and the calibration shall be checked at such intervals as to insure the retention of the accuracy.

(i) The function of each instrument shall be clearly and permanently shown on the instrument itself or on the panel immediately adjacent thereto.

§ 3.40 Transmitter; design, construction, and safety of life requirements.

(a) *Design.* The general design of standard broadcast transmitting equipment [main studio microphone (including telephone lines, if used, as to performance only) to antenna output] shall be in accordance with the following specifications. (In cases where telephone lines are not available to give the performance as required in these specifications a relay transmitter may be authorized to supersede the lines.) For the points not specifically covered below, the principles set out shall be followed: The equipment shall be so designed that:

(1) The maximum rated carrier power (determined by § 3.42) is in accordance with the requirements of § 3.41.

(2) The equipment is capable of satisfactory operation at the authorized operating power or the proposed operating power with modulation of at least 85 to 95 percent with no more distortion than given in (3) below.

(3) The total audio frequency distortion from microphone terminals, including microphone amplifier, to antenna output does not exceed 5 per cent harmonics (voltage measurements of arithmetical sum or r. s. s.) when modulated from 0 to 84 percent, and not over 7.5 percent harmonics (voltage measurements of arithmetical sum or r. s. s.) when modulating 85 percent to 95 percent (distortion shall be measured with modulating frequencies of 50, 100, 400, 1000, 5000 and 7500 cycles up to tenth harmonic or 16000 cycles, or any intermediate frequency that readings on these frequencies indicate is desirable).

(4) The audio frequency transmitting characteristics of the equipment from the microphone terminals (including microphone amplifier unless microphone frequency correction is included in which event proper allowance shall be made accordingly) to the antenna output does not depart more than 2 decibels from that at 1,000 cycles between 100 and 5000 cycles.

(5) The carrier shift (current) at any percentage of modulation does not exceed 5 percent.

(6) The carrier hum and extraneous noise (exclusive of microphone and studio noises) level (unweighted r. s. s.) is at least 50 decibels below 100 percent modulation for the frequency band of 150 to 5000 cycles and at least 40 decibels down outside this range.

(7) The transmitter shall be equipped with suitable indicating instruments in accordance with the requirements of § 3.58 and any other instruments necessary for the proper adjustment and operation of the equipment.

(8) Adequate provision is made for varying the transmitter power output between sufficient limits to compensate for excessive variations in line voltage, or other factors which may affect the power output.

(9) The transmitter is equipped with automatic frequency control equipment capable of maintaining the operating frequency within the limit specified by § 3.59.

(i) The maximum temperature variation at the crystal from the normal operating temperature shall not be greater than,

Plus or minus 0.1° C. when an *X* or *Y* cut crystal is employed, or

Plus or minus 1.0° C. when low temperature coefficient crystal is employed.

(ii) Unless otherwise authorized, a thermometer shall be installed in such manner that the temperature at the crystal can be accurately measured within 0.05° C. for *X* or *Y* cut crystal or 0.5° for low temperature coefficient crystal.

(iii) It is preferable that the tank circuit of the oscillator tube be installed in the temperature controlled chamber.

NOTE: Explanations of excessive frequency deviations will not be accepted when temperature variations are in excess of the values specified.

(10) Means are provided for connection and continuous operation of approved modulation monitor and approved frequency monitor.

(i) The radio frequency energy for operation of the approved frequency monitor shall be obtained from a radio-frequency stage prior to the modulated stage unless the monitor is of such design as to permit satisfactory operation when otherwise connected and the monitor circuits shall be such that the carrier is not heterodyned thereby.

(11) Adequate margin is provided in all component parts to avoid overheating at the maximum rated power output.

(12) Any emission appearing on a frequency removed from the carrier by between 15 kc and 30 kc, inclusive, shall be attenuated at least 25 db below the level of the unmodulated carrier. Compliance with the specification will be deemed to show the occupied bandwidth to be 30 kc or less.

(13) Any emission appearing on a frequency removed from the carrier by more than 30 kc and up to and including 75 kc, inclusive, shall be attenuated at least 35 db below the level of the unmodulated carrier.

(14) Any emission appearing on a frequency removed from the carrier by more than 75 kc shall be attenuated at least 43 + 10 log 10 (power in watts) decibels below the level of the unmodulated carrier, or 80 decibels, whichever is the lesser attenuation.

(b) *Construction.* In general, the transmitter shall be constructed either on racks and panels or in totally enclosed frames protected as required by article 810 of the National Electrical Code (Section 8192(a), (b) and (c)), and as set forth in this paragraph and paragraph (c) of this section.

NOTE: The final stages of high power transmitters may be assembled in open frames provided the equipment is enclosed by a protective fence.

(1) Means shall be provided for making all tuning adjustments, requiring voltages in excess of 350 volts to be applied to the circuit, from the front of the panels with all access doors closed.

(2) Proper bleeder resistors or other automatic means shall be installed across all the condenser banks to remove any charge which may remain after the high voltage circuit is opened (in certain instances the plate circuit of the tubes may provide such protection; however, individual approval of such shall be obtained by the manufacturer in case of standard equipment, and the licensee in case of composite equipment).

(3) All plate supply and other high voltage equipment, including transformers, filters, rectifiers and motor generators, shall be protected so as to prevent injury to operating personnel.

(i) Commutator guards shall be provided on all high voltage rotating machinery (coupling guards on motor generators, although desirable, are not required).

(ii) Power equipment and control panels of the transmitter shall meet the above requirements (exposed 220 volt AC switching equipment on the front of the power control panels is not recommended; however, is not prohibited).

(iii) Power equipment located at a broadcast station but not directly associated with the transmitter (not purchased as part of same), such as power distribution panels, control equipment on indoor or outdoor stations and the substations associated

therewith, are not under the jurisdiction of the Commission; therefore, § 3.46 does not apply.

(iv) It is not necessary to protect the equipment in the antenna tuning house and the base of the antenna with screens and interlocks, provided the doors to the tuning house and antenna base are fenced and locked at all times, with the keys in the possession of the operator on duty at the transmitter. Ungrounded fencing or wires should be effectively grounded, either directly or through proper static leaks. Lighting protection for the antenna system is not specifically required but should be installed.

(v) The antenna, antenna lead-in, counterpoise (if used), etc., shall be installed so as not to present a hazard. The antenna may be located close by or at a distance from the transmitter building. A properly designed and terminated transmission line should be used between the transmitter and the antenna when located at a distance.

(4) Metering equipment. (In addition to the following requirements, instruments shall meet the requirements of §§ 3.39 and 3.58.)

(i) All instruments having more than 1,000 volts potential to ground on the movement shall be protected by a cage or cover in addition to the regular case. (Some instruments are designed by the manufacturer to operate safely with voltages in excess of 1,000 volts on the movement. If it can be shown by the manufacturer's rating that the instrument will operate safely at the applied potential, additional protection is not necessary.)

(ii) In case the plate voltmeter is located on the low potential side of the multiplier resistor with one terminal of the instrument at or less than 1,000 volts above ground, no protective case is required. However, it is good practice to protect voltmeters subject to more than 5,000 volts with suitable over-voltage protective devices across the instrument terminals in case the winding opens.

(iii) The antenna ammeters (both regular and remote and any other radio frequency instrument which it is necessary for the operator to read) shall be so installed as to be easily and accurately read without the operator having to risk contact with circuits carrying high potential radio frequency energy.

(c) *Wiring and shielding.* (1) The transmitter panels or units shall be wired in accordance with standard switchboard practice, either with insulated leads properly cabled and supported or with rigid bus bar properly insulated and protected.

(2) Wiring between units of the transmitter, with the exception of circuits carrying radio frequency energy, shall be installed in conduits or approved fiber or metal raceways to protect it from mechanical injury.

(3) Circuits carrying low level radio frequency energy between units shall be either concentric tube, two wire balanced lines, or properly shielded to prevent the pickup of modulated radio frequency energy from the output circuits.

(4) Each stage (including the oscillator) preceding the modulated stage shall be properly shielded and filtered to prevent unintentional feedback from any circuit following the modulated stage (an exception to this requirement may be made in the case of high level modulated transmitters of approved manufacture which have been properly engineered to prevent reaction).

(5) The crystal chamber, together with the conductor or conductors to the oscillator circuit, shall be totally shielded.

(6) The monitors and the radio frequency lines to the transmitter shall be thoroughly shielded.

(d) *Installation.* (1) The installation shall be made in suitable quarters.

(2) Since an operator must be on duty at the transmitter control point during operation, suitable facilities for his welfare and comfort shall be provided at the control point.

(e) [Reserved.]

(f) *Studio equipment.* (1) The studio equipment shall be subject to all the above requirements where applicable except as follows:

(i) If it is properly covered by an underwriter's certificate, it will be considered as satisfying the safety requirements.

(ii) Section 8191 of article 810 of the National Electrical Code shall apply for voltages only when in excess of 500 volts.

(2) No specific requirements are made relative to the design and acoustical treatment. However, the studios and particularly the main studio should be in accordance with the standard practice for the class of station concerned, keeping the noise level as low as reasonably possible.

§ 3.41 **Maximum rated carrier power; tolerances.** The maximum rated carrier power of a transmitter shall be an even power step as recognized by the Commission's plan of allocation (100 watts, 250 watts, 500 watts, 1 kw., 5 kw., 10 kw., 25 kw., 50 kw.) and shall not be less than the authorized power nor shall it be greater than the value specified in the following table.

Class of station	Maximum power authorized to station	Maximum rated carrier power permitted to be installed
		Watts
Class IV	100 watts	250
	250, 500 or 1,000 watts	1,000
Class III	500 or 1,000 watts	1,000
	5,000 watts	5,000
Class II	250, 500, or 1,000 watts	1,000
	5,000 or 10,000 watts	10,000
	25,000 or 50,000 watts	50,000
Class I	10,000 watts	10,000
	25,000 or 50,000 watts	50,000

§ 3.42 **Maximum rated carrier power; how determined.** The maximum rated carrier power of a standard broadcast transmitter shall be determined as the sum of the applicable power ratings of the vacuum tubes employed in the last radio stage.

§ 3.43 **Changes in equipment; authority for.** No licensee or permittee shall change, in the last radio stage, the number of vacuum tubes, nor change to vacuum tubes of different power rating or class of operation, nor shall it change the system of modulation, without authority of the Commission.

§ 3.44 **Other changes in equipment.** Other changes except as provided for in this subpart which do not affect the maximum power rating or operating power of the transmitter or the operation or precision of the frequency control equipment may be made at any time without authority of the Commission, but in the next succeeding application for renewal of license such changes which affect the information already on file shall be shown in full.

§ 3.45 **Radiating system.** (a) All applicants for new, additional, or different broadcast facilities and all licensees requesting authority to change the transmitter site of an existing station shall specify a radiating system the efficiency of which complies with the requirements of good engineering practice for the class and power of the station. (See §§ 3.186 and 3.189.)

(b) No broadcast station licensee or permittee shall change the physical height of the transmitting antenna, or supporting structures, or make any changes in the radiating system which will measurably alter the radiation patterns, except upon application to and authority from the Commission.

(c) Should any changes occur which would alter the resistance of the antenna system, the licensee shall immediately make a new determination of the antenna resistance (see § 3.54) and shall submit application for authority to determine power by the direct method on the basis of the new measurements.

(d) The antenna and/or supporting structure shall be painted and illuminated in accordance with the specifications supplied by the Commission pursuant to section 303(q) of the Communications Act of 1934 as amended. (See Part 17 of this chapter; Rules Concerning the Construction Marking and Lighting of Antenna Structures.)

(e) The simultaneous use of a common antenna or antenna structure by more than

one standard broadcast station, or by one or more standard broadcast stations and one or more stations of any other class or service may be authorized provided:

(1) Complete verified engineering data are submitted showing that satisfactory operation of each station will be obtained without adversely affecting the operation of the other station.

(2) The minimum antenna height or field intensity for each standard broadcast station concerned complies with paragraph (a) of this section.

(3) Complete responsibility for maintaining the installation and for painting and illuminating the structure in accordance with the pertinent provisions of Part 17 of this chapter is assumed by one of the licensees.

§ 3.46 Transmitter. (a) The transmitter proper and associated transmitting equipment of each broadcast station shall be designed, constructed, and operated in accordance with good engineering practice in all phases not otherwise specifically included in the regulations in this subpart.

(b) The transmitter shall be wired and shielded in accordance with good engineering practice and shall be provided with safety features in accordance with the specifications of article 810 of the current National Electrical Code as approved by the American Standards Association.

(c) The station equipment shall be so operated, tuned, and adjusted that emissions outside the authorized channel do not cause harmful interference to the reception of other radio stations. Standard broadcast stations employing radio transmitters type accepted after January 1, 1960, shall maintain the bandwidth occupied by their emissions in accordance with the specifications set forth in 3.40(a). Stations employing transmitters installed or type accepted prior to January 1, 1960, shall achieve the highest degree of compliance practicable with their existing equipment. In either case, should harmful interference to the reception of other radio stations occur, the licensee may be required to take such further steps as may be necessary to eliminate the interference.

(d) The audio distortion, audio frequency response, carrier hum, noise level, and other essential phases of the operation which control the external effects shall at all times conform to the requirements of good engineering practice.

§ 3.47 Equipment performance measurements. (a) The licensee of each standard broadcast station shall make the following equipment performance measurements at yearly intervals. One such set shall be made during the four-month period preceding the date of filing application for renewal of station license:

(1) Data and curves showing over-all audio frequency response from 30 to 7500 CPS for approximately 25, 50, 85, and 100 (if obtainable) percent modulation. Family of curves should be plotted (one for each percentage above) with DB above and below a reference frequency of 1000 CPS as ordinate and audio frequency as abscissa.

(2) Data and curves showing audio frequency harmonic content for 25, 50, 85, and 100 percent modulation for fundamental frequencies of 50, 100, 400, 1000, 5000, and 75 CPS (either arithmetical or root sum square values up to the tenth harmonic or 16000 CPS). Plot family of curves (one for each percentage above) with percent distortion as ordinate and audio frequency as abscissa.

(3) Data showing percentage carrier shift for 25, 50, 85, and 100 percent modulation with 400 CPS tone.

(4) Carrier hum and extraneous noise generated within the equipment and measured as the level below 100 percent modulation throughout the audio spectrum or by bands.

(5) Measurements or evidence showing that spurious radiations including radio frequency harmonics are suppressed or are not present to a degree capable of causing objectionable interference to other radio services. Field intensity measurements are preferred but observations made with a communications type receiver may be accepted. However, in particular cases involving interference or controversy, the Commission may require actual measurements. Measurements shall be made with the equipment adjusted for normal program operation and shall include all circuits between main studio amplifier input and antenna output including equalizer or cor-

rection circuits normally employed, but without compression if such amplifier is employed.

(b) The data required by paragraph (a) of this section together with a description of instruments and procedure, signed by the engineer making the measurements, shall be kept on file at the transmitter and retained for a period of two years and on request shall be made available during that time to any duly authorized representative of the Federal Communications Commission.

§ 3.48 Acceptability of broadcast transmitters for licensing. (a) In order to facilitate the filing of, and action on applications for station authorizations, transmitters will be accepted for licensing by the Commission under one of the following conditions:

(1) A transmitter may be Type-Accepted upon the request of any manufacturer of transmitters built in quantity by following the type acceptance procedure set forth in Part 2 of this chapter, provided that the data and information submitted indicates that the transmitter meets the requirements of § 3.40. If accepted, such transmitter will be included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment." Applicants specifying transmitters included on such a list need not submit detailed descriptions and diagrams where the correct type number is specified, provided that the equipment proposed is identical with that accepted. Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(2) An application specifying a transmitter not included on the Radio Equipment List, Part B may be accepted upon the request of a prospective licensee submitting with the application for construction permit a complete description of the transmitter, including the circuit diagram, listing of all tubes used, function of each, multiplication in each stage, plate current and voltage applied to each tube, a description of the oscillator circuit together with any devices installed for the purpose of frequency stabilization and the means of varying output power to compensate for power supply voltage variations. However, if this data has been filed with the Commission by a manufacturer in connection with a request for type acceptance, it need not be submitted with the application for construction permit but may be referred to as "on file." Measurement data for type acceptance made in accordance with subparagraph (1) of this paragraph shall be submitted with the license application.

(3) A transmitter shown on an instrument of authorization by manufacturer and type number, or as a composite, and which was in use prior to June 30, 1955, may continue to be used by the licensee, his successors or assignees, provided such transmitter continues to comply with the rules and regulations.

(b) Additional rules with respect to withdrawal of type-acceptance, modification of type-accepted equipment and limitations on the findings upon which type acceptance is based are set forth in Part 2 of this chapter.

§ 3.49 Requirements for approval of frequency monitors. (a) *General requirements.* (1) Any manufacturer desiring to submit a monitor for type approval shall supply the Commission with full specification details (two sworn copies) as well as the test data specified in paragraph (c) of this section. If this information appears to meet the requirements of the rules, shipping instructions will be issued to the manufacturer. The shipping charges to and from the Laboratory at Laurel, Maryland, shall be paid for by the manufacturer. Approval of a monitor will only be given on the basis of the data obtained from the sample monitor submitted to the Commission for test.

(2) In approving a monitor upon the basis of the tests conducted by the Laboratory, the Commission merely recognizes that the type of monitor has the inherent capability of functioning in compliance with the rules, if properly constructed, maintained, and operated. The Commission realizes that the frequency monitor may have limited range over which the visual indicator will determine deviations. Accordingly, it may be necessary that adjunct equipment be used to determine major deviations.

NOTE: In addition to the visual indicator, the range of which may be limited in order to obtain the required accuracy, an aural indicator should also be employed to indicate frequency deviations beyond the range of the visual indicator, particularly where the visual

indicator is so designed that the indication becomes zero when the deviations become considerably greater than the range of the instrument.

(3) Additional rules with respect to withdrawal of type approval, modification of type approval equipment and limitations on the findings upon which type approval is based are set forth in Part 2, Subpart F, of this chapter.

(b) *General specifications.* The general specifications that frequency monitors shall meet before they will be approved by the Commission are as follows:

(1) The unit shall have an accuracy of at least five parts per million under ordinary conditions (temperature, humidity, power supply, and other conditions which may affect its accuracy) encountered in standard broadcast stations throughout the United States.

(2) The range of the indicating device shall be at least from 20 cycles below to 20 cycles above the assigned frequency.

(3) The scale of the indicating device shall be so calibrated as to be accurately read within at least 1 cycle.

(4) The unit shall be equipped with an automatic temperature control chamber (preferably enclosing the tank circuits of the oscillator) such that the maximum temperature variation at the crystal from the normal operating temperature shall not be greater than,

Plus or minus 0.05° C. when *X* or *Y* cut crystal is employed, or

Plus or minus 0.5° C. when low temperature coefficient crystal is employed.

(5) Unless otherwise specifically authorized, the instrument shall be equipped with a thermometer such that the temperature can be accurately measured within 0.025° C. for *X* or *Y* cut crystal or 0.25° C. for low temperature coefficient crystal.

(6) The monitor circuit shall be such that it may be continuously operated and the emitted carrier of the station is not heterodyned thereby.

(7) Means shall be provided for adjustment of the temperature or other means for correction of the indications of the monitor to agree with the external standard.

(c) *Tests to be made by the Laboratory Division of the F. C. C.* The tests to be made at the Laboratory will include the determination of the following:

(1) *Accuracy.* (i) Oscillator frequency, as received.

(ii) Constancy of oscillator frequency, as measured several times in 1 month.

(iii) Accuracy of readings of frequency-difference instrument.

(iv) Functioning of frequency adjustment device.

(v) Effects on frequency of changing tubes and of voltage variations.

(2) *Temperature control stability.* Effect on frequency of variation of room temperature through a range not to exceed 10° to 35° C.

(3) *Sensitivity.* Response of indicating instrument to small changes of frequency.

(4) *General construction.* (i) Inspection to determine ability to stand shipment and service.

(ii) Special tests to determine quality of construction, such as effect of tilting or tipping on frequency.

(5) *Miscellaneous performance.* Various, depending on character of apparatus (e.g., changes after stopping and starting, effect of varying coupling with transmitter, etc.).

(d) The equipment will be operated in a test in the same way and the same conditions under which it will be used in service as specified by the manufacturer. The manufacturer shall supply to the Laboratory Division all instructions or services which will be supplied to the purchaser of the equipment. The equipment, as submitted, shall be adjusted for operation in connection with broadcast stations operating on 1600 kilocycles.

§ 3.50 Requirements for approval of modulation monitors. (a) Any manufacturer desiring to submit a monitor for type approval shall supply the Commission with full specification details (two sworn copies) specified in paragraph (b) of this section. If this information appears to meet the requirements of the rules, shipping instructions will be issued to the manufacturer. The shipping charges to and from the Laboratory at Laurel, Maryland, shall be paid for by the manufacturer. Approval of a monitor

will only be given on the basis of the data obtained from the sample monitor submitted to the Commission for test.

(1) In approving a monitor upon the basis of the tests conducted by the Laboratory, the Commission merely recognizes that the type of monitor has the inherent capability of functioning in compliance with the rules, if properly constructed, maintained, and operated.

(2) Additional rules with respect to withdrawal of type approval, modification of type approval equipment and limitations on the findings upon which type approval is based are set forth in Part 2, Subpart F, of this chapter.

(b) The specifications that the modulation monitor shall meet before it will be approved by the Commission are as follows:

(1) A DC meter for setting the average rectified carrier at a specific value and to indicate changes in carrier intensity during modulation.

(2) A peak indicating light or similar device that can be set at any predetermined value from 50 to 120 percent modulation to indicate on positive peaks, and/or from 50 to 100 percent negative modulation.

(3) A semi-peak indicator with a meter having the characteristics given below shall be used with a circuit such that peaks of modulation of duration between 40 and 90 milliseconds are indicated to 90 percent of full value and the discharge rate adjusted so that the pointer returns from full reading to 10 percent of zero within 500 to 800 milliseconds. A switch shall be provided so that this meter will read either positive or negative modulation and, if desired, in the center position it may read both in a full-wave circuit. The characteristics of the indicating meter are as follows:

(i) The time for one complete oscillation of the pointer shall be 290 to 350 milliseconds. The damping factor shall be between 16 and 200. The useful scale length shall be at least 2.3 inches. The meter shall be calibrated for modulation from 0 to 110 percent and in decibels below 100 percent with 100 percent being 0 DB.

(ii) The accuracy of the reading on percentage of modulation shall be ±2 percent for 100 percent modulation, and ±4 percent of full scale reading at any other percentage of modulation.

(4) The frequency characteristics curve shall not depart from a straight line more than ±½ DB from 30 to 10000 cycles. The amplitude distortion or generation of audio harmonics shall be kept to a minimum.

(5) The modulation meter shall be equipped with appropriate terminals so that an external peak counter can be readily connected.

(6) Modulation will be tested at 115 volts ±5 percent and 60 cycles, and the above accuracies shall be applicable under these conditions.

(7) All specifications not already covered above, and the general design, construction, and operation of these units must be in accordance with good engineering practice.

(c) The modulation monitor may be a part of the frequency monitor.

Technical Operation

§ 3.51 Operating power; how determined. (a) Except as provided in paragraph (b) of this section, the operating power shall be determined by the direct method (the square of the antenna current times the antenna resistance at the point where the current is measured and at the operating frequency).

(b) Operating power shall be determined on a temporary basis by the indirect method: (1) In case of an emergency where the licensed antenna system has been damaged by causes beyond the control of the licensee (see § 3.45), or (2) Pending completion of authorized changes in the antenna system, or (3) If any change is made in the antenna system or any other change is made which may affect the antenna system. (See § 3.45.)

§ 3.52 Operating power; indirect measurement. (a) The operating power determined by indirect measurement from the plate input power of the last radio stage

is the product of the plate voltage (E_p), the total plate current of the last radio stage (I_p), and the proper factor (F) given in paragraph (b) of this section: That is

$$\text{Operating power} = E_p \times I_p \times F$$

(b) Factor to be used.

Factor (F)	Method of modulation	Maximum rated carrier power	Class of amplifier
0.70	Plate	0.1–1.0 kw	
0.80	Plate	5 kw and over	
0.35	Low Level	0.1 kw and over	B
0.65	Low Level	0.1 kw and over	BC [1]
0.35	Grid	0.1 kw and over	

[1] All linear amplifier operation where efficiency approaches that of Class C operation.

(c) In computing operating power by the indirect method, the factor in paragraph (b) of this section shall apply in all cases, and no distinction will be recognized due to the operating power being less than the maximum rated carrier power.

§ 3.53 [Reserved.]

§ 3.54 **Operating power; direct measurement.** (a) Applications to determine the operating power by the direct method shall be made on FCC Form 302.

(b) The resistance variation method, substitution method and bridge method are acceptable methods of measuring the total antenna resistance.

(c) A determination of the resistance of an omni-directioual antenna shall be made by taking a series of measurements at 5, 10, 15, and 20 kc on each side of the operating frequency. The values measured should be plotted with frequency as abscissa and resistance in ohms as ordinate and a smooth curve drawn. The point on the ordinate where this curve interscets the operating frequency gives the value of the antenna resistance.

(d) Antenna resistance for a directional antenna system shall be measured at the point of common radio frequency input to the directional antenna system. The following conditions shall obtain:

(1) The antenna shall be finally adjusted for the required pattern.

(2) The reactance at the operating frequency and at the point of measurement shall be adjusted to zero or as near thereto as practical.

(3) Suitable radio-frequency bridge or other method shall be employed to determine the resistance and reactance at the point of common radio frequency input.

(4) Resistance and reactance measurements at approximately 5, 10, 15, and 20 kc on each side of the operating frequency shall be made. The values measured shall be plotted and the resistance at the operating frequency determined in the same manner as set forth in paragraph (c) of this section.

(5) A permanently installed antenna ammeter shall be placed in each element of the system as well as at the point of measurement of resistance.

(e) The license for a station of power of 5 kw or under which employs a directional antenna will specify the antenna resistance as 92.5 percent of that determined at the point of common input. The resistance specified for stations of a power over 5 kw will be 95 per cent of that determined at the point of common input.

§ 3.55 **Modulation.** The percentage of modulation shall be maintained as high as possible consistent with good quality of transmission and in no case less than 85 percent on peaks nor more than 100 percent on negative peaks of frequent recurrence during any selection which is transmitted at the highest level of the program under consideration.

§ 3.56 **Modulation monitors.** (a) Each station shall have in operation, either at the transmitter or at the place the transmitter is controlled, a modulation monitor of a type approved by the Commission.

NOTE: Approved modulation monitors are included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment." Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(b) In the event that the modulation monitor becomes defective the station may be operated without the monitor pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided,* That:

(1) Appropriate entries shall be made in the operating log of the station showing the date and time the monitor was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the monitor is found to be defective and immediately after the repaired or replacement monitor has been installed and is functioning properly.

(3) The degree of modulation of the station shall be monitored with a cathode ray oscilloscope or other acceptable means.

(c) If conditions beyond the control of the licensee prevent the restoration of the monitor to service within the above allowed period, informal request may be filed with the Engineer in Charge of the radio district in which the station is operating for such additional time as may be required to complete repairs of the defective instrument.

(d) Each station operated by remote control shall continuously, except when other readings are being taken, monitor percent of modulation or shall be equipped with an automatic device to limit percent of modulation on negative peaks to 100.

§ 3.57 Operating power; maintenance of. (a) The operating power of each station shall be maintained as near as practicable to the licensed power and shall not exceed the limits of 5 percent above and 10 percent below the licensed power, except that in an emergency when due to causes beyond control of the licensee it becomes impossible to operate with full licensed power, the station may be operated with reduced power for a period not to exceed 10 days, provided the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified immediately after the emergency develops and also upon the resumption of licensed power.

(b) In addition to maintaining the operating power within the above limitations, stations employing directional antenna systems shall maintain the ratio of the antenna currents in the elements of the system within 5 percent of that specified by the terms of the license or other instrument of authorization.

§ 3.58 Indicating instruments. (a) Each standard broadcast station shall be equipped with indicating instruments which conform with the specifications set forth in § 3.39 for measuring the DC plate circuit current and voltage of the last radio frequency amplifier stage; the radio frequency base current of each antenna element; and, for stations employing directional antenna systems, the radio frequency current at the point of common input to the directional antenna.

(b) In the event that any one of these indicating instruments becomes defective when no substitute which conforms with the required specifications is available, the station may be operated without the defective instrument pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided,* That:

(1) Appropriate entries shall be made in the operating log of the station showing the date and time the meter was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the instrument is found to be defective and immediately after the repaired or replacement instrument has been installed and is functioning properly.

(3) If the defective instrument is the antenna current meter of a nondirectional station which does not employ a remote antenna ammeter, or if the defective instrument is the common point meter of a station which employs a directional antenna, and does not employ a remote common point meter, the operating power shall be determined by the indirect method in accordance with § 3.52 during the entire time the station is operated without the antenna current meter or common point meter.

However, if a remote antenna ammeter or a remote common point meter is employed and the antenna current meter or common point meter becomes defective, the remote meter may be used in determining operating power by the direct method pending the return to service of the regular meter, provided other meters are maintained at same value previously employed.

(c) If conditions beyond the control of the licensee prevent the restoration of the meter to service within the above allowed period, informal request in accordance with § 1.332(d) of this chapter may be filed with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

(d) Remote antenna ammeters and remote common point meters are not required: therefore authority to operate without them is not necessary. However if a remote antenna ammeter or common point meter is employed and becomes defective, the antenna base currents may be read and logged once daily for each mode of operation, pending the return to service of the regular remote meter.

§ 3.59 Frequency tolerance. The operating frequency of each station shall be maintained within 20 cycles of the assigned frequency.

§ 3.60 Frequency monitor. (a) The licensee of each station shall have in operation, either at the transmitter or at the place where the transmitter is controlled, a frequency monitor of a type approved by the Commission which shall be independent of the frequency control of the transmitter.

NOTE: Approved frequency monitors are included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment." Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(b) In the event that the frequency monitor becomes defective the station may be operated without the monitor pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided,* That:

(1) Appropriate entries shall be made in the operating log of the station showing the date and time the monitor was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the monitor is found to be defective and immediately after the repaired or replacement monitor has been installed and is functioning properly.

(3) The frequency of the station shall be measured by an external source at least once each seven days and the results entered in the station log.

(c) If conditions beyond the control of the licensee prevent the restoration of the monitor to service within the above allowed period, informal request in accordance with § 1.332(d) of this chapter may be filed with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

§ 3.61 New equipment; restrictions. The Commission will authorize the installation of new transmitting equipment in a broadcast station or changes in the frequency control of an existing transmitter only if such equipment is so designed that there is reasonable assurance that the transmitter is capable of maintaining automatically the assigned frequency within the limits specified in § 3.59.

§ 3.62 Automatic frequency control equipment; authorization required. New automatic frequency control equipment and changes in existing automatic frequency control equipment that may affect the precision of frequency control or the operation of the transmitter shall be installed only upon authorization from the Commission.

§ 3.63 Auxiliary transmitter. Upon showing that a need exists for the use of an auxiliary transmitter in addition to the regular transmitter of a broadcast station, a license therefor may be issued: *Provided,* That:

(a) An auxiliary transmitter may be installed either at the same location as the main transmitter or at another location.

(b) A licensed operator shall be in control whenever an auxiliary transmitter is placed in operation.

(c) The auxiliary transmitter shall be maintained so that it may be placed in operation at any time for any one of the following purposes:

(1) The transmission of the regular programs upon the failure of the main transmitter.

(2) The transmission of the regular programs during maintenance or modification work on the main transmitter necessitating discontinuance of its operation.

(3) CONELRAD tests, drills or operation, provided the auxiliary transmitter is used in connection with a National Defense Emergency Authorization.

(4) Upon request of a duly authorized representative of the Commission.

(d) The auxiliary transmitter shall be tested at least once each week to determine that it is in proper operating condition and that it is adjusted to the licensed or CONELRAD frequency: *Provided, however,* That the test in any week may be omitted if the auxiliary transmitter has been operated during the week pursuant to paragraph (c) of this section and such operation was satisfactory. Tests on the licensed frequency shall be conducted only between 12 midnight and 9 a.m., local standard time. Tests on a CONELRAD frequency, when such tests are not part of an authorized CONELRAD test, shall be made only when the transmitter output is connected to a dummy load. A record shall be kept of the time and result of each test. Such records shall be retained for a period of two years.

(e) The auxiliary transmitter shall be equipped with satisfactory control equipment which will enable the maintenance of the frequency emitted by the station within the limits prescribed by the regulations in this part.

(f) An auxiliary transmitter which is licensed at a geographical location different from that of the main transmitter shall be equipped with a frequency control which will automatically hold the frequency within the limits prescribed by the regulations in this part without any manual adjustment during operation or when it is being put into operation.

(g) The operating power of an auxiliary transmitter may be less than the authorized power, but in no event shall it be greater than such power.

(h) All regulations as to safety requirements and spurious emissions applying to broadcast transmitting equipment shall apply also to an auxiliary transmitter.

§ 3.64 Alternate main transmitters. The licensee of a standard broadcast station may be licensed for alternate main transmitters provided that a technical need for such alternate transmitters is shown, such as licensees maintaining 24-hour schedule and needing alternate operations for maintenance, or where developmental work requires alternate operation, and that the following conditions are met:

(a) Both transmitters are located at the same place.

(b) The transmitters have the same power rating except at stations operating with different daytime and nighttime power when it shall be permissible to employ transmitters of power ratings appropriate to either the licensed daytime or nighttime power.

(c) The external effects from both transmitters are substantially the same as to frequency stability, reliability of operation, radio harmonics and other spurious emissions, audio frequency range and audio harmonic generation in the transmitter.

§ 3.65 Antenna structure, marking and lighting. Where an antenna structure(s) is required to be painted or lighted see § 17.37, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

Remote Control

§ 3.66 Remote control authorization. (a) Application to operate a station by remote control may be made as a part of the application for construction permit for a new station, provided that the proposal is for non-directional operation with a power of 10 kw or less.

(b) Application to operate an authorized station by remote control shall be made on FCC Form 301-A.

(c) An authorization for remote control will be issued only after a satisfactory showing has been made in regard to the following, among others:

(1) The location of the remote control point(s);

(2) The directional antenna system, if such is authorized, is in proper adjustment and is stable;

(3) The transmitter, if the power rating is in excess of 10 kw, is reliable and capable of being operated by remote control;

(4) The station, if authorized to operate with a directional antenna and/or with power in excess of 10 kw, will be equipped so that it can be satisfactorily operated in accordance with Subpart G of this part, on a CONELRAD frequency with a power of 5 kw or not less than 50 percent of the maximum licensed power whichever is the lesser and that the necessary switching from the licensed frequency to the CONELRAD frequency can be accomplished from the remote control position: *Provided, however,* That the power may be less than 50 percent upon certification by the CONELRAD Field Supervisor that such a power will provide satisfactory service under CONELRAD.

§ 3.67 Remote control operation. (a) Operation by remote control shall be subject to the following conditions:

(1) The equipment at the operating and transmitting positions shall be so installed and protected that it is not accessible to or capable of operation by persons other than those duly authorized by the licensee.

(2) The control circuits from the operating positions to the transmitter shall provide positive on and off control and shall be such that open circuits, short circuits, grounds or other line faults will not actuate the transmitter and any fault causing loss of such control will automatically place the transmitter in an inoperative position.

(3) A malfunction of any part of the remote control equipment and associated line circuits resulting in improper control or inaccurate meter readings shall be cause for the immediate cessation of operation by remote control.

(4) Control and monitoring equipment shall be installed so as to allow the licensed operator at the remote control point to perform all the functions in a manner required by the Commission's rules.

(5) The indications at the remote control point of the antenna current meter on, for directional antennas, the common point current meter and remote base current meters shall be read and entered in the operating log each half hour.

(6) The indications at the transmitter, if a directional antenna station, of the common point current, base currents, phase monitor sample loop currents and phase indications shall be read and entered in the operating log once each day for each pattern. These readings must be made within two hours after the commencement of operation for each pattern.

(b) All stations, whether operating by remote control or direct control, shall be so equipped, in accordance with § 3.932, so as to be able to follow the prescribed CONELRAD alerting procedure set forth in the CONELRAD Manual for Broadcast Stations.

(c) A station operating with a directional antenna and/or with power in excess of 10 kw shall be so equipped that a shift from the licensed operation to an operation in the CONELRAD system can be accomplished from the remote control position.

§ 3.68 Remote control renewal application. (a) An application for renewal of a remote control authorization may be made on the application for renewal of station license.

(b) Stations employing directional antenna and operated by remote control shall make a skeleton proof of performance each year, consisting of three or four measurements on each radial used in the original application and must submit the results of these measurements, plus the monitoring point readings, with the renewal application.

Operation

§ 3.71 Minimum operating schedule. Except Sundays, the licensee of each standard broadcast station shall maintain a minimum operating schedule of two-thirds of the total hours that it is authorized to operate between 6 a.m. and 6 p.m., local standard time, and two-thirds of the total hours it is authorized to operate between 6 p.m. and midnight, local standard time, except that in an emergency when, due to causes

beyond the control of the licensee, it becomes impossible to continue operating, the station may cease operation for a period of not to exeeed 10 days, provided that the Commission and the Engineer in Charge of the radio district in whieh the station is located shall be notifiecl in writing immediately after the emergency develops.

§ 3.72 **Operation during experimental period.** The licensee of each standard broadcast station shall operate or refrain from operating its station during the experimental period as directed by the Commission in order to facilitate frequency measurement or for the determination of interference.

§ 3.73 **Specified hours.** If the license of a station specifies the hours of operation, the schedule so specified shall be adhered to except as provided in §§ 3.71 and 3.72.

§ 3.74 **Sharing time.** If the licenses of stations authorized to share time do not specify hours of operation, the licensees shall endeavor to reach an agreement for a definite schedule of periods of time to be used by each. Such agreement shall be in writing and each licensee shall file the same in triplicate original with each application to the Commission for renewal of license. If and when such written agreements are properly filed in conformity with this section, the file mark of the Commission will be affixed thereto, one copy will be retained by the Commission, one copy forwarded to the Engineer in Charge of the radio district in which the station is located, and one copy returned to the licensee to be posted with the station license and considered as a part thereof. If the license specifies a proportionate time division, the agreement shall maintain this proportion. If no proportionate time division is specified in the license, the licensees shall agree upon a division of time. Such division of time shall not include simultaneous operation of the stations unless specifically authorized by the terms of the license.

§ 3.75 **Sharing time; equivalence of day and night hours.** For the purpose of determining the proportionate division of time of the broadcast day for sharing time stations 1 night hour shall be considered the equivalent of 2 day hours.

§ 3.76 **Sharing time; experimental period.** If the license of a station authorized to share time does not specify the hours of operation, the station may be operated for the transmission of regular programs during the experimental period provided an agreement thereto is reached with the other stations with which the broadcast day is shared and further provided such operation is not in conflict with § 3.72. Time-sharing agreements for operation during the experimental period need not be submitted to the Commission.

§ 3.77 **Sharing time; departure from regular schedule.** A departure from the regular operating schedule set forth in a time-sharing agreement will be permitted only in cases where an agreement to that effect is reduced to writing, is signed by the licensees of the stations affected thereby and filed in triplicate by each licensee with the Commission prior to the time of the proposed change. If time is of the essence, the actual departure in operating schedule may precede the actual filing of written agreement, provided appropriate notice is sent to the Commission and the Engineer in Charge of the radio district in which the station is located.

§ 3.78 **Sharing time stations; notification to Commission.** If the licensees of stations authorized to share time are unable to agree on a division of time, the Commission shall be so notified by statement to that effect filed with the applications for renewals of licenses. Upon receipt of such statement the Commission will designate the applications for a hearing and, pending such hearing, the operating schedule previously adhered to shall remain in full force and effect.

§ 3.79 **License to specify sunrise and sunset hours.** If the licensee of a broadcast station is required to commence or cease operation, or to change the mode of operation of the station at the times of sunrise and sunset at any particular location, the controlling times for each month of the year are set forth in the station's instrument of authorization. Uniform sunrise and sunset times are specified for all of the days of each month, based upon the actual times of sunrise and sunset for the fifteenth day of that month adjusted to the nearest quarter hour. In accordance with a standardized procedure described therein, actual sunrise and sunset times are derived by interpolation in the tables of the 1946 American Nautical Almanac, issued by the Nautical Almanac Office of the United States Naval Observatory.

§ 3.80 **Secondary station; filing of operating schedule.** The licensee of a secondary station authorized to operate limited time and which may resume operation at the time the dominant station (or stations) on the same channel ceases operation shall, with each application for renewal of license, file in triplicate a copy of its regular operating schedule, bearing a signed notation by the licensee of the dominant station of its objection or lack of objection thereto. Upon approval of such operating schedule, the Commission will affix its file mark and return one copy to the licensee authorized to operate limited time, which shall be posted with the station license and considered as a part thereof. Departure from said operating schedule will be permitted only in accordance with the procedure set forth in § 3.77.

§ 3.81 **Secondary station; failure to reach agreement.** If the licensee of a secondary station authorized to operate limited time and a dominant station on a channel are unable to agree upon a definite time for resumption of operation by the station authorized limited time, the Commission shall be so notified by the licensee of the station authorized limited time. After receipt of such statement the Commission will designate for hearing the applications of both stations for renewal of license, and pending the hearing the schedule previously adhered to shall remain in full force and effect.

§ 3.82 **Departure from schedule; material violation.** In all cases where a station licensee is required to prepare and file an operating schedule, any deviation or departure from such schedule, except as herein authorized, shall be considered as a violation of a material term of the license.

§ 3.83 **Local standard time.** All references herein to standard time or local standard time refer to local standard time as determined and fixed by the Interstate Commerce Commission.

§3.84 **Daylight saving time.** If local time is changed from standard time to daylight saving time at the location of all stations sharing time on the same channel, the hours of operation of all such stations on that channel shall be understood to refer to daylight saving time, and not standard time, as long as daylight saving time is observed at such locations. This provision shall govern when the time is changed by provision of law or general observance of daylight saving time by the various communities, and when the time of operation of such stations is specified in the license or is mutually agreed upon by the licensees: *Provided, however,* That when the license specifies average time of sunrise and sunset, local standard time shall be observed. In no event shall a station licensed for daytime only operate on regular schedule prior to local sunrise, or shall a station licensed for greater daytime power than nighttime power or for a different radiation pattern for daytime operation than for nighttime operation operate with the daytime power or radiation pattern prior to local sunrise.

§ 3.85 **Changes in time; agreement between licensees.** Where the local time is not changed from standard time to daylight saving time at the location of all stations sharing time on the same channel, the hours of operation of such stations shall be understood to have reference to standard time, and not daylight saving time, unless said licensees mutually agree upon a new schedule which shall be effective only while daylight saving time is observed at the location of some of these stations.

§ 3.86 **Local standard time; license provisions.** The time of operation of any broadcast station which does not share time with other stations on the same channel shall be understood to have reference to local standard time unless modification of such license with respect to hours of operation is authorized by the Commission.

§ 3.87 **Program transmissions prior to local sunrise.** (a) The provisions of §§ 3.6, 3.8, 3.9, 3.10, 3.23, 3.79, and 3.84 shall not prevent the transmission of programs between 4 o'clock a.m., local standard time, and local sunrise, of standard broadcast stations with their authorized daytime facilities: *Provided,* That the provisions of this section shall not extend to:

(1) Stations regularly sharing time during daytime hours either under licenses pursuant to which time-sharing agreements have been entered into or licenses specifying hours of operation, unless time-sharing agreements have been reached covering

such operation prior to local sunrise. Sections 3.74, 3.77, and 3.78 shall be applicable to such agreements.

(2) Any Class II station causing interference, as determined by the standard broadcast Technical Standards of this subpart, by use of its daytime facilities within the 0.5 mv/m 50 percent skywave contour of any Class I station either of the United States or of any country party to the North American Regional Broadcasting Agreement, except (i) where the Class I station is located east of the Class II station in which case operation may begin at local sunrise at the Class I station; (ii) where an agreement has been reached with the Class I station to begin operation prior to local sunrise.

(3) Operation by use of its daytime facilities of any Class II station on any Class I-A channel not assigned to the United States under the North American Regional Broadcasting Agreement.

(4) Class IV stations authorized for operation with daytime power in excess of 250 watts.

(b) Any station operating during such hours receiving notice from the Commission that undue interference is caused shall refrain from such operation during such hours pending fnrther notice from the Commission.

(c) Nothing contained in outstanding instruments of authorization for such stations shall prohibit such operation except as herein provided.

(d) The period 4 a.m. to 6 a.m., local standard time, shall not be included in determining compliance with § 3.71.

§ 3.88 Blanketing interference. The licensee of each broadcast station is required to satisfy all reasonable complaints of blanketing interference within the 1 v/m contour.

§ 3.89 Use of frequency and modulation monitors at auxiliary transmitters. (a) The following shall govern the installation of approved frequency and modulation monitors at auxiliary transmitters:

(1) In case the auxiliary transmitter location is at a site different from that of the main transmitter, an approved frequency monitor shall be installed at the auxiliary transmitter, except when the frequency of the auxiliary transmitter can be monitored by means of the frequency monitor at the main transmitter.

(2) The provision that the frequency monitor may be located at the site of the main transmitter shall not relieve the obligation that the frequency deviation of the auxiliary transmitter shall be maintained within 20 cycles.

(3) Installation of an approved modulation monitor at the location of the auxiliary transmitter, when different from that of the main transmitter, is optional with the licensee. However, when it is necessary to operate the auxiliary transmitter beyond 2 calendar days, a modulation monitor shall be installed and operated at the auxiliary transmitter. The monitor (if taken from the main transmitter) shall be reinstalled at the main transmitter immediately upon resumption of operation of the main transmitter.

(4) In all cases where the auxiliary transmitter and the main transmitter have the same location, the same frequency and modulation monitor may be used for monitoring both transmitters, provided they are so arranged as to be switched readily from one transmitter to the other.

§ 3.90 Emergency weather warnings. Upon receipt of notification of an Emergency Weather Warning of a condition of immediate danger to life and property from the United States Weather Bureau, all standard broadcast stations may, at their option, during authorized hours of operation only, broadcast CONELRAD Attention Signals (two five second carrier breaks and fifteen seconds of 1,000 CPS tone) followed by the Emergency Weather Warning as outlined in CONELRAD Manual BC-3 (Revised), Appendix A. Nothing herein shall be construed as authorizing a daytime only or limited time station to operate during unauthorized hours.

§ 3.91 Discontinuance of operation. The licensee of each station shall notify the Commission in Washington, D.C., and the Engineer in Charge of the radio district where such station is located of permanent discontinuance of operation at least

two days before operation is discontinued. The licensee shall, in addition, immediately forward the station license and other instruments of authorization to the Washington, D.C., office of the Commission for cancellation.

§3.92 Station and operator licenses; posting of. (a) The station license and any other instrument of station anthorization shall be posted in a conspicuons place and in such manner that all terms are visible, at the place the licensee considers to be the principal control point of the transmitter. At all other control points listed on the station authorization, a photocopy of the station license and other instruments of station authorization shall be posted.

(b) The original operator license, or FCC Form 759, of each station operator shall be posted at the place where he is on duty as an operator.

§ 3.93 Operator requirements. (a) One or more radio operators holding a valid radiotelephone first-class operator license, except as provided in paragraph (b) of this section, shall be in actual charge of the transmitting apparatus and shall be on dnty either at the transmitter location or remote control point.

(b) A station which is authorized for non-directional operation with power of 10 kilowatts or less may be operated by persons holding commercial radio operator license of any class, except an aircraft radiotelephone operator authorization or a temporary limited radiotelegraph second-class operator license, when the equipment is so designed that the stability of the frequency is maintained by the transmitter itself within the limits of tolerance specified, aud none of the operations, except those specified in subparagraphs (1) through (4) of this paragraph, necessary to be performed during the course of normal operation may cause off-frequency operation or result in any unauthorized radiation. (A person holding any class of radio operator licensc or permit who is authorized thereunder to perform limited operation of a standard broadcast station may, when a CONELRAD Radio Alert is called, make adjustments necessary to effect operation on a CONELRAD authorization: *Provided,* That the station's full-time radiotelephone first-class operator shall have previously instructed such person in the adjustments to the transmitter which are necessary to accomplish CONELRAD operation.) Adjustments of transmitting equipment by such operators, except when under the immediate supervision of a radiotelephone first-class operator, shall be limited to the following:

(1) Those necessary to commence or terminate transmitter emissions as a routine matter.

(2) Those external adjustments that may be required as a result of variations of primary power supply.

(3) Those external adjustments which may be necessary to insure modulation within the limits required.

(4) Those adjustments necessary to effect any change in operating power which may be required by the station's instrument of authorization. Should the transmitting apparatus be observed to be operating in a manner inconsistent with the station's instrument of authorization and none of the above adjustments are effective in bringing it into proper operation, a person holding other than a radiotelephone first-class operator license and not acting under the immediate supervision of radiotelephone first-class operator, shall be required to terminate the station's emissions.

(c) The licensee of a station which is operated by one or more operators holding other than a radiotelephone first-class operator license shall have one or more operators holding a radiotelephone first-class operator license in regular full-time employment at the station whose primary duties shall be to effect and insure the proper functioning of the transmitting eqnipment. In the event that the licensee also operates an FM broadcast station in the same community, a regular full-time radiotelephone first-class operator or operators employed in connection with the standard broadcast station may concurrently be employed to satisfy the requirements of § 3.265(c) or § 3.565(c): *Provided,* That the duties of such operator or operators concerning the FM broadcast transmitting equipment shall in nowise interfere with the proper performance of his dnties with respect to the standard broadcast transmitter.

(d) The licensed operator on duty and in charge of a standard broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the

operation of another radio station or stations in accordance with the class of operator's license which he holds and the rnles and regulations governing such other stations: *Provided, however,* That such duties shall in nowise interfere with the proper operation of the standard broadcast transmitter.

§ 3.94 [Reserved.]

§ 3.95 **Equipment tests.** (a) During the process of construction of a standard broadcast station the permittee, after notifying the Commission and Engineer in Charge of the radio district in which the station is located, may without fnrther authority of the Commission, conduct equipment tests during the experimental period for the purpose of such adjustments and measurements as may be necessary to assure compliance with the terms of the construction permit, the technical provisions of the application therefor, the rules and regulations, and the applicable engineering standards. In addition, the Commission may authorize equipment tests other than during the experimental period if such operation is shown to be desirable to the proper completion of construction and adjustment of the transmitting equipment and antenna system. An informal application for such authority, giving full details regarding the need for such tests, shall be filed with the Commission at least two (2) days (not including Sundays and Saturdays and legal holidays when the offices of the Commission are not open) prior to the date on which it is desired to begin such operation.

(b) The Commission may notify the permittee to conduct no tests or may cancel, suspend, or change the date for the beginning of equipment tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Equipment tests may be continued so long as the construction permit shall remain valid and shall be conducted only during the experimental period (12 midnight to local sunrise) unless otherwise specifically authorized.

(d) Inspection of a station will ordinarily be required during the equipment test period and before the commencement of program tests. After construction and after adjustments and measurements have been completed to show compliance with the terms of the construction permit, the technical provisions of the application therefor, the rules and regulations and the applicable engineering standards, the permittee should notify the Engineer in Charge of the radio district in which the station is located that it is ready for inspection.

(e) The authorization for tests embodied in this section shall not be construed as constituting a license to operate but as a necessary part of construction.

§ 3.96 **Program tests.** (a) Upon completion of construction of a standard broadcast station in accordance with the terms of the construction permit, the technical provisions of the application therefor, and the rules and regulations and applicable engineering standards and when an application for station license has been filed showing the station to be in satisfactory operating condition, the permittee may request authority to conduct program tests: *Provided,* That such request shall be filed with the Commission at least ten (10) days prior to the date on which it is desired to begin such operation and that the Engineer in Charge of the radio district in which the station is located is notified. All data necessary to show compliance with the terms and conditions of the construction permit must be filed with the license application. If the station is using a directional antenna, a proof of performance must also be filed as required by § 3.33(b).

(b) Program tests shall not commence until specific Commission authority is received. The Commission reserves the right to change the date of the beginning of such tests or to suspend or revoke the authority for program tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Unless sooner suspended or revoked program test authority continues valid during Commission consideration of the application for license and during this period further extension of the construction permit is not required. Program test authority shall be automatically terminated by final determination upon the application for station license.

(d) All operation on program test authority shall be in strict compliance with the rules governing standard broadcast stations and in strict accordance with representations made in the application for license pursuant to which the tests were authorized.

(e) The granting of program test authority shall not be construed as approval by the Commission of the application for station license.

§ 3.97 Station inspection. The licensee of any radio station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

Other Operating Requirements

§ 3.111 Logs. The licensee or permittee of each standard broadcast station shall maintain program and operating logs and shall require entries to be made as follows:

(a) In the program log:

(1) An entry of the time each station identification announcement (call letters and location) is made.

(2) An entry briefly describing each program broadcast, such as "music," "drama," "speech," etc., together with the name or title thereof, and the sponsor's name, with the time of the beginning and ending of the complete program. If a mechanical record is used, the entry shall show the exact nature thereof, such as "record," "transcription," etc., and the time it is announced as a mechanical record. If a speech is made by a political candidate, the name and political affiliations of such speaker shall be entered.

(3) An entry showing that each sponsored program broadcast has been announced as sponsored, paid for, or furnished by the sponsor.

(4) An entry showing, for each program of network origin, the name of the network originating the program.

(b) In the operating log:

(1) An entry of the time the station begins to supply power to the antenna, and the time it stops.

(2) An entry of the time the program begins and ends.

(3) An entry of each interruption to the carrier wave, its cause, and duration.

(4) An entry of the following each 30 minutes:

(i) Operating constants of last radio stage (total plate current and plate voltage).

(ii) Antenna current.

(iii) Frequency monitor reading.

(5) Any other entries required by the instrument of authorization.

(6) Log of experimental operation during experimental period. (If regular operation is maintained during this period, the above logs shall be kept.)

(i) A log must be kept of all operation during the experimental period. If the entries required above are not applicable thereto, then the entries shall be made so as to fully describe the operation.

(c) Where an antenna structure(s) is required to be illuminated see § 17.38, *Recording of tower light inspections in the station record,* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 3.112 Logs; retention of. Logs of standard broadcast stations shall be retained by the licensee or permittee for a period of two years: *Provided, however,* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee or permittee has been notified, shall be retained by the licensee or permittee until he is specifically authorized in writing by the Commission to destroy them: *Provided, further,* That logs incident to or involved in any claim or complaint of which the licensee or permittee has notice shall be retained by the licensee or permittee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

NOTE: Application forms for licenses and other authorizations require that certain operating and program data be supplied. It is suggested that these application forms be kept in mind in connection with maintenance of station program and operating records.

§ 3.113 Logs; by whom kept. Each log shall be kept by the person or persons competent to do so, having actual knowledge of the facts required, who shall sign

the log when starting duty and again when going off duty. The logs shall be made available upon request by an authorized representative of the Commission.

§ 3.114 **Log form.** The log shall be kept in an orderly manner, in suitable form, and in such detail that the data required for the particular class of station concerned are readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log.

§ 3.115 **Correction of logs.** No log or portion thereof shall be erased, obliterated, or willfully destroyed within the period of retention provided by the rules. Any necessary correction may be made only by the person originating the entry who shall strike out the erroneous portion, initial the correction made, and indicate the date of correction.

§ 3.116 **Rough logs.** Rough logs may be transcribed into condensed form, but in such case the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

§ 3.117 **Station identification.** (a) A licensee of a standard broadcast station shall make station identification announcement (call letters and location) at the beginning and ending of each time of operation and during operation (1) on the hour and (2) either on the half hour or at the quarter hour following the hour and at the quarter hour preceding the next hour: *Provided,*

(b) Such identification announcement need not be made on the hour when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or operatic production of longer duration than 30 minutes. In such cases the identification announcement shall be made at the beginning of the program, at the first interruption of the entertainment continuity, and at the conclusion of the program.

(c) Such identification announcement need not be made on the half hour or quarter hours when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or operatic production. In such cases an identification announcement shall be made at the first interruption of the entertainment continuity and at the conclusion of the program: *Provided,* That an announcement within 5 minutes of the times specified in paragraph (a) (2) of this section will satisfy the requirements of identification announcements.

(d) In the case of variety show programs, baseball game broadcasts, or similar programs of longer duration than 30 minutes, the identification announcement shall be made within 5 minutes of the hour and of the times specified in paragraph (a) (2) of this section.

(e) In the case of all other programs the identification announcement shall be made within 2 minutes of the hour and of the times specified in paragraph (a) (2) of this section.

(f) In making the identification announcement the call letters shall be given only on the channel of the station identified thereby, except as otherwise provided in § 3.287 of the Commission's rules governing FM broadcast stations.

§ 3.118 **Mechanical reproductions.** (a) No mechanically reproduced program consisting of a speech, news event, news commentator, forum, panel discussion, or special event in which the element of time is of special significance, or any other program in which the element of time is of special significance and presentation of which would create, either intentionally or otherwise, the impression or belief on the part of the listening audience that the event or program being broadcast is in fact occurring simultaneously with the broadcast, shall be broadcast without an appropriate announcement being made either at the beginning or end of such reproduction or at the beginning or end of the program in which such reproduction is used that it is a mechanical reproduction or a mechanically reproduced program: *Provided, however,* That each such program of one minute or less need not be announced as such.

(b) The exact form of identifying announcement is not prescribed, but the language shall be clear and in terms commonly used and understood. Any other program mechanically reproduced or series of mechanical reproductions, including a mechanical reproduction used for background music, sound effects, station identification, program identification (theme music of short duration) or identification of sponsorship of the

program proper, need not be announced as provided in paragraph (a) of this section, but the licensee shall not attempt affirmatively to create the impression that any program being broadcast by mechanical reproduction consists of live talent.

(c) The requirements of paragraph (a) of this section are waived with respect to network programs, transcribed and rebroadcast at a later hour because of the time zone differentials between the place where the program originates and where it is rebroadcast, this waiver being applicable whether the off-the-line recording is made by the network itself at one of its key stations or by an individual station, but only when the off-the-line recording is for broadcast at an hour not exceeding the time zone differential between the place where the program originates and where it is rebroadcast. Each station which broadcasts network programs at a later hour in accordance with this waiver shall make an appropriate announcement at least once each day between the hours of 10:00 a.m. and 10:00 p.m., stating that some or all of the network programs which are broadcast by that station are delayed broadcasts by means of transcription. This waiver provision also applies during the annual periods in which daylight saving time will be effective with respect to network programs transcribed and rebroadcast one hour later because of the time differential resulting from the adoption of daylight saving time in some areas.

§ 3.119 Sponsored programs; announcement of. (a) In the case of each program for the broadcasting of which money, services, or other valuable consideration is either directly or indirectly paid or promised to, or charged or received by, any radio broadcast station, the station broadcasting such program shall make, or cause to be made, an appropriate announcement that the program is sponsored, paid for, or furnished, either in whole or in part.

(b) In the case of any political program or any program involving the discussion of public controversial issues for which any records, transcriptions, talent, scripts, or other material or services of any kind are furnished, either directly or indirectly, to a station as an inducement to the broadcasting of such program, an announcement shall be made both at the beginning and conclusion of such program on which such material or services are used that such records, transcriptions, talent, scripts, or other material or services have been furnished to such station in connection with the broadcasting of such program: *Provided, however*, That only one such announcement need be made in the case of any such program of 5 minutes' duration or less, which announcement may be made either at the beginning or the conclusion of the program.

(c) The announcement required by this section shall fully and fairly disclose the true identity of the person or persons by whom or in whose behalf such payment is made or promised, or from whom or in whose behalf such services or other valuable consideration is received, or by whom the material or services referred to in paragraph (b) of this section are furnished. Where an agent or other person contracts or otherwise makes arrangements with a station on behalf of another, and such fact is known to the station, the announcement shall disclose the identity of the person or persons in whose behalf such agent is acting instead of the name of such agent.

(d) In the case of any program, other than a program advertising commercial products or services, which is sponsored, paid for or furnished, either in whole or in part, or for which material or services referred to in paragraph (b) of this section are furnished, by a corporation, committee, association or other unincorporated group, the announcement required by this section shall disclose the name of such corporation, committee, association or other unincorporated group. In each such case the station shall require that a list of the chief executive officers or members of the executive committee or of the board of directors of the corporation, committee, association or other unincorporated group shall be made available for public inspection at one of the radio stations carrying the program.

(e) In the case of programs advertising commercial products or services, an announcement stating the sponsor's corporate or trade name or the name of the sponsor's product, shall be deemed sufficient for the purposes of this section and only one such announcement need be made at any time during the course of the program.

§ 3.120 Broadcasts by candidates for public office. (a) *Definitions.* A "legally qualified candidate" means any person who has publicly announced that he is a candidate for nomination by a convention of a political party or for nomination or election

in a primary, special, or general election, municipal, county, State or national, and who meets the qualifications prescribed by the applicable laws to hold the office for which he is a candidate, so that he may be voted for by the electorate directly or by means of delegates or electors, and who:

(1) Has qualified for a place on the ballot or

(2) Is eligible under the applicable law to be voted for by sticker, by writing in his name on the ballot, or other method, and (i) has been duly nominated by a political party which is commonly known and regarded as such, or (ii) makes a substantial showing that he is a bona fide candidate for nomination or office, as the case may be.

(b) *General requirements.* No station licensee is required to permit the use of its facilities by any legally qualified candidate for public office, but if any licensee shall permit any such candidate to use its facilities, it shall afford equal opportunities to all other such candidates for that office to use such facilities: *Provided,* That such licensee shall have no power of censorship over the material broadcast by any such candidate.

(c) *Rates and practices.* (1) The rates, if any, charged all such candidates for the same office shall be uniform and shall not be rebated by any means direct or indirect. A candidate shall, in each case, be charged no more than the rate the station would charge if the candidate were a commercial advertiser whose advertising was directed to promoting its business within the same area as that encompassed by the particular office for which such person is a candidate. All discount privileges otherwise offered by a station to commercial advertisers shall be available upon equal terms to all candidates for public office.

(2) In making time available to candidates for public office no licensee shall make any discrimination between candidates in charges, practices, regulations, facilities, or services for or in connection with the service rendered pursuant to this part, or make or give any preference to any candidate for public office or subject any such candidate to any prejudice or disadvantage; nor shall any licensee make any contract or other agreement which shall have the effect of permitting any legally qualified candidate for any public office to broadcast to the exclusion of other legally qualified candidates for the same public office.

(d) *Records; inspection.* Every licensee shall keep and permit public inspection of a complete record of all requests for broadcast time made by or on behalf of candidates for public office, together with an appropriate notation showing the disposition made by the licensee of such requests, and the charges made, if any, if request is granted. Such records shall be retained for a period of two years.

(e) A request for equal opportunities must be submitted to the licensee within one week of the day on which the prior use occurred.

(f) A candidate requesting such equal opportunities of the licensee, or complaining of non-compliance to the Commission shall have the burden of proving that he and his opponent are legally qualified candidates for the same public office.

§ 3.121 Rebroadcast. (a) The term "rebroadcast" means reception by radio of the program of a radio station, and the simultaneous or subsequent retransmission of such program by a broadcast station.

NOTE 1: As used in § 3.121, program includes any complete program or part thereof, or any signals if other than A-3 emission.

NOTE 2: In case a program is transmitted from its point of origin to a broadcast station entirely by telephone facilities in which a section of such transmission is by radio, the broadcasting of this program is not considered a rebroadcast.

(b) The licensee of a standard broadcast station may, without further authority of the Commission, rebroadcast the program of a United States standard or FM broadcast station, provided the Commission is notified of the call letters of each station rebroadcast and the licensee certifies that express authority has been received from the licensee of the station originating the program.

NOTE: The notice and certification of consent shall be given within 3 days of any single rebroadcast, but in case of the regular practice of rebroadcasting certain programs of a standard broadcast station several times during a license period, notice and certification

of consent shall be given for the ensuing license period with the application for renewal of license, or at the beginning of such rebroadcast practice if begun during a license period.

(c) (1) The licensee of the standard broadcast station located within a state or the District of Columbia may, without further authority of the Commission, rebroadcast on a noncommercial basis a noncommercial program of a United States international broadcast station.

(2) The licensee of a standard broadcast station located in any territory or insular possession of the United States may, without further authority of the Commission, rebroadcast any program of a United States international broadcast station.

(3) In the case of any rebroadcast under the provisions of this paragraph, the Commission shall be notified of the call letters of each station whose programs are rebroadcast and the licensee shall certify that express authority has been received from the licensee of the station originating the program.

(d) No licensee of a standard broadcast station shall rebroadcast the program of any other class of United States radio station without written authority having first been obtained from the Commission upon application accompanied by written consent or certification of consent of the licensee of the station originating the program.

NOTE 1: The broadcasting of a program relayed by a remote pick-up broadcast station (§ 4.401 of this chapter) is not considered a rebroadcast.

NOTE 2: Informal application may be employed.

NOTE 3: By Order No. 82, dated and effective June 24, 1941, until further order of the Commission, § 3.121(d) is suspended only insofar as it requires prior written authority of the Commission for the rebroadcasting of programs originated for that express purpose by United States Government radio stations.

(e) In case of a program rebroadcast by several standard broadcast stations, such as a chain rebroadcast, the person legally responsible for distributing the program or the network facilities may obtain the necessary authorization for the entire rebroadcast both from the Commission and from the person or licensee of the station originating the program.

(f) Attention is directed to section 325(b) of the Communications Act of 1934, which reads as follows:

No person shall be permitted to locate, use, or maintain a radio broadcast studio or other place or apparatus from which or whereby sound waves are converted into electrical energy, or mechanical or physical reproduction of sound waves produced, and caused to be transmitted or delivered to a radio station in a foreign country for the purpose of being broadcast from any radio station there, having a power output of sufficient intensity, and/or being so located geographically that its emissions may be received consistently in the United States, without first obtaining a permit from the Commission upon proper application therefor. (See § 1.327 of this chapter.)

§ 3.122 Lotteries. (a) An application for construction permit, license, renewal of license, or any other authorization for the operation of a broadcast station, will not be granted where the applicant proposes to follow or continue to follow a policy or practice of broadcasting or permitting "the broadcasting of, any advertisement of or information concerning any lottery, gift enterprise, or similar scheme, offering prizes dependent in whole or in part upon lot or chance, or any list of the prizes drawn or awarded by means of any such lottery, gift enterprise, or scheme, whether said list contains any part or all of such prizes." (See 18 U. S. C. 1304.)

(b) The determination whether a particular program comes within the provisions of paragraph (a) of this section depends on the facts of each case. However, the Commission will in any event consider that a program comes within the provisions of paragraph (a) of this section if in connection with such program a prize consisting of money or thing of value is awarded to any person whose selection is dependent in whole or in part upon lot or chance, if as a condition of winning or competing for such prize, such winner or winners are required to furnish any money or thing of value or are required to have in their possession any product sold, manufactured, furnished or distributed by a sponsor of a program broadcast on the station in question.

Licensing Policies

§ 3.131 **Exclusive affiliation of station.** No license shall be granted to a standard broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization under which the station is prevented or hindered from, or penalized for, broadcasting the programs of any other network organization. (The term "network organization" as used herein includes national and regional network organizations. See ch. VII, J, of Report on Chain Broadcasting.)

§ 3.132 **Territorial exclusivity.** No license shall be granted to a standard broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization which prevents or hinders another station serving substantially the same area from broadcasting the network's programs not taken by the former station, or which prevents or hinders another station serving a substantially different area from broadcasting any program of the network organization. This section shall not be construed to prohibit any contract, arrangement, or understanding between a station and a network organization pursuant to which the station is granted the first call in its primary service area upon the programs of the network organization.

§ 3.133 **Term of affiliation.** No license shall be granted to a standard broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization which provides, by original term, provisions for renewal, or otherwise for the affiliation of the station with the network organization for a period longer than 2 years: *Provided*, That a contract, arrangement, or understanding for a period up to 2 years, may be entered into within six months prior to the commencement of such period.

§ 3.134 **Option time.** No license shall be granted to a standard broadcast station which options for network programs any time subject to call on less than 56 days' notice, or more time than a total of 3 hours within each of four segments of the broadcast day, as herein described. The broadcast day is divided into four segments, as follows: 8 a.m. to 1 p.m.; 1 p.m. to 6 p.m.; 6 p.m. to 11 p.m.; 11 p.m. to 8 a.m. (These segments are to be determined for each station in terms of local time at the location of the station but may remain constant throughout the year regardless of shifts from standard to daylight saving time or vice versa.) Such option may not be exclusive as against other network organizations and may not prevent or hinder the station from optioning or selling any or all of the time covered by the option, or other time, to other network organizations.

NOTE 1: As used in this section, an option is any contract, arrangement, or understanding, express or implied, between a station and a network organization which prevents or hinders the station from scheduling programs before the network agrees to utilize the time during which such programs are scheduled, or which requires the station to clear time already scheduled when the network organization seeks to utilize the time.

NOTE 2: All time options permitted under this section must be for specified clock hours, expressed in terms of any time system set forth in the contract agreed upon by the station and network organization. Shifts from daylight saving to standard time or vice versa may or may not shift the specified hours correspondingly as agreed by the station and network organization.

§ 3.135 **Right to reject programs.** No license shall be granted to a standard broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization which (a) with respect to programs offered pursuant to an affiliation contract, prevents or hinders the station from rejecting or refusing network programs which the station reasonably believes to be unsatisfactory or unsuitable; or which (b) with respect to network programs so offered or already contracted for, prevents the station from rejecting or refusing any program which, in its opinion, is contrary to the public interest, or from substituting a program of outstanding local or national importance.

§ 3.136 **Network ownership of stations.** No license shall be granted to a network organization, or to any person directly or indirectly controlled by or under common control with a network organization, for more than one standard broadcast station where one of the stations covers substantially the service area of the other

station, or for any standard broadcast station in any locality where the existing standard broadcast stations are so few or of such unequal desirability (in terms of coverage, power, frequency, or other related matters) that competition would be substantially restrained by such licensing. (The word "control" as used herein is not limited to full control but includes such a measure of control as would substantially affect the availability of the station to other networks.)

NOTE: Effective date of this section with respect to any station may be extended from time to time in order to permit the orderly disposition of properties; and it shall be suspended indefinitely with respect to regional network organizations.

§ 3.137 Dual network operation. No license shall be issued to a standard broadcast station affiliated with a network organization which maintains more than one network; *Provided,* That this section shall not be applicable if such networks are not operated simultaneously, or if there is no substantial overlap in the territory served by the group of stations comprising each such network.

§ 3.138 Control by networks of station rates. No license shall be granted to a standard broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization under which the station is prevented or hindered from, or penalized for, fixing or altering its rates for the sale of broadcast time for other than the network's programs.

§ 3.139 Special rules relating to contracts providing for reservation of time upon sale of a station. No license, renewal of license, assignment of license, or transfer of control of a corporate licensee shall be granted or authorized to a standard broadcast station which has a contract, arrangement or understanding, express or implied, pursuant to which, as consideration or partial consideration for the assignment of license or transfer of control, the assignor of a station license or the transferor of stock, where transfer of a corporate licensee is involved, or the nominee of such assignor or transferor retains any right of reversion of the license or any right to the reassignment of the license in the future, or reserves the right to use the facilities of the station for any period whatsoever.

(1) A maximum limitation of the time subject to reservation so that no more than 12 hours per week shall be subject to reservation, of which no more than 4 hours shall be on any given day.

(2) A clause providing that the licensee reserves the right to reject or refuse programs which he reasonably believes to be unsatisfactory or unsuitable or for which, in his opinion, a program of outstanding local or national importance should be substituted, but provision may be made for the substitution of other radio time for programs so rejected or for the payment at the station card rate for the time made unavailable.

(3) A prohibition against the resale or reassignment of any of the broadcast time reserved by such modified contract.

(4) An express negation of any right with respect to reversion or reassignment of license.

(5) An express provision setting forth a definite expiration date of the contract, arrangement or understanding. Such expiration date shall not extend beyond February 15, 1964, and shall in no event extend beyond the expiration date originally provided for in any such contract, agreement or understanding, in the event that such expiration date is a date prior to February 15, 1964.

(6) An express provision giving to the licensee the right to terminate the contract, arrangement or understanding for substantial cause, including, but not limited to, the assignment of license or the transfer of control of a corporate licensee, consistent disagreement over programs between the parties, or the acquisition of a network affiliation by the licensee, upon the payment of a lump sum or periodic payments, and providing that the amount initially fixed shall thereafter decrease as the amount of time reserved is decreased by performance of the contract. Any such payment should not be so unduly large as to constitute in practice an effective deterrent to the licensee exercising the right of termination. In determining whether the amount is unduly large, the Commission will consider the amount by which consideration in return for

the transfer of the station was decreased by reason of the reservation of time or the present value of the radio time still reserved and unused as of the date of the exercise of the right of termination.

Data and Measurements

§ 3.150 **Data required with applications for directional antenna systems.** (a) The following engineering data shall be submitted with the application for authority to install a directional antenna:

(1) Complete description of the proposed system showing:

(i) Number of elements,

(ii) Type of each element (i.e., guyed or self-supporting, uniform cross section or tapered (specifying base width), grounded or insulated, etc.),

(iii) Complete engineering details of top loading or sectionalizing, if any,

(iv) Height of vertical lead of each element in feet (height above base insulator or base, if grounded),

(v) Overall height in feet of each element above ground,

(vi) Details including sketches of ground system for each element (length and number of radials, dimensions of ground screen, if used, and depth buried) and outlines of property,

(vii) Ratio of fields from elements (identifying elements).

(2) Calculated horizontal (ground) plane field intensity patterns for each mode of operation plotted to the largest scale possible on standard letter-size polar coordinate paper (main engraving approximately 7″ x 10″) using only scale divisions and subdivisions having values of 1, 2, 2.5, or 5 times $10^{n\text{th}}$ and showing:

(i) Inverse field intensity at 1 mile and effective field intensity (RMS).

(ii) Direction true north shall be shown at zero azimuth.

(iii) Direction and distance to each existing station with which interference may be involved. (All directions shall be determined by accurate calculation or from Lambert Conformal Conic Projection Map such as United States Coast and Geodetic Survey Map, No. 3060a, or map of equal accuracy, and all distances shall be determined by accurate calculation or from United States Albers Equal Area Projection Map scale 1/2,500,000 or map of equal accuracy. These may be obtained from the United States Coast and Geodetic Survey and the United States Department of Interior, Geological Survey.)

(iv) Orientation of array with respect to true north and time phasing of fields from elements (specifying degrees leading [+] or lagging [−]) and space phasing of elements (identifying elements). (Space phasing should be given in feet as well as in degrees.)

(v) The location of all the minima in the pattern.

(3) Calculated field intensity vs. azimuth patterns for every 5 degrees of elevation through 60 degrees in those instances where radiation at angles above the horizontal plane is a pertinent factor in station allocation. These patterns may be plotted in polar or rectangular coordinates but shall be submitted one to a page. Minor lobe and null detail occurring between the 5 degree intervals need not be submitted.

(4) Data used in computing the patterns in subparagraphs (2) and (3) of this paragraph including:

(i) Formula used for calculating the horizontal patterns, sample calculations. (Derivation of formula if other than standard is used.)

(ii) All assumptions made and basis therefor, including electrical height, current distribution and efficiency of each element, and ground conductivity.

(iii) Complete tabulation of final calculated data used in plotting patterns, including data for determination of RMS value of pattern.

(5) Values of field intensity less than 10 percent of the effective field intensity of the patterns in subparagraphs (2) and (3) of this paragraph shown on an enlarged scale.

(6) In the event actual inverse distance field intensities expected to be determined in practice (that is, the values determined from actual measurements, particu-

larly in sharp nulls) are different from the calculated values in subparagraphs (2) and (3) of this paragraph, the maximum expected operating values (MEOV) as well as the calculated values shall be shown on both the full patterns and the enlarged sections.

(7) Any additional information required by the application form.

§ 3.151 Field intensity measurements to establish performance of directional antennas. (a) In addition to the information required by the license application form, the following showing must be submitted to indicate that the pattern obtained for each mode of directional operation is essentially the same as that predicted by the application and required by terms of the authorization and that any specific requirements set out are fully met:

(1) Horizontal field intensity pattern(s) showing the inverse field intensity at 1 mile and effective field intensity (RMS) as determined from field intensity measurements taken and analyzed in accordance with § 3.186 in at least the following directions:

(i) Those specified in the instrument of authorization.

(ii) In major lobes. Generally at least three radials are necessary to establish a major lobe; however, additional radials may be required.

(iii) Along sufficient number of other radials to establish the effective field. In the case of a relatively simple directional antenna pattern, approximately five radials in addition to those in subdivisions (i) and (ii) of this subparagraph are sufficient. However, when more complicated patterns are involved, that is, patterns having several or sharp lobes or nulls, measurements shall be taken along as many radials as may be necessary, to definitely establish the pattern(s).

(2) Pattern(s) plotted with direction true north as zero azimuth and showing the orientation of array with respect to true north, time and space phasing of elements, and both calculated and measured parameters. (Specify degrees leading [+] or lagging [−] and space phasing in feet as well as in degrees.)

(3) Pattern(s) plotted to the largest scale possible on standard letter-size polar coordinate paper (main engraving approximately 7″ x 10″) using divisions and subdivisions having values of 1, 2, 2.5, or 5 times 10^{nth} (no other values shall be used). All values of field intensity less than 10 percent of the RMS field intensity of the pattern shown on an enlarged scale.

(4) Complete tabulation of all data used in plotting the above pattern(s).

(5) The 25 and 5 mv/m field intensity contours and the nighttime interference-free contour, when the pattern is for nighttime operation, as well as auy other contours specified by the instrument of authorization, plotted on a map which has the largest practical scale. These contours need not be shown for distances greater than 20 miles from the antenna except that the field intensity contours on the far side of the business and residential areas of the city in which the main studio is located shall be shown. When the station is limited by interference within the 5 mv/m contour the latter contour need not be shown. In the event the 5 mv/m contour includes and extends beyond the city and beyond 20 miles, the highest signal intensity contour that entirely includes the city may be plotted in lieu of the 5 mv/m contour; in the event that the 5 mv/m contour does not include the city, the contour of highest signal intensity encompassing the city shall be plotted in addition to the 5 mv/m contour.

(6) The actual field intensity measured at each monitoring point established in the various directions for which a limiting field was specified in the instrument of authorization together with accurate and detailed description of each monitoring point together with ordinary snapshots, clear and sharp, taken with the field intensity meter in its measuring position and with the camera so located that its field of view takes in as many pertinent landmarks as possible. In addition, the directions for proceeding to each monitoring point together with a rough sketch or map upon which has been indicated the most accessible approaches to the monitoring points should be submitted.

§ 3.152 Field intensity measurements in support of applications or evidence at hearings. In the determination of interference, groundwave field intensity measurements will take precedence over theoretical values, provided such measurements are

properly taken and presented. When measurements of groundwave signal intensity are presented, they shall be sufficiently complete in accordance with § 3.186 to determine the field intensity at 1 mile in the pertinent directions for that station.

NOTE: The antenna resistance measurements required by § 3.186 need not be taken or submitted.

Standard Broadcast Technical Standards

§ 3.181 Introduction. (a) There are presented herein the Technical Standards giving interpretations and further considerations concerning the rules and regulations of the Federal Communications Commission governing standard broadcast stations. While rules and regulations form the basis of good engineering practice, these standards may go beyond the rules and regulations and set up engineering principles for consideration of various allocation problems. These standards have been approved by the Commission and thus are considered as reflecting the opinion of the Commission in all matters involved.

(b) The Technical Standards set forth herein are those deemed necessary for the construction and operation of standard broadcast stations to meet the requirements of technical regulations and for operation in public interest along technical lines not specifically enunciated in the regulations. These standards are based on the best engineering data available from evidence supplied in formal and informal hearings and extensive surveys conducted in the field by the Commission's personnel. Numerous informal conferences have been held with radio engineers, manufacturers of radio equipment and others for the guidance of the Commission in the formulation of these standards.

(c) These standards are complete in themselves and supersede any previous announcements or policies which may have been enunciated by the Commission on engineering matters concerning standard broadcast stations.

(d) While these standards provide for flexibility and set forth the conditions under which they are applicable, it is not expected that material deviation therefrom as to fundamental principles will be recognized unless full information is submitted as to the reasonableness of such departure and the need therefor.

(e) These standards will necessarily change as progress is made in the art, and accordingly it will be necessary to make revisions from time to time. The Commission will accumulate and analyze engineering data available as to the progress of the art so that its standards may be kept current with the developments.

§ 3.182 Engineering standards of allocation. (a) Sections 3.21 to 3.34, inclusive, govern allocation of facilities in the standard broadcast band of 535 to 1605 kc. Section 3.21 establishes three classes of channels in this band, namely, clear channels for the use of high-powered stations, regional channels for the use of medium-powered stations, and local channels for the use of low-powered stations. The classes and power of standard broadcast stations which will be assigned to the various channels are set forth in § 3.22. The classifications of the standard broadcast stations are as follows:

(1) Class I stations are dominant stations operating on clear channels with powers of not less than 10 or more than 50 kw. These stations are designed to render primary and secondary service over an extended area and at relatively long distances, hence have their primary service areas free from objectionable interference from other stations on the same and adjacent channels and secondary service areas free from objectionable interference from stations on the same channels. (The secondary service area of a Class I station is not protected from adjacent channel interference. However, if it is desired to make a determination of the area in which adjacent channel groundwave interference (10 kc removed) to skywave service exists, it may be considered as the area where the ratio of the desired 50% skywave of the Class I station to the undesired groundwave of a station 10 kc removed is 1 to 4.) From an engineering point of view, Class I stations may be divided into two groups and, hereafter, for the purpose of convenience, the two groups of Class I stations will be termed

Class I-A or I-B in accordance with the assignment to channels allocated by § 3.25(a) or (b).

(i) The Class I stations in group I-A are those assigned to the channels allocated by § 3.25(a), on which except to the extent therein provided, duplicate nighttime operation is not permitted, that is, no other station is permitted to operate on a channel with a Class I station of this group within the limits of the continental United States, excluding Alaska (the Class II stations assigned the channels operate limited time or daytime only), and during daytime the Class I station is protected to the 100 uv/m groundwave contour. Protection is given this class of station to the 500 uv/m groundwave contour from adjacent channel stations for both day and nighttime operations. The power of each such Class I station shall not be less than 50 kw.

(ii) The Class I stations in group I-B are those assigned to the channels allocated by § 3.25(b), on which duplicate operation is permitted, that is, other Class I or Class II stations operating unlimited time may be assigned to such channels. During nighttime hours of operation a Class I station of this group is protected to the 500 uv/m 50 percent skywave contour and during daytime hours of operation to the 100 uv/m groundwave contour from stations on the same channel. Protection is given to the 500 uv/m groundwave contour from stations on adjacent channels for both day and nighttime operations. The operating powers of Class I stations on these frequencies shall be not less than 10 kw nor more than 50 kw.

(2) Class II stations are secondary stations which operate on clear channels with powers not less than 0.25 kw or more than 50 kw. These stations are required to use a directional antenna or other means to avoid causing interference within the normally protected service areas of Class I stations or other Class II stations. These stations normally render primary service only, the area of which depends on the geographical location, power, and frequency. This may be relatively large but is limited by and subject to such interference as may be received from Class I stations. However, it is recommended that Class II stations be so located that the interference received from other stations will not limit the service area to greater than the 2500 uv/m groundwave contour nighttime and 500 uv/m groundwave contour daytime, which are the values for the mutual protection of this class of stations with other stations of the same class.

(3) Class III stations operate on regional channels and normally render primary service to the larger cities and the rural area contiguous thereto, and are subdivided into two classes:

(i) Class III-A stations which operate with powers not less than 1 kw or more than 5 kw are normally protected to the 2500 uv/m groundwave contour nighttime and the 500 uv/m groundwave contour daytime.

(ii) Class III-B stations which operate with powers not less than 0.5 kw, or more than 1 kw nighttime and 5 kw daytime are normally protected to the 4000 uv/m groundwave contour nighttime and 500 uv/m groundwave contour daytime.

(4) Class IV stations operate on local channels normally rendering primary service only to a city or town and the suburban or rural areas contiguous thereto with powers not less than 100 watts, nor more than 250 watts nighttime and 1 kilowatt daytime. The stations are normally protected to the 0.5 mv/m groundwave contour daytime. On local channels the separation required for the daytime protection shall also determine the nighttime separation. Where directional antennas are employed in the daytime by Class IV stations utilizing power in excess of 250 watts, the separations required shall in no case be less than those necessary to afford protection, assuming nondirectional operation with 100 watts or 250 watts, whichever is the nighttime power of the station. In no case will 250 watts nighttime operation be authorized to a station unable to operate omnidirectionally at 250 watts in the daytime. The actual nighttime limitation will be calculated.

NOTE: The following approximate method may be used. It is based on the assumption of 0.25 wavelength antenna height and 88 mv/m at one mile effective field for 250 watts power, using the 10% skywave field intensity curve of Figure 2 of § 3.190. Zones defined by circles of various radii specified below are drawn about the desired station and the interfering 10% skywave signal from each station in a given zone is considered to be the value

tabulated below. The effective interfering 10% skywave signal is taken to be the RSS value of all signals originating within these zones. (Stations beyond 500 miles are not considered.)

Zone	Inner radius	Outer radius	10 percent skywave signal (mv/m)
A	...	60	0.10
B	60	80	0.12
C	80	100	0.14
D	100	250	0.16
E	250	350	0.14
F	350	450	0.12
G	450	500	0.10

Where the power of the interfering station is not 250 watts, the 10% skywave signal should be adjusted by the square root of the ratio of the power to 250 watts.

(b) The class of any station is determined by the channel assignment, the power, and the field intensity contour to which it renders service free of interference from other stations as determined by these standards. No station will be permitted to change to a class normally protected to a contour of less intensity than the contour to which the station actually renders interference-free service. Any station of a class normally protected to a contour of less intensity than that to which the station actually renders interference-free service, will be automatically reclassified according to the class normally protected, the minimum consistent with its power and channel assignment. Likewise, any station to which the interference is reduced so that service is rendered to a contour normally protected for a higher class will be automatically changed to that class if consistent with its power and channel assignment.

(c) When it is shown that primary service is rendered by any station, beyond the normally protected contour, and when primary service to approximately 90% of the population (population served with adequate signal) of the area between the normally protected contour and the contour to which such station actually serves, is not supplied by any other station or stations carrying the same general program service, the contour to which protection may be afforded in such cases will be determined from the individual merits of the case under consideration.

(d) When a station is already limited by interference from other stations to a contour of higher value than that normally protected for its class, this contour shall be the established standard for such station with respect to interference from all other stations.

(e) The several classes of broadcast stations have in general three service areas; namely, primary, secondary, and intermittent service areas. (See § 3.11 for the definitions of primary, secondary, and intermittent service areas.) Class I stations render service to all three service areas. Class II stations render service to a primary area but the secondary and intermittent service areas may be materially limited or destroyed due to interference from other stations depending on the station assignments involved. Class III and IV stations usually have only primary service areas as interference from other stations generally prevents any secondary service and may limit the intermittent service area. However, complete intermittent service may be obtained in many cases depending on the station assignments involved.

(f) The signals necessary to render primary service to different types of service areas are as follows:

Area:	*Field intensity groundwave* [1]
City business or factory areas	10 to 50 mv/m
City residential areas	2 to 10 mv/m
Rural—all areas during winter or northern areas during summer	0.1 to 0.5 mv/m
Rural—southern areas during summer	0.25 to 1.0 mv/m

[1] See § 3.184 for curves showing distance to various groundwave field intensity contours for different frequency and ground conductivities and §3.183.

All these values are based on an absence of objectionable fading, either in changing intensity or selective fading, the usual noise level in the areas, and an absence of limiting interference from other broadcast stations. The values apply both day and night but generally fading or interference from other stations limits the primary service at night in all rural areas to higher values of field intensity than the values given. The Commission will authorize a directive antenna for a Class IV station for daytime operation only with power in excess of 250 watts. In computing the degrees of protection which such antenna will afford, the radiation produced by this antenna shall be assumed to be no less, in any direction, than that which would result from nondirectional operation, utilizing a single element of the directional array, with 100 watts or 250 watts, whichever is the nighttime power of the station.

NOTE: Standards have not been established for interference from atmospherics or man-made electric noise as no uniform method of measuring noise or static has been established. In any individual case objectionable interference from any source, except other broadcast signals, may be determined by comparing the actual noise interference reproduced during reception of a desired broadcast signal to the degree of interference that would be caused by another broadcast signal within 20 cycles of the desired signal and having a carrier ratio of 20 to 1 with both signals modulated 100 percent on peaks of usual programs. Standards of noise measurements and interference ratio for noise are now being studied.

(g) In determining the population of the primary service area, it may be considered that the following signals are satisfactory to overcome man-made noise in towns of the population given.

Population:	*Field intensity groundwave*
Up to 2,500	0.5 mv/m
2,500 to 10,000	2.0 mv/m
10,000 and up	Values given in paragraph (f) of this section

These values are subject to wide variations in individual areas and especial attention must be given to interference from other stations. The values are not considered satisfactory in any case for service to the city in which the main studio of the station is located. The values in paragraph (f) of this section shall apply except as individual consideration may determine.

(h) All classes of broadcast stations have primary service areas subject to limitation by fading and noise, and interference from other stations to the contours set out for each class of station.

(i) Secondary service is delivered in the areas where the sky wave for 50 percent or more of the time has a field intensity of 500 uv/m or greater. (The secondary service area of a Class I-A station should be considered as having this limit only for determination of service in comparison with other stations.) It is not considered that satisfactory secondary service can be rendered to cities unless the skywave approaches in value the groundwave required for primary service. The secondary service is necessarily subject to some interference and extensive fading whereas the primary service area of a station is subject to no objectionable interference or fading. Class I stations only are assigned on the basis of rendering secondary service.

NOTE: Standards have not been established for objectionable fading as such standards would necessarily depend on the receiver characteristics which have been changed considerably in this regard during the last several years. Selective fading causing audio distortion and the signal fading below the noise level are the objectionable characteristics of fading on modern design receivers. The AVC circuits in the better designed modern receivers in general maintain the audio output sufficiently constant to be satisfactory during most fading.

(j) The intermittent service is rendered by the groundwave and begins at the outer boundary of the primary service area and extends to the value of signal where it may be considered as having no further service value. This may be down to only a few microvolts in certain areas and up to several millivolts in other areas of high noise level, interference from other stations, or objectionable fading at night. The

intermittent service area may vary widely from day to night and generally varies from time to time as the name implies. Only Class I stations are assigned for protection from interference from other stations into the intermittent service area.

(k) Section 3.23 provides that the several classes of broadcast stations may be licensed to operate unlimited time, limited time, daytime, sharing time, and specified hours, with full explanation given in the section.

(l) Section 3.24 sets out the general requirements for obtaining an increase in facilities of a licensed station and for a new station. Section 3.24(b) concerns the matter of interference that may be caused by a new assignment or increase in facilities of an existing assignment.

(m) [Reserved.]

(n) [Reserved.]

(o) Objectionable interference from another broadcast station is the degree of interference produced when, at a specified field intensity contour with respect to the desired station, the field intensity of an undesired station (or the root-sum-square value of field intensities of two or more stations on the same frequency) exceeds for ten (10) percent or more of the time the values set forth in these standards. (The secondary service area of a Class I-A station should be considered as having this limit only for determination of service in comparison with other stations.)

(1) With respect to the root-sum-square values of interfering field intensities referred to herein, except in the case of Class IV stations on local channels, calculation is accomplished by considering the signals in order of decreasing magnitude, adding the squares of the values and extracting the square root of the sum, excluding those signals which are less than 50% of the RSS value of the higher signals already included.

(2) The RSS value will not be considered to be increased when a new interfering signal is added which is less than 50% of the RSS value of the interference from existing stations, and which at the same time is not greater than the smallest signal included in the RSS value of interference from existing stations.

(3) It is recognized that application of the above "50% exclusion" method of calculating the RSS interference may result in some cases in anomalies wherein the addition of a new interfering signal or the increase in value of an existing interfering signal will cause the exclusion of a previously included signal and may cause a decrease in the calculated RSS value of interference. In order to provide the Commission with more realistic information regarding gains and losses in service (as a basis for determination of the relative merits of a proposed operation) the following alternate method for calculating the proposed RSS values of interference will be employed wherever applicable.

(4) In the cases where it is proposed to add a new interfering signal which is not less than 50% of the RSS value of interference from existing stations or which is greater than the smallest signal already included to obtain this RSS value, the RSS limitation after addition of the new signal shall be calculated without excluding any signal previously included. Similarly, in cases where it is proposed to increase the value of one of the existing interfering signals which has been included in the RSS value, the RSS limitation after the increase shall be calculated without excluding the interference from any source previously included.

(5) If the new or increased signal proposed in such cases is ultimately authorized, the RSS values of interference to other stations affected will thereafter be calculated by the "50% exclusion" method without regard to this alternate method of calculation.

(6) Examples of RSS interference calculations:

(i) Existing interferences:

Station No. 1—1.0 mv/m.
Station No. 2—0.60 mv/m.
Station No. 3—0.59 mv/m.
Station No. 4—0.58 mv/m.

The RSS value from Nos. 1, 2 and 3 is 1.31 mv/m: therefore interference from No. 4 is excluded for it is less than 50% of 1.31 mv/m.

(ii) Station A receives interference from:

Station No. 1—1.0 mv/m.
Station No. 2—0.60 mv/m.
Station No. 3—0.59 mv/m.

It is proposed to add a new limitation—0.68 mv/m. This is more than 50% of 1.31 mv/m, the RSS value of Nos. 1, 2 and 3. The RSS value of Station No. 1 and of the proposed station would be 1.21 mv/m which is more than twice as large as the limitation from Station No. 2 or No. 3. However, under the above provision the new signal and the three existing interferences are nevertheless calculated for purposes of comparative studies, resulting in an RSS value of 1.47 mv/m. However, if the proposed station is ultimately authorized, only No. 1 and the new signal are included in all subsequent calculations for the reason that Nos. 2 and 3 are less than 50% of 1.21 mv/m, the RSS value of the new signal and No. 1.

(iii) Station A receives interference from:

Station No. 1—1.0 mv/m.
Station No. 2—0.60 mv/m.
Station No. 3—0.59 mv/m.

No. 1 proposes to increase the limitation it imposes on Station A to 1.21 mv/m. Although the limitations from stations Nos. 2 and 3 are less than 50% of the 1.21 mv/m limitation, under the above provision they are nevertheless included for comparative studies, and the RSS limitation is calculated to be 1.47 mv/m. However, if the increase proposed by Station No. 1 is authorized, the RSS value then calculated is 1.21 mv/m because Stations Nos. 2 and 3 are excluded in view of the fact that the limitations they impose are less than 50% of 1.21 mv/m.

(p) Objectionable interference from a station on the same channel shall be considered to exist to a station when, at the field intensity contour specified in paragraph (v) of this section with respect to the class to which the station belongs, the field intensity of an interfering station (or the root-sum-square value of the field intensities of two or more interfering stations) operating on the same channel, exceeds for ten (10) percent or more of the time the value of the permissible interfering signal set forth opposite such class in paragraph (v) of this section.

(q) Objectionable interference from a station on an adjacent channel shall be considered to exist to a station when, at the normally protected contour of a desired station, the field intensity of the ground wave of an undesired station operating on an adjacent channel (or the root-sum-square value of the field intensities of two or more such undesired stations operating on the same adjacent channel) exceeds a value specified in paragraph (w) of this section.

(r) For the purpose of estimating the coverage and the interfering effects of stations in the absence of field intensity measurements, use shall be made of Figure 8 of § 3.190 which describes the estimated effective field for one kilowatt power input of simple vertical omnidirectional antennas of various heights with ground systems of at least 120 one-quarter wavelength radials. Certain approximations, based on the curve or other appropriate theory, may be made when other than such antennas and ground systems are employed, but in any event the effective field to be employed shall not be less than given in the following:

Class of station:	*Effective field*
I	225 mv/m
II and III	175 mv/m
IV	150 mv/m

In case a directional antenna is employed, the interfering signal of a broadcasting station will vary in different directions, being greater than the above values in certain directions and less in others, depending upon the design and adjustment of the directional antenna system. To determine the interference in any direction the measured or calculated radiated field (unabsorbed field intensity at 1 mile from the array)

must be used in conjunction with the appropriate propagation curves. (See § 3.185 for further discussion and solution of a typical directional antenna case.)

(s) The existence or absence of objectionable groundwave interference from stations on the same or adjacent channels shall be determined by actual measurements made according to the method hereinafter described, or, in the absence of such measurements, by reference to the propagation curves of § 3.184. The existence or absence of objectionable interference due to skywave propagation shall be determined by reference to the appropriate propagation curves in Figure 1 or Figure 2 of § 3.190.

(t) In computing the fifty (50) percent skywave field intensity values and the ten (10) percent skywave field intensity values of a station on a clear channel, use shall be made of the appropriate graph set forth in Figure 1 of § 3.190 entitled "Average Skywave Field Intensity" (corresponding to the second hour after sunset at the recording station). These graphs are drawn for a radiated field of 100 mv/m at 1 mile in the horizontal plane from a 0.311 wavelength antenna. In computing the ten (10) percent skywave field intensity of a regional channel station, use shall be made of the appropriate curve in Figure 2 of § 3.190 entitled "10 percent Skywave Signal Range." This graph is drawn for a radiated field of 100 mv/m at 1 mile at the vertical angle pertinent to transmission by one reflection. This curve supersedes the ten (10) percent skywave curve of Figure 1 of § 3.190, only for regional and local channels at the present time. Adoption of revised skywave curves for use on clear channels will await the outcome of the Clear Channel Hearing (Docket No. 6741).

(u) The distance to any specified groundwave field intensity contour for any frequency may be determined from the appropriate curves in § 3.184 entitled "Ground Wave Field Intensity vs. Distance."

(v) Protected service contours and permissible interference signals for broadcast stations are as follows:

Class of station	Class of channel used	Permissible power	Signal intensity contour of area protected from objectionable interference [1]		Permissible interfering signal on same channel [2]	
			Day [3]	Night	Day [3]	Night
I-A	Clear	50 kw	SC 100 uv/m. AC 500 uv/m.	Not duplicated [7]	5 uv/m	Not duplicated.
I-B	Clear	10 kw. to 50 kw	SC 100 uv/m. AC 500 uv/m.	500 uv/m. (50% skywave).	5 uv/m	25 uv/m.
II	Clear	0.25 kw. to 50 kw.	500 uv/m	2500 uv/m [5] (groundwave)	25 uv/m	125 uv/m.
III-A	Regional	1 kw. to 5 kw.	500 uv/m	2500 uv/m (groundwave)	25 uv/m	125 uv/m.
III-B	Regional	0.5 to 1 kw. night, and 5 kw. day.	500 uv/m	4000 uv/m (groundwave)	25 uv/m	200 uv/m.
IV	Local	0.1 kw. to 0.25 kw. night and 0.1 to 1 kw. day	500 uv/m	Not prescribed [6]	25 uv/m	Not prescribed.[6]

[1] When a station is already limited by interference from other stations to a contour of higher value than that normally protected for its class, this contour shall be the established standard for such station with respect to interference from all other stations.

[2] For adjacent channels see paragraph (w) of this section.

[3] Groundwave.

[4] Skywave field intensity for 10 percent or more of the time.

[5] These values are with respect to interference from all stations except Class I-B, which stations may cause interference to a field intensity contour of higher value. However, it is recommended that Class II stations be so located that the interference received from Class I-B stations will not exceed these values. If the Class II stations are limited by Class I-B stations to higher values, then such values shall be the established standard with respect to protection from all other stations.

[6] See paragraph (a)(4) of this section.

[7] On the frequency 770 kc, two Class I stations may be assigned.

SC = same channel.

AC = Adjacent channel.

(w) The following table is to be used for determining the minimum ratio of the field intensity of a desired to an undesired signal for interference-free service. In the case of a desired groundwave signal interfered with by two or more skywave signals on the same frequency, the RSS value of the latter is used. From the table, it is apparent that in many cases stations operating on channels 10 and 20 kilocycles apart may be operated with antenna systems side by side or otherwise in proximity

Frequency separation of desired to undesired signals—	Desired groundwave to—		Desired 50 percent skywave to undesired 10 percent skywave
	Undesired groundwave	Undesired 10 percent skywave	
0 kc	20:1	20:1	20:1
10 kc	1:1	1:5	(1)
20 kc	1:30	....	....

[1] The secondary service area of a Class I station is not protected from adjacent channel interference. However, if it is desired to make a determination of the area in which adjacent channel groundwave interference (10 kc. removed) to skywave service exists, it may be considered as the area where the ratio of the desired 50 percent skywave of the Class I station to the undesired groundwave of a station 10 kc. removed is 1 to 4.

without any indications of interference if the interference is defined only in terms of permissible ratios listed in this paragraph. As a practical matter, serious interference problems may arise when two or more stations with the same general service area are operated on channels 10, 20 and 30 kilocycles apart.

(x) Two stations, one with a frequency twice that of the other, should not be assigned in the same groundwave service area unless special precautions are taken to avoid interference from the second harmonic of the lower frequency. In selecting a frequency, consideration should be given to the fact that occasionally the frequency assignment of two stations in the same area may bear such a relation to the intermediate frequency of some broadcast receivers as to cause so-called "image" interference. However, since this can usually be rectified by readjustment of the intermediate frequency of such receivers, the Commission in general will not take this kind of interference into consideration in allocation problems.

(y) Two stations operating with synchronized carriers and carrying the identical program will have their groundwave service subject to some distortion in areas where the signals from the two stations are of comparable intensity. For the purpose of estimating coverage of such stations areas in which the signal ratio is between 1 to 2 and 2 to 1 will not be considered as having satisfactory service.

NOTE: Two stations are considered to be operated synchronously when the carriers are maintained within one-fifth of a cycle per second of each other and they transmit identical programs.

§ 3.183 **Groundwave signals.** (a) Interference that may be caused by a proposed assignment or an existing assignment during daytime should be determined, when possible, by measurements on the frequency involved or on another frequency over the same terrain and by means of the curves in § 3.184 entitled "Ground Wave Field Intensity versus Distance."

(b) In determining interference based upon field intensity measurements, it is necessary to do the following: First, establish the outer boundary of the protected service area of the desired station in the direction of the station that may cause interference to it. Second, at this boundary, measure the interfering signal from the undesired station. The ratio of the desired to the undesired signal given in § 3.182(w) should be applied to the measured signals and if the required ratio is observed, no objectionable interference is foreseen. When measurements of both the desired and undesired stations are made in one area to determine the point where objectionable interference from groundwave signals occur or to establish other pertinent contours, several measurements of each station shall be made within a few miles of this point or contour. The effective field of the antennas in the pertinent directions of the stations must be established and all measurements must be made in accordance with § 3.186.

(c) In all cases where measurements taken in accordance with the requirements are not available, the groundwave intensity must be determined by means of the

pertinent map of ground conductivity and the groundwave curves of field intensity versus distance. The conductivity of a given terrain may be determined by measurements of any broadcast signal traversing the terrain involved. Figures M3 and R3 of § 3.190 show the conductivity throughout the United States by general areas of reasonably uniform conductivity. When it is clear that only one conductivity value is involved, Figure R3 of § 3.190, which is a replica of Figure M3 and contained in these standards, may be used; in all other situations Figure M3 must be employed. It is recognized that in areas of limited size or over a particular path, the conductivity may vary widely from the values given; therefore, these maps are to be used only when accurate and acceptable measurements have not been made. (For determinations of interference and service requiring a knowledge of ground conductivities in Canada and Mexico, Appendix H to the North American Regional Broadcasting Agreement, Washington, D.C., 1950, may be used. Where different conductivities appear in the maps of the several countries on different sides of the border not explained by geophysical cleavages, such cleavages are to be considered as real. A uniform ground conductivity of 10 millimhos per meter may be assumed for Cuba.)

NOTE: Figure M3 which is incorporated in these Standards by reference, was derived by indicating ground conductivity values in the United States on the United States Albers equal area projection map (based on standard parallels 29½° and 45½°; North American datum; scale 1/2,500,000). Figure M3, consisting of two sections, an eastern and a western half, may be obtained from the Superintendent of Documents, Washington, D.C.

(d) Example of determining interference by the graphs in § 3.184:

It is desired to find whether objectionable interference exists between a 5 kw Class III station on 990 kc and a 1 kw Class III station on 1000 kc, the stations being separated by 130 miles; both stations use nondirectional antennas having such height as to produce an effective field for 1 kw of 175 mv/m. (See §3.185 in case of use of directional antennas.) The conductivity at each station and of the intervening terrain is determined as 6 mmhos/m. The protection to Class III stations during daytime is to the 500 uv/m contour. The distance to the 500 uv/m groundwave contour of the 1 kw station is determined by the use of the appropriate curve in § 3.184, Graph 12. Since the curve is plotted for 100 mv/m at a mile, to find the distance to the 500 uv/m contour of the 1 kw station, it is necessary to determine the distance to the 285 uv/m contour $\left(\frac{100 \times 500}{175} = 285\right)$. From the appropriate curve, the estimated radius of the service area for the desired station is found to be 39.5 miles. Subtracting this distance from the distance between the two stations leaves 90.5 miles for the interfering signal to travel. From the above curve it is found that the signal from the 5 kw station at this distance would be 158 uv/m. Since a one to one ratio applies for stations separated by 10 kc, the undesired signal at that point can have a value up to 500 uv/m without objectionable interference. If the undesired signal had been found to be greater than 500 uv/m, then objectionable interference would exist. For other channel separations, the appropriate ratio of desired to undesired signal should be used.

(e) Where a signal traverses a path over which different conductivities exist, the distance to a particular groundwave field intensity contour shall be determined by the use of the equivalent distance method. Reasonably accurate results may be expected in determining field intensities at a distance from the antenna by application of the equivalent distance method when the unattenuated field of the antenna, the various ground conductivities and the location of discontinuities are known. This method considers a wave to be propagated across a given conductivity according to the curve for a homogeneous earth of that conductivity. When the wave crosses from a region of one conductivity into a region of a second conductivity, the equivalent distance of the receiving point from the transmitter changes abruptly but the field intensity does not. From a point just inside the second region the transmitter appears to be at that distance where, on the curve for a homogeneous earth of the second conductivity, the field intensity equals the value that occurred just across the boundary in the first region. Thus the equivalent distance from the receiving point to the transmitter may be either greater or less than the actual distance. An imaginary transmitter is considered to exist at that equivalent distance. This technique is not

intended to be used as a means of evaluating unattenuated field or ground conductivity by the analysis of measured data. The method to be employed for such determinations is set out in § 3.186.

(f) An example of the use of the equivalent distance method follows:

It is desired to determine the distance to the 0.5 mv/m and 0.025 mv/m contours of a station on a frequency of 1000 kc with an inverse distance field of 100 mv/m at one mile being radiated over a path having a conductivity of 10 mmhos/m for a distance of 15 miles, 5 mmhos/m for the next 20 miles and 15 mmhos/m thereafter. By the use of the appropriate curves in § 3.184--Graph 12, it is seen that at a distance of 15 miles on the curve for 10 mmhos/m the field is 3.45 mv/m. The equivalent distance to this field intensity for a conductivity of 5 mmhos/m is 11 miles. Continuing on the propagation curve for the second conductivity, the 0.5 mv/m contour is encountered at a distance of 27.9 miles from the imaginary transmitter. Since the imaginary transmitter was 4 miles nearer (15 − 11 miles) to the 0.5 mv/m contour, the distance from the contour to the actual transmitter is 31.9 miles (27.9 + 4 miles). The distance to the 0.025 mv/m contour is determined by continuing on the propagation curve for the second conductivity to a distance of 31 miles (11 + 20 miles), at which point the field is read to be 0.39 mv/m. At this point the conductivity changes to 15 mmhos/m and from the curve relating to that conductivity, the equivalent distance is determined to be 58 miles—27 miles more distant than would obtain had a conductivity of 5 mmhos/m prevailed. Using the curve representing the conductivity of 15 mmhos/m the 0.025 mv/m contour is determined to be at an equivalent distance of 172 miles. Since the imaginary transmitter was considered to be 4 miles closer at the first boundary and 27 miles farther at the second boundary, the net effect is to consider the imaginary transmitter 23 miles (27 − 4 miles) more distant than the actual transmitter; thus the actual distance to the 0.025 mv/m contour is determined to be 149 miles (172 − 23 miles).

§ 3.184 Groundwave field intensity charts. (a) Graphs 1–19A show the computed values of groundwave field intensity as a function of the distance from the transmitting antenna. The groundwave field intensity is here considered to be that part of the vertical component of the electric field received on the ground which has not been reflected from the ionosphere nor the troposphere. These 20 charts were computed for 20 different frequencies, a dielectric constant of the ground equal to 15 for land and 80 for sea water (referred to air as unity) and for the ground conductivities (expressed in mmhos/m) given on the curves. The curves show the variation of the groundwave field intensity with distance to be expected for transmission from a short vertical antenna at the surface of a uniformly conducting spherical earth with the ground constants shown on the curves; the curves are for an antenna power and efficiency such that the inverse distance field is 100 mv/m at 1 mile. The curves are valid at distances large compared to the dimensions of the antenna for other than short vertical antennas.

(b) The inverse distance field (100 mv/m divided by the distance in miles) corresponds to the groundwave field intensity to be expected from an antenna with the same radiation efficiency when it is located over a perfectly conducting earth. To determine the value of the groundwave field intensity corresponding to a value of inverse distance field other than 100 mv/m at 1 mile, simply multiply the field intensity as given on these charts by the desired value of inverse distance field at 1 mile divided by 100; for example, to determine the groundwave field intensity for a station with an inverse distance field of 1700 mv/m at 1 mile, simply multiply the values given on the charts by 17. The value of the inverse distance field to be used for a particular antenna depends upon the power input to the antenna, the nature of the ground in the neighborhood of the antenna, and the geometry of the antenna. For methods of calculating the interrelations between these variables and the inverse distance field, see "The Propagation of Radio Waves over the Surface of the Earth and in the Upper Atmosphere," Part II, by Mr. K. A. Norton, Proc. I.R.E., Vol. 25, September 1937, pp. 1203–1236.

(c) At sufficiently short distances (say less than 35 miles), such that the curvature of the earth does not introduce an additional attenuation of the waves, the graphs were computed by means of the plane earth formulas given in the paper, "The Propagation of Radio Waves over the Surface of the Earth and in the Upper At-

mosphere," Part I, by Mr. K. A. Norton, Proc. I.R.E., Vol. 24, October 1936, pp. 1367–1387. At larger distances the additional attenuation of the waves which is introduced by the effect of the curvature of the earth was introduced by the methods outlined in the papers, "The Diffraction of Electromagnetic Waves from an Electrical Point Source round a Finitely Conducting Sphere, with Applications to Radiotelegraphy and the Theory of the Rainbow," by Balth van der Pol and H. Bremmer, Part I, Phil. Mag., Vol. 24, p. 141, July 1937, Part II, Phil. Mag., Vol. 24, p. 825, Suppl., November 1937, "Ergebnisse einer Theorie ueber die Fortpflanzung elektron magnetischer Wellen ueber eine Kugel endlicher Leitfahigkeit," by Balth van der Pol and H. Bremmer, Hochfrequenztechnik und Elektroakustik, Band 51, Heft 6, June 1938, "Further Note on the Propagation of Radio Waves over a Finitely Conducting Spherical Earth," by Balth van der Pol and H. Bremmer, Phil. Mag., Vol. 27, p. 261, March 1939. In order to allow for the refraction of the radio waves in the lower atmosphere due to the variation of the dielectric constant of the air with height above the earth, a radius of the earth equal to 4/3 the actual radius was used in the computations for the effect of the earth's curvature in the manner suggested by C. R. Burrows, "Radio Propagation over Spherical Earth," Proc. I.R.E., May 1935; i.e., the distance corresponding to a given value of attenuation due to the curvature of the earth in the absence of air refraction was multiplied by the factor $(4/3)^{2/3} = 1.21$. The amount of this refraction varies from day to day and from season to season, depending on the air mass conditions in the lower atmosphere. If k denotes the ratio between the equivalent radius of the earth and the true radius, the following table gives the values of k for several typical air masses encountered in the United States.

Air mass type	k	
	Summer	Winter
Tropical Gulf—T_r	1.53	1.43
Polar Continental—P_c	1.31	1.25
Superior—S	1.25	1.25
Average	1.33	

It is clear from this table that the use of the average value of $k = 4/3$ is justified in obtaining a single correction for the systematic effects of atmospheric refraction.

(d) Provided the value of the dielectric constant is near 15, the curves of Graphs 1–19A may be compared with experimental data to determine the appropriate values of the ground conductivity and of the inverse distance field intensity at 1 mile. This is accomplished simply by plotting the measured fields on transparent log-log graph paper similar to that used for Graphs 1–19A and superimposing this chart over the graph corresponding to the frequency involved. The log-log graph sheet is then shifted vertically until the best fit is obtained with one of the curves on the graph; the intersection of the inverse distance line on the graph with the 1-mile abscissa on the chart determines the inverse distance field intensity at 1 mile. For other values of dielectric constant, the following procedure may be used for a determination of the dielectric constant of the ground, conductivity of the ground and the inverse distance field intensity at 1 mile. Graph 20 gives the relative values of groundwave field intensity over a plane earth as a function of the numerical distance p and phase angle b. On graph paper with coordinates similar to those of Graph 20, plot the measured values of field intensity as ordinates versus the corresponding distances from the antenna expressed in miles as abscissae. The data should be plotted only for distances greater than one wavelength (or, when this is greater, five times the vertical height of the antenna in the case of a single element, i.e., nondirectional antenna or 10 times the spacing between the elements of a directional antenna) and for distances less than $50/f_{mc}^{1/3}$ miles (i.e., 50 miles at 1 mc). Then, using a light box, place the sheet with the data plotted on it over the sheet with the curves of Graph 20 and shift the data sheet vertically and horizontally (making sure that the

vertical lines on both sheets are parallel) until the best fit with the data is obtained with one of the curves on Graph 20. When the two sheets are properly lined up, the value of the field intensity corresponding to the intersection of the inverse distance line of Graph 20 with the 1 mile abscissa on the data sheet is the inverse distance field intensity at 1 mile, and the values of the numerical distance at 1 mile, p_1, and of b are also determined. Knowing the values of b and p_1 (the numerical distance at 1 mile), we may substitute in the following approximate formulas to determine the appropriate values of the ground conductivity and dielectric constant.

$$x \cong \frac{\pi}{p} \cdot (R/\lambda)_1 \cdot \cos b \tag{1}$$

$(R/\lambda)_1$ = number of wavelengths in 1 mile.

$$\sigma_{emu} = \frac{x f_{mc}}{17.9731} \cdot 10^{-14} \tag{2}$$

σ_{emu} = conductivity of the ground expressed in electromagnetic units.

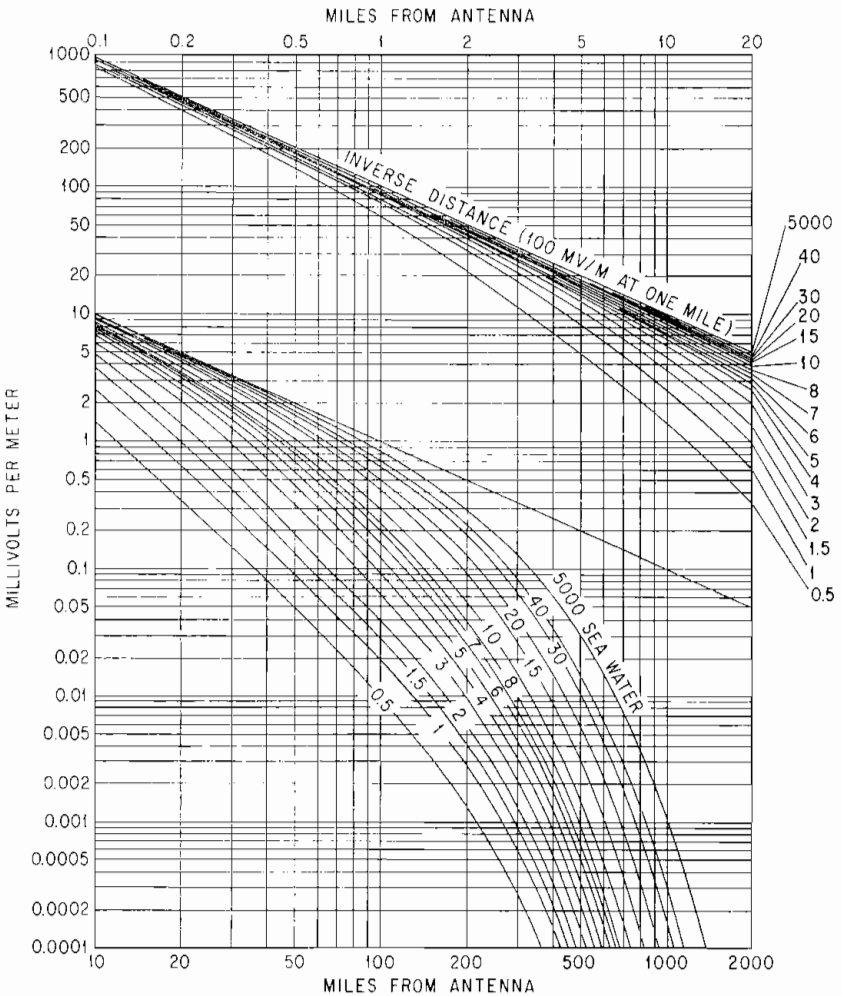
f_{mc} = frequency expressed in megacycles.

$$\epsilon \cong x \tan b - 1 \tag{3}$$

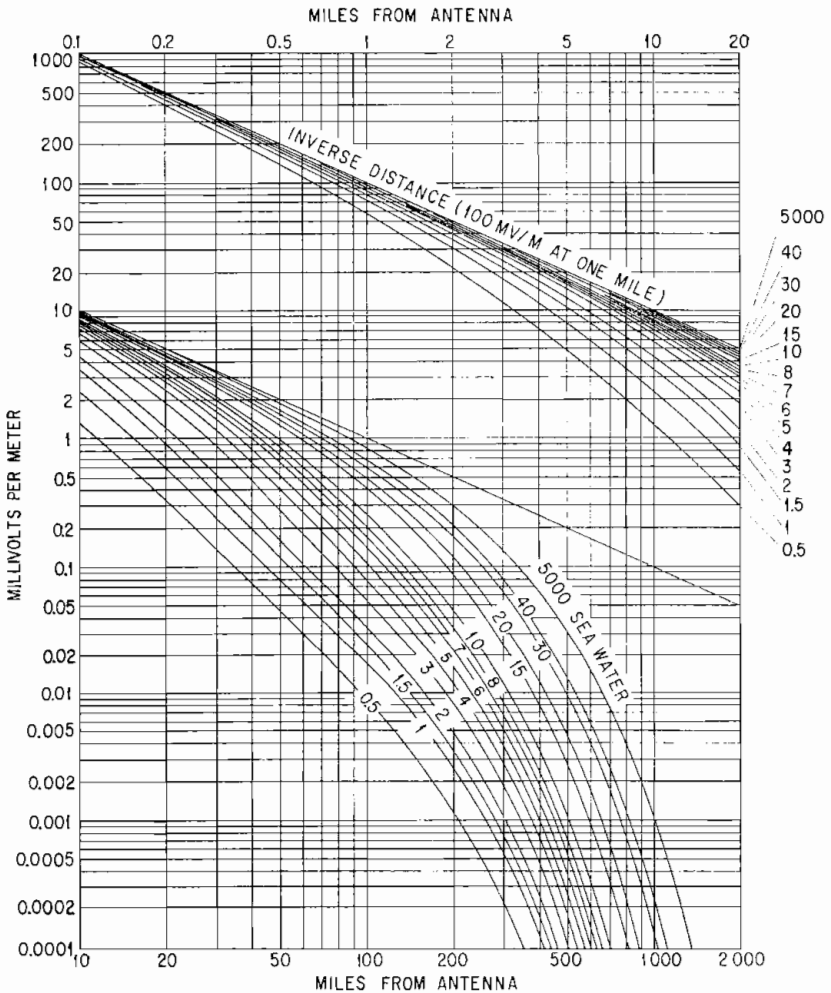
ϵ = dielectric constant of the ground referred to air as unity.

First solve for x by substituting the known values of p_1, $(R/\lambda)_1$, and cos b in equation (1). Equation (2) may then be solved for σ and equation (3) for ϵ. At distances greater than $50/f_{mc}^{1/3}$ miles the curves of Graph 20 do not give the correct relative values of field intensity since the curvature of the earth weakens the field more rapidly than these plane earth curves would indicate. Thus, no attempt should be made to fit experimental data to these curves at the larger distances.

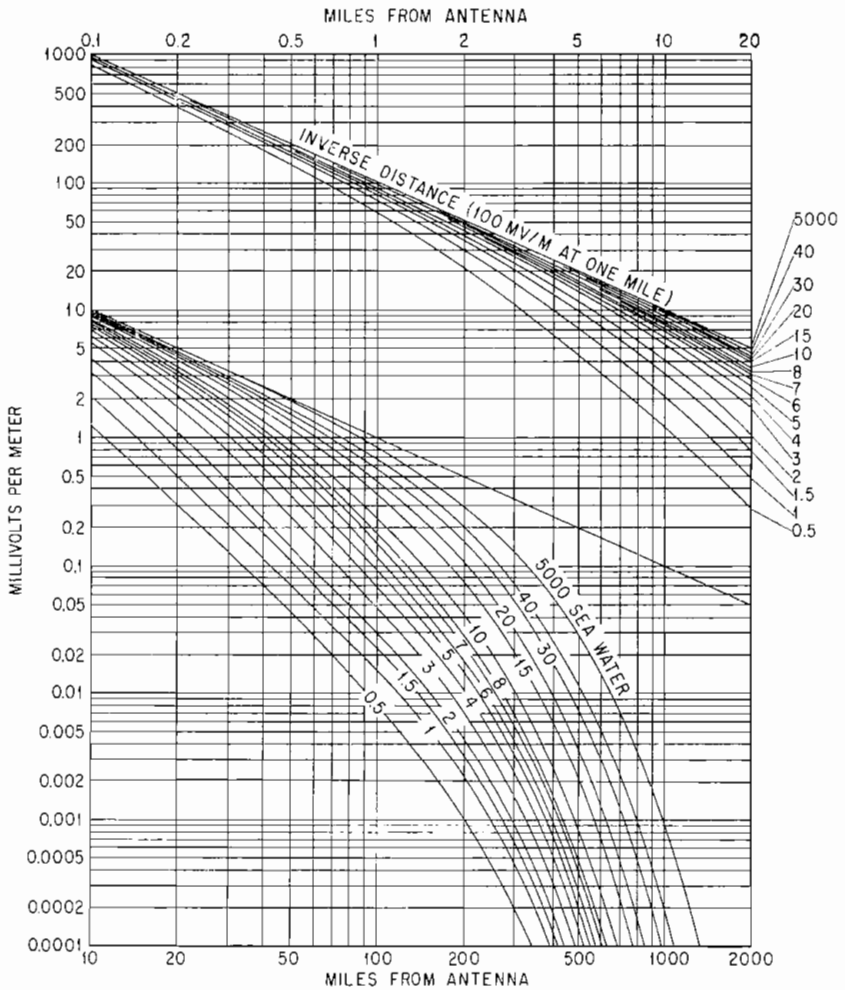
(e) At sufficiently short distances (say less than 35 miles at broadcast frequencies), such that the curvature of the earth does not introduce an additional attenuation of the waves, the curves of Graph 20 may be used for determining the ground wave field intensity for transmitting and receiving antennas at the surface of the earth for any radiated power, frequency, or set of ground constants in the following manner: First, lay off the straight inverse distance line corresponding to the power radiated on transparent log-log graph paper similar to that of Graph 20, labelling the ordinates of the chart in terms of field intensity, and the abscissae in terms of distance. Next, by means of the formulas given on Graph 20, calculate the value of the numerical distance, p, at 1 mile, and the value of b. Then superimpose the log-log chart over Graph 20, shifting it vertically until the inverse distance lines on both charts coincide and shifting it horizontally until the numerical distance at 1 mile on Graph 20 coincides with 1 mile on the log-log graph paper. The curve of Graph 20 corresponding to the calculated value of b is then traced on the log-log graph paper giving the field intensity versus distance in miles.



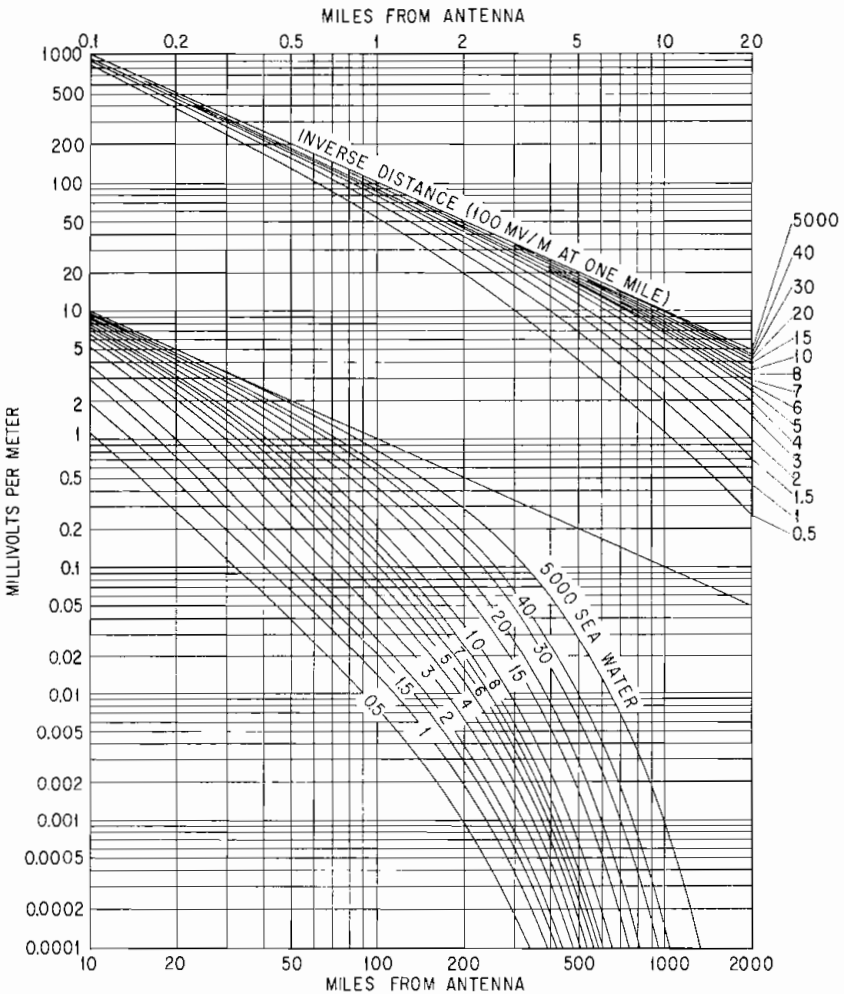
GRAPH 1. Groundwave field intensity vs. distance, 540–560 kc. Computed for 550 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



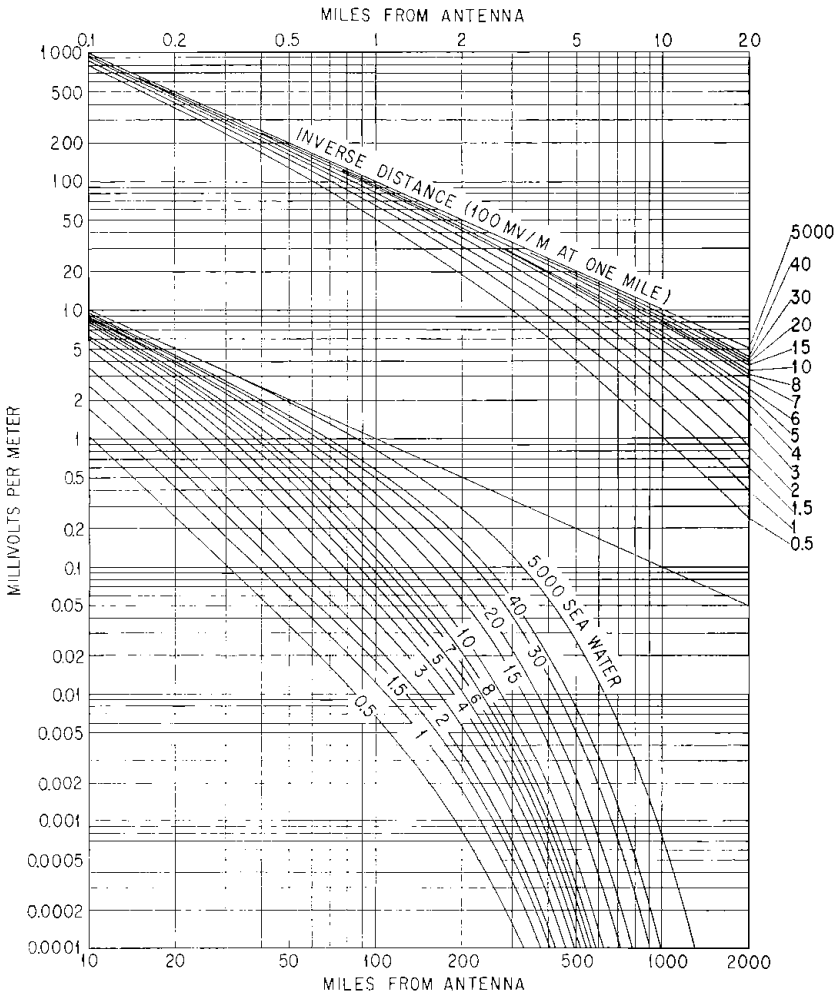
GRAPH 2. Groundwave field intensity vs. distance, 570–590 kc. Computed for 580 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



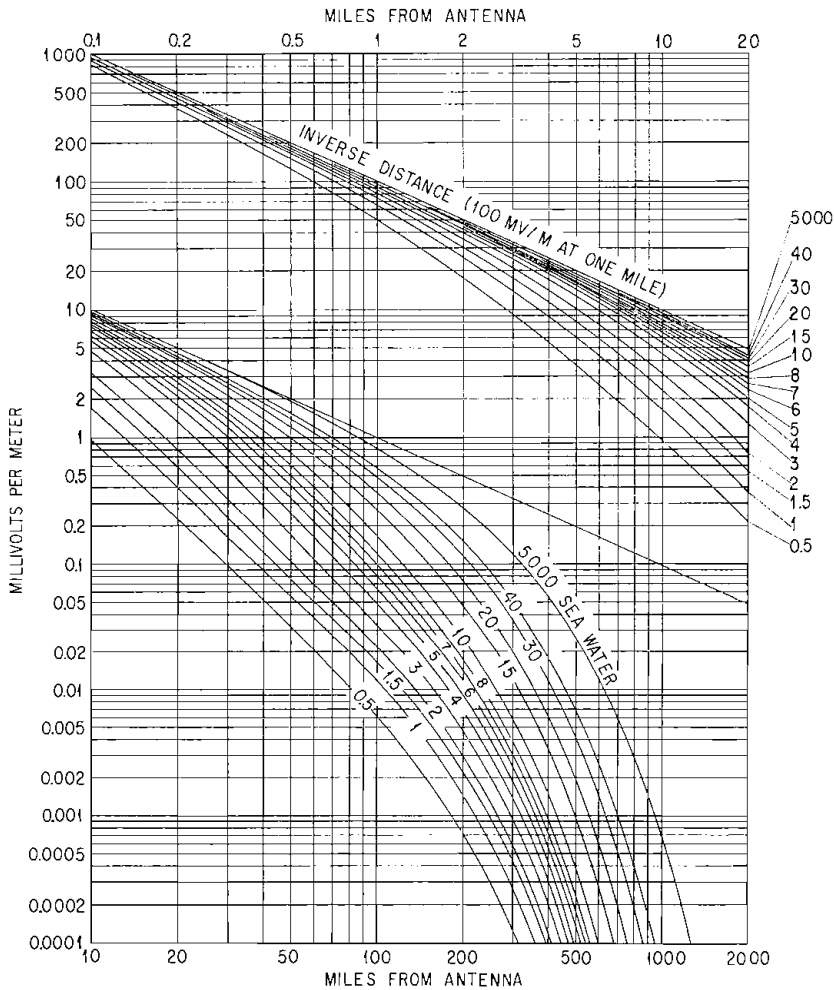
GRAPH 3. Groundwave field intensity vs. distance, 600–620 kc. Computed for 610 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



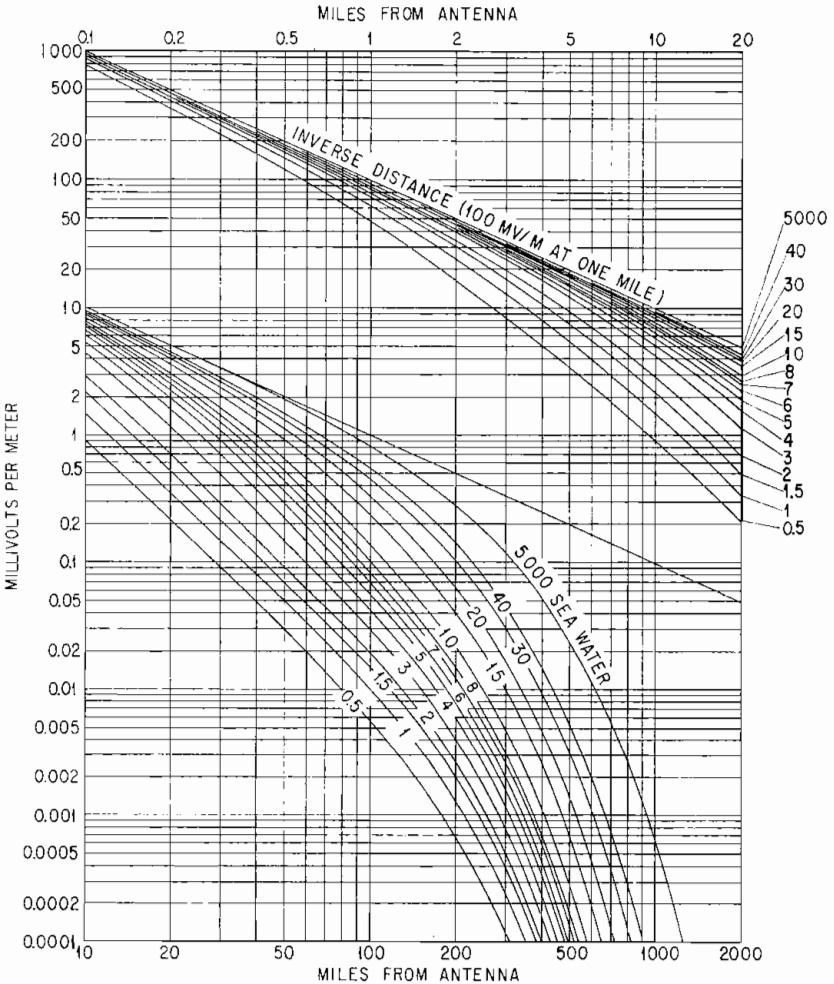
GRAPH 4. Groundwave field intensity vs. distance, 630-650 kc. Computed for 640 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



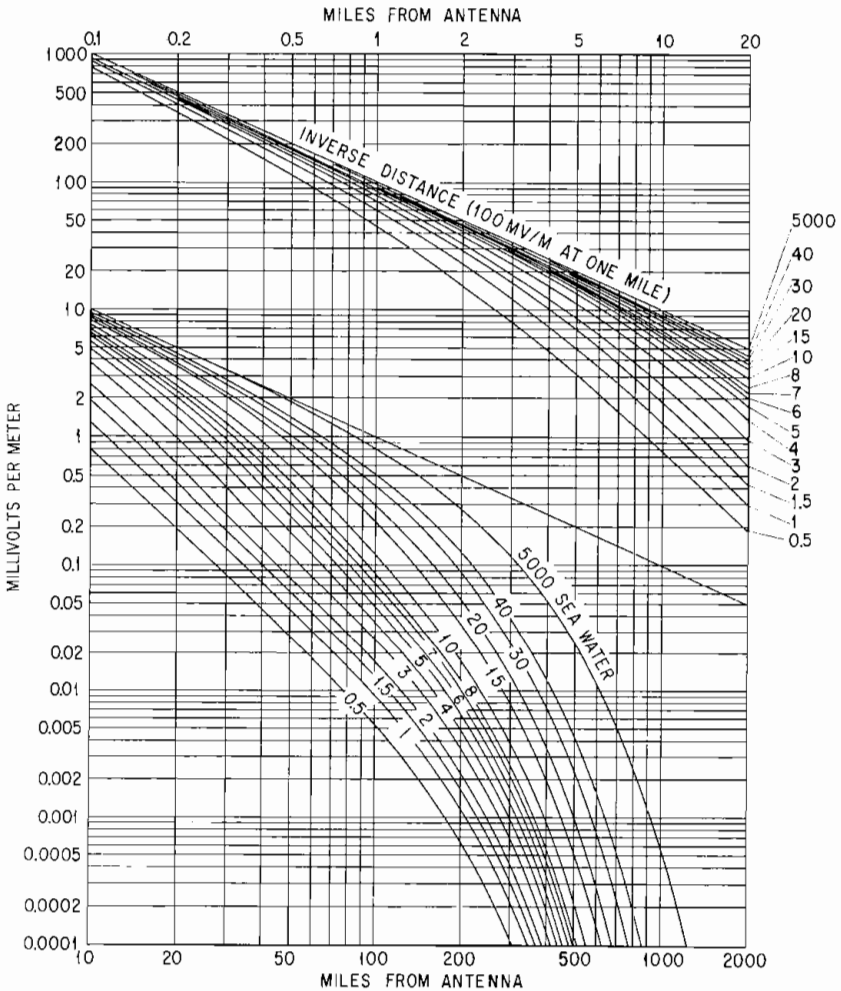
GRAPH 5. Groundwave field intensity vs. distance, 660–680 kc. Computed for 670 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



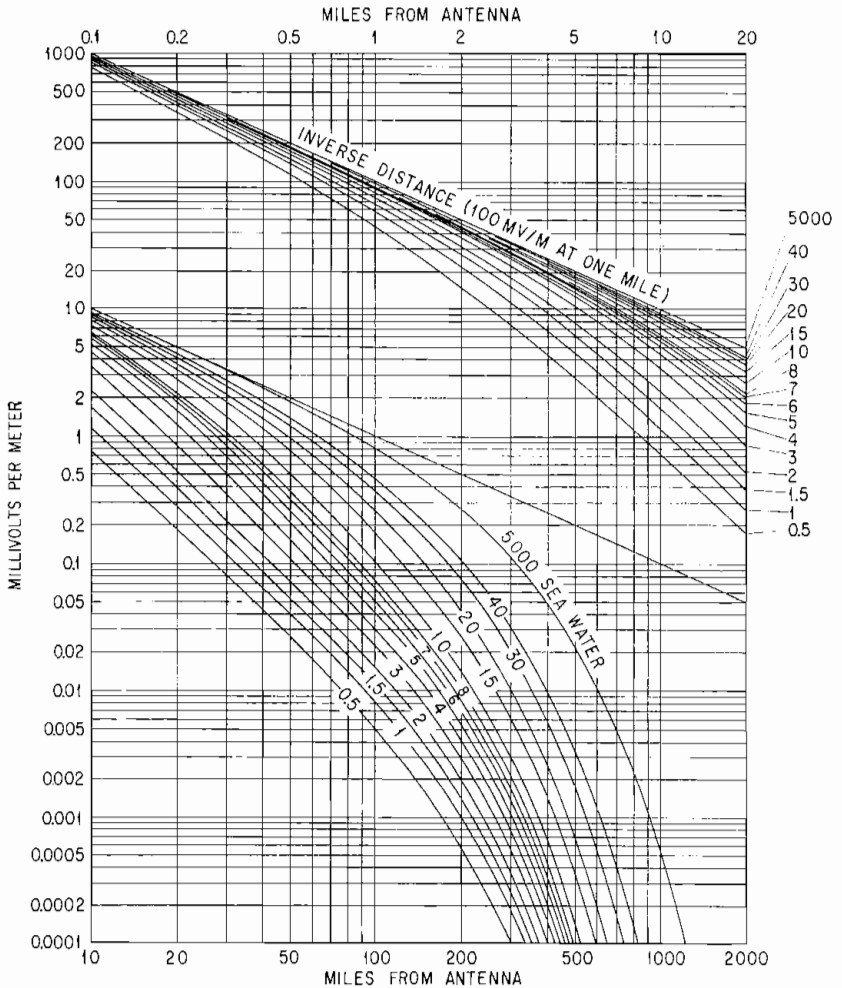
GRAPH 6. Groundwave field intensity vs. distance, 690–710 kc. Computed for 700 kc. $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



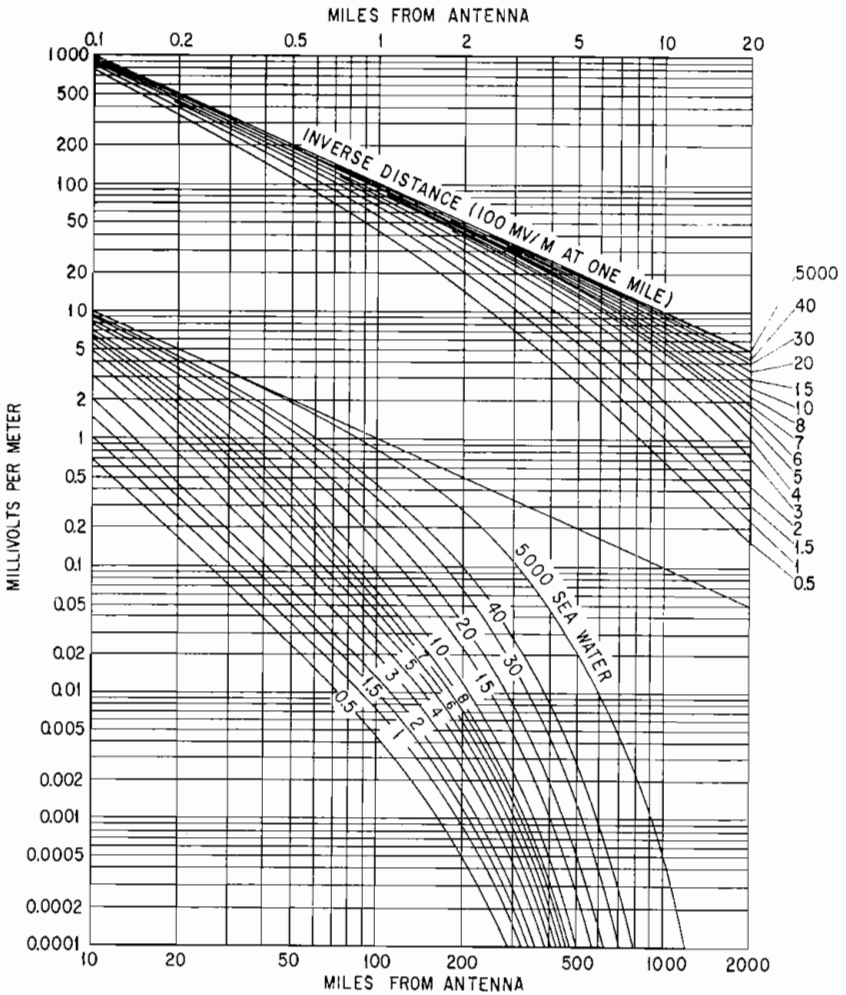
GRAPH 7. Groundwave field intensity vs. distance, 720–760 kc. Computed for 740 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



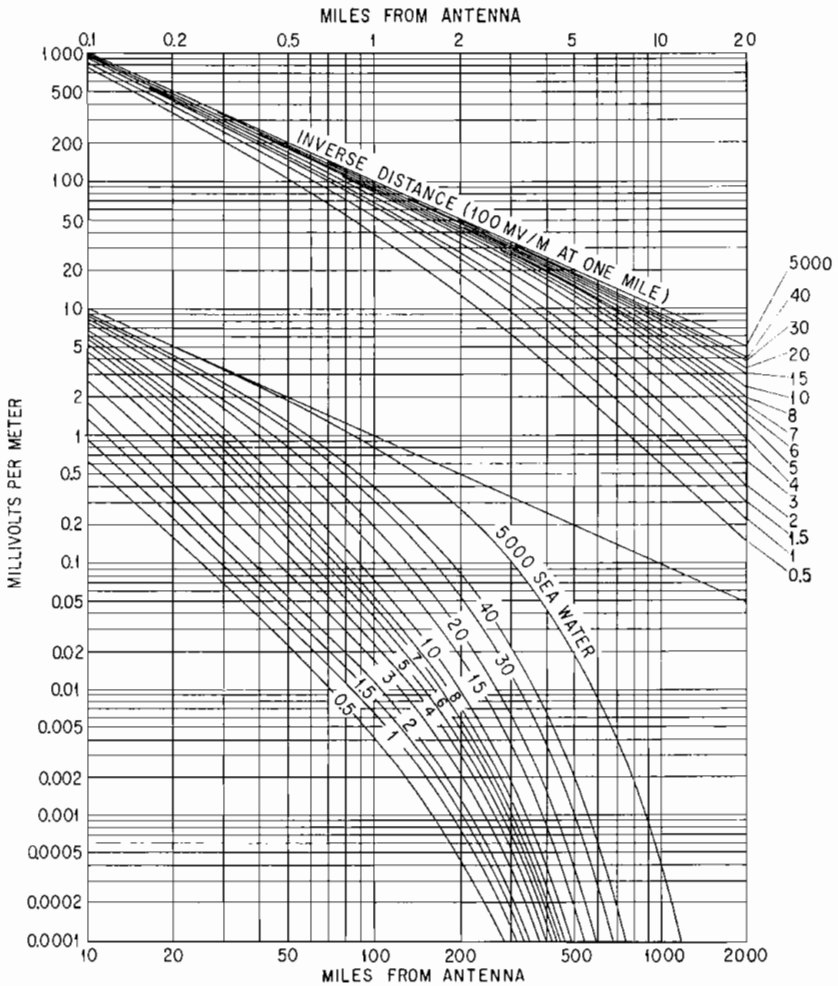
GRAPH 8. Groundwave field intensity vs. distance, 770–810 kc. Computed for 790 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



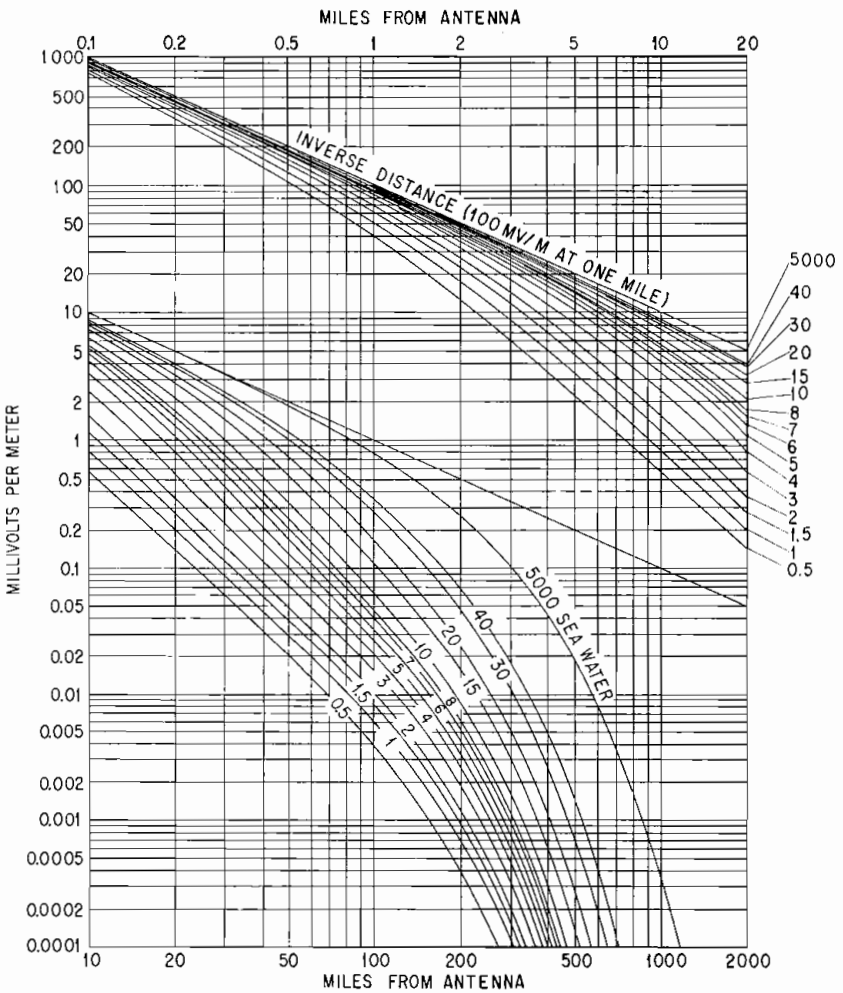
GRAPH 9. Groundwave field intensity vs. distance, 820–860 kc. Computed for 840 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



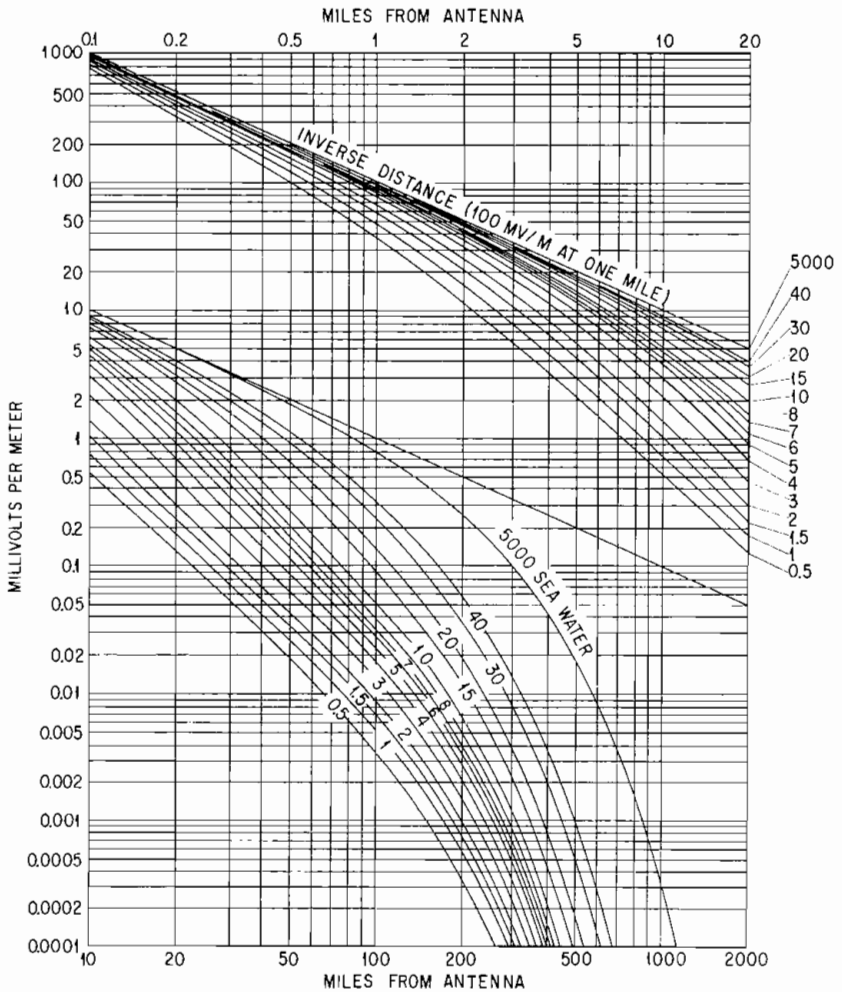
GRAPH 10. Groundwave field intensity vs. distance, 870–910 kc. Computed for 890 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



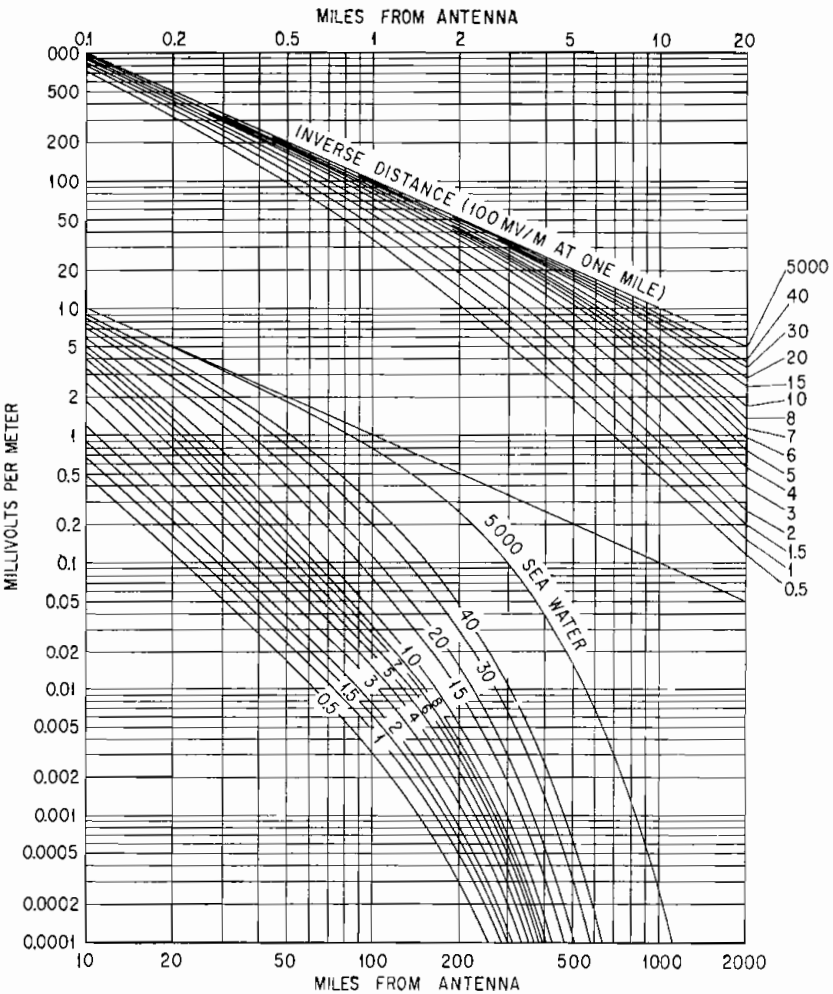
GRAPH 11. Groundwave field intensity vs. distance, 920–960 kc. Computed for 940 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



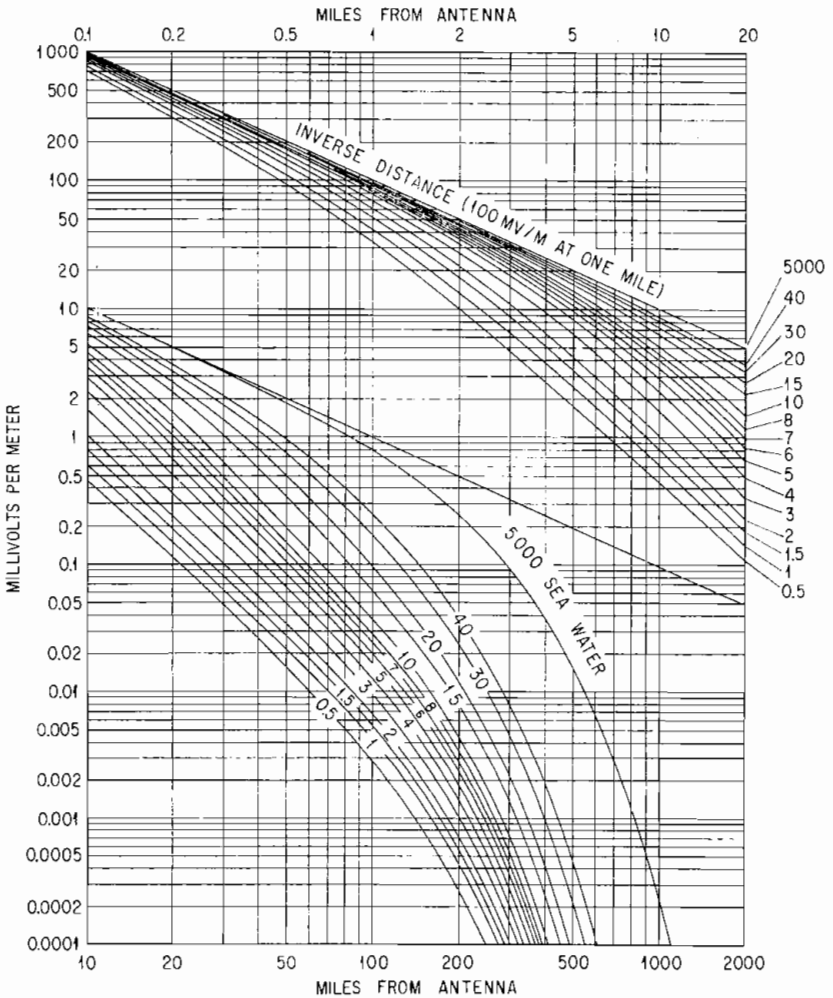
GRAPH 12. Groundwave field intensity vs. distance, 970–1030 kc. Computed for 1000 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



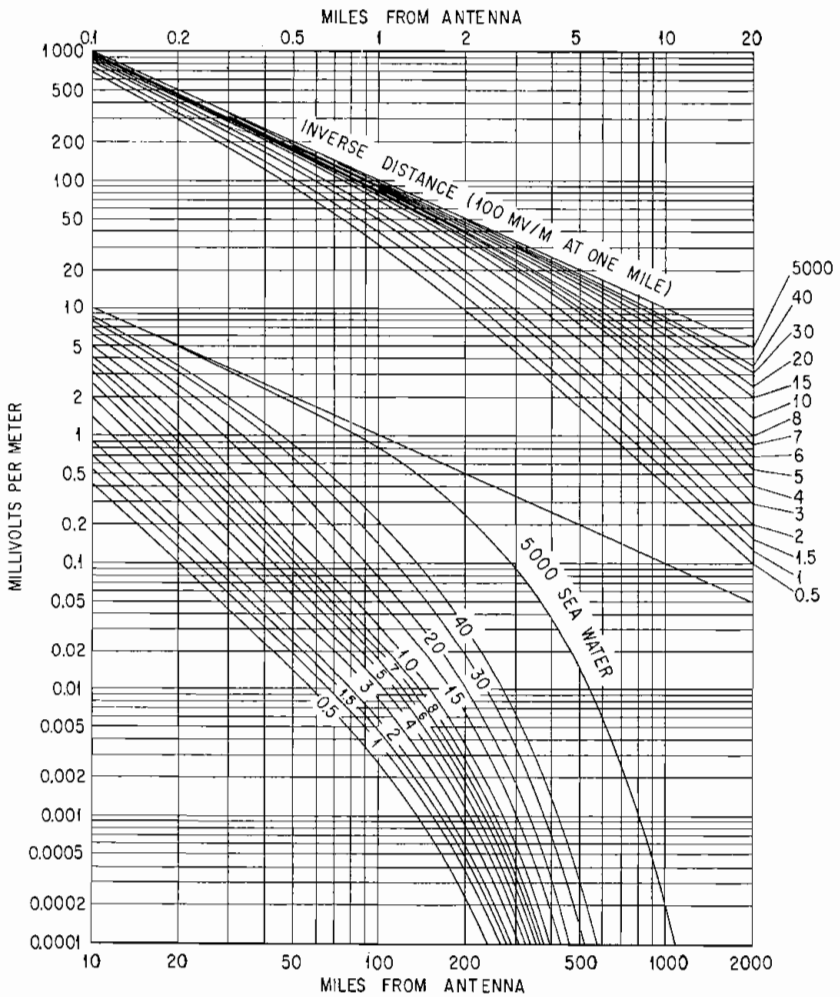
GRAPH 13. Groundwave field intensity vs. distance, 1040–1100 kc. Computed for 1070 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



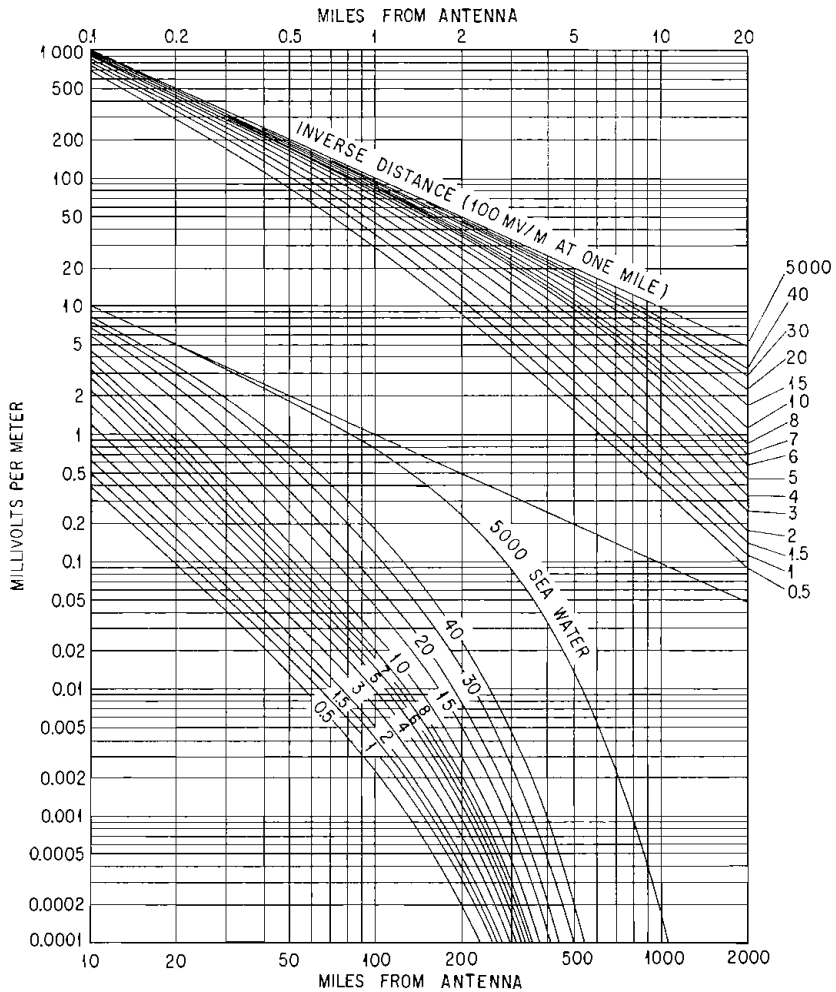
GRAPH 14. Groundwave field intensity vs. distance, 1110–1170 kc. Computed for 1140 kc, ϵ = 15, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



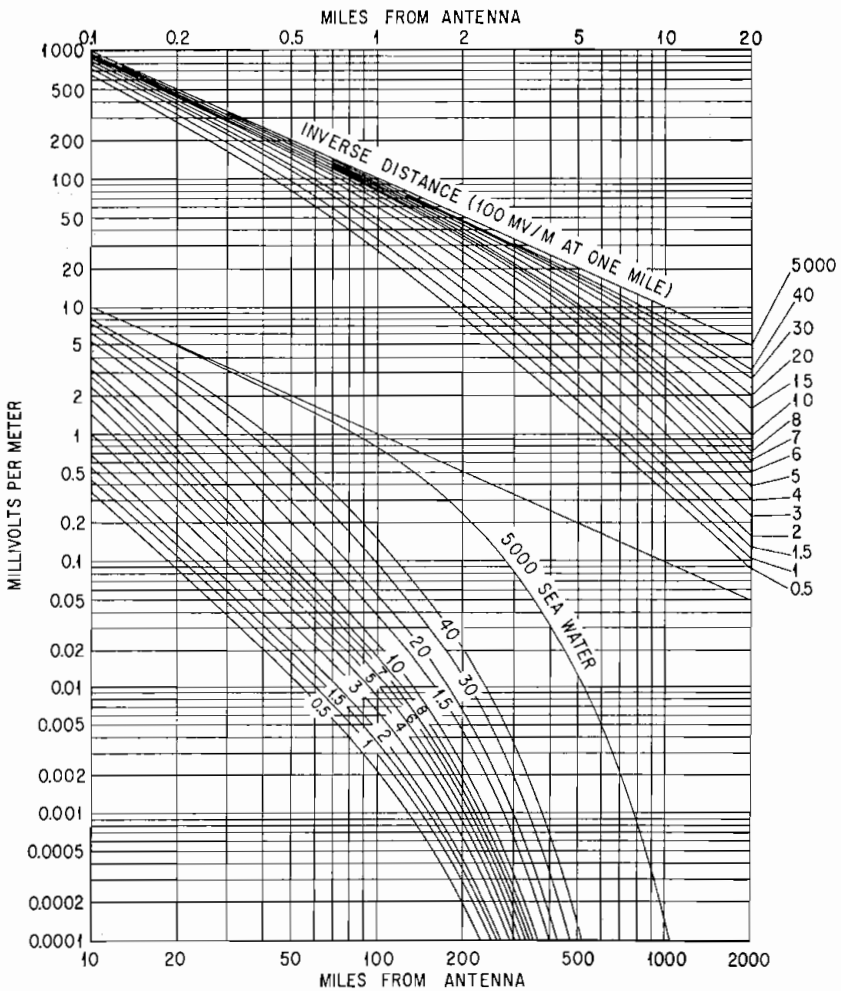
GRAPH 15. Groundwave field intensity vs. distance, 1180–1240 kc. Computed for 1210 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



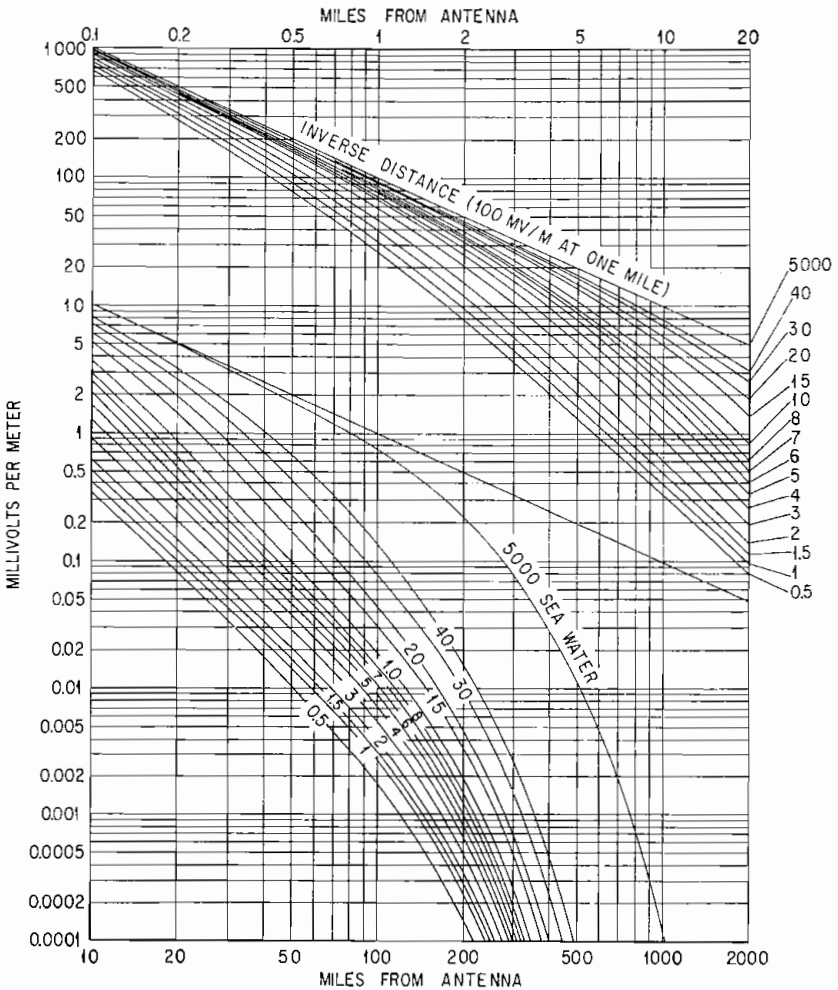
GRAPH 16. Groundwave field intensity vs. distance, 1250–1330 kc. Computed for 1290 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



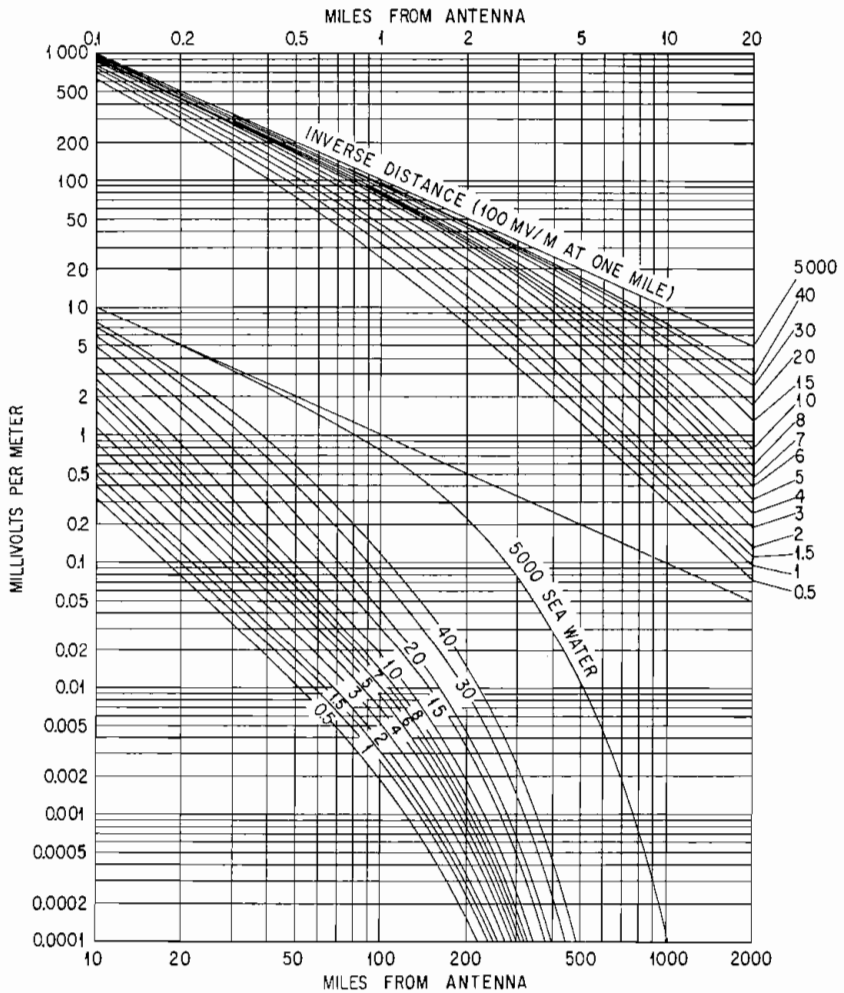
GRAPH 17. Groundwave field intensity vs. distance, 1340–1420 kc. Computed for 1380 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



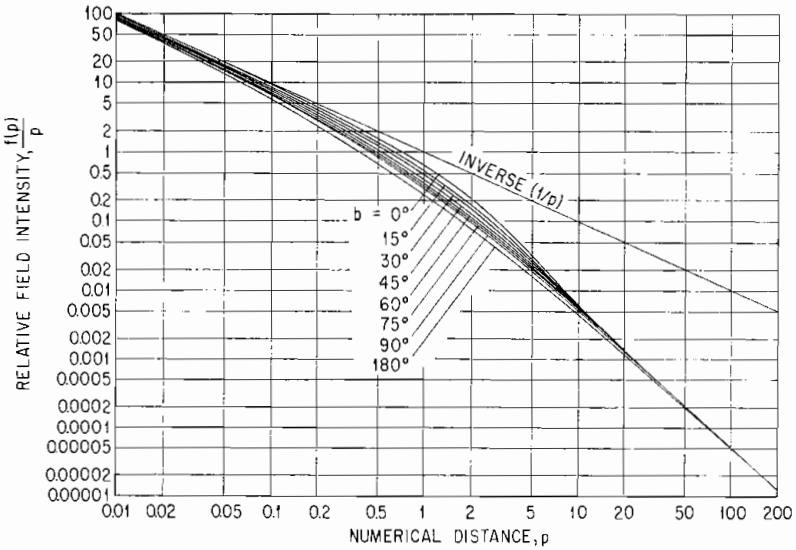
GRAPH 18. Groundwave field intensity vs. distance, 1430–1510 kc. Computed for 1470 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



GRAPH 19. Groundwave field intensity vs. distance, 1520–1600 kc. Computed for 1560 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



GRAPH 19A. Groundwave field intensity vs. distance, 1560–1640 kc. Computed for 1600 kc, $\epsilon = 15$, and the ground conductivities expressed in mmhos/m for which the curves are labeled.



GRAPH 20. Groundwave field intensity vs. numerical distance over a plane earth.

$$p = \frac{\pi}{x}\frac{R}{\lambda}\frac{\cos^2 b''}{\cos b'} \cong \frac{\pi}{x}\frac{R}{\lambda}\cos b$$
$$b = 2\,b'' - b' \cong \tan^{-1}\frac{\epsilon + 1}{x}$$

} vertical polarization.

$$p = \pi\frac{R}{\lambda}\frac{x}{\cos b'}$$
$$b = 180° - b'$$

} horizontal polarization.

$$x = \frac{1.79731 \cdot 10^{15}\sigma\text{emu}}{f_{\text{mc}}}$$

$$\tan b'' = \frac{\epsilon}{x}$$

$$\tan b' = \frac{\epsilon - 1}{x}$$

$\frac{R}{\lambda}$ = distance expressed in wavelengths.

σ = ground conductivity expressed in mmhos/m.

f = frequency expressed in megacycles.

ϵ = dielectric constant of the ground referred to air as unity.

§ 3.185 **Computation of interfering signal from a directional antenna.** (a) In case of an antenna directional in the horizontal plane, the groundwave interference can be readily computed from the calculated horizontal pattern by determining the vectors toward the service area of the station to be protected and applying these values to the groundwave curves set out in § 3.183.

(b) For signals from stations operating on clear channels, in case of determining skywave interference from an antenna with a vertical pattern different from that on which Figure 1 of § 3.190 is predicated (the basis of the night mileage separation tables), it is necessary to compare the appropriate vectors in the vertical plane.

(c) The skywave curves entitled "Average Skywave Field Intensity" (corresponding to the second hour after sunset at the recording station) as shown in Figure 1 of § 3.190 are based on antenna systems having height of 0.311 wave length (112°) and producing a vertical pattern as shown in Figure 5 of § 3.190. A nondirectional antenna system, as well as a directional antenna system having vertical patterns other than essentially the same as shown, must be converted to the pattern of a 0.311 wave length antenna having the same field intensity at the critical angle as does the pattern of the antenna involved.

(d) Example of the use of skywave curves:

Figure 6 of § 3.190 is a graph entitled "Variation with Distance of Two Important Parameters in the Theory of Skywave Propagation." The curve for θ showing the angle above the horizon at which radiation occurs plotted against distance, must be used for this purpose. For instance, assuming the station with which interference may be expected is located at a distance of 450 miles from a proposed station, the critical angle of radiation as determined from this curve is approximately 15°. Therefore, if the vertical pattern of the proposed station in the direction of the other station is such that at 15° above the horizon the radiation is 1.3 times that from an antenna having a vertical patteru as shown in Figure 5 of § 3.190 and producing the same field intensity at 1 mile iu the horizontal plane, the interfering signal would be 1.3 times that determined from Figure 1 of § 3.190 for an antenna having the same field intensity in the horizontal plane. That is, if the field intensity iu the horizontal plane of the proposed station is 124 mv/m the interfering field intensity exceeded 10 percent of the time at the other station would be

$$140 \times 1.30 \times \frac{124}{100} \text{ or } 225 \text{ uv/m}$$

and would cause interference to the 4.5 mv/m groundwave contour of the existing station.

(e) For signals from stations on regional and local channels, in computing the 10% skywave (interference) field intensity values of Class III and Class IV stations, Fig. 2 of § 3.190 is to be used in place of Figure 1 of § 3.190. (Certain simplifying assumptions may be made in the case of Class IV stations on local channels: See note to § 3.182(a)(4).) Since Figure 2 of § 3.190 is predicated upon a radiated field of 100 mv/m at one mile in the pertinent direction, no comparison with the vertical pattern of a 0.311 wavelength antenna is to be made. Instead the appropriate radiated field in the vertical plane corresponding to the distance to the receiving station, divided by 100, is multiplied into the value of 10% skywave field intensity determined from Figure 2 of § 3.190. There are two new factors to be considered, however, namely the variation of received field with latitude of the path and the variation of pertinent vertical angle due to variations of ionosphere height and ionosphere scattering.

(f) Figure 2 of § 3.190, "10% Skywave Signal Range Chart," shows the 10% skywave signal as a function of the latitude of the transmission path and the distance from a transmitting antenna with a radiated field of 100 mv/m at the pertinent angle for the distance. The latitude of the transmission path is defined as the geographic latitude of the midpoint between the transmitter and the receiver. Latitude 35° should be used in case the midpoint of the path lies below 35° North and latitude 50° should be nsed in case the midpoint of the path lies above 50° North.

(g) Figure 6-A of § 3.190, entitled "Angles of Departure vs. Transmission Range,"

is to be used in determining the angles in the vertical pattern of the antenna of an interfering station to be considered as pertinent to transmission by one reflection. Corresponding to any given distance, the curves 4 and 5 indicate the upper and lower angles within which the radiated field is to be considered. The maximum value of field intensity occurring between these angles will be used to determine the multiplying factor for the 10% skywave field intensity determined from Figure 2 of § 3.190. (Curves 2 and 3 are considered to represent the variation due to the variation of the effective height of the E-layer while curves 4 and 5 extend the range of pertinent angles to include a factor which allows for scattering. The dotted lines are included for information only.)

(h) In the case of non-directional vertical antennas, the vertical distribution of relative fields for several heights, assuming sinusoidal distribution of current along the antenna, is shown in Figure 5 of § 3.190. In the case of directional antennas the vertical pattern in the great circle direction toward the point of reception in question must first be calculated. Then for the distance to the points, the upper and lower pertinent angles are determined from Figure 6-A of § 3.190. The ratio of the largest value of radiated field occurring between these angles, to 100 mv/m (for which Figure 2 of § 3.190 is drawn) is then used as the multiplying factor for the value of the field read from the curves of Figure 2 of § 3.190. Note that while the accuracy of the curves is not as well established by measurements for distances less than 250 miles as for distances in excess of 250 miles, the curves represent the most accurate data available today. Pending accumulation of additional data to establish firm standards for skywave calculations in this range, the curves may be used. In cases where the radiation in the vertical plane, in the pertinent azimuth, contains a large lobe at a higher angle than the pertinent angle for one reflection the method of calculating interference will not be restricted to that described above, but each such case will be considered on the basis of the best knowledge available.

(i) Example, suppose it is desired to determine the amount of interference to a Class III station at Portland, Oregon, caused by another Class III station at Los Angeles, California, which is radiating a signal of 560 mv/m unattennated at one mile in the great circle direction of Portland, using a 0.5 wavelength antenna. The distance is 825 miles. From Figure 6-A of § 3.190 the upper and lower pertinent angles are 7° and 3.5°, and from Figure 5 of § 3.190 the maximum radiation within these angles is 99% of the horizontal radiation or 554 mv/m at 1 mile. The latitude of the path is 39.8° N and from Figure 2 of § 3.190, the 10% skywave field at 825 miles is 0.050 mv/m for 100 mv/m radiated. Multiplying by $^{554}/_{100}$ to adjust the value to the actual radiation gives 0.277 mv/m. At 20 to 1 ratio the limitation to the Portland station is to the 5.5 mv/m contour.

(j) When the distance is large, more than one reflection may be involved and due consideration must be given each appropriate vector in the vertical pattern, as well as the constants of the earth where reflection takes place between the transmitting station and the service area to which interference may be caused.

§ 3.186 Field intensity measurements in allocation; establishment of effective field at one mile. (a) Section 3.45 provides that certain minimum field intensities are acceptable in lieu of the required minimum physical vertical heights of the antennas proper. Also in other allocation problems, it is necessary to determine the effective field at 1 mile. The following requirements shall govern the taking and submission of data on the field intensity produced:

(1) Beginning as near to the antenna as possible without including the induction field and to provide for the fact that a broadcast antenna not being a point source of radiation (not less than one wave length or 5 times the vertical height in the case of a single element, i.e., nondirectional antenna or 10 times the spacing between the elements of a directional antenna), measurements shall be made on eight or more radials, at intervals of approximately one-tenth mile up to 2 miles from the antenna, at intervals of approximately one-half mile from 2 miles to 6 miles from the antenna, at intervals of approximately 2 miles from 6 miles to 15 or 20 miles from the antenna, and a few additional measurements if needed at greater distances from the antenna. Where the antenna is rurally located and unobstructed measurements can be made, there shall be as many as 18 or 20 measurements on each radial. However, where the

antenna is located in a city where unobstructed measurements are difficult to make, measurements shall be made on each radial at as many unobstructed locations as possible, even though the intervals are considerably less than stated above, particularly within 2 miles of the antenna. In cases where it is not possible to obtain accurate measurements at the closer distances (even out to 5 or 6 miles due to the character of the intervening terrain), the measurements at greater distances should be made at closer intervals. (It is suggested that "wave tilt" measurements may be made to determine and compare locations for taking field intensity measurements, particularly to determine that there are no abrupt changes in ground conductivity or that reflected waves are not causing abnormal intensities.)

(2) The data required by subparagraph (1) of this paragraph should be plotted for each radial in accordance with either of the two methods set forth below:

(i) Using log-log coordinate paper, plot field intensities as ordinate and distance as abscissa.

(ii) Using semi-log coordinate paper, plot field intensity times distance as ordinate on the log scale and distance as abscissa on the linear scale.

(3) However, regardless of which of the methods in subparagraph (2) of this paragraph is employed, the proper curve to be drawn through the points plotted shall be determined by comparison with the curves in § 3.184 as follows: Place the sheet on which the actual points have been plotted over the appropriate Graph in § 3.184, hold to the light if necessary and adjust until the curve most closely matching the points is found. This curve should then be drawn on the sheet on which the points were plotted, together with the inverse distance curve corresponding to that curve. The field at 1 mile for the radial concerned shall be the ordinate on the inverse distance curve at 1 mile.

(4) When all radials have been analyzed in accordance with subparagraph (3) of this paragraph, a curve shall be plotted on polar coordinate paper from the fields obtained, which gives the inverse distance field pattern at 1 mile. The radius of a circle, the area of which is equal to the area bounded by this pattern, is the effective field. (See § 3.14.)

(5) While making the field intensity survey, the output power of the station shall be maintained at the licensed power as determined by the direct method. To do this it is necessary to determine accurately the total antenna resistance (the resistance variation method, the substitution method or bridge method is acceptable) and to measure the antenna current by means of an ammeter of acceptable accuracy. (See §§ 3.39 and 3.54.)

(b) Complete data taken in conjunction with the field intensity measurements shall be submitted to the Commission in affidavit form including the following:

(1) Tabulation by number of each point of measurement to agree with the map required in (2) below and the field intensity meter reading, the attenuation constant, the field intensity (E), the distance from the antenna (D) and the product of the field intensity and distance (ED) (if data for each radial are plotted on semi-logarithmic paper, see above) for each point of measurement.

(2) Map showing each point of measurement numbered to agree with tabulation required above.

(3) Description of method used to take field intensity measurements.

(4) The family of theoretical curves used in determining the curve for each radial properly identified by conductivity and dielectric constants.

(5) The curves drawn for each radial and the field intensity pattern.

(6) Antenna resistance measurement:

(i) Antenna resistance at operating frequency.

(ii) Description of method employed.

(iii) Tabulation of complete data.

(iv) Curve showing antenna resistance versus frequency.

(7) Antenna current or currents maintained during field intensity measurements.

(8) Description, accuracy, date, and by whom each instrument was last calibrated.

(9) Name, address, and qualifications of the engineer making the measurements.

(10) Any other pertinent information.

§ 3.187 **Limitation on daytime radiation.** (a) No authorization for new or changed Class II facilities will be granted if the proposed Class II station would radiate during two hours following local sunrise and two hours preceding local sunset, in any direction toward the 0.1 mv/m groundwave contour of a co-channel United States Class I station, values in excess of those obtained as provided in paragraph (b) of this section.

(b) To obtain the maximum permissible radiation for a Class II station on a given frequency (f_{kc}) from 640 kc through 990 kc, multiply the radiation value obtained for the given distance and azimuth from the 500 kc chart (Figure 9 of § 3.190) by the appropriate interpolation factor shown in the K_{500} column of paragraph (c) of this section; and multiply the radiation value obtained for the given distance and azimuth from the 1000 kc chart (Figure 10 of § 3.190) by the appropriate interpolation factor shown in the K_{1000} column of paragraph (c) of this section. Add the two products thus obtained; the result is the maximum radiation value applicable to the Class II station in the pertinent directions. For frequencies from 1010 kc to 1580 kc, obtain in a similar manner the proper radiation values from the 1000 kc and 1600 kc charts (Figures 10 and 11 of § 3.190), multiply each of these values by the appropriate interpolation factor in the K'_{1600} and K'_{1600} columns in paragraph (c) of this section, and add the products.

(c) Interpolation factors

(1) Frequencies below 1000 kc

f_{kc}	K_{500}	K_{1000}
640	0.720	0.280
650	0.700	0.300
660	0.680	0.320
670	0.660	0.340
680	0.640	0.360
690	0.620	0.380
700	0.600	0.400
710	0.580	0.420
720	0.560	0.440
730	0.540	0.460
740	0.520	0.480
750	0.500	0.500
760	0.480	0.520
770	0.460	0.540
780	0.440	0.560
800	0.400	0.600
810	0.380	0.620
820	0.360	0.640
830	0.340	0.660
840	0.320	0.680
850	0.300	0.700
860	0.280	0.720
870	0.260	0.740
880	0.240	0.760
890	0.220	0.780
900	0.200	0.800
940	0.120	0.880
990	0.020	0.980

(2) Frequencies above 1000 kc

f'_{kc}	K'_{1000}	K'_{1600}
1010	0.983	0.017
1020	0.967	0.033
1030	0.950	0.050
1040	0.933	0.067
1050	0.917	0.083
1060	0.900	0.100
1070	0.883	0.117
1080	0.867	0.133
1090	0.850	0.150
1100	0.833	0.167
1110	0.817	0.183
1120	0.800	0.200
1130	0.783	0.217
1140	0.767	0.233
1160	0.733	0.267
1170	0.717	0.283
1180	0.700	0.300
1190	0.683	0.317
1200	0.667	0.333
1210	0.650	0.350
1220	0.633	0.367
1500	0.167	0.833
1510	0.150	0.850
1520	0.133	0.867
1530	0.117	0.883
1540	0.100	0.900
1550	0.083	0.917
1560	0.067	0.933
1570	0.050	0.950
1580	0.033	0.967

§ 3.188 **Location of transmitters.** (a) The four primary objectives to be obtained in the selection of a site for a transmitter of a broadcast station are as follows:

(1) To serve adequately the center of population in which the studio is located and to give maximum coverage to adjacent areas.

(2) To cause and experience minimum interference to and from other stations.

(3) To present a minimum hazard to air navigation consistent with objectives (1) and (2).

(4) To fulfill certain other requirements given below.

(b) The site selected should meet the following conditions:

(1) A minimum field intensity of 25 to 50 mv/m will be obtained over the business or factory areas of the city.

(2) A minimum field intensity of 5 to 10 mv/m will be obtained over the most distant residential section.

(3) The absorptiou of the signal is the minimum for any obtainable sites in the area. As a guide in this respect the absorption of the signals from other stations in that area should be followed, as well as the results of tests on other sites.

(4) The population within the blanket contour does not exceed that specified by § 3.24(g).

(c) In selecting a site in the center of a city it is usually necessary to place the radiating system on the top of a building. This building should be large enough to permit the installation of a satisfactory ground and/or counterpoise system. Great care must be taken to avoid selecting a building surrounded by taller buildings or where any nearby building higher than the antenna is located in the direction which it is desired to serve. Such a building will tend to cast "radio shadows" which may materially reduce the coverage of the station in that direction. Irrespective of the height of surrounding buildings, the building on which the antenna is located should not have height of approximately one-quarter wavelength. A study of antenna systems located on buildings tends to indicate that where the building is approximately a quarter wavelength in height, the efficiency of radiation may be materially reduced.

(d) Particular attention must be given to avoiding cross-modulation. In this connection, attention is invited to the fact that it has been found very unsatisfactory to locate broadcast stations so that high signal intensities occur in areas with overhead electric power or telephone distribution systems and sections where the wiring and plumbing are old or improperly installed. These areas are usually found in the older or poorer sections of a city. These conditions give rise to cross-modulation interference due to the nonlinear conductivity characteristics of contacts betweeu wiring, plumbing, or other conductors. This type of interference is independent of the selectivity characteristics of the receiver and normally can be eliminated only by correction of the condition causing the interference. Cross-modulation teuds to increase with frequency and in some areas it has been found impossible to eliminate all sources of cross-modulation, resulting in an unsatisfactory condition for both licensee and listeners. The Commission will not authorize, (1) new stations, (2) increased facilities to existing stations, or (3) auxiliary transmitters, for use with other than the authorized antenna system of the main transmitter, located in such areas or utilizing roof-top antennas, when the operating power would be in excess of 500 watts.

(e) If it is determined that a site should be selected removed from the city, there are several general conditions to be followed in determining the exact site. Three maps should be given consideration if available:

(1) Map of the density of populatiou and number of people by sections in the area. (See Bureau of Census series P–D and H–E available from Superintendent of Documents, Washington 25, D.C.)

(2) Geographical contour map with contour intervals of 20 to 50 feet.

(3) Map showing the type, nature and depth of the soil in the area with special reference to the condition of the moisture throughout the year.

From these maps a site should be selected with a minimum number of intervening hills between it and the center of the city. In general, because of ground conditions, it is better to select a site in a low area rather than on top of a hill, and the only condition under which a site on top of a hill should be selected is that it is only possible by this means to avoid a substantial number of hills, between the site and the center of a city with the resulting radio shadows. If a site is to be selected to serve a city which is on a general sloping area, it is generally better to select a site below the city than above the city.

(f) If a compromise must be made between probable radio shadows from intervening hills and locating the transmitter on top of a hill, it is generally better to compromise in favor of the low area, where an efficient radiating system may be installed which will more than compensate for losses due to shadows being caused by the hills, if not too numerous or too high. Several transmitters have been located on

top of hills, but so far as data has been supplied not a single installation has given superior efficiency of propagation and coverage.

(g) The ideal location of a broadcast transmitter is in a low area of marshy or "crawfishy" soil or area which is damp the maximum percentage of time and from which a clear view over the entire center of population may be had and the tall buildings in the business section of the city would cast a shadow across the minimum residential area.

(h) The type and condition of the soil or earth immediately around a site is very important. Important, to an equal extent, is the soil or earth between the site and the principal area to be served. Sandy soil is considered the worst type, with glacial deposits and mineral-ore areas next. Alluvial, marshy areas and salt-water bogs have been found to have the least absorption of the signal. One is fortunate to have available such an area and, if not available, the next best condition must be selected.

(i) Figure M3 (see Note to § 3.183(c)) and Figure R3 of § 3.190 indicate effective conductivity values in the United States, and are to be used for determining the extent of broadcast station coverage when adequate field intensity measurements over the path in question are not available. Since the values specified are only for general areas and since conductivity values over particular paths may vary widely from those shown, caution must be exercised in using the maps for selection of a satisfactory transmitter site. Where the submission of field intensity measurements is deemed necessary or advisable, the Commission, in its discretion, may require an applicant for new or changed broadcast facilities to submit such data in support of its application.

(j) In general, broadcast transmitters operating with approximately the same power can be grouped in the same approximate area and thereby reduce the interference between them. If the city is of irregular shape, it is often possible to take advantage of this in selecting a suitable location that will give a maximum coverage. The maps giving the density of population will be a key to this. The map giving the elevation by contours will be a key to the obstructing hills between the site and city. The map of the soil conditions will assist in determining the efficiency of the radiating system that may be erected and the absorption of the signal encountered in the surrounding area.

(k) Another factor to be considered is the relation of the site to airports and airways. Procedures and standards with respect to the Commission's consideration of proposed antenna structures which will serve as a guide to persons intending to apply for radio station licenses are contained in Part 17 of this chapter (Rules Concerning the Construction, Marking and Lighting of Antenna Structures).

(l) In finally selecting the site, consideration must be given to the required space for erecting an efficient radiating system, including the ground or counterpoise. It is the general practice to use direct grounds consisting of a radial buried wire system. If the area is such that it is not possible to get such ground system in soil that remains moist throughout the year, it probably will be found better to erect a counterpoise. (Such a site should be selected only as a last resort.) It, like the antenna itself, must of course be designed properly for the operating frequency and other local conditions.

(m) While an experienced engineer can sometimes select a satisfactory site for a 100-watt station by inspection, it is necessary for a higher power station to make a field-intensity survey to determine that the site selected will be entirely satisfactory. There are several facts that cannot be determined by inspection that make a survey very desirable for all locations removed from the city. Often two or more sites may be selected that appear to be of equal promise. It is only by means of field-intensity surveys taken with a transmitter at the different sites or from measurements on the signal of nearby stations traversing the terrain involved that the most desirable site can be determined. There are many factors regarding site efficiency that cannot be determined by any other method. When making the final selection of a site, the need for a field-intensity survey to establish the exact conditions cannot be stressed too strongly. The selection of a proper site for a broadcast station is an important engineering problem and can only be done properly by experienced radio engineers.

§ 3.189 Minimum antenna heights or field intensity requirements. (a) Section 3.45 requires that all applicants for new, additional, or different broadcast facilities and all licensees requesting authority to move the transmitter of an existing station,

shall specify a radiating system, the efficiency of which complies with the requirements of good engineering practice for the class and power of the station.

(b) The specifications deemed necessary to meet the requirements of good engineering practice at the present state of the art are set out in detail below.

(1) The licensee of a standard broadcast station requesting a change in power, time of operation, frequency, or transmitter location must also request authority to install a new antenna system or to make changes in the existing antenna system which will meet the minimum height requirements, or submit evidence that the present antenna system meets the minimum requirements with respect to field intensity, before favorable consideration will be given thereto. (See § 3.186.) In the event it is proposed to make substantial changes in an existing antenna system, the changes shall be such as to meet the minimum height requirements or will be permitted subject to the submission of field intensity measurements showing that it meets the minimum requirements with respect to effective field intensity.

(2) These minimum actual physical vertical heights of antennas permitted to be installed are shown by curves A, B, and C of Figure 7 of § 3.190 as follows:

(i) Class IV stations, 150 feet or a minimum effective field intensity of 150 mv/m for 1 kilowatt (100 watts 47.5 mv/m, and 250 watts 75 mv/m). (This height applies to a Class IV station on a local channel only. In the case of a Class IV station assigned to a regional channel Curve A shall apply.)

(ii) Class II and III stations, or a minimum effective field intensity of 175 mv/m for 1 kilowatt.

(iii) Class I stations, or a minimum effective field intensity of 225 mv/m for 1 kilowatt.

(3) The heights given on the graph for the antenna apply regardless of whether the antenna is located on the ground or on a building. Except for the reduction of shadows, locating the antenna on a building does not necessarily increase the efficiency and where the height of the building is in the order of a quarter wave the efficiency may be materially reduced.

(4) To obtain the maximum efficiency of which any antenna is capable a good ground system must be employed (a counterpoise may be substituted under certain conditions).

(5) At the present development of the art, it is considered that where a vertical radiator is employed with its base on the ground, the ground system should consist of buried radial wires at least one-fourth wave length long. There should be as many of these radials evenly spaced as practicable and in no event less than 90. (120 radials of 0.35 to 0.4 of a wave length in length and spaced 3° is considered an excellent ground system and in case of high base voltage, a base screen of suitable dimensions should be employed.)

(6) It should be borne in mind that the above specifications are the minimum and where possible better antenna and ground systems should be installed.

(7) In case it is contended that the required antenna efficiency can be obtained with an antenna of height or ground system less than the minimum specified, a complete field intensity survey must be supplied to the Commission showing that the field intensity at a mile without absorption fulfills the minimum requirements. (See § 3.186.) This field survey must be made by a qualified engineer using equipment of acceptable accuracy.

(8) The main element or elements of a directional antenna system shall meet the above minimum requirements with respect to height or effective field intensity. No directional antenna system will be approved which is so designed that the effective field of the array is less than the minimum prescribed for the class of station concerned, or in case of a Class I station less than 90 percent of the groundwave field which would be obtained from a perfect antenna of the height specified by Figure 7 of § 3.190 for operation on frequencies below 1000 kilocycles, and in the case of a Class II or III station less than 90 percent of the groundwave field which would be obtained from a perfect antenna of the height specified by Figure 7 of § 3.190 for operation on frequencies below 750 kilocycles.

(9) Before any changes are made in the antenna system, it is necessary to submit full details to the Commission for approval. These data may be submitted by letter.

§ 3.190 Engineering charts. [See Figure 1 to 11.]

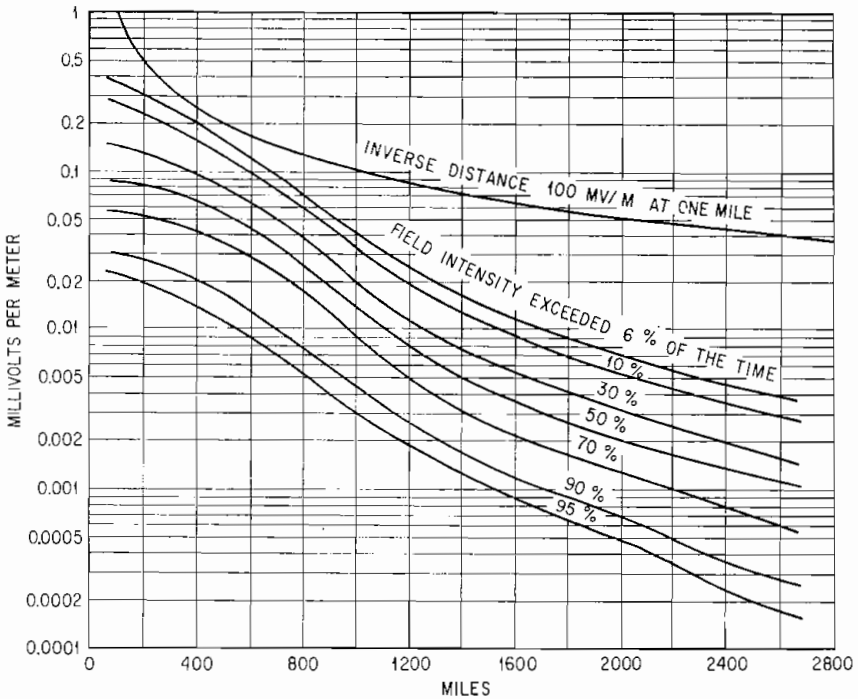


FIGURE 1. Average skywave field intensity (corresponding to the second hour after sunset at the recording station). These curves are not considered to be sufficiently accurate for practical use for distances less than approximately 250 miles.

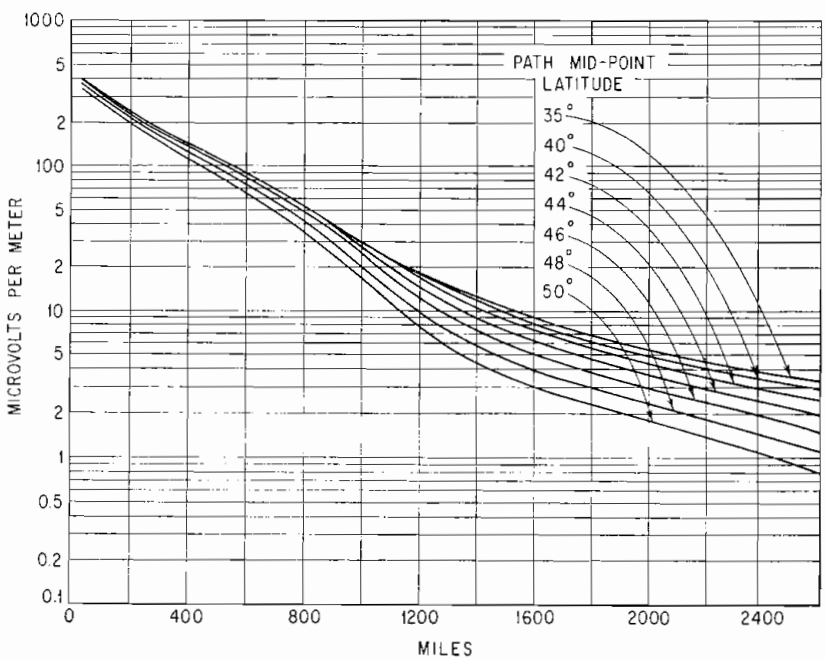


FIGURE 2. 10% skywave signal range, 540 kc to 1600 kc. Hourly median fields for 10% of the year based on 1944 propagation. Resultant skywave fields from an antenna of height $H = 0.311\ \lambda$ radiating 100 mv/m at the angle θ pertinent to transmission by one reflection.

NUMBERS ON MAP REPRESENT ESTIMATED EFFECTIVE GROUND CONDUCTIVITY IN MILLIMHOS PER METER

CONDUCTIVITY OF SEAWATER IS NOT SHOWN ON MAP BUT IS ASSUMED TO BE 5000 MILLIMHOS PER METER

FIGURE 3. Estimated effective ground conductivity in the United States.

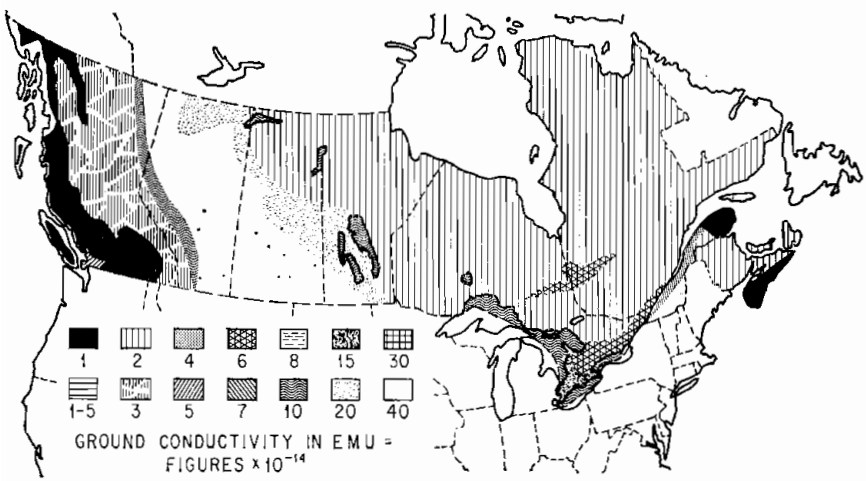


FIGURE 4. Ground conductivity in Canada. Compiled by Radio Division, Department of Transport.

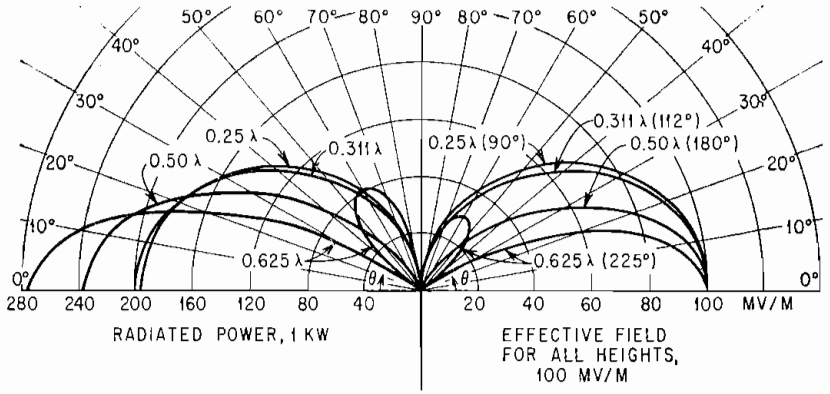


FIGURE 5. Vertical radiation patterns for different heights of vertical wire antennas (sinusoidal current distribution).

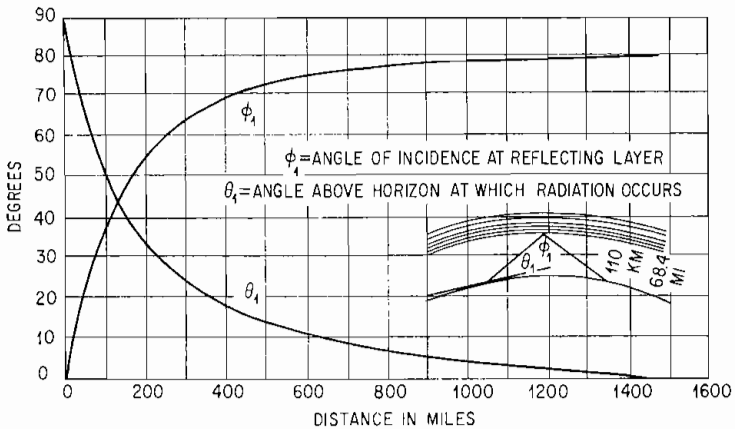


FIGURE 6. Variation with distance of two important parameters in the theory of skywave propagation.

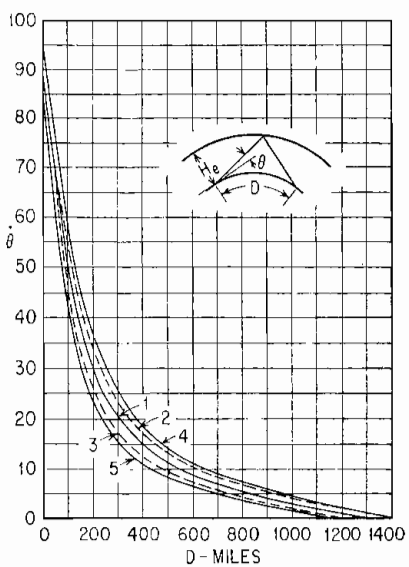


FIGURE 6A. Angles of departure vs. transmission range.

1. θ for 1000 kc average H_θ.
2. θ for 1000 kc maximum H_θ.
3. θ for 1000 kc minimum H_θ.

4 and 5 contain also an estimated correction for deviation from mid-point reflection.

For use in band 540–1600 kc.

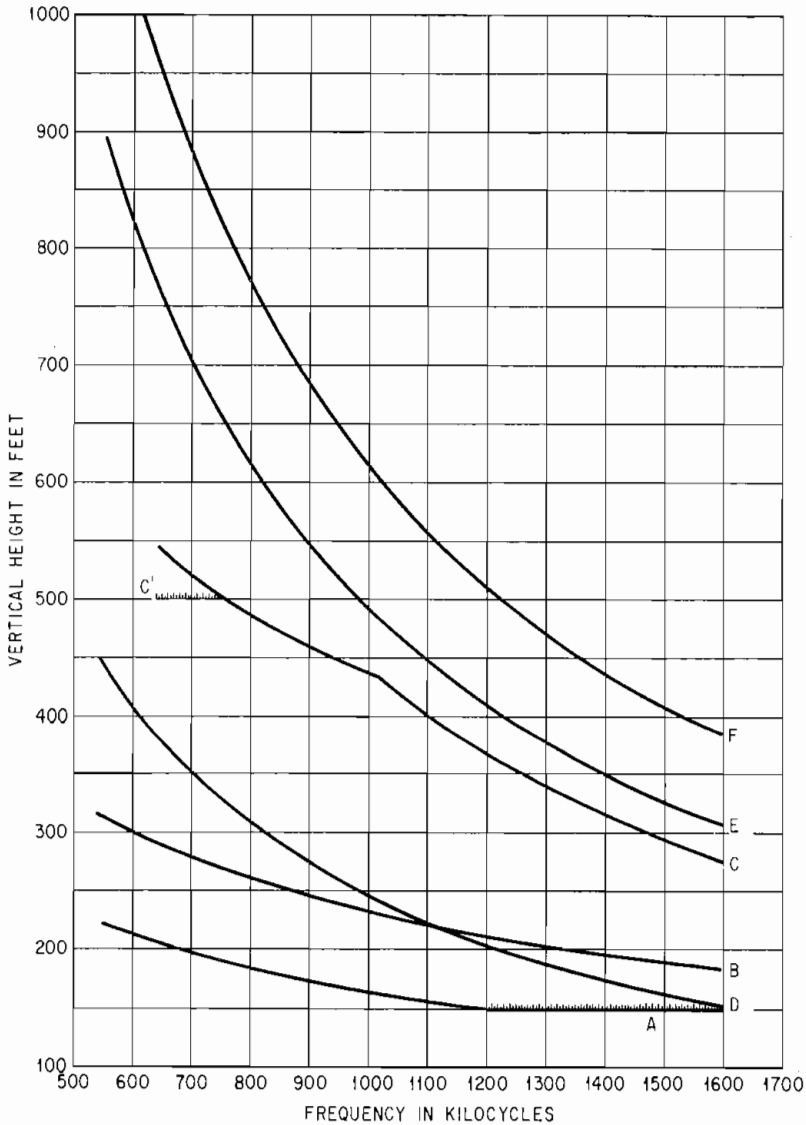


FIGURE 7. Antennas for standard broadcast stations. Minimum vertical height of antennas permitted to be installed (*A*, *B*, and *C*).

A. Class IV stations, or a minimum effective field intensity of 150 mv/m for 1 kw. (100 watts, 47.5 mv/m, and 250 watts, 75 mv/m).

B. Class II and III stations, or a minimum effective field intensity of 175 mv/m for 1 kw.

C. Class I stations, or a minimum effective field intensity of 225 mv/m for 1 kw.

C'. Where it is shown that the Federal Aviation Agency will not approve an antenna having height in excess of 500 feet at any location within the metropolitan area concerned, a height of 500 feet will be accepted.

D. 0.25 wavelength.

E. 0.50 wavelength.

F. 0.625 wavelength.

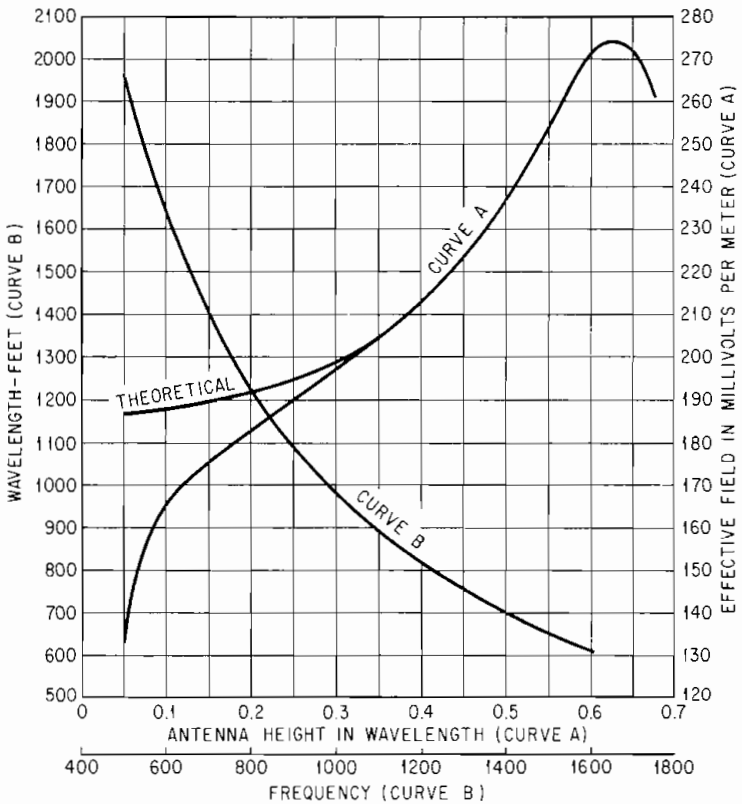


FIGURE 8. Effective field at one mile for one kilowatt (curve A). Use for simple omnidirectional vertical antenna with ground system of at least 120 radials ¼ λ.

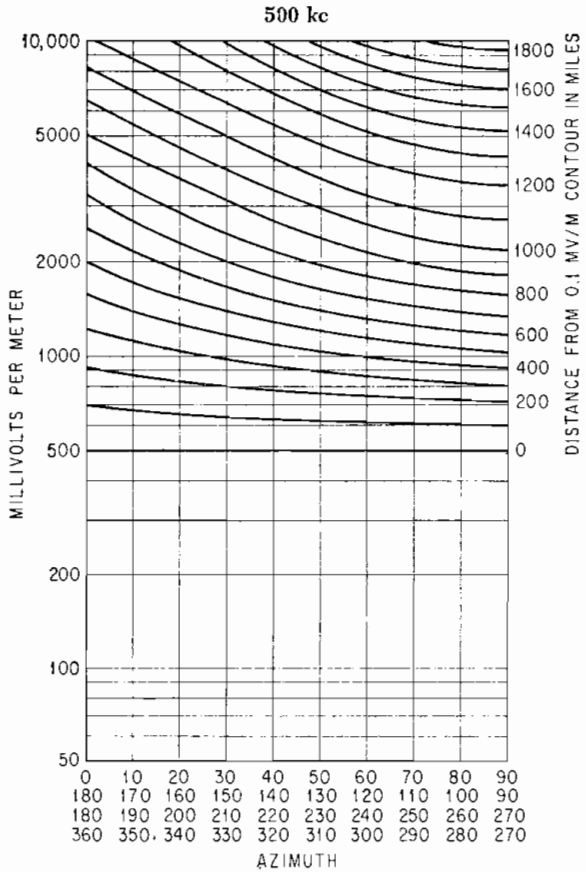


FIGURE 9. Permissible daytime radiation for Class II stations.

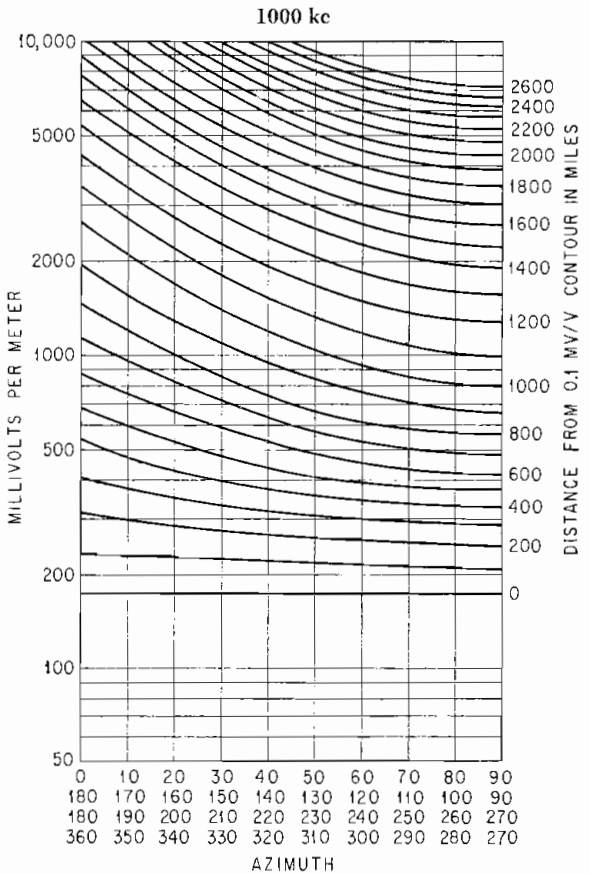


FIGURE 10. Permissible daytime radiation for Class II stations.

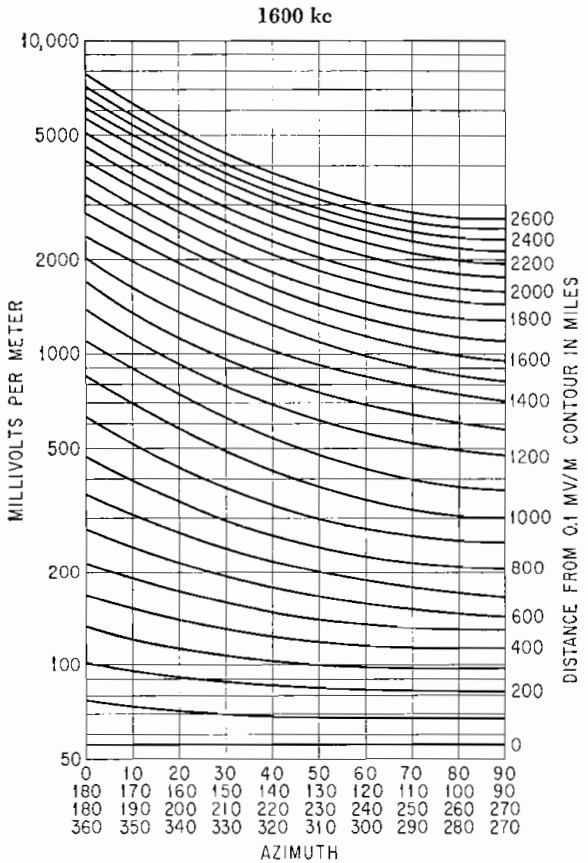


FIGURE 11. Permissible daytime radiation for Class II stations.

SUBPART B—FM BROADCAST STATIONS

Classification of FM Broadcast Stations and Allocation of Frequencies

§ 3.201 **Numerical designation of FM broadcast channels.** For convenience, the frequencies available for FM broadcasting (including those assigned to noncommercial educational broadcasting) are given numerical designations which are shown in the table below:

Frequency (Mc):	*Channel No.*	Frequency (Mc):	*Channel No.*	Frequency (Mc):	*Channel No.*
88.1	201	94.9	235	101.5	268
88.3	202	95.1	236	101.7	269
88.5	203	95.3	237	101.9	270
88.7	204	95.5	238	102.1	271
88.9	205	95.7	239	102.3	272
89.1	206	95.9	240	102.5	273
89.3	207	96.1	241	102.7	274
89.5	208	96.3	242	102.9	275
89.7	209	96.5	243	103.1	276
89.9	210	96.7	244	103.3	277
90.1	211	96.9	245	103.5	278
90.3	212	97.1	246	103.7	279
90.5	213	97.3	247	103.9	280
90.7	214	97.5	248	104.1	281
90.9	215	97.7	249	104.3	282
91.1	216	97.9	250	104.5	283
91.3	217	98.1	251	104.7	284
91.5	218	98.3	252	104.9	285
91.7	219	98.5	253	105.1	286
91.9	220	98.7	254	105.3	287
92.1	221	98.9	255	105.5	288
92.3	222	99.1	256	105.7	289
92.5	223	99.3	257	105.9	290
92.7	224	99.5	258	106.1	291
92.9	225	99.7	259	106.3	292
93.1	226	99.9	260	106.5	293
93.3	227	100.1	261	106.7	294
93.5	228	100.3	262	106.9	295
93.7	229	100.5	263	107.1	296
93.9	230	100.7	264	107.3	297
94.1	231	100.9	265	107.5	298
94.3	232	101.1	266	107.7	299
94.5	233	101.3	267	107.9	300
94.7	234				

§ 3.202 **Areas of the United States.** For the purpose of allocation the United States is divided into two areas. The first area—area I—includes southern New Hampshire; all of Massachusetts, Rhode Island, and Connecticut; southeastern New York as far north as Albany-Troy-Schenectady; all of New Jersey, Delaware, and the District of Columbia; Maryland as far west as Hagerstown; and eastern Pennsylvania as far west as Harrisburg. The second area—area II—comprehends the remainder of the United States not included in area I.

NOTE: In some of the territory contiguous to area I, the demand for frequencies requires that applications be given careful study and consideration to insure an equitable distribution of facilities throughout the region. This region includes the remainder of Maryland, Pennsylvania, and New York (except the northeastern corner) not included in area I; Virginia, West Virginia, North Carolina, South Carolina, Ohio, and Indiana; southern Michigan as far north as Saginaw; eastern Illinois as far west as Rockford-Decatur; and southeastern Wisconsin as far north as Sheboygan. Other regions may be added as required.

§ 3.203 **Class A stations.** (a) A Class A station is a station which operates on a Class A channel and is designed to render service primarily to a community or to a city or town other than the principal city of an area, and the surrounding rural area. The coverage of a Class A station shall be not more than the equivalent of 1 kilowatt effective radiated power and antenna height of 250 feet above average terrain, as determined by the methods prescribed in the Technical Standards of this subpart. (For the purpose of determining equivalent coverage, the 1 mv/m contour should be used.) A Class A station will not be licensed with more than 1 kilowatt effective radiated power. The power rating of the transmitter used for a Class A station shall be not less than 250 watts nor more than 1 kilowatt. The signal intensity requirements of § 3.311 shall determine the minimum coverage of a Class A station. Class A stations will normally be protected to the 1 mv/m contour; however, assignments will be made in a manner to insure, insofar as possible, a maximum of service to all listeners, whether urban or rural, giving consideration to the minimum signal capable of providing service.

(b) The following frequencies, except as provided in paragraphs (c) and (d) of this section, are designated as Class A channels and are assigned for use by Class A stations:

Frequency (Mc):	*Channel No.*	Frequency (Mc):	*Channel No.*	Frequency (Mc):	*Channel No.*
92.1	221	97.7	249	103.1	276
92.7	224	98.3	252	103.9	280
93.5	228	99.3	257	104.9	285
94.3	232	100.1	261	105.5	288
95.3	237	100.9	265	106.3	292
95.9	240	101.7	269	107.1	296
96.7	244	102.3	272		

These channels are available for assignment (1) in cities which are not the central city or cities of a metropolitan district, and (2) in central cities of metropolitan districts which have fewer than six Class B stations.

(c) In Hawaii, the frequency band 98–108 Mc is allocated for nonbroadcast use. The frequencies 98.1 through 107.9 Mc, inclusive (Channels 251 through 300 inclusive) will not be assigned in Hawaii for use by FM broadcast stations.

(d) In Alaska the frequency band 88–100 Mc is allocated to Government radio services and the non-Government fixed service only. The frequencies 88.1 Mc through 99.9 Mc (Channels 201 through 260 inclusive) will not be assigned in Alaska for use by FM broadcast stations.

§ 3.204 **Class B stations.** (a) A Class B station is a station which operates on a Class B channel and is designed to render service primarily to a metropolitan district or principal city and the surrounding rural area, or to rural areas removed from large centers of population. The service area of a Class B station will not be protected beyond the 1 mv/m contour; however, Class B assignments will be made in a manner to insure, insofar as possible, a maximum of service to all listeners, whether urban or rural, giving consideration to the minimum signal capable of providing service. Standard power ratings of transmitters used for Class B stations shall be 1 kw or greater. The signal intensity requirements of § 3.311 shall determine the minimum coverage of a Class B station. In the following subparagraphs antenna height above average terrain and effective radiated power are to be determined by the methods prescribed in the Technical Standards of this subpart.

(1) The coverage of a Class B station in Area 1 shall be not more than the equivalent of 20 kilowatts effective radiated power and antenna height of 500 feet above average terrain. (For the purpose of determining equivalent coverage, the 1 mv/m contour should be used.) A Class B station in Area I will not be licensed with an effective radiated power greater than 20 kilowatts.

(2) The coverage of a Class B station in Area II shall normally be not more than the equivalent of 20 kilowatts effective radiated power and antenna height of 500 feet above average terrain. (For the purpose of determining equivalent coverage, the 1 mv/m contour should be used.) The use of greater power and antenna height will be

encouraged in those portions of Area II where such use would not result in undue interference to stations already authorized or to probable assignments insofar as can be determined at the time of the grant. In such case, the power, antenna height, and area will be determined on the merits of each application with particular attention being given to rural areas which would not otherwise receive service.

(b) The following frequencies, except as provided in paragraphs (c) and (d) of this section, are designated as Class B channels and are assigned for use by Class B stations:

Frequency (Mc):	*Channel No.*	Frequency (Mc):	*Channel No.*	Frequency (Mc):	*Channel No.*
92.3	222	97.5	248	102.9	275
92.5	223	97.9	250	103.3	277
92.9	225	98.1	251	103.5	278
93.1	226	98.5	253	103.7	279
93.3	227	98.7	254	104.1	281
93.7	229	98.9	255	104.3	282
93.9	230	99.1	256	104.5	283
94.1	231	99.5	258	104.7	284
94.5	233	99.7	259	105.1	286
94.7	234	99.9	260	105.3	287
94.9	235	100.3	262	105.7	289
95.1	236	100.5	263	105.9	290
95.5	238	100.7	264	106.1	291
95.7	239	101.1	266	106.5	293
96.1	241	101.3	267	106.7	294
96.3	242	101.5	268	106.9	295
96.5	243	101.9	270	107.3	297
96.9	245	102.1	271	107.5	298
97.1	246	102.5	273	107.7	299
97.3	247	102.7	274	107.9	300

(c) In Hawaii the frequency band 98–108 Mc is allocated for nonbroadcast use. The frequencies 98.1 through 107.9 Mc inclusive (Channels 251 through 300, inclusive) will not be assigned in Hawaii for use by FM broadcast stations.

(d) In Alaska the frequency band 88–100 Mc is allocated exclusively to Government radio services and the non-Government fixed service. The frequencies 88.1 Mc through 99.9 Mc (Channels 201 through 260 inclusive) will not be assigned in Alaska for use by FM broadcast stations.

§ 3.205 **Station location and program origination.** (a) Except as provided in paragraph (b) of this section, each FM broadcast station will be licensed to serve primarily a particular city, town, or other political subdivision which will be specified in the station license and the station will be considered to be located in such place. Each station shall maintain a studio, which will be known as the main studio, in the place where the station is located provided that the main studio may be located at the transmitter site whether or not the transmitter site is in the place where the station is located. A majority (computed on the basis of duration and not number) of a station's programs or in the case of a station affiliated with a network, two-thirds of such station's non-network programs, whichever is smaller, shall originate from the main studio or from other studios or remote points situated in the place where the station is located.

(b) Stations will be licensed to serve more than one city, town, or other political subdivision, only where a satisfactory showing is made that each such place meets all the requirements of the rules and Technical Standards of this subpart with respect to the location of main studios; that the station can and will originate a substantial number of local live programs from each such place; and that the requirements as to origination of programs contained in paragraph (a) of this section would place an unreasonable burden on the station if it were licensed to serve only one city, town or other political subdivision. A station licensed to serve more than one place shall be considered to be located in and shall maintain main studios in each such place. With respect to such station the requirements as to origination of programs contained in

paragraph (a) of this section shall be satisfied by the origination of programs from any or all of the main studios or from other studios and remote points situated in any or all of the places in which the main studios are located.

(c) The transmitter of each FM broadcast station shall be so located that satisfactory service is delivered to the city where the main studio is located, in accordance with the Technical Standards of this subpart: *Provided, however,* Upon special showing of need, authorization may be granted to locate the transmitter so that adequate service is not rendered to this city, but in no event shall this city be beyond the 50 uv/m contour.

Administrative Procedure

§ 3.214 **Cross reference.** See Sections 1.300 to 1.364, subpart D of Part 1 of this chapter, for general requirements as to applications, filing of applications and descriptions of application forms, other forms and information to be filed with the Commission, the manner in which applications are processed, and provisions applying to action on applications.

§ 3.215 **Notification of filing of applications.** In order to minimize harmful interference at the National Radio Astronomy Observatory site located at Green Bank, Pocahontas County, West Virginia, and at the Naval Radio Research Observatory at Sugar Grove, Pendleton County, West Virginia, an applicant for authority to construct a new FM broadcast station or for authority to make changes in the frequency, power, antenna height, or antenna directivity of an existing station within the area bounded by 39°15′ N on the north, 78°30′ W on the east, 37°30′ N on the south and 80°30′ W on the west shall, at the time of filing such application with the Commission, simultaneously notify the Director, National Radio Astronomy Observatory, P.O. Box #2, Green Bank, West Virginia, in writing, of the technical particulars of the proposed station. Such notification shall include the geographical coordinates of the antenna, antenna height, antenna directivity if any, proposed frequency, type of emission, and power. In addition, the applicant shall indicate in his application to the Commission the date notification was made to the Observatory. After receipt of such applications, the Commission will allow a period of twenty (20) days for comments or objections in response to the notifications indicated. If an objection to the proposed operation is received during the twenty day period from the National Radio Astronomy Observatory for itself or on behalf of the Naval Radio Research Observatory, the Commission will consider all aspects of the problem and take whatever action is deemed appropriate.

§ 3.216 **Equipment tests.** (a) During the process of construction of an FM broadcast station, the permittee, after notifying the Commission and Engineer in Charge of the radio district in which the station is located, may without fnrther authority of the Commission, conduct equipment tests for the purpose of such adjustments and measurements as may be necessary to assure compliance with the terms of the construction permit, the tcchnical provisions of the application therefor, the rules and regnlations, and the applicable engineering standards.

(b) The Commission may notfy the permittee to conduct no tests or may cancel, suspend, or change the date for the beginning of equipment tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Equipment tests may be continued so long as the construction permit shall remain valid.

(d) Inspection of a station will ordinarily be required during the equipment test period and before the commencement of the program test. After construction and after adjustments and measurements have been completed to show compliance with the terms of the construction permit, the technical provisions of the application therefor, the rules and regulations and the applicable engineering standards, the permittee should notify the Engineer in Charge of the radio district in which the station is located that it is ready for inspection.

(e) The authorization for tests embodied in this section shall not be construed as constituting a license to operate but as a necessary part of construction.

§ 3.217 **Program tests.** (a) Upon completion of construction of an FM broadcast station in accordance with the terms of the construction permit, the technical pro-

visions of the application therefor, and the rules and regulations and the applicable engineering standards, and when an application for station license has been filed showing the station to be in satisfactory operating condition, the permittee may request authority to conduct program tests: *Provided,* That such request shall be filed with the Commission at least ten (10) days prior to the date on which it is desired to begin such operation and that the Engineer in Charge of the radio district in which the station is located is notified. (All data necessary to show compliance with the terms and conditions of the construction permit must be filed with the license application.)

(b) Program tests shall not commence until specific Commission authority is received. The Commission reserves the right to change the date of the beginning of such tests or to suspend or revoke the authority for program tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Unless sooner suspended or revoked program test authority continues valid during Commission consideration of the application for license and during this period further extension of the construction permit is not required. Program test authority shall be automatically terminated by final determination upon the application for station license.

(d) All operation under program test authority shall be in strict compliance with the rules governing FM broadcast stations and in strict accordance with representations made in the application for license pursuant to which the tests were authorized.

(e) The granting of program test authority shall not be construed as approval by the Commission of the application for station license.

§ 3.218 Normal license period. (a) All FM broadcast station licenses will be issued for a normal license period of three years. Licenses will be issued to expire at the hour of 3:00 a.m., e.s.t. in accordance with the following schedule and at three-year intervals thereafter.

(1) For stations located in Delaware and Pennsylvania, August 1, 1957.

(2) For stations located in Maryland, District of Columbia, Virginia, West Virginia, October 1, 1957.

(3) For stations located in North Carolina, South Carolina, December 1, 1957.

(4) For stations located in Florida, Puerto Rico and Virgin Islands, February 1, 1958.

(5) For stations located in Alabama and Georgia, April 1, 1958.

(6) For stations located in Arkansas, Louisiana and Mississippi, June 1, 1958.

(7) For stations located in Tennessee, Kentucky and Indiana, August 1, 1958.

(8) For stations located in Ohio and Michigan, October 1, 1958.

(9) For stations located in Illinois and Wisconsin, December 1, 1958.

(10) For stations located in Iowa and Missouri, February 1, 1956.

(11) For stations located in Minnesota, North Dakota, South Dakota, Montana and Colorado, April 1, 1956.

(12) For stations located in Kansas, Oklahoma, Nebraska, June 1, 1956.

(13) For stations located in Texas, August 1, 1956.

(14) For stations located in Wyoming, Nevada, Arizona, Utah, New Mexico and Idaho, October 1, 1956.

(15) For stations located in California, December 1, 1956.

(16) For stations located in Washington, Oregon, Alaska and Hawaii, February 1, 1957.

(17) For stations located in Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont, April 1, 1957.

(18) For stations located in New Jersey and New York, June 1, 1957.

Licensing Policies

§ 3.231 Exclusive affiliation of station. No license shall be granted to an FM broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization under which the station is prevented or hindered from, or penalized for, broadcasting the programs of any other network organization.

(The term "network organization" as used herein includes national and regional network organizations. See ch. VII, J, of Report on Chain Broadcasting.)

§ 3.232 **Territorial exclusivity.** No license shall be granted to an FM broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization which prevents or hinders another broadcast station serving substantially the same area from broadcasting the network's programs not taken by the former station, or which prevents or hinders another broadcast station serving a substantially different area from broadcasting any program of the network organization. This section shall not be construed to prohibit any contract, arrangement, or understanding between a station and a network organization pursuant to which the station is granted the first call in its primary service area upon the programs of the network organization.

§ 3.233 **Term of affiliation.** No license shall be granted to an FM broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization which provides, by original terms, provisions for renewal, or otherwise for the affiliation of the station with the network organization for a period longer than 2 years: *Provided,* That a contract, arrangement, or understanding for a period up to 2 years, may be entered into within 6 months prior to the commencement of such period.

§ 3.234 **Option time.** No license shall be granted to an FM broadcast station which options for network programs any time subject to call on less than 56 days' notice, or more time than a total of 3 hours within each of four segments of the broadcast day, as herein described. The broadcast day is divided into four segments, as follows: 8 a.m. to 1 p.m.; 1 p.m. to 6 p.m.; 6 p.m. to 11 p.m.; 11 p.m. to 8 a.m. (These segments are to be determined for each station in terms of local time at the location of the station but may remain constant throughout the year regardless of shifts from standard to daylight saving time or vice versa.) Such options may not be exclusive as against other network organizations and may not prevent or hinder the station from optioning or selling any or all of the time covered by the option, or other time, to other network organizations.

NOTE 1: As used in this section, an option is any contract, arrangement, or understanding, express or implied, between a station and a network organization which prevents or hinders the station from scheduling programs before the network agrees to utilize the time during which such programs are scheduled, or which requires the station to clear time already scheduled when the network organization seeks to utilize the time.

NOTE 2: All time options permitted under this section must be specified clock hours, expressed in terms of any time system set forth in the contract agreed upon by the station and network organization. Shifts from daylight saving to standard time or vice versa may or may not shift the specified hours correspondingly as agreed by the station and network organization.

§ 3.235 **Right to reject programs.** No license shall be granted to an FM broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization which (a), with respect to programs offered pursuant to an affiliation contract, prevents or hinders the station from rejecting or refusing network programs which the station reasonably believes to be unsatisfactory or unsuitable; or which (b), with respect to network programs so offered or already contracted for prevents the station from rejecting or refusing any program which, in its opinion, is contrary to the public interest, or from substituting a program of outstanding local or national importance.

§ 3.236 **Network ownership of stations.** No license shall be granted to a network organization, or to any person directly or indirectly controlled by or under common control of a network organization, for an FM broadcast station in any locality where the existing FM broadcast stations are so few or of such unequal desirability (in terms of coverage, power, frequency, or other related matters) that competition would be substantially restrained by such licensing. (The word "control" as used herein is not limited to majority stock ownership, but includes actual working control in whatever manner exercised.)

§ 3.237 **Dual network operation.** No license shall be issued to an FM broadcast

station affiliated with a network organization which maintains more than one network of FM broadcast stations: *Provided,* That this section shall not be applicable if such networks are not operated simultaneously, or if there is no substantial overlap in the territory served by the group of stations comprising each such network.

§ 3.238 **Control by networks of station rates.** No license shall be granted to an FM broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization under which the station is prevented or hindered from, or penalized for, fixing or altering its rates for the sale of broadcast time for other than the network's programs.

§ 3.239 **Use of common antenna site.** No FM broadcast station license or renewal of FM broadcast station license will be granted to any person who owns, leases, or controls a particular site which is peculiarly suitable for FM broadcasting in a particular area and (a) which is not available for use by other FM broadcast station licensees; and (b) no other comparable site is available in the area; and (c) where the exclusive use of such site by the applicant or licensee would nndnly limit the number of FM broadcast stations that can be authorized in a particular area or would unduly restrict competition among FM broadcast stations.

§ 3.240 **Multiple ownership.** No license for an FM broadcast station shall be granted to any party (including all parties under common control) if:

(a) Such party directly or indirectly owns, operates, or controls another FM broadcast station which serves substantially the same service area; or

(b) Such party, or any stockholder, officer or director of such party, directly or indirectly owns, operates, controls, or has any interest in, or is an officer or director of any other FM broadcast station if the grant of such license would result in a concentration of control of FM broadcasting in a manner inconsistent with public interest, convenience, or necessity. In determining whether there is such a concentration of control, consideration will be given to the facts of each case with particular reference to such factors as the size, extent and location of areas served, the number of people served, classes of stations involved, and the extent of other competitive service to the areas in question. The Commission, however, will in any event consider that there would be such a concentration of control contrary to the public interest, convenience or necessity for any party or any of its stockholders, officers or directors to have a direct or indirect interest in, or be stockholders, officers, or directors of, more than seven FM broadcast stations.

NOTE 1: The word "control" as used herein is not limited to majority stock ownership, but includes actual working control in whatever manner exercised.

NOTE 2: In applying the foregoing provisions to the stockholders of a corporation which has more than 50 voting stockholders, only those stockholders need be considered who are officers or directors or who directly or indirectly own 1 percent or more of the outstanding voting stock.

§ 3.241 **Special rules relating to contracts providing for reservation of time upon sale of a station.** (a) No license, renewal of license, assignment of license, or transfer of control of a corporate licensee shall be granted or authorized to a FM broadcast station which has a contract, arrangement or understanding, express or implied, pursuant to which, as consideration or partial consideration for the assignment of license or transfer of control, the assignor of a station license or the transferor of stock, where transfer of a corporate licensee is involved, or the nominee of such assignor or transferor retains any right of reversion of the license or any right to the reassignment of the license in the future, or reserves the right to nse the facilities of the station for any period whatsoever.

Equipment

§ 3.250 **Acceptability of broadcast transmitters for licensing.** (a) In order to facilitate the filing of, and action on applications for station authorizations, transmitters will be accepted for licensing by the Commission under one of the following conditions:

(1) A transmitter may be type-accepted upon the request of any manufacturer of transmitters built in quantity by following the type acceptance procedure set forth in Part 2 of this chapter, provided that the data and information submitted indicates that the transmitter meets the requirements of § 3.317. If accepted, such transmitter will be included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment." Applicants specifying transmitters included on such a list need not submit detailed descriptions and diagrams where the correct type number is specified, provided that the equipment proposed is identical with that accepted. Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(2) An application specifying a transmitter not included on the Radio Equipment List, Part B, may be accepted upon the request of a prospective licensee submitting with the application for construction permit a complete description of the transmitter, including the circuit diagram, listing of all tubes used, function of each, multiplication in each stage, plate current and voltage applied to each tube, a description of the oscillator circuit together with any devices installed for the purpose of frequency stabilization and the means of varying output power to compensate for power supply voltage variations. However, if this data has been filed with the Commission by a manufacturer in connection with a request for type acceptance, it need not be submitted with the application for construction permit but may be referred to as "on file." Measurement data for type acceptance made in accordance with subparagraph (1) of this paragraph shall be submitted with the license application.

(3) A transmitter shown on an instrument of authorization by manufacturer and type number, or as a composite, and which was in use prior to June 30, 1955, may continue to be used by the licensee, his successors or assignees, provided such transmitter continues to comply with the rules and regulations.

(b) Additional rules with respect to withdrawal of type-acceptance, modification of type-accepted equipment and limitations on the findings upon which type acceptance is based are set forth in Part 2 of this chapter.

§ 3.251 Transmitter power. The standard power rating and operating power range of transmitters shall be in accordance with § 3.317.

§ 3.252 Frequency monitor. (a) The licensee of each station shall have in operation, either at the transmitter or at the place where the transmitter is controlled, a frequency monitor of a type approved by the Commission which shall be independent of the frequency control of the transmitter.

NOTE: Approved frequency monitors are included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment." Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(b) In the event that the frequency monitor becomes defective the station may be operated without the monitor pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided,* That:

(1) Appropriate entries shall be made in the operating log of the station showing the date and time the monitor was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the monitor is found to be defective and immediately after the repaired or replacement monitor has been installed and is functioning properly.

(3) The frequency of the station shall be compared with an external frequency source of known accuracy at sufficiently frequent intervals to insure that the frequency is maintained within the tolerance prescribed in § 3.269. An entry shall be made in the station log as to the method used and the results thereof.

(c) If conditions beyond the control of the licensee prevent the restoration of the monitor to service within the above allowed period, informal request in accordance with § 1.332(d) of this chapter may be filed with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

§ 3.253 Modulation monitor. (a) The licensee of each station shall have in

operation, either at the transmitter or at the place where the transmitter is controlled, a modulation monitor of the type approved by the Commission.

NOTE: Approved modulation monitors are included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment." Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(b) In the event that the modulation monitor becomes defective the station may be operated without the monitor pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided*, That:

(1) Appropriate entries shall be made in the operating log of the station showing the date and time the monitor was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the monitor is found to be defective and immediately after the repaired or replacement monitor has been installed and is functioning properly.

(3) During the period when the station is operated without the modulation monitor the licensee shall provide other suitable means for insuring that the modulation is maintained within the tolerance prescribed in § 3.268.

(c) If conditions beyond the control of the licensee prevent the restoration of the monitor to service within the above allowed period, informal request in accordance with § 1.332(d) of this chapter may be filed with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

§ 3.254 Required transmitter performance. (a) The construction, installation, operation and performance of the FM broadcast transmitting system shall be in accordance with § 3.317.

(b) The licensee of each FM broadcast station shall make the following equipment performance measurements at least at yearly intervals. (One such set of measurements shall be made during the four-month period preceding the date of filing application for renewal of station license.)

(1) Audio frequency response from 50 to 15,000 cycles for approximately 25, 50 and 100 percent modulation. Measurements shall be made on at least the following audio frequencies: 50, 100, 400, 1000, 5000, 10,000 and 15,000 cycles. The frequency response measurements should normally be made without deemphasis; however, standard 75 microsecond deemphasis may be employed in the measuring equipment or system provided the accuracy of the deemphasis circuit is sufficient to insure that the measured response is within the prescribed limits.

(2) Audio frequency harmonic distortion for 25, 50 and 100 percent modulation for the fundamental frequencies of 50, 100, 400, 1000, and 5000 cycles. Audio frequency harmonics for 100 percent modulation for fundamental frequencies of 10,000 and 15,000 cycles. Measurements shall normally include harmonics to 30,000 cycles. The distortion measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

(3) Output noise level (frequency modulation) in the band of 50 to 15,000 cycles in decibels below the audio frequency level representing a frequency swing of 75 kilocycles. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

(4) Output noise level (amplitude modulation) in the band of 50 to 15,000 cycles in decibels below the level representing 100 percent amplitude modulation. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system. All measurements shall be made with the equipment adjusted for normal program operation and shall include all circuits between the main studio microphone terminals and the antenna output, including telephone lines, preemphasis circuits and any equalizers employed except for microphones, and without compression if a compression amplifier is installed.

(c) The data required by paragraph (b) of this section together with a description of instruments and procedure signed by the engineer making the measurements shall be kept on file at the transmitter and retained for a period of two years and

shall be made available during that time upon request to any duly authorized representative of the Federal Communications Commission.

§ 3.255 **Auxiliary transmitter.** Upon showing that a need exists for the use of an auxiliary transmitter in addition to the regular transmitter of an FM broadcast station, a license therefor may be issued: *Provided*, That:

(a) An auxiliary transmitter may be installed either at the same location as the main transmitter or at another location.

(b) A licensed operator shall be in control whenever an auxiliary transmitter is placed in operation.

(c) The auxiliary transmitter shall be maintained so that it may be put into immediate operation at any time for the following purposes:

(1) The transmission of the regular programs upon the failure of the main transmitter.

(2) The transmission of regular programs during maintenance or modification work on the main transmitter, necessitating discontinuance of its operation for a period not to exceed 5 days. (This includes the equipment changes which may be made without authority as set forth elsewhere in the rules and regulations or as authorized by the Commission by letter or by construction permit. Where such operation is required for periods in excess of 5 days, request therefor shall be in accordance with § 1.324 of this chapter.)

(3) Upon request by a duly authorized representative of the Commission.

(d) The auxiliary transmitter shall be tested at least once each week to determine that it is in proper operating condition and that it is adjusted to the proper frequency, except that in the case of operation in accordance with paragraph (c) of this section during any week, the test in that week may be omitted provided the operation under paragraph (c) of this section is satisfactory. Tests shall be conducted only between midnight and 6 a.m., local standard time. A record shall be kept of the time and result of each test. Such records shall be retained for a period of two years.

(e) The auxiliary transmitter shall be equipped with satisfactory control equipment which will enable the maintenance of the frequency emitted by the station within the limits prescribed by the regulations in this part.

(f) The operating power of an auxiliary transmitter may be less than the authorized power of the main transmitter, but in no event shall it be greater than such power.

§ 3.256 **Alternate main transmitters.** The licensee of an FM broadcast station may be licensed for alternate main transmitters provided that a technical need for such alternate transmitters is shown (such as licensees maintaining 24-hour schedule and needing alternate operation for maintenance, or where developmental work requires alternate operation) and that the following conditions are met:

(a) Both transmitters are located at the same place.

(b) Both transmitters shall have the same power rating.

(c) Both transmitters shall meet the construction, installation, operation, and performance requirements of § 3.317.

§ 3.257 **Changes in equipment and antenna system.** Licensees of FM broadcast stations shall observe the following provisions with regard to changes in equipment and antenna system:

(a) No changes in equipment shall be made:

(1) That would result in the emission of signals outside of the authorized channel.

(2) That would result in the external performance of the transmitter being in disagreement with that prescribed in § 3.317.

(b) Specific authority, upon filing formal application (FCC Form 301) therefor, is required for a change in service area or for any of the following changes:

(1) Changes involving an increase or decrease in the power rating of the transmitter.

(2) A replacement of the transmitter as a whole.

(3) Change in the location of the transmitting antenna.

(4) Change in antenna system, including transmission line.

(5) Change in location of main studio, if it is proposed to move the main studio to a different city from that specified in the license.

(6) Change in the power delivered to the antenna.
(7) Change in frequency control and/or modulation system.
(8) Change in the authorized transmitter remote control point(s).

(c) Other changes, except as above provided for in this section or in the Technical Standards of this subpart, may be made at any time without the authority of the Commission: *Provided*, That the Commission shall be promptly notified thereof and such changes shall be shown in the next application for renewal of license.

§ 3.258 Indicating instruments. (a) Each FM broadcast station shall be equipped with indicating instruments, which conform with the specifications set forth in § 3.320, for measuring the direct plate voltage and current of the last radio stage and the transmission line radio frequency current, voltage or power.

(b) In the event that any one of these indicating instruments becomes defective when no substitute which conforms with the required specifications is available, the station may be operated without the defective instrument pending its repair or replacement for a period not in excess of 60 days: *Provided*, That:

(1) Appropriate entries shall be made in the operating log of the station showing the date and time the meter was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified immediately after the instrument is found to be defective and immediately after the repaired or replaced instrument has been installed and functioning properly.

(3) If the defective instrument is a plate voltmeter or plate ammeter in the last radio stage, the operating power shall be maintained by means of the radio frequency transmission line meter.

(c) If conditions beyond the control of the licensee prevent the restoration of the meter to service within the above allowed period, informal request may be filed in accordance with § 1.332(d) of this chapter with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

Technical Operation

§ 3.261 Time of operation. All FM broadcast stations will be licensed for unlimited time operation. A minimum of 36 hours per week during the hours of 6:00 a.m. to midnight, consisting of not less than 5 hours in any one day, except Sunday, must be devoted to the FM broadcast operation; time devoted to operations conducted pursuant to a Subsidiary Communications Authorization (see §§ 3.293–3.295) shall not be included in meeting this 36-hour broadcast requirement. In an emergency when, due to causes beyond the control of a licensee, it becomes impossible to continue operation, the station may cease operation for a period not to exceed 10 days, provided that the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified in writing immediately after the emergency develops.

§ 3.262 Experimental operation. The period between 1:00 a.m. and 6:00 a.m., local standard time, may be used for experimental purposes in testing and maintaining apparatus by the licensee of any FM broadcast station on its assigned frequency and not in excess of its authorized power without specific authorization by the Commission.

§ 3.263 Station inspection. The licensee of any FM broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 3.264 Station and operator licenses; posting of. (a) The station license and any other instrument of station authorization shall be posted in a conspicuous place and in such manner that all terms are visible, at the place the licensee considers to be the principal control point of the transmitter. At all other control points listed on the station authorization, a photocopy of the station license and other instruments of station authorization shall be posted.

(b) The original operator license, or FCC Form 759, of each station operator shall be posted at the place where he is on duty as an operator.

§ 3.265 **Operator requirements.** (a) One or more radio operators holding a valid radiotelephone first-class operator license, except as provided in paragraph (b) of this section, shall be in actual charge of the transmitting apparatus and shall be on duty either at the transmitter location or remote control point.

(b) A station which is authorized with transmitter power output of 10 kilowatts or less may be operated by persons holding commercial radio operator license of any class, except an aircraft radiotelephone operator authorization or a temporary limited radiotelegraph second-class operator license, when the equipment is so designed that the stability of the frequency is maintained by the transmitter itself within the limits of tolerance specified, and none of the operations, except those specified in subparagraphs (1), (2) and (3) of this paragraph, necessary to be performed during the course of normal operation may cause off-frequency operation or result in any unauthorized radiation. Adjustments of transmitting equipment by such operators, except when under the immediate supervision of a radiotelephone first-class operator shall be limited to the following:

(1) Those necessary to commence or terminate transmitter emissions as a routine matter.

(2) Those external adjustments that may be required as a result of variations of primary power supply.

(3) Those external adjustments which may be necessary to insure modulation within the limits required.

Should the transmitting apparatus be observed to be operating in a manner inconsistent with the station's instrument of authorization and none of the above adjustments are effective in bringing it into proper operation, a person holding other than a radiotelephone first-class operator license and not acting under the immediate supervision of a radiotelephone first-class operator, shall be required to terminate the station's emissions.

(c) The licensee of a station which is operated by one or more operators holding other than a radiotelephone first-class operator license shall have one or more operators holding a radiotelephone first-class operator license in regular full-time employment at the station whose primary duties shall be to effect and insure the proper functioning of the transmitting equipment. In the event that the licensee also operates a standard broadcast station in the same community, a regular full-time radiotelephone first-class operator or operators employed in connection with the FM broadcast station may concurrently be employed to satisfy the requirements of § 3.93(c): *Provided,* That the duties of such operator or operators concerning the standard broadcast transmitting equipment shall in nowise interfere with the proper performance of his duties with respect to the FM broadcast transmitter.

(d) The licensed operator on duty and in charge of an FM broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another radio station or stations in accordance with the class of operator's license which he holds and the rules and regulations governing such other stations: *Provided, however,* That such duties shall in nowise interfere with the proper operation of the FM broadcast transmitter.

§ 3.266 **Facsimile broadcasting and multiplex transmission.** (a) FM broadcast stations may transmit simplex facsimile in accordance with transmission standards set forth in § 3.318 during periods not devoted to FM aural broadcasting. Such transmissions may not exceed one hour during the period between 7 a.m. and midnight (no limit for the hours between midnight and 7 a.m.) and may not be counted toward the minimum operation required by § 3.261. The Commission shall be notified by the licensee of the FM broadcast station of its intent to transmit such facsimile.

(b) FM broadcast stations may, upon securing authorization from the Commission, transmit multiplex facsimile in accordance with transmission standards set forth in § 3.318: *Provided,* That the transmission of such facsimile does not reduce the quality of aural programs simultaneously transmitted by the licensee below that required by the Technical Standards of this subpart and that no degradation of such aural programs will result from such facsimile transmissions when received on FM receivers not equipped with filter or other additional equipment.

§ 3.267 **Operating power; determination and maintenance of.** (a) The operating power of each station shall be determined by the indirect method. This is the product of the plate voltage (E_p) and the plate current (I_p) of the last radio stage, and an efficiency factor, F; that is:

$$\text{Operating power} = E_p \times I_p \times F$$

The efficiency factor, F, shall be established by the transmitter manufacturer for each type of transmitter for which Commission approval is requested, and shall be specified in the instruction books supplied to the customer with each transmitter. In the case of composite equipment the factor, F, shall be furnished to the Commission along with a statement of the basis used in determining such factor.

(b) The operating power of each station shall be maintained as near as practicable to the authorized operating power, and shall not exceed the limits of 5 percent above and 10 percent below the authorized power, except that in an emergency when it becomes impossible to operate with the authorized power, the station may be operated with reduced power for a period not to exceed 10 days, provided the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified immediately after the emergency develops, and also upon the resumption of normal operating power.

§ 3.268 **Modulation.** The percentage of modulation of FM broadcast stations shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice and in no case less than 85 percent nor more than 100 percent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration.

§ 3.269 **Frequency tolerance.** The center frequency of each FM broadcast station shall be maintained within 2000 cycles of the assigned center frequency.

§ 3.270 **Antenna structure, marking and lighting.** Where an antenna structure(s) is required to be painted or lighted see § 17.29, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 3.271 **Discontinuance of operation.** The licensee of each station shall notify the Commission in Washington, D.C., and the Engineer in Charge of the radio district where such station is located of permanent discontinuance of operation at least two days before operation is discontinued. The licensee shall, in addition, immediately forward the station license and other instruments of authorization to the Washington, D.C., office of the Commission for cancellation.

§ 3.272 **Field intensity measurements.** The Commission may require field intensity measurements in connection with applications and in other cases where such measurements are found to be necessary. For example, any application which asserts that interference predicted under the Technical Standards of this subpart would not be realized may require supplementary data including appropriate field intensity measurements. Furthermore, in order that FM broadcast station coverage data may be accumulated it is desirable that existing FM broadcast stations make such measurements where feasible and file the data with the Commission.

§ 3.273 **Emergency antenna.** In the event it becomes impossible to operate with the regularly authorized antenna, the station may, without further authority, be operated with an emergency antenna for a period of 10 days or less pending necessary repairs: *Provided,* That the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified in writing immediately upon the beginning of such operation and upon the resumption of normal operation.

§ 3.274 **Remote control authorization.** (a) Application to operate a station by remote control may be made as a part of the application for construction permit for a new station. Application to operate an authorized station shall be made on FCC Form 301-A.

(b) An authorization for remote control will be issued only after a satisfactory showing has been made in regard to the following, among others:

(1) The location of the remote control point(s);

(2) The transmitter, if the power rating is in excess of 10 kw, is reliable and capable of being operated by remote control.

§ 3.275 Remote control operation. (a) Operation by remote control shall be subject to the following conditions:

(1) The equipment at the operating and transmitting positions shall be so installed and protected that it is not accessible to or capable of operation by persons other than those duly authorized by the licensee.

(2) The control circuits from the operating position to the transmitter shall provide positive on and off control and shall be such that open circuits, short circuits, grounds or other line faults will not actuate the transmitter and any fault causing loss of such control will automatically place the transmitter in an inoperative position.

(3) A malfunction of any part of the remote control equipment and associated line circuits resulting in improper control or inaccurate meter readings shall be the cause for the immediate cessation of operation by remote control.

(4) Control and monitoring equipment shall be installed so as to allow the licensed operator at the remote control point to perform all the functions in a manner required by the Commission's rules.

(b) All stations, whether operating by remote control or direct control, shall be so equipped, in accordance with § 3.932, so as to be able to follow the prescribed CONELRAD alerting procedure set forth in the CONELRAD Manual for Broadcast Stations.

Other Operating Requirements

§ 3.281 Logs. The licensee or permittee of each FM broadcast station shall maintain separate program and operating logs for such station: *Provided, however,* If the same licensee or permittee operates an FM broadcast station and a standard broadcast station and simultaneously broadcasts the same programs over the facilities of both such stations, one program log may be maintained for both stations for such periods as both stations simultaneously broadcast the same programs. Such licensee or permittee shall require entries to be made as follows:

(a) In the program log:

(1) An entry of the time each station identification announcement (call letters and location) is made.

(2) An entry briefly describing each program broadcast, such as "music," "drama," "speech," etc., together with the name or title thereof and the sponsor's name, with the time of the beginning and ending of the complete program. If a mechanical record is used, the entry shall show the exact nature thereof, such as "record," "transcription," etc., and the time it is announced as a mechanical reproduction. If a speech is made by a political candidate, the name and political affiliations of such speaker shall be entered.

(3) An entry showing that each sponsored program broadcast has been announced as sponsored, paid for, or furnished by the sponsor.

(4) An entry showing, for each program of network origin, the name of the network originating the program.

(b) In the operating log:

(1) An entry of the time the station begins to supply power to the antenna, and the time it stops.

(2) An entry of the time the program begins and ends.

(3) An entry of each interruption to the carrier wave, its cause, and duration.

(4) An entry of the following each 30 minutes:

(i) Operating constants of last radio stage (total plate current and plate voltage).

(ii) RF transmission line meter reading.

(iii) Frequency monitor reading.

(5) Log of experimental operation during experimental period (if regular operation is maintained during this period, the above logs shall be kept).

(i) A log must be kept of all operation during the experimental period. If the entries required above are not applicable thereto, then the entries shall be made so as to fully describe the operation.

(c) Where an antenna structure(s) is required to be illuminated see § 17.38, *Recording of tower light inspections in the station record,* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 3.282 **Logs; retention of.** Logs of FM broadcast stations shall be retained by the licensee or permittee for a period of two years: *Provided, however,* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee or permittee has been notified, shall be retained by the licensee or permittee until he is specifically authorized in writing by the Commission to destroy them: *Provided, further,* That logs incident to or involved in any claim or complaint of which the licensee or permittee has notice shall be retained by the licensee or permittee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

§ 3.283 **Logs; by whom kept.** Each log shall be kept by the person or persons competent to do so, having actual knowledge of the facts required, who shall sign the log when starting duty and again when going off duty. The logs shall be made available upon request by an authorized representative of the Commission.

§ 3.284 **Log form.** The log shall be kept in an orderly manner, in suitable form, and in such detail that the data required for the particular class of station concerned are readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log.

§ 3.285 **Correction of logs.** No log or portion thereof shall be erased, obliterated, or willfully destroyed within the period of retention provided by the rules. Any necessary correction may be made only by the person originating the entry who shall strike out the erroneous portion, initial the correction made, and indicate the date of correction.

§ 3.286 **Rough logs.** Rough logs may be transcribed into condensed form, but in such case the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

§ 3.287 **Station identification.** (a) A licensee of an FM broadcast station shall make separate station identification announcement (call letters and location) for such station: *Provided, however,* That, if the same licensee operates an FM broadcast station and a standard broadcast station and simultaneously broadcasts the same programs over the facilities of both such stations, station identification announcements may be made jointly for both stations for periods of such simultaneous operation. If the call letters of the FM station do not clearly reveal that it is an FM station, the joint announcement shall state that one of the stations is an FM station. Station identification announcement shall be made at the beginning and ending of each time of operation and during operation (1) on the hour and (2) either on the half hour or at the quarter hour following the hour and at the quarter hour preceding the next hour: *Provided,*

(b) Such identification announcement need not be made on the hour when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or operatic production of longer duration than 30 minutes. In such cases the identification announcement shall be made at the beginning of the program, at the first interruption of the entertainment continuity, and at the conclusion of the program.

(c) Such identification announcement need not be made on the half hour or quarter hours when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or operatic production. In such cases an identification announcement shall be made at the first interruption of the entertainment continuity and at the conclusion of the program: *Provided,* That an announcement within 5 minutes of the times specified in paragraph (a)(2) of this section will satisfy the requirements of identification announcements.

(d) In the case of variety show programs, baseball game programs or similar programs of longer duration than 30 minutes, the identification announcement shall be made within 5 minutes of the hour and of the times specified in paragraph (a)(2) of this section.

(e) In the case of all other programs, the identification announcement shall be

made within 2 minutes of the hour and of the times specified in paragraph (a)(2) of this section.

(f) In making the identification announcement the call letters shall be given only on the channel of the station identified thereby except as otherwise provided herein.

§ 3.288 Mechanical reproductions. (a) No mechanically reproduced program consisting of a speech, news event, news commentator, forum, panel discussion, or special event in which the element of time is of special significance, or any other program in which the element of time is of special significance and presentation of which would create, either intentionally or otherwise, the impression or belief on the part of the listening audience that the event or program being broadcast is in fact occurring simultaneously with the broadcast, shall be broadcast without an appropriate announcement being made either at the beginning or end of such reproduction or at the beginning or end of the program in which such reproduction is used that it is a mechanical reproduction or a mechanically reproduced program: *Provided, however,* That each such program of one minute or less need not be announced as such.

(b) The exact form of identifying announcement is not prescribed, but the language shall be clear and in terms commonly used and understood. Any other program mechanically reproduced or series of mechanical reproductions, including a mechanical reproduction used for background music, sound effects, station identification, program identification (theme music of short duration) or identification of sponsorship of the program proper, need not be announced as provided in paragraph (a) of this section, but the licensee shall not attempt affirmatively to create the impression that any program being broadcast by mechanical reproduction consists of live talent.

(c) The requirements of paragraph (a) of this section are waived with respect to network programs, transcribed and rebroadcast at a later hour because of the time zone differential between the place where the program originates and where it is rebroadcast, this waiver being applicable whether the off-the-line recording is made by the network itself at one of its key stations or by an individual station, but only when the off-the-line recording is for broadcast at an hour not exceeding the time zone differential between the place where the program originates and where it is rebroadcast. Each station which broadcasts network programs at a later hour in accordance with this waiver shall make an appropriate announcement at least once each day between the hours of 10:00 a.m. and 10:00 p.m., stating that some or all of the network programs which are broadcast by that station are delayed broadcasts by means of transcription. This waiver provision also applies during the annual periods in which daylight saving time will be effective with respect to network programs transcribed and rebroadcast one hour later because of the time differential resulting from the adoption of daylight saving time in some areas.

§ 3.289 Sponsored programs; announcement of. (a) In the case of each program for the broadcasting of which money, services, or other valuable consideration is either directly or indirectly paid or promised to, or charged or received by, any radio broadcast station, the station broadcasting such program shall make, or cause to be made, an appropriate announcement that the program is sponsored, paid for, or furnished, either in whole or in part.

(b) In the case of any political program or any program involving the discussion of public controversial issues for which any records, transcriptions, talent, scripts, or other material or services of any kind are furnished, either directly or indirectly, to a station as an inducement to the broadcasting of such program, an announcement shall be made both at the beginning and conclusion of such program on which such material or services are used that such records, transcriptions, talent, scripts, or other material or services have been furnished to such station in connection with the broadcasting of such program: *Provided, however,* That only one such announcement need be made in the case of any such program of 5 minutes' duration or less, which announcement may be made either at the beginning or conclusion of the program.

(c) The announcement required by this section shall fully and fairly disclose the true identity of the person or persons by whom or in whose behalf such payment is made or promised, or from whom or in whose behalf such services or other valuable consideration is received, or by whom the material or services referred to in paragraph (b) of this section are furnished. Where an agent or other person contracts

or otherwise makes arrangements with a station on behalf of another, and such fact is known to the station, the announcement shall disclose the identity of the person or persons in whose behalf such agent is acting instead of the name of such agent.

(d) In the case of any program, other than a program advertising commercial products or services, which is sponsored, paid for, or furnished, either in whole or in part, or for which material or services referred to in paragraph (b) of this section are furnished, by a corporation, committee, association or other unincorporated group, the announcement required by this section, shall disclose the name of such corporation, committee, association or other unincorporated group. In each such case the station shall require that a list of the chief executive officers or members of the executive committee or of the board of directors of the corporation, committee, association or other unincorporated group shall be made available for public inspection at one of the radio stations carrying the program.

(e) In the case of programs advertising commercial products or services, an announcement stating the sponsor's corporate or trade name or the name of the sponsor's product, shall be deemed sufficient for the purposes of this section and only one such announcement need be made at any time during the course of the program.

§ 3.290 **Broadcasts by candidates for public office.** (a) *Definitions.* A "legally qualified candidate" means any person who has publicly announced that he is a candidate for nomination by a convention of a political party or for nomination or election in a primary, special, or general election, municipal, county, state or national, and who meets the qualifications prescribed by the applicable laws to hold the office for which he is a candidate, so that he may be voted for by the electorate directly or by means of delegates or electors, and who—

(1) Has qualified for a place on the ballot or

(2) Is eligible under the applicable law to be voted for by sticker, by writing in his name on the ballot, or other method, and (i) has been duly nominated by a political party which is commonly known and regarded as such, or (ii) makes a substantial showing that he is a bona fide candidate for nomination or office, as the case may be.

(b) *General requirements.* No station licensee is required to permit the use of its facilities by any legally qualified candidate for public office, but if any licensee shall permit any such candidate to use its facilities, it shall afford equal opportunities to all other such candidates for that office to use such facilities: *Provided,* That such licensee shall have no power of censorship over the material broadcast by any such candidate.

(c) *Rates and practices.* (1) The rates, if any, charged all such candidates for the same office shall be uniform and shall not be rebated by any means direct or indirect. A candidate shall, in each case, be charged no more than the rate the station would charge if the candidate were a commercial advertiser whose advertising was directed to promoting its business within the same area as that encompassed by the particular office for which such person is a candidate. All discount privileges otherwise offered by a station to commercial advertisers shall be available upon equal terms to all candidates for public office.

(2) In making time available to candidates for public office no licensee shall make any discrimination between candidates in charges, practices, regulations, facilities, or services for or in connection with the service rendered pursuant to this part, or make or give any preference to any candidate for public office or subject any such candidate to any prejudice or disadvantage; nor shall any licensee make any contract or other agreement which shall have the effect of permitting any legally qualified candidate for any public office to broadcast to the exclusion of other legally qualified candidates for the same public office.

(d) *Inspection of records.* Every licensee shall keep and permit public inspection of a complete record of all requests for broadcast time made by or on behalf of candidates for public office, together with an appropriate notation showing the disposition made by the licensee of such requests, and the charges made, if any, if request is granted. Such records shall be retained for a period of two years.

(e) A request for equal opportunities must be submitted to the licensee within one week of the day on which the prior use occurred.

(f) A candidate requesting equal opportunities of the licensee, or complaining of non-compliance to the Commission shall have the burden of proving that he and his opponent are legally qualified candidates for the same public office.

§ 3.291 Rebroadcast. (a) The term "rebroadcast" means reception by radio of the program of a radio station, and the simultaneous or subsequent retransmission of such program by a broadcast station.

NOTE 1: As used in this section, program includes any complete program or part thereof.
NOTE 2: In case a program is transmitted from its point of origin to a broadcast station entirely by telephone facilities in which a section of such transmission is by radio, the broadcasting of this program is not considered a rebroadcast.

(b) The licensee of an FM broadcast station may, without further authority of the Commission, rebroadcast the program of a United States standard, FM or non-commercial educational FM broadcast station, provided the Commission is notified of the call letters of each station rebroadcast and the licensee certifies that express authority has been received from the licensee of the station originating the program.

NOTE: The notice and certification of consent shall be given within 3 days of any single rebroadcast, but in case of the regular practice of rebroadcasting certain programs of a standard or FM broadcast station several times during a license period, notice and certification of consent shall be given for the ensuing license period with the application for renewal of license, or at the beginning of such rebroadcast practice if begun during a license period.

(c) (1) The licensee of an FM broadcast station located within a State or the District of Columbia may, without further authority of the Commission, rebroadcast on a noncommercial basis a noncommercial program of a United States international broadcast station.

(2) The licensee of an FM broadcast station located in any territory or insular possession of the United States may, without further authority of the Commission, rebroadcast any program of a United States international broadcast station.

(3) In the case of any rebroadcast under the provisions of this paragraph, the Commission shall be notified of the call letters of each station whose program is rebroadcast and the licensee shall certify that express authority has been received from the licensee of the station originating the program.

(d) No licensee of an FM broadcast station shall rebroadcast the program of any United States radio station not designated in paragraph (b) or (c) of this section without written authority having first been obtained from the Commission upon application (informal) accompanied by written consent or certification of consent of the licensee of the station originating the program.

NOTE 1: The broadcasting of a program relayed by a remote pickup broadcast station or an ST broadcast station is not considered a rebroadcast.
NOTE 2: By Order No. 82, dated and effective June 24, 1941, until further order of the Commission, § 3.291(d) is suspended only insofar as it requires prior written authority of the Commission for the rebroadcasting of programs originated for that express purpose by United States Government radio stations.

§ 3.292 Lotteries. (a) An application for construction permit, license, renewal of license, or any other authorization for the operation of a broadcast station, will not be granted where the applicant proposes to follow or continue to follow a policy or practice of broadcasting or permitting "the broadcasting of, any advertisement of or information concerning any lottery, gift enterprise, or similar scheme, offering prizes dependent in whole or in part upon lot or chance, or any list of the prizes drawn or awarded by means of any such lottery, gift enterprise, or scheme, whether said list contains any part or all of such prizes." (See 18 U. S. C. 1304.)

(b) The determination whether a particular program comes within the provisions of paragraph (a) of this section depends on the facts of each case. However, the Commission will in any event consider that a program comes within the provisions of paragraph (a) of this section if in connection with such program a prize consisting of money or thing of value is awarded to any person whose selection is dependent in

whole or in part upon lot or chance, if as a condition of winning or competing for such prize, such winner or winners are required to furnish any money or thing of value or are required to have in their possession any product sold, manufactured, furnished or distributed by a sponsor of a program broadcast on the station in question.

§ 3.293 Subsidiary Communications Authorizations. An FM broadcast licensee or permittee may apply for a Subsidiary Communications Authorization (SCA) to engage in a limited type of non-broadcast service. These services are restricted to those involving programming consisting of news, music, time, weather, and other similar program categories. (The functional music services whereby FM stations undertake to supply programs of a predominantly musical nature to commercial establishments is an example of such an SCA service.) FCC Form 318—Application for Subsidiary Communications Authorization—shall be submitted; the applicant for the SCA shall there specify the particular nature or purposes of the SCA operation or operations sought. New SCA operations will be authorized only for multiplexing. Outstanding Subsidiary Communications Authorizations for simplex operations will not be extended beyond March 1, 1958. SCA operations on a multiplex basis may be carried on without restriction as to time. Simplex operations pursuant to outstanding authorizations shall be conducted during those times not devoted to the 36 hours required under § 3.261 for FM broadcast operation.

§ 3.294 Nature of the SCA. (a) The SCA is of a subsidiary or secondary nature and shall not exist apart from the FM license or permit. No transfer or assignment of it shall be made separate from the FM broadcast license, and failure to transfer the SCA (through application on FCC Form 318) with the FM license or permit renders the SCA void. The licensee or permittee must seek renewal of the SCA (on FCC Form 318) at the same time it applies for its renewal of FM license or permit; failure to renew the latter automatically terminates the SCA.

(b) The grant or renewal of an FM license or permit shall not be furthered or promoted by the proposed or past operation under an SCA; the licensee must establish that his broadcast operation is in the public interest wholly apart from the SCA activities. (Violation of rules applicable to the SCA operation would, of course, reflect on the licensee's qualifications to hold its broadcast license or permit.)

§ 3.295 Operation under the SCA. (a) The SCA holder must restrict its operation to the uses or purposes granted by the Commission in acting upon his application; prior permission to engage in any additional or new activity must be obtained from the Commission.

(b) Supersonic tones or other similar devices may be employed with respect to material transmitted during the SCA operation in order to promote or maintain its commercial marketability, with the station using appropriate actuating devices with the subscribers' receivers.

(c) In all arrangements entered into under the SCA with outside parties, the licensee or permittee must pass on all material to be transmitted over the station's facilities, with the right to reject any material which it deems inappropriate or undesirable; when the SCA operation is conducted on a simplex basis, the licensee must be able, through appropriate contractual arrangement, to substitute a broadcast program at any time it deems it in the public interest to do so.

(d) The requirements of §§ 3.290 and 3.291 are equally applicable when the FM licensee or permittee is engaged in operations pursuant to the SCA.

(e) The requirements of § 3.287 with respect to station identification announcements must be met by identification on the main carrier when a station is engaged in SCA operations. The licensee may prevent their reception on subscribers' receivers through the use of supersonic tones capable of deactivating these specialized receivers.

(f) The requirements of §§ 3.288 and 3.289 are applicable to the SCA operation when the latter is conducted on a simplex basis; provided that the station may employ supersonic tones or other devices to prevent the reception of such announcements over subscribers' receivers. The requirement of § 3.289 shall be deemed to have been met by the SCA operator by the latter's announcement that the program is being transmitted for a fee to commercial subscribers.

(g) The FM licensee or permittee shall maintain logs for the SCA operations. In the program log, the following entries shall be made:

(1) An entry of the time each station identification announcement (call letters and location) is made.

(2) An entry describing the material transmitted in each hour segment. If a speech is made by a political candidate, the name and political affiliations of such speaker shall be entered.

(3) An entry showing that sponsorship and mechanical record announcements, when required under paragraph (f) of this section, have been made, and the time of the latter announcements.

(h) The requirements of § 3.281(b), (1)-(4), inclusive and (c), and §§ 3.282 to 3.286, inclusive, are equally applicable to logs to be maintained during the SCA operation.

(i) The requirements of § 3.265 with respect to operators and the provisions of § 3.274 relating to remote control operation are equally applicable to operation during the SCA period.

(j) The licensee must observe all technical rules and standards applicable to FM broadcast stations when conducting the SCA operation. (For criteria applicable to the multiplex SCA operation, see § 3.318.)

§ 3.296 Emergency weather warnings. Upon receipt of notification of an Emergency Weather Warning of a condition of immediate danger to life and property from the United States Weather Bureau, all FM broadcast stations may, at their option, broadcast CONELRAD Attention Signals (two five second carrier breaks and fifteen seconds of 1,000 CPS tone) followed by the Emergency Weather Warning as outlined in CONELRAD Manual BC-3 (Revised), Appendix A.

FM Technical Standards

§ 3.301 Introduction. (a) There are presented herein the Commission's engineering standards relating to the allocation and operation of FM broadcast stations. These standards also apply to noncommercial educational FM broadcast stations, except as noted herein. The Commission's rules and regulations contain references to these standards, which have been approved by the Commission and thus are considered as reflecting its opinion in all matters involved.

(b) The standards set forth herein are those deemed necessary for the construction and operation of FM broadcast stations to meet the requirements of technical regulations and for operation in the public interest along technical lines not otherwise enunciated. These standards are based upon the best engineering data available, including evidence at hearings, conferences with radio engineers, and data supplied by manufacturers of radio equipment and by licensees of FM broadcast stations. These standards are complete in themselves and supersede previous engineering standards or policies of the Commission concerning FM broadcast stations. While these standards provide for flexibility and indicate the conditions under which they are applicable, it is not expected that material deviation from the fundamental principles will be recognized unless full information is submitted as to the need and reasons therefor.

(c) These standards will necessarily be revised from time to time as progress is made in the art. The Commission will accumulate and analyze engineering data available as to the progress of the art so that these standards may be kept current with technical developments.

§ 3.310 Definitions. (a) *FM broadcast station.* The term "FM broadcast station" means a station employing frequency modulation in the FM broadcast band and licensed primarily for the transmission of radiotelephone emissions intended to be received by the general public.

(b) *Frequency modulation.* The term "frequency modulation" means a system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous amplitude of the modulating signal (amplitude of modulating signal to be measured after pre-emphasis, if used) and the instantaneous radio frequency is independent of the frequency of the modulating signal.

(c) *FM broadcast band.* The term "FM broadcast band" means the band of frequencies extending from 88 to 108 megacycles, which includes those assigned to noncommercial educational broadcasting.

(d) *Center frequency.* The term "center frequency" means:

(1) The average frequency of the emitted wave when modulated by a sinusoidal signal.

(2) The frequency of the emitted wave without modulation.

(e) *Frequency swing.* The term "frequency swing" means the instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

(f) *FM broadcast channel.* The term "FM broadcast channel" means a band of frequencies 200 kilocycles wide and is designated by its center frequency. Channels for FM broadcast stations begin at 88.1 megacycles and continue in successive steps of 200 kilocycles to and including 107.9 megacycles.

(g) *Antenna field gain.* The term "antenna field gain" of an FM broadcast antenna means the ratio of the effective free space field intensity produced at one mile in the horizontal plane expressed in millivolts per meter for 1 kilowatt antenna input power to 137.6 mv/m.

(h) *Free space field intensity.* The term "free space field intensity" means the field intensity that would exist at a point in the absence of waves reflected from the earth or other reflecting objects.

(i) *Multiplex transmission.* The term "multiplex transmission" means the simultaneous transmission of two or more signals within a single channel. Multiplex transmission as applied to FM broadcast stations means the transmission of facsimile or other signals in addition to the regular broadcast signals.

(j) *Percentage modulation.* The term "percentage modulation" as applied to frequency modulation means the ratio of the actual frequency swing to the frequency swing defined as 100 percent modulation, expressed in percentage. For FM broadcast stations a frequency swing of ± 75 kilocycles is defined as 100 percent modulation.

(k) *Effective radiated power.* The term "effective radiated power" means the product of the antenna power (transmitter output power less transmission line loss) times (1) the antenna power gain, or (2) the antenna field gain squared. Where circular or elliptical polarization is employed the term effective radiated power is applied separately to the horizontal and vertical components of radiation. For allocation purposes, the effective radiated power authorized is the horizontally polarized component of radiation only.

(l) *Service area.* The term "service area" as applied to FM broadcasting means the service resulting from an assigned effective radiated power and antenna height above average terrain.

(m) *Antenna height above average terrain.* (1) The term "antenna height above average terrain" means the height of the radiation center of the antenna above the terrain 2 to 10 miles from the antenna. (In general a different antenna height will be determined for each direction from the antenna. The average of these various heights is considered as the antenna height above average terrain.)

(2) Where circular or elliptical polarization is employed the antenna height above average terrain shall be based upon the height of the radiation center of the antenna which transmits the horizontal component of radiation.

(n) *Field intensity.* The term "field intensity" as used in these standards shall mean the electric field intensity in the horizontal direction.

(o) *Index of cooperation.* The index of cooperation as applied to facsimile broadcasting is the product of the number of lines per inch, the available line length in inches, and the reciprocal of the line-use ratio (e.g., $105 \times 8.2 \times 8/7 = 984$).

(p) *Line-use ratio.* The term "line-use ratio" as applied to facsimile broadcasting is the ratio of the available line to the total length of scanning line.

(q) *Available line.* The term "available line" means the portion of the total length of scanning line that can be used specifically for picture signals.

(r) *Rectilinear scanning.* The term "rectilinear scanning" means the process of scanning an area in a predetermined sequence of narrow straight parallel strips.

(s) *Optical density.* The term "optical density" means the logarithm (to the base 10) of the ratio of incident to transmitted or reflected light.

§ 3.311 Engineering standards of allocation. (a) Sections 3.202 to 3.205 inclusive of the rules and regulations describe the basis for allocation of FM broadcast stations, including the division of the United States into Areas I and II.

(b) FM broadcast stations shall determine the extent of their 1 mv/m and 50 uv/m contours in accordance with the methods prescribed in these Standards.

(c) Although some service is provided by tropospheric waves, the service area is considered to be only that served by the ground wave. The extent of service is determined by the point at which the ground wave is no longer of sufficient intensity to provide satisfactory broadcast service. The field intensity considered necessary for service is as follows:

Area:	*Median field intensity*
City business or factory areas	1 mv/m
Rural areas	50 uv/m

A median field intensity of 3 to 5 mv/m should be placed over the principal city to be served and for class B stations, a median field intensity of 1 mv/m should be placed over the business district of cities of 10,000 or greater within the metropolitan district served. A field intensity of 5 mv/m should be provided over the main studio of a class B station except as otherwise provided in § 3.205. These figures are based upon the usual noise levels encountered in the several areas and upon the absence of interference from other FM stations.

(d) A basis for allocation of satellite stations has not yet been determined. For the present, applications will be considered on their individual merits.

(e) The service area is predicted as follows: Profile graphs must be drawn for at least eight radials from the proposed antenna site. These profiles should be prepared for each radial beginning at the antenna site and extending to 10 miles therefrom. Normally the radials are drawn for each 45° of azimuth; however, where feasible the radials should be drawn for angles along which roads tend to follow. (The latter method may be helpful in obtaining topographical data where otherwise unavailable, and is particularly useful in connection with mobile field intensity measurements of the station and the correlation of such measurements with predicted field intensities.) In each case one or more radials must include the principal city or cities to be served, particularly in cases of rugged terrain, even though the city may be more than 10 miles from the antenna site. The profile graph for each radial should be plotted by contour intervals of from 40 to 100 feet and, where the data permits, at least 50 points of elevation (generally uniformly spaced) should be used for each radial. In instances of very rugged terrain where the use of contour intervals of 100 feet would result in several points in a short distance, 200- or 400-foot contour intervals may be used for such distances. On the other hand, where the terrain is uniform or gently sloping the smallest contour interval indicated on the topographic map (see below) should be nsed, although only a relatively few points may be available. The profile graph should accurately indicate the topography for each radial, and the graphs should be plotted with the distance in miles as the abscissa and the elevation in feet above mean sea level as the ordinate. The profile graphs should indicate the source of the topographical data employed. The graph should also show the elevation of the center of the radiating system. The graph may be plotted either on rectangular coordinate paper or on special paper which shows the curvature of the earth. It is not necessary to take the curvature of the earth into consideration in this procedure, as this factor is taken care of in the chart showing signal intensities (Fig. 1 of § 3.333).

(f) The average elevation of the 8-mile distance between 2 and 10 miles from the antenna site should then be determined from the profile graph for each radial. This may be obtained by averaging a large number of equally spaced points, by using a planimeter, or by obtaining the median elevation (that exceeded for 50 percent of the distance) in sectors and averaging these values.

(g) To determine the distance to a particular contour, Figure 1 of § 3.333 con-

cerning the range of FM broadcast stations should be used. This chart has been prepared for a frequency in the center of the band and is to be used for all FM broadcast channels, since little change results over this frequency range. The distance to a contour is determined by the effective radiated power and the antenna height. The height of the antenna used in connection with Figure 1 of § 3.333 should be the height of the center of the proposed antenna radiator above the average elevation obtained by the preceding method. The distances shown by Fig. 1 of § 3.333 are based upon an effective radiated power of 1 kilowatt; to use the chart for other powers, the sliding scale associated with the chart should be trimmed and used as the ordinate scale. This sliding scale is placed on the chart with the appropriate graduation for power in line with the lower line of the top edge of the chart. The right edge of the scale is placed in line with the appropriate antenna height graduations and the chart then becomes direct reading for this power and antenna height. Where the antenna height is not one of those for which a scale is provided, the signal strength or distance is determined by interpolation between the curves connecting the equidistant points.

(h) The foregoing process of determining the extent of the required contours shall be followed in determining the boundary of the proposed service area. The areas within the required contours must be determined and submitted with each application for an FM broadcast station. Each application shall include a map showing these contours, and for this purpose sectional aeronautical charts or other maps having a convenient scale may be used. The map shall show the radials along which the profile charts and expected field strengths have been determined. The area within each contour should then be measured (by planimeter or other approximate means) to determine the number of square miles therein. In computing the area within the contours, exclude (1) areas beyond the borders of the United States, and (2) large bodies of water, such as ocean areas, gulfs, sounds, bays, large lakes, etc., but not rivers.

(i) In cases where the terrain in one or more directions from the antenna site departs widely from the average elevation of the 2 to 10 mile sector, the application of this prediction method may indicate contour distances that are different from those which may be expected in practice. In such cases the prediction method should be followed, but a showing may be made if desired concerning the distance to the contour as determined by other means. Such showing should include data concerning the procedure employed and sample calculations. For example, a mountain ridge may indicate the practical limit of service although the prediction method may indicate the contour elsewhere. In cases of such limitation, the map of predicted coverage should show both the regular predicted area and the area as limited or extended by terrain. Both areas should be measured as previously described; the area obtained by the regular prediction method should be given in the application form, with a supplementary note giving the limited or extended area. In special cases the Commission may require additional information as to the terrain in the proposed service area.

(j) In determining the population served by FM broadcast stations, it is considered that the built-up city areas and business districts in cities having over 10,000 population and located beyond the 1 mv/m contour do not receive adequate service. Minor civil division maps (1950 census) should be used in making population comts, excluding cities not receiving adequate service. Where a contour divides a minor division, uniform distribution of population within the division should be assumed in order to determine the population included within the contour unless a more accurate count is available.

§ 3.312 Topographic data. (a) In the preparation of the profile graphs previously described, and in determining the location and height above mean sea level of the antenna site, the elevation or contour intervals shall be taken from United States Geological Survey Topographic Quadrangle Maps, United States Army Corps of Engineers Maps or Tennessee Valley Authority maps, whichever is the latest, for all areas for which such maps are available. If such maps are not published for the area in question, the next best topographic information should be used. Topographic

data may sometimes be obtained from state and municipal agencies. The data from the Sectional Aeronautical Charts (including bench marks) or railroad depot elevations and highway elevations from road maps may be used where no better information is available. In cases where limited topographic data can be obtained, use may be made of an altimeter in a car driven along roads extending generally radially from the transmitter site.

(b) The Commission will not ordinarily require the submission of topographical maps for areas beyond 15 miles from the antenna site, but the maps must include the principal city or cities to be served. If it appears necessary, additional data may be requested.

(c) The United States Geological Survey Topography Quadrangle Sheets may be obtained from the United States Geological Survey Department of the Interior, Washington, D.C., for 20 cents each. The Sectional Aeronautical Charts are available from the United States Coast and Geodetic Survey, Department of Commerce, Washington, D.C., for 25 cents each. These maps may also be secured from branch offices and from authorized agents or dealers in most principal cities.

§ 3.313 Interference standard. (a) Field intensity measurements are preferable in predicting interference between FM broadcast stations and should be used, when available, in determining the extent of interference. (For methods and procedure, see § 3.314.) In lieu of measurements, the interference should be predicted in accordance with the method described herein.

(b) Objectionable interference is considered to exist when the interfering signal exceeds that given by the following ratios. (The desired signal is median field and the undesired signal is the tropospheric signal intensity exceeded for 1 percent of the time.)

Channel separation:	*Ratio of desired to undesired signals*
Same channel	10:1.
200 kc	2:1.
400 kc	1:10.
600 kc	1:100.
800 kc and above	No restriction.[1]

[1] Intermediate frequency amplifiers of most FM broadcast receivers are designed to operate on 10.7 megacycles. For this reason the assignment of two stations in the same area, one with a frequency 10.6 or 10.8 megacycles removed from that of the other, should be avoided if possible.

(c) Stations normally will not be authorized to operate in the same city or in nearby cities with a frequency separation of less than 800 kc: *Provided,* That stations may be authorized to operate in nearby cities with a frequency separation of not less than 400 kc where necessary in order to provide an equitable and efficient distribution of facilities: *And provided further,* That class B stations will not be authorized in the same metropolitan district with a frequency separation of less than 800 kc. In the assignment of FM broadcast facilities the Commission will endeavor to provide the optimum use of the channels in the band, and accordingly may assign a channel different from that requested in an application.

(d) In predicting the extent of interference within the ground wave service area of a station, use should be made of the groundwave chart. (Figure 1 of § 3.333.)

(e) In determining the points at which the interference ratio is equal to the values shown in paragraph (b) of this section, the field intensities for the two interfering signals under consideration should be computed for a considerable number of points along the line between the two stations. Using this data, field intensity versus distance curves should be plotted (e.g., cross-curves on graph paper) in order to determine the points on this path where the interference ratios exist. The points established by this method together with the points along the contours where the same ratios are determined, are considered to be generally sufficient to predict the area of interference. Additional points may be required in the case of irregular terrain or the use of directional antenna systems.

(f) The area of interference, if any, shall be shown in connection with the map

of predicted coverage required by the application form, together with the basic data employed in computing such interference. The map shall show the interference within the 50 uv/m contour.

§ 3.314 **Field intensity measurements in allocation.** (a) When field intensity measurements are required by the Commission's rules or when employed in determining the extent of service or interference of existing stations, such measurements should be made in accordance with the procedure outlined herein.

(b) Measurements made to determine the service and interference areas of FM broadcast stations should be made with mobile equipment along roads which are as close and similar as possible to the radials showing topography which were submitted with the application for construction permit. Suitable measuring equipment and a continuous recording device must be employed, the chart of which is either directly driven from the speedometer of the automobile in which the equipment is mounted or so arranged that distances and identifying landmarks may be readily noted. The measuring equipment must be calibrated against recognized standards of field intensity and so constructed that it will maintain an acceptable accuracy of measurement while in motion or when stationary. The equipment should be so operated that the recorder chart can be calibrated directly in field intensity in order to facilitate analysis of the chart. The receiving antenna shall be primarily responsive to the horizontal electric field and should be nondirectional unless otherwise authorized. Authorization to use a half-wave dipole may be requested by filing application with the Commission prior to the making of measurements. The application may be filed by letter describing the proposed antenna, the method of installation and operation, and calibration procedures. Such authorization will remain in effect throughout the series of measurements for which granted.

(c) Mobile measurements should be made with a minimum chart speed of 3 inches per mile and preferably 5 or 6 inches per mile. Locations shall be noted on the recorder chart as frequently as necessary to definitely fix the relation between the measured field intensity and the location. The time constant of the equipment should be such to permit adequate analysis of the charts, and the time constant employed shall be shown. Measurements should be made to a point on each radial well beyond the particular contour under investigation. The transmitter power shall be maintained as close as possible to the authorized power throughout the survey.

(d) After the measurements are completed, the recorder chart shall be divided into not less than 15 sections on each equivalent radial from the station. The field intensity in each section of the chart shall be analyzed to determine the field intensity received 50 percent of the distance (median field) throughout the section, and this median field intensity associated with the corresponding sector of the radial. The field intensity figures must be corrected for a receiving antenna elevation of 30 feet and for any directional effects of the automobile not otherwise compensated. This data should be plotted for each radial, using log-log coordinate paper with distance as the abscissa and field intensity as the ordinate. A smooth curve should be drawn through these points (of median fields for all sectors), and this curve used to determine the distance to the desired contour. The distances obtained for each radial may then be plotted on the map of predicted coverage or on polar coordinate paper (excluding water areas, etc.) to determine the service and interference areas of a station.

(e) In making measurements to establish the field intensity contours of a station, mobile recordings should be made along each of the radials drawn in § 3.311(e). Measurements should extend from the vicinity of the station out to the 1 mv/m measured contour and somewhat beyond (at the present time it is not considered practical to conduct mobile measurements far beyond this contour due to the fading ratio at weak fields, which complicates analysis of the charts). These measurements would be made for the purpose of determining the variation of the measured contours from those predicted, and it is expected that initially the correlation of the measured 1 mv/m with the predicted 1 mv/m contour will be used as a basis in determining adherence to authorized service areas within the 50 mv/m contour.

(f) In addition to the 1 mv/m contour, the map of measured coverage shall show the 50 uv/m contour as determined by employing Figure 1 of § 3.333 and the dis-

tance to the 1 mv/m contour along each radial. The sliding scale shall be placed on the figure at the appropriate antenna height for the radial in question and then moved so the distance to the 1 mv/m contour (as measured) and the 1 mv/m mark are opposite. The distance to the 50 uv/m contour is then given opposite the 50 uv/m mark on the scale.

(g) In certain cases the Commission may desire more information or recordings and in these instances special instructions will be issued. This may include fixed location measurements to determine tropospheric propagation and fading ratios.

(h) Complete data taken in conjunction with field intensity measurements shall be submitted to the Commission in affidavit form including the following:

(1) Map or maps showing the roads or points where measurements were made, the service and/or interference areas determined by the prediction method and by the measurements, and any unusual terrain characteristics existing in these areas. (This map may preferably be of a type showing topography in the area.)

(2) If a directional transmitting antenna is employed, a diagram on polar coordinate paper showing the predicted free space field intensity in millivolts per meter at one mile in all directions. (See § 3.316.)

(3) A full description of the procedures and methods employed including the type of equipment, the method of installation and operation, and calibration procedures.

(4) A representative sample of the recording tape, including calibration.

(5) Antenna system and power employed during the survey.

(6) Name, address, and qualifications of the engineer or engineers making the measurements.

(i) All data shall be submitted to the Commission in triplicate.

§ 3.315 Transmitter location. (a) The transmitter location should be as near the center of the proposed service area as possible consistent with the applicant's ability to find a site with sufficient elevation to provide service throughout the area. Location of the antenna at a point of high elevation is necessary to reduce to a minimum the shadow effect on propagation due to hills and buildings which may reduce materially the intensity of the station's signals in a particular direction. The transmitting site should be selected consistent with the purpose of the station, i.e., whether it is intended to serve a small city, a metropolitan area, or a large region. Inasmuch as service may be provided by signals of 1 mv/m or greater field intensities in metropolitan areas, and inasmuch as signals as low as 20 uv/m may provide service in rural areas, considerable latitude in the geographical location of the transmitter is permitted; however, the necessity for a high elevation for the antenna may render this problem difficult. In general, the transmitting antenna of a station should be located at the most central point at the highest elevation available. In providing the best degree of service to an area, it is usually preferable to use a high antenna rather than a lower antenna with increased transmitter power. The location should be so chosen that line-of-sight can be obtained from the antenna over the principal city or cities to be served; in no event should there be a major obstruction in this path.

(b) The transmitting location should be selected so that the 1 mv/m contour encompasses the urban population within the area to be served and the 50 uv/m or the interference free contour coincides generally with the limits of the area to be served. It is recognized that topography, shape of the desired service area, and population distribution may make the choice of a transmitter location difficult. In such cases consideration may be given to the use of a directional antenna system, although it is generally preferable to choose a site where a nondirectional antenna may be employed.

(c) In cases of questionable antenna locations it is desirable to conduct propagation tests to indicate the field intensity expected in the principal city or cities to be served and in other areas, particularly where severe shadow problems may be expected. In considering applications proposing the use of such locations, the Commission may require site tests to be made. Such tests should be made in accordance with the measurement procedure previously described, and full data thereon must be supplied to the Commission. Test transmitters should employ an antenna having a height as close as possible to the proposed antenna height, using a balloon or other

support if necessary and feasible. Information concerning the authorization of site tests may be obtained from the Commission upon request.

(d) Present information is not sufficiently complete to establish "blanket areas" of FM broadcast stations, which are defined as those areas adjacent to the transmitters in which the reception of other stations is subject to interference due to the strong signal from the stations. Where it is found necessary to locate the transmitter in a residential area where blanketing problems may appear to be excessive, the application must inculde a showing concerning the availability of other sites. The authorization of station construction in areas where blanketing problems appear to be excessive will be on the basis that the applicant will assume full responsibility for the adjustment of reasonable complaints arising from excessively strong signals of the applicant's station. As a means of minimizing interference problems it is expected that stations adjacent in location will generally be assigned frequencies that are generally adjacent. Insofar as is feasible, frequency assignments for stations at separated locations will also be separated.

(e) Cognizance must of course be taken regarding the possible hazard of the proposed antenna structure to aviation and the proximity of the proposed site to airports and airways. Procedures and standards with respect to the Commission's consideration of proposed antenna structures which will serve as a guide to persons intending to apply for radio station licenses are contained in Part 17 of this chapter (Rules Concerning the Construction, Marking and Lighting of Antenna Structures).

§ 3.316 Antenna systems. (a) It shall be standard to employ horizontal polarization; however, circular or elliptical polarization may be employed if desired. Clockwise or counterclockwise rotation may be used. The supplemental vertically polarized effective radiated power required for circular or elliptical polarization shall in no event exceed the effective radiated power authorized.

(b) The antenna must be constructed so that it is as clear as possible of surrounding buildings or objects that would cause shadow problems.

(c) Applications proposing the use of directional antenna systems must be accompanied by the following:

(1) Complete description of the proposed antenna system.

(2) Orientation of array with respect to true north; time phasing of fields from elements (degrees leading or lagging); space phasing of elements (in feet and in degrees); ratio of fields from elements.

(3) Calculated field intensity pattern (on letter-size polar coordinate paper) giving the free space field intensity in millivolts per meter at one mile in the horizontal plane, together with the formula used, constants employed, sample calculations and tabulation of calculation data.

(4) Name, address, and qualifications of the engineer making the calculations.

(d) Applications proposing the use of FM broadcast antennas in the immediate vicinity (i.e., 200 feet or less) of (1) other FM broadcast antennas, or (2) television broadcast antennas for frequencies adjacent to the FM broadcast band, must include a showing as to the expected effect, if any, of such proximate operation.

(e) In cases where it is proposed to use a tower of a standard broadcast station as a supporting structure for an FM broadcast antenna, an application for construction permit (or modification of construction permit) for such station must be filed for consideration with the FM application. Applications may be required for other classes of stations when their towers are to be used in connection with FM broadcast stations.

(f) When an FM broadcast antenna is mounted on a nondirectional standard broadcast antenna, new resistance measurements must be made of the standard broadcast antenna after installation and testing of the FM broadcast antenna. During the installation and until the new resistance determination is approved, the standard broadcast station licensee should apply for authority (informal application) to operate by the indirect method of power determination. The FM broadcast license application will not be considered until the application form concerning resistance measurements is filed for the standard broadcast station.

(g) When an FM broadcast antenna is mounted on an element of a standard

broadcast directional antenna, a full engineering study concerning the effect of the FM broadcast antenna on the directional pattern must be filed with the application concerning the standard broadcast station. Depending upon the individual case, the Commission may require readjustment and certain field intensity measurements of the standard broadcast station following the completion of the FM broadcast antenna system.

(h) When the proposed FM broadcast antenna is to be mounted on a tower in the vicinity of a standard broadcast directional array and it appears that the operation of the directional antenna system may be affected, an engineering study must be filed with the FM broadcast application concerning the effect of the FM broadcast antenna on the directional pattern. Readjustment and field intensity measurements of the standard broadcast station may be required following construction of the FM broadcast antenna.

(i) Information regarding data required in connection with standard broadcast directional antenna systems may be found in § 3.150 of this chapter. (See also Standard Broadcast Technical Standards.)

(j) In the event a common tower is used by two or more licensees for antenna and/or antenna supporting purposes, the licensee who is owner of the tower shall assume full responsibility for the installation and maintenance of any painting or lighting requirements. In the event of shared ownership, one licensee shall assume such responsibility and advise the Commission accordingly.

(k) It is recommended that an emergency FM broadcast antenna be installed, or, alternately, an auxiliary transmission line or lines if feasible in the particular circumstances. Data thereon should be supplied with the application for construction permit; if proposed after station construction, an informal application should be submitted to the Commission.

(l) When necessary for the protection of air navigation, the antenna and supporting structure shall be painted and illuminated in accordance with the specifications supplied by the Commission pursuant to section 303(q) of the Communications Act of 1934, as amended.

§ 3.317 Transmitters and associated equipment. (a) *Electrical performance standards.* The general design of the FM broadcast transmitting system (from input terminals of microphone preamplifier, through audio facilities at the studio, through lines or other circuits between studio and transmitter, through audio facilities at the transmitter, and through the transmitter, but excluding equalizers for the correction of deficiencies in microphone response) shall be in accordance with the following principles and specifications:

(1) Standard power ratings and operating power range of FM broadcast transmitters shall be in accordance with the following table:

Standard power rating:	*Operating power range*
10 watts [1]	10 watts or less.
250 watts	250 watts or less.
1 kw	250 watts–1 kw.
3 kw	1–3 kw.
5 kw	1–5 kw.
10 kw	3–10 kw.
25 kw	10–25 kw.
50 kw	10–50 kw.
100 kw	50–100 kw.

[1] For noncommercial educational FM stations.

(i) Composite transmitters may be authorized with a power rating different from the above table, provided full data is supplied in the application concerning the basis employed in establishing the rating and the need therefor. The operating range of such transmitters shall be from one-third of the power rating to the power rating.

(ii) The transmitter shall operate satisfactorily in the operating power range with a frequency swing of ±75 kilocycles, which is defined as 100 percent modulation.

(2) The transmitting system shall be capable of transmitting a band of frequencies

from 50 to 15,000 cycles. Preemphasis shall be employed in accordance with the impedance-frequency characteristic of a series inductance-resistance network having a time constant of 75 microseconds. (See Fig. 2 of § 3.333.) The deviation of the system response from the standard preemphasis curve shall lie between two limits as shown in Figure 2 of § 3.333. The upper of these limits shall be uniform (no deviation) from 50 to 15,000 cycles. The lower limit shall be uniform from 100 to 7,500 cycles, and 3 db below the upper limit; from 100 to 50 cycles the lower limit shall fall from the 3 db limit at a uniform rate of 1 db per octave (4 db at 50 cycles); from 7,500 to 15,000 cycles the lower limit shall fall from the 3 db limit at a uniform rate of 2 db per octave (5 db at 15,000 cycles).

(3) At any modulation frequency between 50 and 15,000 cycles and at modulation percentages of 25, 50, and 100 percent, the combined audio frequency harmonics measured in the output of the system shall not exceed the root-mean-square values given in the following table:

Modulating frequency:	*Distortion percent*
50 to 100 cycles	3.5
100 to 7,500 cycles	2.5
7,500 to 15,000 cycles	3.0

(i) Measurements shall be made employing 75 microsecond deemphasis in the measuring equipment and 75 microsecond preemphasis in the transmitting equipment, and without compression if a compression amplifier is employed. Harmonics shall be included to 30 kc.

(ii) It is recommended that none of the three main divisions of the system (transmitter, studio to transmitter circuit, and audio facilities) contribute over one-half of these percentages since at some frequencies the total distortion may become the arithmetic sum of the distortions of the divisions.

(4) The transmitting system output noise level (frequency modulation) in the band of 50 to 15,000 cycles shall be at least 60 decibels below 100 percent modulation (frequency swing of ±75 kilocycles). The measurement shall be made using 400 cycle modulation as a reference. The noise-measuring equipment shall be provided with standard 75 microsecond deemphasis; the ballistic characteristics of the instrument shall be similar to those of the standard VU meter.

(5) The transmitting system output noise level (amplitude modulation) in the band of 50 to 15,000 cycles shall be at least 50 decibels below the level representing 100 percent amplitude modulation. The noise-measuring equipment shall be provided with standard 75 microsecond deemphasis; the ballistic characteristics of the instrument shall be similar to those of the standard VU meter.

(6) Automatic means shall be provided in the transmitter to maintain the assigned center frequency within the allowable tolerance (±2000 cycles).

(7) The transmitter shall be equipped with suitable indicating instruments for the determination of operating power and with other instruments as are necessary for proper adjustment, operation, and maintenance of the equipment (see § 3.320).

(8) Adequate provision shall be made for varying the transmitter output power to compensate for excessive variations in line voltage or for other factors affecting the output power.

(9) Adequate provision shall be provided in all component parts to avoid overheating at the rated maximum output power.

(10) Means should be provided for connection and continuous operation of approved frequency and modulation monitors.

(11) If a limiting or compression amplifier is employed, precaution should be maintained in its connection in the circuit due to the use of preemphasis in the transmitting system.

(12) Any emission appearing on a frequency removed from the carrier by between 120 kc and 240 kc inclusive shall be attenuated at least 25 decibels below the level of the unmodulated carrier. Compliance with this specification will be deemed to show the occupied bandwidth to be 240 kc or less.

(13) Any emission appearing on a frequency removed from the carrier by more

than 240 kc and up to and including 600 kc shall be attenuated at least 35 db below the level of the unmodulated carrier.

(14) Any emission appearing on a frequency removed from the carrier by more than 75 kc shall be attenuated at least 43 + 10 log 10 (power, in watts) decibels below the level of the unmodulated carrier or 80 decibels, whichever is the lesser attenuation.

(b) *Construction.* In general, the transmitter shall be constructed either on racks and panels or in totally enclosed frames protected as required by article 810 of the National Electrical Code and set forth below:

NOTE: The pertinent sections of article 810 of the National Electrical Code read as follows:

"8191. *General.* Transmitters shall comply with the following:

"a. *Enclosing.* The transmitter shall be enclosed in a metal frame or grille, or separated from the operating space by a barrier or other equivalent means, all metallic parts of which are effectually connected to ground.

"b. *Grounding of controls.* All external metallic handles and controls accessible to the operating personnel shall be effectually grounded. No circuit in excess of 150 volts shall have any parts exposed to direct contact. A complete dead-front type of switchboard is preferred.

"c. *Interlocks on doors.* All access doors shall be provided with interlocks which will disconnect all voltages in excess of 350 volts when any access door is opened."

(1) Means shall be provided for making all tuning adjustments, requiring voltages in excess of 350 volts to be applied to the circuit, from the front of the panels with all access doors closed.

(2) Proper bleeder resistors or other automatic means shall be installed across all capacitor banks to lower any voltage which may remain accessible with access door open to less than 350 volts within 2 seconds after the access door is opened.

(3) All plate supply and other high voltage equipment, including transformers, filters, rectifiers and motor generators, shall be protected so as to prevent injury to operating personnel.

(i) Commutator guards shall be provided on all high voltage rotating machinery. Coupling guards should be provided on motor generators.

(ii) Power equipment and control panels of the transmitter shall meet the above requirements (exposed 220 volt AC switching equipment on the front of the power control panels is not recommended but is not prohibited).

(iii) Power equipment located at a broadcast station but not directly associated with the transmitter (not purchased as part of same), such as power distribution panels, are not under the jurisdiction of the Commission; therefore § 3.254 does not apply.

(4) Metering equipment:

(i) All instruments having more than 1,000 volts potential to ground on the movement shall be protected by a cage or cover in addition to the regular case. (Some instruments are designed by the manufacturer to operate safely with voltages in excess of 1,000 volts on the movement. If it can be shown by the manufacturer's rating that the instrument will operate safely at the applied potential, additional protection is not necessary.)

(ii) In case the plate voltmeter is located on the low potential side of the multiplier resistor with the potential of the high potential terminal of the instrument at or less thau 1,000 volts above ground, no protective case is required. However, it is good practice to protect voltmeters subject to more than 5,000 volts with suitable over-voltage protective devices across the instrument terminals in case the winding opens.

(iii) Transmission line meters and any other radio frequency instrument which may be necessary for the operator to read shall be so installed as to be easily and accurately read without the operator having to risk contact with circuits carrying high potential radio frequency energy.

(5) It is recommended that component parts comply as much as possible with the component specifications designated by the Army-Navy Electronics Standards Agency.

(c) *Wiring and shielding.* (1) The transmitter panels or units shall be wired in

accordance with standard switchboard practice, either with insulated leads properly cabled and supported or with rigid bus bar properly insulated and protected.

(2) Wiring between units of the transmitter, with the exception of circuits carrying radio frequency energy, shall be installed in conduits or approved fiber or metal raceways for protection from mechanical injury.

(3) Circuits carrying radio frequency energy between units shall be coaxial, two wire balanced lines, or properly shielded.

(4) All stages or units shall be adequately shielded and filtered to prevent interaction and radiation.

(5) The frequency and modulation monitors and associated radio frequency lines to the transmitter shall be thoroughly shielded.

(d) *Installation.* (1) The installation shall be made in suitable quarters.

(2) Since an operator must be on duty at the transmitter control point during operation, suitable facilities for his welfare and comfort shall be provided at the control point.

(e) An accurate circuit diagram and list of required spare tubes, as furnished by the manufacturer of the equipment, shall be retained at the transmitter location.

(f) *Operation.* In addition to specific requirements of the rules governing FM broadcast stations, the following operating requirements are specified:

(1) The maximum percentage of modulation shall be maintained in accordance with § 3.268. However, precautions shall be taken so as not to substantially alter the dynamic characteristics of musical programs.

(2) The station equipment shall be so operated, tuned, and adjusted that emissions outside of the authorized channel do not cause harmful interference to the reception of other radio stations. FM broadcast stations employing transmitters type accepted after January 1, 1960, shall maintain the bandwidth occupied by their emissions in accordance with the specifications set forth in paragraph (a) of this section. Stations employing transmitters installed or type accepted prior to January 1, 1960, shall achieve the highest degree of compliance practicable with their existing equipment. In either case, should harmful interference to the reception of other radio stations occur, the licensee may be required to take such further steps as may be necessary to eliminate the interference.

(3) If a limiting or compression amplifier is employed, care should be maintained in its use due to preemphasis in the transmitting system.

(g) *Studio equipment.* (1) Studio equipment shall be subject to all the above requirements where applicable except as follows:

(i) If properly covered by an underwriter's certificate, it will be considered as satisfying safety requirements.

(ii) Section 8191 of article 810 of the National Electrical Code shall apply for voltages only in excess of 500 volts.

(2) No specific requirements are made with regard to the microphones to be employed. However, microphone performance (including compensating networks, if employed) shall be compatible with the required performance of the transmitting system.

(3) No specific requirements are made relative to the design and acoustical treatment of studios. However, the design of studios, particularly the main studio, shall be compatible with the required performance characteristics of FM broadcast stations.

§ 3.318 Facsimile: engineering standards. The following standards apply to facsimile broadcasting under § 3.266:

(a) Rectilinear scanning shall be employed, with scanning spot progressing from left to right and scanned lines progressing from top to bottom of subject copy.

(b) The standard index of cooperation shall be 984.

(c) The number of scanning lines per minute shall be 360.

(d) The line-use ratio shall be ⅞, or 315° of the full scanning cycle.

(e) The ⅛ cycle or 45° not included in the available scanning line shall be divided into 3 equal parts, the first 15° being used for transmission at approximately white level, the second 15° for transmission at approximately black level, and the third 15° for transmission at approximately white level.

(f) An interval of not more than 12 seconds shall be available between two pages of subject copy, for the transmission of a page-separation signal and/or other services.

(g) Amplitude or frequency (frequency-shift) modulation of the sub-carrier shall be used.

(h) Subcarrier modulation shall normally vary approximately linearly with the optical density of the subject copy.

(i) Negative modulation shall be used, i.e., for amplitude modulation of subcarrier, maximum subcarrier amplitude and maximum radio frequency swing on black; for frequency modulation of subcarrier, highest instantaneous frequency of subcarrier on black.

(j) Subcarrier noise level shall be maintained at least 30 db. below maximum (black) picture modulation level, at the radio transmitter input.

(k) The facsimile subcarrier transmission shall be conducted in the frequency range between 22 and 28 kilocycles. Should amplitude modulation of the subcarrier be employed the subcarrier frequency shall be 25 kilocycles with sidebands extending not more than 3 kilocycles in either direction from the subcarrier frequency. Should frequency modulation of the subcarrier be employed the total swing of the subcarrier shall be within the range from 22 to 28 kilocycles, with 22 kilocycles corresponding to white and 28 kilocycles corresponding to black on the transmitted copy. In multiplex operation the modulation of the FM carrier by the modulated subcarrier shall not exceed 5 percent. In simplex operation the modulation of the FM carrier by the modulated subcarrier shall not exceed 30 percent.

(l) During periods of multiplex facsimile transmission, frequency modulation of the FM carrier caused by the aural signals shall, in the frequency range from 20 to 30 kilocycles, be at least 60 db. below 100 percent modulation. Frequency modulation of the FM carrier caused by the facsimile signals shall, in the frequency range from 50 to 15,000 cycles, be at least 60 db. below 100 percent modulation.

§ 3.319 **Subsidiary communications multiplex operations: engineering standards.** The following standards apply to subsidiary communications multiplex operations under §§ 3.293 to 3.295.

(a) Frequency modulation of subcarrier shall be used.

(b) The instantaneous frequency of the subcarriers shall at all times lie within the range 20 to 75 kilocycles.

(c) The arithmetic sum of the modulation of the main carrier by the subcarriers shall not exceed 30 percent.

NOTE: Inasmuch as presently approved FM modulation monitors have been designed to meet requirements for modulation frequencies of from 50 to 15,000 cycles, the use of such monitors for reading the modulation percentages during multiplex operation may not be appropriate since the subcarriers utilized are above 20,000 cycles.

(d) The total modulation of the main carrier, including the subcarriers, shall meet the requirements of § 3.268.

(e) Frequency modulation of the main carrier caused by the subcarrier operation shall, in the frequency range 50 to 15,000 cycles, be at least 60 db. below 100 percent modulation.

§ 3.320 **Indicating instruments—specifications.** The following requirements and specifications shall apply to indicating instruments used by FM broadcast stations:

(a) Instruments indicating the plate current or plate voltage of the last radio stage (linear scale instruments) shall meet the following specifications:

(1) Length of scale shall be not less than $2\frac{3}{10}$ inches.

(2) Accuracy shall be at least 2 percent of the full scale reading.

(3) Scale shall have at least 40 divisions.

(4) Full scale reading shall not be greater than five times the minimum normal indication.

(b) Instruments indicating transmission line current or voltage shall meet the following specifications:

(1) Instruments having linear scales shall meet the requirements of paragraph (a)(1), (2), (3), and (4) of this section.

(2) Instruments having logarithmic or square law scales:

(i) Shall meet the requirements of paragraph (a)(1) and (2) of this section for linear scale instruments.

(ii) Full scale reading shall not be greater than three times the minimum normal indication.

(iii) No scale division above one-third full scale reading shall be greater than one-thirtieth of the full scale reading.

(c) Radio frequency instruments having expanded scales:

(1) Shall meet the requirements of paragraph (a)(1), (2), and (4) of this section for linear scale instruments.

(2) No scale division above one-fifth full scale reading shall be greater than one-fiftieth of the full scale reading.

(3) The meter face shall be marked with the words "Expanded scale" or the abbreviation thereof (E. S.).

(d) No required instrument, the accuracy of which is questionable, shall be employed. Repairs and recalibration of instruments shall be made by the manufacturer, or by an authorized instrument repair service of the manufacturer, or by some other properly qualified and equipped instrument repair service. In any event the repaired instrument must be supplied with a certificate of calibration.

(e) Recording instruments may be employed in addition to the indicating instruments to record the transmission line current or voltage and the direct plate current and/or direct plate voltage of the last radio stage, provided that they do not affect the operation of the circuits or accuracy of the indicating instruments. If the records are to be used in any proceeding before the Commission as representative of operation, the accuracy must be the equivalent of the indicating instruments and the calibration shall be checked at such intervals as to insure the retention of the accuracy.

(f) The function of each instrument used in the equipment shall be clearly and permanently shown on the instrument itself or on the panel immediately adjacent thereto.

§ 3.321 Auxiliary transmitters. Auxiliary transmitters may not exceed the power rating or operating power range of the main transmitter, but need not conform to the performance characteristics specified by § 3.317(a)(2) to (a)(5) inclusive. The subsequent portions of § 3.317 apply to auxiliary transmitters.

§ 3.330 Frequency and modulation monitors at auxiliary transmitters. (a) The following shall govern the installation of approved frequency and modulation monitors at auxiliary transmitters of FM broadcast stations in compliance with these rules:

(1) In case the auxiliary transmitter location is at a site different from that of the main transmitter, an approved frequency monitor shall be installed at the auxiliary transmitter except when the frequency of the auxiliary transmitter can be monitored by means of the frequency monitor at the main transmitter. When the auxiliary transmitter is operated without a frequency monitor under this exemption, it shall be monitored by means of the frequency monitor at the main transmitter.

(2) The licensee will be held strictly responsible for any center frequency deviation of the auxiliary transmitter in excess of 2,000 cycles from the assigned frequency, even though exempted by the above from installing an approved frequency monitor.

(3) Installation of an approved modulation monitor at the location of the auxiliary transmitter, when different from that of the main transmitter, is optional with the licensee. However, when it is necessary to operate the auxiliary transmitter beyond two calendar days, a modulation monitor shall be installed and operated at the auxiliary transmitter. The monitor (if taken from the main transmitter) shall be reinstalled at the main transmitter immediately upon resumption of operation of the main transmitter.

(4) In all cases where the auxiliary transmitter and the main transmitter have the same location, the same frequency and modulation monitors may be used for monitoring both transmitters, provided they are so arranged as to be readily switched from one transmitter to the other.

§ 3.331 Requirements for type approval of frequency monitors. (a) *General requirements.* (1) Any manufacturer desiring to submit a monitor for type approval

shall supply the Commission with full specification details (two sworn copies) as well as the test data specified in paragraph (c) of this section. If this information appears to meet the requirements of the rules, shipping instructions will be issued to the manufacturer. The shipping charges to and from the Laboratory at Laurel, Maryland, shall be paid for by the manufacturer. Approval of a monitor will only be given on the basis of the data obtained from the sample monitor submitted to the Commission for test.

(2) In approving a monitor upon the basis of the tests conducted by the Laboratory, the Commission merely recognizes that the type of monitor has the inherent capability of functioning in compliance with the rules, if properly constructed, maintained, and operated. The Commission realizes that the frequency monitor may have limited range over which the visual indicator will determine deviations. Accordingly, it may be necessary that adjunct equipment be used to determine major deviations.

(3) Additional rules with respect to withdrawal of type approval, modification of type approval equipment and limitations of the findings upon which type approval is based are set forth in Part 2, Subpart F, of this chapter.

(b) *General specifications.* The general specifications that frequency monitors shall meet before they will be approved by the Commission are as follows:

(1) The unit shall have an accuracy of at least ±1000 cycles under ordinary conditions (temperature, humidity, power supply variations and other conditions which may affect its accuracy) encountered in FM broadcast stations throughout the United States, for any channel within the FM broadcast band.

(2) The range of the indicating device shall be at least from 2000 cycles below to 2000 cycles above the assigned center frequency.

(3) The scale of the indicating device shall be so calibrated as to be accurately read within at least 100 cycles.

(4) Means shall be provided for adjustment of the monitor indication to agree with an external standard.

(5) The monitor shall be capable of continuous operation and its circuit shall be such as to permit continuous monitoring of the transmitter center frequency.

(6) Operation of the monitor shall have no deleterious effect on the operation of the transmitter or the signal emitted therefrom.

(c) *Tests to be made for approval of FM broadcast frequency monitors.* The manufacturer of a monitor shall submit data on the following at the time of requesting approval:

(1) Constancy of oscillator frequency as measured several times in 1 month.

(2) Constancy of oscillator frequency when subjected to vibration tests which would correspond to the treatment received in shipping, handling and installing the instrument.

(3) Accuracy of readings of the frequency deviation instrument.

(4) Functioning of frequency adjnstment device.

(5) Effects on frequency and readings, of the changing of tubes, of voltage variations, and of variations of room temperature through a range not to exceed 10° to 40° C.

(6) Response of indicating instrument to small changes of frequency.

(7) General information on the effect of tilting or tipping or other tests to determine ability of equipment to withstand shipment.

(d) Various other tests may be made or required, such as effects of variation of input from the transmitter depending upon the character of the apparatus.

(e) Tests shall be conducted in such a manner as to approximate actual operating conditions as nearly as possible. The equipment under test shall be operated on any channel in the FM broadcast band.

§ 3.332 **Requirements for type approval of modulation monitors.** (a) Any manufacturer desiring to submit a monitor for type approval shall supply the Commission with full specification details (two sworn copies) specified in paragraph (b) of this section. If this information appears to meet the requirements of the rules, shipping instructions will be issued to the manufacturer. The shipping charges to and from the Laboratory at Laurel, Maryland, shall be paid for by the manufacturer. Approval

of a monitor will only be given on the basis of the data obtained from the sample monitor submitted to the Commission for test.

(1) In approving a monitor upon the basis of the tests conducted by the Laboratory, the Commission merely recognizes that the type of monitor has the inherent capability of functioning in compliance with the rules, if properly constructed, maintained and operated.

(2) Additional rules with respect to withdrawal of type approval, modification of type approval equipment and limitations on the findings upon which type approval is based are set forth in Part 2, Subpart F, of this chapter.

(b) The specifications that the modulation monitor shall meet before it will be approved by the Commission are as follows:

(1) A means for insuring that the transmitter input to the modulation monitor is proper.

(2) A modulation peak indicating device that can be set at any predetermined value from 50 to 120 percent modulation (±75 kc swing is defined as 100 percent modulation) and for either positive or negative swings (i.e., either above or below transmitter center frequency).

(3) A semi-peak indicator with a meter having the characteristics given below shall be used with a circuit such that peaks of modulation of duration between 40 and 90 milliseconds are indicated to 90 percent of full value and the discharge rate adjusted so that the pointer returns from full reading to 10 percent of zero within 500 to 800 milliseconds. A switch shall be provided so that this meter will read either positive or negative swings.

(i) The characteristics of the indicating meter are: (*a*) *Speed.* The time for one complete oscillation of the pointer shall be 290 to 350 milliseconds. The damping factor shall be between 16 and 200. (*b*) *Scale.* The meter scale shall be similar in appearance to that of a standard VU meter. The scale length between 0 and 100 percent modulation markings should be at least 2.3 inches. In addition to other markings a small mark for 133 percent modulation and designated as such should be included for the purpose of testing transmitters with 100 kc swing.

(4) The accuracy of reading of percentage of modulation shall be within ±5 percent modulation percentage at any percentage of modulation up to 100 percent modulation.

(5) The frequency characteristic curve shall not depart from a straight line more than ±½ db. from 50 to 15,000 cycles. Distortion shall be kept to a minimum.

(6) The monitor shall not absorb appreciable power from the transmitter.

(7) Operation of the monitor shall have no deleterious effect on the operation of the transmitter.

(8) General design, construction, and operation shall be in accordance with good engineering practice.

(c) The modulation monitor may be a part of the frequency monitor.

§ 3.333 **Engineering charts.** [See Figures 1 and 2.]

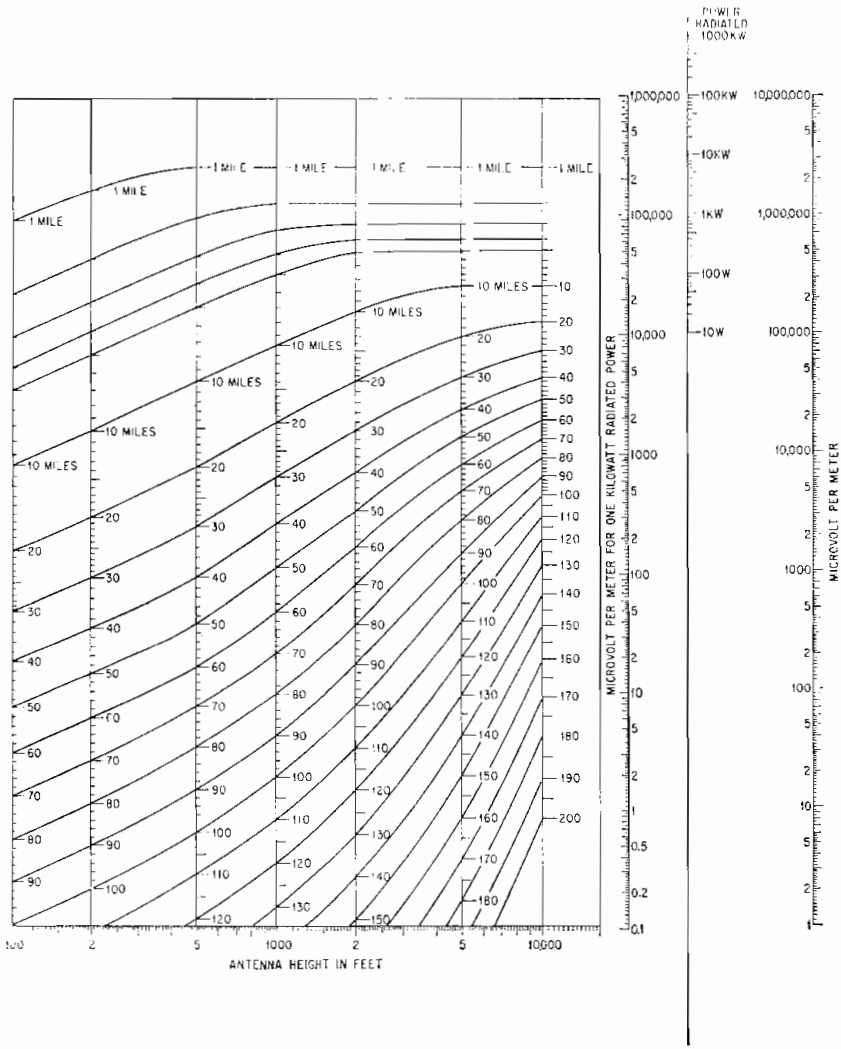


FIGURE 1. Groundwave signal range for FM broadcasting. 98 mc, $\sigma = 5 \times 10^{-14}$ emu, $\epsilon = 15$, receiving antenna height 30 feet for horizontal (and approx. for vertical) polarization.

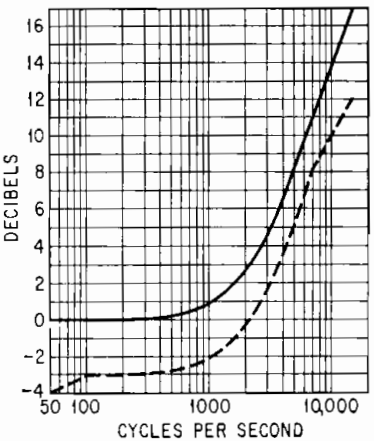


FIGURE. 2. Standard pre-emphasis curve. Time constant 75 microseconds (solid line). Frequency response limits shown by use of solid and dashed lines.

SUBPART C—NONCOMMERCIAL EDUCATIONAL FM BROADCAST STATIONS

Classification of Stations and Allocation of Frequencies

§ 3.501 Channels available for assignment. (a) The following frequencies, except as provided in paragraph (b) of this section, are available for noncommercial educational FM broadcasting:

(b) In Alaska, the frequency band 88–100 Mc is allocated exclusively to Government radio services and the non-Government fixed service. The frequencies 88.1 Mc through 91.9 Mc (Channels 201 through 220, inclusive) will not be assigned in Alaska for use by noncommercial educational FM broadcast stations; however, frequencies in the 100.1–107.9 Mc (Channels 261 through 300, inclusive) are available for such use.

Frequency (Mc):	*Channel No.*	Frequency (Mc):	*Channel No.*	Frequency (Mc):	*Channel No.*
88.1	201	89.5	208	90.9	215
88.3	202	89.7	209	91.1	216
88.5	203	89.9	210	91.3	217
88.7	204	90.1	211	91.5	218
88.9	205	90.3	212	91.7	219
89.1 [1]	206	90.5	213	91.9	220
89.3	207	90.7	214		

[1] The frequency 89.1 Mc in the New York City metropolitan area is reserved for the use of the United Nations with the equivalent of an antenna height of 500 feet above average terrain and effective radiated power of 20 kw, and the Commission will make no assignments which would cause objectionable interference with such use.

§ 3.502 State-wide plans. In considering the assignment of a channel for a noncommercial educational FM broadcast station, the Commission will take into consideration the extent to which each application meets the requirements of any state-wide plan for noncommercial educational FM broadcast stations filed with the Commission, provided that such plans afford fair treatment to public and private educational institutions, urban and rural, at the primary, secondary, higher, and adult educational levels, and appear otherwise fair and equitable.

§ 3.503 Licensing requirements and service. The operation of, and the service furnished by, noncommercial educational FM broadcast stations shall be governed by the following:

(a) A noncommercial educational FM broadcast tsation will be licensed only to a nonprofit educational organization and upon showing that the station will be used for the advancement of an educational program.

(1) In determining the eligibility of publicly supported educational organizations, the accreditation of their respective state departments of education shall be taken into consideration.

(2) In determining the eligibility of privately controlled educational organizations, the accreditation of state departments of education and/or recognized regional and national educational accrediting organizations shall be taken into consideration.

(b) Each station may transmit programs directed to specific schools in a system or systems for use in connection with the regular courses as well as routine and administrative material pertaining thereto and may transmit educational, cultural, and entertainment programs to the public.

(c) Each station shall furnish a nonprofit and noncommercial broadcast service. No sponsored or commercial program shall be transmitted nor shall commercial announcements of any character be made. A station shall not transmit the programs of other classes of broadcast stations unless all commercial announcements and commercial references in the continuity are eliminated.

§ 3.504 Frequency, power and service area. (a) In the assignment of frequency and power to a noncommercial educational FM broadcast station the Commission will consider with the application: (1) the area served by applicant's existing educational facilities; and (2) the provisions of any statewide plan on file with the Commission which meets the requirements of § 3.502. A station licensed for transmitter power output of 10 watts or less normally will be licensed to operate on the frequency 88.1 megacycles; however, should it appear that operation on this frequency would cause objectionable interference, such station may be licensed to operate on the next higher frequency that would not cause objectionable interference.

(b) The license of each noncommercial educational FM broadcast station licensed for transmitter power output of 10 watts or less shall specify the maximum authorized operating power output of the transmitter. The license of each noncommercial educational FM broadcast station licensed for transmitter power output above 10 watts shall specify the authorized effective radiated power of the station and the authorized operating power output of the transmitter.

(c) Each application for a new noncommercial educational FM broadcast station or increase in facilities of an existing station which proposes transmitter power output above 10 watts shall contain a determination of the antenna height above average terrain and the extent of the 1 mv/m and 50 uv/m contours of the proposed station by the methods prescribed in the FM Technical Standards in Subpart B of this part.

§ 3.505 Standards of good engineering practice. The definitions and interference standards contained in the FM Technical Standards in Subpart B of this part shall be applicable to noncommercial educational FM broadcast stations. Other portions of such Standards shall be applicable to the extent specifically prescribed by this part.

Administrative Procedure

§ 3.514 Cross reference. See §§ 1.300 to 1.364, Subpart D of Part 1 of this chapter, for general requirements as to applications, filing of applications and description of application forms, other forms and information to be filed with the Commission, the manner in which applications are processed, and provisions applying to action on applications.

§ 3.515 In order to minimize possible harmful interference at the National Radio Astronomy Observatory site located at Green Bank, Pocahontas County, West Virginia, and at the Naval Radio Research Observatory site at Sugar Grove, Pendleton County, West Virginia, an applicant for authority to construct a new noncommercial educational FM broadcast station or for authority to make changes in the frequency, power, antenna height, or antenna directivity of an existing station within the area bounded by 39°15′ N on the north, 78°30′ W on the east, 37°30′ N on the south and 80°30′ W on the west shall, at the time of filing such application with the Commis-

sion, simultaneously notify the Director, National Radio Astronomy Observatory, P.O. Box #2, Green Bank, West Virginia, in writing, of the technical particulars of the proposed station. Such notification shall include the geographical coordinates of the antenna, antenna height, antenna directivity if any, proposed frequency, type of emission, and power. In addition, the applicant shall indicate in his application to the Commission the date notification was made to the Observatory. After receipt of such applications, the Commission will allow a period of twenty (20) days for comments or objections in response to the notifications indicated. If an objection to the proposed operation is received during the twenty day period from the National Radio Astronomy Observatory for itself or on behalf of the Naval Radio Research Observatory, the Commission will consider all aspects of the problem and take whatever action is deemed appropriate.

§ 3.516 **Equipment tests.** (a) During the process of construction of a noncommercial educational FM broadcast station, the permittee, after notifying the Commission and Engineer in Charge of the radio district in which the station is located, may without further authority of the Commission, conduct equipment tests for the purpose of such adjustments and measurements as may be necessary to assure compliance with the terms of the construction permit, the technical provisions of the application therefor, the rules and regulations, and the applicable engineering standards.

(b) The Commission may notify the permittee to conduct no tests or may cancel, suspend, or change the date for the beginning of equipment tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Equipment tests may be continued so long as the construction permit shall remain valid.

(d) Inspection of a station will ordinarily be required during the equipment test period and before the commencement of the program test. After construction and after adjustments and measurements have been completed to show compliance with the terms of the construction permit, the technical provisions of the application therefor, the rules and regulations and the applicable engineering standards, the permittee should notify the Engineer in Charge of the radio district in which the station is located that it is ready for inspection.

(e) The authorization for tests embodied in this section shall not be construed as constituting a license to operate but as a necessary part of construction.

§ 3.517 **Program tests.** (a) Upon completion of construction of a noncommercial educational FM broadcast station in accordance with the terms of the construction permit, the technical provisions of the application therefor, and the rules and regulations and applicable engineering standards, and when an application for station license has been filed showing the station to be in satisfactory operating condition, the permittee may request authority to conduct program tests: *Provided*, That such request shall be filed with the Commission at least ten (10) days prior to the date on which it is desired to begin such operation and that the Engineer in Charge of the radio district in which the station is located is notified. (All data necessary to show compliance with the terms and conditions of the construction permit must be filed with the license application.)

(b) Program tests shall not commence until specific Commission authority is received. The Commission reserves the right to change the date of the beginning of such tests, or to suspend or revoke the authority for program tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Unless sooner suspended or revoked program test authority continues valid during Commission consideration of the application for license and during this period further extension of the construction permit is not required. Program test authority shall be automatically terminated by final determination upon the application for station license.

(d) All operation under program test authority shall be in strict compliance with the rules governing noncommercial educational FM broadcast stations and in strict accordance with representations made in the application for license pursuant to which the tests were authorized.

(e) The grant of program test authority shall not be construed as approval by the Commission of the application for station license.

§ 3.518 **Normal license period.** (a) All noncommercial educational FM broadcast station licenses will be issued for a normal license period of three years. Licenses will be issued to expire at the hour of 3:00 a.m., e.s.t., in accordance with the following schedule and at three-year intervals thereafter.

(1) For stations located in Delaware and Pennsylvania, August 1, 1957.

(2) For stations located in Maryland, District of Columbia, Virginia, West Virginia, October 1, 1957.

(3) For stations located in North Carolina, South Carolina, December 1, 1957.

(4) For stations located in Florida, Puerto Rico, and Virgin Islands, February 1, 1958.

(5) For stations located in Alabama and Georgia, April 1, 1958.

(6) For stations located in Arkansas, Louisiana, and Mississippi, June 1, 1958.

(7) For stations located in Tennessee, Kentucky, and Indiana, August 1, 1958.

(8) For stations located in Ohio and Michigan, October 1, 1958.

(9) For stations located in Illinois and Wisconsin, December 1, 1958.

(10) For stations located in Iowa and Missouri, February 1, 1956.

(11) For stations located in Minnesota, North Dakota, South Dakota, Montana, and Colorado, April 1, 1956.

(12) For stations located in Kansas, Oklahoma, Nebraska, June 1, 1956.

(13) For stations located in Texas, August 1, 1956.

(14) For stations located in Wyoming, Nevada, Arizona, Utah, New Mexico, and Idaho, October 1, 1956.

(15) For stations located in California, December 1, 1956.

(16) For stations located in Washington, Oregon, Alaska, and Hawaii, February 1, 1957.

(17) For stations located in Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont, April 1, 1957.

(18) For stations located in New Jersey and New York, June 1, 1957.

Equipment

§ 3.550 **Acceptability of broadcast transmitters for licensing.** (a) In order to facilitate the filing of, and action on, applications for station authorizations, transmitters will be accepted for licensing by the Commission under one of the following conditions:

(1) A transmitter may be type-accepted upon the request of any manufacturer of transmitters built in quantity by following the type acceptance procedure set forth in Part 2 of this chapter, provided that the data and information submitted indicates that the transmitter meets the requirements of § 3.317. If accepted, such transmitter will be included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment." Applicants specifying transmitters included on such a list need not submit detailed descriptions and diagrams where the correct type number is specified, provided that the equipment proposed is identical with that accepted. Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(2) An application specifying a transmitter not included on the Radio Equipment List, Part B, may be accepted upon the request of a prospective licensee submitting with the application for construction permit a complete description of the transmitter, including the circuit diagram, listing of all tubes used, function of each, multiplication in each stage, plate current and voltage applied to each tube, a description of the oscillator circuit together with any devices installed for the purpose of frequency stabilization and the means of varying output power to compensate for power supply voltage variations. However, if this data has been filed with the Commission by a manufacturer in connection with a request for type acceptance, it need not be submitted with the application for construction permit but may be referred to as "on file." Measurement data for type acceptance made in accordance with subparagraph (1) of this paragraph shall be submitted with the license application.

(3) A transmitter shown on an instrument of authorization by manufacturer and

type number, or as a composite, and which was in use prior to June 30, 1955, may continue to be used by the licensee, his successors or assignees, provided such transmitter continues to comply with the rules and regulations.

(b) Additional rules with respect to withdrawal of type acceptance, modification of type-accepted equipment and limitations on the findings upon which type acceptance is based are set forth in Part 2 of this chapter.

§ 3.551 **Transmitter power.** (a) The standard power rating of the transmitter of a noncommercial educational FM broadcast station licensed for transmitter power output above 10 watts shall be in accordance with § 3.317.

(b) The standard power rating of the transmitter of a noncommercial educational FM broadcast station licensed for transmitter power output of 10 watts or less shall be not less than the authorized operating power and not more than 10 watts.

§ 3.552 **Frequency monitor.** (a) The licensee of each station licensed for transmitter power output above 10 watts shall have in operation, either at the transmitter or at the place where the transmitter is controlled, a frequency monitor of a type approved by the Commission which shall be independent of the frequency control of the transmitter.

NOTE: Approved frequency monitors are included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment." Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(b) In the event that the frequency monitor becomes defective the station may be operated without the monitor pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided*, That:

(1) Appropriate entries shall be made in the operating log of the station showing the date and time the monitor was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the monitor is found to be defective and immediately after the repaired or replacement instrument has been installed and is functioning properly.

(3) The frequency of the station shall be compared with an external frequency source of known accuracy at sufficiently frequent intervals to insure that the frequency is maintained within the tolerance prescribed in § 3.568. An entry shall be made in the station log as to the method used and the results thereof.

(c) If conditions beyond the control of the licensee prevent the restoration of the monitor to service within the above-allowed period, informal request may be filed in accordance with § 1.332(d) of this chapter with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

(d) The licensee of each noncommercial educational FM broadcast station licensed for transmitter power output of 10 watts or less shall provide for the measurement of the station frequency by a means independent of the frequency control of the transmitter. The station frequency shall be measured (1) when the transmitter is initially installed, (2) at any time the frequency determining elements are changed, and (3) at any time the licensee may have reason to believe the frequency has shifted beyond the tolerance specified by the Commission's rules.

§ 3.553 **Modulation monitor.** (a) The licensee of each station licensed for transmitter power output above 10 watts shall have in operation, either at the transmitter or at the place where the transmitter is controlled, a modulation monitor of a type approved by the Commission.

NOTE: Approved modulation monitors are included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment." Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(b) In the event that the modulation monitor becomes defective the station may be operated without the monitor pending its repair or replacement for a period not in excess of 60 days: *Provided*, That:

(1) Appropriate entries shall be made in the operating log of the station showing the date and time the monitor was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the monitor is found to be defective and immediately after the repaired or replacement monitor has been installed and is functioning properly.

(3) During the period when the station is operated without the modulation monitor the licensee shall provide other suitable means for insuring that the modulation is maintained within the tolerance prescribed in § 3.568.

(c) If conditions beyond the control of the licensee prevent the restoration of the monitor to service within the above allowed period, informal request may be filed in accordance with § 1.332(d) of this chapter with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

(d) The licensee of each noncommercial educational FM broadcast station licensed for transmitter power output of 10 watts or less shall provide a percentage modulation indicator or a calibrated program level meter from which a satisfactory indication of the percentage of modulation of the transmitter can be determined.

§ 3.554 Transmitter performance. (a) The transmitter proper and associated transmitting equipment of each noncommercial educational FM broadcast station licensed for transmitter power output above 10 watts shall be designed, constructed and operated in accordance with § 3.317.

(b) The transmitter proper and associated transmitting equipment of each noncommercial educational FM broadcast station licensed for transmitter power output of 10 watts or less, although not required to meet all requirements of § 3.317 shall be constructed with safety features in accordance with the specifications of article 810 of the current National Electrical Code as approved by the American Standards Association and shall be so operated, tuned, and adjusted that emissions are not radiated outside the authorized band which cause or which are capable of causing interference to the communications of other stations. The audio distortion, audio frequency range, carrier hum, noise level, and other essential phases of the operation which control the external effects, shall at all times be capable of providing satisfactory broadcast service. Studio equipment properly covered by an underwriter's certificate will be considered as satisfying safety requirements.

§ 3.555 Auxiliary transmitter. Upon showing that a need exists for the use of an auxiliary transmitter in addition to the regular transmitter of a broadcast station, a license therefor may be issued: *Provided*, That:

(a) An auxiliary transmitter may be installed either at the same location as the main transmitter or at another location.

(b) A licensed operator shall be in control whenever an auxiliary transmitter is placed in operation.

(c) The auxiliary transmitter shall be maintained so that it may be placed into immediate operation at any time for the following purposes:

(1) The transmission of the regular programs upon the failure of the main transmitter.

(2) The transmission of regular programs during maintenance or modification work on the main transmitter, necessitating discontinuance of its operation for a period not to exceed 5 days. (This includes the equipment changes which may be made without authority as set forth elsewhere in the rules and regulations or as authorized by the Commission by letter or by construction permit. Where such operation is required for periods in excess of 5 days, request therefor shall be in accordance with § 1.331 of this chapter.)

(3) Upon request by a duly authorized representative of the Commission.

(d) The auxiliary transmitter shall be tested at least once each week to determine that it is in proper operating condition and that it is adjusted to the proper frequency, except that in case of operation in accordance with paragraph (c) of this section during any week, the test in that week may be omitted provided the operation under

paragraph (c) is satisfactory. A record shall be kept of the time and result of each test. Such records shall be retained for a period of two years.

(e) The auxiliary transmitter shall be equipped with satisfactory control equipment which will enable the maintenance of the frequency emitted by the station within the limits prescribed by the regulations in this part.

(f) The operating power of an auxiliary transmitter may be less than the authorized power of the main transmitter, but in no event shall it be greater than such power.

§ 3.556 Alternate main transmitters. The licensee of a noncommercial educational FM broadcast station may be licensed for alternate main transmitters provided that a technical need for such alternate transmitters is shown (such as licensees maintaining 24-hour schednle and needing alternate operation for maintenance, or where developmental work requires alternate operation) and that the following conditions are met:

(a) Both transmitters are located at the same place.

(b) Both transmitters shall have the same power rating.

(c) Both transmitters shall meet the requirements of § 3.554.

§ 3.557 Changes in equipment and antenna system. Licenses of noncommercial educational FM broadcast stations shall observe the following provisions with regard to chauges in equipment and antenna system:

(a) No changes in equipment shall be made:

(1) That would result in the emission of signals outside of the authorized channel.

(2) That would result in the external performance of the transmitter being in disagreement with § 3.554.

(b) Specific authority, upon filing formal application (FCC Form 340) therefor, is required for a change in service area or for any of the following changes:

(1) Changes involving an increase or decrease in the power rating of the transmitter.

(2) A replacement of the transmitter as a whole.

(3) Change in the location of the transmitting antenna.

(4) Change in antenna system, including transmission line.

(5) Change in location of main studio, if it is proposed to move the main studio to a different city from that specified in the license.

(6) Chauge in the power delivered to the antenna.

(7) Change in frequency control and/or modulation system.

(8) Change in the authorized transmitter remote control point(s).

(c) Other changes, except as above provided for in this section, may be made at any time without the authority of the Commission, provided that the Commission shall be promptly notified thereof and such changes shall be shown in the next application for renewal of license.

§ 3.558 Indicating instruments. (a) Each noncommercial FM broadcast station licensed for transmitter power above 10 watts shall be equipped with indicating instruments, which conform with the specifications set forth in § 3.320 for measuring the direct plate voltage and current of the last radio stage and the transmission line radio frequency current, voltage, or power.

(b) In the event that any one of these indicating instruments becomes defective when no substitnte which conforms with the required specifications is available, the station may be operated without the defective instrument pending its repair or replacement for a period not in excess of 60 days: *Provided*, That:

(1) Appropriate entries shall be made in the operating log of the station showing the date and time the meter was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the instrument is found to be defective and immediately after the repaired or replaced instrument has been installed and functioning properly.

(3) If the defective instrnment is a plate voltmeter or plate ammeter in the last radio stage, the operating power shall be maintained by means of the radio frequency transmission line meter.

(c) If conditions beyond the control of the licensee prevent the restoration of the meter to service within the above allowed period, informal request may be filed in accordance with § 1.337 of this chapter with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

Technical Operation

§ 3.561 Operating schedule. Noncommercial educational FM broadcast stations are not required to operate on a regular schedule and no minimum number of hours of operation is specified; but the hours of actual operation during a license period shall be taken into consideration in considering the renewal of noncommercial educational FM broadcast licenses wherever it appears that the channels available for such stations are insufficient to meet the demand.

§ 3.562 Experimental operation. The period between 1:00 a.m. and 6:00 a.m., local standard time, may be used for experimental purposes in testing and maintaining apparatus by the licensee of any noncommercial educational FM broadcast station on its assigned frequency and not in excess of its authorized power, without specific authorization from the Commission.

§ 3.563 Station inspection. The licensee of any noncommercial educational FM broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 3.564 Station and operator licenses; posting of. (a) The station license and any other instrument of station authorization shall be posted in a conspicuous place and in such manner that all terms are visible, at the place the licensee considers to be the principal control point of the transmitter. At all other control points listed on the station authorization, a photocopy of the station license and other instruments of station authorization shall be posted.

(b) The original operator license, or FCC Form 759, of each station operator shall be posted at the place where he is on duty as an operator.

§ 3.565 Operator requirements. (a) One or more radio operators holding a valid radiotelephone first-class operator license, except as provided in paragraph (b) of this section, shall be in actual charge of the transmitting apparatus and shall be on duty either at the transmitter location or remote control point.

(b) A station which is authorized with transmitter power output of 10 kilowatts or less may be operated by persons holding commercial radio operator license of any class, except an aircraft radiotelephone operator authorization or a temporary limited radiotelegraph second-class operator license, when the equipment is so designed that the stability of the frequency is maintained by the transmitter itself within the limits of tolerance specified, and none of the operations, except those specified in subparagraphs (1), (2) and (3) of this paragraph, necessary to be performed during the course of normal operation may cause off-frequency operation or result in any unauthorized radiation. Adjustments of transmitting equipment by such operators, except when under the immediate supervision of radiotelephone first-class operator, shall be limited to the following:

(1) Those necessary to commence or terminate transmitter emissions as a routine matter.

(2) Those external adjustments that may be required as a result of variations of primary power supply.

(3) Those external adjustments which may be necessary to insure modulation within the limits required.

Should the transmitting apparatus be observed to be operating in a manner inconsistent with the station's instrument of authorization and none of the above adjustments are effective in bringing into proper operation, a person holding other than a radiotelephone first-class operator license and not acting under the immediate supervision of a radiotelephone first-class operator, shall be required to terminate the station's emissions.

(c) The licensee of a station which is operated by one or more operators holding other than a radiotelephone first-class operator license shall have one or more operators holding a radiotelephone first-class operator license in regnlar full-time employment at the station, whose primary duties shall be to effect and insnre the proper functioning of the transmitting equipment. In the event that the licensee also operates a standard broadcast station in the same community, a regular full-time radiotelephone first-class operator or operators employed in connection with the FM broadcast station may concurrently be employed to satisfy the requirements of § 3.93(c): *Provided,* That the duties of such operator or operators concerning the standard broadcast transmitting equipment shall in nowise interfere with the proper performance of his duties with respect to the FM broadcast transmitter: Except, that (1) if the transmitter power output is in excess of 10 watts but not greaer than 1 kw, an operator holding radiotelephone second-class operator license may be on duty and perform the functions required of the radiotelephone first-class operator, or (2) if the transmitter power outpnt is 10 watts or less, a radiotelephone second-class or radiotelegraph first- or second-class operator may be on duty and perform the functions of the radiotelephone first-class operator but need not be in regular full-time employment at the station.

(d) The licensed operator on duty and in charge of a noncommercial educational FM broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another radio station or stations in accordance with the class of operator's license which he holds and the rules and regulations governing such other stations: *Provided, however,* That snch duties shall in nowise interfere with the proper operation of the FM broadcast transmitter.

§ 3.566 Facsimile broadcasting and multiplex transmission. (a) Noncommercial educational FM broadcast stations may transmit simplex facsimile in accordance with transmission standards set forth in § 3.318 during periods not devoted to FM aural broadcasting. Such transmissions may not exceed one hour during the period between 7 a.m. and midnight (no limit is placed upon the hours between midnight and 7 a.m.). The Commission shall he notified by the licensee of the noncommercial educational FM broadcast station of its intent to transmit such facsimile.

(b) Noncommercial educational FM broadcast stations may, npon securing authorization from the Commission, transmit multiplex facsimile in accordance with transmission standards set forth in § 3.318: *Provided,* That the transmission of such facsimile does not reduce the quality of the aural program simultaneously transmitted by the licensee below that required by the FM Technical Standards in Subpart B of this part and that no degradation of snch aural programs will result from such facsimile transmissions when received on FM receivers not equipped with filters or other additional equipment.

§ 3.567 Operating power; determination and maintenance of. (a) The operating power of each station shall be determined by the indirect method. This is the product of the plate voltage (E_p) and the plate current (I_p) of the last radio stage, and an efficiency factor, F; that is:

$$\text{Operating power} = E_p \times I_p \times F$$

The efficiency factor, F, shall be established by the transmitter manufacturer for each type of transmitter for which Commission approval is requested, and shall be specified in the instruction books supplied to the customer with each transmitter. In the case of composite equipment the factor, F, shall be furnished to the Commission along with a statement of the basis used in determining such factor.

(b) The operating power of each station licensed for transmitter power output above 10 watts shall be maintained as near as practicable to the authorized power, and shall not exceed the limits of 5 percent above and 10 percent below the authorized power, except that in an emergency when it becomes impossible to operate with the authorized power, the station may be operated with reduced power for a period not to exceed 10 days provided the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified immediately after the emer-

gency develops and also upon the resumption of normal operating power. With respect to each station licensed for transmitter power output of 10 watts or less, the power at which the station is operated may be less than the licensed power, but shall in no event be more than 5 percent above the licensed power. The transmitter of each station shall be so maintained as to be capable of operation at a maximum licensed power.

§ 3.568 **Modulation.** The percentage of modulation of all stations shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice and in no case less than 85 percent or more than 100 percent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration.

§ 3.569 **Frequency tolerance.** (a) The center frequency of each noncommercial educational FM broadcast station licensed for transmitter power output of 10 watts or less shall be maintained within 3,000 cycles of the assigned center frequency.

(b) The center frequency of each noncommercial educational FM broadcast station licensed for transmitter power ontput above 10 watts shall be maintained within 2,000 cycles of the assigned center frequency.

§ 3.570 **Antenna structure, marking and lighting.** Where an antenna strncture(s) is required to be painted or lighted see § 17.37, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 3.571 **Discontinuance of operation.** The licensee of each station shall notify the Commission in Washington, D.C., and the Engineer in Charge of the radio district in which the station is located of permanent discontinuance of operation at least two days before operation is discontinued. The licensee shall, in addition, immediately forward the station license and other instruments of authorization to the Washington, D.C., office of the Commission for cancellation.

§ 3.572 **Remote control authorization.** (a) Application to operate a station by remote control may be made as a part of the application for constrnction permit for a new station. Application to operate an authorized station shall be made on FCC Form 301-A.

(b) An authorization for remote control will be issued only after a satisfactory showing has been made in regard to the following, among others:

(1) The location of the remote control point(s);

(2) The transmitter, if the power rating is in excess of 10 kw, is reliable and capable of being operated by remote control.

§ 3.573 **Remote control operation.** (a) Operation by remote control shall be subject to the following conditions:

(1) The equipment at the operating and transmitting positions shall be so installed and protected that it is not accessible to or capable of operation by persons other than those duly authorized by the licensee.

(2) The control circuits from the operating position to the transmitter shall provide positive on and off control and shall be such that open circuits, short circuits, grounds or other line faults will not actuate the transmitter and any fault causing loss of such control will automatically place the transmitter in an inoperative position.

(3) A malfunction of any part of the remote control equipment and associated line circuits resulting in improper control or inaccurate meter readings shall be cause for the immediate cessation of operation by remote control.

(4) Control and monitoring equipment shall be installed so as to allow the licensed operator at the remote control point to perform all the functions in a manner required by the Commission's rules.

(b) All stations, whether operating by remote control or direct control, shall be so equipped, in accordance with § 3.1003(a), so as to be able to follow the prescribed CONELRAD procedure.

Other Rules Relating to Operation

§ 3.581 Logs. The licensee or permittee of each noncommercial educational FM broadcast station shall maintain program and operating logs and shall require entries to be made as follows:

(a) In the program log:

(1) An entry of the time each station identification announcement (call letters and location) is made.

(2) An entry briefly describing each program broadcast, such as "music," "drama," "speech," etc., together with the name or title thereof, with the time of the beginning and ending of the complete program. If a mechanical record is used, the entry shall show the exact nature thereof, such as "record," "transcription," etc., and the time it is announced. If the program is of network origin, its source shall be indicated. If the broadcast is under the auspices of an institution or organization other than the licensee, its name shall be noted.

(b) In the operating log:

(1) An entry of the time the station begins to supply power to the antenna, and the time it stops.

(2) An entry of the time the program service begins and ends.

(3) An entry of each interruption to the carrier wave, its cause and duration.

(4) For each station licensed for transmitter power output above 10 watts, an entry of the following each 30 minutes:

(i) Operating constants of last radio stage (total plate current and plate voltage).

(ii) Radio frequency transmission line meter reading.

(iii) Frequency monitor reading.

(5) A log must be kept of all operation during the experimental period. If the entries required above are not applicable thereto, then the entries shall be made so as to fully describe the operation.

(c) Where an antenna structure(s) is required to be illuminated see § 17.38, *Recording of tower light inspections in the station record*, of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 3.582 Logs; retention of. Logs of noncommercial educational FM broadcast stations shall be retained by the licensee or permittee for a period of two years: *Provided, however,* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee or permittee has been notified, shall be retained by the licensee or permittee until he is specifically authorized in writing by the Commission to destroy them: *Provided, further,* That logs incident to or involved in any claim or complaint of which the licensee or permittee has notice shall be retained by the licensee or permittee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

§ 3.583 Logs; by whom kept. Each log shall be kept by the person or persons competent to do so, having actual knowledge of the facts required, who shall sign the log when starting duty and again when going off duty. The logs shall be made available upon request by an authorized representative of the Commission.

§ 3.584 Log form. The log shall be kept in an orderly manner, in suitable form, and in such detail that the data required for the particular class of station concerned are readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log.

§ 3.585 Correction of logs. No log or portion thereof shall be erased, obliterated, or willfully destroyed within the period of retention provided by the rules. Any necessary correction may be made only by the person originating the entry who shall strike out the erroneous portion, initial the correction made, and indicate the date of correction.

§ 3.586 Rough logs. Rough logs may be transcribed into condensed form, but in such case the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

§ 3.587 **Station identification.** (a) A licensee of a noncommercial educational FM broadcast station shall make at least the following station identification announcements (call letters and location): (1) at the beginning and ending of each time of operation; and (2) within 2 minutes of each hour and each half hour during operation: *Provided,*

(b) Such identification announcement need not be made on the hour or half hour when to make such announcement would interrupt a single continuous program of longer duration than 30 minutes. In such cases the identification announcement shall be made at the beginning of the program, at the first interruption of the continuity, and at the conclusion of the program.

(c) In making the identification announcement, the call letters shall be given only on the channel of the station identified thereby.

§ 3.588 **Mechanical reproductions.** (a) No mechanically reproduced program consisting of a speech, news event, news commentator, forum, panel discussion, or special event in which the element of time is of special significance, or any other program in which the element of time is of special significance and presentation of which would create, either intentionally or otherwise, the impression or belief on the part of the listening audience that the event or program being broadcast is in fact occurring simultaneously with the broadcast, shall be broadcast without an appropriate announcement being made either at the beginning or end of such reproduction or at the beginning or end of the program in which such reproduction is used that it is a mechanical reproduction or a mechanically reproduced program: *Provided, however,* That each such program of one minute or less need not be announced as such.

(b) The exact form of identifying announcement is not prescribed, but the language shall be clear and in terms commonly used and understood. Any other program mechanically reproduced or series of mechanical reproductions, including a mechanical reproduction used for background music, sound effects, station identification, program identification (theme music of short duration) or identification of sponsorship of the program proper, need not be announced as provided in paragraph (a) of this section, but the licensee shall not attempt affirmatively to create the impression that any program being broadcast by mechanical reproduction consists of live talent.

(c) The requirements of paragraph (a) of this section are waived with respect to network programs, transcribed and rebroadcast at a later hour because of the time zone differential between the place where the program originates and where it is rebroadcast, this waiver being applicable whether the off-the-line recording is made by the network itself at one of its key stations or by an individual station, but only when the off-the-line recording is for broadcast at an hour not exceeding the time zone differential between the place where the program originates and where it is rebroadcast. Each station which broadcasts network programs at a later hour in accordance with this waiver shall make an appropriate announcement at least once each day between the hours of 10:00 a.m. and 10:00 p.m., stating that some or all of the network programs which are broadcast by that station are delayed broadcasts by means of transcription. This waiver provision also applies during the annual periods in which daylight saving time will be effective with respect to network programs transcribed and rebroadcast one hour later because of the time differential resulting from the adoption of daylight saving time in some areas.

§ 3.589 [Reserved.]

§ 3.590 **Broadcasts by candidates for public office.** (a) *Definitions.* A "legally qualified candidate" means any person who has publicly announced that he is a candidate for nomination by a convention of a political party or for nomination or election in a primary, special, or general election, municipal, county, state or national, and who meets the qualifications prescribed by the applicable laws to hold the office for which he is a candidate, so that he may be voted for by the electorate directly or by means of delegates or electors, and who–

(1) Has qualified for a place on the ballot or

(2) Is eligible under the applicable law to be voted for by sticker, by writing in his name on the ballot, or other method and (i) has been duly nominated by a political party which is commonly known and regarded as such, or (ii) makes a

substantial showing that he is a bona fide candidate for nomination or office, as the case may be.

(b) *General requirements.* No station licensee is required to permit the use of its facilities by any legally qualified candidate for public office, but if any licensee shall permit any such candidate to use its facilities, it shall afford equal opportunities to all other such candidates for that office to use such facilities: *Provided,* That such licensee shall have no power of censorship over the material broadcast by any such candidate.

(c) *Practices.* No licensee shall make any discrimination in practices, regulations, facilities, or services for or in connection with the service rendered pursuant to this part, or make or give any preference to any candidate for public office or subject any such candidate to any prejudice or disadvantage; nor shall any licensee make any contract or other agreement which shall have the effect of permitting any legally qualified candidate for any public office to broadcast to the exclusion of other legally qualified candidates for the same public office.

(d) *Records; inspection.* Every licensee shall keep and permit public inspection of a complete record of all requests for broadcast time made by or on behalf of candidates for public office, together with an appropriate notation showing the disposition made by the licensee of such requests. Such records shall be retained for a period of two years.

(e) A request for equal opportunities must be submitted to the licensee within one week of the day on which the prior use occurred.

(f) A candidate requesting such opportunities of the licensee, or complaining of non-compliance to the Commission shall have the burden of proving that he and his opponent are legally qualified candidates for the same public office.

§ 3.591 Rebroadcast. (a) The term "rebroadcast" means reception by radio of the program of a radio station, and the simultaneous or subsequent retransmission of such program by a broadcast station. The broadcasting of a program relayed by a remote pick-up broadcast station or studio transmitter link is not considered a rebroadcast. In case a program is transmitted from its point of origin to a broadcast station entirely by telephone facilities in which a section of such transmission is by radio, the broadcasting of this program is not considered a rebroadcast.

NOTE: As used in this section, program includes any complete program or part thereof.

(b) The licensee of a noncommercial educational FM broadcast station may, without further authority of the Commission, rebroadcast the program of a United States standard, FM, noncommercial educational, or international broadcast station, provided the Commission is notified of the call letters of each station rebroadcast and the licensee certifies that express authority has been received from the licensee of the station originating the program.

NOTE 1: The notice and certification of consent shall be given within 3 days of any single rebroadcast, but in case of the regular practice of rebroadcasting certain programs several times during a license period, notice and certification of consent shall be given for the ensuing license period with the application for renewal of license, or at the beginning of such rebroadcast practice if begun during a license period.

NOTE 2: See § 3.503(c).

(c) No licensee of a noncommercial educational FM broadcast station shall rebroadcast the program of any United States radio station not designated in paragraph (b) of this section without written authority having first been obtained from the Commission upon application (informal) accompanied by written consent or certification of consent of the licensee of the station originating the program.

NOTE: By Order No. 82, dated and effective June 24, 1941, until further order of the Commission, § 3.591(c) is suspended only insofar as it requires prior written authority of the Commission for the rebroadcasting of programs originated for the express purpose by U.S. Government radio stations.

SUBPART D [RESERVED]

SUBPART E—TELEVISION BROADCAST STATIONS

General

§ 3.601 Scope of subpart. This subpart contains the rules and regulations (including engineering standards) governing television broadcast stations, including noncommercial educational television broadcast stations, in the United States, its Territories and possessions.

§ 3.602 Other pertinent rules. Other pertinent provisions of the Commission's rules and regulations relating to the television broadcast service are included in the following parts of this chapter:

Part 1—Practice and procedure.
Part 2—Frequency allocations and radio treaty matters; general rules and regulations.
Part 4—Experimental and auxiliary broadcast services.
Part 17—Construction, marking, and lighting of antenna towers and/or their supporting structures.

§ 3.603 Numerical designation of television channels. (a)

Channel No.	Frequency band (megacycles)	Channel No.	Frequency band (megacycles)	Channel No.	Frequency band (megacycles)	Channel No.	Frequency band (megacycles)
2	54–60	23	524–530	44	650–656	64	770–776
3	60–66	24	530–536	45	656–662	65	776–782
4	66–72	25	536–542	46	662–668	66	782–788
5	76–82	26	542–548	47	668–674	67	788–794
6	82–88	27	548–554	48	674–680	68	794–800
7	174–180	28	554–560	49	680 686	69	800–806
8	180–186	29	560–566	50	686–692	70	806–812
9	186–192	30	566–572	51	692–698	71	812–818
10	192–198	31	572–578	52	698–704	72	818–824
11	198–204	32	578–584	53	704–710	73	824–830
12	204–210	33	584–590	54	710–716	74	830–836
13	210–216	34	590–596	55	716–722	75	836–842
14	470–476	35	596–602	56	722–728	76	842–848
15	476–482	36	602–608	57	728–734	77	848–854
16	482–488	37	608–614	58	734–740	78	854–860
17	488–494	38	614–620	59	740–746	79	860–866
18	494–500	39	620–626	60	746–752	80	866–872
19	500–506	40	626–632	61	752–758	81	872–878
20	506–512	41	632–638	62	758–764	82	878–884
21	512–518	42	638–644	63	764–770	83	884–890
22	518–524	43	644–650				

(b) In Alaska and Hawaii the frequency bands 76–82 Mc and 82–88 Mc are allocated for non-Broadcast use. These frequency bands (Channels 5 and 6) will not be assigned in Alaska or Hawaii for use by television broadcast stations.

Channel Utilization

§ 3.606 Table of assignments. (a) *General.* The following table of assignments contains the channels assigned to the listed communities in the United States, its Territories, and possessions. Channels designated with an asterisk are assigned for use by noncommercial educational broadcast stations only. A station on a channel

identified by a plus or minus mark is required to operate with its carrier frequencies offset 10 kc above or below, respectively, the normal carrier frequencies.

(b) *Table of assignments.*

	Channel No.
Alabama:	
Andalusia	°2 -, 29
Anniston	70+
Auburn	°56
Bessemer	54
Birmingham	6–, °10–, 13 -, 42+, 48
Brewton	23+
Clanton	14
Cullman	60+
Decatur	23–
Demopolis	18
Dothan	9+, 19–
Enterprise	40+
Eufaula	44
Florence	15
Fort Payne	19
Gadsden	21+, 37–
Greenville	49–
Guntersville	40–
Huntsville	31+
Jasper	17
Mobile	5+, 10+, °42, 48+
Montgomery	12, 20, °26+, 32
Mumford	°7–
Opelika	22–
Selma	8–, 58+
Sheffield	47–
Sylacauga	24–
Talladega	64
Thomasville	27–
Troy	38–
Tuscaloosa	45, 51–
Tuskegee	16–
University	°74+
Alaska:	
Anchorage	2 -, °7–, 11, 13–
Fairbanks	2+, 4+, 7+, °9+, 11+, 13+
Juneau	°3, 8, 10
Ketchikan	2, 4, °9
Seward	4–, 9–
Sitka	13
Arizona:	
Ajo	14–
Bisbee	15
Casa Grande	18–
Clifton	25–
Coolidge	30+
Douglas	3–
Eloy	24
Flagstaff	9, 13
Globe	34+
Holbrook	14
Kingman	6–
Mesa	12–
Miami	28+
Morenci	31
Nogales	17–
Phoenix	3+, 5–, °8+, 10–
Prescott	15
Safford	21
Tucson	4–, °6+, 9–, 13–
Williams	25
Winslow	16–
Yuma	11–, 13+
Arkansas:	
Arkadelphia	34+
Batesville	30–
Benton	40
Blytheville	64+, 74
Camden	50
Conway	62
El Dorado	10–, 26–
Fayetteville	°13 -, 41–
Forrest City	22+
Fort Smith	5 -, °16, 22, 39
Harrison	24
Helena	54
Hope	15–
Hot Springs	9+, 52+
Jonesboro	8, 39+
Little Rock	°2–, 4, 11+, 17 -, 23+
Magnolia	28+
Malvern	46
Morrilton	43–
Newport	28
Paragould	58
Pine Bluff	7–, 36
Russellville	19
Searcy	33
Springdale	35–
Stuttgart	14+
California:	
Alturas	9
Bakersfield	10 -, 29
Bishop	19
Brawley	25+
Chico	12–
Corona	52
Delano	37+
El Centro	16, 56
Eureka	3–, 6–, 13–
Fresno	12+, °18–, 24, 47, 53
Hanford	21
Los Angeles	2, 4, 5, 7, 9, 11, 13, 22, °28, 34
Madera	59
Merced	34–, 66
Modesto	14+, 58
Monterey. (*See* Salinas.)	
Napa	62
Oakland. (*See* San Francisco.)	
Oxnard	32
Palm Springs	14
Petaluma	68
Pittsburg	16
Port Chicago	70
Porterville	55
Red Bluff	15

	Channel No.
California—(*Continued*)	
Redding	7
Riverside	40, 46
Sacramento	3, °6, 10, 40–, 46+
Salinas-Monterey	8+, 35
San Bernardino	18, °24–, 30
San Buenaventura	38–
San Diego	8, 10, °15+, 21–, 27, 33, 39
San Francisco-Oakland	2+, 4–, 5+, 7–, °9+, 20–, 26–, 32+, 38, 44–
San Jose	11+, 48, °54, 60
San Luis Obispo	6+
Santa Barbara	3–, 20, 26
Santa Cruz	56
Santa Maria	44
Santa Paula	16+
Santa Rosa	50
Stockton	13+, 36, °42, 64
Tulare	27+
Ukiah	18
Visalia	43, 49
Watsonville	22–
Yreka City	19
Yuba City	52–
Colorado:	
Alamosa	3–, 19+
Boulder	°12, 22+
Canon City	36
Colorado Springs	11, 13, °17+, 23+
Craig	19
Delta	24–
Denver	2, 4–, °6–, 7, 9–, 20, 26+
Durango	6+, 15
Fort Collins	44+
Fort Morgan	15+
Grand Junction	5–, 21+
Greeley	50
La Junta	24
Lamar	12–, 18–
Leadville	14+
Longmont	32
Loveland	38
Montrose	10+, 18
Pueblo	5, °8, 28+, 34–
Salida	25
Sterling	3, 25–
Trinidad	21–
Walsenburg	30–
Connecticut:	
Bridgeport	43–, 49–, °71
Hartford	3+, 18–, °24
Meriden	65–
New Britain	30+
New Haven	8+, 59+
New London	26+, 81
Norwalk. (*See* Stamford.)	
Norwich	57+, °63–
Stamford-Norwalk	27
Waterbury	53
Delaware:	
Dover	40
Wilmington	12, °59–, 83+

	Channel No.
District of Columbia:	
Washington	4–, 5–, 7+, 9, 14–, 20+, °26–, 50–
Florida:	
Belle Glade	27+
Bradenton	28–
Clearwater	32+, 50
Daytona Beach	2–, 53
De Land	44+
Fort Lauderdale	17–, 39
Fort Myers	11+
Fort Pierce	19
Gainesville	°5–, 20+
Jacksonville	4+, °7, 12–, 30+, 36–
Key West	14+, 20
Lake City	33+
Lakeland	16+, 22+
Lake Wales	14
Leesburg	26–
Marianna	17+
Melbourne	37–
Miami	°2, 4, 6, 7–, 10+, 23–, 33
Ocala	15+
Orlando	6–, 9, 18, °24–, 47
Palatka	17
Panama City	7+, °30, 36+
Pensacola	3–, 15–, °21, 46
Quincy	54+
St. Augustine	25+
St. Petersburg. (*See* Tampa.)	
Sanford	35+
Sarasota	34+
Tallahassee	°11–, 24, 51
Tampa-St. Petersburg	°3, 8–, 10–, 13–, 38
West Palm Beach	5, 12, °15, 21+
Georgia:	
Albany	10, 25
Americus	31
Athens	°8, 60–
Atlanta	2, 5–, 11+, °30, 36
Augusta	6+, 12+
Bainbridge	35–
Brunswick	28+, 34–
Cairo	45+
Carrollton	33
Cartersville	63–
Cedartown	53–
Columbus	4, 28, °34
Cordele	43
Dalton	25+
Douglas	32–
Dublin	15
Elberton	24+
Fitzgerald	53+
Fort Valley	18+
Gainesville	52
Griffin	39+
La Grange	50
Macon	13+, °41+, 47+
Marietta	57+
Milledgeville	51+
Moultrie	48–

	Channel No.
Newnan	61+
Rome	59
Savannah	3+, °9–, 11
Statesboro	22
Swainsboro	20–
Thomasville	6, 27
Tifton	14–
Toccoa	35
Valdosta	37+
Vidalia	26
Waycross	8+, 16
Hawaiian Islands:	
Hilo, Hawaii	2, °4, 7, 9, 11, 13
Honolulu, Oahu	2+, 4–, °7+, 9–, 11+, 13–
Lihue, Kauai	3+, °8–, 10+, 12–
Wailuku, Maui	3, 8, °10, 12
Idaho:	
Blackfoot	33
Boise	2, °4+, 7
Burley	15–
Caldwell	9–
Emmett	26–
Gooding	23
Idaho Falls	3, 8+
Jerome	17
Kellogg	33–
Lewiston	3–
Moscow	12–, °15
Nampa	6, 12+
Payette	14+
Pocatello	6–, 10
Preston	41
Rexburg	27+
Rupert	21
Sandpoint	23–
Twin Falls	11, 13–
Wallace	27–
Weiser	20–
Illinois:	
Alton	48
Aurora	75
Belleville	54+
Bloomington	15–
Cairo	24–
Carbondale	34, °61–
Centralia	32+, 59+
Champaign-Urbana	3+, °12–, 21, 27, 33
Chicago	2–, 5, 7, 9+, °11, 20, 26, 32, 38, 44
Danville	24
Decatur	17, 23+
De Kalb	°67
Dixon	47+
Elgin	83
Freeport	23
Galesburg	77
Harrisburg	22
Jacksonville	49–
Joliet	48+
Kankakee	14
Kewanee	60–
La Salle	35
Lincoln	53+
Macomb	61+
Marion	40
Mattoon	46–
Moline. (*See* Davenport, Iowa.)	
Mt. Vernon	38–
Olney	16–
Pekin	69+
Peoria	19, 25+, 31+, °37–, 43+
Quincy	10–, 21+
Rockford	13+, 39+, °45+
Rock Island. (*See* Davenport, Iowa.)	
Springfield	20+, 26–, 36–, °66+
Streator	65–
Urbana. (*See* Champaign.)	
Vandalia	28–
Waukegan	79+
Indiana:	
Anderson	26+, 61
Angola	77
Bedford	68
Bloomington	4, °30–, 36
Columbus	42–
Connersville	38+
Elkhart. (*See* South Bend.)	
Evansville	7, °9+, 14–, 50–
Fort Wayne	15+, 21+, °27+, 33–, 69
Gary	50, °66
Hammond	56–
Indianapolis	6, 8–, 13–, °20–, 39, 67–
Jasper	19+
Kokomo	29+
Lafayette	18, °47, 59
Lebanon	79+
Logansport	51
Madison	25–
Marion	31
Michigan City	62+
Muncie	49, 55+, °71
Plymouth	34–
Princeton	52+
Richmond	32–
Shelbyville	58+
South Bend-Elkhart	16, 22, 28+, °52
Tell City	78
Terre Haute	2+, 10, °57+, 63–, 73+
Vincennes	44+
Washington	60+
Iowa:	
Algona	37+
Ames	5, 25–
Atlantic	45–
Boone	19–
Burlington	32–, 38+
Carroll	39
Cedar Rapids	2, 9–, 20–, °26+
Centerville	31–
Charles City	18–
Cherokee	14
Clinton	64
Creston	43

	Channel No.
Iowa—(*Continued*)	
Davenport-Rock Island-Moline, Ill.	4+, 6+, 8, °30+, 42–, 68
Decorah	44+
Des Moines	8–, °11+, 13–, 17+, 23–
Dubuque	56+, 62–
Estherville	24+
Fairfield	54
Fort Dodge	21
Fort Madison	50+
Grinnell	71
Iowa City	°12+, 24–
Keokuk	44–
Knoxville	33–
Marshalltown	49
Mason City	3+, 35–
Muscatine	58
Newton	65+
Oelwein	28
Oskaloosa	52+
Ottumwa	15+, 63
Red Oak	32+
Shenandoah	20+
Sioux City	4–, 9, °30, 36–
Spencer	42+
Storm Lake	34+
Waterloo	7+, 16–, °22–, 46+
Webster City	27
Kansas:	
Abilene	31+
Arkansas City	49
Atchison	60+
Chanute	50–
Coffeyville	33–
Colby	22–
Concordia	47–
Dodge City	6+, 23
El Dorado	55+
Emporia	39–
Fort Scott	27
Garden City	9, 11+
Goodland	10, 31
Great Bend	2, 28
Hays	7–, 20–
Hutchinson	12, 18
Independence	20
Iola	44+
Junction City	29+
Larned	15–
Lawrence	°11, 17–
Leavenworth	54–
Liberal	14
McPherson	26–
Manhattan	°8, 23+
Newton	14+
Olathe	52–
Ottawa	21–
Parsons	46–
Pittsburg	7+, 38–
Pratt	36+
Salina	34
Topeka	13+, 42, °48+
Wellington	24–
Wichita	3–, 10–, 16–, °22+
Winfield	43+
Kentucky:	
Ashland	59–
Bowling Green	13, 17+
Campbellsville	40+
Corbin	16
Danville	35+
Elizabethtown	23
Frankfort	43–
Glasgow	28+
Harlan	73+
Hazard	19–
Hopkinsville	20
Lexington	18+, 27–, 64, 70+
Louisville	3–, 11+, °15, 21–, 41–, 51–
Madisonville	26
Mayfield	63
Maysville	24+
Middlesborough	57, 63+
Murray	33–
Owensboro	56–, 62
Paducah	6+, 43, 72
Pikeville	14–
Princeton	45–
Richmond	60
Somerset	29–
Winchester	37+
Louisiana:	
Abbeville	27+
Alexandria	5, 62+, 74
Bastrop	53+
Baton Rouge	2, 18–, 28, °34, 40–
Bogalusa	69, 78
Crowley	76
De Ridder	70
Ennice	64–
Franklin	46+
Hammond	57
Houma	11, 30+
Jackson	59
Jennings	48
Lafayette	10, 38–, 67–
Lafayette-Lake Charles	3
Lake Charles	7–, °14, 25, 60+
Minden	30
Monroe	8+, °13, 43+
Morgan City	36+
Natchitoches	17+
New Iberia	15+
New Orleans	4+, 6+, °8, 12, 20–, 26, 32+, 61
Oakdale	54+
Opelousas	58
Ruston	20
Shreveport	3–, 12
Thibodaux	24
Winnfield	22–
Maine:	
Auburn	23+
Augusta	10–, 29+
Bangor	2–, 5+, °16–

	Channel No.
Bar Harbor	22–
Bath	65
Belfast	41–
Biddeford	59
Calais	7–, 20–
Dover-Foxcroft	18+
Fort Kent	17+
Foxcroft. (*See* Dover.)	
Houlton	24
Lewiston	8–, 17
Millinocket	14+
Orono	°12–
Portland	6–, 13+, °47–, 53+
Presque Isle	8, 10+, 19
Rockland	25–
Rumford	55–
Van Buren	15–
Waterville	35+
Maryland:	
Annapolis	53–
Baltimore	2+, 11–, 13+, 18, °24+, 72–
Cambridge	22+
Cumberland	17+, 30–
Frederick	62
Hagerstown	52, 68+
Salisbury	16+
Massachusetts:	
Amherst	°82
Barnstable	25+
Boston	°2+, 4–, 5–, 7+, 38, 44+, 56
Brockton	62
Easthampton	61
Fall River	46–, 68
Greenfield	32+, 58–
Holyoke. (*See* Springfield.)	
Lawrence	72
Lowell	78
New Bedford	6+, 28–, 34+
North Adams	19, °80+
Pittsfield	64+
Springfield-Holyoke	22, 40
Worcester	14, 20
Michigan:	
Alma	41+
Alpena	9+, °11, 30
Ann Arbor	20+, °26–
Bad Axe	46–
Battle Creek	58–, 64–
Bay City	5–, 63–, °73+
Benton Harbor	40+
Big Rapids	39
Cadillac	13–, 45
Calumet	5
Cheboygan	4+, 36+
Coldwater	24–
Detroit	2+, 4, 7–, 50–, °56, 62
East Lansing	60+
East Tawas	25–
Escanaba	3+, °49
Flint	12–, 16–, °22–, 28
Gladstone	40–
Grand Rapids	8+, °17+, 23–
Houghton	19, °25
Iron Mountain	8–, 27
Iron River	33–
Ironwood	12+, 31–
Jackson	48
Kalamazoo	3–, 46, °74
Lansing	6–, 54
Ludington	18+
Manistee	15
Manistique	14+
Marquette	6–, 13+, 17, °35
Midland	19+
Mount Pleasant	47–
Muskegon	29–, 35+
Parma-Onondaga	10–
Petoskey	31
Pontiac	44+
Port Huron	34+
Rogers City	24
Saginaw	51–, 57–
Sault Ste. Marie	8, 10+, 28–, °34
Traverse City	7+, 20–, °26+
West Branch	21
Minnesota:	
Albert Lea	57–
Alexandria	7, 36
Austin	6–, 51+
Bemidji	9, 24–
Brainerd	12–
Cloquet	44
Crookston	21–
Detroit Lakes	18+
Duluth-Superior, Wis.	3, 6+, °8, 10+, 32, 38
Ely	16
Fairmont	40+
Faribault	20
Fergus Falls	16–
Grand Rapids	20–
Hastings	29+
Hibbing	13–
International Falls	11
Little Falls	14+
Mankato	12, 15–
Marshall	22+
Minneapolis-St. Paul	°2–, 4, 5–, 9+, 11–, 17, 23+
Montevideo	19
New Ulm	43–
Northfield	26
Owatonna	45
Red Wing	63–
Rochester	10, 55–
St. Cloud	33
St. Paul. (*See* Minneapolis.)	
Stillwater	39–
Thief River Falls	15
Virginia	26+
Wadena	27+
Willmar	31+
Winona	61
Worthington	32
Mississippi:	
Biloxi	13+, °44+, 50–

	Channel No.
Mississippi—(*Continued*)	
Brookhaven	37+
Canton	16
Clarksdale	32
Columbia	35+
Columbus	4–, 28–
Corinth	41
Greenville	21–, 27
Greenwood	6, 24+
Grenada	44
Gulfport	56–
Hattiesburg	9, 17–
Jackson	3+, 12+, °19+, 25–, 47
Kosciusko	52–
Laurel	33–
Laurel-Pachuta	7
Louisville	46–
McComb	31–
Meridian	11–, 30–, °36–
Natchez	29+
Pachuta. (*See* Laurel-Pachuta.)	
Pascagoula	22
Picayune	14–
Starkville	34–
State College	°2+
Tupelo	9–, 38
University	°20+
Vicksburg	41+
West Point	56+
Yazoo City	49
Missouri:	
Cape Girardeau	12, 18+, 69
Carthage	56–
Caruthersville	27–
Chillicothe	14–
Clinton	49–
Columbia	8+, 16+, 22–
Farmington	52
Festus	25–
Fulton	24+
Hannibal	7–, 27+
Jefferson City	13, 33+
Joplin	12+, 30+
Kansas City	4, 5+, 9+, °19+, 25+, 65
Kennett	21
Kirksville	3–, 18
Lebanon	23
Marshall	40+
Maryville	26
Mexico	45
Moberly	35+
Monett	14
Nevada	18–
Poplar Bluff	15+
Rolla	46
St. Joseph	2–, 30–, °36
St. Louis	2, 4–, 5–, °9, 11–, 30, 42+
Sedalia	6–, 28+
Sikeston	37
Springfield	3+, 10, °26+, 32
West Plains	20–
Montana:	
Anaconda	2+
Billings	2, 8, °11
Bozeman	°9, 22–
Butte	4, 6+, °7–, 15+
Cut Bank	20+
Deer Lodge	25+
Dillon	20
Glasgow	16
Glendive	5+, 18–
Great Falls	3+, 5+, °23–
Hamilton	17+
Hardin	4+
Havre	9+, 11+
Helena	10+, 12
Kalispell	9–
Laurel	14+
Lewistown	13
Livingston	16–
Miles City	3–, °6, 10
Missoula	8–, °11–, 13–, 21+
Polson	18
Red Lodge	18+
Shelby	14–
Sidney	14
Whitefish	16+
Wolf Point	20–
Nebraska:	
Alliance	13–, 21
Beatrice	40
Broken Bow	14–
Columbus	49+
Fairbury	35
Falls City	38
Fremont	52
Grand Island	11–, 21+
Hastiugs	5–, 27–
Hay Springs	4+
Hayes Center	6
Kearney	13, 19
Lexingtou	23–
Lincoln	10+, °12–, 18+, 24
McCook	8–, 17
Nebraska City	50
Norfolk	33+
North Platte	2–, 9+
Omaha	3, 6+, 7, °16, 22, 28–
Scottsbluff	10–, 16+
York	15
Nevada:	
Boulder City	4+
Carlin	14
Carson City	37
Elko	10–
Ely	3–, 6+
Fallon	29–
Goldfield	5–
Hawthorne	31
Henderson	2–
Las Vegas	8–, °10+, 13–
Lovelock	18+
McGill	8+
Reno	4, 8, °21+, 27–
Tonopah	9–
Winnemucca	7+
Yerington	33

	Channel No.
New Hampshire:	
Berlin	26
Claremont	37
Concord	75+
Durham	°11
Hanover	°27+
Keene	45–
Laconia	43
Littleton	24–
Manchester	9–, 48+
Nashua	54
Portsmouth	15
Rochester	51
New Jersey:	
Andover	°69
Asbury Park	58
Atlantic City	46, 52+
Bridgeton	64–
Camden	°80
Freehold	°74
Hammonton	°70
Montclair	°77
Newark	13–
New Brunswick	°19–, 47+
Paterson	37+
Trenton	41+
Wildwood	48–
New Mexico:	
Alamogordo	17
Albuquerque	4+, °5+, 7+, 13+
Artesia	21+
Atrisco-Five Points	18+
Belen	24+
Carlsbad	6–, 23
Clayton	27–
Clovis	12+, 35
Deming	14+
Farmington	12+, 17–
Five Points. (*See* Atrisco.)	
Gallup	3, °8–, 10
Hobbs	46
Hot Springs	19
Las Cruces	22–
Las Vegas	14–
Lordsburg	23+
Los Alamos	20–
Lovington	27
Portales	22+
Raton	46–, °52
Roswell	°3+, 8, 10–
Santa Fe	2+, °9+, 11–
Silver City	°10+, 12
Socorro	15+
Tucumcari	25+
New York:	
Albany-Schenectady-Troy	6, 13, °17+, 23–, 35, 41
Amsterdam	52–
Batavia	33–
Binghamton	12–, 40–, °46+, 56+
Buffalo	17, °23
Buffalo-Niagara Falls	2, 4–, 7+, 29+
Carthage	7–
Clymer	37
Cortland	72
Dunkirk	46
Elmira	18+, 24–, 30
Glens Falls	39+
Gloversville	29–
Hornell	50
Ithaca	°14+, 20–
Jamestown	58+
Kingston	66–
Lake Placid	5
Malone	20+, °66
Massena	14–
Middletown	60
New York	2, 4, 5+, 7, 9+, 11+, °25, 31–
Niagara Falls. (*See* Buffalo-Niagara Falls.)	
Ogdensburg	24+
Olean	54+
Oneonta	62–
Oswego	31
Patchogue	75
Plattsburg	28+
Poughkeepsie	21–, °83
Rochester	5–, 10+, 15–, °21, 27+
Rome. (*See* Utica.)	
Saranac Lake	18
Schenectady. (*See* Albany.)	
Syracuse	3–, 8, °43+
Troy. (*See* Albany.)	
Utica-Rome	2–, °25+, 54–
Vail Mills	10–
Watertown	48
North Carolina:	
Ahoskie	53
Albermarle	20
Asheville	13–, °56–, 62+, 78
Burlington	63
Burnsville	18
Chapel Hill	°4+
Charlotte	3, 9+, 36+, °42+
Durham	11+, °40–, 46+, 73–
Elizabeth City	31+
Fayetteville	18–, 54–
Gastonia	48
Goldsboro	34, 72
Greensboro	2–, °51–, 57–
Greenville	9–
Henderson	52–
Hendersonville	27
Hickory	30–
High Point	15+
Jacksonville	16
Kannapolis	59+
Kinston	45
Laurinburg	41–
Lumberton	21+
Mount Airy	55
New Bern	12+
Raleigh	5, °22–, 28–
Roanoke Rapids	30+
Rocky Mount	50+
Salisbury	80
Sanford	38

	Channel No.
North Carolina—(*Continued*)	
Shelby	39
Southern Pines	49
Statesville	64–
Washington	7
Wilmington	3–, 6, 29–, °35+
Wilson	56
Winston-Salem	12, 26+, °32–
North Dakota:	
Bismarck	5, 12–, 18, °24
Bottineau	16+
Carrington	26–
Devils Lake	8+, 14–
Dickinson	2+, 4, °17
Fargo	6, 11+, °34–, 40
Grafton	17
Grand Forks	°2, 10
Harvey	22+
Jamestown	7–, 42
Lisbon	23
Minot	°6+, 10–, 13+
New Rockford	20+
Rugby	38–
Valley City	4–, 32–
Wahpeton	45+
Williston	8–, 11–, °34+
Ohio:	
Akron	49+, °55–, 61+
Ashtabula	15
Athens	62–
Bellefontaine	63
Bowling Green	°70
Cambridge	26
Canton	29
Chillicothe	56+
Cincinnati	5–, 9, 12, °48–, 54–, 74–
Cleveland	3, 5+, 8, 19, °25+, 65+
Columbus	4–, 6+, 10+, °34, 40–
Coshocton	20
Dayton	2, 7+, °16+, 22+
Defiance	43
Findlay	53
Fremont	59+
Gallipolis	72
Hamilton-Middletown	65
Lancaster	28–
Lima	35–, 73
Lorain	31–
Mansfield	36+
Marion	17–
Massillon	23+
Middletown. (*See* Hamilton.)	
Mount Vernon	58
Newark	60–
Oxford	°14+
Piqua	44–
Portsmouth	30
Sandusky	42+
Springfield	52–, 76
Steubenville. (*See* Wheeling, W. Va.)	
Tiffin	47+
Toledo	11–, 13, °30+, 79
Warren	67+
Youngstown	21–, 27, 73–
Youngstown, Ohio-New Castle, Pa.	45–
Zanesville	18–, 50+
Oklahoma:	
Ada	10+, 50+
Altus	36
Alva	30
Anadarko	58–
Ardmore	12–, 55–
Bartlesville	62–
Blackwell	51–
Chickasha	64
Claremore	15
Clinton	32–
Duncan	39–
Durant	27–
Elk City	8+, 15+, 26+
El Reno	56+
Enid	5, 21, °27+
Frederick	44
Guthrie	48
Guymon	20+
Hobart	23+
Holdenville	14–
Hugo	21+
Lawton	7+, °28+, 34–
McAlester	47
Miami	58+
Muskogee	°45+, 66+
Norman	31–, °37–
Oklahoma City	4–, 9–, °13, 19+, 25–
Okmulgee	26
Pauls Valley	61
Ponca City	40–
Pryor Creek	54
Sapulpa	42–
Seminole	59
Shawnee	53–
Stillwater	29–, °69
Tulsa	2+, 6, 8–, °11–, 17+, 23
Vinita	28–
Woodward	35+
Oregon:	
Albany	55+
Ashland	14–
Astoria	30–
Baker	37+
Bend	15–
Brookings	8+
Burns	16
Coos Bay	11
Corvallis	°7–, 49–
Eugene	9+, 13, 20+, 26
Grants Pass	30
Klamath Falls	2–, 17
La Grande	13+
Lebanon	43+
McMinnville	46–
Medford	5
North Bend	16+
Pendleton	28
Portland	2, 6+, 8–, °10, 12, 21–, 27+

	Channel No.
Roseburg	4+, 23+
Salem	3+, °18, 24+, 66
Springfield	37–
The Dalles	32
Pennsylvania:	
Allentown	39, 67
Altoona	10–, 23–
Bethlehem	51–
Bradford	80–
Butler	43–
Chambersburg	46–
Du Bois	31+
Easton	57–
Emporium	42–
Erie	12, 35+, °41–, 66+
Harrisburg	27–, 55+, 71+
Hazleton	63
Johnstown	6, 19+, 56–
Lancaster	8–, 21+
Lebanon	15+
Lewistown	75–
Lock Haven	32
Meadville	62+
New Castle. (*See* Youngstown, Ohio.)	
Oil City	64
Philadelphia	3, 6–, 10, 17–, 23+, 29, °35–
Pittsburgh	2, 4+, 11, °13–, 16, 47, 53+
Reading	33+, 61+
Scranton	16–, 22–, 44
Shamokin	65
Sharon	39+
Shinglehouse	26–
State College	°48+
Sunbury	38
Uniontown	11
Washington	63–
Wilkes-Barre	28, 34
Williamsport	36–
York	43, 49
Rhode Island:	
Providence	10–, 12+, 16, °36+
South Carolina:	
Aiken	54
Anderson	40, 58–
Camden	14
Charleston	2+, 4, 5+, °13, 17+
Clemson	°68
Columbia	10, °19+, 25–, 67+
Conway	23–
Florence	8–, 60
Georgetown	27–
Greenville	4–, 23+, °29
Greenwood	21–
Lake City	55+
Lancaster	31–
Laurens	45–
Marion	43–
Newberry	70
Orangeburg	44–
Rock Hill	61–
Spartanburg	7+, 17–, 74–
Sumter	47
Union	65–
South Dakota:	
Aberdeen	9–, 17+
Belle Fourche	23+
Brookings	°8, 25
Hot Springs	17+
Huron	12+, 15+
Lead	5–, 26
Madison	46
Mitchell	5+, 20–
Mobridge	27–
Pierre	10+, °22+
Rapid City	3+, 7+, 15–
Reliance	6–
Sioux Falls	11, 13+, 38+, °44–
Sturgis	20
Vermillion	°2+, 41
Watertown	3–, 35+
Winner	18–
Yankton	17–
Tennessee:	
Athens	14+
Bristol, Tenn.-Bristol, Va.	5+, 46–
Chattanooga	3+, 9, 12–, 43+, 49+, °55–
Clarksville	53
Cleveland	38+
Columbia	39–
Cookeville	24, °69
Crossville	°77
Covington	19–
Dyersburg	46+
Elizabethton	22+
Fayetteville	27+
Gallatin	48+
Harriman	67
Humboldt	25
Jackson	7+, 16+
Johnson City	11–, 34+
Kingsport	28
Knoxville	6, 10+, °20+, 26–
Lawrenceburg	50+
Lebanon	58
Lexington	°11
McMinnville	46
Maryville	51
Memphis	3, 5+, °10+, 13+, 42, 48–
Morristown	54+
Murfreesboro	18–
Nashville	°2–, 4+, 5, 8+, 30+, 36+
Oak Ridge	32+
Paris	51+
Pulaski	44–
Shelbyville	56
Sneedville	°2+
Springfield	42
Tullahoma	68–
Union City	55
Texas:	
Abilene	9+, 33–
Alice	34+

	Channel No.
Texas—(*Continued*)	
Alpine	12–
Amarillo	°2–, 4, 7, 10
Athens	25+
Austin	7+, 18–, 24, °70–
Ballinger	25
Bay City	33
Beaumont-Port Arthur	4–, 6–, 12–, 31+, °37
Beeville	38–
Big Spring	4–, 34+
Bonham	43
Borger	33
Brady	15–
Breckenridge	14+
Brenham	52–
Brownfield	15
Brownsville	36
Brownsville-Harlingen-Weslaco [1]	4+, 5–
Brownwood	19
Bryan	54–
Bryan-College Station (*also see* College Station)	3+
Childress	40
Cleburne	57
Coleman	21–
College Station (*also see* Bryan-College Station)	°48–
Conroe	20+
Corpus Christi	6+, 10–, °16+, 22, 43
Corsicana	47+
Crockett	56
Crystal City	28+
Cuero	25–
Dalhart	16
Dallas	4+, 8, °13+, 23, 29, 73
Del Rio	16–
Denison	52
Denton	°2, 17
Eagle Pass	26
Edinburg	26–
El Campo	27
El Paso	4, °7, 9, 13, 20+, 26+
Falfurrias	52
Floydada	45
Fort Stockton	22
Fort Worth	5+, 11–, 20–, °26–
Gainesville	49–
Galveston	35–, 41–, °47–
Gonzales	64+
Greenville	69–
Harlingen (*also see Brownsville-*Harlingen-Weslaco)	23
Hebbronville	58
Henderson	42+
Hereford	19–
Hillsboro	63
Houston	2–, °8–, 11+, 13–, 23+, 29–, 39–
Huntsville	15
Jacksonville	36–
Jasper	49+
Kermit	14
Kilgore	59–
Kingsville	40
Lamesa	28
Lampasas	40–
Laredo	8, 13, °15+
Levelland	38–
Littlefield	32
Longview	32, 38+
Lubbock	5–, 11, 13–, °20, 26
Lufkin	9, 46–
McAllen	20–
McKinney	65–
Marfa	19+
Marshall	16
Mercedes	32
Mexia	50–
Midland	2+, 18
Mineral Wells	38
Mission	14
Monahans	9–
Mount Pleasant	35
Nacogdoches	19–, 40+
New Braunfels	62–
Odessa	7–, 24–
Orange	43–
Pampa	17–
Paris	33+
Pearsall	31
Pecos	16+
Perryton	22
Plainview	29+
Port Arthur. (*See* Beaumont.)	
Quanah	42
Raymondville	42
Rosenberg	17–
San Angelo	3–, 8+, 17+, °23–
San Antonio	4, 5, °9–, 12+, 35+, 41+
San Benito	48
San Marcos	53+
Seguin	14–
Seymour	24+
Sherman	46+
Snyder	30+
Stephenville	32+
Sulphur Springs	41
Sweetwater	12
Taylor	58+
Temple	6, 16, 22+
Terrell	53
Texarkana	6+, °18, 24–
Tyler	7, 61+, 72
Uvalde	20
Vernon	18+
Victoria	19+
Waco	10+, °28–, 34
Waxahachie	45–
Weatherford	51
Weslaco. (*See* Brownsville-Harlingen-Weslaco.)	
Wichita Falls	3, 6–, °16+, 22–

[1] These assignments may be utilized in any community lying within the area of the triangle formed by Brownsville, Harlingen and Weslaco.

	Channel No.
Utah:	
Brigham	36–
Cedar City	5
Logan	12–, 30, °46
Ogden	9+, °18–, 24
Price	6
Provo	11+, 22, °28
Richfield	13+
St. George	13+
Salt Lake City	2–, 4–, 5+, °7–, 20+, 26
Tooele	44
Vernal	3+
Vermont:	
Bennington	74+
Brattleboro	77+
Burlington	3, °16+, 22+
Montpelier	57
Newport	46
Rutland	49+
St. Albans	34–
St. Johnsbury	30
Virginia:	
Blacksburg	°60+
Bristol. (*See* Bristol, Tenn.)	
Charlottesville	°45+, 64+
Covington	44+
Danville	24–
Emporia	25+
Farmville	19
Fredericksburg	47
Front Royal	39–
Harrisonburg	3–, 34–
Lexington	54
Lynchburg	13, 16–
Marion	50
Martinsville	35–
Newport News. (*See* Norfolk-Portsmouth-Newport News.)	
Norfolk-Portsmouth	27
Norfolk-Portsmouth-Newport News	3+, 10+, 13–, 15, °21–, 33
Norton	52+
Petersburg	8, 41
Portsmouth. (*See* Norfolk-Portsmouth and *also see* Norfolk-Portsmouth-Newport News.)	
Pulaski	37–
Richmond	6+, 12–, °23, 29+
Roanoke	7–, 10, 27+, °33–
South Boston	14+
Staunton	36
Waynesboro	42
Williamsburg	17
Winchester	28+
Washington:	
Aberdeen	58
Anacortes	34
Bellingham	12+, 18+, 24–
Bremerton	44, 50
Centralia	17
Clarkston	34+, 40+
Ellensburg	49, °65
Ephrata	16–, 43
Everett	22–, 28–
Grand Coulee	37
Hoquiam	52
Kelso	39
Kennewick	31
Kennewick-Richland-Pasco	°41
Longview	33
Moses Lake	61
Okanogan. (*See* Omak.)	
Olympia	60
Omak-Okanogan	°35–
Pasco (*also see* Kennewick-Richland-Pasco)	19–
Port Angeles	16+
Pullman	°10–, 24
Richland (*also see* Kennewick-Richland-Pasco)	25
Seattle	4, 5+, 7, °9, 20, 26+
Spokane	2–, 4–, 6–, °7+
Tacoma	11+, 13–, °56, 62
Walla Walla	5–, 8, °22
Wenatchee	°45, 55, 67
Yakima	23+, 29+, °47
West Virginia:	
Beckley	4, 21, 66
Bluefield	6–, 41+
Charleston	8+, °43+, 49–
Clarksburg	12+, 22, 69–
Elkins	40+
Fairmont	35
Hinton	31
Huntington	3+, 13+, °53–
Logan	23–
Martinsburg	58–
Morgantown	°24
Parkersburg	15–
Welch	25
Weston	5, 32
Wheeling	°57+
Wheeling-Steubenville, Ohio	7, 9+, 51+
Williamson	17
Wisconsin:	
Adams	°58+
Appleton	42+
Ashland	15+
Beaver Dam	37
Beloit	57
Chilton	°24+
Eau Claire	13, °19+, 25+
Fond du Lac	54+
Green Bay	2+, 5+, 70+
Janesville	63+
Kenosha	61–
La Crosse	8+, °32+, 38–, 72
Madison	3, °21–, 27–, 33+
Manitowoc	65
Marinette	11+, 32–, °38+
Milwaukee	4–, °10+, 12, 19–, 25, 31–
Oshkosh	48–
Park Falls	°18
Portage	17–

	Channel No.
Wisconsin—(*Continued*)	
Prairie du Chien	34
Racine	49–, 55
Rhinelander	22
Rice Lake	21+
Richland Center	15, °66–
Sheboygan	59–
Shell Lake	°30–
Sparta	50
Stevens Point	20+, 26–
Sturgeon Bay	44–
Superior. (*See* Duluth, Minn.)	
Wausau	7–, 9, 16+, °46–
Whitefish Bay	6
Wisconsin Rapids	14–
Wyoming:	
Buffalo	29
Casper	2+, 6+
Cheyenne	5+
Cody	24–
Douglas	14
Evanston	14–
Gillette	31–
Green River	16
Greybull	40
Lander	17–
Laramie	°8+, 18+
Lovell	36+
Lusk	19–
Newcastle	28+
Powell	30+
Rawlins	11–
Riverton	10+
Rock Springs	13
Sheridan	9–, 12+
Thermopolis	15
Torrington	27
Wheatland	24+
Worland	34
U. S. TERRITORIES AND POSSESSIONS	
Guam:	
Agana	8, 10
Puerto Rico:	
Arecibo-Aguadilla	12+
Caguas	11–
Fajardo	13+
Mayaguez	3+, 5–
Ponce	7+, 9–
San Juan	2+, 4–, °6+
Virgin Islands:	
Charlotte Amalie	10–
Christiansted	8+

§ 3.607 Availability of channels. (a) Subject to the provisions of paragraph (b) of this section, applications may be filed to construct television broadcast stations only on the channels assigned in the Table of Assignments (§ 3.606(b)) and only in communities listed therein. Applications which fail to comply with this requirement, whether or not accompanied by a petition to amend the Table, will not be accepted for filing: *Provided, however,* That applications specifying channels which accord with publicly announced Commission Orders changing the Table of Assignments will be accepted for filing even though such applications are tendered before the effective dates of such channel changes.

(b) A channel assigned to a community listed in the Table of Assignments is available upon application in any unlisted community which is located within 15 miles of the listed community. In addition, a channel assigned to a community listed in the Table of Assignments and not designated for use by noncommercial educational stations only, is available upon application in any other community within 15 miles thereof which, although listed in the Table, is assigned only a channel designated for use only by noncommercial educational stations. Where channels are assigned to two or more communities listed in combination in the Table of Assignments the provisions of this paragraph shall apply separately to each community so listed. The distance between communities shall be determined by the distance between the respective coordinates thereof as set forth in the publication of the United States Department of Commerce entitled "Air Line Distance Between Cities in the United States." (This publication may be purchased from the Government Printing Office, Washington, D.C.) If said publication does not contain the coordinates of either or both communities, the coordinates of the main post office in either or both of such communities shall be used. The method to be followed in making the measurements is set forth in § 3.611(d).

§ 3.608 International agreements Authorizations issued by the Commission for television broadcast facilities will be subject to the provisions of any agreements entered into by the United States with Canada and Mexico concerning television assignments and authorizations. Where, pursuant to such an agreement, timely objection is received from the foreign country involved to an authorization granted by

the Commission, the Commission may, on its own motion, set aside such authorization pending consideration of such objection. Upon receipt of such objection, the Commission will notify the person to whom such authorization has been issued.

§ 3.609 **Zones.** (a) For the purpose of allocation and assignment, the United States is divided into three zones as follows:

(1) Zone I consists of that portion of the United States located within the confines of the following lines drawn on the United States Albers Equal Area Projection Map (based on standard parallels 29½° and 45½°; North American datum): Beginning at the most easterly point on the State boundary line between North Carolina and Virginia; thence in a straight line to a point on the Virginia, West Virginia boundary line located at North Latitude 37° 49′ and West Longitude 80° 12′ 30″; thence westerly along the southern boundary lines of the States of West Virginia, Ohio, Indiana and Illinois to a point at the junction of the Illinois, Kentucky, and Missouri State boundary lines; thence northerly along the western boundary line of the State of Illinois to a point at the junction of the Illinois, Iowa, and Wisconsin State boundary lines; thence easterly along the northern State boundary line of Illinois to the 90th meridian; thence north along this meridian to the 43.5° parallel; thence east along this parallel to the 71st meridian; thence in a straight line to the intersection of the 69th meridian and the 45th parallel; thence east along the 45th parallel to the Atlantic Ocean. When any of the above lines pass through a city, the city shall be considered to be located in Zone I. (See Figure 1 of § 3.699.)

(2) Zone II consists of that portion of the United States which is not located in either Zone I or Zone III, and Puerto Rico, Alaska, Hawaiian Islands and the Virgin Islands.

(3) Zone III consists of that portion of the United States located south of a line, drawn on the United States Albers Equal Area Projection Map (based on standard parallels 29½° and 45½°; North American datum), beginning at a point on the east coast of Georgia and the 31st parallel and ending at the United States-Mexican border, consisting of arcs drawn with a 150 mile radius to the north from the following specified points:

	North latitude	*West longitude*
(*a*)	29°40′00″	83°24′00″
(*b*)	30°07′00″	84°12′00″
(*c*)	30°31′00″	86°30′00″
(*d*)	30°48′00″	87°58′30″
(*e*)	30°00′00″	90°38′30″
(*f*)	30°04′30″	93°19′00″
(*g*)	29°46′00″	95°05′00″
(*h*)	28°43′00″	96°30′30″
(*i*)	27°52′30″	97°32′00″

When any of the above arcs pass through a city, the city shall be considered to be located in Zone II. (See Figure 2 of § 3.699.)

§ 3.610 **Separations.** (a) The provisions of this section relate to assignment separations and station separations. Petitions to amend the Table of Assignments (§ 3.606(b)) (other than those also expressly requesting amendment of this section or § 3.609) will be dismissed and all applications for new television broadcast stations or for changes in the transmitter sites of existing stations will not be accepted for filing if they fail to comply with the requirements specified in paragraphs (b), (c) and (d) of this section:

NOTE: Licensees and permittees of television broadcast stations which were operating on April 14, 1952, pursuant to one or more separations below those set forth in § 3.610 may continue to so operate, but in no event may they further reduce the separations below the minimum. As the existing separations of such stations are increased, the new separations will become the required minimum separations until separations are reached which comply with the requirements of § 3.610. Thereafter, the provisions of said section shall be applicable.

(b) Minimum co-channel assignment and station separations:
(1)

Zone	Channels 2–13	Channels 14–83
	Miles	*Miles*
I	170	155
II	190	175
III	220	205

(2) The minimum co-channel mileage separation between a station in one zone and a station in another zone shall be that of the zone requiring the lower separation.

(c) Minimum assignment and station adjacent channel separations applicable to all zones: *

(1) Channels 2–13 Channels 14–83
60 miles 55 miles

(2) Due to the frequency spacing which exists between Channels 4 and 5, between Channels 6 and 7, and between Channels 13 and 14, the minimum adjacent channel separations specified above shall not be applicable to these pairs of channels (see § 3.603).

(d) In addition to the requirements of paragraphs (a), (b) and (c) of this section, the minimum assignment and station separations between stations on Channels 14–83, inclusive, as set forth in Table IV of § 3.698 must be met in either rule-making proceedings looking towards the amendment of the Table of Assignments (§ 3.606(b)) or in licensing proceedings. No channel listed in column (1) of Table IV of § 3.698 will be assigned to any city, and no application for an authorization to operate on such a channel will be granted unless the mileage separations indicated at the top of columns (2)–(7), inclusive, are met with respect to each of the channels listed in those columns and parallel with the channel in column (1).

(e) The zone in which the transmitter of a television station is located or proposed to be located determines the applicable rules with respect to co-channel mileage separations where the transmitter is located in a different zone from that in which the channel to be employed is located.

§ 3.611 Reference points and distance computations. (a) In considering petitions to amend the Table of Assignments (§ 3.606(b)), the following reference points shall be used by the Commission in determining assignment separations between communities:

(1) Where transmitter sites for the pertinent channels have been authorized in communities involved in a petition to amend the Table of Assignments, separations between such communities shall be determined by the distance between the coordinates of the authorized transmitter sites in the respective communities as set forth in the Commission's authorizations therefor.

(2) Where an authorized transmitter site is available for use as a reference point in one community but not in the other for the pertinent channels, separations shall be determined by the distance between the coordinates of the transmitter site as set forth in the Commission's authorization therefor and the coordinates of the other community as set forth in the publication of the United States Department of Commerce entitled "Air Line Distances Between Cities in the United States." If said publication does not contain the coordinates for said other community, the coordinates of the main post office thereof shall be used.

(3) Where no authorized transmitter sites are available for use as reference points in both communities for the pertinent channels, the distance between the two communities listed in the above publication shall be used. If said publication does not contain such distance, the separation between the two communities shall be determined by the distance between the coordinates thereof as set forth in said publication.

* See Doc. 13340 for proposed revision of VHF adjacent channel separations.

Where such coordinates are not contained in said publication, the coordinates of the main post offices of said communities shall be used.

(4) Where the distance between the reference point in a community to which a channel is proposed to be assigned and the reference point in another community or communities does not meet the minimum separation requirements of § 3.610, the channel may be assigned to such community upon a showing that a transmitter site is available that would meet the minimum separation requirements of § 3.610 and the minimum field intensity requirements of § 3.685. In such cases, where a station is not authorized in the community or communities to which measurements from the proposed channel assignment must be made pursuant to § 3.610, a showing should also be made that the distance between suitable transmitter sites in such other community or communities and the proposed transmitter site for the new channel meet the Commission's minimum spacing and coverage requirements.

(b) Station separations in licensing proceedings shall be determined by the distance between the coordinates of the proposed transmitter site in one community and

(1) The coordinates of an authorized transmitter site for the pertinent channel in the other community; or, where such transmitter site is not available for use as a reference point,

(2) The coordinates of the other community as set forth in the above-described publication of the United States Department of Commerce; or, if not contained therein,

(3) The coordinates of the main post office of such other community.

(4) In addition, where there are pending applications in other communities which, if granted, would have to be considered in determining station separations, the coordinates of the transmitter sites proposed in such applications must be used to determine whether the requirements with respect to minimum separations between the proposed stations in the respective cities have been met.

(c) In measuring assignment and station separations involving cities listed in the Table in combination, where there is no authorized transmitter site in any of the combination cities on the channel involved, separation measurements shall be made from the reference point which will result in the lowest separation.

(d) The distance between reference points is considered to be the length of the hypotenuse of a right triangle, one side of which is the difference in latitude of the reference points and the other side the difference in longitude of the two reference points, and shall be computed as follows: (This method is appropriate for determining distances up to 220 miles, and for such distances will normally be more accurate than using spherical trigonometry without correction for the spheroidal shape of the earth. However, its accuracy deteriorates rapidly at distances beyond 300 miles and this method should not be used to compute greater distances.)

(1) Determine the difference in latitude and the difference in longitude between the two reference points. Convert these two differences into degrees and decimal parts of a degree in accordance with Table I of § 3.698.

(2) Determine the middle latitude of the two reference points to the nearest second of latitude (average the latitudes of the two points).

(3) Multiply the difference in latitude by the number of miles per degree of latitude difference obtained from Table II of § 3.698 for the appropriate middle latitude (interpolate linearly). This determines the North-South distance in statute miles.

NOTE: In determining necessary distance computations for the Territories, the appropriate mileage per degree may be obtained by linear interpolation of the data given on pages 122 and 123 of the tables in publication H. O. No. 9 (Bowditch-American Practical Navigator—1943 Edition) of the U.S. Navy Dept., Hydrographic Office. This publication may be purchased from the Government Printing Office, Washington, D.C.

(4) Multiply the difference in longitude by the number of miles per degree of longitude difference obtained from Table III of § 3.698, for the appropriate middle latitude (interpolate linearly). This determines the East-West distance in statute miles.

(5) Determine the distance between the two reference points by the square root of the sum of the squares of the distances obtained in subparagraphs (3) and (4) of this paragraph, i.e.

$$D = (L_a^2 + L_o^2)^{1/2}$$

where D = distance in statute miles
L_a = North-South distance in miles from (3) above
L_o = East-West distance in miles from (4) above

In computing the above, sufficient decimal figures shall be used to determine the distance to the nearest mile.

§ 3.612 Protection from interference. Permittees and licensees of television broadcast stations are not protected from any interference which may be caused by the grant of a new station or of authority to modify the facilities of an existing station in accordance with the provisions of this subpart. The nature and extent of the protection from interference accorded to television broadcast stations is limited solely to the protection which results from the minimum assignment and station separation requirements and the rules with respect to maximum powers and antenna heights set forth in this subpart.

NOTE: The nature and extent of the protection from interference accorded to television broadcast stations which were authorized prior to April 14, 1952, and which were operating on said date is limited not only as specified above but is further limited by any smaller separations existing between such stations on said date. Where, as a result of the adoption of the Table of Assignments, or of changes in transmitter sites made by such stations after said date, separations smaller than the required minimum are increased but still remain lower than the required minimum, protection accorded such stations will be limited to the new separations.

§ 3.613 Main studio location. (a) The main studio of a television broadcast station shall be located in the principal community to be served. Where the principal community to be served is a city, town, village or other political subdivision, the main studio shall be located within the corporate boundaries of such city, town, village or other political subdivision. Where the principal community to be served does not have specifically defined political boundaries, applications will be considered on a case-to-case basis in the light of the particular facts involved to determine whether the main studio is located within the principal community to be served.

(b) In cases where an adequate showing is made that there is good cause for locating a main studio outside the principal community to be served and that to do so would not be inconsistent with the operation of the station in the public interest, the Commission will permit the use of a main studio location other than that specified in paragraph (a) of this section. The licensee or permittee of a television broadcast station shall not move his main studio outside the principal community in which it is located without first securing a modification of construction permit or license. Such licensee or permittee shall notify the Commission promptly of any change of the location of the main studio within the community. In any case where the main studio is located outside the principal community to be served, the licensee or permittee of a television broadcast station shall not move his main studio without first securing a modification of construction permit or license.

§ 3.614 Power and antenna height requirements. (a) *Minimum requirements.* Applications will not be accepted for filing if they specify less than −10 dbk (100 watts) visual effective radiated power in any horizontal direction. No minimum antenna height above average terrain is specified.

(b) *Maximum power.* Applications will not be accepted for filing if they specify a power in excess of that provided for in this paragraph. Except as provided in subparagraph (1) of this paragraph, the maximum effective radiated powers of television broadcast stations operating on the channels set forth below with antenna heights not in excess of 2,000 feet above average terrain shall be as follows:

Channel Nos.	Maximum visual effective radiated power in db. above one kilowatt (dbk.)
2–6	20 dbk. (100 kw.)
7–13	25 dbk. (316 kw.)
14–83	37 dbk. (5000 kw.)[1]

[1] The maximum visual effective radiated power of television broadcast stations operating on Channels 14–83 within 250 miles of the Canadian-USA border may not be in excess of 30 dbk (1000 kw).

(1) In Zone I, on Channels 2–13, inclusive, the maximum powers specified above for these channels may be used only with antenna heights not in excess of 1,000 feet above average terrain. Where antenna heights exceeding 1,000 feet above average terrain are used on Channels 2–13, or antenna heights exceeding 2,000 feet above average terrain are used on Channels 14–83, the maximum power shall be based on the chart designated as Figure 3 of § 3.699.

NOTE: This limitation shall not apply to any licensee or permittee in Zone I who received an authorization after March 22, 1951, to relocate its transmitter site and construct a new tower and antenna to a height in excess of 1000 feet above average terrain and who constructed or who had substantially completed construction of said tower and antenna prior to April 14, 1952. In such case, maximum power may be utilized at the height above average terrain specified in the authorization. The limitation shall apply, however, where the tower or other principal supporting structure had been constructed prior to the date of such authorization.

(2) In Zones II and III, the maximum powers which may be used by television broadcast stations operating on the respective channels set forth in the above table with antenna heights exceeding 2,000 feet above average terrain shall be based on the chart designated as Figure 4 of § 3.699.

(3) The effective radiated power in any horizontal or vertical direction may not exceed the maximum values permitted by this section and Figures 3 and 4 of § 3.699.

(4) The maximum effective radiated power in any direction above the horizontal plane shall be as low as the state of the art permits and may not exceed the effective radiated power in the horizontal direction in the same vertical plane.

(c) *Determination of applicable rules.* The zone in which the transmitter of a television station is located or proposed to be located determines the applicable rules with respect to maximum antenna heights and powers for VHF stations when the transmitter is located in Zone I and the channel to be employed is located in Zone II, or the transmitter is located in Zone II and the channel to be employed is located in Zone I.

§ 3.615 Administrative changes in authorizations. In the issuance of television broadcast station authorizations, the Commission will specify the transmitter output power and effective radiated power to the nearest 0.1 dbk. Powers specified by kilowatts shall be obtained by converting dbk to kilowatts to 3 significant figures. Antenna heights above average terrain will be specified to the nearest 10 feet. Midway figures will be authorized in the lower alternative.

Applications and Authorizations

§ 3.620 Cross reference. See § 1.300 to 1.364, Subpart D of Part 1 of this chapter, for general requirements as to applications, filing of applications and description of application forms, other forms and information to be filed with the Commission, the manner in which applications are processed, and provisions applying to action on applications.

§ 3.621 Noncommercial educational stations. In addition to the other provisions of this subpart, the following shall be applicable to noncommercial educational television broadcast stations:

(a) Except as provided in paragraph (b) of this section, noncommercial educational broadcast stations will be licensed only to nonprofit educational organizations upon a showing that the proposed stations will be used primarily to serve the educational needs of the community; for the advancement of educational programs; and to furnish a nonprofit and noncommercial television broadcast service.

(1) In determining the eligibility of publicly supported educational organizations, the accreditation of their respective state departments of education shall be taken into consideration.

(2) In determining the eligibility of privately controlled educational organizations, the accreditation of state departments of education or recognized regional and national educational accrediting organizations shall be taken into consideration.

(b) Where a municipality or other political subdivision has no independently constituted educational organization such as, for example, a board of education having autonomy with respect to carrying out the municipality's educational program, such municipality shall be eligible for a noncommercial educational television broadcast station. In such circumstances, a full and detailed showing must be made that a grant of the application will be consistent with the intent and purpose of the Commission's Rules relating to such stations.

(c) Noncommercial educational television broadcast stations may transmit educational, cultural and entertainment programs, and programs designed for use by schools and school systems in connection with regular school courses, as well as routine and administrative material pertaining thereto.

(d) An educational station may not broadcast programs for which a consideration is received, except programs produced by or at the expense of or furnished by others than the licensee for which no other consideration than the furnishing of the program is received by the licensee. The payment of line charges by another station or network shall not be considered as being prohibited by this paragraph.

(e) To the extent applicable to programs broadcast by a noncommercial educational station produced by or at the expense of or furnished by others than the licensee of said station, the provisions of § 3.654 relating to announcements regarding sponsored programs shall be applicable, except that no announcements (visual or aural) promoting the sale of a product or service shall be transmitted in connection with any program; provided, however, that where a sponsor's name or product appears on the visual image during the course of a simultaneous or rebroadcast program, either on the backdrop or in similar form, the portions of the program showing such information need not be deleted.

§ 3.622 Applications for sharing television channels. Separate applications shall be filed by each applicant for the voluntary sharing of television channels. Such applications shall be accompanied by copies of the time-sharing agreements under which the applicants propose to operate.

§ 3.623 In order to minimize harmful interference at the National Radio Astronomy Observatory site located at Green Bank, Pocahontas County, West Virginia, and at the Naval Radio Research Observatory at Sugar Grove, Pendleton County, West Virginia, an applicant for authority to construct a new television broadcast station or for authority to make changes in the frequency, power, antenna height, or antenna directivity of an existing station within the area bounded by 39°15′ N on the north, 78°30′ W on the east, 37°30′ N on the south and 80°30′ W on the west shall, at the time of filing such application with the Commission, simultaneously notify the Director, National Radio Astronomy Observatory, P.O. Box #2, Green Bank, West Virginia, in writing, of the technical particulars of the proposed station. Such notification shall include the geographical coordinates of the antenna, antenna height, antenna directivity if any, proposed frequency, type of emission, and power. In addition, the applicant shall indicate in his application to the Commission the date notification was made to the Observatory. After receipt of such applications, the Commission will allow a period of twenty (20) days for comments or objections in response to the notifications indicated. If an objection to the proposed operation is received during the twenty-day period from the National Radio Astronomy Observatory for itself or on behalf of the Naval Radio Research Observatory, the Commission

will consider all aspects of the problem and take whatever action is deemed appropriate.

§ 3.628 **Equipment tests.** (a) During the process of construction of a television broadcast station, the permittee, after notifying the Commission and Engineer in Charge of the radio district in which the station is located may, without further authority of the Commission, conduct equipment tests for the purpose of such adjustments and measurements as may be necessary to assure compliance with the terms of the construction permit, the technical provisions of the application therefor, and the rules and regulations.

(b) The Commission may notify the permittee to conduct no tests or may cancel, suspend, or change the date for the beginning of equipment tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Equipment tests may be continued so long as the construction permit shall remain valid.

(d) Inspection of a station will ordinarily be required during the equipment test period and before the commencement of program tests. After construction and after adjustments and measurements have been completed to show compliance with the terms of the construction permit, the technical provisions of the application therefor, and the rules and regulations, the permittee should notify the Engineer in Charge of the radio district in which the station is located that it is ready for inspection.

(e) The authorization for tests embodied in this section shall not be construed as constituting a license to operate but as a necessary part of construction.

§ 3.629 **Program tests.** (a) Upon completion of construction of a television broadcast station in accordance with the terms of the construction permit, the technical provisions of the application therefor, and the rules and regulations, and when an application for station license has been filed showing the station to be in satisfactory operating condition, the permittee may request authority to conduct program tests: *Provided,* That such request shall be filed with the Commission at least ten (10) days prior to the date on which it is desired to begin such operation and that the Engineer in Charge of the radio district in which the station is located is notified. (All data necessary to show compliance with the terms and conditions of the construction permit must be filed with the license application.)

(b) Program tests shall not commence until specific Commission authority is received. The Commission reserves the right to change the date of the beginning of such tests or to suspend or revoke the authority for program tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Unless sooner suspended or revoked, the program test authority continues valid during Commission consideration of the application for license and during this period further extension of the construction permit is not required. Program test authority shall be automatically terminated by final determination upon the application for station license.

(d) All operation under program test authority shall be in strict compliance with the rules governing television broadcast stations and in strict accordance with representations made in the application for license pursuant to which the tests were authorized.

(e) The granting of program test authority shall not be construed as approval by the Commission of the application for station license.

§ 3.630 **Normal license period.** (a) All television broadcast station licenses will be issued for a normal license period of three years. Licenses will be issued to expire at the hour of 3:00 a.m., e.s.t., in accordance with the following schedule and at three-year intervals thereafter.

(1) For stations located in Delaware and Pennsylvania, August 1, 1957.

(2) For stations located in Maryland, District of Columbia, Virginia, West Virginia, October 1, 1957.

(3) For stations located in North Carolina, South Carolina, December 1, 1957.

(4) For stations located in Florida, Puerto Rico, and Virgin Islands, February 1, 1958.

(5) For stations located in Alabama and Georgia, April 1, 1958.

(6) For stations located in Arkansas, Louisiana, and Mississippi, June 1, 1958.
(7) For stations located in Tennessee, Kentucky, and Indiana, August 1, 1958.
(8) For stations located in Ohio and Michigan, October 1, 1958.
(9) For stations located in Illinois and Wisconsin, December 1, 1958.
(10) For stations located in Iowa and Missouri, February 1, 1956.
(11) For stations located in Minnesota, North Dakota, South Dakota, Montana, and Colorado, April 1, 1956.
(12) For stations located in Kansas, Oklahoma, Nebraska, June 1, 1956.
(13) For stations located in Texas, August 1, 1956.
(14) For stations located in Wyoming, Nevada, Arizona, Utah, New Mexico, and Idaho, October 1, 1956.
(15) For stations located in California, December 1, 1956.
(16) For stations located in Washington, Oregon, Alaska, Guam and Hawaii, February 1, 1960.
(17) For stations located in Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, April 1, 1957.
(18) For stations located in New Jersey and New York, June 1, 1957.

§ 3.632 Emergency weather warnings. Upon receipt of notification of an Emergency Weather Warning of a condition of immediate danger to life and property from the United States Weather Bureau, all television broadcast stations may, at their option, broadcast CONELRAD Attention Signals (two five-second carrier breaks and fifteen seconds of 1,000 CPS tone sound carrier only) followed by the Emergency Weather Warning as outlined in CONELRAD Manual BC-3 (Revised), Appendix A.

§ 3.635 Use of common antenna site. No television license or renewal of a television license will be granted to any person who owns, leases, or controls a particular site which is peculiarly suitable for television broadcasting in a particular area and (a) which is not available for use by other television licensees; and (b) no other comparable site is available in the area; and (c) where the exclusive use of such site by the applicant or licensee would unduly limit the number of television stations that can be authorized in a particular area or would unduly restrict competition among television stations.

§ 3.636 Multiple ownership. (a) No license for a television broadcast station shall be granted to any party (including all parties under common control) if:

(1) Such party directly or indirectly owns, operates, or controls another television broadcast station which serves substantially the same area; or

(2) Such party, or any stockholder, officer or director of such party, directly or indirectly owns, operates, controls, or has any interest in, or is an officer or director of any other television broadcast station if the grant of such license would result in a concentration of control of television broadcasting in a manner inconsistent with public interest, convenience, or necessity. In determining whether there is such a concentration of control, consideration will be given to the facts of each case with particular reference to such factors as the size, extent and location of area served, the number of people served, and the extent of other competitive service to the areas in question. The Commission, however, will in any event consider that there would be such a concentration of control contrary to the public interest, convenience or necessity for any party or any of its stockholders, officers or directors to have a direct or indirect interest in, or be stockholders, officers, or directors of, more than seven television broadcast stations, no more than five of which may be in the VHF band.

(b) Paragraph (a) of this section is not applicable to noncommercial educational stations.

NOTE 1: The word "control" as used herein is not limited to majority stock ownership, but includes actual working control in whatever manner exercised.

NOTE 2: In applying the provisions of paragraph (a) of this section to the stockholders of a corporation which has more than 50 voting stockholders, only those stockholders need be considered who are officers or directors or who directly or indirectly own 1 percent or more of the outstanding voting stock.

§ 3.637 Alternate main transmitters. The licensee of a television broadcast station may be licensed for alternate main transmitters provided that a technical need for such alternate transmitters is shown and that the following conditions are met:

(a) Both transmitters are located at the same place.

(b) Both transmitters shall have the same power rating.

(c) Both transmitters shall meet the construction, installation, operation and performance requirements of this subpart.

§ 3.638 Auxiliary transmitter. Upon showing that a need exists for the use of auxiliary transmitters in addition to the regular transmitters of a television station, a license therefor may be issued: *Provided,* That:

(a) Auxiliary transmitters may be installed either at the same location as the main transmitters or at another location.

(b) A licensed operator shall be in control whenever auxiliary transmitters are placed in operation.

(c) The auxiliary transmitters shall be maintained so that they may be put into immediate operation at any time for the following purposes:

(1) The transmission of the regular programs upon the failure of the main transmitters.

(2) The transmission of regular programs during maintenance or modification work on the main transmitters necessitating discontinuance of their operation for a period not to exceed 5 days.

NOTE: This includes the equipment changes which may be made without authority as set forth elsewhere in the rules and regulations or as authorized by the Commission by letter or by construction permit. Where such operation is required for periods in excess of 5 days, request therefor shall be in accordance with § 1.324 of the Commission's rules.

(3) Upon request by a duly authorized representative of the Commission.

(d) The auxiliary transmitters shall be tested at least once each week to determine that they are in proper operating condition and that they are adjusted to the proper frequency, except that in the case of operation in accordance with paragraph (c) of this section during any week, the test in that week may be omitted provided the operation under paragraph (c) of this section is satisfactory. A record shall be kept of the time and result of each test. Such records shall be retained for a period of two years.

(e) The auxiliary transmitters shall be equipped with satisfactory control equipment which will enable the maintenance of the frequency emitted by the station within the limits prescribed by the regulations in this subpart.

(f) The operating power of an auxiliary transmitter may be less than the authorized power of the main transmitters, but in no event shall it be greater thau such power.

§ 3.639 Changes in equipment and antenna system. Licensees of television broadcast stations shall observe the following provisions with regard to changes in equipment and antenna system:

(a) No changes in equipment shall be made:

(1) That would result in the emission of signals outside of the authorized channel.

(2) That would result in the external performance of the transmitter being in disagreement with that prescribed in this subpart.

(b) Specific authority, upon filing formal application therefor (FCC Form 301 or such other form as is provided therefor), is required for any of the following changes:

(1) Changes involving an increase or decrease in the power rating of the transmitters.

(2) A replacement of the transmitters as a whole.

(3) Change in the location of the transmitting antenna.

(4) Change in antenna system, including transmission line.

(5) Change in the power delivered to the antenna.

(6) Change in frequency control and/or modulation system.

(c) Other changes, except as above provided for in this section or in the provisions of this subpart, may be made at any time without the authority of the Commission, provided that the Commission shall be promptly notified thereof and such changes shall be shown in the next application for renewal of license.

§ 3.640 Acceptability of broadcast transmitters for licensing. (a) In order to facilitate the filing of, and action on, applications for station authorizations, trans-

mitters will be accepted for licensing by the Commission under one of the following conditions:

(1) A transmitter may be type-accepted upon the request of any manufacturer of transmitters built in quantity by following the type acceptance procedure set forth in Part 2 of this chapter, provided that the data and information submitted indicates that the transmitter meets the requirements of § 3.687. If accepted, such transmitter will be included on the Commission's "Radio Equipment List, Part A, Television Broadcast Equipment." Applicants specifying transmitters included on such a list need not submit detailed descriptions and diagrams where the correct type number is specified, provided that the equipment proposed is identical with that accepted. Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(2) An application specifying a transmitter not included on the Radio Equipment List, Part A, may be accepted upon the request of a prospective licensee submitting with the application for construction permit a complete description of the transmitter, including the circuit diagram, listing of all tubes used, function of each, multiplication in each stage, plate current and voltage applied to each tube, a description of the oscillator circuit together with any devices installed for the purpose of frequency stabilization and the means of varying output power to compensate for power supply voltage variations. However, if this data has been filed with the Commission by a manufacturer in connection with a request for type acceptance, it need not be submitted with the application for construction permit but may be referred to as "on file." Measurement data for type acceptance made in accordance with subparagraph (1) of this paragraph shall be submitted with the license application.

(3) A transmitter shown on an instrument of authorization by manufacturer and type number, or as a composite, and which was in use prior to June 30, 1955, may continue to be used by the licensee, his successors or assignees, provided such transmitter continues to comply with the rules and regulations.

(b) Additional rules with respect to withdrawal of type-acceptance, modification of type-accepted equipment and limitations on the findings upon which type acceptance is based are set forth in Part 2 of this chapter.

General Operating Requirements

§ 3.651 Time of operation. (a) All television broadcast stations will be licensed for unlimited time operation. Each such station shall maintain a regular program operating schedule as follows: not less than 2 hours daily in any five broadcast days per week and not less than a total of 12 hours per week during the first 18 months of the station's operation; not less than 2 hours daily in any 5 broadcast days per week and not less than a total of 16 hours, 20 hours and 24 hours per week for each successive 6-month period of operation, respectively; and not less than 2 hours in each of the 7 days of the week and not less than a total of 28 hours per week thereafter. "Operation" includes the period during which a station is operated pursuant to special temporary authority or during program tests, as well as during the license period. Time devoted to test patterns, or to aural presentations accompanied by the incidental use of fixed visual images which have no substantial relationship to the subject matter of such aural presentations, shall not be considered in computing periods of program service. If, in the event of an emergency due to causes beyond the control of a licensee, it becomes impossible to continue operation, the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified in writing immediately after the emergency develops and immediately after the emergency ceases and operation is resumed.

(b) Noncommercial educational television broadcast stations are not required to operate on a regular schedule and no minimum number of hours of operation is specified; but the hours of actual operation during a license period shall be taken into consideration in considering the renewal of noncommercial educational television broadcast licenses.

(c) (1) The aural transmitter of a television station shall not be operated separately from the visual transmitter except for the following purposes:

(i) For actual tests of station equipment or actual experimentation in accordance with § 3.666; and

(ii) For emergency "fills" in case of visual equipment failure or unscheduled and unavoidable delays in presenting visual programs. In such situations the aural transmitter may be used to advise the audience of difficulties and to transmit for a short period program material of such nature that the audience will be enabled to remain tuned to the station; for example, music or news accompanying a test pattern or other visual presentation.

(2) During periods of transmission of a test pattern on the visual transmitter of a television station, aural transmission shall consist only of a single tone or series of variable tones. During periods when still pictures or slides are employed to produce visual transmissions which are accompanied by aural transmissions, the aural and visual transmissions shall be integral parts of a program or announcement and shall have a substantial relationship to each other: *Provided*, That nothing herein shall preclude the transmission of a test pattern, still pictures or slides for the following purposes and periods:

(i) To accompany aural announcements of the station's program schedule and aural news broadcasts or news commentaries, for a total period not to exceed one hour in any broadcast day.

(ii) To accompany aural transmissions for a period of time not to exceed fifteen minutes immediately prior to the commencement of a programming schedule.

Examples. (1) Duplication of AM or FM programs on the aural transmitter of a television station while the same program is broadcast on the visual transmitter (i.e., a "simulcast") is consistent with this paragraph.

(2) Duplication of AM or FM programs on the aural transmitter of a television station while a test pattern is broadcast on the visual transmitter is not consistent with this paragraph, except for the specific purposes and periods specified in paragraph (c)(2).

(3) A travel lecture in which the words of the lecturer are broadcast simultaneously with still pictures or slides of scenes illustrating the lecture, and a newscast in which the words of the newscaster are broadcast simultaneously with still pictures or slides of the news events, are examples of programs in which the aural and visual transmissions are integral parts of the same program having a substantial relationship to each other, within the meaning of paragraph (c)(2). Mood music unrelated to the visual transmission is not consistent with this paragraph.

(4) The broadcast of a test pattern accompanied by a musical composition for the purpose of demonstration, sale, installation or orientation of television receivers, or receiving antennas is not consistent with this paragraph.

(5) Music accompanying the transmission of a test pattern upon which is visually imposed a moving text consisting of continuous program material, such as a running newscast or news commentary, is consistent with this paragraph.

(6) Music accompanying the transmission of a test pattern upon which is visually imposed a clock indicating the time of day, or a text that is changed at spaced intervals, is not consistent with this paragraph.

§ 3.652 Station identification. (a) A licensee of a television broadcast station shall make station identification announcement (call letters and location) at the beginning and ending of each time of operation and during the operation on the hour. The announcement at the beginning and ending of each time of operation shall be by both aural and visual means. Other announcements may be by either aural or visual means.

(b) Identification announcements during operation need not be made when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or any type of production. In such cases, the identification announcement shall be made at the first interruption of the entertainment continuity and at the conclusion thereof.

§ 3.653 Mechanical reproductions. (a) No mechanically reproduced program, whether visual or aural, consisting of a speech, news event, news commentator, forum, panel discussion, or special event in which the element of time is of special significance, or any other program in which the element of time is of special significance and presentation of which would create, either intentionally or otherwise, the impression or belief on the part of the listening audience that the event or program being broad-

cast is in fact occurring simultaneously with the broadcast, shall be broadcast without an appropriate announcement being made either at the beginning or end of such reproduction or at the beginning or end of the program in which such reproduction is used that it is a mechanical reproduction or a mechanically reproduced program: *Provided, however,* That each such program of one minute or less need not be announced as such.

(b) The exact form of identifying announcement is not prescribed, but the language shall be clear and in terms commonly used and understood. Any other program mechanically reproduced or series of mechanical reproductions, including a mechanical reproduction used for background music, sound effects, station identification, program identification (theme music of short duration) or identification of sponsorship of the program proper, need not be announced as provided in paragraph (a) of this section, but the licensee shall not attempt affirmatively to create the impression that any program being broadcast by mechanical reproduction consists of live talent.

(c) The requirements of paragraph (a) of this section are waived with respect to network programs, transcribed and rebroadcast at a later hour because of the time zone differential between the place where the program originates and where it is rebroadcast, this waiver being applicable whether the off-the-line recording is made by the network itself at one of its key stations or by an individual station, but only when the off-the-line recording is for broadcast at an hour not exceeding the time zone differential between the place where the program originates and where it is rebroadcast. Each station which broadcasts network programs at a later hour in accordance with this waiver shall make an appropriate announcement at least once each day between the hours of 10:00 a.m. and 10:00 p.m., stating that some or all of the network programs which are broadcast by that station are delayed broadcasts by means of transcription. This waiver provision also applies during the annual periods in which daylight saving time will be effective with respect to network programs transcribed and rebroadcast one hour later because of the time differential resulting from the adoption of daylight saving time in some areas.

§ 3.654 Sponsored programs, announcement. (a) In the case of each program for the broadcasting of which money, services, or other valuable consideration is either directly or indirectly paid or promised to, or charged or received by, any television broadcast station, the station broadcasting such program shall make, or cause to be made, an appropriate announcement that the program is sponsored, paid for, or furnished, either in whole or in part.

(b) In the case of any political program or any program involving the discussion of public controversial issues for which any films, records, transcriptions, talent, scripts, or other material or services of any kind are furnished, either directly or indirectly, to a station as an inducement to the broadcasting of such program, an announcement shall be made both at the beginning and conclusion of such program on which such material or services are used that such films, records, transcriptions, talent, scripts, or other material or services have been furnished to such station in connection with the broadcasting of such program: *Provided, however,* That only one such announcement need be made in the case of any such program of 5 minutes' duration or less, which announcement may be made either at the beginning or conclusion of the program.

(c) The announcement required by this section shall fully and fairly disclose the true identity of the person or persons by whom or in whose behalf such payment is made or promised, or from whom or in whose behalf such services or other valuable consideration is received, or by whom the material or services referred to in paragraph (b) of this section are furnished. Where an agent or other person contracts or otherwise makes arrangements with a station on behalf of another, and such fact is known to the station, the announcement shall disclose the identity of the person or persons in whose behalf such agent is acting instead of the name of such agent.

(d) In the case of any program, other than a program advertising commercial products or services, which is sponsored, paid for or furnished, either in whole or in part, or for which material or services referred to in paragraph (b) of this section are furnished, by a corporation, committee, association or other unincorporated group,

the announcement required by this section shall disclose the name of such corporation, committee, association or other unincorporated group. In each such case the station shall require that a list of the chief executive officers or members of the executive committee or of the board of directors of the corporation, committee, association or other unincorporated group shall be made available for public inspection at one of the television broadcast stations carrying the program.

(e) In the case of programs advertising commercial products or services, an announcement stating the sponsor's corporate or trade name or the name of the sponsor's product, shall be deemed sufficient for the purposes of this section and only one such announcement need be made at any time during the course of the program.

§ 3.655 Rebroadcast. (a) The term "rebroadcast" as used below means reception by radio of the program of a television broadcast station, and the simultaneous or subsequent retransmission of such program by a broadcast station. The broadcasting of a program relayed by an auxiliary broadcast station licensed to the television broadcast station is not considered a rebroadcast. (As used in this section, program includes any complete program or part thereof.)

(b) The licensee of a television broadcast station may, without further authority of the Commission, rebroadcast the program of a United States television broadcast station, provided the Commission is notified of the call letters of each station rebroadcast and the licensee certifies that express authority has been received from the licensee of the station originating the program.

NOTE: The notice and certification of consent shall be given within 3 days of any single rebroadcast, but in case of the regular practice of rebroadcasting certain programs of a television broadcast station several times during a license period, notice and certification of consent shall be given for the ensuing license period with the application for renewal of license, or at the beginning of such rebroadcast practice if begun during a license period.

(c) No licensee of a television broadcast station shall rebroadcast the program of any United States radio station not designated in paragraph (b) of this section without written authority having first been obtained from the Commission upon application (informal) accompanied by written consent or certification of consent of the licensee of the station originating the program.

NOTE: By Order No. 82, dated and effective June 24, 1941, until further order of the Commission, § 3.655(c) is suspended only insofar as it requires prior written authority of the Commission for the rebroadcasting of programs originated for that express purpose by U.S. Government radio stations.

§ 3.656 Lotteries. (a) An application for construction permit, license, renewal of license, or any other authorization for the operation of a broadcast station, will not be granted where the applicant proposes to follow or continue to follow a policy or practice of broadcasting or permitting "the broadcasting of, any advertisement of or information concerning any lottery, gift enterprise, or similar scheme, offering prizes dependent in whole or in part upon lot or chance, or any list of the prizes drawn or awarded by means of any such lottery, gift enterprise, or scheme, whether said list contains any part or all of such prizes." (See 18 U. S. C. 1304.)

(b) The determination whether a particular program comes within the provisions of paragraph (a) of this section depends on the facts of each case. However, the Commission will in any event consider that a program comes within the provisions of paragraph (a) of this section if in connection with such program a prize consisting of money or thing of value is awarded to any person whose selection is dependent in whole or in part upon lot or chance, if as a condition of winning or competing for such prize, such winner or winners are required to furnish any money or thing of value or are required to have in their possession any product sold, manufactured, furnished or distributed by a sponsor of a program broadcast on the station in question.

§ 3.657 Broadcasts by candidates for public office. (a) *Legally qualified candidate.* A "legally qualified candidate" means any person who has publicly announced that he is a candidate for nomination by a convention of a political party or for nomination or election in a primary, special, or general election, municipal, county, state or national, and who meets the qualifications prescribed by the applicable laws to

hold the office for which he is a candidate, so that he may be voted for by the electorate directly or by means of delegates or electors, and who:

(1) Has qualified for a place on the ballot, or

(2) Is eligible under the applicable law to be voted for by sticker, by writing in his name on the ballot, or other method, and (i) has been duly nominated by a political party which is commonly known and regarded as such, or (ii) makes a substantial showing that he is a bona fide candidate for nomination or office, as the case may be.

(b) *General requirements.* No station licensee is required to permit the use of its facilities by any legally qualified candidate for public office, but if any licensee shall permit any such candidate to use its facilities, it shall afford equal opportunities to all other such candidates for that office to use such facilities: *Provided,* That such licensee shall have no power of censorship over the material broadcast by any such candidate.

(c) *Rates and practices.* (1) The rates, if any, charged all such candidates for the same office shall be uniform and shall not be rebated by any means direct or indirect. A candidate shall, in each case, be charged no more than the rate the station would charge if the candidate were a commercial advertiser whose advertising was directed to promoting its business within the same area as that encompassed by the particular office for which such person is a candidate. All discount privileges otherwise offered by a station to commercial advertisers shall be available upon equal terms to all candidates for public office.

(2) In making time available to candidates for public office no licensee shall make any discrimination between candidates in charges, practices, regulations, facilities, or services for or in connection with the service rendered pursuant to this part, or make or give any preference to any candidate for public office or subject any such candidate to any prejudice or disadvantage; nor shall any licensee make any contract or other agreement which shall have the effect of permitting any legally qualified candidate for any public office to broadcast to the exclusion of other legally qualified candidates for the same public office.

(d) *Inspection of records.* Every licensee shall keep and permit public inspection of a complete record of all requests for broadcast time made by or on behalf of candidates for public office, together with an appropriate notation showing the disposition made by the licensee of such requests, and the charges made, if any, if request is granted. Such records shall be retained for a period of two years.

(e) A request for equal opportunities must be submitted to the licensee within one week of the day on which the prior use occurred.

(f) A candidate requesting such equal opportunities of the licensee, or complaining of non-compliance to the Commission shall have the burden of proving that he and his opponent are legally qualified candidates for the same public office.

§ 3.658 **Affiliation agreements.** (a) *Exclusive affiliation of station.* No license shall be granted to a television broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization under which the station is prevented or hindered from, or penalized for, broadcasting the programs of any other network organization. (The term "network organization" as used herein includes national and regional network organizations. See ch. VII, J, of Report on Chain Broadcasting.)

(b) *Territorial exclusivity.* No license shall be granted to a television broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization which prevents or hinders another broadcast station located in the same community from broadcasting the network's programs not taken by the former station, or which prevents or hinders another broadcast station located in a different community from broadcasting any program of the network organization. This section shall not be construed to prohibit any contract, arrangement, or understanding between a station and a network organization pursuant to which the station is granted the first call in its community upon the programs of the network organization. As employed in this paragraph, the term "community" is defined as the community specified in the instrument of authorization as the location of the station.

(c) *Term of affiliation.* No license shall be granted to a television broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization which provides, by original terms, provisions for renewal, or otherwise for the affiliation of the station with the network organization for a period longer than 2 years: *Provided,* That a contract, arrangement, or understanding for a period up to 2 years may be entered into within 6 months prior to the commencement of such period.

(d) *Option time.* No license shall be granted to a television broadcast station which options for network programs any time subject to call on less than 56 days' notice, or more time than a total of 3 hours within each of four segments of the broadcast day, as herein described. The broadcast day is divided into four segments, as follows: 8 a.m. to 1 p.m.; 1 p.m. to 6 p.m.; 6 p.m. to 11 p.m.; 11 p.m. to 8 a.m. (These segments are to be determined for each station in terms of local time at the location of the station but may remain constant throughout the year regardless of shifts from standard to daylight saving time or vice versa.) Such options may not be exclusive as against other network organizations and may not prevent or hinder the station from optioning or selling any or all of the time covered by the option, or other time, to other network organizations.

NOTE 1: As used in this section, an option is any contract, arrangement, or understanding, express or implied, between a station and a network organization which prevents or hinders the station from scheduling programs before the network agrees to utilize the time during which such programs are scheduled, or which requires the station to clear time already scheduled when the network organization seeks to utilize the time.

NOTE 2: All time options permitted under this section must be specified clock hours, expressed in terms of any time system set forth in the contract agreed upon by the station and network organization. Shifts from daylight saving to standard time or vice versa may or may not shift the specified hours correspondingly as agreed by the station and network organization.

(e) *Right to reject programs.* No license shall be granted to a television broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization which (1), with respect to programs offered pursuant to an affiliation contract, prevents or hinders the station from rejecting or refusing network programs which the station reasonably believes to be unsatisfactory or unsuitable; or which (2) with respect to network programs so offered or already contracted for, prevents the station from rejecting or refusing any program which, in its opinion, is contrary to the public interest, or from substituting a program of outstanding local or national importance.

(f) *Network ownership of stations.* No license shall be granted to a network organization, or to any person directly or indirectly controlled by or under common control of a network organization, for a television broadcast station in any locality where the existing television broadcast stations are so few or of such unequal desirability (in terms of coverage, power, frequency, or other related matters) that competition would be substantially restrained by such licensing. (The word "control" as used in this section, is not limited to full control but includes such a measure of control as would substantially affect the availability of the station to other networks.)

(g) *Dual network operation.* No license shall be issued to a television broadcast station affiliated with a network organization which maintains more than one network of television broadcast stations: *Provided,* That this section shall not be applicable if such networks are not operated simultaneously, or if there is no substantial overlap in the territory served by the group of stations comprising each such network.

(h) *Control by networks of station rates.* No license shall be granted to a television broadcast station having any contract, arrangement, or understanding, express or implied, with a network organization under which the station is prevented or hindered from, or penalized for, fixing or altering its rates for the sale of broadcast time for other than the network's programs.

§ 3.659 Special rules relating to contracts providing for reservation of time upon sale of a station. No license, renewal of license, assignment of license, or transfer

of control of a corporate licensee shall be granted or authorized to a television broadcast station which has a contract, arrangement or understanding, express or implied, pursuant to which, as consideration or partial consideration for the assignment of license or transfer of control, the assignor of a station license or the transferor of stock, where transfer of a corporate licensee is involved, or the nominee of such assignor or transferor retains any right of reversion of the license or any right to the reassignment of the license in the future, or reserves the right to use the facilities of the station for any period whatsoever.

§ 3.660 Station license, posting of. The original of each station license shall be posted in the transmitter room.

§ 3.661 Operator requirements. One or more licensed radio-telephone first class operators shall be on duty at the place where the transmitting apparatus of each station is located and in actual charge thereof whenever it is being operated. The original license (or FCC Form 759) of each station operator shall be posted at the place where he is on duty. The licensed operator on duty and in charge of a television broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of operator's license which he holds and by the rules and regulations governing such stations. However, such duties shall in nowise interfere with the operation of the broadcast transmitter.

§ 3.662 Antenna structure, marking and lighting. Where an antenna structure(s) is required to be painted or lighted see § 17.37, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 3.663 Logs; maintenance of. The licensee or permittee of each television station shall maintain program and operating logs and shall require entries to be made as follows:

(a) In the program log:

(1) An entry of the time each station identification announcement (call letters and location) is made.

(2) An entry briefly describing each program broadcast, such as "music," "drama," "speech," etc., together with the name or title thereof and the sponsor's name, with the time of the beginning and ending of the complete program. If a mechanical reproduction, either visual or aural, is used, the entry shall show the exact nature thereof and the time it is announced as a mechanical reproduction. If a speech is made by a political candidate, the name and political affiliations of such speaker shall be entered.

(3) An entry showing that each sponsored program broadcast has been announced as sponsored, paid for, or furnished by the sponsor; or that the broadcast is under the auspices of a nonprofit educational organization other than the licensee or permittee.

(4) An entry showing, for each program of network origin, the name of the network originating the program.

(b) In the operating log:

(1) An entry of the time the station begins to supply power to the antenna, and the time it stops.

(2) An entry of the time the program begins and ends.

(3) An entry of each interruption to the carrier wave, its cause, and duration.

(4) An entry of the following each 30 minutes:

(i) Operating constants of last radio stage of the aural transmitter (total plate current and plate voltage).

(ii) Transmission line meter readings for both transmitters.

(iii) Frequency monitor readings.

(5) Log of experimental operation during experimental period (if regular operation is maintained during this period, the above logs shall be kept).

(i) A log must be kept of all operation during the experimental period. If the

entries required above are not applicable thereto, then the entries shall be made so as to describe the operation fully.

(c) Where an antenna structure(s) is required to be illuminated see § 17.38, *Recording the tower light inspections in the station record*, of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 3.664 Logs; retention of, etc. (a) *Logs; retention of.* Logs of television broadcast stations shall be retained by the licensee or permittee for a period of two years: *Provided, however,* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee or permittee has been notified, shall be retained by the licensee or permittee until he is specifically authorized in writing by the Commission to destroy them: *Provided further,* That logs incident to or involved in any claim or complaint of which the licensee or permittee has notice shall be retained by the licensee or permittee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

(b) *Logs, by whom kept.* Each log shall be kept by the person or persons competent to do so, having actual knowledge of the facts required, who shall sign the log when starting duty and again when going off duty. The logs shall be made available upon request by an authorized representative of the Commission.

(c) *Log form.* The log shall be kept in an orderly manner, in suitable form, and in such detail that the data required for the particular class of station concerned are readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log.

(d) *Correction of logs.* No log or portion thereof shall be erased, obliterated, or wilfully destroyed within the period of retention provided by the rules. Any necessary correction may be made only by the person originating the entry who shall strike out the erroneous portion, initial the correction made, and indicate the date of correction.

(e) *Rough logs.* Rough logs may be transcribed into condensed form, but in such case the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

§ 3.665 Station inspection. The licensee of a television broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 3.666 Experimental operation. Television broadcast stations may (upon informal application) conduct technical experimentation directed to the improvement of technical phases of operation and for such purposes may utilize a signal other than the standard television signal subject to the following conditions:

(a) That the licensee complies with the provisions of § 3.651 with regard to the minimum number of hours of transmission with a standard television signal.

(b) That no transmissions are radiated outside of the authorized channel and subject to the condition that no interference is caused to the transmissions of a standard television signal by other television broadcast stations.

(c) No charges either direct or indirect shall be made by the licensee of a television broadcast station for the production or transmission of programs when conducting technical experimentation.

§ 3.667 Discontinuance of operation. The licensee of each station shall notify the Commission in Washington, D.C., and the Engineer in Charge of the radio district where such station is located of permanent discontinuance of operation at least two days before operation is discontinued. The licensee shall, in addition, immediately forward the station license and other instruments of authorization to the Washington, D.C., office of the Commission for cancellation.

§ 3.668 Frequency tolerance. (a) The carrier frequency of the visual transmitter shall be maintained within ±1000 cycles of the authorized carrier frequency.

(b) The center frequency of the aural transmitter shall be maintained 4.5 megacycles, ±1000 cycles, above the visual carrier frequency.

TV Technical Standards

§ 3.681 Definitions.

Amplitude modulation (AM). A system of modulation in which the envelope of the transmitted wave contains a component similar to the wave form of the signal to be transmitted.

Antenna height above average terrain. The average of the antenna heights above the terrain from two to ten miles from the antenna for the eight directions spaced evenly for each 45 degrees of azimuth starting with True North. (In general, a different antenna height will be determined in each direction from the antenna. The average of these various heights is considered the antenna height above the average terrain. In some cases less than 8 directions may be used. See § 3.684(d).)

Antenna power gain. The square of the ratio of the root-mean-square free space field intensity produced at one mile in the horizontal plane, in millivolts per meter for one kilowatt antenna input power to 137.6 mv/m. This ratio should be expressed in decibels (db). (If specified for a particular direction, antenna power gain is based on the field strength in that direction only.)

Aspect ratio. The ratio of picture width to picture height as transmitted.

Aural transmitter. The radio equipment for the transmission of the aural signal only.

Aural center frequency. (1) The average frequency of the emitted wave when modulated by a sinusoidal signal; (2) the frequency of the emitted wave without modulation.

Blanking level. The level of the signal during the blanking interval, except the interval during the scanning synchronizing pulse and the chrominance subcarrier synchronizing burst.

Chrominance. The colorimetric difference between any color and a reference color of equal luminance, the reference color having a specific chromaticity.

Chrominance subcarrier. The carrier which is modulated by the chrominance information.

Color transmission. The transmission of color television signals which can be reproduced with different values of hue, saturation, and luminance.

Effective radiated power. The product of the antenna input power and the antenna power gain. This product should be expressed in kilowatts and in decibels above one kilowatt (dbk). (If specified for a particular direction, effective radiated power is based on the antenna power gain in that direction only. The licensed effective radiated power is based on the average antenna power gain for each horizontal plane direction.)

Field. Scanning through the picture area once in the chosen scanning pattern. In the line interlaced scanning pattern of two to one, the scanning of the alternate lines of the picture area once.

Frame. Scanning all of the picture area once. In the line interlaced scanning pattern of two to one, a frame consists of two fields.

Free space field intensity. The field intensity that would exist at a point in the absence of waves reflected from the earth or other reflecting objects.

Frequency modulation (FM). A system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous amplitude of the modulating signal (amplitude of modulating signal to be measured after pre-emphasis, if used) and the instantaneous radio frequency is independent of the frequency of the modulating signal.

Frequency swing. The instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

Interlaced scanning. A scanning process in which successively scanned lines are spaced an integral number of line widths, and in which the adjacent lines are scanned during successive cycles of the field frequency.

Luminance. Luminous flux emitted, reflected, or transmitted per unit solid angle per unit projected area of the source.

Monochrome transmission. The transmission of television signals which can be reproduced in gradations of a single color only.

Negative transmission. Where a decrease in initial light intensity causes an increase in the transmitted power.

Peak power. The power over a radio frequency cycle corresponding in amplitude to synchronizing peaks.

Percentage modulation. As applied to frequency modulation, the ratio of the actual frequency swing to the frequency swing defined as 100 percent modulation, expressed in percentage. For the aural transmitter of television broadcast stations, a frequency swing of ±25 kilocycles is defined as 100 percent modulation.

Polarization. The direction of the electric field as radiated from the transmitting antenna.

Reference black level. The level corresponding to the specified maximum excursion of the luminance signal in the black direction.

Reference white level of the luminance signal. The level corresponding to the specified maximum excursion of the luminance signal in the white direction.

Scanning. The process of analyzing successively, according to a predetermined method, the light values of picture elements constituting the total picture area.

Scanning line. A single continuous narrow strip of the picture area containing highlights, shadows, and half-tones, determined by the process of scanning.

Standard television signal. A signal which conforms to the television transmission standards.

Synchronization. The maintenance of one operation in step with another.

Television broadcast band. The frequencies in the band extending from 54 to 890 megacycles which are assignable to television broadcast stations. These frequencies are 54 to 72 megacycles (channels 2 through 4), 76 to 88 megacycles (channels 5 and 6), 174 to 216 megacycles (channels 7 through 13), and 470 to 890 megacycles (channels 14 through 83).

Television broadcast station. A station in the television broadcast band transmitting simultaneous visual and aural signals intended to be received by the general public.

Television channel. A band of frequencies 6 megacycles wide in the television broadcast band and designated either by number or by the extreme lower and upper frequencies.

Television transmission standards. The standards which determine the characteristics of a television signal as radiated by a television broadcast station.

Television transmitter. The radio transmitter or transmitters for the transmission of both visual and aural signals.

Vestigial sideband transmission. A system of transmission wherein one of the generated sidebands is partially attenuated at the transmitter and radiated only in part.

Visual carrier frequency. The frequency of the carrier which is modulated by the picture information.

Visual transmitter. The radio equipment for the transmission of the visual signal only.

Visual transmitter power. The peak power output when transmitting a standard television signal.

§ 3.682 Transmission standards and changes. (a) *Transmission standards.* (1) The width of the television broadcast channel shall be six megacycles per second.

(2) The visual carrier frequency shall be nominally 1.25 mc above the lower boundary of the channel.

(3) The aural center frequency shall be 4.5 mc higher than the visual carrier frequency.

(4) The visual transmission amplitude characteristic shall be in accordance with the chart designated as Fig. 5 of § 3.699.

(5) The chrominance subcarrier frequency shall be 3.579545 mc ± 10 cycles per second with a maximum rate of change not to exceed one tenth cycle per second per second.

(6) For monochrome and color transmissions the number of scanning lines per frame shall be 525, interlaced two to one in successive fields. The horizontal scanning frequency shall be $\frac{2}{455}$ times the chrominance subcarrier frequency; this corre-

sponds nominally to 15,750 cycles per second (with an actual value of 15,734.264 ± 0.044 cycles per second). The vertical scanning frequency is $\frac{2}{525}$ times the horizontal scanning frequency; this corresponds nominally to 60 cycles per second (the actual value is 59.94 cycles per second). For monochrome transmissions only, the nominal values of line and field frequencies may be used.

(7) The aspect ratio of the transmitted television picture shall be 4 units horizontally to 3 units vertically.

(8) During active scanning intervals, the scene shall be scanned from left to right horizontally and from top to bottom vertically, at uniform velocities.

(9) A carrier shall be modulated within a single television channel for both picture and synchronizing signals. For monochrome transmission, the two signals comprise different modulation ranges in amplitude, in accordance with the charts designated as Figures 5 and 7 of § 3.699. For color transmission, the two signals comprise different modulation ranges in amplitude except where the chrominance penetrates the synchronizing region and the burst penetrates the picture region, in accordance with the charts designated as Figures 5 and 6 of § 3.699.

(10) A decrease in initial light intensity shall cause an increase in radiated power (negative transmission).

(11) The reference black level shall be represented by a definite carrier level, independent of light and shade in the picture.

(12) The blanking level shall be transmitted at 75 ± 2.5 percent of the peak carrier level.

(13) The reference white level of the luminance signal shall be 12.5 ± 2.5 percent of the peak carrier level.

(14) The signals radiated shall have horizontal polarization.

(15) An effective radiated power of the aural transmitter not less than 50 percent nor more than 70 percent of the peak radiated power of the visual transmitter shall be employed.

(16) The peak-to-peak variation of transmitter output within one frame of video signal due to all causes, including hum, noise, and low-frequency response, measured at both scanning synchronizing peak and blanking level, shall not exceed 5 percent of the average scanning synchronizing peak signal amplitude. This provision is subject to change but is considered the best practice under the present state of the art. It will not be enforced pending a further determination thereof.

(17) The reference black level shall be separated from the blanking level by the setup interval, which shall be 7.5 ± 2.5 percent of the video range from blanking level to the reference white level.

(18) For monochrome transmission, the transmitter output shall vary in substantially inverse logarithmic relation to the brightness of the subject. No tolerances are set at this time. This provision is subject to change but is considered the best practice under the present state of the art. It will not be enforced pending a further determination thereof.

(19) The color picture signal shall correspond to a luminance component transmitted as amplitude modulation of the picture carrier and a simultaneous pair of chrominance components transmitted as the amplitude modulation sidebands of a pair of suppressed subcarriers in quadrature.

(20) Equation of complete color signal.

(i) The color picture signal has the following composition:

$$E_M = E_Y' + \{E_Q' \sin(\omega t + 33°) + E_I' \cos(\omega t + 33°)\}$$

where $E_Q' = 0.41(E_B' - E_Y') + 0.48(E_R' - E_Y')$

$E_I' = -0.27(E_B' - E_Y') + 0.74(E_R' - E_Y')$

$E_Y' = 0.30E_R' + 0.59E_G' + 0.11E_B'$

For color-difference frequencies below 500 kc (see (iii) below), the signal can be represented by:

$$E_M = E_Y' + \left\{\frac{1}{1.14}\left[\frac{1}{1.78}(E_B' - E_Y')\sin\omega t + (E_R' - E_Y')\cos\omega t\right]\right\}$$

(ii) The symbols in subdivision (i) of this subparagraph have the following significance:

E_M is the total video voltage, corresponding to the scanning of a particular picture element, applied to the modulator of the picture transmitter.

E_Y' is the gamma-corrected voltage of the monochrome (black-and-white) portion of the color picture signal, corresponding to the given picture element.

NOTE: Forming of the high frequency portion of the monochrome signal in a different manner is permissible and may in fact be desirable in order to improve the sharpness on saturated colors.

E_Q' and E_I' are the amplitudes of two orthogonal components of the chrominance signal corresponding respectively to narrow-band and wide-band axes.

E_R', E_G', and E_B' are the gamma-corrected voltages corresponding to red, green, and blue signals during the scanning of the given picture element.

ω is the angular frequency and is 2π times the frequency of the chrominance subcarrier.

The portion of each expression between brackets in (i) represents the chrominance subcarrier signal which carries the chrominance information.

The phase reference in the E_M equation in (i) is the phase of the burst + 180°, as shown in Figure 8 of § 3.699. The burst corresponds to amplitude modulation of a continuous sine wave.

(iii) The equivalent bandwidth assigned prior to modulation to the color difference signals E_Q' *and* E_I' are as follows:

Q-channel bandwidth:
At 400 kc less than 2 db down.
At 500 kc less than 6 db down.
At 600 kc at least 6 db down.
I-channel bandwidth:
At 1.3 mc less than 2 db down.
At 3.6 mc at least 20 db down.

(iv) The gamma corrected voltages E_R', E_G', and E_B' are suitable for a color picture tube having primary colors with the following chromaticities in the CIE system of specification:

	x	y
Red (R)	0.67	0.33
Green (G)	0.21	0.71
Blue (B)	0.14	0.08

and having a transfer gradient (gamma exponent) of 2.2 associated with each primary color. The voltages E_R', E_G', and E_B' may be respectively of the form $E_R^{1/\epsilon}$, $E_G^{1/\epsilon}$, and $E_B^{1/\gamma}$ although other forms may be used with advances in the state of the art.

NOTE: At the present state of the art it is considered inadvisable to set a tolerance on the value of gamma and correspondingly this portion of the specification will not be enforced.

(v) The radiated chrominance subcarrier shall vanish on the reference white of the scene.

NOTE: The numerical values of the signal specification assume that this condition will be reproduced as CIE Illuminant C ($x = 0.310$, $y = 0.316$).

(vi) E_Y', E_Q', E_I', and the components of these signals shall match each other in time to 0.05 μsecs.

(vii) The angles of the subcarrier measured with respect to the burst phase, when reproducing saturated primaries and their complements at 75 percent of full amplitude, shall be within ±10° and their amplitudes shall be within ±20 percent of the

values specified above. The ratios of the measured amplitudes of the subcarrier to the luminance signal for the same saturated primaries and their complements shall fall between the limits of 0.8 and 1.2 of the values specified for their ratios. Closer tolerances may prove to be practicable and desirable with advance in the art.

(21) The interval beginning with the last 12 μsecs of line 17 and continuing through line 20 of the vertical blanking interval of each field may be used for the transmission of test signals subject to the conditions set forth below. Test signals may include signals used to supply reference modulation levels so that variations in light intensity of the scene viewed by the camera will be faithfully transmitted; signals designed to check the performance of the overall transmission system or its individual components; and cue and control signals related to the operation of the television broadcast station. Figures 6 and 7 of § 3.699 identify the numbered lines referred to in this subparagraph.

(i) Modulation of the television transmitter by such signals shall be confined to the area between the reference white level and the blanking level except where such test signals are composed of chrominance subcarrier frequencies, in which case their negative excursions may extend into the synchronizing peak amplitude. In no case may the modulation excursions produced by test signals extend beyond peak-of-sync level.

(ii) The use of test signals shall not result in significant degradation of the program transmissions of the television broadcast station nor create emission components in excess of those permitted for normal program transmissions.

(iii) Test signals may not be transmitted during that portion of each line devoted to horizontal blanking.

(iv) A guard interval of no less than one-half line shall be maintained at all times between the last test signal and the beginning of the first picture scanning line.

(b) *Changes in transmission standards.* The Commission will consider the question whether a proposed change or modification of transmission standards adopted for television would be in the public interest, convenience and necessity, upon petition being filed by the person proposing such change or modification, setting forth the following:

(1) The exact character of the change or modification proposed;

(2) The effect of the proposed change or modification upon all other transmission standards that have been adopted by the Commission for television broadcast stations;

(3) The experimentation and field tests that have been made to show that the proposed change or modification accomplishes an improvement and is technically feasible;

(4) The effect of the proposed change or modification in the adopted standards upon operation and obsolescence of receivers;

(5) The change in equipment required in existing television broadcast stations for incorporating the proposed change or modification in the adopted standards; and

(6) The facts and reasons upon which the petitioner bases his conclusion that the proposed change or modification would be in the public interest, convenience, and necessity.

Should a change or modification in the transmission standards be adopted by the Commission, the effective date thereof will be determined in the light of the considerations mentioned in subparagraph (4) of this paragraph.

§ 3.683 Field intensity contours. (a) In the authorization of television broadcast stations, two field intensity contours are considered. These are specified as Grade A and Grade B and indicate the approximate extent of coverage over average terrain in the absence of interference from other television stations. Under actual conditions, the true coverage may vary greatly from these estimates because the terrain over any specific path is expected to be different from the average terrain on which the field strength charts were based. The required field intensities, F (50, 50), in decibels above one microvolt per meter (dbu) for the Grade A and Grade B contours are as follows:

	Grade A (dbu)	Grade B (dbu)
Channels 2–6	68*	47*
Channels 7–13	71*	56*
Channels 14–83	71*	64

*See Doc. 13340 for proposed revision of these values, and to change the service grades to Principal City and Normal service.

NOTE: It should be realized that the F (50, 50) curves when used for Channels 14–83 are not based on measured data at distances beyond about 30 miles. Theory would indicate that the field intensities for Channels 14–83 should decrease more rapidly with distance beyond the horizon than for Channels 2–6, and modification of the curves for Channels 14–83 may be expected as a result of measurements to be made at a later date. For these reasons, the curves should be used with appreciation of their limitations in estimating levels of field intensity. Further, the actual extent of service will usually be less than indicated by these estimates due to interference from other stations. Because of these factors, the predicted field intensity contours give no assurance of service to any specific percentage of receiver locations within the distances indicated. In licensing proceedings these variations will not be considered.

(b) The field intensity contours provided for herein shall be considered for the following purposes only:

(1) In the estimation of coverage resulting from the selection of a particular transmitter site by an applicant for a television station.

(2) In connection with problems of coverage arising out of application of § 3.636.

(3) [Reserved.]

(4) In determining compliance with § 3.685(a) concerning the minimum field intensity to be provided over the principal community to be served.

§ 3.684 Prediction of coverage. (a) All predictions of coverage made pursuant to this paragraph shall be made without regard to interference and shall be made only on the basis of estimated field intensities. The peak power of the visual signal is used in making predictions of coverage.

(b) Predictions of coverage shall be made only for the same purposes as relate to the use of field intensity contours as specified in § 3.683(b).

(c) In predicting the distance to the field intensity contours, the F (50, 50) field intensity charts (Figures 10 and 11 of § 3.699) shall be used. If the 50 percent field intensity is defined as that value exceeded for 50 percent of the time, these F (50, 50) charts give the estimated 50 percent field intensities exceeded at 50 percent of the locations in decibels above one microvolt per meter. The charts are based on an effective power of one kilowatt radiated from a half-wave dipole in free space, which produces an unattenuated field strength at one mile of about 103 db above one microvolt per meter (137.6 millivolts per meter). To use the charts for other powers, the sliding scale associated with the charts should be trimmed and used as the ordinate scale. This sliding scale is placed on the charts with the appropriate gradation for power in line with the horizontal 40 db line on the charts. The right edge of the scale is placed in line with the appropriate antenna height gradations, and the charts then become direct reading (in μv/m and in db above 1 μv/m) for this power and antenna height. Where the antenna height is not one of those for which a scale is provided, the signal strength or distance is determined by interpolation between the curves connecting the equidistant points. Dividers may be used in lieu of the sliding scale. In predicting the distance to the Grade A and Grade B field intensity contours, the effective radiated power to be used is that in the horizontal plane in the pertinent direction. In predicting other field intensities over areas not in the horizontal plane, the effective radiated power to be used is the power in the direction of such areas; the appropriate vertical plane radiation pattern must, of course, be considered in determining this power.

(d) The antenna height to be used with these charts is the height of the radiation center of the antenna above the average terrain along the radial in question. In determining the average elevation of the terrain, the elevations between 2 and 10

miles from the antenna site are employed. Profile graphs shall be drawn for 8 radials beginning at the antenna site and extending 10 miles therefrom. The radials should be drawn for each 45 degrees of azimuth starting with True North. At least one radial must include the principal community to be served even though such community may be more than 10 miles from the antenna site. However, in the event none of the evenly spaced radials include the principal community to be served and one or more such radials are drawn in addition to the 8 evenly spaced radials, such additional radials shall not be employed in computing the antenna height above average terrain. Where the 2 to 10 mile portion of a radial extends in whole or in part over large bodies of water as specified in paragraph (e) of this section or extends over foreign territory but the Grade B intensity contour encompasses land area within the United States beyond the 10 mile portion of the radial, the entire 2 to 10 mile portion of the radial shall be included in the computation of antenna height above average terrain. However, where the Grade B contour does not so encompass United States land area and (1) the entire 2 to 10 mile portion of the radial extends over large bodies of water or foreign territory, such radial shall be completely omitted from the computation of antenna height above average terrain, and (2) where a part of the 2 to 10 mile portion of a radial extends over large bodies of water or over foreign territory, only that part of the radial extending from the 2 mile sector to the outermost portion of land area within the United States covered by the radial shall be employed in the computation of antenna height above average terrain. The profile graph for each radial should be plotted by contour intervals of from 40 to 100 feet and, where the data permits, at least 50 points of elevation (generally uniformly spaced) should be used for each radial. In instances of very rugged terrain where the use of contour intervals of 100 feet would result in several points in a short distance, 200- or 400-foot contour intervals may be used for such distances. On the other hand, where the terrain is uniform or gently sloping the smallest contour interval indicated on the topographic map (see paragraph (g) of this section) should be used, although only relatively few points may be available. The profile graphs should indicate the topography accurately for each radial, and the graphs should be plotted with the distance in miles as the abscissa and the elevation in feet above mean sea level as the ordinate. The profile graphs should indicate the source of the topographical data employed. The graph should also show the elevation of the center of the radiating system. The graph may be plotted either on rectangular coordinate paper or on special paper which shows the curvature of the earth. It is not necessary to take the curvature of the earth into consideration in this procedure, as this factor is taken care of in the charts showing signal intensities. The average elevation of the 8-mile distance between 2 and 10 miles from the antenna site should then be determined from the profile graph for each radial. This may be obtained by averaging a large number of equally spaced points, by using a planimeter, or by obtaining the median elevation (that exceeded for 50 percent of the distance) in sectors and averaging those values.

NOTE 1: This paragraph does not apply to any application designated for hearing in which the engineering portions have been heard or the engineering exhibits exchanged prior to June 1, 1953, the effective date of the amendment of this subsection unless the subsection as amended would materially affect the outcome of the hearing.

NOTE 2: The Commission will, upon a proper showing by an existing station that the application of this rule will result in an unreasonable power reduction in relation to other stations in close proximity, consider requests for adjustment in power on the basis of a common average terrain figure for the stations in question as determined by the Commission.

(e) In instances where it is desired to determine the area in square miles within the Grade A and Grade B field intensity contours, the area may be determined from the coverage map by planimeter or other approximate means; in computing such areas, exclude (1) areas beyond the borders of the United States, and (2) large bodies of water, such as ocean areas, gulfs, sounds, bays, large lakes, etc., but not rivers.

(f) In cases where the terrain in one or more directions from the antenna site

departs widely from the average elevation of the 2 to 10 mile sector, the prediction method may indicate contour distances that are different from what may be expected in practice. For example, a mountain ridge may indicate the practical limit of service although the prediction method may indicate otherwise. In such cases the prediction method should be followed, but a supplemental showing may be made concerning the contour distances as determined by other means. Such supplemental showing should describe the procedure employed and should include sample calculations. Maps of predicted coverage should include both the coverage as predicted by the regular method and as predicted by a supplemental method. When measurements of area are required, these should include the area obtained by the regular prediction method and the area obtained by the supplemental method. In directions where the terrain is such that negative antenna heights or heights below 100 feet for the 2 to 10 mile sector are obtained, a supplemental showing of expected coverage must be included together with a description of the method employed in predicting such coverage. In special cases, the Commission may require additional information as to terrain and coverage.

(g) In the preparation of the profile graphs previously described, and in determining the location and height above sea level of the antenna site, the elevation or contour intervals shall be taken from the United States Geological Survey Topographic Quadrangle Maps, United States Army Corps of Engineers maps or Tennessee Valley Authority maps, whichever is the latest, for all areas for which such maps are available. If such maps are not published for the area in question, the next best topographic information should be used. Topographic data may sometimes be obtained from State and municipal agencies. Data from Sectional Aeronautical Charts (including bench marks) or railroad depot elevations and highway elevations from road maps may be used where no better information is available. In cases where limited topographic data is available, use may be made of an altimeter in a car driven along roads extending generally radially from the transmitter site. Ordinarily the Commission will not require the submission of topographical maps for areas beyond 15 miles from the antenna site, but the maps must include the principal community to be served. If it appears necessary, additional data may be requested. United States Geological Survey Topographic Quadrangle Maps may be obtained from the Department of the Interior, Geological Survey, Washington, D.C. Sectional Aeronautical Charts are available from the Department of Commerce, Coast and Geodetic Survey, Washington, D.C.

§ 3.685 **Transmitter location and antenna system.** (a) The transmitter location shall be chosen so that, on the basis of the effective radiated power and antenna height above average terrain employed, the following minimum field intensity in decibels above one microvolt per meter (dbu) will be provided over the entire principal community to be served (see explanation on page 1–209):

Channels 2–6	Channels 7–13	Channels 14–83
74 dbu	77 dbu	80 dbu

(b) Location of the antenna at a point of high elevation is necessary to reduce to a minimum the shadow effect on propagation due to hills and buildings which may reduce materially the intensity of the station's signals. In general, the transmitting antenna of a station should be located at the most central point at the highest elevation available. To provide the best degree of service to an area, it is usually preferable to use a high antenna rather than a low antenna with increased transmitter power. The location should be so chosen that line-of-sight can be obtained from the antenna over the principal community to be served; in no event should there be a major obstruction in this path. The antenna must be constructed so that it is as clear as possible of surrounding buildings or objects that would cause shadow problems. It is recognized that topography, shape of the desired service area, and population distribution may make the choice of a transmitter location difficult. In such cases, consideration may be given to the use of a directional antenna system,

although it is generally preferable to choose a site where a nondirectional antenna may he employed.

(c) In cases of questionable antenna locations it is desirable to conduct propagation tests to indicate the field intensity expected in the principal community to be served and in other areas, particularly where severe shadow problems may be expected. In considering applications proposing the use of such locations, the Commission may require site tests to be made. Such tests should be made in accordance with the measurement procedure hereafter described, and full data thereon must be supplied to the Commission. Test transmitters should employ an antenna having a height as close as possible to the proposed antenna height, using a balloon or other support if necessary and feasible. Information concerning the authorization of site tests may be obtained from the Commission upon request.

(d) Present information is not sufficiently complete to establish "blanket areas" of television broadcast stations. A "blanket area" is that area adjacent to a transmitter in which the reception of other stations is subject to interference due to the strong signal from this station. The authorization of station construction in areas where blanketing is found to be excessive will be on the basis that the applicant will assume full responsibility for the adjustment of reasonable complaints arising from excessively strong signals of the applicant's station or take other corrective action.

(e) A directional antenna is considered to be an antenna that is designed or altered for the purpose of obtaining a noncircular radiation pattern. Directional antennas may not be used for the purpose of reducing minimum mileage separation requirements but may be employed for the purpose of improving service or for the purpose of using a particular site; however, directional antennas with a ratio of minimum to maximum radiation in the horizontal plane of more than 10 decibels will not be permitted.

(f) Applications proposing the use of directional antenna systems must be accompanied by the following:

(1) Complete description of the proposed antenna system.

(2) Orientation of array with respect to True North; time phasing of fields from elements (degrees leading or lagging); space phasing of elements (in feet and degrees); and ratio of fields from elements.

(3) Horizontal and vertical plane radiation patterns showing the free space field intensity in millivolts per meter at 1 mile and the effective radiated power, in dbk, for each direction. The method by which the radiation patterns were computed or measured shall be fully described, including formulas used, equipment employed, sample calculations and tabulations of data. Sufficient vertical plane patterns shall be included to indicate clearly the radiation characteristics of the antenna above and below the horizontal plane. The horizontal plane pattern shall be plotted on polar coordinate paper with reference to True North. The vertical plane patterns shall be plotted on rectangular coordinate paper with reference to the horizontal plane.

(4) Name, address, and qualifications of the engineer making the calculations.

(g) Applications proposing the use of television broadcast antennas within 200 feet of other television broadcast antennas operating on a channel within 20 percent in frequency of the proposed channel, or proposing the use of television broadcast antennas on Channels 5 or 6 within 200 feet of FM broadcast antennas, must include a showing as to the expected effect, if any, of such proximate operation.

(h) Where simultaneous use of antennas or antenna structures is proposed, the following provisions shall apply:

(1) In cases where it is proposed to use a tower of a standard broadcast station as a supporting structure for a television broadcast antenna, an appropriate application for changes in the radiating system of the standard broadcast station must be filed by the licensee thereof. A formal application (FCC Form 301) will be required if the proposal involves substantial change in the physical height or radiation characteristics of the standard broadcast antennas; otherwise an informal application will be acceptable. (In case of doubt, an informal application (letter) together with complete engineering data should be submitted.) An application may be required for other classes of stations when the tower is to be used in connection with a television station.

(2) When the proposed television antenna is to be mounted on a tower in the vicinity of a standard broadcast directional array and it appears that the operation of the directional antenna system may be affected, an engineering study must be filed with the television application concerning the effect of the television antenna on the directional pattern. Readjustment and field intensity measurements of the standard broadcast station may be required following construction of the television antenna.

(i) The provisions of Part 17 of this chapter shall govern the construction, marking and lighting requirements of antenna structures used by television broadcast stations. In the event a common tower is used by two or more licensees or permittees for antenna and/or antenna supporting purposes, the licensee or permittee who is owner of the tower shall assume full responsibility for the installation and maintenance of any painting and/or lighting requirements. In the event of shared ownership, one licensee or permittee shall assume such responsibility and advise the Commission accordingly.

§ 3.686 Measurements for rule making purposes and upon request of the Commission. (a) Except as provided for in § 3.612, television broadcast stations shall not be protected against any type of interference or propagation effect. Persons desiring to submit testimony, evidence, or data to the Commission for the purpose of showing that the technical standards contained in this subpart do not properly reflect any given types of interference or propagation effects may do so only in appropriate rule making proceedings to amend such technical standards. Persons making field intensity measurements for formal submission to the Commission in rule making proceedings, or making such measurements upon the request of the Commission, should comply with the procedure for making such measurements as outlined below.

(b) Measurements made to determine field intensities of television broadcast stations should be made with mobile equipment along roads which are as close and similar as possible to the radials showing topography which were submitted with the application for construction permit. Cluster and spot measurements may also be submitted, if accompanied by a complete showing of the procedures employed. Suitable measuring equipment and a continuous recording device must be employed, the chart of which is either directly driven from the speedometer of the automobile in which the equipment is mounted or so arranged that distances and identifying landmarks can be readily noted. The measuring equipment must be calibrated against recognized standards of field intensity and so constructed that it will maintain an acceptable accuracy of measurement while in motion or when stationary. The equipment should be so operated that the recorder chart can be calibrated directly in field intensity in order to facilitate analysis of the chart. The receiving antenna must be horizontally polarized and should be nondirectional.

(c) Mobile measurements should be made with a minimum chart speed of 3 inches per mile and preferably 5 or 6 inches per mile. Locations shall be noted on the recorder chart as frequently as necessary to fix definitely the relation between the measured field intensity and the location. The time constant of the equipment should be such as to permit adequate analysis of the charts, and the time constant employed shall be shown. Measurements should be made to a point on each radial well beyond the particular contour under investigation.

(d) While making field intensity measurements either the visual or the aural transmitter may be used. If the visual transmitter is used, it is recommended that a black picture be transmitted or that the transmitter be operated at black level without synchronization peaks. Operation at a power somewhat less than black level is permissible but too great a reduction in power is not recommended due to the difficulty of recording weak signals. In any event, an appropriate factor shall be used to convert the readings obtained to the field strength that would exist on synchronization peaks while operating at the authorized power.

(e) After the measurements are completed, the recorder chart should be divided into not less than 15 sections on each equivalent radial from the station. The field intensity in each section of the chart should be analyzed to determine the field intensity received 50 percent of the distance (median field) throughout the section, and this median field intensity associated with the corresponding sector of the

radial. The field intensity figures must be corrected for a receiving antenna elevation of 30 feet and for any directional effects of the automobile and receiving antenna not otherwise compensated. This data should be plotted for each radial, using log-log coordinate paper with distance as the abscissa and field intensity as the ordinate. A smooth curve should be drawn through these points (of median fields for all sectors) and this curve used to determine the distance to the desired contour. The distances obtained for each radial may then be plotted on the map of predicted coverage or on polar coordinate paper (excluding water areas, etc.) to determine the service and interference areas of a station.

(f) In certain cases the Commission may desire more information or recordings and in these instances special instructions will be issued.

(g) Data obtained in conjunction with field intensity measurements shall be submitted to the Commission in affidavit form in triplicate, including the following:

(1) Map or maps showing the roads or points where measurements were made, the service and/or interference areas determined by the prediction method and by the measurements, and any unusual terrain characteristics existing in these areas. The maps, preferably of a type showing topography in the area, should show the Grade A and Grade B field intensity contours.

(2) If a directional transmitting antenna is employed, a diagram on polar coordinate paper showing the predicted free space field intensity in millivolts per meter at 1 mile in all directions.

(3) A full description of the procedures and methods employed, including the type of equipment, the method of installation and operation, and calibration procedures.

(4) Complete data obtained during the survey, including calibration. (Only the original or one photostatic copy of the recording tapes, or representative samples, need to be submitted.)

(5) Antenna system and power employed during the survey.

(6) Name, address, and qualifications of the engineer or engineers making the measurements.

§ 3.687 Transmitters and associated equipment. (a) *Visual transmitter.* (1) For monochrome transmission only, the overall attenuation characteristics of the transmitter, measured in the antenna transmission line after the vestigial sideband filter (if used), shall not be greater than the following amounts below the ideal demodulated curve. (See Figure 11 of § 3.699.)

2 db at 0.5 mc.	6 db at 3.0 mc.
2 db at 1.25 mc.	12 db at 3.5 mc.
3 db at 2.0 mc.	

The curve shall be substantially smooth between these specified points, exclusive of the region from 0.75 to 1.25 mc. Output measurements shall be made with the transmitter operating into a dummy load of pure resistance and the demodulated voltage measured across this load. The ideal demodulated curve is that shown in Figure 11 of § 3.699.

(2) For color transmission, the standard given by subparagraph (1) of this paragraph applies except as modified by the following: A sine wave of 3.58 mc introduced at those terminals of the transmitter which are normally fed the composite color picture signal shall produce a radiated signal having an amplitude (as measured with a diode on the R. F. transmission line supplying power to the antenna), which is down 6 ± 2 db with respect to a signal produced by a sine wave of 200 kc. In addition, the amplitude of the signal shall not vary by more than ±2 db between the modulating frequencies of 2.1 and 4.18 mc.

(3) The field strength or voltage of the lower sideband, as radiated or dissipated and measured as described in subparagraph (4) of this paragraph, shall not be greater than −20 db for a modulating frequency of 1.25 mc or greater and in addition, for color, shall not be greater than −42 db for a modulating frequency of 3.579545 mc (the color subcarrier frequency). For both monochrome and color, the field strength or voltage of the upper sideband as radiated or dissipated and

measured as described in subparagraph (4) of this paragraph shall not be greater than −20 db for a modulating frequency of 4.75 mc or greater.

NOTE: Field strength measurements are desired. It is anticipated that these may not yield data which are consistent enough to prove compliance with the attenuation standards prescribed above. In that case, measurements with a dummy load of pure resistance, together with data on the antenna characteristics, shall be taken in place of over-all field measurements.

(4) The attenuation characteristics of a visual transmitter shall be measured by application of a modulating signal to the transmitter input terminals in place of the normal composite television video signal. The signal applied shall be a composite signal composed of a synchronizing signal to establish peak output voltage plus a variable frequency sine wave voltage occupying the interval between synchronizing pulses. (The "synchronizing signal" referred to in this section means either a standard synchronizing wave form or any pulse that will properly set the peak.) The axis of the sine wave in the composite signal observed in the output monitor shall be maintained at an amplitude 0.5 of the voltage at synchronizing peaks. The amplitude of the sine wave input shall be held at a constant value. This constant value should be such that at no modulating frequency does the maximum excursion of the sine wave, observed in the composite output signal monitor, exceed the value 0.75 of peak output voltage. The amplitude of the 200 kilocycle sideband shall be measured and designated zero db as a basis for comparison. The modulation signal frequency shall then be varied over the desired range and the field strength or signal voltage of the corresponding sidebands measured. As an alternate method of measuring, in those cases in which the automatic d-c insertion can be replaced by manual control, the above characteristic may be taken by the use of a video sweep generator and without the use of pedestal synchronizing pulses. The d-c level shall be set for midcharacteristic operation.

(5) A sine wave, introduced at those terminals of the transmitter which are normally fed the composite color picture signal, shall produce a radiated signal having an envelope delay, relative to the average envelope delay between 0.05 and 0.20 mc, of zero microseconds up to a frequency of 3.0 mc; and then linearly decreasing to 4.18 mc so as to be equal to −0.17 μsecs at 3.58 mc. The tolerance on the envelope delay shall be ±0.05 μsecs at 3.58 mc. The tolerance shall increase linearly to ±0.1 μsec down to 2.1 mc, and remain at ±0.1 μsec down to 0.2 mc. (Tolerances for the interval of 0.0 to 0.2 mc are not specified at the present time.) The tolerance shall also increase linearly to ±0.1 μsec at 4.18 mc.

(6) The radio frequency signal, as radiated, shall have an envelope as would be produced by a modulating signal in conformity with § 3.682 and Fig. 6 or 7 of § 3.699, as modified by vestigial sideband operation specified in Fig. 5 of § 3.699.

(7) The time interval between the leading edges of successive horizontal pulses shall vary less than one half of one percent of the average interval. However, for color transmissions, § 3.682(a)(5) and § 3.682(a)(6) shall be controlling.

(8) The rate of change of the frequency of recurrence of the leading edges of the horizontal synchronizing signals shall be not greater than 0.15 percent per second, the frequency to be determined by an averaging process carried out over a period of not less than 20, nor more than 100 lines, such lines not to include any portion of the blanking interval. However, for color transmissions, § 3.682(a)(5) and § 3.682(a)(6) shall be controlling.

(9) For color transmission the transfer characteristic (that is the relationship between the transmitter RF output and video signal input) shall be substantially linear between the reference black and reference white levels.

(b) *Aural transmitter.* (1) The transmitter shall operate satisfactorily with a frequency swing of ±25 kilocycles, which is considered 100 percent modulation. It is recommended, however, that the transmitter be designed to operate satisfactorily with a frequency swing of at least ±40 kilocycles.

(2) The transmitting system (from input terminals of microphone pre-amplifier, through audio facilities at the studio, through telephone lines or other circuits be-

tween studio and transmitter, through audio facilities at the transmitter, and through the transmitter, but excluding equalizers for the correction of deficiencies in microphone response) shall be capable of transmitting a band of frequencies from 50 to 15,000 cycles. Pre-emphasis shall be employed in accordance with the impedance-frequency characteristic of a series inductance-resistance network having a time constant of 75 microseconds. (See Figure 12 of § 3.699.) The deviation of the system response from the standard preemphasis curve shall lie between two limits as shown by Figure 12 of § 3.699. The upper of these limits shall be uniform (no deviation) from 50 to 15,000 cycles. The lower limit shall be uniform from 100 to 7,500 cycles, and three db below the upper limit; from 100 to 50 cycles the lower limit shall fall from three db limit at a uniform rate of one db per octave (4 db at 50 cycles); from 7,500 to 15,000 cycles the lower limit shall fall from three db limit at a uniform rate of two db per octave (5 db at 15,000 cycles).

(3) At any modulating frequency between 50 and 15,000 cycles and at modulation percentages of 25 percent, 50 percent, and 100 percent, the combined audio frequency harmonics measured in the output of the system shall not exceed the root-mean-square values given in the following table:

Modulation frequency	*Distortion (percent)*
50 to 100 cycles	3.5
100 to 7,500 cycles	2.5
7,500 to 15,000 cycles	3.0

(i) Measurement shall be made employing 75 microsecond de-emphasis in the measuring equipment and 75 microsecond pre-emphasis in the transmitting equipment, and without compression if a compression amplifier is employed. Harmonics shall be included to 30 kc.

NOTE: Measurements of distortion using de-emphasis in the measuring equipment are not practical at the present time for the range 7,500 to 15,000 cycles for 25 and 50 percent modulation. Therefore, measurements should be made at 100 percent modulation and on at least the following modulating frequencies: 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 cycles. At 25 and 50 percent modulation, measurements should be made on at least the following modulating frequencies: 50, 100, 400, 1,000 and 5,000 cycles.

(ii) It is recommended that none of the three main divisions of the system (transmitter, studio to transmitter circuit, and audio facilities) contribute over one-half of these percentages, since at some frequencies the total distortion may become the arithmetic sum of the distortions of the divisions.

(4) The transmitting system output noise level (frequency modulation) in the band of 50 to 15,000 cycles shall be at least 55 db below the audio frequency level representing a frequency swing of ±25 kc.

NOTE: For the purpose of these measurements, the visual transmitter should be inoperative since the exact amount of noise permissible from that source is not known at this time.

(5) The transmitting system output noise level (amplitude modulation) in the band of 50 to 15,000 cycles shall be at least 50 db below the level representing 100 percent amplitude modulation.

NOTE: For the purpose of these measurements, the visual transmitter should be inoperative since the exact amount of noise permissible from that source is not known at this time.

(6) If a limiting or compression amplifier is employed, precaution should be maintained in its connection in the circuit due to the use of pre-emphasis in the transmitting system.

(7) The percentage of modulation of the aural transmissions shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice and in no case less than 85 percent nor more than 100 percent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration.

(c) *Requirements applicable to both visual and aural transmitters.* (1) Automatic means shall be provided in the visual transmitter to maintain the carrier frequency within ±1 kilocycle of the authorized frequency; automatic means shall be provided in the aural transmitter to maintain the carrier frequency 4.5 megacycles above the actual visual carrier frequency within ±1 kilocycle.

(2) The transmitters shall be equipped with suitable indicating instruments for the determination of operating power and with other instruments necessary for proper adjustment, operation, and maintenance of the equipment.

(3) Adequate provision shall be made for varying the output power of the transmitters to compensate for excessive variations in line voltage or for other factors affecting the output power.

(4) Adequate provisions shall be provided in all component parts to avoid overheating at the rated maximum output powers.

(d) *Construction.* In general, the transmitters shall be mounted either on racks and panels or in totally enclosed frames protected as required by article 810 of the National Electrical Code (Section 8192(a), (b), and (c)), and as set forth below:

(1) Means shall be provided for making all tuning adjustments, requiring voltages in excess of 350 volts to be applied to the circuit, from the front of the panels with all access doors closed.

(2) Proper bleeder resistors or other automatic means shall be installed across all the capacitor banks to lower any voltage which may remain accessible with access door open to less than 350 volts within two seconds after the access door is opened.

(3) All plate supply and other high voltage equipment, including transformers, filters, rectifiers and motor generators, shall be protected so as to prevent injury to operating personnel.

(i) Commutator guards shall be provided on all high voltage rotating machinery. Coupling guards should be provided on motor generators.

(ii) Power equipment and control panels of the transmitters shall meet the above requirements (exposed 220-volt A.C. switching equipment on the front of the power control panels is not recommended but is not prohibited).

(iii) Power equipment located at a television broadcast station not directly associated with the transmitters (not purchased as part of same), such as power distribution panels, are not subject to the provisions of this subpart.

(4) The following provisions shall be applicable to metering equipment:

(i) All instruments having more than 1,000 volts potential to ground on the movement shall be protected by a cage or cover in addition to the regular case. (Some instruments are designed by the manufacturers to operate safely with voltages in excess of 1,000 volts on the movement. If it can be shown by the manufacturer's rating that the instrument will operate safely at the applied potential, additional protection is not necessary.)

(ii) In case the plate voltmeters are located on the low potential side of the multiplier resistors with the high potential terminal of the instruments at or less than 1,000 volts above ground, no protective case is required. However, it is good practice to protect voltmeters subject to more than 5,000 volts with suitable over-voltage protective devices across the instrument terminals in case the winding opens.

(iii) Transmission line meters and any other radio frequency instrument which may be necessary for the operator to read shall be so installed as to be read easily and accurately without the operator having to risk contact with circuits carying high potential radio frequency energy.

(e) *Wiring and shielding.* (1) The transmitter panels or units shall be wired in accordance with standard practice, such as insulated leads properly cabled and supported, coaxial cables, or rigid bus bar properly insulated and protected.

(2) Wiring between units of the transmitters, with the exception of circuits carrying radio frequency energy or video energy, shall be installed in conduits or approved fiber or metal raceways to protect it from mechanical injury.

(3) Circuits carrying radio frequency or video energy between units shall be coaxial cables, two wire balanced lines, or properly shielded lines.

(4) All stages or units shall be adequately shielded and filtered to prevent interaction and radiation.

(5) The frequency and modulation monitors and associated radio frequency lines to the transmitter shall be thoroughly shielded.

(f) *Auxiliary transmitters.* Auxiliary transmitters may not exceed the power rating of the main transmitters. As a general guide, specifications for auxiliary transmitters should conform as much as possible to those of the main transmitters. No requirements are set forth at this time.

(g) *Installation.* (1) The installation of transmitting equipment shall be made in suitable quarters. (2) Suitable facilities shall be provided for the welfare and comfort of the operator.

(h) An accurate circuit diagram and list of required spare tubes, as furnished by the manufacturer of the equipment, shall be supplied and retained at the transmitter location.

(i) *Operation.* (1) Spurious emissions, including radio frequency harmonics, shall be maintained at as low a level as the state of the art permits. As measured at the output terminals of the transmitter (including harmonic filters, if required) all emissions removed in frequency in excess of 3 Mc above or below the respective channel edge shall be attenuated no less than 60 db. below the visual transmitted power. (The 60 db. value for television transmitters specified in this rule should be considered as a temporary requirement which may be increased at a later date, especially when more higher-powered equipment is utilized. Stations should, therefore, give consideration to the installation of equipment with greater attenuation than 60 db.) In the event of interference caused to any service greater attenuation will be required.

(2) If a limiting or compression amplifier is used in conjunction with the aural transmitter, due operating precautions should be maintained because of pre-emphasis in the transmitting system.

(j) *Studio equipment.* Studio equipment shall be subject to all the above requirements where applicable, except as follows:

(1) If properly covered by an underwriter's certificate, it will be considered as satisfying safety requirements.

(2) Section 8191 of article 810 of the National Electrical Code shall apply for voltages only in excess of 500 volts.

(3) No specific requirements are made relative to the design and acoustical treatment of studios. However, the design of studios, particularly the main studio, shall be compatible with the required performance characteristics of television broadcast stations.

§ 3.688 Indicating instruments. (a) Each television broadcast station shall be equipped with indicating instruments for measuring the direct plate voltage and current of the last radio stage of the visual and aural transmitters and the transmission line radio frequency current, voltage, or power of both transmitters; such instruments shall conform to the specifications therefor set forth in this subpart.

(b) The following requirements and specifications shall apply to indicating instruments used by television broadcast stations in compliance with paragraph (a) of this section:

(1) Length of scale shall be not less than $2\frac{3}{10}$ inches.

(2) Accuracy shall be at least 2 percent of the full scale reading.

(3) Scale shall have at least 40 divisions.

(4) Full scale reading shall be not greater than five times the minimum normal indication.

(5) No specifications are prescribed at this time regarding the peak indicating device required by § 3.689(b).

(c) Any required instrument, the accuracy of which is questionable, shall not be employed. Repairs and calibration of instruments shall be made by the manufacturer, or by an authorized instrument repair service of the manufacturer, or by some other properly qualified or equipped instrument repair service. In any case, the repaired instrument must be supplied with a certificate of calibration.

(d) Recording instruments may be employed in addition to the indicating instruments to record the direct plate current and/or voltage to the last radio stage provided that they do not affect the operation of the circuits or accuracy of the indicating instruments. If the records are to be used in any proceeding before the Commission, as representative of operation, the accuracy must be the equivalent of the indicating instruments and the calibration shall be checked at such intervals as to insure the retention of such accuracy.

(e) The function of each instrument used in the equipment shall be clearly and permanently shown on the instrument itself or on the panel immediately adjacent thereto.

(f) In the event that any one of the indicating instruments required by paragraph (a) of this section becomes defective when no substitute which conforms with the required specifications is available, the station may be operated without the defective instrument pending its repair or replacement for a period not in excess of 60 days: *Provided,* That—

(1) Appropriate entries shall be made in the operating log of the station, showing the date and time the meter was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the instrument is found to be defective and immediately after the repaired or replacement instrument has been installed and is functioning properly.

(3) If the defective instrument is a plate voltmeter or plate ammeter in the last radio stage, the operating power shall be maintained by means of the radio frequency transmission line meter.

(4) If conditions beyond the control of the licensee prevent the restoration of the meter to service within the above allowed period, informal request may be filed in accordance with § 1.332(d) of this chapter with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

§ 3.689 Operating power. (a) *Determination*—(1) *Visual transmitter.* The operating power of the visual transmitter shall be determined at the output terminal of the vestigial sideband filter, if such filter is used; otherwise, at the transmitter output terminal. The average power shall be measured while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission line surge impedance, while transmitting a standard black television picture. The peak power shall be the power obtained by this method, multiplied by the factor 1.68. During this measurement the direct plate voltage and current of the last radio stage and the peak output voltage or current shall be read for use below.

(2) *Aural transmitter.* The operating power of the aural transmitter shall be determined by the indirect method. This is the product of the plate voltage (E_p) and the plate current (I_p) of the last radio stage, and an efficiency factor, F; that is:

$$\text{Operating power} = E_p \times I_p \times F$$

(i) The efficiency factor, F, shall be established by the transmitter manufacturer for each type of transmitter for which he submits data to the Commission, and shall be shown in the instruction books supplied to the customer with each transmitter. In the case of composite equipment, the factor F shall be furnished to the Commission by the applicant along with a statement of the basis used in determining such factor.

(b) *Maintenance*—(1) *Visual transmitter.* The peak power shall be monitored by a peak reading device which reads proportionally to voltage, current, or power in the radio frequency transmission line, the meter to be calibrated during the measurement described in paragraph (a) (1) of this section. The operating power as so monitored shall be maintained as near as practicable to the authorized operating power and shall not exceed the limits of 10 percent above and 20 percent below the authorized power except in emergencies. As a further check, both the plate voltage and plate current of the output stage shall be measured with a standard black television picture with the transmitter operating into the antenna. These values must agree substantially with corresponding readings taken under paragraph (a) (1) of this section.

(2) *Aural transmitter.* The operating power of the aural transmitter shall be maintained as near as practicable to the authorized operating power, and shall not exceed the limits of 10 percent above and 20 percent below the authorized power except in emergencies.

(3) *Reduced power.* In the event it becomes impossible to operate with the authorized power, the station may be operated with reduced power for a period of 10 days or less provided the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified in writing immediately thereafter and also upon the resumption of the normal operating power.

Monitoring Equipment

§ 3.690 Frequency monitors. (a) The licensee of each television broadcast station shall have in operation at the transmitter approved frequency monitors independent of the frequency control of the transmitters. (The requirement of this paragraph is postponed until June 1, 1960.)

NOTE: Approved frequency monitors are included on the Commission's "Radio Equipment List, Part A, Television Broadcast Equipment." Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(b) In the event the visual or aural frequency monitor becomes defective, the station may be operated without such equipment pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided,* That:

(1) Appropriate entries shall be made in the operating log of the station to show the date and time the equipment was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the equipment is found to be defective and immediately after the repaired or replacement equipment has been installed and is functioning properly.

(3) During the period when the station is operated without the visual or aural frequency monitor, the respective carrier frequency shall be compared with an external frequency source of known accuracy at sufficiently frequent intervals to insure that the frequency is maintained within the tolerance prescribed in § 3.687(c)(1). An entry shall be made in the station log as to the method used and the results thereof.

(4) If conditions beyond the control of the licensee or permittee prevent the restoration of the monitor or monitoring equipment to service within the period specified above, an informal request in accordance with § 1.332(d) of this chapter may be filed with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument or equipment.

§ 3.691 Modulation monitors. (a) The licensee of each television broadcast station shall have in operation at the transmitter an approved modulation monitor for the aural transmitter. There shall also be employed sufficient monitoring equipment for the visual signal to determine that the signal complies with the requirements of this subpart. (The requirement for use of type-approved aural modulation monitors is postponed until June 1, 1960.)

NOTE: Approved aural modulation monitors are included on the Commission's "Radio Equipment List, Part A, Television Broadcast Equipment." Copies of this list are available for inspection at the Commission's office in Washington, D.C., and at each of its field offices.

(b) In the event the visual monitoring equipment or the aural modulation monitor becomes defective, the station may be operated without such equipment pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided,* That:

(1) Appropriate entries shall be made in the operating log of the station to show the date and time the equipment was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the equipment is found to be defective and immediately after the repaired or replacement equipment has been installed and is functioning properly.

(3) During the period when the station is operated without the aural modulation monitor or the visual monitoring equipment, the licensee shall provide other suitable means for insuring that the aural modulation is maintained within the tolerance prescribed in § 3.687(b)(7) and that the visual signal is maintained in accordance with the requirements of this subpart.

(4) If conditions beyond the control of the licensee or permittee prevent the restoration of the monitor or monitoring equipment to service within the period specified above, an informal request in accordance with § 1.332(d) of this chapter may be filed with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument or equipment.

§ 3.692 General requirements for type approval of frequency and modulation monitors. (a) Any manufacturer desiring to submit a monitor for type approval shall supply the Commission with full specification details (two sworn copies) as well as the test data specified in §§ 3.693 and 3.694. If this information appears to meet the requirements of the rules, shipping instructions will be issued to the manufacturer. The shipping charges to and from the Laboratory at Laurel, Maryland, shall be paid for by the manufacturer. Approval of a monitor will only be given on the basis of the data obtained from the sample monitor submitted to the Commission for test.

(b) In approving a monitor upon the basis of the tests conducted by the Laboratory, the Commission merely recognizes that the type of monitor has the inherent capability of functioning in compliance with the rules, if properly constructed, maintained, and operated. The Commission realizes that the frequency monitor may have limited range over which the visual indicator will determine deviations. Accordingly, it is necessary that adjunct equipment be used to determine major deviations.

(c) Additional rules with respect to withdrawal of type approval, modification of type approved equipment and limitations on the findings upon which type approval is based are set forth in Part 2, Subpart F, of the Commission's Rules.

§ 3.693 Requirements for type approval of frequency monitors. (a) The specifications that frequency monitors shall meet before they will be approved by the Commission are as follows:

(1) The monitor shall have as accuracy of better than 500 cycles for 30 days on VHF operation, or for 10 days on UHF operation, and under ordinary conditions (ambient temperature from 10° centigrade to 40° centigrade above zero, humidity from 10 percent to 95 percent relative humidity, power supply variations from 90 percent to 110 percent, and other conditions which may affect its accuracy) encountered in television broadcast stations throughout the United States.

(2) The range of the indicating device for the aural monitor shall be at least 3000 cycles below to 3000 cycles above the assigned center frequency. Alternatively, the aural monitor may use an indicating device with a similar scale to indicate the difference-frequency between the aural and visual carriers. The range of the indicating device for the visual monitor shall be at least 1500 cycles below to 1500 cycles above the assigned carrier frequency.

(3) The scale of the indicating device shall be calibrated in divisions of not more than 100 cycles.

(4) Means shall be provided for adjustment of the monitor indication to agree with an external standard.

(5) The monitors shall be capable of continuous operation and the circuits shall be such as to permit continuous monitoring of the transmitter carrier frequencies, and the difference-frequency between the visual and aural carriers if this method of measurement is used.

(6) Operation of the monitors shall have no adverse effect on the operation of either the aural or visual transmitters or the signals emitted therefrom and shall be independent of the frequency control of the transmitters.

(7) Means shall be provided for insuring power input level.

(8) General design, construction and operation shall be in accordance with good engineering practice.

(b) Tests to be made for approval of television broadcast frequency monitors. The manufacturer of a monitor shall submit data on the following at the time of requesting approval:

(1) Constancy of oscillator frequency, as measured daily for one month, or more.

(2) Constancy of oscillator frequency when subject to vibration tests which would correspond to the treatment received in shipping, handling and installing the instrument.

(3) Accuracy of reading of the frequency deviation instrument.

(4) Functioning of frequency adjustment device.

(5) Effects on frequency readings, of the changing of tubes, of voltage variations, and of variations of room temperature through a range from 10° to 40°C.

(6) Response of indicating instrument to small changes of frequency.

(7) General information on the effect of tilting or tipping or other tests to determine ability of equipment to withstand shipment.

(c) Various other tests may be made or required, such as effects of variation of input from the transmitter depending upon the character of the apparatus.

(d) Tests shall be conducted in such a manner as to approximate actual operating conditions as nearly as possible. The equipment shall be tested on the highest channel for which it is designed.

§ 3.694 Requirements for type approval of aural modulation monitors. (a) The required aural modulation monitor may or may not be a part of the frequency monitor.

(b) The specifications that the aural modulation monitor shall meet before it will be approved by the Commission are as follows:

(1) Means shall be provided for indicating that the signal input to the modulation monitor is in the range required for proper operations.

(2) A modulation peak indicating device shall be provided that can be set at any pre-determined value from 50 to 120 percent modulation (±25 kc swing is defined as 100 percent modulation) and for either positive or negative swings (i.e., either above or below transmitter center frequency).

(3) A quasi-peak indicator with a meter having the characteristics given below shall be used with a circuit such that peaks of modulation of duration between 40 and 90 milliseconds are indicated to 90 percent of full value and the discharge rate adjusted so that the pointer returns from full reading to within 10 percent of zero within 500 to 800 milliseconds. A switch shall be provided so that this meter will read either positive or negative swings.

(4) When modulation of a magnitude necessary to produce a deflection equivalent to 100 percent modulation is suddenly applied and left on, the indicating instrument shall not deflect beyond 110 percent on the first passage of the 100 percent mark and shall have excursion from the final value of less than 1 percent after one second or more.

(5) The meter scale shall be similar in appearance to that of a standard VU meter. The scale length between 0 and 100 percent modulation markings shall be at least 2.3 inches. In addition to other markings a small marker for 133 percent modulation, designated as such, should be included for the purpose of testing the transmitter with 33.3 kc swing.

(6) The indicated reading in percentage shall be accurate within ±5 (based on 100 percent modulation) at any percentage of modulation up to 100.

(7) The frequency characteristic curve as measured at 50 percent modulation shall not depart from a straight line more than ±½ db from 50 to 15,000 cycles. Distortion shall be kept to a minimum.

(8) The monitor shall not absorb appreciable power from the transmitter.

(9) Operation of the monitor shall have no adverse effect on the operation of the transmitter.

(10) General design, construction, and operation shall be in accordance with good engineering practice.

(c) Tests to be made for approval of television broadcast aural modulation monitors. The manufacturer of a monitor shall submit data on the following at the time of requesting approval:

(1) Audio frequency response of the monitor from 50 to 15,000 cycles in db from the response at 400 cycles.

(2) Distortion in the response.

(3) Input signal power required.

(4) Permissible tolerance on input signal power to keep the meter reading correct within 5 percent units.

(5) Ballistic characteristics of the monitor indicator.

(d) Various other tests may be made or required depending on the character of the apparatus.

(e) Tests shall be conducted in such a manner as to approximate actual operating conditions as nearly as possible. The equipment shall be tested on the highest channel for which it is designed.

§§ 3.695–3.697 [Reserved.]

§ 3.698 Tables.

TABLE

MINUTES TO DECIMAL PARTS OF A DEGREE

Minutes	Degrees	Minutes	Degrees
1	0.01667	31	0.51667
2	.03333	32	.53333
3	.05	33	.55
4	.06667	34	.56667
5	.08333	35	.58333
6	.10	36	.60
7	.11667	37	.61667
8	.13333	38	.63333
9	.15	39	.65
10	.16667	40	.66667
11	.18333	41	.68333
12	.20	42	.70
13	.21667	43	.71667
14	.23333	44	.73333
15	.25	45	.75
16	.26667	46	.76667
17	.28333	47	.78333
18	.30	48	.80
19	.31667	49	.81667
20	.33333	50	.83333
21	.35	51	.85
22	.36667	52	.86667
23	.38333	53	.88333
24	.40	54	.90
25	.41667	55	.91667
26	.43333	56	.93333
27	.45	57	.95
28	.46667	58	.96667
29	.48333	59	.98333
30	.50	60	1.00

TABLE I—(*Continued*)

SECONDS TO DECIMAL PARTS OF A DEGREE

Seconds	Degrees	Seconds	Degrees
1	0.00028	31	0.00861
2	.00056	32	.00889
3	.00083	33	.00917
4	.00111	34	.00994
5	.00139	35	.00972
6	.00167	36	.01
7	.00194	37	.01028
8	.00222	38	.01056
9	.0025	39	.01083
10	.00278	40	.01111
11	.00306	41	.01139
12	.00333	42	.01167
13	.00361	43	.01194
14	.00389	44	.01222
15	.00417	45	.0125
16	.00444	46	.01278
17	.00472	47	.01306
18	.005	48	.01333
19	.00528	49	.01361
20	.00556	50	.01389
21	.00583	51	.01417
22	.00611	52	.01444
23	.00639	53	.01472
24	.00667	54	.015
25	.00694	55	.01528
26	.00722	56	.01556
27	.0075	57	.01583
28	.00778	58	.01611
29	.00806	59	.01639
30	.00833	60	.01667

TABLE II

MILES PER DEGREE OF LATITUDE DIFFERENCE

Middle latitude	Statute miles	Middle latitude	Statute miles
° ′		° ′	
25 0	68.828	38 0	68.968
30	68.833	30	68.974
26 0	68.837	39 0	68.980
30	68.842	30	68.986
27 0	68.847	40 0	68.992
30	68.852	30	68.998
28 0	68.857	41 0	69.004
30	68.862	30	69.011
29 0	68.867	42 0	69.017
30	68.873	30	69.023
30 0	68.878	43 0	69.029
30	68.883	30	69.035
31 0	68.889	44 0	69.041
30	68.894	30	69.047
32 0	68.899	45 0	69.053
30	68.905	30	69.060
33 0	68.911	46 0	69.066
30	68.916	30	69.072
34 0	68.922	47 0	69.078
30	68.928	30	69.084
35 0	68.933	48 0	69.090
30	68.939	30	69.096
36 0	68.945	49 0	69.102
30	68.951	30	69.108
37 0	68.957	50 0	69.115
30	68.962		

Middle latitude degrees	Miles per degree of longitude											
	25	26	27	28	29	30	31	32	33	34	35	36
Minutes												
0	62.728	62.211	61.675	61.120	60.547	59.955	59.345	58.716	58.070	57.406	56.725	56.026
1	62.720	62.202	61.666	61.111	60.537	59.945	59.335	58.706	58.059	57.395	56.713	56.014
2	62.712	62.193	61.657	61.101	60.528	59.935	59.324	58.695	58.048	57.384	56.702	56.002
3	62.703	62.184	61.648	61.092	60.517	59.925	59.314	58.684	58.037	57.373	56.690	55.991
4	62.694	62.176	61.639	61.082	60.508	59.915	59.303	58.674	58.026	57.362	56.678	55.979
5	62.686	62.167	61.630	61.073	60.498	59.905	59.293	58.663	58.015	57.350	56.667	55.967
6	62.677	62.158	61.621	61.064	60.488	59.895	59.282	58.652	58.004	57.339	56.655	55.955
7	62.669	62.149	61.611	61.054	60.478	59.885	59.272	58.642	57.994	57.328	56.644	55.943
8	62.660	62.140	61.602	61.045	60.469	59.875	59.262	58.631	57.983	57.316	56.632	55.931
9	62.652	62.132	61.593	61.035	60.459	59.865	59.252	58.620	57.972	57.305	56.621	55.920
10	62.644	62.123	61.584	61.026	60.449	59.855	59.241	58.610	57.961	57.294	56.610	55.908
11	62.635	62.114	61.575	61.017	60.440	59.845	59.231	58.599	57.950	57.283	56.598	55.896
12	62.627	62.105	61.566	61.007	60.430	59.835	59.221	58.588	57.939	57.271	56.586	55.884
13	62.618	62.096	61.557	60.997	60.420	59.825	59.210	58.578	57.928	57.260	56.575	55.872
14	62.609	62.088	61.547	60.988	60.410	59.814	59.200	58.567	57.917	57.249	56.563	55.860
15	62.601	62.079	61.538	60.979	60.400	59.804	59.189	58.556	57.906	57.238	56.552	55.849
16	62.592	62.070	61.529	60.969	60.390	59.794	59.179	58.546	57.895	57.227	56.540	55.837
17	62.583	62.061	61.520	60.959	60.381	59.784	59.168	58.535	57.884	57.215	56.529	55.825
18	62.575	62.052	61.510	60.950	60.371	59.774	59.158	58.524	57.873	57.204	56.517	55.813
19	62.567	62.044	61.501	60.940	60.361	59.764	59.147	58.514	57.862	57.192	56.505	55.802
20	62.559	62.035	61.492	60.931	60.352	59.754	59.137	58.503	57.851	57.181	56.493	55.790
21	62.550	62.026	61.483	60.921	60.342	59.744	59.127	58.492	57.840	57.170	56.482	55.778
22	62.541	62.017	61.474	60.912	60.332	59.734	59.116	58.481	57.829	57.159	56.470	55.766
23	62.532	62.008	61.465	60.902	60.322	59.723	59.106	58.470	57.818	57.147	56.459	55.754
24	62.524	61.999	61.455	60.893	60.312	59.713	59.095	58.460	57.807	57.136	56.447	55.742
25	62.515	61.990	61.446	60.883	60.302	59.703	59.085	58.449	57.796	57.125	56.435	55.730
26	62.507	61.981	61.437	60.874	60.292	59.693	59.074	58.438	57.785	57.113	56.424	55.718
27	62.498	61.972	61.428	60.865	60.282	59.683	59.064	58.428	57.774	57.102	56.412	55.706
28	62.489	61.963	61.419	60.855	60.273	59.672	59.054	58.417	57.763	57.090	56.401	55.694
29	62.480	61.955	61.409	60.845	60.263	59.662	59.043	58.406	57.752	57.079	56.389	55.682
30	62.472	61.946	61.400	60.836	60.253	59.652	59.033	58.396	57.741	57.068	56.378	55.671
31	62.463	61.937	61.391	60.826	60.243	59.642	59.022	58.385	57.729	57.057	56.366	55.659
32	62.455	61.928	61.381	60.817	60.233	59.632	59.012	58.374	57.718	57.045	56.354	55.647
33	62.446	61.918	61.372	60.807	60.223	59.622	59.001	58.363	57.707	57.034	56.343	55.635
34	62.438	61.909	61.363	60.798	60.213	59.611	58.991	58.352	57.696	57.022	56.331	55.623
35	62.429	61.900	61.354	60.788	60.203	59.601	58.980	58.341	57.685	57.011	56.319	55.611
36	62.420	61.891	61.344	60.778	60.194	59.591	58.970	58.331	57.674	56.999	56.308	55.599
37	62.412	61.882	61.335	60.768	60.184	59.581	58.960	58.320	57.663	56.988	56.296	55.587
38	62.403	61.874	61.325	60.759	60.174	59.571	58.949	58.309	57.652	56.977	56.284	55.575
39	62.395	61.865	61.316	60.750	60.164	59.561	58.939	58.298	57.641	56.966	56.273	55.563
40	62.386	61.856	61.307	60.740	60.154	59.550	58.928	58.288	57.629	56.954	56.261	55.551
41	62.377	61.847	61.298	60.730	60.144	59.540	58.917	58.277	57.618	56.943	56.249	55.539
42	62.369	61.838	61.289	60.721	60.134	59.530	58.907	58.266	57.607	56.931	56.238	55.527
43	62.360	61.829	61.279	60.711	60.124	59.520	58.896	58.255	57.596	56.919	56.226	55.515
44	62.351	61.820	61.270	60.701	60.114	59.510	58.886	58.244	57.585	56.908	56.214	55.503
45	62.342	61.811	61.261	60.692	60.104	59.500	58.875	58.233	57.574	56.897	56.202	55.491
46	62.334	61.802	61.252	60.682	60.094	59.489	58.865	58.223	57.563	56.885	56.191	55.479
47	62.325	61.793	61.242	60.672	60.084	59.479	58.854	58.212	57.552	56.874	56.179	55.467
48	62.316	61.784	61.233	60.663	60.074	59.468	58.843	58.201	57.541	56.863	56.167	55.455
49	62.308	61.775	61.223	60.654	60.065	59.458	58.833	58.190	57.529	56.851	56.156	55.443
50	62.299	61.766	61.214	60.644	60.055	59.448	58.822	58.179	57.518	56.840	56.144	55.431
51	62.290	61.757	61.205	60.634	60.045	59.438	58.812	58.168	57.507	56.829	56.132	55.419
52	62.281	61.748	61.195	60.625	60.035	59.427	58.801	58.157	57.496	56.817	56.120	55.407
53	62.272	61.739	61.186	60.615	60.025	59.417	58.790	58.147	57.485	56.805	56.109	55.395
54	62.264	61.730	61.176	60.605	60.015	59.406	58.780	58.136	57.473	56.794	56.097	55.383
55	62.255	61.721	61.167	60.595	60.005	59.396	58.769	58.125	57.462	56.782	56.085	55.371
56	62.246	61.712	61.158	60.586	59.995	59.386	58.759	58.114	57.451	56.771	56.073	55.359
57	62.237	61.702	61.148	60.576	59.985	59.376	58.748	58.103	57.440	56.759	56.061	55.347
58	62.228	61.693	61.139	60.566	59.975	59.365	58.737	58.092	57.429	56.748	56.050	55.335
59	62.220	61.684	61.129	60.557	59.965	59.355	58.727	58.081	57.418	56.737	56.038	55.323

difference (statute miles)

37	38	39	40	41	42	43	44	45	46	47	48	49
55.311	54.578	53.828	53.063	52.280	51.482	50.669	49.839	48.995	48.135	47.260	46.371	45.468
55.299	54.565	53.816	53.050	52.267	51.469	50.655	49.825	48.980	48.120	47.245	46.356	45.453
55.286	54.553	53.803	53.037	52.254	51.455	50.641	49.811	48.966	48.106	47.231	46.341	45.438
55.274	54.541	53.791	53.024	52.241	51.442	50.627	49.797	48.952	48.091	47.216	46.326	45.422
55.262	54.528	53.778	53.011	52.229	51.429	50.614	49.783	48.937	48.077	47.201	46.311	45.407
55.250	54.516	53.765	52.998	52.215	51.415	50.600	49.769	48.923	48.063	47.187	46.296	45.392
55.238	54.503	53.753	52.985	52.201	51.402	50.586	49.755	48.909	48.048	47.172	46.281	45.377
55.226	54.491	53.740	52.972	52.188	51.388	50.573	49.741	48.895	48.034	47.158	46.266	45.362
55.213	54.479	53.727	52.959	52.175	51.375	50.559	49.727	48.881	48.019	47.143	46.252	45.346
55.201	54.466	53.715	52.946	52.162	51.361	50.545	49.713	48.867	48.005	47.128	46.237	45.331
55.189	54.454	53.702	52.933	52.149	51.348	50.531	49.699	48.852	47.990	47.114	46.222	45.317
55.177	54.441	53.689	52.920	52.135	51.335	50.517	49.685	48.838	47.975	47.099	46.207	45.301
55.165	54.429	53.677	52.907	52.122	51.321	50.504	49.671	48.824	47.961	47.084	46.192	45.286
55.153	54.417	53.664	52.894	52.109	51.307	50.490	49.657	48.809	47.946	47.069	46.177	45.270
55.141	54.404	53.651	52.881	52.096	51.294	50.476	49.643	48.795	47.932	47.054	46.162	45.255
55.128	54.392	53.639	52.868	52.082	51.280	50.462	49.629	48.781	47.917	47.040	46.147	45.240
55.116	54.380	53.626	52.855	52.069	51.267	50.449	49.615	48.767	47.903	47.025	46.132	45.225
55.104	54.367	53.613	52.842	52.056	51.253	50.435	49.601	48.752	47.888	47.010	46.117	45.210
55.093	54.354	53.601	52.830	52.043	51.240	50.421	49.587	48.738	47.874	46.995	46.102	45.194
55.080	54.342	53.588	52.817	52.030	51.226	50.408	49.573	48.724	47.859	46.980	46.087	45.179
55.068	54.330	53.575	52.804	52.016	51.213	50.394	49.559	48.709	47.845	46.966	46.072	45.164
55.056	54.317	53.562	52.791	52.003	51.199	50.380	49.545	48.695	47.830	46.951	46.057	45.149
55.043	54.304	53.549	52.778	51.990	51.185	50.366	49.531	48.681	47.816	46.936	46.042	45.134
55.031	54.292	53.536	52.765	51.977	51.172	50.352	49.517	48.667	47.801	46.921	46.027	45.118
55.019	54.280	53.524	52.752	51.963	51.159	50.338	49.503	48.653	47.787	46.906	46.012	45.103
55.007	54.267	53.511	52.739	51.950	51.145	50.325	49.489	48.638	47.772	46.891	45.997	45.088
54.995	54.255	53.498	52.726	51.936	51.132	50.311	49.475	48.623	47.758	46.877	45.982	45.073
54.983	54.242	53.486	52.713	51.923	51.118	50.297	49.461	48.609	47.743	46.862	45.967	45.057
54.970	54.230	53.473	52.700	51.910	51.104	50.283	49.447	48.595	47.729	46.847	45.952	45.042
54.958	54.217	53.460	52.687	51.897	51.091	50.270	49.433	48.581	47.714	46.832	45.937	45.026
54.946	54.205	53.448	52.674	51.883	51.077	50.256	49.419	48.567	47.699	46.818	45.922	45.011
54.934	54.192	53.435	52.661	51.870	51.064	50.242	49.405	48.552	47.685	46.803	45.906	44.996
54.922	54.180	53.422	52.648	51.857	51.050	50.228	49.391	48.538	47.671	46.788	45.891	44.981
54.909	54.167	53.409	52.635	51.843	51.036	50.214	49.377	48.524	47.656	46.773	45.876	44.965
54.897	54.155	53.396	52.622	51.830	51.023	50.200	49.362	48.509	47.641	46.759	45.861	44.950
54.885	54.142	53.384	52.608	51.817	51.010	50.186	49.348	48.494	47.627	46.744	45.846	44.935
54.872	54.130	53.371	52.595	51.804	50.996	50.173	49.334	48.480	47.612	46.729	45.831	44.920
54.861	54.117	53.358	52.582	51.790	50.982	50.159	49.320	48.466	47.597	46.714	45.816	44.904
54.848	54.104	53.345	52.569	51.777	50.968	50.145	49.306	48.452	47.583	46.699	45.801	44.889
54.836	54.092	53.332	52.556	51.763	50.955	50.131	49.292	48.437	47.568	46.684	45.786	44.874
54.824	54.080	53.320	52.543	51.750	50.942	50.117	49.277	48.423	47.553	46.669	45.771	44.858
54.811	54.067	53.307	52.530	51.736	50.928	50.103	49.263	48.409	47.539	46.654	45.756	44.843
54.799	54.054	53.294	52.517	51.723	50.914	50.089	49.249	48.395	47.524	46.639	45.741	44.827
54.787	54.042	53.281	52.504	51.710	50.901	50.076	49.235	48.380	47.509	46.624	45.726	44.812
54.775	54.030	53.268	52.491	51.697	50.887	50.062	49.221	48.365	47.495	46.609	45.710	44.797
54.762	54.017	53.255	52.478	51.684	50.873	50.048	49.207	48.351	47.480	46.595	45.695	44.782
54.750	54.005	53.243	52.465	51.670	50.860	50.034	49.193	48.336	47.465	46.580	45.680	44.766
54.738	53.992	53.230	52.452	51.657	50.846	50.020	49.179	48.322	47.451	46.565	45.665	44.751
54.726	53.979	53.217	52.438	51.643	50.833	50.006	49.165	48.308	47.436	46.551	45.650	44.736
54.713	53.967	53.204	52.425	51.630	50.819	49.992	49.151	48.293	47.421	46.536	45.635	44.720
54.701	53.955	53.191	52.412	51.616	50.805	49.978	49.136	48.279	47.407	46.521	45.620	44.705
54.688	53.942	53.178	52.399	51.603	50.792	49.965	49.122	48.265	47.392	46.506	45.604	44.689
54.676	53.929	53.165	52.386	51.590	50.778	49.951	49.108	48.250	47.377	46.491	45.589	44.674
54.664	53.917	53.152	52.373	51.576	50.764	49.937	49.094	48.236	47.363	46.476	45.574	44.659
54.652	53.904	53.140	52.359	51.563	50.751	49.923	49.080	48.222	47.348	46.461	45.559	44.643
54.639	53.891	53.127	52.346	51.549	50.737	49.909	49.066	48.207	47.333	46.446	45.544	44.628
54.627	53.879	53.114	52.333	51.536	50.723	49.895	49.051	48.192	47.319	46.431	45.529	44.613
54.614	53.867	53.101	52.320	51.523	50.710	49.881	49.037	48.178	47.304	46.416	45.514	44.597
54.602	53.854	53.088	52.307	51.509	50.696	49.867	49.023	48.163	47.289	46.401	45.499	44.582
54.590	53.841	53.075	52.294	51.496	50.682	49.853	49.009	48.149	47.275	46.386	45.484	44.566

TABLE IV

(1) Channel	(2) 20 miles (IF beat)	(3) 20 miles (inter-modulation)	(4) 55 miles (adjacent channel)	(5) 60 miles (oscil-lator)	(6) 60 miles (sound image)	(7) 75 miles (picture image)
14	22	16–19	15	21	28	29
15	23	17–20	14, 16	22	29	30
16	24	14, 18–21	15, 17	23	30	31
17	25	14–15, 19–22	16, 18	24	31	32
18	26	14–16, 20 23	17, 19	25	32	33
19	27	14–17, 21–24	18, 20	26	33	34
20	28	15–18, 22–25	19, 21	27	34	35
21	29	16–19, 23–26	20, 22	28, 14	35	36
22	30, 14	17–20, 24–27	21, 23	29, 15	36	37
23	31, 15	18–21, 25–28	22, 24	30, 16	37	38
24	32, 16	19 22, 26–29	23, 25	31, 17	38	39
25	33, 17	20–23, 27–30	24, 26	32, 18	39	40
26	34, 18	21–24, 28–31	25, 27	33, 19	40	41
27	35, 19	22–25, 29–32	26, 28	34, 20	41	42
28	36, 20	23–26, 30–33	27, 29	35, 21	42, 14	33
29	37, 21	24–27, 31–34	28, 30	36, 22	43, 15	44, 14
30	38, 22	25–28, 32–35	29, 31	37, 23	44, 16	45, 15
31	39, 23	26–29, 33–36	30, 32	38, 24	45, 17	46, 16
32	40, 24	27–30, 34–37	31, 33	39, 25	46, 18	47, 17
33	41, 25	28–31, 35–38	32, 34	40, 26	47, 19	48, 18
34	42, 26	29–32, 36–39	33, 35	41, 27	48, 20	49, 19
35	43, 27	30–33, 37–40	34, 36	42, 28	49, 21	50, 20
36	44, 28	31–34, 38–41	35, 37	43, 29	50, 22	51, 21
37	45, 29	32–35, 39–42	36, 38	44, 30	51, 23	52, 22
38	46, 30	33–36, 40–43	37, 39	45, 31	52, 24	53, 23
39	47, 31	34–37, 41–44	38, 40	46, 32	53, 25	54, 24
40	48, 32	35–38, 42–45	39, 41	47, 33	54, 26	55, 25
41	49, 33	36–39, 43–46	40, 42	48, 34	55, 27	56, 26
42	50, 34	37–40, 44–47	41, 43	49, 35	56, 28	57, 27
43	51, 35	38–41, 45–48	42, 44	50, 36	57, 29	58, 28
44	52, 36	39–42, 46–49	43, 45	51, 37	58, 30	59, 29
45	53, 37	40–43, 47–50	44, 46	52, 38	59, 31	60, 30
46	54, 38	41–44, 48–51	45, 47	53, 39	60, 32	61, 31
47	55, 39	42–45, 49–52	46, 48	54, 40	61, 33	62, 32
48	56, 40	43–46, 50–53	47, 49	55, 41	62, 34	63, 33
49	57, 41	44–47, 51–54	48, 50	56, 42	63, 35	64, 34
50	58, 42	45–48, 52–55	49, 51	57, 43	64, 36	65, 35
51	59, 43	46–49, 53–56	50, 52	58, 44	65, 37	66, 36
52	60, 44	47–50, 54–57	51, 53	59, 45	66, 38	67, 37
53	61, 45	48–51, 55–58	52, 54	60, 46	67, 39	68, 38
54	62, 46	49–52, 56 59	53, 55	61, 47	68, 40	69, 39
55	63, 47	50–53, 57–60	54, 56	62, 48	69, 41	70, 40
56	64, 48	51–54, 58–61	55, 57	63, 49	70, 42	71, 41
57	65, 49	52 55, 59–62	56, 58	64, 50	71, 43	72, 42
58	66, 50	53–56, 60–63	57, 59	65, 51	72, 44	73, 43
59	67, 51	54–57, 61–64	58, 60	66, 52	73, 45	74, 44
60	68, 52	55–58, 62–65	59, 61	67, 53	74, 46	75, 45
61	69, 53	56 59, 63–66	60, 62	68, 54	75, 47	76, 46
62	70, 54	57–60, 64–67	61, 63	69, 55	76, 48	77, 47
63	71, 55	58–61, 65–68	62, 64	70, 56	77, 49	78, 48
64	72, 56	59–62, 66–69	63, 65	71, 57	78, 50	79, 49
65	73, 57	60–63, 67–70	64, 66	72, 58	79, 51	80, 50
66	74, 58	61–64, 68–71	65, 67	73, 59	80, 52	81, 51
67	75, 59	62–65, 69–72	66, 68	74, 60	81, 53	82, 52
68	76, 60	63–66, 70–73	67, 69	75, 61	82, 54	83, 53
69	77, 61	64–67, 71–74	68, 70	76, 62	83, 55	54
70	78, 62	65–68, 72–75	69, 71	77, 63	56	55

TABLE IV *(Continued)*

(1) Channel	(2) 20 miles (IF beat)	(3) 20 miles (intermodulation)	(4) 55 miles (adjacent channel)	(5) 60 miles (oscillator)	(6) 60 miles (sound image)	(7) 75 miles (picture image)
71	79, 63	66–69, 73–76	70, 72	78, 64	57	56
72	80, 64	67–70, 74–77	71, 73	79, 65	58	57
73	81, 65	68–71, 75–78	72, 74	80, 66	59	58
74	82, 66	69–72, 76–79	73, 75	81, 67	60	59
75	83, 67	70–73, 77–80	74, 76	82, 68	61	60
76	68	71–74, 78–81	75, 77	83, 69	62	61
77	69	72–75, 79–82	76, 78	70	63	62
78	70	73–76, 80–83	77, 79	71	64	63
79	71	74–77, 81–83	78, 80	72	65	64
80	72	75–78, 82–83	79, 81	73	66	65
81	73	76–79, 83	80, 82	74	67	66
82	74	77–80	81, 83	75	68	67
83	75	78–81	82	76	69	68

NOTE: The parenthetical reference beneath the mileage figures in columns 2 through 7, inclusive, indicate, in abbreviated form, the bases for the required mileage separations. For a discussion of these bases, see the "Sixth Report and Order" of the Commission (FCC 52–294). The hyphenated numbers listed in column (3) are both inclusive.

§ 3.699 **Engineering charts.** [See Figures 1 to 12.]

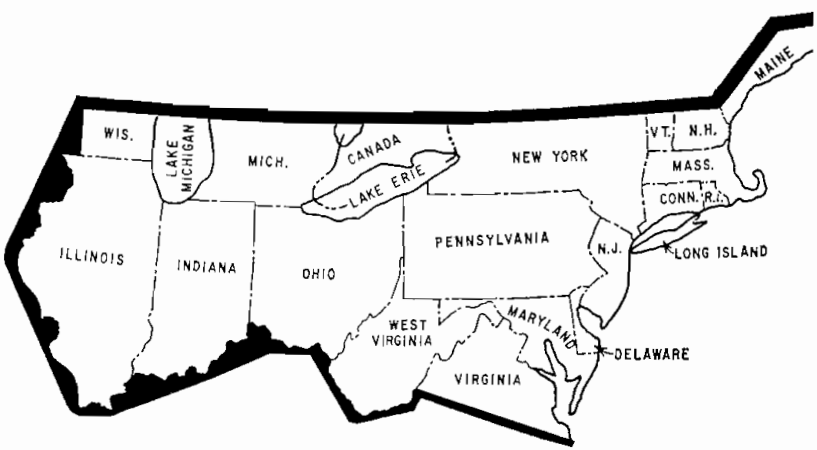


FIGURE 1. Zone I.

FIGURE 2. Zone III.

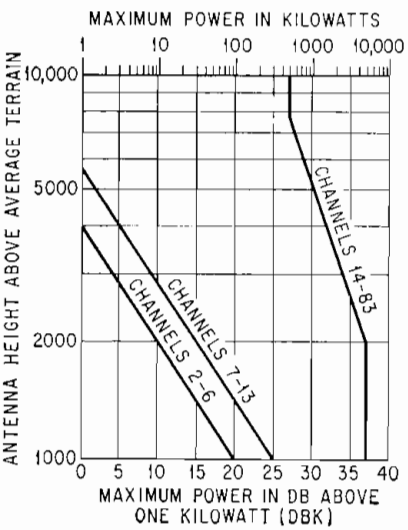


FIGURE 3. Maximum power vs. antenna height for Zone I.

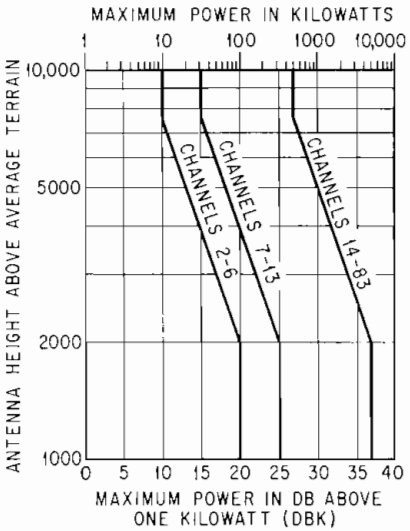


FIGURE 4. Maximum power vs. antenna height for Zones II and III.

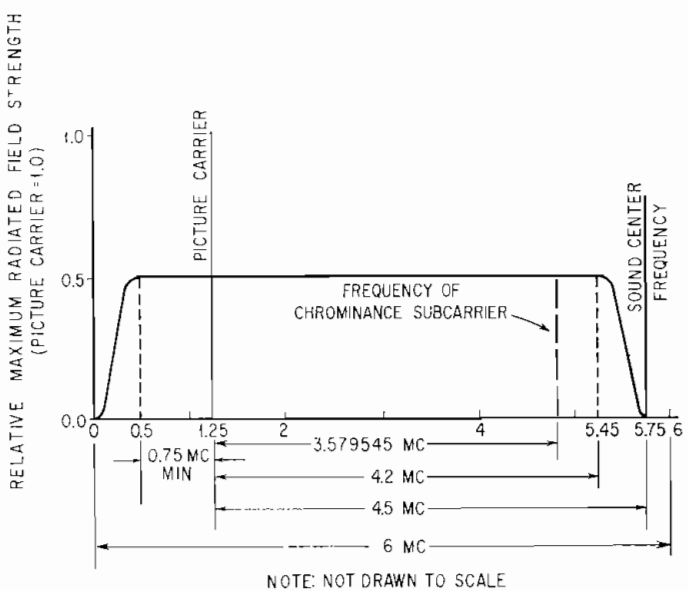
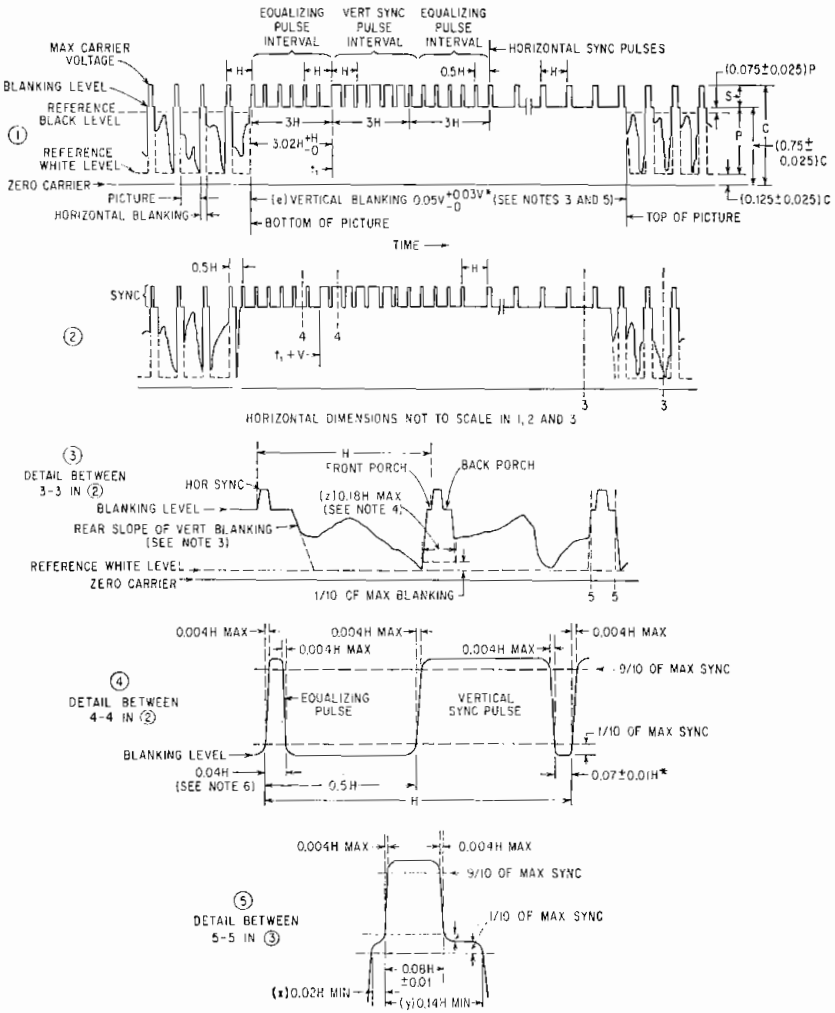


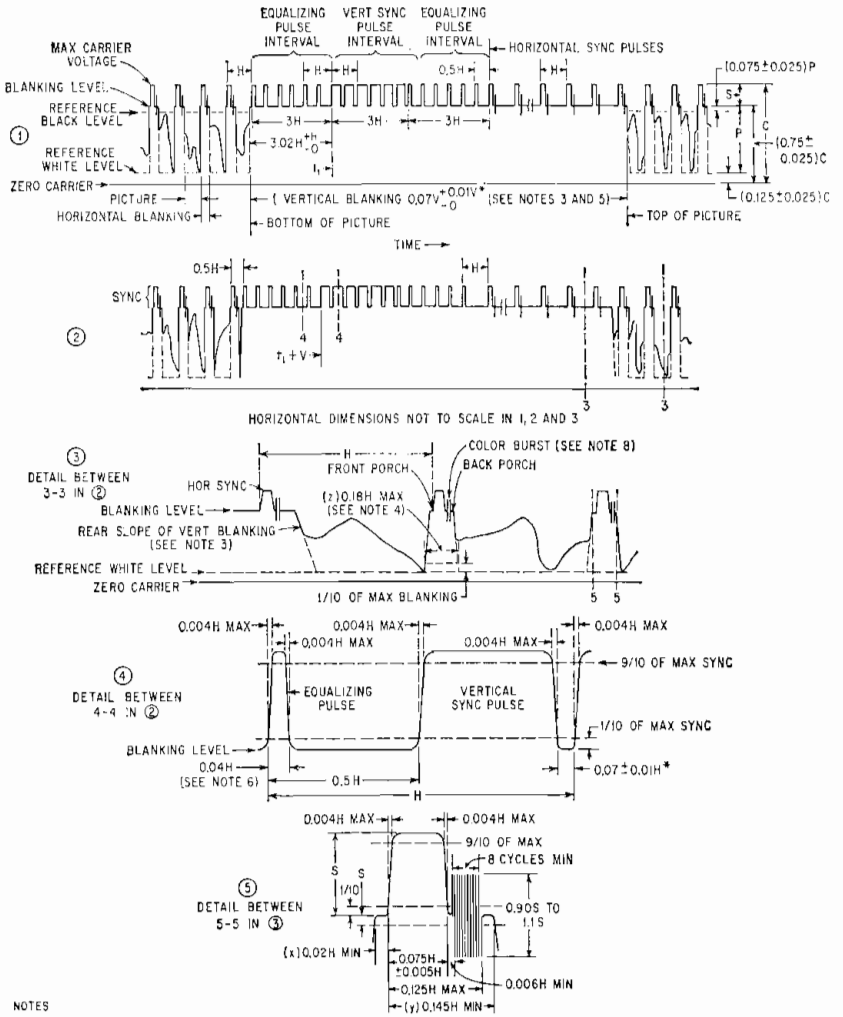
FIGURE 5. Idealized picture transmission amplitude characteristic.



NOTES

1 H = TIME FROM START OF ONE LINE TO START OF NEXT LINE
2 V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD
3 LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1H
4 LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MINIMUM AND MAXIMUM VALUES OF (x+y) AND (z) UNDER ALL CONDITIONS OF PICTURE CONTENT
*5 DIMENSIONS MARKED WITH ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES
6 EQUALIZING PULSE ARE SHALL BE BETWEEN 0.45 AND 0.5 OF AREA OF A HORIZONTAL SYNC PULSE
7 REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES

FIGURE 6. Television synchronizing waveform for monochrome transmission only.



NOTES

1. H = TIME FROM START OF ONE LINE TO START OF NEXT LINE.
2. V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD.
3. LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1H.
4. LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MINIMUM AND MAXIMUM VALUES OF (x+y) AND (z) UNDER ALL CONDITIONS OF PICTURE CONTENT.
*5 DIMENSIONS MARKED WITH ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES.
6. EQUALIZING PULSE AREA SHALL BE BETWEEN 0.45 AND 0.5 OF AREA OF A HORIZONTAL SYNC PULSE.
7. COLOR BURST FOLLOWS EACH HORIZONTAL PULSE, BUT IS OMITTED FOLLOWING THE EQUALIZING PULSES AND DURING THE BROAD VERTICAL PULSES
8. COLOR BURSTS TO BE OMITTED DURING MONOCHROME TRANSMISSION.
9. THE BURST FREQUENCY SHALL BE 3.579545MC. THE TOLERANCE ON THE FREQUENCY SHALL BE ±10 CYCLES WITH A MAXIMUM RATE OF CHANGE OF FREQUENCY NOT TO EXCEED 1/10 CYCLE PER SECOND PER SECOND.
10. THE HORIZONTAL SCANNING FREQUENCY SHALL BE 2/455 TIMES THE BURST FREQUENCY.
11. THE DIMENSIONS SPECIFIED FOR THE BURST DETERMINE THE TIMES OF STARTING AND STOPPING THE BURST, BUT NOT ITS PHASE. THE COLOR BURST CONSISTS OF AMPLITUDE MODULATION OF A CONTINUOUS SINE WAVE.
12. DIMENSION "P" REPRESENTS THE PEAK EXCURSION OF THE LUMINANCE SIGNAL FROM BLANKING LEVEL, BUT DOES NOT INCLUDE THE CHROMINANCE SIGNAL. DIMENSION "S" IS THE SYNC AMPLITUDE ABOVE BLANKING LEVEL. DIMENSION "C" IS THE PEAK CARRIER AMPLITUDE
13. REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES

FIGURE 7. Television synchronizing waveform for color transmission.

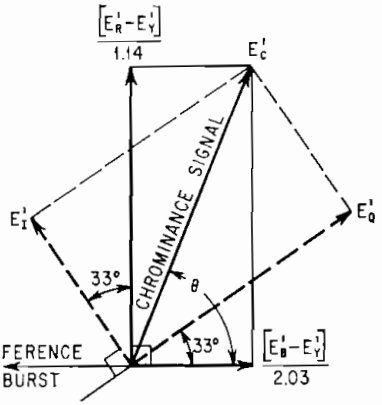


FIGURE 8

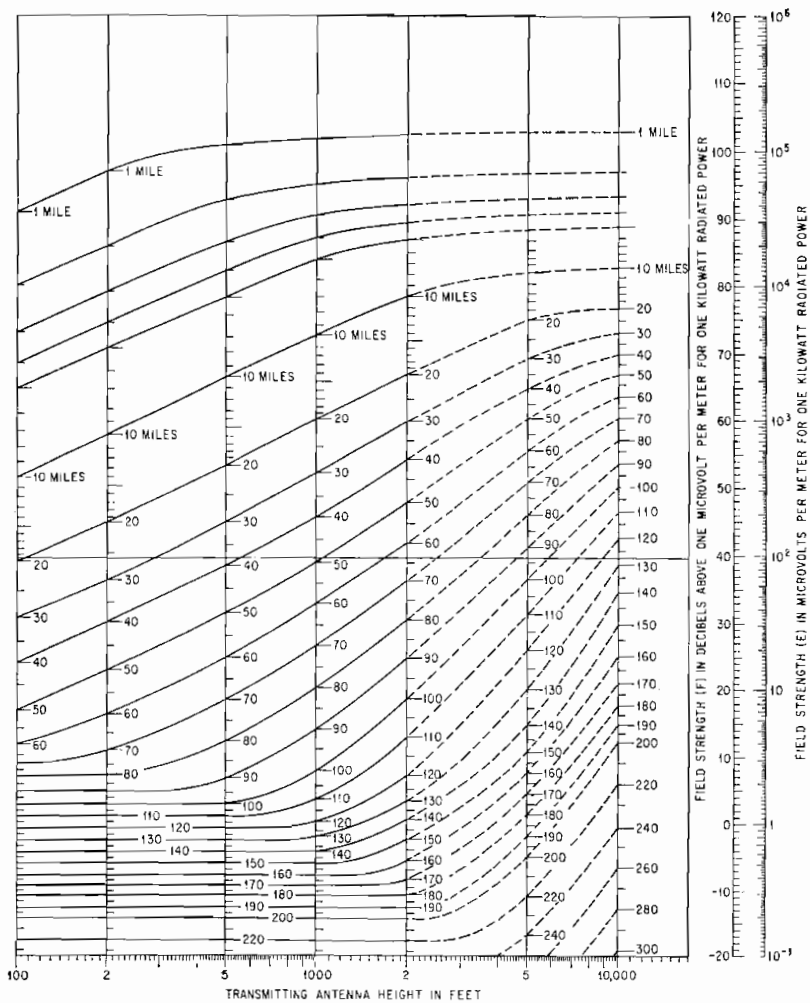


FIGURE 9. Television Channels 2–6, 14–83. Estimated field strength exceeded at 50 percent of the potential receiver locations for at least 50 percent of the time at a receiving antenna height of 30 feet.

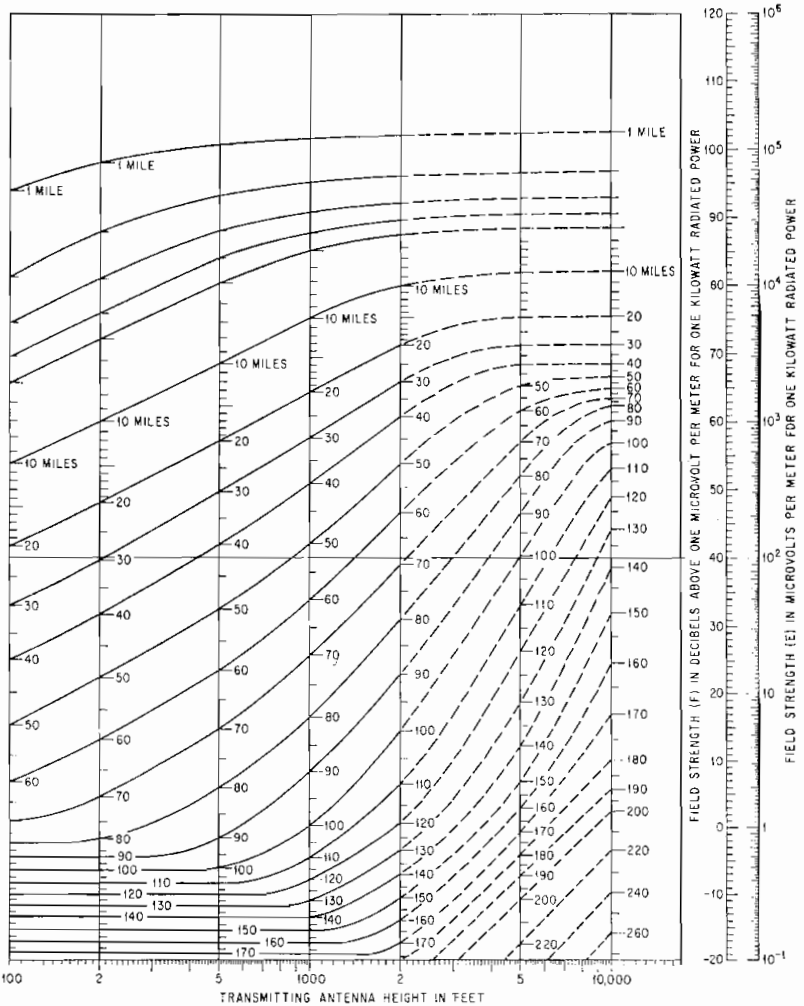


FIGURE 10. Television Channels 7–13. Estimated field strength exceeded at 50 percent of the potential receiver locations for at least 50 percent of the time at a receiving antenna height of 30 feet.

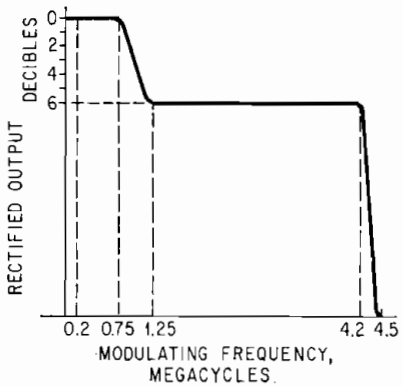


FIGURE 11. Assumed ideal detector output.

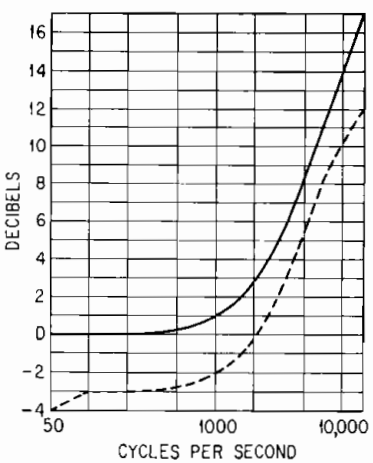


FIGURE. 12. Standard pre-emphasis curve. Time constant 75 microseconds (solid line). Frequency response limits shown by use of solid and dashed lines.

SUBPART F—INTERNATIONAL BROADCAST STATIONS

Definitions and Allocation of Facilities

§ 3.701 Definitions. The following definitions apply to terminology employed in this subpart:

(a) *International broadcast station.* A broadcasting station employing frequencies allocated to the broadcasting service between 5950 and 26100 kc, whose transmissions are intended to be received directly by the general public in foreign countries.

(b) *Frequency-hour.* One frequency used for one hour.

(c) *Day.* Any twenty-four hour period beginning 0000 EST and ending 2400 EST.

(d) *Sunspot number.* The predicted 12 month running average of the number of sunspots for any month as indicated in the National Bureau of Standards CRPL Series D publications.

(e) *Vernal equinox season.* That period of any calendar year starting at 0000 EST on 1 February and ending at 2400 EST on 30 April.

(f) *Summer season.* That period of any calendar year starting at 0000 EST on 1 May and ending at 2400 EST on 31 July.

(g) *Autumnal equinox season.* That period of any calendar year starting at 0000 EST on 1 August and ending at 2400 EST on 31 October.

(h) *Winter season.* That period of any calendar year starting at 0000 EST on 1 November and ending at 2400 EST on 31 January.

(i) *Maximum usable frequency (MUF).* The highest frequency which is returned to the surface of the earth for a particular path and time of day on 50 percent of the days of the reference month.

(j) *Optimum working frequency (OWF).* The frequency which is returned to the surface of the earth for a particular path and time of day on 90 percent of the days of the reference month.

(k) *Reference month.* The middle month of any season listed in § 3.704 "Daily Frequency Hour Availability Table."

(l) *Delivered median field intensity or field intensity.* The field intensity incident upon the target area expressed in microvolts per meter, or decibels above one microvolt per meter, which is exceeded by the hourly median value on 50 percent of the days of the reference month.

(m) *Target area.* Geographic area in which the reception of particular programs is specifically intended and in which adequate broadcast coverage is contemplated.

(n) *Contract operation.* Any non-Government operation of an international broadcast station pursuant to a contract with an agency of the United States Government and subject to Governmental control as to program content, target areas to be covered, and time of broadcast.

(o) *Private operation.* Any non-Government operation of an International Broadcast station which is not contract operation.

§ 3.702 Assignment and use of frequencies.

NOTE: Paragraphs (c) through (k) do not apply to stations when engaged in contract operations as defined in § 3.701.

(a) Frequencies will be assigned by the Commission from time to time and in accordance with the provisions of this section, to authorized international broadcast stations for use at specified hours and for transmission to specified target areas. Licensees may request the assignment of specific frequencies for transmission during given hours of operation to specified target areas by filing informal requests in triplicate with the Commission no less than 15 days prior to the start of a new season. Such requests will be honored to the extent that interference and propagation conditions permit and that they are otherwise in accordance with the provisions of this section. Requests for changes in frequency or hour assignments at other times during the year or which are received less than 15 days before the start of a new season

will be processed as rapidly as practical. All specific frequency authorizations will be made only on the express understanding that they are subject to immediate cancellation or change without hearing whenever the Commission determines that interference or propagation conditions so require and that each assignment of frequency hours for a given season is unique unto itself and not subject to renewal, with the result that completely new assignments must be secured for the forthcoming season. Where a station is simultaneously engaged in both private and contract broadcasting, as defined in § 3.701, it must receive separate frequency hour authorizations for each of these operations.

(b) Any foreign standard target areas shown in Figure 1 of § 3.792 may be specified by the licensee, in which case field intensity calculations should be based on the transmission path between the corresponding reference points listed in § 3.703. In the event a broadcast is to be directed to more than one target area in the same region, the *primary* target area should be specified and the reasons for selecting that particular target area given, with special reference to the nature and special suitability, if any, of the programming proposed. Field intensity calculations should be based on the transmission path to the standard reference point in § 3.703 for the primary target area. In the event a licensee wishes to specify target areas other than those shown in Figure 1 of § 3.792, adequate justification must be given to show that the use of standard target areas is inappropriate, with special reference given to any specialized programming proposed which appears suitable only for the nonstandard target areas designated. When nonstandard target areas are proposed, special reference points must be specified (by geographical coordinates) and reasonably chosen so as to insure complete and adequate coverage of the target areas.

(c) Frequencies assigned by the Commission will be within the following bands:

	Kilocycles
Band A	5950–6200
Band B	9500–9775
Band C	11700–11975
Band D	15100–15450
Band E	17700–17900
Band F	21450–21750
Band G	25600–26100

(d) No frequency will be assigned which would provide a Delivered Median Field Intensity, either measured or calculated, of less than 150 uv/m—50 percent or 43.5 decibels above one uv/m at the distant foreign target area. (This value of Delivered Median Field Intensity is expected to provide protection against atmospheric and industrial noise for at least 90 percent of each hour during 90 percent of the days of the month.) With each request for frequency assignment, licensees must submit computations which adequately show that this requirement would be met.

NOTE: Standard OWF propagation curves and Delivered Median Field Intensity curves for the various hours and seasons throughout the eleven year sunspot cycle have been computed for transmission paths between standard reference points listed in § 3.703 for the standard target areas shown in Figure 1 of § 3.792. These curves, which were developed and used at the Mexico City High Frequency Broadcasting Conference (1948–1949), are available at the Commission's Washington offices and may be used in calculating the propagation data which licensees are required to provide under these Rules. The methods used in computing these data are described in Chapter 7, paragraph 7.7 of the National Bureau of Standards Circular 462. In lieu of that data, and in all cases where nonstandard target areas are specified as provided in paragraph (b) of this section, licensees must develop their own propagation curves for use in computing values of OWF and Delivered Median Field Intensity for the particular transmission paths involved. In doing so, use may be made of the published propagation data of the National Bureau of Standards known as CRPL Series D, "Basic Radio Propagation Predictions," published monthly in conjunction with National Bureau of Standards Circular 465, "Instructions for the Use of Basic Radio Propagation Predictions." These publications are available from the Superintendent of Documents, Washington 25, D.C. A typical example of a computation for a transmission path between standard target areas is from New York (Area 8) to Buenos

Aires (Area 15). The Delivered Median Field Intensity for the equinox season, sunspot 5, and for the 6 Mc band for the hours 0200 to 0400 GMT is indicated by the appropriate propagation curve as 24 decibels above one microvolt per meter for 1 kw radiated power. The transmitter power output of 20 decibels (100 kw) is added. The transmitting antenna gain of 12 decibels is added. The resultant total (56 decibels) exceeds the level of 43.5 decibels required to deliver a median field intensity of 150 uv/m at the distant target area.

(e) Frequencies assigned will be as near as possible to the Optimum Working Frequency. In no case will they exceed the Maximum Usable Frequency for more than a total of 15 minutes during any period of transmission. With each request for frequency assignment, licensees must submit computations which adequately show that this requirement would be met. (See note in paragraph (d) of this section regarding methods for computation.)

(f) Not more than one frequency will be authorized for use at any one time for any one program transmission except in instances where a program is intended for reception in more than one target area and the intended target areas cannot be served by a single frequency.

(g) No authorization for use of a particular frequency will be issued which fails to provide a minimum co-channel Delivered Median Field Intensity protection ratio of 40 db to the transmissions of other broadcasting stations at the reference point in the target area being served by such stations which, in the opinion of the Commission, have priority of assignment.

(h) Authorization for use of a particular frequency will not be issued which does not provide a minimum adjacent channel Delivered Median Field Intensity protection ratio of 11 db to the transmissions of other international broadcasting stations at the reference points in the target areas being served by such stations which, in the opinion of the Commission, have priority of assignment.

(i) Any frequency authorized to an international broadcast station shall also be available for assignment to other international broadcast stations.

(j) Not more than one frequency shall be used simultaneously under the same authorization and call letter and equipment installation number designation.

(k) Subject to all other pertinent provisions of this subpart, the total maximum number of frequency-hours which will be authorized to all licensees of private international broadcast stations for private operation combined in any frequency band for any pertinent season during any one day will be those in § 3.704 less the number of frequency-hours in these bands scheduled for use by both (1) government international broadcasting stations, and (2) international broadcast stations licensed by the Commission to use frequencies in these bands for contract operations.

(l) In the event the total number of frequency hours in any band scheduled for both (1) government international broadcasting stations, and (2) international broadcast stations licensed by the Commission to use frequencies in these bands for contract operations equals or exceeds 75 percent of the frequency hour figures given in § 3.704, the maximum number of frequency-hours which will be authorized to all licensees of international broadcast stations for private operation in any frequency band for any pertinent season during any one day will be 25 percent of the frequency hours shown in § 3.704.

(m) If the requests for international broadcasting frequency-hours for private operation in any band or bands exceed those available under the terms of these Rules, in the absence of any voluntary agreement for reduction of frequency-hours requested, the Commission will designate all requests for frequency-hours in the band or bands in question for hearing. Pending such hearing the Commission will temporarily assign the available frequency-hours equally among the several applicants: *Provided, however,* That with respect to such temporary allocation:

(1) An existing license shall not, to the extent such frequency-hours are available, receive less than the number of frequency-hours utilized during the preceding season or requested for the forthcoming season, whichever is lesser.

(2) Where the number of frequency-hours available for private international broad-

casting during a forthcoming season are insufficient to permit existing licensees to secure a temporary allocation equal to that previously utilized or requested, whichever is lesser, the allocation shall be pro-rated among such persons in a manner which will give them a share of the available frequency-hours proportionate to that utilized in the preceding season.

(3) In any event, where an applicant's share of the available frequency hours would be more than requested, the surplus shall be divided among the remaining applicants in the manner herein prescribed.

§ 3.703 Latitude and longitude of areas used for field intensity calculations.

Area No.	Latitude degrees	Longitude degrees	Area No.	Latitude degrees	Longitude degrees
1	65 N.	150 W.	34	55 N.	140 E.
2	60 N.	125 W.	35	55 N.	160 E.
3	60 N.	100 W.	36	40 N.	25 W.
4	60 N.	80 W.	37	30 N.	0°
5	70 N.	40 W.	38	30 N.	20 E.
6	40 N.	120 W.	39	30 N.	40 E.
7	40 N.	100 W.	40	30 N.	60 E.
8	40 N.	80 W.	41	20 N.	80 E.
9	50 N.	60 W.	42	40 N.	85 E.
10	20 N.	100 W.	43	35 N.	100 E.
11	10 N.	80 W.	44	30 N.	120 E.
12	10 S.	70 W.	45	35 N.	140 E.
13	10 S.	50 W.	46	10 N.	5 W.
14	30 S.	60 W.	47	10 N.	20 E.
15	25 S.	50 W.	48	10 N.	40 E.
16	45 S.	70 W.	49	15 N.	100 E.
17	65 N.	20 W.	50	10 N.	120 E.
18	65 N.	15 E.	51	0°	140 E.
19	65 N.	40 E.	52	10 S.	20 E.
20	70 N.	60 E.	53	10 S.	40 E.
21	70 N.	80 E.	54	5 S.	105 E.
22	70 N.	100 E.	55	15 S.	140 E.
23	70 N.	120 E.	56	20 S.	165 E.
24	65 N.	140 E.	57	30 S.	25 E.
25	65 N.	160 E.	58	25 S.	120 E.
26	65 N.	180 E.	59	35 S.	150 E.
27	50 N.	0°	60	40 S.	170 E.
28	50 N.	20 E.	61	20 N.	160 W.
29	50 N.	40 E.	62	20 S.	170 W.
30	50 N.	60 E.	63	20 S.	150 W.
31	50 N.	80 E.	64	15 N.	145 E.
32	50 N.	100 E.	65	10 N.	170 E.
33	50 N.	120 E.			

§ 3.704 **Daily frequency hour availability table.**

Band	Season	Sunspot Numbers								
		0–20	20–35	35–50	50–65	65–80	80–95	95–110	110–125	125–140
Mc.										
6	June	0	0	0	0	0	0	0	0	0
	March–September	29	21	14	7	0	0	0	0	0
	December	45	47	48	49	50	.....	.....	.....	32
9	June	34	30	27	24	21	16	11	5	2
	March–September	52	42	36	31	27	23	19	12	10
	December	54	50	47	44	42	39	36	33	32
11	June	53	50	48	46	45	39	31	23	14
	March–September	47	50	52	54	55	49	40	31	24
	December	31	34	36	38	39	34	30	26	22
15	June	84	88	91	94	96	87	79	69	58
	March–September	49	54	58	61	64	47	33	21	7
	December	35	35	35	35	35	33	31	29	27
17	June	23	32	40	47	53	59	66	75	84
	March–September	23	22	22	21	20	24	29	34	39
	December	14	18	21	23	25	23	20	17	16
21	June	2	9	14	18	22	39	52	68	80
	March–September	0	9	16	22	27	36	45	56	65
	December	6	11	15	18	21	29	36	47	53
26	.....	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Totals	June	196	209	220	229	237	240	239	239	238
	March–September	200	198	198	196	193	179	166	154	145
	December	185	195	202	207	212	158	153	152	181

(1) No limit.

Administrative Procedure

§ 3.710 **Cross reference.** See § 1.300 to 1.364, Subpart D of Part 1 of this chapter, for general requirements as to applications, filing of applications and description of application forms, other forms and information to be filed with the Commission, the manner in which applications are processed, and provisions applying to action on applications.

§ 3.711 **Application for international broadcast stations.** (a) If the application is for a construction permit or for modification of an existing authorization, FCC Form 309 shall be filed; if for a license, FCC Form 310 shall be filed; if for a renewal of license, FCC Form 311 shall be filed.

NOTE: Until these forms are revised, information required by these Rules and not required by the forms shall be submitted as a supplement to the application and will be considered a part thereof.

(b) Authorizations issued to international broadcast stations by the Commission will not specify the frequencies or hours of use, but will be authorizations to permit the construction or use of a particular transmitting equipment combination and related antenna systems for international broadcasting.

NOTE: Requests for the use of frequencies and frequency hours for transmissions to specific target areas should be submitted separately as provided in § 3.702.

(c) In the case of applications for authorizations to permit contract operations, as defined in § 3.701(n), the contracting agency and contract number should be indicated for each operation.

§ 3.712 **Notification of filing of applications.** In order to minimize harmful interference at the National Radio Astronomy Observatory site located at Green Bank, Pocahontas County, West Virginia, and at the Naval Radio Research Observatory at Sugar Grove, Pendleton County, West Virginia, an applicant for authority to construct a new international broadcast station or for authority to make changes in the frequency, power, antenna height, or antenna directivity of an existing station within the

area bounded by 39° 15′ N on the north, 78° 30′ W on the east, 37° 30′ N on the south and 80° 30′ W on the west shall, at the time of filing such application with the Commission, simultaneously notify the Director, National Radio Astronomy Observatory, P.O. Box #2, Green Bank, West Virginia, in writing, of the technical particulars of the proposed station. Such notification shall include the geographical coordinates of the antenna, antenna height, antenna directivity if any, proposed frequency, type of emission, and power. In addition, the applicant shall indicate in his application to the Commission the date notification was made to the Observatory. After receipt of such applications, the Commission will allow a period of twenty (20) days for comments or objections in response to the notifications indicated. If an objection to the proposed operation is received during the twenty-day period from the National Radio Astronomy Observatory for itself or on behalf of the Naval Radio Research Observatory, the Commission will consider all aspects of the problem and take whatever action is deemed appropriate.

§ 3.716 **Equipmeut tests.** (a) During the process of construction of an international broadcast station, the permittee after notifying the Commission and Engineer in Charge of the radio district in which the station is located may, without further authority of the Commission, conduct equipment tests for the purpose of such adjustments and measurements as may be necessary to assure compliance with the terms of the construction permit, the technical provisions of the application therefor, and the rules and regulations. No programming shall be conducted during equipment tests.

(b) The Commission may notify the permittee to conduct no tests or may cancel, suspend, or change the date for the beginning of equipment tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Equipment tests may be continued so long as the construction permit shall remain valid.

(d) Inspection of a station will ordinarily be required during the equipmeut test period. After construction and after adjustments and measurements have been completed to show compliance with the terms of the construction permit, the technical provisions of the application therefor, and the rules and regulations, the permittee should notify the Engineer in Charge of the radio district in which the station is located that it is ready for inspection.

(e) The authorization for tests embodied in this section shall not be construed as constituting a license to operate but as a necessary part of construction.

§ 3.717 [Reserved.]

§ 3.718 **Normal license period.** All international broadcast station licenses will be issued so as to expire at the hour of 3 a.m. eastern standard time and will be issued for a normal license period of 1 year expiring November 1.

Licensing Policies

§ 3.731 **Licensing requirements; necessary showing.** A license for an international broadcast station will be issued only after a satisfactory showing has been made in regard to the following, among others:

(a) That there is a need for the international broadcast service proposed to be rendered.

(b) That the necessary program sources are available to the applicant to render an effective international service.

(c) That directive antennas and other technical facilities will be employed to deliver maximum signals to the target area or areas for which the service is designed.

(d) That the production of the program service and the technical operation of the proposed station will be conducted by qualified persons.

(e) That the applicant is technically and financially qualified and possesses adequate technical facilities to carry forward the service proposed.

(f) That the public interest, convenience and necessity will be served through the operation of the proposed station.

Equipment

§ 3.751 **Power requirement.** No international broadcast station will be authorized to install equipment or licensed for operation with a power less than 50 kilowatts.

§ 3.752 **Frequency control.** The transmitter of each international broadcast station shall be equipped with automatic frequency control apparatus so designed and constructed that it is capable of maintaining the operating frequency within 0.003% of the assigned frequency.

§ 3.753 **Antenna.** The antenna shall be so designed and operated that the signal (field intensity) toward the specific foreign country or countries served shall be at least 3.16 times the average effective signal from the station (power gain of 10).

§ 3.754 **Frequency monitors.** (a) The licensee of each international broadcast station shall operate at the transmitter a frequency monitor independent of the frequency control of the transmitter.

(b) The frequency monitor shall be designed and constructed in accordance with good engineering practice and shall have an accuracy sufficient to determine that the operating frequency is within one-half of the allowed tolerance.

§ 3.755 **Modulation monitors.** The licensee of each international broadcast station shall have in operation at the transmitter a modulation monitor.

§ 3.756 **Required transmitter performance.** (a) The construction, installation, operation, and performance of the international broadcast transmitter system shall be in accordance with good engineering practice.

NOTE: The establishment of specific levels of attenuation for spurious emissions will be the subject of further Rule Making in Docket 10962 pending the completion of additional studies of this matter.

(b) In addition to the requirements of paragraph (a) of this section in the event spurious emissions cause harmful interference, such additional steps as may be necessary to eliminate the interference must be taken immediately by the licensee.

§ 3.757 **Auxiliary transmitters.** Upon showing that a need exists for the use of auxiliary transmitters in addition to the regular transmitters of an international broadcast station, a license therefor may be issued provided that:

(a) Auxiliary transmitters may be installed either at the same location as the main transmitters or at another location.

(b) A licensed operator shall be in control whenever auxiliary transmitters are placed in operation.

(c) The auxiliary transmitters shall be maintained so that they may be put into immediate operation at any time for the following purposes:

(1) The transmission of the regular programs upon the failure of the main transmitters.

(2) The transmission of regular programs during maintenance or modification work on the main transmitter, necessitating discontinuance of its operation for a period not to exceed 5 days. (This includes the equipment changes which may be made without authority as set forth elsewhere in the Rules and Regulations or as authorized by the Commission by letter or by construction permit. Where such operation is required for periods in excess of 5 days, request therefor shall be in accordance with § 1.324 of this chapter.)

(3) Upon request by a duly authorized representative of the Commission.

(d) The auxiliary transmitters shall be tested at least once each week to determine that they are in proper operating condition and that they are adjusted to the proper frequency except that in the case of operation in accordance with paragraph (c) of this section during any week, the test in that week may be omitted provided the operation under paragraph (c) of this section is satisfactory. A record shall be kept of the time and result of each test. Such records shall be retained for a period of two years.

(e) The auxiliary transmitters shall be equipped with satisfactory control equipment which will enable the maintenance of the frequency emitted by the station within the limits prescribed by the regulations in this part.

(f) The operating power of an auxiliary transmitter may be less than the authorized power of the main transmitters, but in no event shall it be greater than such power.

§ 3.758 **Alternate main transmitters.** The licensee of an international broadcast station may be licensed for alternate main transmitters provided that a technical need for such alternate transmitters is shown and that the following conditions are met:

(a) Both transmitters are located at the same place.

(b) Both transmitters shall have the same power rating.

(c) Both transmitters shall meet the construction, installation, operation, and performance requirements of good engineering practice.

§ 3.759 **Changes in equipment and antenna system.** Licensees of international broadcast stations shall observe the following provisions with regard to changes in equipment and antenna system:

(a) No changes in equipment shall be made:

(1) That would result in the emission of signals outside of the authorized channel.

(b) Specific authority, upon filing formal application (FCC Form 309) therefor, is required for any of the following changes:

(1) Changes involving an increase or decrease in the power rating of the transmitters.

(2) A replacement of the transmitters as a whole.

(3) Change in the location of the transmitting antenna.

(4) Change in location of main studio, if it is proposed to move the main studio to a different city from that specified in the license.

(5) Change in the power delivered to the antenna.

(6) Change in frequency control and/or modulation system.

(c) Other changes, except as above provided for in this section, may be made at any time without the authority of the Commission, provided that the Commission shall be promptly notified thereof and such changes shall be shown in the next application for renewal of license.

Technical Operation

§ 3.761 **Time of operation.** (a) All international broadcast stations will be licensed for unlimited time operations except as may be directed by the Commission from time to time. In an emergency however, when, due to causes beyond the control of the licensee, it becomes impossible to continue operation, the station may cease operation for a period not to exceed 10 days, provided that the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified in writing immediately after the emergency develops.

(b) Persons desiring to enter into a voluntary sharing arrangement of an international channel may file application therefor with the Commission. Copies of the time-sharing agreement should be filed with the application.

§ 3.762 **Station inspection.** The licensee of any international broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 3.763 **Station license, posting of.** The original of each station license shall be posted in the transmitter room.

§ 3.764 **Operator requirements.** One or more licensed radiotelephone first class operators shall be on duty at the place where the transmitting apparatus of each station is located and in actual charge thereof whenever it is being operated. The original license (or FCC Form 759) of each station operator shall be posted at the place where he is on duty. The licensed operator on duty and in charge of an international broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of operator's license which he holds and by the rules and regulations governing such stations. However, such duties shall in nowise interfere with the operation of the broadcast transmitter.

§ 3.765 **Operating power; how determined.** The operating power, and its maintenance, of each international broadcast station shall be in conformity with good engineering practice.

§ 3.766 **Modulation.** The percentage of modulation of the transmissions shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice and in no case less than 50 percent nor more than 100 percent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration.

§ 3.767 **Frequency tolerance.** The operating frequencies of international broadcast station transmitters shall, at all times, be maintained within the frequency tolerances specified in § 3.752.

§ 3.768 **Antenna structure, marking and lighting.** Where an antenna structure(s) is required to be painted or lighted see § 17.37, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 3.769 **Discontinuance of operation.** The licensee of each station, except stations operating in Alaska, shall notify the Engineer in Charge of the radio district in which the station is located of any of the following changes in the status of such station at least two days before such change:

(a) Temporary discontinuance of operation for a period of ten days or more;

(b) The date of resumption of operation after temporary discontinuance of operation for a period of ten days or more;

(c) Permanent discontinuance of operation.

In all cases of permanent discontinuance of operation the licensee shall, in addition to notifying the Engineer in Charge of the radio district in which the station is located of intention to discontinue operation, immediately forward the station license to the Washington, D.C., office of the Commission for cancellation.

Other Operation

§ 3.781 **Logs.** The licensee or permittee of each international broadcast station shall maintain program and operating logs in the following manner:

(a) In the program log:

(1) An entry of the time each station identification announcement (call letters and location) is made.

(2) An entry briefly describing each program broadcast, such as "music," "drama," "speech," etc., together with the name or title thereof, language, and the sponsor's name, with the time of the beginning and ending of the complete program.

(3) An entry showing, for each program of network origin, the name of the network originating the program.

(b) In the operating log:

(1) An entry of the time the station begins to supply power to the antenna, and the time it stops.

(2) An entry of the time the program begins and ends.

(3) An entry of each interruption to the carrier wave, its cause, and duration.

(4) An entry of the following each 30 minutes:

(i) Operating constants of last radio stage of the transmitter (total plate current and plate voltage).

(ii) Frequency monitor reading.

(5) A log must be kept of all experimental operation. If the entries required above are not applicable thereto, then the entries shall be made so as to fully describe the operation.

(c) Where an antenna structure(s) is required to be illuminated, see § 17.38, *Recording of tower light inspections in the station record,* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 3.782 **Logs; retention of.** Logs of international broadcast stations shall be retained by the licensee or permittee for a period of two years: *Provided, however,* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee or permittee has been notified, shall be retained by the licensee or per-

mittee until he is specifically authorized in writing by the Commission to destroy them: *Provided, further,* That logs incident to or involved in any claim or complaint of which the licensee or permittee has notice shall be retained by the licensee or permittee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

§ 3.783 **Logs; by whom kept.** Each log shall be kept by the person or persons competent to do so, having actual knowledge of the facts required, who shall sign the log when starting duty and again when going off duty. The logs shall be made available upon request by an authorized representative of the Commission.

§ 3.784 **Log form.** The log shall be kept in an orderly manner, in suitable form, and in such detail that the data required for the particular class of station concerned are readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log.

§ 3.785 **Correction of logs.** No log or portion thereof shall be erased, obliterated, or willfully destroyed within the period of retention provided by the rules. Any necessary correction may be made only by the person originating the entry who shall strike out the erroneous portion, initial the correction made, and indicate the date of correction.

§ 3.786 **Rough logs.** Rough logs may be transcribed into condensed form, but in such case, the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

§ 3.787 **Station identification.** (a) A licensee of an international broadcast station shall make station identification announcement (call letters and location), at the beginning and ending of each time of operation and during the operation on the hour.

(b) Station identification, program announcements, and oral continuity shall be made with international significance (language particularly) which is designed for the foreign country or countries for which the service is primarily intended.

(c) Identification announcements during operation need not be made when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or any type of production. In such cases the identification announcement shall be made at the first interruption of the entertainment continuity and at the conclusion thereof.

§ 3.788 **Service; commercial or sponsored programs.** (a) A licensee of an international broadcast station shall render only an international broadcast service which will reflect the culture of this country and which will promote international goodwill, understanding, and cooperation. Any program solely intended for, and directed to an audience in the continental United States does not meet the requirements for this service.

(b) Such international broadcast service may include commercial or sponsored programs: *Provided,* That:

(1) Commercial program continuities give no more than the name of the sponsor of the program and the name and general character of the commodity, utility or service, or attraction advertised.

(2) In case of advertising a commodity, the commodity is regularly sold or is being promoted for sale on the open market in the foreign country or countries to which the program is directed in accordance with paragraph (c) of this section.

(3) In case of advertising an American utility or service to prospective tourists or visitors to the United States, the advertisement continuity is particularly directed to such persons in the foreign country or countries where they reside and to which the program is directed in accordance with paragraph (c) of this section.

(4) In case of advertising an international attraction (such as a world fair, resort, spa, etc.) to prospective tourists or visitors to the United States, the oral continuity concerning such attraction is consistent with the purpose and intent of this section.

(5) In case of any other type of advertising, such advertising is directed to the foreign country or countries to which the program is directed and is consistent with the purpose and intent of this section.

(c) The geographic areas to be served by international broadcast stations are the

foreign standard target areas shown in Figure 1 of § 3.792, or foreign nonstandard target areas as provided in § 3.702(d), and directive antennas shall be employed to direct the transmission to these specific target areas.

(d) An international broadcast station may transmit the program of a standard broadcast station or network system: *Provided*, The conditions in paragragh (b) of this section in regard to any commercial continuities are observed and when station identifications are made, only the call letter designation of the international station is given on its assigned frequency: *And provided further*, That in the case of chain broadcasting the program is not carried simultaneously by another international station (except another station owned by the same licensee operated on a frequency in a different group to obtain continuity of signal service), the signals from which are directed to the same area. (See section 3(p) of the Communications Act of 1934 for the definition of "chain broadcasting.")

§ 3.789 **Sponsored programs; announcement of.** (a) In the case of each program for the broadcasting of which money, services, or other valuable consideration is either directly or indirectly paid or promised to, or charged or received by, any radio broadcast station, the station broadcasting such program shall make, or cause to be made, an appropriate announcement that the program is sponsored, paid for, or furnished, either in whole or in part.

(b) In the case of any political program or any program involving the discussion of public controversial issues for which any films, records, transcriptions, talent, scripts, or other material or services of any kind are furnished, either directly or indirectly, to a station as an inducement to the broadcasting of such program, an announcement shall be made both at the beginning and conclusion of such program on which such material or services are used that such films, records, transcriptions, talent, scripts, or other material or services have been furnished to such station in connection with the broadcasting of such program: *Provided, however*, That only one such announcement need be made in the case of any such program of 5 minutes' duration or less, which announcement may be made either at the beginning or conclusion of the program.

(c) The announcement required by this section shall fully and fairly disclose the true identity of the person or persons by whom or in whose behalf such payment is made or promised, or from whom or in whose behalf such services or other valuable consideration is received, or by whom the material or services referred to in paragraph (b) of this section are furnished. Where an agent or other person contracts or otherwise makes arrangements with a station on behalf of another, and such fact is known to the station, the announcement shall disclose the identity of the person or persons in whose behalf such agent is acting instead of the name of such agent.

(d) In the case of any program, other than a program advertising commercial products or services, which is sponsored, paid for or furnished, either in whole or in part, or for which material or services referred to in paragraph (b) of this section are furnished, by a corporation, committee, association or other unincorporated group, the announcement required by this section, shall disclose the name of such corporation, committee, association, or other unincorporated group. In each such case the station shall require that a list of the chief executive officers or members of the executive committee or of the board of directors of the corporation, committee, association, or other unincorporated group shall be made available for public inspection at one of the international broadcast stations carrying the program.

(e) In the case of programs advertising commercial products or services, an announcement stating the sponsor's corporate or trade name or the name of the sponsor's product, shall be deemed sufficient for the purposes of this section and only one such announcement need be made at any time during the course of the program.

§ 3.790 **Rebroadcast.** (a) The licensee of an international broadcast station may, without further authority of the Commission, rebroadcast the program of a United States standard, FM noncommercial educational, or FM broadcast station, provided the Commission is notified of the call letters of each station rebroadcast and the licensee certifies that express authority has been received from the licensee of the station originating the program. The notice and certification of consent must be

given within 3 days of any single rebroadcast, but in case of the regular practice of rebroadcasting certain programs of another broadcast station several times during a license period, notice and certification of consent must be given for the ensuing license period with the application for renewal of license, or at the beginning of such rebroadcast practice if begun during a license period.

NOTE: The broadcasting of a program relayed by a remote pickup broadcast station is not considered a rebroadcast.

(b) No licensee of an international broadcast station shall rebroadcast the programs of any other class of United States radio station without written authority having first been obtained from the Commission.

(c) A licensee of an international broadcast station may authorize the rebroadcast of its programs by any station outside the limits of the North American continent without permission from the Commission: *Provided,* That the station rebroadcasting the programs cannot be received consistently in the United States.

§ 3.791 Supplemental report with renewal application. A supplemental report shall be filed with and made a part of each application for renewal of license and shall include statements of the following:

(a) The number of hours operated on each frequency, listing contract operations and private operations separately.

(b) Outline of reports of reception and interference and conclusions with regard to propagation characteristics of assigned frequencies. (If such information is not available to the applicant in the case of contract operations, a statement to this effect will be considered adequate.)

§ 3.752 Engineering chart. [See Figure 1.]

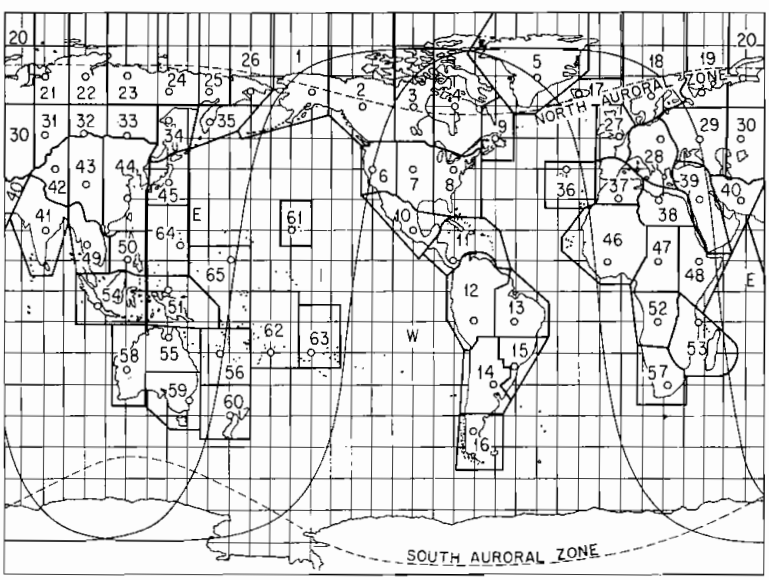


FIGURE 1. World map showing zones covered by predicted charts and auroral zones.

SUBPART G—CONELRAD FOR STANDARD, FM, AND TELEVISION BROADCAST STATIONS

Scope and Objective

§ 3.901 **Scope of subpart.** This subpart applies to all standard, FM and TV broadcast stations and is for the purpose of providing for operation of certain stations located within the Continental United States during periods of enemy air attack or imminent threat thereof.

§ 3.902 **Object of plan.** The aim of this plan is to minimize the navigational aid that may be obtained from the continued operation of broadcast stations while at the same time providing for transmission of civil defense information to the public. During CONELRAD radio alert periods, when not broadcasting civil defense programs or alert or all-clear notification messages, these stations may, on their own responsibility, broadcast such other programs as they may desire.

Definitions

§ 3.910 **CONELRAD.** The word CONELRAD is a contraction of the words Control of Electromagnetic Radiation and is the general name given to required procedures under authority of Executive Order 10312 dated December 10, 1951 (3 CFR, 1951 Supp.)

§ 3.911 **Air Defense Control Center (ADCC).** An air operations center from which an air division (defense) commander supervises and coordinates air defense activities within an air defense sector, including dissemination of warnings, identification and security control of air traffic and utilization of available combat forces in support of the national air defense effort.

§ 3.912 **Basic key station.** A station that receives the radio alert by telephone directly from the ADCC. Basic key stations relay radio alerts to other stations by radio and by telephone.

§ 3.913 **Relay key station.** A station that receives the radio alert by telephone or radio broadcast from a basic key station or other relay key station. Relay key stations pass the radio alert on to other stations by radio broadcast or telephone.

§ 3.914 **Skywave key station.** A station designated to disseminate a radio alert by broadcast primarily during the experimental period as an alternate for local key stations which may not be in operation. It will normally be capable of disseminating the alert over a wide area by means of skywave transmission.

§ 3.915 **Radio alert.** The radio alert is the Department of Defense order to operate stations in accordance with CONELRAD requirements for a period of time, as determined by the Air Division Commander or higher military authority.

§ 3.916 **Radio all clear.** The radio all clear is the Department of Defense order to discontinue CONELRAD requirements, as imposed by an outstanding radio alert, with authorization to return to normal operation. It is initiated by the Air Division Commander or higher military authority.

§ 3.917 **Cluster.** A cluster is a group of broadcast stations serving a single area, all operating on the same CONELRAD system frequency. All stations in a cluster will be inter-connected by wire lines and will carry a common program.

§ 3.918 **Sequential control lines.** Sequential control lines are the wire lines inter-connecting the several stations in a cluster. By means of a mechanical, manual or electronic device at a central control point, the stations in a cluster are turned on and off in sequence over the circuits provided by the sequential control lines. In some cases these lines may also carry the cluster program.

§ 3.919 **CONELRAD manual.** The CONELRAD manual is the document containing the detailed description of how broadcast stations will be alerted and operated in the CONELRAD system. The manual will be subject to modification from time to time as experience indicates a need for such changes.

Supervision

§ 3.920 **Zones.** CONELRAD activities under the authority of FCC are under the immediate supervision of three FCC Zone Supervisors whose respective zones are coextensive with the three Air Defense Force Areas. (Each broadcast station will be furnished the name and address of the Zone Supervisor of its Zone.)

§ 3.921 **Divisions.** Each zone is divided into several divisions corresponding to the USAF Air Divisions. An FCC Coordinating Engineer is assigned to each Air Division and has responsibility under the Zone Supervisor for all CONELRAD activities under the authority of FCC in his division.

Radio Alerts

§ 3.930 **Notification of a radio alert.** (a) All notifications of radio alerts and all clears shall be issued by the Air Defense Control Center(s) (ADCC) under the authority of the Air Division Commander or his duly authorized representative, to all basic key stations. All relay key stations will, in turn, be notified by the basic key stations or other relay key stations. The remaining stations will then be notified by basic key stations or relay key stations. These notifications will be accomplished either by telephone messages or by radio broadcast.

(b) During the experimental period many of the regular key stations may be off the air. All standard, FM and TV stations will be supplied with the list of skywave key stations at least one of which must be monitored during any period of operation when the regularly used key station is not on the air.

§ 3.931 **Reception of a radio alert.** All standard, FM and TV broadcast stations, including basic key and relay key stations, must install the necessary equipment to receive notifications of radio alerts and radio all clears by means of reception of radio broadcast messages, and must maintain this equipment in a state of readiness for reception, including arrangements for human listening watch or automatic alarm devices or both. Such equipment should have its termination at the transmitter control location.

§ 3.932 **Operation during a radio alert.** (a) Immediately upon receipt of a radio alert, either by radio broadcast or telephone, all standard, FM and TV broadcast stations, including such stations operating under equipment or program test authority, will follow the prescribed procedure and transmit an approved sign-off message as set forth in the CONELRAD Manual For Broadcast Stations, then remove the transmitter from the air.

(b) Those stations which are authorized to participate in the operating system will immediately take necessary steps and begin operations on assigned frequencies in accordance with the terms of their CONELRAD authorizations and current operating instructions. All other broadcast stations will observe radio silence until the radio all clear.

(c) No identification may be broadcast between the time the radio alert is received and the time the radio all clear is announced, unless expressly authorized by the FCC. The transmission of any information which would serve to identify the geographical location of the station is prohibited.

(d) A station operating in the CONELRAD system may transmit in accordance with its CONELRAD authorization during a radio alert beyond its normal hours and nothing in its regular license or other instrument of authorization shall prevent such operation in the CONELRAD system.

(e) Prior to commencing routine operation or originating any emissions under program test, equipment test, experimental or other authorization or for any other purpose, licensees or permittees shall first ascertain whether a state of radio alert exists and if so shall refrain from operation or operate in the CONELRAD system whichever is appropriate.

§ 3.933 **Emergency weather warnings.** Upon receipt of notification of an Emergency Weather Warning of a condition of immediate danger to life and property from the United States Weather Bureau, all standard, FM, and television broadcast

stations may, at their option, during authorized hours of operation only, broadcast the CONELRAD Attention Signals in connection therewith, as provided in §§ 3.90, 3.296, and 3.632, respectively, and as outlined in CONELRAD Manual BC-3 (Revised), Appendix A. Nothin herein shall be construed as permitting a standard broadcast station licensed to operate daytime only or limited time, to operate during unauthorized hours.

Radio All Clear

§ 3.940 **Notification of a radio all clear.** The radio all clear notification will be transmitted through the same channels as the radio alert. Stations operating in the CONELRAD system will transmit the radio all clear message on the CONELRAD system frequency. Key stations will, as soon as possible thereafter, follow the prescribed procedure and broadcast the radio all clear message on their regular operating frequency. All stations, including FM and TV stations, upon resuming regular operation will follow the prescribed procedure and immediately broadcast the radio all clear message.

System Operation

§ 3.950 **Procedure.** Each broadcast station permitted to operate during a radio alert must observe operating procedures for the mode of operation to which it is assigned, as set forth in detail in the CONELRAD Manual For Broadcast Stations.

§ 3.951 **Participation.** (a) Any standard broadcast station desiring to participate in a CONELRAD operating system should contact the Zone Supervisor, indicate the station's willingness to make such technical modification of the station equipment as might be necessary to permit operation on a system frequency and with such power limitations as might be necessary. The Commission will then issue a CONELRAD authorization to the station specifying the frequency to be used by the station. Stations which have indicated a willingness to participate in CONELRAD on a voluntary basis prior to the effective date of this rule need not take any further steps.

(b) At such time as technical consideration may warrant the inclusion of FM and TV broadcast stations within the operating CONELRAD system, appropriate announcement will be made by the Commission and application for participation made as above set forth.

(c) Any station participating in CONELRAD system operations may withdraw from the system by giving thirty days' notice to the FCC Zone Supervisor in writing and by submitting its CONELRAD authorization for cancellation.

(d) Broadcast stations are specifically exempt from complying with § 3.57 while operating under their CONELRAD authorization.

Tests

§ 3.960 **Alerting system.** Tests of the alerting system will be conducted periodically.

§ 3.961 **Sequential control lines.** Sequential control and program lines must be tested at frequent intervals and results reported in the prescribed manner to the FCC Zone Supervisor.

§ 3.962 **Entire system.** Tests of the entire system will be conducted from time to time. During such tests, all stations which are authorized to operate in the CONELRAD system will operate in accordance with terms of the CONELRAD authorization. Other stations will not be required to go off the air during such tests but will be subject to any interference which might result from the CONELRAD operation. Such tests will be scheduled to take place during the experimental period. Industry representatives will be consulted prior to conducting CONELRAD system tests to obtain views relative to the action and to coordinate the activity.

§ 3.963 **Equipment.** The licensee of each station authorized to participate in CONELRAD system operation shall make such tests of his equipment as may be necessary to assure it is ready for instant use.

§ 3.964 **Log entries.** Appropriate entries of all tests shall be made in the station log.

Drills

§ 3.970 **Notification of a drill.** At some time it may be necessary to conduct an Air Defense Drill under conditions of simulated attack. Industry representatives will be consulted prior to conducting CONELRAD drills to obtain views relative to the action and to coordinate the activity. Such drills will only be called when the Department of Defense, the Office of Defense Mobilization, and the Federal Communications Commission concurrently agree that the drill is necessary. All stations will be notified well in advance of such a drill.

§ 3.971 **Operation during a drill.** During a drill, all standard, FM and TV broadcast stations will take the same steps as such stations would be required to take in the event of an actual radio alert under this part of the rules and current operating instructions as set forth in the CONELRAD Manual For Broadcast Stations, except for special drill messages.

SUBPART H—CONELRAD FOR NONCOMMERCIAL EDUCATIONAL FM AND INTERNATIONAL BROADCAST STATIONS

§ 3.1001 **Scope and objective.** (a) This subpart applies to all radio stations in the noncommercial educational FM and the international broadcast services located in the Continental U. S., and is for the purpose of providing for the alerting and operation of radio stations in these services during periods of air attack or imminent threat thereof.

(b) The objective of the CONELRAD regulations in this subpart is to minimize the navigational aid that an enemy might obtain from the electromagnetic radiations from radio stations in the noncommercial educational FM and international broadcast services, while simultaneously providing for a continued radio service under controlled conditions when such operation is essential to the public welfare.

§ 3.1002 **Alerting.** (a) All radio stations in the noncommercial educational FM and the international broadcast services licensed by the Federal Communications Commission are responsible for making provisions to receive the CONELRAD Radio Alert Message and the CONELRAD Radio All Clear. (As used in this subpart the term "licensed by" includes every form of authority issued by FCC pursuant to which a radio station may be operated, including construction permits, station licenses, temporary authorizations, etc.)

(b) The CONELRAD Radio Alert will be initiated by the Commanding Officer of the Air Division (Defense) or higher military authority.

(c) The provision of an adequate receiver, to monitor any standard, FM or TV broadcast station either by aural or by automatic means, during all hours of operation of noncommercial educational FM or international broadcast stations, will be considered as compliance with the requirements of paragraph (a) of this section. Other means of receiving the CONELRAD Radio Alert may be authorized by the Federal Communications Commission in special cases.

NOTE: Every standard, FM and TV broadcast station will be notified of the Radio Alert by telephone calls or by radio broadcasts. Immediately upon receipt of the Radio Alert, each standard, FM and TV broadcast station will proceed as follows on its normally assigned frequency:

(1) Discontinue the normal program in progress.

(2) Cut the transmitter carrier for approximately 5 seconds. (Sound carrier only for television stations.)

(3) Return the carrier to the air for approximately 5 seconds.

(4) Cut transmitter carrier for approximately 5 seconds.

(5) Return carrier to the air.

(6) Broadcast 1,000 cycle (approximately) steady state tone for fifteen seconds.

(7) Broadcast the CONELRAD Radio Alert Message as follows: "We interrupt our normal program to cooperate in security and Civil Defense measures as requested by the United States Government. This is a CONELRAD Radio Alert. Normal broadcasting

will now be discontinued for an indefinite period. Civil Defense information will be broadcast in most areas at 640 and 1240 on your regular radio receiver."

(8) The CONELRAD Radio Alert Message will then be repeated.

The CONELRAD Radio Alert Message, as set forth in (7) of this note is worded in a manner suitable for reception by the public; however, the message is also the CONELRAD Radio Alert. When this CONELRAD Radio Alert Message is received, all licensees must immediately comply with the CONELRAD operating procedure. The precise CONELRAD Radio Alert Message, above, will be broadcast only in the event of the actual Alert. In the event of a CONELRAD test or drill, broadcast stations will make an announcement that a test or drill is taking place.

§ 3.1003 **Operating during a CONELRAD Radio Alert.** (a) Noncommercial educational FM broadcast stations, upon receipt of a CONELRAD Radio Alert, will interrupt the program in progress, and broadcast the CONELRAD Radio Alert Message as in subdivisions (7) and (8) of the note to § 3.1002. The station will then discontinue its carrier and maintain radio silence for the duration of the CONELRAD Radio Alert.

(b) International broadcast stations, upon receipt of a CONELRAD Radio Alert, will interrupt the program in progress, may make a brief sign-off announcement not longer than one minute, and, except for those stations specifically authorized by the Federal Communications Commission to continue transmitting, stations in this service will leave the air and maintain radio silence. Stations in the international broadcast service permitted to continue transmitting will be individually authorized to transmit by the Federal Communications Commission with concurrence of the Secretary of Defense, and the Director, Office of Defense Mobilization, and will transmit only urgent government broadcasts or messages. The stations' carrier must be removed from the air during periods of no broadcast or message transmissions.

§ 3.1004 **Identification.** After receipt of a CONELRAD Radio Alert, noncommercial educational FM broadcast and international broadcast stations shall make no station identification either by announcement of regularly assigned call signals or by announcement of geographical location.

§ 3.1005 **Radio All Clear.** The Radio All Clear will be initiated only by the Air Division (Defense) Commander or higher military authority and will be disseminated over the same channels as the CONELRAD Radio Alert. Radio stations in the noncommercial educational FM and the international broadcast services may resume normal operating schedules when the CONELRAD Radio All Clear is received, unless otherwise restricted by order of the Commission.

§ 3.1006 Tests. Tests of the CONELRAD alerting and operating systems of the noncommercial educational FM and the international broadcast services may be conducted at appropriate intervals. Reports of the results of such tests may be required in a form to be prescribed by the Commission.

§ 3.1007 **Log entries.** Appropriate entries of all CONELRAD tests, drills or operations shall be made in the station log.

Part 4

FEDERAL COMMUNICATIONS COMMISSION
PART 4 — EXPERIMENTAL, AUXILIARY, AND SPECIAL BROADCAST SERVICES

TITLE 47—TELECOMMUNICATION

Chapter I—Federal Communications Commission

Part 4—Experimental, Auxiliary, and Special Broadcast Services

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General

§ 4.1 **Broadcast services covered by this part.** The following broadcast services are covered by this part:

(a) Experimental and developmental broadcast:
  (1) Experimental television broadcast (Subpart A).
  (2) Experimental facsimile broadcast (Subpart B).
  (3) Developmental broadcast (Subpart C).

(b) Auxiliary broadcast:
  (1) Remote pickup broadcast (Subpart D).
  (2) Standard and FM broadcast STL and FM intercity relay (Subpart E).
  (3) Television pickup (Subpart F).
  (4) Television STL (Subpart F).
  (5) Television intercity relay (Subpart F).

(c) Special broadcast:
  (1) Television broadcast translator (Subpart G).

Administrative Procedure

§ 4.11 **Cross reference.** See § 1.300 to 1.337, Subpart D of Part 1 of this chapter, for general requirements as to applications, filing of applications and description of application forms.

§ 4.12 **Notification of filing of applications.** In order to minimize harmful interference at the National Radio Astronomy Observatory site located at Greenbank, Pocahontas County, West Virginia and at the Naval Radio Research Observatory at Sugar Grove, Pendleton County, West Virginia, an applicant for authority to construct any class of station covered in § 4.1 except Remote Pickup Broadcast Mobile and TV Pickup Stations, or for authority to make changes in the frequency, power, antenna height, or antenna directivity of an existing station within an area bounded by 39° 15′ N on the north, 78° 30′ W on the east, 37° 30′ N on the south and 80° 30′ W on the west shall, at the time of filing such application with the Commission simultaneously notify the Director, National Radio Astronomy Observatory, P.O. Box 2, Green Bank, West Virginia, in writing, of the technical particulars of the proposed station. Such notification shall include the geographic coordinates of the antenna, antenna height, antenna directivity if any, proposed frequency, type of emission, and power. In addition, the applicant shall indicate in his application to the Commission the date notification was made to the Observatory. After receipt of such applications, the Commission will allow a period of twenty (20) days for comments or objections in response to the notifications indicated. If an objection to the proposed operation is received during the twenty (20) day period from the National Radio Astronomy Observatory for itself or on behalf of the Naval Radio Research Observatory, the Commission will consider all aspects of the problem and take whatever action is deemed appropriate.

§ 4.13 **Equipment tests.** (a) During the process of construction of any class of radio station listed in this part, the permittee, after notifying the Commission and Engineer in Charge of the district in which the station is located, may without further authority of the Commission, conduct equipment tests for the purpose of such adjustments and measurements as may be necessary to assure compliance with the terms of the construction permit, the technical provisions of the application therefor, the rules and regulations, and the applicable engineering standards.

(b) The Commission may notify the permittee to conduct no tests or may cancel, suspend, or change the date for the beginning of equipment tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Equipment tests may be continued so long as the construction permit shall remain valid.

(d) The authorization for tests embodied in this section shall not be construed as constituting a license to operate but as a necessary part of construction.

§ 4.14 **Service or program tests.** (a) Upon completion of construction of a radio station in accordance with the terms of the construction permit, the technical provisions of the application therefor, and the rules and regulations and applicable engineering standards, and when an application for station license has been filed showing the station to be in satisfactory operating condition, the permittee of any class of station listed in this part may, without further authority of the Commission, conduct service or program tests: *Provided,* That the Engineer in Charge of the district in which the station is located and the Commission are notified at least two (2) days (not including Sundays and Saturdays and legal holidays when the offices of the Commission are not open) in advance of the beginning of such operation.

(b) The Commission may notify the permittee to conduct no tests or may cancel, suspend, or change the date for the beginning of such tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Unless sooner suspended or revoked program test authority will continue valid during Commission consideration of the application for license and during this period further extension of the construction permit is not required. Program test authority shall be automatically terminated by final determination upon the application for station license.

(d) The authorization for tests embodied in this section shall not be construed as approval by the Commission of the application for station license.

§ 4.15 **License period.** (a) Licenses for the following classes of broadcast stations normally will be issued for a period of one year expiring as follows:

Class of Station and Date of Expiration

Experimental television broadcast station: Apr. 1.
Experimental facsimile broadcast station: Mar. 1.
Developmental broadcast station: May 1.
Television broadcast translator station: June 1.

(b) Licenses for stations in the Auxiliary Broadcast Services will be issued for a period running concurrently with the licenses of the broadcast station with which such auxiliary stations are used. A remote pickup broadcast station licensed for use with more than one broadcast station will be licensed for a period running concurrently with the license of the broadcast station having the longer license record.

§ 4.16 **Temporary extension of station licenses.** Where there is pending before the Commission any application, investigation or proceeding which, after hearing, might lead to or make necessary the modification of, revocation of, or the refusal to renew an existing auxiliary or experimental broadcast station license or a television broadcast translator station license, the Commission may, in its discretion, grant a temporary extension of such license: *Provided, however,* That no such temporary extension shall be construed as a finding by the Commission that the operation of any radio station thereunder will serve public interest, convenience, and necessity beyond the express terms of such temporary extension of license: *And provided further,* That such temporary extension of license will in no wise affect or limit the action of the Commission with respect to any pending application or proceeding.

CONELRAD

§ 4.51 **Scope and objective.** (a) Sections 4.51 to 4.57 apply to all radio stations in the Experimental, Auxiliary and Special Broadcast Services located within the Continental United States and are for the purpose of providing for the alerting and operation of radio stations in these services during periods of enemy air attack or imminent threat thereof.

(b) The objective of these CONELRAD rules is to minimize the navigational aid that an enemy might obtain from the electromagnetic radiations from radio stations in the Experimental, Auxiliary and Special Broadcast Services, while simultaneously providing for a continued radio service under controlled conditions when such operation is essential to the public welfare.

§ 4.52 **Alerting.** (a) Licensees of all radio stations in the Experimental, Auxiliary, and Special Broadcast Services are responsible for making provisions to receive the CONELRAD Radio Alert and the CONELRAD Radio All Clear, which will be initiated only by the Commanding Officer of the Air Division (Defense) or higher military authority.

(b) The CONELRAD Radio Alert for the Experimental, Auxiliary, and Special Broadcast Services shall be received by one or more of the following methods:

(1) By monitoring any standard, FM or TV broadcast station to receive the CONELRAD Radio Alert message.

(2) By reception of the CONELRAD Radio Alert from a point that received the Radio Alert directly from a standard, FM or TV broadcast station.

(3) Radio stations in the services affected by this plan may be specifically authorized by the FCC to receive the CONELRAD Radio Alert by other means.

(c) When the radio station is not in operation it is not necessary to make provisions to receive the CONELRAD Radio Alert, however, before starting a radio transmission, caution must be used to insure that a CONELRAD Radio Alert is not in progress.

§ 4.53 **Operation during a CONELRAD Radio Alert.** Stations in the Experimental, Auxiliary and Special Broadcast Services on receipt of a CONELRAD Radio Alert, will interrupt any communications in progress, may make a brief announcement, must then leave the air and maintain radio silence for the duration of the CONELRAD Radio Alert.

§ 4.54 **Special conditions.** Certain stations in the Experimental, Auxiliary and Special Broadcast Services may be specifically authorized by the Federal Communications Commission to operate in a manner not provided in §§ 4.51 to 4.57, if such operation is essential to the public welfare.

§ 4.55 **Radio All Clear.** The Radio All Clear will be initiated only by the Air Division (Defense) Commander or higher military authority and will be disseminated over the same channels as the CONELRAD Radio Alert. Radio stations and systems licensed in the Experimental, Auxiliary and Special Broadcast Services may resume normal operation when the CONELRAD Radio All Clear message is received, unless otherwise restricted by order of the Federal Communications Commission.

§ 4.56 **Tests.** Tests of the CONELRAD alerting and operating systems for the Experimental, Auxiliary and Special Broadcast Services may be conducted at appropriate intervals. Reports of the results of such tests may be required in a form to be prescribed by the Commission.

§ 4.57 **Station records.** Appropriate entries of all CONELRAD tests, drills, and operations shall be made in the station records.

SUBPART A—EXPERIMENTAL TELEVISION BROADCAST STATIONS

Definitions and Allocation of Frequencies

§ 4.101 **Experimental television broadcast station.** The term "experimental television broadcast station" means a station licensed for experimental transmission of transient visual images of moving or fixed objects for simultaneous reception and reproduction by the general public.

NOTE: The transmission of synchronized sound (aural broadcast) is considered an essential phase of television broadcast and one license will authorize both visual and aural broadcast.

§ 4.102 **Purpose.** A license for an experimental television broadcast station will be issued for the purpose of carrying on research and experimentation for the advancement of television broadcasting which may include tests of equipment, training of personnel, and experimental programs as are necessary for the experimentation.

§ 4.103 **Frequency assignment.** (a) Frequencies allocated to television broadcasting and the various categories of television auxiliary stations, in the Commission's

Table of Frequency Allocations (Part 2 of this chapter), may be assigned respectively to experimental television broadcast and experimental television auxiliary stations.

(b) More than one frequency may be assigned upon a satisfactory showing of the need therefor.

(c) Frequencies best suited to the purpose of the experimentation and on which there appears to be the least likelihood of interference to established stations, shall be selected.

(d) In a case of important experimentation which cannot be feasibly conducted on frequencies allocated to television broadcasting or the various categories of television auxiliary stations, the Commission may authorize an experimental television station of any class to operate on other frequencies upon a satisfactory showing of the need therefor and a showing that the proposed operation can be conducted without causing harmful interference to established services: *Provided, however,* That experimental operation which looks toward the development of radio transmitting apparatus or the rendition of any type of regular service using such frequencies, will not be authorized prior to a determination by the Commission that the development of such apparatus or the rendition of such service would serve the public interest.

Administrative Procedure

§ 4.111 Cross reference. See §§ 4.11 to 4.16 inclusive.

§ 4.112 Supplementary statements to be filed with application for construction permit. A supplementary statement shall be filed with and made a part of each application for construction permit for any experimental television broadcast station confirming the applicant's understanding:

(a) That all operation upon the frequency requested is for experimental purposes only.

(b) That the frequency requested may not be the best suited to the particular experimental work to be carried on, and

(c) That the frequency requested need not be allocated for any service that may be developed as a result of the experimental operation,

(d) That any frequency which may be assigned is subject to change without advance notice or hearing,

(e) That any authorization issued pursuant to the application may be cancelled at any time without notice or hearing.

§ 4.113 Supplementary reports to be filed with application for renewal of license. (a) A report shall be filed with each application for renewal of experimental television broadcast station license which shall include a statement of each of the following:

(1) Number of hours operated.

(2) Full data on research and experimentation conducted including the type of transmitting and studio equipment used and their mode of operation.

(3) Data on expense of research and operation during the period covered.

(4) Power employed, field intensity measurements and visual and aural observations and the types of instruments and receivers utilized to determine the station service area and the efficiency of the respective types of transmissions.

(5) Estimated degree of public participation in reception and the results of observations as to the effectiveness of types of transmission.

(6) Conclusions, tentative and final.

(7) Program for further developments in television broadcasting.

(8) All developments and major changes in equipment.

(9) Any other pertinent developments.

(b) Special or progress reports shall be submitted from time to time as the Commission shall direct.

Licensing Policies

§ 4.131 Licensing requirements, necessary showing. (a) An applicant for a new experimental television broadcast station, change in facilities of any existing station,

or modification of license is required to make a satisfactory showing of compliance with the general requirements of the Communications Act of 1934, as amended, as well as the following:

(1) That the applicant has a definite program of research and experimentation in the technical phases of television broadcasting, which indicates reasonable promise of substantial contribution to the developments of the television art.

(2) That upon the authorization of the proposed station the applicant can and will proceed immediately with its program of research and experimentation.

(3) That the transmission of signals by radio is essential to the proposed program of research and experimentation.

(4) That the program of research and experimentation will be conducted by qualified personnel.

(b) A license for an experimental television broadcast station will not authorize exclusive use of any frequency. In case interference would be caused by simultaneous operation of stations licensed experimentally, such licensees shall endeavor to arrange satisfactory time division. If such agreement cannot be reached, the Commission will determine and specify the time division.

(c) A license for an experimental television broadcast station will be issued only on the condition that no objectionable interference will result from the transmissions of the station to the regular program transmissions of television broadcast stations. It shall at all times be the duty of the licensee of an experimental television broadcast station to ascertain that no interference will result from the transmissions of its station. With regard to interference with the transmissions of an experimental television broadcast station or the experimental or test transmissions of a television broadcast station, the licensees shall make arrangements for operations to avoid interference.

§ 4.132 **Power limitations.** Experimental television broadcast stations will be licensed with a power output not in excess of that necessary to render satisfactory service. The license for these stations will specify the maximum authorized power. The operating power shall not be greater than necessary to carry on the service and in no event more than 5 percent above the maximum power specified. Engineering standards have not been established for these stations. The efficiency factor for the last radio stage of transmitters employed will be subject to individual determination but shall be in general agreement with values normally employed for similar equipment operated within the frequency range authorized.

§ 4.133 **Emission authorized.** In case emission of a different type than that specified in the license is necessary or desirable in carrying on any phases of experimentation, application setting out fully the needs shall be made by informal application.

§ 4.134 **Multiple ownership.** No persons (including all persons under common control) shall control directly or indirectly, two or more experimental television broadcast stations (other than television relay broadcast stations) unless a showing is made that the character of the programs of research require a licensing of two or more separate stations.

Equipment

§ 4.151 **Equipment changes.** The licensee of an experimental television broadcast station may make any changes in the equipment that are deemed desirable or necessary provided:

(a) That the operating frequency is not permitted to deviate more than the allowed tolerance;

(b) That the emissions are not permitted outside the authorized band;

(c) That the power output complies with the license and the regulations governing the same; and

(d) That the transmitter as a whole or output power rating of the transmitter is not changed.

Technical Operation

§ 4.161 **Frequency tolerance.** The licensee of an experimental television broadcast station operating below 450 megacycles shall maintain the operating frequency of its station within plus or minus 0.01 percent of the assigned frequency. The licensee of an experimental television broadcast station operating above 450 megacycles shall maintain the operating frequency of its station within plus or minus 0.05 percent of the assigned frequency. However, where a lesser tolerance is necessary in order to prevent interference, the Commission will specify the tolerance.

§ 4.162 **Frequency monitors and measurements.** The licensee of an experimental television broadcast station shall provide the necessary means for determining that the frequency of the station is within the allowed tolerance. The date and time of each frequency check, the frequency as measured, and a description or identification of the method employed shall be entered in the station log. Sufficient observations shall be made to insure that the assigned carrier frequency is maintained within the prescribed tolerance.

§ 4.163 **Time of operation.** (a) A licensee of an experimental television broadcast station is not required to adhere to a regular schedule of operation but shall actively conduct a program of research and experimentation.

(b) The program of research and experimentation as offered by an applicant in compliance with the requirements for obtaining a license for an experimental television broadcast station shall be adhered to in the main, unless the licensee is authorized to do otherwise by the Commission.

(c) The Commission may from time to time require that a station licensed experimentally conduct such experiments as are deemed desirable and reasonable for the development of the service.

§ 4.164 **Station inspection.** The licensee of each experimental television broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 4.165 **Station and operator licenses; posting of.** (a) The station license and any other instrument of authorization or individual order concerning the construction of the equipment or manner of operation of the station shall be posted so that all terms thereof are visible in a conspicuous place in the room in which the transmitter is located. However, if the station is licensed for portable-mobile operation, the station license or a photo copy thereof shall be affixed to the equipment or kept in the possession of the operator on duty at the transmitter. If a photo copy is used the original license shall be available for inspection by an authorized Government representative.

NOTE: The term portable-mobile as here used is intended to include any type of portable or mobile operation.

(b) The original license of each station operator shall be posted at the place where he is on duty: *Provided, however,* If the original license of a station operator is posted at another radio transmitting station in accordance with the rules governing that class of station and is there available for inspection by an authorized Commission representative, or if the station operated is licensed for portable-mobile operation, a verification card (Form 758-F) is acceptable in lieu of the posting of such license.

§ 4.166 **Operator requirements.** One or more radio operators holding radiotelephone first-class or radiotelephone second-class operator licenses shall be on duty at the place where the transmitting apparatus of any experimental television broadcast station is located and in actual charge of its operation. The licensed operator on duty and in charge of a broadcast transmitter may at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of operator's license which he holds and the rules and regulations governing such stations. However, such duties shall in no wise interfere with the operation of the broadcast transmitter.

§ 4.167 **Antenna structure, marking and lighting.** Where an antenna structure(s)

is required to be painted or lighted see § 17.37, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 4.168 Additional orders. In case the rules contained in this part do not cover all phases of operation or experimentation with respect to external effects, the Commission may make supplemental or additional orders in each case as may be deemed necessary.

Other Operating Requirements

§ 4.181 Station records. (a) The licensee of each experimental television broadcast station shall maintain adequate records of the operation, including:

(1) Hours of operation.

(2) Program transmitted.

(3) Frequency check.

(4) Pertinent remarks concerning transmission.

(5) In case of relay or pickup station, an entry giving points of program origination and receiver location shall be included.

(6) Research and experimentation conducted.

(b) Where an antenna structure(s) is required to be illuminated see § 17.38, *Recording of tower light inspections in the station record,* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

(c) Station records shall be retained for a period of two years.

§ 4.182 Charges. No charges, either direct or indirect, shall be made by the licensee of an experimental television broadcast station for the production or transmission of either aural or visual programs transmitted by such station except that this section shall not apply to the transmission of commercial programs by an experimental television relay or pickup broadcast station for retransmission by a television broadcast station.

§ 4.183 Station identification. Each experimental television broadcast station shall make aural and visual announcements of its call letters and location at the beginning and end of each period of operation, and during operation, at least once every hour.

§ 4.184 Rebroadcasts. (a) The term "rebroadcast" means reception by radio of the program of a radio station, and the simultaneous or subsequent retransmission of such program by a broadcast station.

NOTE 1: As used in this section the word "program" includes any complete program or part thereof.

NOTE 2: In case a program is transmitted from its point of origin to a broadcast station primarily by telephone facilities in which a section of such transmission is by radio, the broadcasting of this program is not considered a rebroadcast. The broadcasting of a program relayed by a remote pickup broadcast station is not considered a rebroadcast.

(b) No licensee of any experimental television broadcast station shall rebroadcast the program of any radio station without written authority having first been obtained from the Commission upon application. Informal application may be employed.

(c) An application for authority to rebroadcast the program of any radio station shall be accompanied by written consent or certification of consent of the licensee of the station originating the program.

SUBPART B—EXPERIMENTAL FACSIMILE BROADCAST STATIONS

Definitions and Allocation of Frequencies

§ 4.201 Facsimile broadcast station. The term "facsimile broadcast station" means a station licensed to transmit images of still objects for record reception by the general public.

§ 4.202 **Frequency assignment.** (a) Frequencies allocated to broadcasting and the various categories of broadcast auxiliary stations, in the Commission's Table of Frequency Allocations (Part 2 of this chapter), may be assigned respectively to experimental facsimile broadcast or experimental facsimile broadcast auxiliary stations.

(b) More than one frequency may be assigned upon a satisfactory showing of the need therefor.

(c) Frequencies best suited to the purpose of the experimentation and on which there appears to be the least likelihood of interference to established stations, shall be selected.

(d) In a case of important experimentation which cannot be feasibly conducted on frequencies allocated to broadcasting or the various categories of broadcast auxiliary stations, the Commission may authorize an experimental facsimile broadcast station of any class to operate on other frequencies upon a satisfactory showing of the need therefor and a showing that the proposed operation can be conducted without causing harmful interference to established services: *Provided, however,* That experimental operation which looks toward the development of radio transmitting apparatus or the rendition of any type of regular service using such frequencies, will not be authorized prior to a determination by the Commission that the development of such apparatus or the rendition of such service would serve the public interest.

Administrative Procedure

§ 4.211 **Administrative procedure.** See §§ 4.11 to 4.16, inclusive.

§ 4.212 **Supplementary statements to be filed with application for construction permit.** A supplementary statement shall be filed with and made a part of each application for construction permit for any experimental facsimile broadcast station confirming the applicant's understanding:

(a) That all operation upon the frequency requested is for experimental purposes only,

(b) That the frequency requested may not be the best suited to the particular experimental work to be carried on,

(c) That the frequency requested need not be allocated for any service that may be developed as a result of the experimental operation,

(d) That any frquency which may be assigned is subject to change without advance notice or hearing,

(e) That any authorization issued pursuant to the application may be cancelled at any time without notice or hearing.

§ 4.213 **Supplemental report with renewal application.** A supplemental report shall be filed with and made a part of each application for renewal of license and shall include statements of the following:

(a) Number of hours operated for transmission of facsimile programs.

(b) Comprehensive report of research and experimentation conducted.

(c) Conclusions and program for further developments of the facsimile broadcast service.

(d) All developments and major changes in equipment.

(e) Any other pertinent developments.

Licensing Policies

§ 4.231 **Licensing requirements, necessary showing.** (a) An applicant for a construction permit for a new experimental facsimile broadcast station, change in facilities of any existing station, or modification of license is required to make a satisfactory showing of compliance with the general requirements of the Communications Act of 1934, as amended, as well as with regard to the following:

(1) That the applicant has a program of research and experimentation which indicates reasonable promise of substantial contribution to the development of the facsimile broadcast service.

(2) That sufficient facsimile recorders will be distributed to accomplish the experimental program proposed.

(3) That the program of research and experimentation will be conducted by qualified personnel.

(b) A license for an experimental facsimile broadcast station will not authorize exclusive use of any frequency. In case interference would be caused by simultaneous operation of stations licensed experimentally, such licensees shall endeavor to arrange satisfactory time division. If such agreement cannot be reached, the Commission will determine and specify the time division.

§ 4.232 **Power limitations.** Experimental facsimile broadcast stations will be licensed with a power output not in excess of that necessary to render satisfactory service. The license for these stations will specify the maximum authorized power. The operating power shall not be greater than necessary to carry on the service and in no event more than 5 percent above the maximum power specified. Engineering standards have not been established for these stations. The efficiency factor for the last radio stage of transmitters employed will be subject to individual determination but shall be in general agreement with values normally employed for similar equipment operated within the frequency range authorized.

§ 4.233 **Emission authorized.** In case emission of a different type than that specified in the license is necessary or desirable in carrying on any phases of experimentation, application setting out fully the needs shall be made by informal application.

§ 4.234 **Multiple ownership.** No persons (including all persons under common control) shall control, directly or indirectly, two or more experimental facsimile broadcast stations unless a showing is made that the character of the programs of research require a licensing of two or more separate stations.

Equipment

§ 4.251 **Equipment changes.** The licensee of an experimental facsimile broadcast station may make any changes in the equipment that are deemed desirable or necessary provided:

(a) That the operating frequency is not permitted to deviate more than the allowed tolerance;

(b) That the emissions are not permitted outside the authorized band;

(c) That the power output complies with the license and the regulations governing the same; and

(d) That the transmitter as a whole or output power rating of the transmitter is not changed.

Technical Operation

§ 4.261 **Frequency tolerance.** The licensee of an experimental facsimile broadcast station shall maintain the operating frequency of its station within plus or minus 0.01 percent of the assigned frequency. However, where a lesser tolerance is necessary in order to prevent interference, the Commission will specify the tolerance.

§ 4.262 **Frequency monitors and measurements.** The licensee of an experimental facsimile broadcast station shall provide the necessary means for determining that the frequency of the station is within the allowed tolerance. The date and time of each frequency check, the frequency as measured, and a description or identification of the method employed shall be entered in the station log. Sufficient observations shall be made to insure that the assigned carrier frequency is maintained within the prescribed tolerance.

§ 4.263 **Time of operation.** (a) A licensee of an experimental facsimile broadcast station is not required to adhere to a regular schedule of operation but shall actively conduct a program of research and experimentation.

(b) The program of research and experimentation as offered by an applicant in compliance with the requirements for obtaining a license for an experimental facsimile

broadcast station shall be adhered to in the main, unless the licensee is authorized to do otherwise by the Commission.

(c) The Commission may from time to time require that a station licensed experimentally conduct such experiments as are deemed desirable and reasonable for the development of the service.

§ 4.264 Station inspection. The licensee of each experimental facsimile broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 4.265 Station and operator licenses; posting of. (a) The station license and any other instrument of authorization or individual order concerning the construction of the equipment or manner of operation of the station shall be posted so that all terms thereof are visible in a conspicuous place in the room in which the transmitter is located.

(b) The original license of each station operator shall be posted at the place where he is on duty: *Provided, however,* If the original license of a station operator is posted at another radio transmitting station in accordance with the rules governing that class of station and is there available for inspection by an authorized Commission representative, a verification card (Form 758-F) is acceptable in lieu of the posting of such license.

§ 4.266 Operator requirements. One or more radio operators holding radiotelephone first-class or radiotelephone second-class operator licenses shall be on duty at the place where the transmitting apparatus of any experimental facsimile broadcast station is located and in actual charge of its operation. The licensed operator on duty and in charge of a broadcast transmitter may at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of operator's license which he holds and the rules and regulations governiug such stations. However, such duties shall in no wise interfere with the operation of the broadcast transmitter.

§ 4.267 Antenna structure, marking and lighting. Where an antenna structure(s) is required to be painted or lighted see § 17.37, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 4.268 Additional orders. In case the rules contained in this part do not cover all phases of operation or experimentation with respect to external effects, the Commission may make supplemental or additional orders in each case as may be deemed necessary.

Other Operating Requirements

§ 4.281 Station records. (a) The licensee of each experimental facsimile broadcast station shall maintain adequate records of the operation, including:

(1) Hours of operation.
(2) Program transmitted.
(3) Frequency check.
(4) Pertinent remarks concerning transmission.
(5) Research and experimentation conducted.

(b) Where an antenna structure(s) is required to be illuminated see § 17.38, *Recording of tower light inspections in the station record,* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

(c) Station records shall be retained for a period of two years.

§ 4.282 Charges. (a) A licensee of an experimental facsimile broadcast station shall not make any charge, directly or indirectly, for the transmission of programs.

(b) No licensee of any standard or FM broadcast station shall make any additional charge, directly or indirectly, for the transmission of some phase of its programs by an associated experimental facsimile broadcast station.

§ 4.283 Station identification. Each experimental facsimile broadcast station shall transmit visual information which will permit it to be identified at the beginning and end of each period of operation, and during operation, at least once every hour.

§ 4.284 **Rebroadcasts.** (a) The term "rebroadcast" means reception by radio of the program of a radio station, and the simultaneous or subsequent retransmission of such program by a broadcast station.

NOTE 1: As used in this section the word "program" includes any complete program or part thereof.

NOTE 2: In case a program is transmitted from its point of origin to a broadcast station primarily by telephone facilities in which a section of such transmission is by radio, the broadcasting of this program is not considered a rebroadcast. The broadcasting of a program relayed by a remote pickup broadcast station is not considered a rebroadcast.

(b) No licensee of any experimental facsimile broadcast station shall rebroadcast the program of any radio station without written authority having first been obtained from the Commission upon application. Informal application may be employed.

(c) An application for authority to rebroadcast the program of any radio station shall be accompanied by written consent or certification of consent of the licensee of the station originating the program.

SUBPART C—DEVELOPMENTAL BROADCAST STATIONS

Definitions and Allocation of Frequencies

§ 4.301 **Developmental broadcast station.** The term "developmental broadcast station" means a station licensed experimentally to carry on development and research primarily in radiotelephony for the advancement of the broadcast services.

§ 4.302 **Frequency assignment.** (a) Frequencies allocated to the various classes of aural broadcasting stations and broadcast auxiliary stations, in the Commission's Table of Frequency Allocations (Part 2 of this chapter), may be assigned to developmental broadcast stations.

(b) More than one frequency may be assigned upon a satisfactory showing of the need therefor.

(c) Frequencies best suited to the purpose of the experimentation and on which there appears to be the least likelihood of interference to established stations, shall be selected.

(d) In a case of important experimentation which cannot be feasibly conducted on frequencies allocated to the various classes of aural broadcasting stations and broadcast auxiliary stations, the Commission may authorize a developmental broadcast station to operate on other frequencies upon a satisfactory showing of the need therefor and a showing that the proposed operation can be conducted without causing harmful interference to established services: *Provided, however,* That experimental operation which looks toward the development of radio transmitting apparatus or the rendition of any type of regular service using such frequencies, will not be authorized prior to a determination by the Commission that the development of such apparatus or the rendition of such service would serve the public interest.

Administrative Procedure

§ 4.311 **Cross reference.** See §§ 4.11 to 4.16, inclusive.

§ 4.312 **Supplementary statements to be filed with application for construction permit.** A supplementary statement shall be filed with and made a part of each application for construction permit for any developmental broadcast station confirming the applicant's understanding:

(1) That all operation upon the frequency requested is for experimental purposes only,

(2) That the frequency requested may not be the best suited to the particular experimental work to be carried on, and

(3) That the frequency requested need not be allocated for any service that may be developed as a result of the experimental operation,

(4) That any frequency which may be assigned is subject to change without advance notice or hearing,

(5) That any authorization issued pursuant to the application may be cancelled at any time without notice or hearing.

§ 4.313 Supplemental report with renewal application. A supplemental report shall be filed with and made a part of each application for renewal of license and shall include statements of the following, among others:

(a) The number of hours operated.

(b) Comprehensive report on research and experiments conducted.

(c) Conclusions and program for further development of the broadcast service.

(d) All developments and major changes in equipment.

(e) Any other pertinent developments.

Licensing Policies

§ 4.331 Licensing requirements; necessary showing. (a) An applicant for a construction permit for a new developmental broadcast station, change of facilities or modification of an existing license is required to make a satisfactory showing of compliance with the general requirements of the Communications Act of 1934, as amended, as well as with regard to the following:

(1) That the applicant has a program of research and experimentation which can best be carried on under the license requested.

(2) That the program of research has reasonable promise of substantial contribution to the development of broadcasting.

(3) That the program of research and experimentation will be conducted by qualified personnel.

(b) A license for a developmental broadcast station will not authorize exclusive use of any frequency. In case interference would be caused by simultaneous operation of stations licensed experimentally, such licensees shall endeavor to arrange satisfactory time division. If such agreement cannot be reached, the Commission will determine and specify the time division.

§ 4.332 Power limitations. Developmental broadcast stations will be licensed with a power output not in excess of that necessary to render satisfactory service. The license for these stations will specify the maximum authorized power. The operating power shall not be greater than necessary to carry on the service and in no event more than 5 percent above the maximum power specified. Engineering standards have not been established for these stations. The efficiency factor for the last radio stage of transmitters employed will be subject to individual determination but shall be in general agreement with values normally employed for similar equipment operated within the frequency range authorized.

§ 4.333 Emission authorized. In case emission of a different type than that specified in the license is necessary or desirable in carrying on any phases of experimentation, application setting out fully the needs shall be made by informal application.

Equipment

§ 4.351 Equipment changes. The licensee of a developmental broadcast station may make any changes in the equipment that are deemed desirable or necessary: *Provided,*

(a) That the operating frequency is not permitted to deviate more than the allowed tolerance;

(b) That the emissions are not permitted outside the authorized band;

(c) That the power output complies with the license and the regulations governing the same; and

(d) That the transmitter as a whole or output power rating of the transmitter is not changed. This limitation shall not apply to developmental broadcast stations licensed to operate in connection with the development and testing of commercial broadcast equipment.

Technical Operation

§ 4.361 **Frequency tolerance.** The licensee of a developmental broadcast station operating below 450 megacycles shall maintain the operating frequency of its station within plus or minus 0.01 percent of the assigned frequency. The licensee of a developmental broadcast station operating above 450 megacycles shall maintain the operating frequency of its station within plus or minus 0.05 percent of the assigned frequency. However, where a lesser tolerance is necessary in order to prevent interference, the Commission will specify the tolerance.

§ 4.362 **Frequency monitors and measurements.** The licensee of a developmental broadcast station shall provide the necessary means for determining that the frequency of the station is within the allowed tolerance. The date and time of each frequency check, the frequency as measured, and a description or identification of the method employed shall be entered in the station log. Sufficient observations shall be made to insure that the assigned carrier frequency is maintained within the prescribed tolerance.

§ 4.363 **Time of operation.** (a) A licensee of a developmental broadcast station is not required to adhere to a regular schedule of operation but shall actively conduct a program of research and experimentation. However, licensees of developmental broadcast stations which are licensed to conduct special intermittent experiments, such as the development and testing of commercial broadcast equipment, are authorized to operate only when there is a need therefor.

(b) The program of research and experimentation as offered by an applicant in compliance with the requirements for obtaining a license for a developmental broadcast station shall be adhered to in the main, unless the licensee is authorized to do otherwise by the Commission.

(c) The Commission may from time to time require that a station licensed experimentally conduct such experiments as are deemed desirable and reasonable for the development of the service.

§ 4.364 **Station inspection.** The licensee of each developmental broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 4.365 **Station and operator licenses; posting of.** (a) The station license and any other instrument of authorization or individual order concerning the construction of the equipment or manner of operation of the station shall be posted so that all terms thereof are visible in a conspicuous place in the room in which the transmitter is located. However, if the station is licensed for portable-mobile operation, the station license or a photo copy thereof shall be affixed to the equipment or kept in the possession of the operator on duty at the transmitter. If a photo copy is used the original license shall be available for inspection by an authorized Government representative.

NOTE: The term portable-mobile as here used is intended to include any type of portable or mobile operation.

(b) The original license of each station operator shall be posted at the place where he is on duty: *Provided, however,* If the original license of a station operator is posted at another radio transmitting station in accordance with the rules governing that class of station and is there available for inspection by an authorized Commission representative, or if the station operated is licensed for portable-mobile operation, a verification card (Form 758-F) is acceptable in lieu of the posting of such license.

§ 4.366 **Operator requirements.** One or more radio operators holding radiotelephone first-class or radiotelephone second-class operator licenses shall be on duty at the place where the transmitting apparatus of any developmental broadcast station is located and in actual charge of its operation. The licensed operator on duty and in charge of a broadcast transmitter may at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of operator's license which he holds and the rules and regulations governing

such stations. However, such duties shall in no wise interfere with the operation of the broadcast transmitter.

§ 4.367 Antenna structure, marking and lighting. Where an antenna structure(s) is required to be painted or lighted see § 17.37, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 4.368 Additional orders. In case the rules contained in this part do not cover all phases of operation or experimentation with respect to external effects, the Commission may make supplemental or additional orders in each case as may be deemed necessary.

Other Operating Requirements

§ 4.381 Station records. (a) The licensee of each developmental broadcast station shall maintain adequate records of the operation, including:

(1) Hours of operation.

(2) Program transmitted.

(3) Frequency check.

(4) Pertinent remarks concerning transmission.

(5) In case of relay or remote pickup station, an entry giving points of program origination and receiver location shall be included.

(6) Research and experimentation conducted.

(b) Where an antenna structure(s) is required to be illuminated see § 17.38, *Recording of tower light inspections in the station record,* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

(c) Station records shall be retained for a period of two years.

§ 4.382 Program service; charges prohibited; announcements. (a) A licensee of a developmental broadcast station shall broadcast programs only when they are necessary to the experiments being conducted. No regular program service shall be broadcast unless specifically authorized. If the license authorizes the carrying of programs, the developmental broadcast station may transmit the programs of a standard, or FM broadcast station or networks, provided, that during the broadcast a statement is made identifying the station or network originating the program (by giving the call letters of the station or name of the network) and announcing that the program is being broadcast in connection with the experimental operation of a developmental broadcast station.

(b) No licensee of any standard, or FM broadcast station shall make any additional charge, directly or indirectly, for the transmission of programs by a developmental broadcast station.

(c) The provisions of paragraphs (a) and (b) of this section shall be applicable to rebroadcasts of the programs of a standard or FM broadcast station or network by a developmental broadcast station.

§ 4.383 Station identification. Each developmental broadcast station shall announce its call letters at the beginning and end of each period of operation, and during operation, at least once every hour.

§ 4.384 Rebroadcasts. (a) The term "rebroadcast" means reception by radio of the program of a radio station, and the simultaneous or subsequent retransmission of such program by a broadcast station.

NOTE 1: As used in this section the word "program" includes any complete program or part thereof.

NOTE 2: In case a program is transmitted from its point of origin to a broadcast station primarily by telephone facilities in which a section of such transmission is by radio, the broadcasting of this program is not considered a rebroadcast. The broadcasting of a program relayed by a remote pickup broadcast station is not considered a rebroadcast.

(b) No licensee of any developmental broadcast station shall rebroadcast the program of any radio station without written authority having first been obtained from the Commission upon application. Informal application may be employed.

(c) An application for authority to rebroadcast the program of any radio station shall be accompanied by written consent or certification of consent of the licensee of the station originating the program.

SUBPART D—REMOTE PICKUP BROADCAST STATIONS

Definitions and Allocation of Frequencies

§ 4.401 Classes of stations. (a) *Remote pickup broadcast mobile station.* A land mobile station, licensed for the transmission of program material from remote points of origination to a broadcasting station for simultaneous or delayed broadcasting and for the transmission of orders pertaining to such programs.

(b) *Remote pickup broadcast base station.* A base station licensed for the transmission of program material from remote points of origination to a broadcasting station for simultaneous or delayed broadcasting and for the transmission of orders pertaining to such programs.

(c) *Remote pickup broadcast station.* The term "remote pickup broadcast station" as used in this subpart includes the definitions in paragraphs (a) and (b) of this section.

§ 4.402 Frequency assignment. (a) The following frequencies are allocated for assignment to remote pickup broadcast base and mobile stations:

(1)

Group A (*kc*)
[1] 1606
1622
1646

(2)

Group D (*Mc*)	*Group E* (*Mc*)	*Group F* (*Mc*)	*Group G* (*Mc*)	*Group H* (*Mc*)
[2] 25.87	[2] 25.91	[2] 25.95	[2] 25.99	[2] 26.03
26.15	26.17	26.19	26.21	26.23
26.25	26.27	26.29	26.31	26.33
26.35	26.37	26.39	26.41	26.43

(3)

Group I (*Mc*)	*Group J* (*Mc*)
[2] 26.07	[2] 26.09
26.11	26.13
26.45	26.47

(4)

Group K [3] (*Mc*)		
152.87	153.05	153.23
152.93	153.11	153.29
152.99	153.17	153.35

(5)

Group L (*Mc*)	*Group M* (*Mc*)
[4] 166.25	[4] 170.15

[1] Subject to the condition that no harmful interference is caused to the reception of standard broadcast stations.

[2] Subject to the condition that no harmful interference is caused to the reception of broadcasting stations.

[3] Subject to the condition that no harmful interference is caused to the Industrial Radio Services.

[4] Operation on the frequencies 166.25 Mc and 170.15 Mc is not authorized (i) within the area bounded on the west by the Mississippi River, on the north by the parallel of latitude 37° 30′ N., and on the east and south by that arc of the circle with center at Springfield, Ill., and radius equal to the airline distance between Springfield, Ill., and Montgomery,

(6)

Group N (Mc)			
450.05	450.55	455.05	455.55
450.15	450.65	455.15	455.65
450.25	450.75	455.25	455.75
450.35	450.85	455.35	455.85
450.45	450.95	455.45	455.95

Alabama, subtended between the foregoing west and north boundaries; (ii) within 150 miles of New York City; and (iii) outside the continental United States; and is subject to the condition that no harmful interference is caused to government radio stations in the band 162–174 Mc.

(b) The following frequencies are allocated for assignment to remote pickup base and mobile stations in the Island of Puerto Rico only:

Mc	*Mc*	*Mc*
159.51	159.69	159.87
159.57	159.75	159.93
159.63	159.81	159.99

NOTE: Use of these frequencies by remote pickup stations is subject to the condition that no harmful interference is caused to stations in the Land Transportation Radio Services.

(c) A licensee is not limited with respect to the number of remote pickup broadcast stations which may be licensed for operation in a single area and each such station may be assigned one or more frequencies: *Provided, however,* That such frequency assignments shall be limited to those within a single frequency Group in any subparagraph of paragraph (a) of this section. This limitation does not preclude the assignment of frequencies listed in different subparagraphs to the same licensee. Applicants shall request the assignment of only those frequencies on which operation is contemplated and the transmitter shall be suitably equipped to operate on all assigned frequencies.

(d) Remote pickup broadcast stations will not be granted exclusive frequency assignments, and the same frequency or frequencies may be assigned to other licensees in the same area.

§ 4.403 Frequency selection to avoid interference. (a) Where two or more remote pickup broadcast stations are licensed for the same frequency or group of frequencies in the same area and when simultaneous operation is contemplated, the licensees shall endeavor to select frequencies or schedule operation in such manner as to avoid mutual interference. If a mutual agreement to this effect cannot be reached the Commission shall be notified and it will specify the freqeuncy or frequencies on which each station is to be operated.

(b) The following order of priority of transmissions shall be observed on all frequencies except those listed in § 4.402(a)(3): (1) The transmission of program material for broadcast, (2) the transmission of orders immediately necessary thereto, and (3) other transmissions permitted under § 4.431(a). On frequencies listed in § 4.402(a)(3), transmissions permitted under § 4.431 shall have priority over transmissions permitted under § 4.432(e).

Administrative Procedure

§ 4.411 Administrative procedure. See §§ 4.11 to 4.16, inclusive.

Licensing Policies

§ 4.431 Purpose of remote pickup broadcast stations. (a) The license of a remote pickup broadcast station authorizes the transmission of program material, orders concerning such program material, and related communications necessary to the accomplishment of such transmissions, to an associated broadcast station (a broadcast

station with which the remote pickup station is licensed as an auxiliary facility), to such other stations as are also broadcasting the same program material, or to the network with which the broadcast station is regularly affiliated. A license issued within the provisions of § 4.432(e) authorizes the additional communications therein provided. Remote pickup broadcast stations may be operated in conjunction with other broadcast stations not aforementioned: *Provided*, That the transmissions by the remote pickup broadcast station shall be under the control of the remote pickup broadcast station licensee, and that such operation shall not exceed a total of 10 days in any 30-day period.

(b) In the event of damage or impairment of the regular circuits of a broadcast station due to storms or other emergencies, remote pickup broadcast stations may be used to provide temporary emergency circuits for program transmission and cue purposes pending completion of repairs. However, remote pickup broadcast stations may not be used for such circuits on a regular basis.

(c) The license of a remote pickup broadcast station authorizes operation on only one of the assigned frequencies at any one time. A licensee may operate two or more remote pickup broadcast stations simultaneously. Remote pickup broadcast stations may be used to transmit orders and related communications from the program control point to the remote pickup point.

(d) Remote pickup broadcast stations licensed in Alaska, Hawaii, Puerto Rico, and the Virgin Islands of the United States may be used for any auxiliary broadcast purpose including inter-city relay circuits which may be operated by the licensee for the purpose of maintaining studios at locations other than that of the main studio: *Provided, however*, That such stations shall not be used for transmissions intended to be received by the public directly.

§ 4.432 Licensing requirements. (a) A license for a remote pickup broadcast station will be issued only to the licensee of a broadcast station. Remote pickup broadcast stations will be licensed to television broadcast stations upon an interim basis pending development of equipment capable of transmitting the aural and the visual portions of television programs within the bands of frequencies allocated for television pickup stations. A separate license is required for each remote pickup broadcast station. Each application for construction permit for a new remote pickup broadcast station or for a change in the facilities of an existing station shall be specific with regard to the frequency or frequencies requested.

(b) In case a licensee has two or more broadcast stations of different services (standard, FM, television, etc.) located in the same city, it shall, in applying for a new remote pickup broadcast station or for renewal of license of an existing station, designate each of the stations with which the remote pickup broadcast station is to be operated.

(c) In case a licensee has two or more broadcast stations located in different cities, it shall, in applying for a new remote pickup station or for renewal of license of an existing station, designate the broadcast station, or stations under the provisions of paragraph (b) of this section, in conjunction with which the remote pickup station is to be operated.

(d) A remote pickup broadcast station may be licensed for portable or mobile operation in accordance with § 4.401(a), or for operation at a fixed location in accordance with § 4.401(b). An application for a new remote pickup broadcast station or for modification of license of an existing station requesting portable or mobile operation shall specify the area in which the proposed station is intended to be employed.

(e) Remote pickup broadcast base stations will be licensed for the purpose of providing communication between the studio and the transmitter of broadcast stations which utilize a broadcast STL station for program transmission, provided that such operation shall not be conducted on frequencies other than those listed in § 4.402(a)(3). The term "broadcast STL station" as used in this section includes "FM broadcast STL," "standard broadcast STL," and "television STL" stations.

§ 4.433 Temporary authorizations. (a) Special temporary authority may be granted for operation, as a remote pickup broadcast station, of equipment already

licensed to another class of station or equipment in use by a class of station which under the Communications Act of 1934 does not require a construction permit.

(b) An application for special temporary authority for the operation of a remote pickup broadcast station shall be filed with the Commission at least 10 days previous to the date of operation. Any application received within less than 10 days may be accepted upon due showing of sufficient reasons for the delay in submitting such request. The application shall set forth full particulars of the purpose for which the request is made and shall show the licensee, call letters, and type of equipment of the station proposed to be used and specify the frequency or frequencies, time and date, location, transmitter power, and type emission proposed and the purpose of the operation requested.

(c) An application for special temporary authority to operate another class of station as a remote pickup broadcast station [6] shall specify a frequency or frequencies allocated in § 4.402: *Provided, however,* In case of events of national interest and importance which cannot be transmitted successfully on these frequencies, other frequencies under the jurisdiction of the Commission may be requested, if it is shown that the operation thereon will not cause interference to established stations: *And provided further,* That no remote pickup operation will be authorized on frequencies employed in the emergency service or otherwise employed for the safety of life and property.

(d) An application for special temporary authority to operate equipment as a remote pickup broadcast station [6] filed by a person other than the licensee of such equipment shall contain a statement to show that temporary control of the transmissions therefrom has been secured for the duration of the special operation proposed. An application for special temporary authority to operate another class of station as a remote pickup broadcast station filed by a person other than the licensee of a standard or FM broadcast station shall contain a statement to show which broadcast station or stations contemplate broadcast of the program proposed to be transmitted.

NOTE: Informal application may be employed.

§ 4.434 Remote control operation. Remote control operation of remote pickup stations will be permitted subject to the following conditions.

(a) A percentage modulation indicator or calibrated program level meter shall be provided at the operating position.

(b) The operator shall have off-and-on control of the power to the last radio stage.

(c) The transmitter shall be so installed and protected that it is not accessible to other than duly authorized persons.

§ 4.435 Power limitations. Remote pickup broadcast stations will be licensed with a power output not in excess of that necessary to render satisfactory service. The license for these stations will specify the maximum authorized power. The operating power shall not be greater than necessary to carry on the service and in no event more than 5 percent above the maximum power specified. Engineering standards have not been established for these stations. The efficiency factor for the last radio stage of transmitters employed will be subject to individual determination but shall be in general agreement with values normally employed for similar equipment operated within the frequency range authorized.

§ 4.436 Emission authorized. (a) The license for a remote pickup broadcast station operating on frequencies below 25 Mc. will normally authorize A3 emission and may in addition authorize A1 and A2 emission where a need therefor is shown. A license for a remote pickup broadcast station operating on frequencies above 25 Mc. will authorize A3 or F3 emission, depending upon the equipment employed. Stations licensed to employ F3 emission shall limit the frequency swing so that the bandwidth of emission will conform to the requirements of the channel widths authorized as follows:

(1) For stations operating on the frequencies 26.11 to 26.47 Mc, 20 kilocycles.

(2) For stations operating on the frequencies 152.87 to 153.35, 159.51 to 159.99, 166.25, and 170.15 Mc, 60 kilocycles.

(3) For stations operating on the frequencies 450.05 to 451.95 Mc, 100 kilocycles.

NOTE: The term "frequency swing" means the instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

(b) Any emissions outside the authorized channel shall be limited to such an extent as not to constitute a source of potential interference to other stations and in no event shall such emissions be in excess of minus 40 decibels as compared to the emissions within the authorized channel.

§ 4.437 Special rules relating to low power broadcast auxiliary stations. (a) The devices which will be licensed under this section are those which are normally intended to be operated over distances not in excess of a few hundred feet and will fall into two general categories: studio cueing transmitters and wireless microphones. Paragraphs (b) to (j) of this section will govern the licensing of such devices.

(b) A license for a low power broadcast auxiliary station will be issued only to the licensee of a standard, FM, or television broadcast station and for use with a specific station or combination of such broadcast stations within the same city. Such stations may be operated at other locations from time-to-time in accordance with the provisions of paragraph (f) of this section.

(c) The license of a low power broadcast auxiliary station authorizes the transmission of cues and orders to production personnel and participants in broadcast programs and in the preparation thereof, and the transmission of program material by means of a wireless microphone worn by a performer or other participant in a broadcast program during rehearsal and the actual performance. Such transmissions shall be intended for reception at a receiving point within the same studio, building, stadium, or similarly limited indoor or outdoor area.

(d) An application for a new low power broadcast auxiliary station or for a change in an existing authorization shall specify the broadcast station or combination of stations in the same city, as set forth in paragraph (b) of this section, with which it is to be used principally. A single application, filed on FCC Form 313, in duplicate, may be used in applying for authority to construct and operate one or more low power broadcast auxiliary transmitting units provided that such transmitting units are designed for operation in a common frequency band and will be normally operated with the same broadcast station or combination of stations in a single city.

(e) The operation of low power broadcast auxiliary stations will be authorized only in the bands 26.10–26.48 Mc and 450–451 Mc. Transmitting units may be operated on any frequency within the band of frequencies for which the station is licensed, provided that the emissions are confined to the authorized band. Transmitting units are not required to maintain a constancy of frequency beyond that necessary to insure compliance with the above requirement.

(f) A low power broadcast auxiliary station may be used in conjunction with broadcast stations of other licensees located in the same area as the broadcast station or stations with which it is licensed without further authority of the Commission, provided that such operation is conducted by the licensee of the low power broadcast auxiliary station. Low power broadcast auxiliary stations may also be operated in conjunction with broadcast stations of its licensee or other licensees in other locations provided that such operation is conducted by the licensee of the low power broadcast auxiliary station and provided further that if such operation is to be conducted over a consecutive period of more than one day, the Engineer in Charge of the radio district in which the low power broadcast auxiliary station is licensed and the Engineer in Charge of the radio district in which the operation is to be conducted shall be notified in writing at least two days in advance of such operation and of the expected duration of the proposed operation.

(g) Low power broadcast auxiliary stations will not be licensed for a power input to the plate of the final radio frequency amplifier in excess of 1 watt and all operation thereof is subject to the condition that no harmful interference is caused to remote pickup broadcast base and mobile stations. Unusual transmitting antennas or antenna elevations shall not be used to extend the range of these low power devices beyond the limited areas defined in paragraph (c) of this section.

(h) No operator's license is required of the person actually using a low power broadcast auxiliary transmitting unit, provided that an operator holding any commer-

cial radio operator license or permit, except an aircraft radiotelephone operator authorization or a temporary radiotelegraph second-class operator license, is on duty at the place where the transmitting unit is being operated to take immediate steps to correct any condition of improper operation observed. Any adjustments or repairs that could affect the proper operation of transmitting units shall be made by or under the immediate supervision of an operator holding a valid first- or second-class radiotelephone license.

(i) Call signs will not be assigned to low power broadcast auxiliary stations. In lieu thereof, an announcement shall be made at the beginning and end of each period of operation at a single location, over the transmitting unit being operated, identifying the type of transmitting unit, its location, and the call sign of the broadcast station with which it is being used. Transmitting units will normally fall into one of two types: a cueing transmitter or a wireless microphone. A period of operation may consist of a continuous transmission or intermittent transmissions in connection with a single program.

(j) The licensee of each low power broadcast auxiliary station shall maintain adequate records at the main studio or transmitter of the broadcast station with which the auxiliary is principally used, which will accurately show the current location of all transmitting units, the periods of operation at such locations and any other pertinent remarks concerning transmissions.

Equipment

§ 4.451 Equipment changes. The licensee of a remote pickup broadcast station may make any changes in the equipment that are deemed desirable or necessary: *Provided,*

(a) That the operating frequency is not permitted to deviate more than the allowed tolerance;

(b) That the emissions are not permitted outside the authorized band;

(c) That the power output complies with the license and the regulations governing the same; and

(d) That the transmitter as a whole or output power rating of the transmitter is not changed.

Rules Relating to Technical Operation

§ 4.461 Frequency tolerance. The licensee of a remote pickup broadcast station shall maintain the operating frequency of its station in accordance with the following:

Frequency range	Tolerance (percent)	
	Base station	Mobile station
1606 to 2830 kc:		
200 watts or less	0.01	0.02
Over 200 watts [1]	.005	.02
26.11 to 26.47 Mc:		
5 watts or less	.005	.02
Over 5 watts	.005	.005
152.87 to 153.35, 159.51 to 159.99, 166.25, and 170.15 Mc:		
5 watts or less	.005	.01
Over 5 watts	.005	.005
450.05 to 451.95 Mc: All powers	.01	.01

[1] The listing of tolerance for power over 200 watts is in accordance with treaty values and shall not be construed as a finding that such power will be authorized.

§ 4.462 Frequency monitors and measurements. (a) The licensee of a remote pickup broadcast station shall provide the necessary means for determining that the frequency of the station is within the allowed tolerance. The date and time of each frequency check, the frequency as measured, and a description or identification of the method employed shall be entered in the station log. Sufficient observations shall be made to insure that the assigned carrier frequency is maintained within the prescribed tolerance.

(b) Each frequency for which the remote pickup broadcast station is licensed shall be measured at least once during each calendar year.

§ 4.463 Station inspection. The licensee of each remote pickup broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 4.464 Station and operator licenses; posting of. (a) The station license and any other instrument of authorization or individual order concerning the construction of the equipment or manner of operation of the station shall be posted so that all terms thereof are visible in a conspicuous place in the room in which the transmitter is located: *Provided:*

(1) If the transmitter operator is located at a distance from the transmitter pursuant to § 4.434, the station license shall be posted in the above-described manner at the operating position.

(2) If the station is licensed for portable-mobile operation, the station license or a photo copy thereof shall be affixed to the equipment or kept in the possession of the operator on duty at the transmitter. If a photo copy is used the original license shall be available for inspection by an authorized Government representative.

(b) The original license of each station operator shall be posted at the place where he is on duty: *Provided, however,* If the original license of a station operator is posted at another radio transmitting station in accordance with the rules governing that class of station and is there available for inspection by an authorized Commission representative, or if the station operated is licensed for portable-mobile operation, a verification card (Form 758-F) is acceptable in lieu of the posting of such license: *Provided further, however,* That if the operator on duty holds a restricted radiotelephone operator permit of the card form (as distinguished from the diploma form) he shall not post that permit but shall keep it in his personal possession.

NOTE: The term portable-mobile as here used is intended to include any type of portable or mobile operation.

§ 4.465 Operator requirements. One or more radio operators holding any class of commercial radio operator license or permit shall be on duty at the place where the transmitting apparatus of any remote pickup broadcast station is located, except as provided in § 4.434, and in actual charge of its operation. Further provisions and restrictions concerning the operator's authority are contained in Part 13 of this chapter. The licensed operator on duty and in charge of a broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of operator's license which he holds and the rules and regulations governing such stations. However, such duties shall in no wise interfere with the operation of the broadcast transmitter.

§ 4.466 Antenna structure, marking and lighting. Where an antenna structure(s) is required to be painted or lighted see § 17.37, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 4.467 Additional orders. In case the rules contained in this part do not cover all phases of operation or experimentation with respect to external effects, the Commission may make supplemental or additional orders, in each case as may be deemed necessary.

Other Operating Requirements

§ 4.481 **Station records.** (a) The licensee of each remote pickup broadcast station shall maintain adequate records of the operation, including:

(1) Hours of operation.
(2) Program transmitted.
(3) Frequency check.
(4) Pertinent remarks concerning transmission.
(5) An entry giving points of program origination and receiver location.

(b) Where an antenna structure(s) is required to be illuminated see § 17.38, *Recording of tower light inspections in the station record,* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

(c) Station records shall be retained for a period of two years.

§ 4.482 **Station identification.** Each remote pickup broadcast station shall announce its call letters at the beginning and end of each period of operation, and during operation, at least once every hour it shall either announce its call letters or make an announcement which will permit it to be identified. (Such as announcement during program operation of the call letters of the broadcast station with which the remote pickup broadcast station is regularly affiliated.)

SUBPART E—STANDARD AND FM BROADCAST STL AND FM INTERCITY RELAY STATIONS

Definitions and Allocation of Frequencies

§ 4.501 **Classes of stations.** (a) FM Broadcast STL Station: A fixed station utilizing telephony to transmit from a studio of an FM broadcasting station to the transmitter of that broadcasting station, programs to be broadcast by that station.

(b) Standard broadcast STL station: A fixed station utilizing telephony to transmit from a studio of a standard broadcasting station to the transmitter of that broadcasting station, programs to be broadcast by that station.

(c) FM intercity relay station: A fixed station used for the transmission of FM broadcasting programs from one FM broadcasting station to other FM broadcasting stations to provide simultaneous network FM broadcasting and operated only by FM broadcast licensees.

NOTE 1: The term "FM broadcasting station" as used in this part of the rules includes non-commercial educational FM broadcasting stations.

NOTE 2: The abbreviation "STL" is derived from "studio-transmitter link."

§ 4.502 **Frequency assignment.** (a) An FM broadcast STL station may be licensed on one of the following frequencies:

942.5 Mc	946.0 Mc	949.5 Mc
943.0 Mc	946.5 Mc	950.0 Mc
943.5 Mc	947.0 Mc	950.5 Mc
944.0 Mc	947.5 Mc	951.0 Mc
944.5 Mc	948.0 Mc	951.5 Mc
945.0 Mc	948.5 Mc	
945.5 Mc	949.0 Mc	

(b) Any standard broadcast STL station or FM broadcast STL station for which there was outstanding a valid construction permit or license on April 16, 1958, specifying operation on any frequency between 890 Mc and 942 Mc, may continue to be operated on such frequencies for the remainder of the term specified in such authorization and may upon appropriate application therefor be granted a renewal of such license, subject to the condition that no harmful interference shall be caused to the radiopositioning service operating in the band 890–942 Mc and subject to the further condition that the licensee must accept any interference which may be caused by the

operation of radiopositioning stations in the band 890–942 Mc and industrial, scientific, and medical (ISM) equipment in the band 890–940 Mc.

(c) FM inter-city relay stations may be licensed to operate on any of the frequencies listed in paragraph (a) of this section, subject to the condition that no harmful interference is caused to stations operating in the band 942–952 Mc in accordance with the Table of Frequency Allocations contained in § 2.104(a) of this chapter.

§ 4.503 Frequency selection. (a) Each application for a new station or change in an existing station shall be specific with regard to frequency. In general, the lowest suitable frequency will be assigned which, on an engineering basis, will not cause harmful interference to other stations operating in accordance with existing frequency allocations.

(b) Any standard broadcast STL station or FM broadcast STL station for which there was outstanding a valid construction permit or license on April 16, 1958, specifying operation on any frequency between 890 Mc and 942 Mc, may continue to be operated on such frequencies for the remainder of the term specified in such authorization and may upon appropriate application therefor be granted a renewal of such license, subject to the condition that no harmful interference shall be caused to the radiopositioning service operating in the band 890–942 Mc and subject to the further condition that the licensee must accept any interference which may be caused by the operation of radiopositioning stations in the band 890–942 Mc and industrial, scientific, and medical (ISM) equipment in the band 890–940 Mc.

Administrative Procedure

§ 4.511 Cross reference. See §§ 4.11 to 4.16, inclusive.

Licensing Policies

§ 4.531 Licensing requirements. (a) An FM broadcast STL station will be licensed only to the licensee of an FM broadcasting station as an auxiliary to a particular FM broadcasting station of that licensee.

(b) A standard broadcast STL station will be licensed only to the licensee of a standard broadcast station as an auxiliary to a particular standard broadcast station of that licensee.

(c) An FM intercity relay station will be licensed only to the licensee of an FM broadcast station and only upon a satisfactory showing that suitable common carrier facilities are not available. An application for construction permit for a new FM intercity relay station or for renewal of license of an existing station shall be accompanied by a verified statement containing the following:

(1) A full statement as to why the applicant requires the requested facilities including reasons why common carrier facilities cannot be utilized; and,

(2) A showing that the applicant has, at the earliest time reasonably practicable, requested the appropriate common carrier or common carriers serving the general area involved to furnish the intercity FM transmission service required by the applicant, including in such showing a copy of the request or requests and of the reply or replies received from such common carriers.

(d) More than one broadcast STL station or FM intercity relay stations will be licensed for use with single broadcast station only upon a showing that, (1) more than one transmitter is required for the effective operation of a single STL or intercity relay circuit due to distance of transmission, terrain anomalies, or similar circumstances; or, (2) more than one STL circuit is needed to connect additional studios or more than one FM intercity relay circuit is needed to connect additional FM broadcast stations in the network; and it is shown that the nature and extent of use of such additional circuits is such as to justify their authorization.

(e) Each station shall be licensed at a fixed location and the direction of radiation of the antenna shall be fixed.

§ 4.532 Service. (a) The license of an FM broadcast STL station or a standard

broadcast STL station authorizes the relaying of programs from a studio to the transmitter of the broadcast station with which it is licensed, for simultaneous or delayed broadcast: *Provided, however,* That where the licensee of an FM broadcast STL station or a standard broadcast STL station is the licensee of an FM broadcast station and a standard broadcast station in the same city or metropolitan district, the license of each such STL station authorizes the relaying to be made to either or both such broadcast stations.

(b) The license of an FM intercity relay station authorizes the relaying of FM broadcast programs and communications relating thereto between FM broadcasting stations located in different cities in order to provide network FM broadcasting. The operation of FM intercity relay stations is subject to the condition that no harmful interference is caused to other radio stations, present or future, operating in accordance with the Table of Frequency Allocations set forth in § 2.104(a) of this chapter.

(c) Each FM broadcast STL station, standard broadcast STL station, or FM intercity relay station will be licensed for unlimited time operation.

(d) During periods in which it is not a part of the broadcast circuit, the transmitting equipment may be used for the transmisson of communications which pertain to the broadcast operations. If the transmitter and receiver are equipped with a multiplex circuit, communications during broadcast periods may be authorized upon application therefor. Such a circuit, if used, shall be designed and operated in a manner which will not cause spurious emissions or derogation of the program transmission. Studio to transmitter and transmitter to studio communication may also be provided by equipment operated under the remote pickup broadcast station rules. Superfluous transmissions are not permitted.

§ 4.533 Remote control and unattended operation. (a) Broadcast STL or FM intercity relay stations may be operated by remote control: *Provided,* That such operation is conducted in accordance with the conditions listed in this section: *And provided further,* That the Commission is notified at least 10 days prior to such operation and that such notification is accompanied by a detailed description of the proposed remote control installation showing the manner of compliance with the following couditions:

(1) The operating position shall be under the control and supervision of the licensee and shall be the place at which a licensed operator meeting the requirements of § 4.565 and responsible for the operation of the transmitter is stationed;

(2) A carrier operated device shall be provided at the operating position which shall give a continuous visual indication when the transmitter is radiating; or, in lieu thereof, a device shall be provided which will give a continuous visual indication when any transmitter control circuits have been placed in a coudition to produce radiatiou;

(3) Facilities shall be provided at the operating position which will permit the operator to turn the transmitter carrier on and off at will; and

(4) The transmitter and all of its operating controls shall be so installed and protected that they are not accessible to other than authorized personnel.

(b) FM intercity relay stations, and broadcast STL stations where the circuit requires the use of more than one STL transmitter, may be operated unattended: *Provided,* That such operation is conducted in accordance with the conditions listed below: *And provided further,* That the Commission is notified at least 10 days prior to the beginning of such operation and that such notification is accompanied by a detailed description of the proposed installation showing the manner of compliance with the following conditions:

(1) The transmitter is capable of retransmitting by self-actuating means a radio signal received from another radio station or stations;

(2) The transmitter shall be provided with adequate safeguards to prevent improper operation of the equipment;

(3) The tranmsitter shall be so installed and protected that it is not accessible to other than duly authorized persons;

(4) Appropriate observations shall be made, at intervals not exceeding one hour during the period of its operations, at the receiving end of the circuit by a person

holding a valid first or second class radiotelephone operator license who shall immediately institute measures sufficient to assure prompt correction of any condition of improper operation that is observed; and

(5) The station licensee shall remain responsible for the proper operation of the station, and all adjustments or tests during or coincident with the installation, servicing, or maintenance of the station which may affect its proper operation, shall be performed by or under the immediate supervision and responsibility of a person holding a valid first or second class radiotelephone operator license.

(c) The Commission may notify the licensee not to commence remote control or unattended operation, or to cancel, suspend, or change the date of the beginning of such operation as and when such action may appear to be in the public interest, convenience and necessity.

§ 4.534 Power limitations. Broadcast STL and FM intercity relay stations will be licensed with a power output not in excess of that necessary to render satisfactory service. The license for these stations will specify the maximum authorized power. The operating power shall not be greater than necessary to carry on the service and in no event more than 5 percent above the maximum power specified. Engineering standards have not been established for these stations. The efficiency factor for the last radio stage of transmitters employed will be subject to individual determination but shall be in general agreement with values normally employed for similar equipment operated within the frequency range authorized.

§ 4.535 Emission authorized. (a) Broadcast STL and FM intercity relay stations normally will be authorized to employ frequency modulation only.

(b) The maximum frequency swing employed shall not be in excess of 200 kilocycles.

NOTE: The term "frequency swing" means the instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

§ 4.536 Directional antenna required. Each broadcast STL or FM intercity relay station is required to employ a directional antenna. Considering one kilowatt of radiated power as a standard for comparative purposes, such antenna shall provide a free space field intensity at one mile of not less than 435 mv/m in the main lobe of radiation toward the receiver and not more than 20 percent of the maximum value in any azimuth 30 degrees or more off the line to the receiver. Where more than one antenna is authorized for use with a single station, the radiation pattern of each shall be in accordance with the foregoing requirement.

Equipment

§ 4.551 Equipmeut changes. The licensee of a broadcast STL or FM intercity relay station may make any changes in the equipment that are deemed desirable or necessary provided:

(a) That the operating frequency is not permitted to deviate more than the allowed tolerance;

(b) That the emissions are not permitted outside the authorized band;

(c) That the power output complies with the license and the regulations governing the same; and

(d) That the transmitter as a whole or output power rating of the transmitter is not changed.

Technical Operation

§ 4.561 Frequency tolerance. The licensee of each broadcast STL or FM intercity relay station shall maintain the operating frequency of the station within plus or minus 0.005 percent of the assigned frequency.

§ 4.562 Frequency monitors and measurements. The licensee of a broadcast STL or FM intercity relay station shall provide the necessary means for determining that the frequency of the station is within the allowed tolerance. The date and time of

each frequency check, the frequency as measured, and a description or identification of the method employed shall be entered in the station log. Sufficient observations shall be made to insure that the assigned carrier frequency is maintained within the prescribed tolerance.

§ 4.563 Station inspection. The licensee of each broadcast STL or FM intercity relay station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 4.564 Station and operator license; posting of. (a) The station license and any other instrument of authorization or individual order concerning the construction of the equipment or manner of operation of the station shall be posted so that all terms thereof are visible, in a conspicuous place in the room in which the transmitter is located: *Provided,* That if the transmitter operator is located at a distance from the transmitter pursuant to § 4.533 the station license shall be posted in the above-described manner at the operating position.

(b) The original license of each station operator shall be posted at the place where he is on duty: *Provided, however,* If the original license of a station operator is posted at another radio transmitting station in accordance with the rules governing that class of station and is there available for inspection by an authorized Commission representative, a verification card (Form 758-F) is acceptable in lieu of the posting of such license: *Provided further, however,* That if the operator on duty holds a restricted radiotelephone operator permit of the card form (as distinguished from the diploma form) he shall not post that permit but shall keep it in his personal possession.

§ 4.565 Operator requirements. One or more radio operators holding any class of commercial radio operator license or permit shall be on duty at the place where the transmitting apparatus is located, except as provided in § 4.533, and in actual charge of its operation. Further provisions and restrictions concerning the operator's authority are contained in Part 13 of this chapter. The licensed operator on duty and in charge of a broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of operator's license which he holds and the rules and regulations governing such stations. However, such duties shall in no wise interfere with the operation of the broadcast transmitter.

§ 4.566 Antenna structure, marking and lighting. Where an antenna structure(s) is required to be painted or lighted see § 17.37, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 4.567 Additional orders. In case the rules contained in this part do not cover all phases of operation or experimentation with respect to external effects, the Commission may make supplemental or additional orders in each case as may be deemed necessary.

Other Operating Requirements

§ 4.581 Station records. (a) The licensee of each broadcast STL or FM intercity relay station shall maintain adequate records of the operation, including:

(1) Hours of operation.

(2) Program transmitted.

(3) Frequency check.

(4) Pertinent remarks concerning transmission.

(b) Where an antenna structure(s) is required to be illuminated see § 17.38 of this chapter.

(c) Station records shall be retained for a period of two years.

§ 4.582 Station identification. Each broadcast STL or FM intercity relay station shall announce its call letters at the beginning and end of each period of operation, and during operation, at least once every hour, it shall either announce its call letters or make an announcement which will permit it to be identified. (Such as announcement during program operation of the call letters of the broadcast station with which the broadcast STL station is operated.)

SUBPART F—TELEVISION AUXILIARY BROADCAST STATIONS

Definitions and Allocation of Frequencies

§ 4.601 Classes of stations. (a) Television pickup station: A land mobile station used for the transmission of television program material and related communications from the scenes of events occurring at points removed from television broadcast station studios to television broadcast stations.

(b) Television STL station (studio-transmitter link): A fixed station used for the transmission of television program material and related communications from the studio to the transmitter of a television broadcast station.

(c) Television inter-city relay station: A fixed station used for inter-city transmission of television program material and related communications for use by television broadcast stations.

NOTE: Wherever used in this subpart the term "television broadcast station licensee" includes a television broadcast station permittee.

§ 4.602 Frequency assignment. (a) The following frequencies are allocated for assignment to television pickup, television STL, and television inter-city relay stations:

Band A (Mc)	Band B (Mc)	Band C (Mc)	Band D (Mc)	
1990–2008	6875–6900	10550–10575	12700–12725	12975–13000
2008–2025	6900–6925	10575–10600	12725–12750	13000–13025
2025–2042	6925–6950	10600–10625	12750–12775	13025–13050
2042–2059	6950–6975	10625–10650	12775–12800	13050–13075
2059–2076	6975–7000	10650–10675	12800–12825	13075–13100
2076–2093	7000–7025	10675–10700	12825–12850	13100–13125
2093–2110	7025–7050	.....	12850–12875	13125–13150
2450–2467	[1] 7050–7075	.....	12875–12900	13150–13175
2467–2484	[1] 7075–7100	.....	12900–12925	13175–13200
2484–2500	[1] 7100–7125	.....	12925–12950	13200–13225
.....	.....	.....	12950–12975	.....

[1] Pending further order by the Commission, frequencies between 7050 Mc and 7125 Mc will be reserved for use by communications common carriers to provide television pickup and television STL service to television broadcast stations.

Frequencies in the bands 16000–18000 Mc and 26000–30000 Mc are available for assignment on a case-by-case basis for television pickup, STL and intercity relay purposes. Channel widths and frequency tolerance will be specified in individual authorizations. Frequencies shown above between 2450 and 2500 Mc in Band A and between 17850 and 18000 Mc are allocated to accommodate the incidental radiations of industrial, scientific, and medical (ISM) equipment, and stations operating therein must accept any interference that may be caused by the operation of such equipment. ISM frequencies are also shared with other communication services and exclusive channel assignments will not be made, nor is the channeling shown above necessarily that which will be employed by such other services.

(b) Except as provided above each television broadcast station licensee in an area may request the assignment of one channel in Band A or Band B and one channel in Band D on an exclusive basis. In making such exclusive assignments, priority will be based on the filing date of an appropriate application (FCC Form 313) completed in accordance with the instructions thereon. Frequency assignments will normally be made as requested if the requested frequency is not assigned to another licensee on an exclusive basis. However, the Commission reserves the right to assign frequencies other than those requested if, in its opinion, such action is warranted.

(c) Where the relative locations of the studio and transmitter are such as to permit co-channel operation of television STL stations by two or more licensees in the same

area such licensees may, by mutual agreement, request the assignment of a common channel for STL use on an exclusive basis. In the event that such a shared assignment is made each participating licensee may request the assignment of an individual exclusive channel in Band A, Band B, or Band D in addition to the shared STL channel.

(d) A television broadcast station licensee will normally be limited to the assignment of not more than three channels in Bands A and B combined, only one of which will be assigned on an exclusive basis: *Provided, however,* That additional channels in Bands A and B may be assigned on a non-exclusive basis upon a satisfactory showing that additional channels are necessary and that such additional channels, if assigned, will not be needed to provide an exclusive channel to some other licensee in the same area within the foreseeable future. The number of channels in Bands C and D that may be assigned to a licensee in a single area is not restricted.

(e) Non-exclusive channel assignments are subject to withdrawal without advance notice to provide an exclusive channel assignment to a licensee pursuant to the provisions of paragraph (b) of this section. The Commission reserves the right to select the non-exclusive channel assignment to be withdrawn; however, withdrawals will normally be made in the following order:

(1) The most recent channel assignment to the licensee having the greatest number of assignments in Band A, B, or D. Determination as to whether the withdrawal shall be made in Band A, Band B, or Band D, will be based on the design of the equipment proposed to be used by the applicant for whom the exclusive channel is required.

(2) Where two or more licensees are assigned individually an equal number of non-exclusive channels in the same band and a greater number of channels in that band than any one of the other licensees, the assignment of most recent date.

(3) In all other cases the assignment of most recent date of a non-exclusive channel.

(f) The use of frequencies in the bands 1990–2110 Mc, 6875–7125Mc, and 12,700–13,200 Mc, by television inter-city relay stations shall be on a secondary basis and is subject to the condition that no harmful interference is caused to stations operating in accordance with the table of frequency allocations in § 2.104(a) of this subchapter.

(g) In the event that a television broadcast station licensee engages a communications common carrier to provide television pickup or television STL service, the frequencies available to that licensee may be assigned to the communications common carrier for the purpose of providing such service to that licensee. For the purpose of applying the provisions with respect to exclusive channel assignments and the withdrawal of channels, channels assigned to communications common carriers to provide television pickup or television STL service to an individual television broadcast station licensee will be considered to be assigned to that television broadcast licensee.

§ 4.603 Sound channels. (a) The frequencies listed in § 4.602(a) may be used for the simultaneous transmission of the picture and sound portions of television broadcast programs and for cue and order circuits, either by means of multiplexing or by the use of a separate transmitter within the same channel. When multiplexing of a television STL station is contemplated consideration should be given to the requirements of § 3.687 of this subchapter regarding the overall system performance requirements. Applications for new television pickup, television STL, and television intercity relay stations shall clearly indicate the nature of any multiplexing proposed. Multiplexing equipment may be installed on licensed equipment without further authority of the Commission: *Provided,* That the Commission in Washington, D.C., and the Commission's engineer-in-charge of the radio district in which the station is located shall be promptly notified of the installation of such apparatus: *And provided further,* That the installation of such apparatus on a television STL station shall not result in degradation of the overall system performance of the television broadcast station below that permitted by § 3.687 of this subchapter.

(b) The following additional frequencies are allocated for assignment to television STL stations and television intercity stations for the transmission of the sound portion only of television program material or communications relating thereto: [1]

[1] Shared with other services. See § 2.104(a) of this chapter.

890.5 Mc	895.0 Mc	899.0 Mc	903.0 Mc	907.0 Mc
891.0	895.5	899.5	903.5	907.5
891.5	896.0	900.0	904.0	908.0
892.0	896.5	900.5	904.5	908.5
892.5	897.0	901.0	905.0	909.0
893.0	897.5	901.5	905.5	909.5
893.5	898.0	902.0	906.0	910.0
894.0	898.5	902.5	906.5	910.5
894.5				

Stations operating on these frequencies must accept any interference that may be experienced from the operation of industrial, scientific, and medical equipment in the 890–940 Mc band.

(c) Remote pickup broadcast stations may be used in conjunction with television pickup stations for the transmission of the aural portion of television programs or events that occur outside a television studio and for the transmission of cues, orders, and other related communications necessary thereto. The rules governing remote pickup broadcast stations are contained in Subpart D of this part.

§ 4.604 Frequency selection to avoid interference. (a) Applicants for new television pickup, television STL, and television inter-city relay station shall endeavor to select frequency assignments which will be least likely to result in mutual interference with other licensees in the same area. Consideration should be given to the relative locations of receiving points, normal transmission path, and nature of the contemplated operation.

(b) Because of the more or less continuous nature of the operation of television STL stations, frequency assignments to such stations will normally be designated as the exclusive channel of the licensee pursuant to § 4.602(b).

(c) Where two or more licensees are assigned a common channel for television pickup, television STL, or television inter-city relay purposes in the same area and simultaneous operation is contemplated, they shall take such steps as may be necessary to avoid mutual interference. If a mutual agreement to this effect cannot be reached, the Commission shall be notified and it will take such action as may be necessary, including time-sharing arrangements, to assure an equitable distribution of available facilities.

Administrative Procedure

§ 4.621 Cross reference. See §§ 4.11 through 4.16.

§ 4.631 Purpose of television auxiliary stations. (a) The license of a television pickup station authorizes the transmission of program material, orders concerning such program material, and related communications necessary to the accomplishment of such transmissions, from the scenes of events occurring in places other than a television studio, to its associated television broadcast station, to such other stations as are broadcasting the same program material, or to the network or networks with which the television broadcast station is affiliated. Television pickup stations may be operated in conjunction with other television broadcast stations not aforementioned: *Provided,* That the transmissions by the television pickup station are under the control of the licensee of the television pickup station and that such operation shall not exceed a total of 10 days in any 30-day period. Television pickup stations may be used to provide temporary studio-transmitter links or intercity relay circuits consistent with § 4.632, without further authority of the Commission: *Provided, however,* That prior Commission authority shall be obtained if the transmitting antenna to be installed will increase the height of any natural formation or man-made structure by more than 20 feet and will be in existence for a period of more than 2 consecutive days.

NOTE: As used in this subpart, "associated television broadcast station" means a television broadcast station licensed to the licensee of the television auxiliary broadcast station and with which the television auxiliary station is licensed as an auxiliary facility.

(b) The license of a television STL station authorizes the transmission of program material, orders concerning such program material, and related communications necessary to the accomplishment of such transmissions, from the studio or studios of the associated television broadcast station to the transmitter of that station. A television STL station may be authorized to operate in the direction from the transmitter to the studio upon a showing that such operation is necessary and that it may be effected without the assignment of frequencies in addition to those available for assignment to the applicant under these rules.

(c) The license of a television intercity relay station authorizes the transmission of program material, orders concerning such program material and related communications necessary to the accomplishment of such transmissions between television broadcast stations for the purpose of simultaneous programming or network broadcasting.

§ 4.632 Licensing requirements. (a) A license for a television pickup, television STL, or television intercity relay station will be issued only to the licensee of a television broadcast station. A separate application is required for each transmitter and the application shall be specific with regard to the frequency requested. Except as provided in § 4.604(b), the first channel assigned in Band A or Band B to a licensee will be considered to be the exclusive assignment provided in § 4.602(b). Exclusive channel assignments in Band D will be designated only upon request. A licensee may request a change in its exclusive channel assignment only where there are unassigned channels available. In making such changes, the priority set forth in § 4.602(b) will be observed.

(b) A license for a television intercity relay station may be issued in any case where the circuit will operate between television broadcast stations either by means of "off-the-air" pickup and relay or location of the initial relay station at the studio or transmitter of a television broadcast station.

(c) An application for construction permit for a new television pickup station or for renewal of license of an existing station shall designate the television broadcast station with which it is to be operated and specify the area in which the proposed operation is intended.

(d) In case a licensee has two or more television broadcast stations located in different cities, it shall, in applying for a new television pickup station or for renewal of license of an existing station, designate the television broadcasting station in conjunction with which it is to be operated principally, and it shall not thereafter operate the television pickup station in conjunction with another of its television broadcast stations located in a different city for a total of more than 10 days in any 30-day period.

§ 4.633 Temporary authorizations. (a) Special temporary authority may be granted for the operation, as a television auxiliary broadcast station, of equipment licensed to another television broadcast station, or other class of station, or equipment of suitable design not heretofore licensed. Such authority will normally be granted only for special operation of a temporary nature.

(b) A request for special temporary authority for the operation of a television auxiliary broadcast station may be made by informal application, which shall be filed with the Commission at least 10 days prior to the date of the proposed operation: *Provided*, That an application filed within less than 10 days of the proposed operation may be accepted upon a satisfactory showing of the reasons for the delay in submitting the request.

(c) An application for special temporary authority shall set forth full particulars of the purpose for which the request is made, and shall show the type of equipment, power output, emission, and frequency or frequencies proposed to be used, as well as the time, date and location of the proposed operation. In the event that the proposed antenna installation will increase the height of any natural formation, or existing man-made structure, by more than 20 feet, a vertical plan sketch showing the height of the structure proposed to be erected, the height above ground of any existing structure, the elevation of the site above mean sea level, and the geographic coordinates of the proposed site, shall be submitted with the application.

(d) A request for special temporary authority shall specify a channel or channels consistent with the provisions of § 4.602: *Provided,* That in the case of events of widespread interest and importance which cannot be transmitted successfully on these frequencies, frequencies assigned to other services may be requested upon a showing that operation thereon will not cause interference to established stations: *And provided further,* That in no case will a television auxiliary broadcast operation be authorized on frequencies employed for the safety of life and property.

§ 4.634 Remote control operation. (a) A television auxiliary station may be operated by remote control provided that such operation is conducted in accordance with the conditions listed below, and provided further that the Commission is notified at least 10 days prior to such operation and that such notification is accompanied by a detailed description of the proposed remote control installation showing the manner of compliance with the following conditions:

(1) The operating position shall be under the control and supervision of the licensee and shall be the place at which a licensed operator, meeting the requirements of § 4.665 and responsible for the operation of the transmitter, is stationed.

(2) A carrier operated device shall be provided at the operating position which shall give a continuous visual indication when the transmitter is radiating; or, in lieu thereof, a device shall be provided which will give a continuous visual indication when any transmitter control circuits have been placed in a condition to produce radiation;

(3) Facilities shall be provided at the operating position which will permit the operator to turn the transmitter carrier on and off at will; and

(4) The transmitter and all of its operating controls shall be so installed and protected that they are not accessible to other than duly authorized personnel.

(b) The Commission may notify the licensee not to commence remote control operation, or to cancel, suspend, or change the date of beginning for such operation as and when such action may appear to be in the public interest, convenience, and necessity.

§ 4.635 Unattended operation. (a) Television inter-city relay stations and television STL stations, where the circuit requires the use of more than one STL transmitter, may be operated unattended: *Provided,* That such operation is conducted in accordance with the conditions listed below: *And provided further,* That the Commission is notified at least 10 days prior to the beginning of such operation and that such notification is accompanied by a detailed description of the proposed installation showing the manner of compliance with the following conditions:

(1) The transmitter is capable of retransmitting by self-actuating means a radio signal received from another radio station or stations;

(2) The transmitter shall be provided with adequate safeguards to prevent improper operation of the equipment;

(3) The transmitter shall be so installed and protected that it is not accessible to other than duly authorized persons;

(4) Appropriate observations shall be made, at intervals not exceeding one hour during the period of its operation, at the receiving end of the circuit by a person holding a valid first or second class radiotelephone operator license who shall immediately institute measures sufficient to assure prompt correction of any condition of improper operation that is observed; and

(5) The station licensee shall remain responsible for the proper operation of the station, and all adjustments or tests during or coincident with the installation, servicing, or maintenance of the station which may affect its proper operation, shall be performed by or under the immediate supervision and responsibility of a licensed operator as provided in § 4.665.

(b) The Commission may notify the licensee not to commence unattended operation, or to cancel, suspend, or change the date of the beginning of such operation as and when such action may appear to be in the public interest, convenience, and necessity.

§ 4.636 Power limitations. Television auxiliary broadcast stations will be licensed with a power output not in excess of that necessary to render satisfactory service.

The license for these stations will specify the maximum authorized power. The operating power shall not be greater than necessary to carry on the service and in no event more than 10 percent above the maximum power specified. Engineering standards have not been established for these stations. The efficiency factor for the last radio stage of transmitters employed will be subject to individual determination but shall be in general agreement with values normally employed for similar equipment operated within the frequency range authorized.

§ 4.637 **Emission and bandwidth.** (a) Television auxiliary broadcast stations operating on frequencies above 1500 Mc may be authorized to employ any type of emission suitable for the transmission of the visual and accompanying aural signals. The emission of such stations shall be confined to the assigned channel.

(b) Television auxiliary broadcast stations operating on frequencies below 1500 Mc may be authorized to employ either frequency modulation or amplitude modulation, or both, depending upon the equipment employed. The emissions of such stations shall be confined to the assigned channel.

Equipment

§ 4.651 **Equipment changes.** (a) Commission authority upon appropriate formal application (FCC Form 313) therefor is required for any of the following equipment changes:

(1) A change of the transmitter as a whole (except replacement with an identical transmitter), or a change in the power output.

(2) A change of frequency assignment.

(3) A change in the location of a television STL or television intercity relay station (except relocation of the equipment within the same building) or a change in the area of operation of a television pickup station.

(4) Any change in the antenna system of a television STL or television intercity relay station which will result in a change of more than 20 feet in the height above ground of the antenna and supporting structure, or that will result in a change of the direction of the main radiation lobe.

(b) Other equipment changes not specifically referred to above may be made at the discretion of the licensee provided that the engineer-in-charge of the radio district in which the station is located, and the Commission at its Washington office, are notified in writing upon the completion of such changes, and provided that the changes are appropriately reflected in the next application for renewal of license of the television auxiliary broadcast station filed by the licensee.

Technical Operation

§ 4.661 **Frequency tolerance.** (a) The licensee of a television auxiliary broadcast station shall maintain the operating frequency of its station so that the normal sideband energy shall fall within the assigned channel. If transmission is by asymmetrical sideband operation, suitable filters or other devices shall be employed to insure a minimum of radiated energy outside the assigned channel.

(b) Television STL stations operating on frequencies shown in § 4.603(b) shall maintain their operating frequency within 0.005 percent of the assigned frequency.

§ 4.662 **Frequency monitors and measurements.** The licensee of a television auxiliary broadcast station shall provide means for measuring the operating frequency in order to insure that the emissions are confined to the authorized channel. The date and time of each frequency check, the frequency as measured and a description or identification of the method employed shall be entered in the station log.

§ 4.663 **Station inspection.** The licensee of each television auxiliary broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 4.664 **Station and operator licenses; posting of.** (a) The station license and any other instrument of authorization or individual order concerning the construction of the equipment or manner of operation of the station shall be posted so that all

terms thereof are visible in a conspicuous place in the room in which the transmitter is located: *Provided:*

(1) If the transmitter operator is located at a distance from the transmitter pursuant to § 4.634 the station license shall be posted in the above-described manner at the operating position.

(2) If the station is licensed for mobile operation, the station license or a photo copy thereof shall be affixed to the equipment or kept in the possession of the operators on duty at the transmitter. If a photo copy is used the original license shall be available for inspection by an authorized government representative.

(b) The original license of each station operator shall be posted at the place where he is on duty: *Provided, however,* That if the original license of a station operator is posted at another radio transmitting station in accordance with the rules governing that class of station and is there available for inspection by an authorized Commission representative, a duly issued verified statement (Form 759) may be posted at the television auxiliary broadcast station in lieu of such original license: *And provided further,* That if the television auxiliary broadcast station is licensed for mobile operation, a duly issued verification card (Form 758-F) attesting to the existence of such original license may be carried on the person of the operator in lieu of the posting of such license or verified statement.

NOTE: The term mobile as here used is intended to include any type of mobile operation.

§ 4.665 Operator requirements. (a) One or more radio operators holding valid radiotelephone first-class or radiotelephone second-class operator licenses shall be on duty at the place where the transmitting apparatus of any television auxiliary broadcast station is located and in actual charge of its operation: *Provided, however,* That if a station is operated by remote control as provided in § 4.634, such operator or operators must be on duty at the control point in lieu of the transmitting location: *And provided further,* That, in case a station is operated unattended as provided in § 4.635 such an operator shall be on duty at the receiving end of the circuit and shall be responsible for the required observations and the proper operation of the station within the terms of its license.

(b) The licensed operator on duty and in charge of a television auxiliary broadcast station may, at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of operators license which he holds and the regulations governing such stations; however, such duties shall in nowise interfere with the operation of the television auxiliary broadcast station.

§ 4.666 Antenna structure, marking and lighting. Where an antenna structure(s) is required to be painted or lighted see § 17.37, *Inspection of tower lights and associated control equipment;* § 17.39, *Cleaning and repainting;* § 17.40, *Time when lights shall be exhibited;* § 17.41, *Spare lamps;* and § 17.42, *Lighting equipment;* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

§ 4.667 Additional orders. In case the rules contained in this part do not cover all phases of operation or experimentation with respect to external effects, the Commission may make supplemental or additional orders in each case as may be deemed necessary.

§ 4.681 Station logs. (a) The licensee of each television auxiliary broadcast station shall maintain adequate records of the operation including:

(1) Hours of operation.

(2) Call letters of broadcast station to which program transmitted.

(3) Frequency check.

(4) Pertinent remarks concerning transmission.

(b) Where an antenna structure(s) is required to be illuminated see § 17.38, *Recording of tower light inspections in the station record,* of Part 17 of this chapter (Construction, Marking and Lighting of Antenna Structures).

(c) Station records shall be retained for a period of two years.

§ 4.682 Station identification. (a) Each television auxiliary broadcast station shall identify itself by transmitting its call sign at the beginning and end of each

period of operation; and during operation, shall identify itself on the hour by transmitting its own call sign or the call sign of the television broadcast station with which it is associated.

(b) Identification transmissions during operation need not be made when to make such transmission would interrupt a single consecutive speech, play, religious service, symphony concert, or any type of production. In such cases, the identification transmission shall be made at the first interruption of the entertainment continuity and at the conclusion thereof.

(c) Where more than one television auxiliary broadcast station is employed in an integrated relay system, the station at the point of origination may originate the transmission of the call signs of all the stations in the relay system.

(d) The transmission of the call sign shall normally employ the type of emission for which the station is authorized, i.e., a visual transmitter shall employ visual identification and an aural transmitter shall employ aural identification: *Provided, however,* When the transmitter is used for visual transmission only, the identifying call sign may be transmitted in international Morse code by keying the radio frequency carrier or a modulating signal impressed on the carrier. The Commission may, at its discretion, specify other methods of identification.

SUBPART G—TELEVISION BROADCAST TRANSLATOR STATIONS

Definitions and Allocation of Frequencies

§ 4.701 Television broadcast translator station and primary station. (a) A television broadcast translator station is a station in the broadcasting service operated solely for the purpose of retransmitting the signals of a television broadcast station or another television broadcast translator station, by means of direct frequency conversion and amplification of the incoming signals and without significantly altering any characteristic of the incoming signal other than its frequency and amplitude, for the purpose of providing television reception to the general public.

(b) A primary station is the television broadcasting station radiating the signals which are retransmitted by a television broadcast translator station.

§ 4.702 Frequency assignment. (a) An application for a television broadcast translator station shall be specific with regard to the channel requested. One of the following channels may be assigned:

Channel No.	Frequency band	Visual carrier frequency	Aural carrier frequency
	Mc.	*Mc.*	*Mc.*
70	806–812	807.25	811.75
71	812–818	813.25	817.75
72	818–824	819.25	823.75
73	824–830	825.25	829.75
74	830–836	831.25	835.75
75	836–842	837.25	841.75
76	842–848	843.25	847.75
77	848–854	849.25	853.75
78	854–860	855.25	859.75
79	860–866	861.25	865.75
80	866–872	867.25	871.75
81	872–878	873.25	877.75
82	878–884	879.25	883.75
83	884–890	885.25	889.75

(b) An applicant for a television broadcast translator station shall endeavor to select a channel on which its operation will not cause interference to other television broadcast translator stations.

(c) A channel listed in paragraph (a) of this section will not be assigned to a television broadcast translator station located:

(1) Within 20 miles of a television broadcast channel assignment on the second, third, fourth, fifth, or eighth channel below or above the requested channel;

(2) Within 55 miles of a television broadcast channel assignment on an adjacent channel;

(3) Within 60 miles of a television broadcast channel assignment on the seventh channel above or below or the fourteenth channel below the requested assignment;

(4) Within 75 miles of a television broadcast channel assignment on the fifteenth channel below the requested assignment;

(5) Within 155 miles of a television broadcast channel assignment on the same channel as that requested for the television broadcast translator station.

The distances specified above in this paragraph are to be determined with respect to channels having the above relationship, between the proposed site of the television broadcast translator station and the Post Office location in any city listed in § 3.606 of this chapter unless the channel shown therein has been assigned to a television broadcast station, in which case the distance shall be determined between the proposed site of the translator and the transmitter site of the television broadcast station. Changes in the Table of Assignments of § 3.606(b) of this chapter may be made without regard to existing or proposed television broadcast translator stations and where such changes result in minimum separations less than those specified above, the licensee of an affected television broadcast translator station shall file an application for a change in channel assignment to comply with the required separations.

(d) No minimum distance separation is specified between television broadcast translator stations operating on the same channel. However, the separation shall in all cases be adequate to prevent mutual interference. Adjacent channel assignments will not be made to television broadcast translator stations intended to serve all or a part of the same area.

§ 4.703 Interference. (a) An application for a new television broadcast translator station or for changes in the facilities of an existing station will not be granted where it is apparent that mutual interference will result within the area or areas intended to be served by such stations. In general, the licensee of a new television broadcast translator station shall protect existing television broadcast translator stations from interference resulting from its operation.

(b) It shall be the responsibility of the licensee of a television broadcast translator station to correct any condition of interference which results from the radiation of radio frequency energy by its equipment on any frequency outside the assigned channel. Upon notice by the Commission to the station licensee or operator that such interference is being caused, the operation of the television broadcast translator station shall be suspended immediately and shall not be resumed until the interference has been eliminated, or it can be demonstrated that the interference is not due to spurious emissions by the television broadcast translator station: *Provided, however,* That short test transmissions may be made during the period of suspended operation to check the efficacy of remedial measures.

(c) In each instance where suspension of operation is required, the licensee shall submit a full report to the Commission after operation is resumed, containing details of the nature of the interference, the source of the interfering signals, and the remedial steps taken to eliminate the interference.

Administrative Procedure

§ 4.711 Administrative procedure. See §§ 4.11 to 4.16, inclusive.

Licensing Policies

§ 4.731 Purpose and permissible service. (a) Television broadcast translator stations provide a means whereby the signals of television broadcast stations may be retransmitted to areas in which direct reception of such television broadcast stations is unsatisfactory due to distance or intervening terrain barriers.

(b) A television broadcast translator station may be used only for the purpose of retransmitting to the general public, on one of the channels provided herein, the sig-

nals of a television broadcast station, or of another television broadcast translator station operating on a channel other than the one on which the retransmission is made. The retransmitted signals shall not be significantly altered as to content or technical characteristics other than in frequency and amplitude.

(c) A television broadcast translator station may retransmit the signals of different television broadcast stations or different television broadcast translator stations during different periods of its operation in order to provide programs best suited to the needs of a particular community.

(d) Retransmission of the signals of any station shall be made only in accordance with the provisions of § 4.784.

§ 4.732 Eligibility and licensing requirements. (a) A license for a television broadcast translator station may be issued to any qualified individual, organized group of individuals, broadcast station licensee, or local civil governmental body upon an appropriate showing that plans for financing the installation and operation of the station are sufficiently sound to insure continuation of the operation for the period of the license.

(b) More than one television broadcast translator station may be licensed to the same applicant whether or not such stations serve substantially the same area, upon an appropriate showing of need for such additional stations.

(c) Only one channel will be assigned to each television broadcast translator station. Additional television broadcast translator stations may be authorized to provide additional reception. A separate application is required for each television broadcast translator station and each application shall be complete in all respects.

§ 4.733 [Reserved]

§ 4.734 Remote control operation. (a) A television broadcast translator station may be operated by remote control, provided that such operation is conducted in accordance with conditions set forth in subparagraphs (1) through (5) of this paragraph.

(1) The control point shall be located on premises under the control and supervision of the licensee or its agent. Facilities shall be provided at the control point to enable the operator to observe the transmissions of the television broadcast translator station at any time, and which will permit the operator to turn the transmitter on and off at will.

(2) An operator holding a commercial radio operator's license of any class issued by the Commission except a Temporary Limited Radiotelegraph Second-Class License or an Aircraft Radiotelephone Operator Authorization, shall be in charge of this control point and shall observe the transmissions of the television broadcast translator station at the control point within one hour after the start of any period of operation and during operation at intervals of no more than six hours. The operator in charge shall promptly correct any condition of improper operation observed and if unable or not qualified to do so under the provisions of § 4.750(d), shall immediately suspend operation until suitable repairs can be made.

(3) A carrier operated device shall be installed at the control point which shall give a continuous visual indication whenever the transmitter is radiating; or, in lieu thereof, a device shall be provided which will give a continuous visual indication when any transmitter control circuits have been placed in a condition to produce radiation.

(4) The control circuits shall be so designed and installed that failure of any part of the circuit which results in loss of control from the remote control point will place the transmitter in an inoperative condition.

(5) The transmitter and its associated controls shall be so installed and protected that they are not accessible to other than duly authorized persons.

(b) In the event that the control point is not continuously manned by a qualified operator, the transmitter shall be equipped with suitable automatic devices which will place it in an inoperative condition when no signal is available for retransmission. In addition to the automatic and manual controls, a television broadcast translator station may be turned on and off by a time switch.

(c) If remote control is proposed at a new television broadcast translator station, the application for construction permit shall be accompanied by a showing as to the

manner of compliance with the above conditions. Any proposal to change a television broadcast translator station from direct control to remote control shall be submitted in the form of an application for modification of existing authorization accompanied by the above showing of compliance.

§ 4.735 Power limitations. (a) A television broadcast translator station will not be authorized to operate with transmitter power output in excess of the rated power output of the transmitter and in no event shall the rated peak visual power output of the transmitter be in excess of 100 watts. No minimum power is specified for television broadcast translator stations.

(b) No limit is placed upon the effective radiated power which may be obtained by the use of horizontally or vertically directive transmitting antennas.

§ 4.736 Emissions and bandwidth. (a) The license of a television broadcast translator station authorizes the transmission of the visual signal by amplitude modulation (A5) and the accompanying aural signal by frequency modulation (F3).

(b) Standard width television channels will be assigned and the emissions of a television broadcast translator station shall be confined to the authorized channel in accordance with the Television Technical Standards contained in Part 3, Subpart E of this chapter.

(c) Spurious emissions, including radio frequency harmonics, more than 3 Mc above or below the upper and lower edges, respectively, of the assigned channel shall be attenuated no less than 60 decibels below the visual transmitter power. These requirements shall not be applicable to transmitters installed prior to January 1, 1960: *Provided, however,* That in the event that interference is caused to other radio stations, the licensee shall take such steps as may be necessary to eliminate the interference. Greater attenuation will be required if such spurious emissions cause interference to any radio service.

§ 4.737 Antenna location. (a) An applicant for a new television broadcast translator station or for a change in the facilities of an existing station shall endeavor to select a site which will provide a line-of-sight transmission path to the entire area intended to be served and at which there is available a suitable signal from the primary station or stations. The transmitting antenna should be placed above growing vegetation and trees lying in the direction of the area intended to be served to minimize the possibility of signal absorption by foliage.

(b) A site within 5 miles of the area intended to be served is to be preferred if the conditions in paragraph (a) of this section can be met.

(c) Consideration should be given to accessibility of the site at all seasons of the year and to the availability of facilities for the maintenance and operation of the television broadcast translator station.

(d) The transmitting antenna should be located as near as is practical to the transmitter to avoid the use of long transmission lines and the associated power losses.

(e) Consideration should be given to the existence of strong radio frequency fields from other transmitters at the translator site and the possibility that such fields may result in the retransmission of signals originating on frequencies other than that of the primary station.

Equipment

§ 4.750 Equipment and installation. (a) An application for construction permit for a new television broadcast translator station or for changes in the facilities of an existing station shall specify equipment which has been type approved by the Commission.

(b) Type approval will be granted only after tests have been made at the Commission's Laboratory, Laurel, Maryland. Manufacturers may submit a production model for type approval and such approval, if granted, will be considered to apply to all identical models manufactured under that type number. No change, either mechanical or electrical, may be made in any type approved apparatus without prior approval of the Commission upon appropriate application therefor. Type approval may be withdrawn at any time if the apparatus fails to meet the requirements under which type approval was granted.

(c) Type approval will be granted only if the apparatus meets the following requirements:

(1) The frequency converter and associated amplifiers shall be so designed that the electrical characteristics of the incoming signal will not be altered significantly upon retransmission except as to frequency and amplitude.

(2) The overall characteristics of the apparatus shall be such that emissions on any discrete frequency more than 3 Mc above or below the upper and lower limits respectively, of the assigned channel shall be attenuated no less than 60 decibels below the visual transmitted power, regardless of whether such emissions are generated within the translator or are produced as the result of an external signal introduced into the input circuits of the translator apparatus.

NOTE: These requirements shall not be applicable to transmitters installed prior to January 1, 1960: *Provided, however,* That in the event that interference is caused to other radio stations, the licensee shall take such steps as may be necessary to eliminate the interference. Type approvals granted prior to September 1, 1959, will be designated as Limited Type Approval. Such approval will be granted only if it is found that reasonable precautions have been taken in the design of equipment, to minimize interference resulting from spurious emissions.

(3) The local oscillator employed in the frequency converter shall be sufficiently stable that, subject to variations in ambient temperature between −15° and +55° Centigrade and power main voltage variations of 15 percent, its frequency will not vary more than 0.01 percent.

(4) The translator shall be so designed and adjusted that its overall characteristics will remain essentially linear under all conditions of operation. It shall be equipped with suitable automatic circuits to maintain a constant output under conditions where the intensity of the received signal varies 20 decibels. If a manual adjustment is provided to compensate for differing average signal intensities which may be encountered in various locations and installations, provision shall be made for determining the proper setting of the manual adjustment by means of a meter or meter jack to measure direct current or voltage of appropriate circuits in the translator. If improper adjustment of the manual control could result in improper operation of the translator, a label shall be affixed at the adjustment control bearing a suitable warning.

NOTE: These requirements shall not be applicable to transmitters installed prior to January 1, 1960: *Provided, however,* That in the event that interference is caused to other radio stations, the licensee shall take such steps as may be necessary to eliminate the interference. Type approvals granted prior to September 1, 1959, will be designated as Limited Type Approval. Such approval will be granted only if it is found that reasonable precautions have been taken in the design of equipment, to minimize interference resulting from spurious emissions.

(5) The tube or tubes employed in the final radio frequency amplifier shall be of the proper rating to supply the rated power output. The rated maximum peak visual power output of the translator shall not be greater than 100 watts. The translator shall be capable of delivering the rated power in continuous service when driven with an input signal modulated by a video wave form corresponding to a black picture and a sound signal power equal to 50% of the peak visual power. Translators rated at more than 10 watts maximum peak visual power output shall be equipped with a suitable device for indicating the peak visual power output. Where the composite aural and visual signal powers are measured together the output indicating device shall be calibrated in terms of the peak visual power component of the combined visual and aural signals when the input television signal is modulated by a wave form corresponding to a black picture and when the sound signal power is equal to 50% of the peak visual power.

(6) The apparatus shall be equipped with suitable automatic devices which will place it in an inoperative condition in the absence of a visual and aural signal from the primary station. Such automatic devices may be provided with reasonable time constants to prevent momentary failures of the incoming signal from interrupting the operation.

(7) In general, the transmitter shall be mounted on racks and panels or in totally enclosed frames protected as required by Article 810 of the National Electrical Code.

(8) (i) Any manufacturer desiring to submit a translator for type approval shall supply the Commission with full specification details (two sworn copies) as well as the test data specified in this section. If this information appears to meet the requirements of the rules, shipping instructions will be issued to the manufacturer. The shipping charges to and from the Laboratory at Laurel, Maryland, shall be paid for by the manufacturer. Approval of a translator will only be given on the basis of the data obtained from a sample translator submitted to the Commission for test.

(ii) In approving a translator upon the basis of the tests conducted by the Laboratory, the Commission merely recognizes that the type of translator has the inherent capability of functioning in compliance with the Rules, if properly constructed, maintained, and operated.

(iii) Additional rules with respect to withdrawal of type approval, modification of type approval equipment, and limitations on the findings upon which type approval is based are set forth in Part 2, Subpart F, of this chapter.

(d) The installation of a television broadcast translator station shall be made only by, or under the direct supervision of, a qualified electronics engineer, and any repairs or adjustments made during or subsequent to the installation, which could result in improper operation, shall be made by or under the direct supervision of an operator holding a valid first or second class radiotelephone operator's license issued by the Commission.

(e) The choice of transmitting and receiving antennas is left to the discretion of the applicant. In general, the transmitting antenna should be designed to provide maximum signal over the area intended to be served and to minimize radiation over other areas, particularly those in which interference could be caused to the reception of other stations. The Commission reserves the right to require the use of suitable directive transmitting antennas in order to permit the assignment of the same channel to two or more television broadcast translator stations located in the same general area. An application for construction permit for a new television broadcast translator station or for changes in the facilities of an existing station, shall supply complete details of the proposed receiving and retransmitting antenna systems, including an accurate plot of the field pattern of the transmitting antenna, if directive.

§ 4.751 Equipment changes. (a) No change, either mechanical or electrical, may be made in type approved apparatus except upon instructions of the manufacturer of the equipment, based upon Commission approval for the change granted to the manufacturer in accordance with § 4.750(b).

(b) Formal application (FCC Form 346) is required for any of the following changes:

(1) Replacement of the transmitter as a whole, except by one of an identical type.

(2) A change in the transmitting antenna system, including the direction of radiation, directive antenna pattern, or transmission line.

(3) An increase in the overall height of the antenna above ground of more than 20 feet or which will result in an overall height above ground of more than 170 feet.

(4) A change of the control point of a remotely controlled television broadcast translator station or any change in the control circuits.

(5) Any change in the location of the transmitter except a move within the same building or upon the same tower or pole, and any horizontal change in the location of the transmitting antenna in excess of 500 feet.

(6) A change of frequency assignment.

(7) A change of authorized operating power.

(8) A change of the primary TV station or stations being retransmitted.

(c) Other equipment changes not specifically referred to above may be made at the discretion of the licensee, provided that the Engineer in Charge of the radio district in which the television broadcast translator station is located and the Commission's Washington, D.C., office, are notified in writing upon completion of such changes, and provided, further, that the changes are appropriately reflected in the next application for renewal of license of the television broadcast translator station.

Technical Operation

§ 4.761 **Frequency tolerance.** The licensee of a television broadcast translator station shall maintain the visual carrier frequency and the aural center frequency at the outpnt of the translator within 0.01 percent of its assigned frequencies when the primary station is operating exactly on its assigned frequencies. This tolerance shall not be exceeded at times when the primary station is not on its assigned frequencies, by more than the amount of the departure by the primary station.

§ 4.762 **Frequency monitors and measurements.** (a) The licensee of a television broadcast translator station is not required to provide means for measuring the operating frequencies of the transmitter. However, only equipment having the required stability will be approved for use at a television broadcast translator station.

(b) In the event that a television broadcast translator station is found to be operating beyond the frequency tolerance prescribed in § 4.761, the licensee shall promptly suspend operation of the translator and shall not resume operation until the translator has been restored to its assigned frequencies. Adjustment of the frequency determining circuits of a television broadcast translator station shall be made only by a qualified person in accordance with § 4.750(d).

(c) The licensee of a television broadcast translator station may, at its discretion, provide means for comparing the frequency of the translator with an external frequency source of known accuracy as a preventive measure to avoid unnecessary interruptions to service.

§ 4.763 **Time of operation.** (a) A television broadcast translator station is not required to adhere to any regular schedule of operation. However, the licensee of a television translator station is expected to provide a dependable service to the extent that such is within its control and to avoid unwarranted interruptions to the service provided.

(b) If causes beyond the control of the licensee require that a television broadcast translator station remain inoperative for a period in excess of 10 days, the Engineer in Charge of the radio district in which the station is located shall be notified promptly in writing, describing the cause of failure and the steps taken to place the station in operation again, and shall be notified promptly when the operation is resumed.

(c) Failure of a television broadcast translator station to operate for a period of 30 days or more, except for causes beyond the control of the licensee, shall be deemed evidence of discontinuance of operation and the license of the station will be cancelled.

(d) A television broadcast translator station shall not be permitted to radiate during extended periods when signals of the primary station are not being retransmitted.

§ 4.764 **Station inspection.** The licensee of a television broadcast translator station shall make the station and the records required to be kept by the rules in this subpart, available for inspection by representatives of the Commission.

§ 4.765 **Posting of station and operators licenses.** (a) The station license and any other instrument of authorization or individual order concerning the construction of the equipment or manner of operation shall be posted in a conspicuous place in the room in which the transmitter is located so that all terms thereof are visible; *Provided:*

(1) If the transmitter is operated by remote control pursuant to § 4.734, the station license shall be posted in the above described manner at the control point.

(2) If the transmitter is installed so as to be exposed to the elements and posting of the license would result in its being so exposed, the license or a photo copy thereof may be kept in the possession of the operator in charge of the transmitter. If a photo copy is used, the original license shall be conveniently available for inspection by a representative of the Commission.

(b) The original of each station operator license shall be posted at the place where he is on duty: *Provided, however,* That if the original license of a station operator is posted at another radio transmitting station in accordance with the Rules governing that class of station and is there available for inspection by a representative of the Commission, a verification card (Form 758-F) is acceptable in lieu of the posting of

such license: *Provided, further, however,* That if the operator in charge holds a restricted radiotelephone operator permit of the card form (as distinguished from the diploma form), he shall not post that permit but shall keep it in his personal possession.

§ 4.766 Operator requirements. (a) The actual operation of the transmitting apparatus at a television broadcast translator station shall be carried on only by a person holding a valid commercial radio operator's license or permit of any class issued by the Commission except a Temporary Limited Radiotelegraph Second-Class License or an Aircraft Radiotelephone Operator Authorization who shall provide supervision to no less extent than that required by § 4.734 and who shall be responsible for the proper operation of the apparatus with respect to those functions under his control. This responsibility, however, shall in no way relieve the licensee of its responsibility for the proper operation of the station.

(b) Any repairs or adjustments to a television broadcast translator station which might result in improper operation of the equipment shall be made only by or under the direct supervision of a person holding a valid first or second class radiotelephone operator's license issued by the Commission.

(c) The licensed operator on duty and in charge of a television broadcast translator station may, at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of license which he holds and the rules and regulations governing such stations. However, such duties shall in nowise interfere with the operation of the television broadcast translator station.

§ 4.767 Marking and lighting of antenna structures. The marking and lighting of antenna structures employed at a television broadcast translator station, where required, will be specified in the authorization issued by the Commission. Part 17 of this chapter sets forth the conditions under which such marking and lighting will be required and the responsibility of the licensee with regard thereto.

§ 4.768 Additional orders. In case the rules contained in this part do not cover all phases of operation or experimentation with respect to external effects, the Commission may make supplemental or additional orders, in each case as may be deemed necessary.

§ 4.769 Copies of rules. The licensee of a television broadcast translator station shall have current copies of Part 3, Part 4, and Part 17 of this chapter available for use by the operator in charge, and is expected to be familiar with those rules relating to the operation of a television broadcast translator station. Copies of the Commission's rules may be obtained from the Superintendent of Documents, Government Printing Office, Washington 25, D.C., at nominal cost.

Operation

§ 4.781 Station records. (a) The licensee of a television broadcast translator station shall maintain an operating log showing the following:

(1) Hours of operation.

(2) Call letters, channel, and location of primary station or stations.

(3) Time of periodic observation required by § 4.734(a)(2), and operating conditions signed by the operator making the observation.

(4) A record of all repairs, adjustments, maintenance, tests, and equipment changes, showing the date of such events, the name and qualifications of the person performing the operation, and a brief description of the matter logged.

(b) Where an antenna structure is required to be illuminated, see § 17.38 of this chapter.

(c) The operating log shall be made available upon request to any authorized representative of the Commission.

(d) Station records shall be retained for a period of two years.

§ 4.782 [Reserved]

§ 4.783 Station identification. (a) The call sign of a television broadcast translator station shall be transmitted in international Morse Code by means of an automatic keying device, at the beginning and end of each period of operation and during

operation, within 5 minutes of the hour and half hour. This transmission may be accomplished either by turning the visual and aural carriers of the translator on and off in the proper sequence or by superimposing an audio frequency tone containing the telegraphic identification, on the visual and aural carriers radiated by the translator. The modulation level of the identifying signal shall not be less than 30 percent of the aural signal.

(b) The Commission may, in its discretion, specify other methods of identification.

(c) Call signs for television broadcast translator stations will be made up of the initial letter K or W followed by the channel number assigned to the translator and two letters. The use of the initial letter will generally follow the pattern used in the broadcast service, i.e., stations west of the Mississippi River will be assigned an initial letter K and those east of the mississippi River the letter W. The two letter combinations following the channel number will be assigned in order and requests for the assignment of particular combinations of letters will not be considered.

§ 4.784 **Rebroadcasts.** (a) The term "rebroadcast" means the reception by radio of the programs or other signals of a radio or television station and the simultaneous or subsequent retransmission of such programs or signals for direct reception by the general public.

(b) The licensee of a television broadcast translator station shall not rebroadcast the programs of any television broadcast station or other television broadcast translator station without obtaining prior consent of the station whose signals or programs are proposed to be retransmitted. The Commission shall be notified of the call letters of each station rebroadcast and the licensee of the television broadcast translator station shall certify that express authority has been received from the licensee of the station whose programs are retransmitted.

(c) A television broadcast translator station is not authorized to rebroadcast the transmissions of any class of station other than a television broadcast station or another television broadcast translator station.

Part 5

FEDERAL COMMUNICATIONS COMMISSION
PART 13 — COMMERCIAL RADIO OPERATORS

TITLE 47—TELECOMMUNICATION

Chapter I—Federal Communications Commission

Part 13—Commercial Radio Operators

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MISCELLANEOUS

13.71 Issue of duplicate or replacement licenses.
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SERVICE

13.91 Endorsement of service record.
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General

§ 13.1 **Licensed operators required.** Unless otherwise specified by the Commission, the actual operation of any radio station for which a station license is required shall be carried on only by a licensed radio operator of the required class (see § 13.61).

NOTE A: Whenever the term "license" is used generally to denote an authorization from the Commission, it includes "license," "permit," and "authorization."

NOTE B: Provision is made in Parts 5, 6, 7, 8, 9, 10, 11, 16, and 19 of the Commission's rules for operation of certain radio stations without licensed operators subject to limitations and conditions specified therein.

§ 13.2 Classes of operator licenses. The classes of commercial radio operator licenses issued by the Commission are classified basically as radiotelegraph and radiotelephone licenses, and are further classified in accordance with international usage as follows:

(a) General radio operator group:
(1) General radiotelegraph certificates:
(i) Radiotelegraph first-class operator license.
(ii) Radiotelegraph second-class operator license.
(2) General radiotelephone certificates (classification by international usage):
(i) Radiotelephone first-class operator license.
(ii) Radiotelephone second-class operator license.
(b) Restricted radio operator group:
(1) Special radiotelegraph certificate (classification by international usage):
(i) Radiotelegraph third-class operator permit.
(2) Restricted radiotelephone certificate (classification by international usage):
(i) Radiotelephone third-class operator permit.
(c) Limited radio operator group:
(1) Limited radiotelephone operator certificate:
(i) Restricted radiotelephone operator permit.

§ 13.3 Dual holding of licenses. A person may not hold more than one radiotelegraph operator license or permit at the same time.

§ 13.4 Term of licenses. Commercial operator licenses (except restricted radiotelephone operator permits) will normally be issued for a term of five years from date of issuance. Restricted radiotelephone operator permits will normally be issued for the lifetime of the operator. The term of all restricted radiotelephone operator permits issued prior to November 15, 1953, which are outstanding on that date is extended to encompass the lifetime of such operators.

§ 13.5 Eligibility for new license. (a) Under the provisions of section 303(1) of the Communications Act of 1934, as amended, United States citizens who are found qualified by the Commission are the only persons to whom radio operator licenses may be issued.

(b) Notwithstanding any other provisions of the Commission's rules, no person otherwise eligible shall be deemed to be eligible to be examined for or to receive a commercial radio operator license of any class, (1) whose commercial radio operator license is under suspension or is involved in a suspension proceeding, (2) who is involved in any pending litigation based on an alleged violation of the Communications Act of 1934, as amended, or (3) who is afflicted with complete deafness or complete muteness or complete inability for any other reason to transmit correctly and to receive correctly by telephone spoken messages in English.

(c) No applicant who is eligible to apply for any commercial radio operator license shall, by reason of any physical handicap, other than as set forth in paragraph (b) of this section, be denied the privilege of applying and being permitted to attempt to prove his qualifications (by examination if examination is required) for such commercial radio operator license in accordance with established procedure; nor, subject to the following conditions, shall such applicant be denied the issuance of any commercial radio operator license for which he is found qualified:

(1) If the applicant is afflicted with an uncorrected physical handicap which would clearly prevent the performance of all or any part of the duties of a radio operator, under the license for which application is made, at a station under emergency conditions involving the safety of life or property, he may be issued the license for which he is found qualified: *Provided,* that any license so received, if of the diploma form (as distinguished from such document of the card form), shall bear the following restrictive endorsement as follows:

This license is not valid for the performance of any operating duties, other than installation, service and maintenance duties, at any station licensed by the Federal Communications Commission which is required, directly or indirectly, by any treaty, statute or rule or regulation pursuant to statute to be provided for safety purposes.

Provided further, that in the case of a diploma-form license for which no examination in technical matters is required, the endorsement will be modified by deleting the reference therein to installation, service, and maintenance duties.

(2) In any case where an applicant, who normally would receive or has received a commercial radio operator license bearing the endorsement prescribed by subparagraph (1) of this paragraph, indicates his desire to operate a station falling within the prohibitive terms of the endorsement, he may request in writing that such endorsement not be placed upon, or be removed from, his license, and may submit in support of his request any written comment or statement of himself or any interested party.

(3) An applicant who shows that he has theretofore performed satisfactorily (by means of the service record appearing on the appropriate license document of the applicant or such other proof as may be appropriate under the circumstances of the particular case) the duties of a radio operator at a station required, directly or indirectly, by any treaty, statute, or rule or regulation pursuant to statute to be provided for safety purposes, during a period when he was afflicted by uncorrected physical handicaps of the same kind and to the same degree as the physical handicaps shown by his current application (this showing may be made by means of the applicant's written, sworn statement or such other documentary proof as may be appropriate under the circumstances of the particular case), shall not be deemed to be within the provisions of subparagraph (1) of this paragraph.

§ 13.6 **Operator license, posting of.** The original license of each station operator shall be posted at the place where he is on duty, except as otherwise provided in this part or in the rules governing the class of station concerned.

§ 13.7 **Operators, place of duty.** (a) Except as may be provided in the rules governing a particular class of station, one or more licensed radio operators of the grade specified by this part shall be on duty at the place where the transmitting apparatus of each licensed radio station is located and in actual charge thereof whenever it is being operated: *Provided, however,* That, (1) subject to the provisions of paragraph (b) of this section, where remote control of the transmitting apparatus has been authorized to be used, the Commission may modify the foregoing requirements upon proper application and showing being made so that such operator or operators may be on duty at the control point in lieu of the place where the transmitting apparatus is located; (2) in the case of two or more stations, except amateur and broadcast, licensed in the name of the same person to use frequencies above 30 megacycles only, a licensed radio operator holding a valid radiotelegraph or radiotelephone first- or second-class license who has the station within his effective control may be on duty at any point within the communication range of such stations in lieu of the transmitter location or control point during the actual operation of the transmitting apparatus and shall supervise the emissions of all such stations so as to insure the proper operation in accordance with the station license.

(b) An operator may be on duty at a remote control point in lieu of the location of the transmitting apparatus in accordance with the provisions of paragraph (a)(1) of this section: *Provided,* That all of the following conditions are met: (1) The transmitter shall be so installed and protected that it is not accessible to other than duly authorized persons; (2) the emissions of the transmitter shall be continuously monitored at the control point by a licensed operator of the grade specified for the class of station involved; (3) provision shall be made so that the transmitter can quickly and without delay be placed in an inoperative condition by the operator at the control point in the event there is a deviation from the terms of the station license; (4) the radiation of the transmitter shall be suspended immediately when there is a deviation from the terms of the station license.

§ 13.8 **Provisional radio operator certificate.** In circumstances requiring immediate authority to operate a radio station pending submission of proof of eligibility or of qualifications or pending a determination by the Commission as to these matters,

an applicant for a radio operator license may request a provisional radio operator certificate. Any such request may be in letter form and shall be in addition to the formal application. If the Commission finds that the public interest will be served it may issue such certificate for a period not to exceed six months with such additional limitation as may be indicated. In no case will the Commission issue a provisional radio operator certificate if the applicant has not fulfilled examination or service requirements, if any, for the license applied for.

Applications

§ 13.11 Procedure. (a) *General.* Applications shall be governed by applicable rules in force on the date when application is filed (see § 13.28). The application in the prescribed form and including all required subsidiary forms and documents, properly completed and signed, shall be submitted in person or by mail to the office at which the applicant desires his application to be considered and acted upon, which office will make the final arrangements for conducting any required examination. If the application is for renewal of license, it may be filed at any time during the final year of the license term or during a one-year period of grace after the date of expiration of the license sought to be renewed. During this one-year period of grace an expired license is not valid. A renewed license issued upon the basis of an application filed during the grace period will be dated currently and will not be back-dated to the date of expiration of the license being renewed. A renewal application shall be accompanied by the license sought to be renewed. If the prescribed service requirements for renewal without examination (see § 13.28) are fulfilled, the renewed license may be issued by mail. If the service record on the reverse side of the license does not fully describe or cover the service desired by the applicant to be considered in connection with license renewal (as might occur in the case of service rendered at U.S. government stations), the renewal application shall be supported by documentary evidence describing in detail the service performed and showing that the applicant actually performed such service in a satisfactory manner.

(b) *Restricted radiotelephone operator permit.* No oral or written examination is required for this permit. If the application is properly completed and signed, and if the applicant is found to be qualified, the permit may be issued forthwith by personal delivery to the applicant or by mail.

§ 13.12 Special provisions, radiotelegraph first class. An applicant for the radiotelegraph first-class operator license must be at least 21 years of age at the time the license is issued and shall have had an aggregate of 1 year of satisfactory service as a radiotelegraph operator manipulating the key of a manually operated radiotelegraph station on board a ship or in a manually operated coastal telegraph station.

§ 13.13 Age limit, restricted radiotelephone operator permit. An applicant for a restricted radiotelephone operator permit must be at least 14 years of age at the time the permit is issued.

Examinations

§ 13.21 Examination elements. Written examinations will comprise questions from one or more of the following examination elements:

1. *Basic law.* Provisions of laws, treaties and regulations with which every operator should be familiar.
2. *Basic operating practice.* Radio operating procedures and practices generally followed or required in communicating by means of radiotelephone stations.
3. *Basic radiotelephone.* Technical, legal and other matters applicable to the operation of radiotelephone stations other than broadcast.
4. *Advanced radiotelephone.* Advanced technical, legal and other matters particularly applicable to the operation of the various classes of broadcast stations.
5. *Radiotelegraph operating practice.* Radio operating procedures and practices generally followed or required in communicating by means of radiotelegraph stations primarily other than in the maritime mobile services of public correspondence.
6. *Advanced radiotelegraph.* Technical, legal and other matters applicable to the oper-

ation of all classes of radiotelegraph stations, including operating procedures and practices in the maritime mobile services of public correspondence, and associated matters such as radio navigational aids, message traffic routing and accounting, etc.

7. *Aircraft radiotelegraph.* Basic theory and practice in the operation of radio communication and radio navigational systems in general use on aircraft.

8. *Ship radar techniques.* Specialized theory and practice applicable to the proper installation, servicing and maintenance of ship radar equipment in general use for marine navigational purposes.

§ 13.22 **Examination requirements.** Applicants for original licenses will be required to pass examinations as follows:

(a) *Radiotelephone second-class operator license:*

(1) Ability to transmit and receive spoken messages in English.

(2) Written examination elements: 1, 2, and 3.

(b) *Radiotelephone first-class operator license:*

(1) Ability to transmit and receive spoken messages in English.

(2) Written examination elements: 1, 2, 3, and 4.

(c) *Radiotelegraph second-class operator license:*

(1) Ability to transmit and receive spoken messages in English.

(2) Transmitting and receiving code test of sixteen (16) code groups per minute.

(3) Written examination elements: 1, 2, 5, and 6.

(d) *Radiotelegraph first-class operator license:*

(1) Ability to transmit and receive spoken messages in English.

(2) Transmitting and receiving code test of twenty-five (25) words per minute plain language and twenty (20) code groups per minute.

(3) Written examination elements: 1, 2, 5, and 6.

(e) *Radiotelephone third-class operator permit:*

(1) Ability to transmit and receive spoken messages in English.

(2) Written examination elements: 1 and 2.

(f) *Radiotelegraph third-class operator permit:*

(1) Ability to transmit and receive spoken messages in English.

(2) Transmitting and receiving code test of sixteen (16) code groups per minute.

(3) Written examination elements: 1, 2, and 5.

(g) *Restricted radiotelephone operator permit:* No oral or written examination is required for this permit. In lieu thereof, applicants will be required to certify in writing to a declaration which states that the applicant has need for the requested permit; can receive and transmit spoken messages in English; can keep at least a rough written log in English or in some other language in general use that can be readily translated into English; is familiar with the provisions of treaties, laws and rules and regulations governing the authority granted under the requested permit; and understands that it is his responsibility to keep currently familiar with all such provisions.

§ 13.23 **Form of writing.** Written examination shall be in English and shall be written by the applicant in longhand in ink, except that diagrams may be in pencil.

§ 13.24 **Passing mark.** A passing mark of 75 percent of a possible 100 percent will be required on each element of a written examination.

§ 13.25 **New class, additional requirements.** The holder of a license who applies for another class of license will be required to pass only the added examination requirements for the new class of license: *Provided,* That the holder of a radiotelegraph third-class operator permit who takes an examination for a radiotelegraph second-class operator license more than one year after the issuance date of the third-class permit will also be required to pass the code test prescribed therefor: *Provided further,* That no person holding a new, duplicate, or replacement Restricted Radiotelephone Operator Permit issued upon the basis of a declaration, or a renewed restricted radiotelephone operator permit which renews a permit issued upon the basis of a declaration, shall, by reason of the declaration or the holding of such permit, be relieved in any respect of qualifying by examination when applying for any other class of license.

§ 13.26 **Canceling and issuing new licenses.** If the holder of a license qualifies

for a higher class in the same group, the license held will be canceled upon the issuance of the new license. Similarly, if the holder of a restricted operator permit qualifies for a first- or second-class operator license of the corresponding type, the permit held will be canceled upon issuance of the new license.

§ 13.27 Eligibility for reexamination. An applicant who fails an examination element will be ineligible for 2 months to take an examination for any class of license requiring that element. Examination elements will be graded in the order listed (see § 13.21), and an applicant may, without further application, be issued the class of license for which he qualifies.

NOTE: A month after date is the same day of the following month, or if there is no such day, the last day of such month. This principle applies for other periods. For example, in the case of the 2-month period to which this note refers, an applicant examined December 1 may be reexamined February 1, and an applicant examined December 29, 30, or 31 may be reexamined the last day of February while one examined February 28 may be reexamined April 28.

§ 13.28 Renewal service requirements, renewal examinations, and exceptions. A restricted radiotelephone operator permit normally is issued for the lifetime of the holder and need not be renewed. An aircraft radiotelephone operator authorization or a temporary limited radiotelegraph second-class operator license is not renewable. A license of any other class may be renewed without examination provided that the service record on the reverse side of the license (see §§ 13.91 to 13.94) shows at least two years of satisfactory service in the aggregate during the license term and while actually employed as a radio operator under that license. If this two-year renewal service requirement is not fulfilled, but the service record shows at least one year of satisfactory service in the aggregate during the last three years of the license term and while actually employed as a radio operator under that license, the license may be renewed upon the successful completion of a renewal examination, which may be taken at any time during the final year of the license term or during a one-year period of grace after the date of expiration of the license sought to be renewed. The renewal examination will consist of the highest numbered examination element normally required for a new license of the class sought to be renewed, plus the code test (if any) required for such a new license. If the renewal examination is not successfully completed before expiration of the aforementioned one-year period of grace, the license will not be renewed on any basis.

NOTE: By order dated and effective April 4, 1951, the Commission temporarily waved the requirement of prior service as a radio operator or examination for renewal in the case of any applicant for renewal of his commercial radio operator license. This order is applicable to commercial radio operator licenses which expired after June 30, 1950 until further order of the Commission.

Code Tests

§ 13.41 Transmitting speed requirements. An applicant is required to transmit correctly in the International Morse code for 1 minute at the rate of speed prescribed in this part for the class of license desired.

§ 13.42 Transmitting test procedure. Transmitting tests shall be performed by the use of the conventional Morse key except that a semi-automatic key, if furnished by the applicant, may be used in transmitting code tests of 25 words per minute.

§ 13.43 Receiving speed requirements. An applicant is required to receive the International Morse code by ear, and legibly transcribe, consecutive words or code groups for a period of 1 minute without error at the rate of speed specified in the rules for the class of license for which the application is made.

§ 13.44 Receiving test procedure. Receiving code tests shall be written in longhand either in ink or pencil except that in the case of the 25 words per minute code test a typewriter may be used when furnished by the applicant.

§ 13.45 Computing words or code groups. Each five characters shall be counted as one word or code group. Punctuation marks or figures count as two characters.

Scope of Authority

§ 13.61 Operating authority. The various classes of commercial radio operator licenses issued by the Commission authorize the holders thereof to operate radio stations, except amateur, as follows (see also § 13.62(c) for additional operating authority with respect to standard and FM broadcast stations):

(a) *Radiotelegraph first-class operator license.* Any station except:

(1) Stations transmitting television, or

(2) Any of the various classes of broadcast stations other than remote pickup and ST broadcast stations, or

(3) On a cargo vessel (other than a vessel operated exclusively on the Great Lakes) required by treaty or statute to be equipped with a radiotelegraph installation, the holder of this class of license may not act as chief or sole operator until he has had at least 6 months' satisfactory service in the aggregate as a qualified radiotelegraph operator in a station on board a ship or ships of the United States.

(4) On an aircraft employing radiotelegraphy, the holder of this class of license may not operate the radiotelegraph station during the course of normal rendition of service unless he has satisfactorily completed a supplementary examination qualifying him for that duty, or unless he has served satisfactorily as chief or sole radio operator on an aircraft employing radiotelegraphy prior to February 15, 1950. The supplementary examination shall consist of:

(i) Written examination element: 7.

(5) At a ship radar station licensed in the Ship Service, the holder of this class of license may not supervise or be responsible for the performance of any adjustments or tests during or coincident with the installation, servicing or maintenance of the radar equipment while it is radiating energy unless he has satisfactorily completed a supplementary examination qualifying him for that duty and received a ship radar endorsement on his license certifying to that fact: *Provided,* That nothing in this subparagraph shall be construed to prevent persons holding licenses not so endorsed from making replacements of fuses or of receiving-type tubes. The supplementary examination shall consist of:

(i) Written examination element: 8.

(b) *Radiotelegraph second-class operator license.* Any station except:

(1) Stations transmitting television, or

(2) Any of the various classes of broadcast stations other than remote pickup and ST broadcast stations, or

(3) On a passenger vessel (a ship shall be considered a passenger ship if it carries or is licensed or certificated to carry more than 12 passengers; a cargo ship means any ship not a passenger ship) required by treaty or statute to maintain a continuous radio watch by operators or on a vessel having continuous hours of service for public correspondence, the holder of this class of license may not act as chief operator, or

(4) On a vessel (other than a vessel operated exclusively on the Great Lakes) required by treaty or statute to be equipped with a radiotelegraph installation, the holder of this class of license may not act as chief or sole operator until he has had at least 6 months' satisfactory service in the aggregate as a qualified radiotelegraph operator in a station on board a ship or ships of the United States.

(5) On an aircraft employing radiotelegraphy, the holder of this class of license may not operate the radiotelegraph station during the course of normal rendition of service unless he is at least eighteen (18) years of age and has satisfactorily completed a supplementary examination qualifying him for that duty, or unless he has served satisfactorily as chief or sole radio operator on an aircraft employing radiotelegraphy prior to February 15, 1950. The supplementary examination shall consist of:

(i) Transmitting and receiving code test at twenty-five (25) words per minute plain language and twenty (20) code groups per minute.

(ii) Written examination element: 7.

(6) At a ship radar station licensed in the Ship Service, the holder of this class of license may not supervise or be responsible for the performance of any adjustments

or tests during or coincident with the installation, servicing or maintenance of the radar equipment while it is radiating energy unless he has satisfactorily completed a supplementary examination qualifying him for that duty and received a ship radar endorsement on his license certifying to that fact: *Provided,* That nothing in this subparagraph shall be construed to prevent persons holding licenses not so endorsed from making replacements of fuses or of receiving-type tubes. The supplementary examination shall consist of:

(i) Written examination element: 8.

(c) [Deleted]

(d) *Radiotelegraph third-class operator permit.* Any station except:

(1) Stations transmitting television, or

(2) Any of the various classes of broadcast stations other than noncommercial educational FM broadcast stations using transmitters with power ratings of 10 watts or less, remote pickup broadcast stations and ST broadcast stations, or

(3) Coastal telephone stations (other than when transmitting manual radiotelegraphy for identification or for testing) at which the power in the antenna of the unmodulated carrier wave is authorized to exceed 250 watts, or

(4) Coastal harbor telephone stations (other than in Alaska and other than when transmitting manual radiotelegraphy for identification or for testing) at which the power in the antenna of the unmodulated carrier wave is authorized to exceed 250 watts, or

(5) Ship stations or aircraft stations other than those at which the installation is used solely for telephony and at which the power in the antenna of the unmodulated carrier wave is not authorized to exceed 250 watts, or

(6) Ship telegraph, coastal telegraph or marine-relay stations open to public correspondence, or

(7) Radiotelegraph stations on board a vessel required by treaty or statute to be equipped with a radio installation, or

(8) Aircraft stations while employing radiotelegraphy:

Provided, That (1) such operator is prohibited from making any adjustments that may result in improper transmitter operation, and (2) the equipment is so designed that the stability of the frequencies of the transmitter is maintained by the transmitter itself within the limits of tolerance specified by the station license, and none of the operations necessary to be performed during the course of normal rendition of the service of the station may cause off-frequency operation or result in any unauthorized radiation, and (3) any needed adjustments of the transmitter that may affect the proper operation of the station are regularly made by or under the immediate supervision and responsibility of a person holding a first- or second-class commercial radio operator license, either radiotelephone or radiotelegraph as may be appropriate for the class of station involved (as determined by the scope of the authority of the respective licenses as set forth in paragraphs (a), (b), (c), (e) and (f) of this section and § 13.62), who shall be responsible for the proper functioning of the station equipment, and (4) in the case of ship radiotelephone or aircraft radiotelephone stations when the power in the antenna of the unmodulated carrier wave is authorized to exceed 100 watts, any needed adjustments of the transmitter that may affect the proper operation of the station are made only by or under the immediate supervision and responsibility of an operator holding a first- or second-class radiotelegraph license, who shall be responsible for the proper functioning of the station equipment.

(e) *Radiotelephone first-class operator license.* Any station except:

(1) Stations transmitting telegraphy by any type of the Morse Code, or

(2) Ship stations licensed to use telephony and power in excess of 100 watts for communication with coastal telephone stations.

(3) At a ship radar station licensed in the Ship Service, the holder of this class of license may not supervise or be responsible for the performance of any adjustments or tests during or coincident with the installation, servicing or maintenance of the radar equipment while it is radiating energy unless he has satisfactorily completed a supplementary examination qualifying him for that duty and received a ship radar

endorsement on his license certifying to that fact: *Provided,* That nothing in this subparagraph shall be construed to prevent persons holding licenses not so endorsed from making replacements of fuses or of receiving-type tubes. The supplementary examination shall consist of:

(i) Written examination element: 8.

(f) *Radiotelephone second-class operator license.* Any station except:

(1) Stations transmitting telegraphy by any type of the Morse Code, or

(2) Standard broadcast stations, or

(3) International broadcast stations, or

(4) FM broadcast stations, or

(5) Non-commercial educational FM broadcast stations with transmitter power rating in excess of 1 kilowatt, or

(6) Television broadcast stations licensed for commercial operation, or

(7) Ship stations licensed to use telephony and power in excess of 100 watts for communication with coastal telephone stations.

(8) At a ship radar station licensed in the Ship Service, the holder of this class of license may not supervise or be responsible for the performance of any adjustments or tests during or coincident with the installation, servicing or maintenance of the radar equipment while it is radiating energy unless he has satisfactorily completed a supplementary examination qualifying him for that duty and received a ship radar endorsement on his license certifying to that fact: *Provided,* That nothing in this subparagraph shall be construed to prevent persons holding licenses not so endorsed from making replacements of fuses or of receiving-type tubes. The supplementary examination shall consist of:

(i) Written examination element: 8.

(g) *Radiotelephone third-class operator permit.* Any station except:

(1) Stations transmitting television, or

(2) Stations transmitting telegraphy by any type of the Morse code, or

(3) Any of the various classes of broadcast stations other than noncommercial educational FM broadcast stations using transmitters with power ratings of 10 watts or less, remote pickup broadcast stations and ST broadcast stations, or

(4) Coastal telephone stations at which the power in the antenna of the unmodulated carrier wave is authorized to exceed 250 watts, or

(5) Coastal harbor telephone stations, other than in Alaska, at which the power in the antenna of the unmodulated carrier wave is authorized to exceed 250 watts, or

(6) Ship stations or aircraft stations other than those at which the installation is used solely for telephony and at which the power in the antenna of the unmodulated carrier wave is not authorized to exceed 250 watts:

Provided, That (1) such operator is prohibited from making any adjustments that may result in improper transmitter operation, and (2) the equipment is so designed that the stability of the frequencies of the transmitter is maintained by the transmitter itself within the limits of tolerance specified by the station license, and none of the operations necessary to be performed during the course of normal rendition of the service of the station may cause off-frequency operation or result in any unauthorized radiation, and (3) any needed adjustments of the transmitter that may affect the proper operation of the station are regularly made by or under the immediate supervision and responsibility of a person holding a first- or second-class commercial radio operator license, either radiotelephone or radiotelegraph as may be appropriate for the class of station involved (as determined by the scope of the authority of the respective licenses as set forth in paragraphs (a), (b), (c), (e), and (f) of this section and § 13.62), who shall be responsible for the proper functioning of the station equipment, and (4) in the case of ship radiotelephone or aircraft radiotelephone stations when the power in the antenna of the unmodulated carrier wave is authorized to exceed 100 watts, any needed adjustments of the transmitter that may affect the proper operation of the station are made only by or under the immediate supervision and responsibility of an operator holding a first- or second-class radiotelegraph license, who shall be responsible for the proper functioning of the station equipment.

(h) *Restricted radiotelephone operator permit.* Any station except:

(1) Stations transmitting television, or

(2) Stations transmitting telegraphy by any type of the Morse Code, or

(3) Any of the various classes of broadcast stations other than remote pickup, broadcast STL, and FM intercity relay stations, or

(4) Ship stations licensed to use telephony for communication with Class I coast stations on frequencies between 4000 kc and 30 Mc, or

(5) Radio stations provided on board vessels for safety purposes pursuant to statute or treaty, or

(6) Coast stations other than in Alaska while employing a frequency below 30 Mc, or

(7) Coast stations at which the power in the antenna of the unmodulated carrier wave is authorized to exceed 250 watts;

(8) At a ship radar station the holder of this class of license may not supervise or be responsible for the performance of any adjustments or tests during or coincident with the installation, servicing or maintenance of the radar equipment while it is radiating energy: *Provided,* That nothing in this subparagraph shall be construed to prevent any person holding such a license from making replacements of fuses or of receiving type tubes:

Provided, That, with respect to any station which the holder of this class of license may operate, such operator is prohibited from making any adjustments that may result in improper transmitter operation, and the equipment is so designed that the stability of the frequencies of the transmitter is maintained by the transmitter itself within the limits of tolerance specified by the station license, and none of the operations necessary to be performed during the course of normal rendition of the service of the station may cause off-frequency operation or result in any unauthorized radiation, and any needed adjustments of the transmitter that may affect the proper operation of the station are regularly made by or under the immediate supervision and responsibility of a person holding a first- or second-class commercial radio operator license, either radiotelephone or radiotelegraph, who shall be responsible for the proper functioning of the station equipment.

§ 13.62 **Special privileges.** In addition to the operating authority granted under § 13.61, the following special privileges are granted the holders of commercial radio operator licenses:

(a) [Reserved.]

(b) The holder of any class of radiotelephone operator license, whose license authorizes him to operate a station while transmitting telephony, may operate the same station when transmitting on the same frequencies, any type of telegraphy under the following conditions:

(1) When transmitting telegraphy by automatic means for identification, for testing, or for actuating an automatic selective signaling device, or

(2) When properly serving as a relay station and for that purpose retransmitting by automatic means, solely on frequencies above 50 megacycles, the signals of a radiotelegraph station, or

(3) When transmitting telegraphy as an incidental part of a program intended to be received by the general public, either directly or through the intermediary of a relay station or stations.

(c) The holder of a commercial radio operator license of any class may operate broadcast stations under the following conditions:

(1) A standard broadcast station with authorized operating power of 10 kw or less and employing a nondirectional antenna, an FM broadcast station with authorized transmitter output power of 10 kw or less, or a noncommercial educational FM broadcast station with authorized transmitter output power of more than 1 kw but not in excess of 10 kw: *Provided,* That adjustments of transmitting equipment by such operators, except when under the immediate supervision of a radiotelephone first-class operator, and except as provided in paragraph (d) of this section, shall be limited to the following:

(i) Those necessary to commence or terminate transmitter emissions as a routine matter.

(ii) Those external adjustments that may be required as a result of variations of primary power supply.

(iii) Those external adjustments which may be necessary to insure modulation within the limits required.

(iv) Those adjustments necessary to effect any changes in operating power which may be required by the station's instrument of authorization.

(2) A noncommercial educational FM broadcast station with authorized transmitter power output of more than 10 watts but not in excess of 1 kw: *Provided,* That adjustments of transmitting equipment by such operators, except under the immediate supervision of a radiotelephone first- or second-class operator, shall be limited to those adjustments set forth in subparagraph (1)(i), (ii), and (iii) of this paragraph.

(3) A noncommercial educational FM broadcast station with authorized transmitter power output of 10 watts or less: *Provided,* That adjustments of transmitting equipment by such operators, except under the immediate supervision of a radiotelephone first- or second-class operator or a radiotelegraph first- or second-class operator, shall be limited to those adjustments set forth in subparagraph (1)(i), (ii), and (iii) of this paragraph.

(4) Should the broadcast transmitting apparatus be observed to be operating in a manner inconsistent with the station's instrument of authorization and none of the adjustments specifically described under subparagraph (1), (2) or (3) of this paragraph are effective in bringing it into proper operation, an operator holding a lesser grade license than that which authorizes unlimited adjustment, with respect to the class of broadcast station involved, and not acting under the supervision of a person holding the higher grade license permitting such unlimited adjustment, shall terminate the station's emissions.

(5) Except in the case of noncommercial educational FM broadcast stations with authorized transmitter output power of 10 watts or less, the special operating authority granted in this section with respect to broadcast stations is subject to the condition that there shall be in regular full-time employment at the station one or more operators of a class authorized to make or supervise all adjustments, whose primary duty shall be to effect and insure the proper functioning of the transmitting equipment. In the case of a noncommercial educational FM broadcast station with authorized transmitter output power of 10 watts or less such operator(s) shall nevertheless be available on call to make or supervise any needed adjustments.

(d) When a CONELRAD Alert is called, a person holding any class of radio operator license or permit who is authorized thereunder to perform limited operation of a standard broadcast station may make any adjustments necessary to effect operation on a CONELRAD frequency in accordance with the station's CONELRAD authorization: *Provided,* That the station's responsible first-class radiotelephone operator(s) shall have previously instructed such person in the adjustments to the transmitter which are necessary to accomplish CONELRAD operation.

§ 13.63 Operator's responsibility. The licensed operator responsible for the maintenance of a transmitter may permit other persons to adjust a transmitter in his presence for the purpose of carrying out tests or making adjustments requiring specialized knowledge or skill, provided that he shall not be relieved thereby from responsibility for the proper operation of the equipment.

§ 13.64 Obedience to lawful orders. All licensed radio operators shall obey and carry out the lawful orders of the master or person lawfully in charge of the ship or aircraft on which they are employed.

§ 13.65 Damage to apparatus. No licensed radio operator shall willfully damage, or cause or permit to be damaged, any radio apparatus or installation in any licensed radio station.

§ 13.66 Unnecessary, unidentified, or superfluous communications. No licensed radio operator shall transmit unnecessary, unidentified, or superfluous radio communications or signals.

§ 13.67 **Obscenity, indecency, profanity.** No licensed radio operator or other person shall transmit communications containing obscene, indecent, or profane words, language, or meaning.

§ 13.68 **False signals.** No licensed radio operator shall transmit false or deceptive signals or communications by radio, or any call letter or signal which has not been assigned by proper authority to the radio station he is operating.

§ 13.69 **Interference.** No licensed radio operator shall willfully or maliciously interfere with or cause interference to any radio communication or signal.

§ 13.70 **Fraudulent licenses.** No licensed radio operator or other person shall obtain or attempt to obtain, or assist another to obtain an operator's license by fraudulent means.

Miscellaneous

§ 13.71 **Issue of duplicate or replacement licenses.** (a) An operator whose license, permit or authorization has been lost, mutilated or destroyed shall immediately notify the Commission. A properly executed application for duplicate should be submitted to the office of issue, embodying a statement of the circumstances involved in the loss, mutilation or destruction of the license or permit for which a duplicate is desired. If the license or permit has been lost, the applicant must state that reasonable search has been made for it, and further, that in the event it be found either the original or the duplicate will be returned for cancellation. The applicant should also submit documentary evidence of the service that has been obtained under the original license or permit, or a statement under oath or affirmation embodying that information.

(b) The holder of any license, permit or authorization whose name is legally changed may make application for replacement document to indicate the new legal name, by submitting a properly executed application to the office of issue, accompanied by the license, permit or authorization affected and by documentary evidence of the legality of the name change.

§ 33.72 **Exhibiting signed copy of application.** When a duplicate or replacement operator license or permit has been requested, or request has been made for renewal upon service or for an endorsement or a verification card, the operator shall exhibit in lieu of the original document a signed copy of the application which has been submitted by him.

§ 13.73 **Verification card.** The holder of an operator license or permit of the diploma form (as distinguished from such document of the card form) may, by filing a properly executed application accompanied by his license or permit, obtain a verification card (Form 758-F). This card may be carried on the person of the operator in lieu of the original license or permit when operating any station at which posting of an operator license is not required: *Provided,* That the license is readily accessible within a reasonable time for inspection upon demand by an authorized Government representative.

§ 13.74 **Posting requirements for operator.** (a) Performing duties other than, or in addition to, service or maintenance, at two or more stations. The holder of any class of radio operator license or permit of the diploma form (as distinguished from the card form) who performs any radio operating duties, as contrasted with but not necessarily exclusive of service or maintenance duties, at two or more stations at which posting of his license or permit is required shall post at one such station his operator license or permit and shall post at all other such stations a duly issued verified statement (Form 759).

(b) Performing service or maintenance duties at one or more stations. The holder of a radiotelephone or radiotelegraph first- or second-class radio operator license who performs, or supervises, and is responsible for service or maintenance work on any transmitter of any station for which a station license is required, shall post his license at the transmitter involved whenever the transmitter is in actual operation while service or maintenance work is being performed: *Provided,* That in lieu of posting his license, he may have on his person either his license or a verification card (Form 758-F): *And provided further,* That if he performs operating duties in addition to

service or maintenance duties he shall, in lieu of complying with the foregoing provisions of this paragraph, comply with the posting requirements applicable to persons performing such operating duties, as set forth in paragraph (a) of this section, and in the rules and regulations applicable to each service.

(c) One or more verified statements (Form 759), as necessary, will be issued to the holder of a restricted radiotelephone operator permit (card form license) who because of an operator license posting requirement at one station would not otherwise be able to comply with a license posting requirement or to carry his permit on his person when so required at another station or stations.

§ 13.75 **Record of service and maintenance duties performed.** In every case where a station log or service and maintenance records are required to be kept and where service or maintenance duties are performed which may affect the proper operation of a station, the responsible operator shall sign and date an entry in the log of the station concerned, or in the station maintenance records if no log is required, giving:

(a) Pertinent details of all service and maintenance work performed by him or under his supervision;

(b) His name and address; and

(c) The class, serial number and expiration date of his license:

Provided, That the responsible operator shall not be subject to requirements of paragraphs (b) and (c) of this section in relation to a station, or stations of one licensee at a single location, at which he is regularly employed as an operator on a full time basis and at which his license is properly posted.

Service

§ 13.91 **Endorsement of service record.** A station licensee, or his duly authorized agent, or the master of a vessel acting as the agent of a licensee, shall endorse the service record appearing on said operator license, showing the call letters and types of emission of the station operated, the nature and period of employment, and quality of performance of duty.

§ 13.92 **Aviation service endorsement.** If the operator has operated more than three stations in the aviation service, the service may be shown by giving the name of the aviation chain or company in lieu of listing the call letters of the several stations.

§ 13.93 **Service acceptability.** Credit will be allowed only for satisfactory service obtained under conditions that required the employment of licensed operators, or when obtained at United States Government stations.

§ 13.94 **Statement in lieu of service endorsement.** The holder of a radiotelegraph license or a restricted radiotelegraph operator permit desiring an endorsement to be placed thereon attesting to an aggregate of at least 6 months' satisfactory service as a qualified operator on a vessel of the United States may, in the event documentary evidence cannot be produced, submit to any office of the Commission a statement under oath accompanied by the license to be endorsed or the application, embodying the following:

(a) Names of ships at which employed;

(b) Call letters of stations;

(c) Types of emission used;

(d) Type of service performed as follows:

(1) Manual radiotelegraph operation only; and

(2) Transmitter control only; or

(3) Combination of (1) and (2) running concurrently;

(e) Whether service was satisfactory or unsatisfactory;

(f) Period of employment;

(g) Name of master, employer, licensee, or his duly authorized agent.

Part 6

FEDERAL COMMUNICATIONS COMMISSION
PART 17 — CONSTRUCTION, MARKING, AND LIGHTING OF ANTENNA STRUCTURES

TITLE 47—TELECOMMUNICATION

Chapter I—Federal Communications Commission

Part 17—Construction, Marking, and Lighting of Antenna Structures

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NOTE: All functions of the Civil Aeronautics Administration (CAA) referred to in Part 17 of the FCC Rules have now been assumed by the Federal Aviation Authority (FAA). Reference to the CAA should therefore be interpreted to mean the FAA.

Subpart A—General Information

§ 17.1 Basis and purpose. (a) The rules in this part are issued pursuant to the authority contained in Title III of the Communications Act of 1934, as amended, which vests authority in the Federal Communications Commission to issue licenses for radio stations when it is found that the public interest, convenience or necessity would be served thereby, and to require the painting, and/or illumination of radio towers if and when in its judgment such towers constitute, or there is a reasonable possibility that they may constitute, a menace to air navigation.

(b) The purpose of the rules in this part is to prescribe certain procedures and standards with respect to the Commission's consideration of proposed antenna structures which will serve as a guide to persons intending to apply for radio station licenses. The standards have been worked out in conjunction with the Civil Aeronautics Administration, the Department of Defense and other Government agencies.

§ 17.2 Definitions. (a) *Airport reference point.* The airport reference point is a point selected and marked at the approximate geometric center of the airport landing area.

(b) *Antenna structures.* The term antenna structures includes the radiating system, its supporting structures and any surmounting appurtenances.

(c) *Approach surfaces and approach areas.* The approach surface is an imaginary inclined plane through the air space located directly above the approach area. The dimensions of the approach area are measured horizontally. This inclined plane extends upward and outward from the beginning of the approach area starting at the elevation of the runway end.

(1) *Length.* The approach area has a length of 10,000 feet beginning 200 feet (1,000 feet for regular Department of Defense Air Bases) from the end of each runway and extending outward, ending at a point 10,200 feet (11,000 feet for regular Department of Defense Air Bases) from the end of the runway on the extended center line of the runway. In addition the approach areas of all runways which may be used for instrument operation shall extend outward an additional 40,000 feet. The approach area requirements for instrument runways shall apply to all runways which may be used for instrument operations and to both ends of such runways.

(2) *Width.* The approach area is symmetrically located with respect to the extended runway center line, and for all instrument runways has a total width of 1,000 feet (1,500 feet for regular Department of Defense Air Bases) at the end adjacent to the runway. The approach area flares uniformly to a total width of 4,000 feet at the end of the 10,000-foot section and to a total width of 16,000 feet at the end of the additional 40,000-foot section. For all other runways not designated for instrument operation, the approach area has a total width at the end adjacent to the runway, and at the approach end, respectively, as follows: For express air carrier service and larger airports, 500 feet and 2,500 feet; for trunk line air carrier service airports, 400 feet and 2,400 feet; for feeder air carrier service airports, 300 feet and 2,300 feet; for secondary airports, 250 feet and 2,250 feet.

(3) *Slope.* For instrument runways the slope of the approach surface along the runway center line extended is 50:1 (an elevation of 1 foot for each 50 feet of hori-

zontal distance) for the inner 10,000-foot section and 40:1 (an elevation of 1 foot for each 40 feet of horizontal distance) for the outer 40,000-foot section. All other runways, not designated for instrument operation which meet or exceed the minimum runway length requirements for feeder air carrier service shall have a slope of 40:1. On airports with shorter runway lengths than those specified for feeder air carrier service, the slope of the approach surface is 20:1 (an elevation of 1 foot for each 20 feet of horizontal distance) for all runways.

(d) *Conical surface.* The conical surface is an imaginary surface through the air space extending upward and outward from the periphery of the horizontal surface and having a slope of 20:1 measured in a vertical plane passing through the airport reference point. Measuring radially outward, from the periphery of the horizontal surface, the conical surface extends for a horizontal distance of 7,000 feet for intercontinental express airports, intercontinental airports and Department of Defense Air Bases; and 5,000 feet for continental, express, trunk line and feeder airports, and 3,000 feet for all smaller airports.

(e) *Designated air traffic control areas.* Areas established and designated by the Administrator of Civil Aeronautics for air traffic control purposes. Information concerning the location of these areas can be obtained from CAA publications and by contacting the CAA regional office.

(f) *Established airport elevation.* The established elevation of the airport is the elevation of the highest point of the usable landing area.

(g) *Established coastal corridors.* Certain established corridors in which low level flight is required for Department of Defense and Coast Guard air operations conducted from air stations located within 20 statute miles of the Atlantic, Pacific and Gulf Coast. These corridors will be ten miles in width extending from coastal air stations to the nearby sea coast. Information with respect to these established corridors will be published along with the information on civil airways.

(h) *Civil airways.* A system of aerial routes designated by the Administrator of Civil Aeronautics for Air Navigation and Traffic Control purposes. Information concerning the location of civil airways can be obtained from aeronautical charts, CAA publications, and by contacting the CAA regional offices.

(i) *Final approach minimum flight altitude.* An altitude designated by appropriate federal authority which is normally established from the highest point within five statute miles of the center line of the final approach course of the radio facility used for final let-down for an airport, and extending for a distance of ten statute miles along this course outward from the radio facility. The radio facilities used for final let-down and the final approach minimum flight altitudes are published in Instrument Approach and Landing Charts and the Flight Information Manual.

(j) *Horizontal surface.* The horizontal surface is an imaginary plane through the air space, circular in shape, with its height 150 feet above the established airport elevation and having a radius from the airport reference point as indicated in the following table:

	Feet
Intercontinental express airports and Department of Defense Air Bases	13,000
Intercontinental airports	11,500
Continental airports	10,000
Express airports	8,500
Trunk line airports	7,000
Feeder airports	6,000
All smaller airports	5,000

The category of every airport in accordance with the above classification is designated by the Administrator of Civil Aeronautics.

(k) *Instrument approach area.* An approach area where instrument approaches are authorized. The dimensions of the approach area and instrument approach area are contained in paragraph (c) of this section.

(l) *Landing area.* A landing area means any locality, either of land or water,

including airports and intermediate landing fields, which is used, or approved for use,[1] for the landing and takeoff of aircraft whether or not facilities are provided for the shelter, servicing, or repair of aircraft, or for receiving or discharging passengers or cargo.

(m) *Minimum flight altitude.* Minimum altitudes designated by the Administrator of Civil Aeronautics to provide aircraft a safe clearance of all obstructions within the area designated. The necessary information concerning the locations of these areas and the established minimum flight altitude can be obtained from the CAA publications and by contacting the CAA regional offices.

(n) *Transitional surfaces.* The transitional surfaces are imaginary inclined planes through the air space having a slope of 7:1 (an elevation of 1 foot for each 7 feet of horizontal distance) measured upward and outward in a vertical plane at right angles to the axis of the runway. The transitional surfaces, symmetrically located on either side of the runway, extend upward and outward from a line on either side of the runway which is parallel to and level with the runway center line. These parallel lines are at a horizontal distance from the runway center line equal to one-half of the minimum width of the approach area indicated in paragraph (c)(2) of this section. Transitional surfaces extend from the edges of all approach surfaces upward and outward to the intersection with the horizontal surface or the conical surface. The approach surfaces for instrument runways projecting through and beyond the limits of the conical surface shall have 7:1 transitional surfaces extending a distance of 5,000 feet measured horizontally from the edge of the approach surfaces and at right angles to the runway axis.

§ 17.3 Form to be used to describe proposed antenna structures. Applications for radio facilities in the Radio Broadcast Services shall be accompanied by FCC Form 301, Section V-G (antenna); applications in the Aviation Services shall be accompanied by FCC Form 406 (Part 11); and applications in all other services shall be accompanied by FCC Form 401-A (revised) when:

(a) The antenna structures proposed to be erected will exceed an over-all height of 170 feet above ground level, except that where the antenna is mounted on top of an existing man-made structure other than an antenna structure and does not increase the over-all height of such man-made structure by more than 20 feet, no Form 401-A need be filed, or

(b) The antenna structures proposed to be erected will exceed an over-all height of 1 foot above the established airport (landing area) elevation for each 200 feet of distance, or fraction thereof, from the nearest boundary of such landing area, except that, where the antenna does not exceed 20 feet above the ground or if the antenna is mounted on top of an existing man-made structure, other than an antenna structure, or natural formation and does not increase the over-all height of such man-made structure or natural formation by more than 20 feet, no Form 401-A need be filed.

§ 17.4 Commission consideration of proposed antenna structure with respect to possible hazard to air navigation. (a) All applications which in the light of the criteria set forth in Subpart B require special aeronautical study will be referred by the Commission through appropriate channels to the Airspace Subcommittee of the Air Coordinating Committee for its recommendation.

(b) All applications which do not require special aeronautical study in view of the criteria set forth in Subpart B will be deemed not to involve a hazard to air navigation and will be considered by the Commission without reference to the Airspace Subcommittee of the Air Coordinating Committee.

(c) Whenever a recommendation for approval of any application that has been submitted to the Airspace Subcommittee of the Air Coordinating Committee has been received from that Committee, the application will be deemed not to involve a hazard to air navigation and will be processed by the Commission accordingly.

(d) Whenever a report recommending denial of any application or any report

[1] Consideration to aeronautical facilities not in existence at the time of the filing of the application for radio facilities will be given only when proposed airport construction or improvement plans are on file with the CAA as of the filing date of the application for such radio facilities.

which indicates a lack of agreement among the members of the Airspace Subcommittee of the Air Coordinating Committee has been received from that Committee, the applicant will be so advised and the Commission will take such further action as might be appropriate.

Subpart B—Criteria for Determining Whether Applications for Radio Towers Require Special Aeronautical Study

§ 17.11 Antenna structures over 500 feet in height. Antenna structures over 500 feet in height above the ground will require special aeronautical study irrespective of their location.

§ 17.12 Antenna structures over 170 feet up to and including 500 feet in height. Antenna structures over 170 feet up to and including 500 feet in height above the ground will not require special aeronautical study except:

(a) Where antenna structures less than 500 feet in height would necessitate the raising of the minimum flight altitude within the Civil Airways and designated air traffic control areas in the country.

(b) In areas of established coastal corridors.

(c) Where the antenna structure would project above the landing area, or the limiting heights or surfaces, specified in § 17.15, of all airports now in existence or provided for in approved plans.[1]

§ 17.13 Antenna structures 170 feet in height and under. Antenna structures 170 feet and under in height above the ground will not require special aeronautical study, except in the areas outlined in § 17.15.

§ 17.14 Certain antenna structures exempt from special aeronautical study. Antenna structures 20 feet or less in height mounted on top of natural formations, and antenna structures increasing by 20 feet or less the height of existing man-made structures other than an existing antenna structure, will not require special aeronautical study.

§ 17.15 Antenna structures in airports and approach areas. Antenna structures in the vicinity of airports and approach areas will require special aeronautical study if they project above the following heights above ground or surfaces (in case of conflict the lowest height will prevail).

(a) In instrument approach areas, more than 100 feet above the ground or 100 feet above the elevation of the approach end of the runway, whichever gives the higher elevation of the structure, within three statute miles of the runway end, and increasing in height above ground in the proportion of 25 feet for each additional statute mile of distance outward from the runway but not to exceed 250 feet within ten miles of the runway end. The approach area requirements for instrument runways shall apply to both ends of such runways.

(b) More than 170 feet above the ground or the established airport elevation, whichever gives the higher elevation of the structure within three statute miles of the reference point of a feeder or larger class airport and increasing in height above ground in the proportion of 100 feet for each additional statute mile of distance from the airport but not to exceed a maximum of 500 feet above ground.

(c) Antenna structures of an elevation which would increase the final approach minimum flight altitude.

(d) In addition to the requirements mentioned above, antenna structures which project above the landing area or any of the following imaginary surfaces will require special aeronautical study:

(1) Approach surface.

(2) Horizontal surface.

(3) Conical surface.

(4) Transitional surface.

(e) Under most conditions, the limits prescribed in paragraphs (a), (b) and (c) of this section will be the determining factor. However, in the areas immediately adjacent to the runways and under certain conditions where the terrain rises rapidly in the airport area, the surfaces specified in paragraph (d) of this section become a more limiting factor from the absolute height of requirements.

§ 17.16 Shielded antenna structures. In any special aeronautical study conducted under the provisions of this subpart, the circumstances that the antenna structure will be shielded by natural formations or existing man-made structures will be taken into account.

§ 17.17 Existing structures. (a) Nothing in these criteria concerning antenna structures or locations shall apply to those structures now existing or to those structures authorized prior to the effective date of these criteria.

(b) No change in any of these criteria or relocation of airports shall at any time impose a new restriction upon any then existing or authorized antenna structure or structures.

Subpart C—Specifications for Obstruction Marking and Lighting of Antenna Structures

§ 17.21 Painting and lighting, when required. Antenna structures shall be painted and lighted when:

(a) They require special aeronautical study; or

(b) They exceed 170 feet in height above the ground.

(c) The Commission may modify the above requirement for painting and/or lighting of antenna structures, when it is shown by the applicant that the absence of such marking would not impair the safety of air navigation, or that a lesser marking requirement would insure the safety thereof.

§ 17.22 Particular specifications to be used. (a) Where special aeronautical study is not required, the Commission will assign painting and lighting specifications as set forth in this subpart.

(b) Where special aeronautical study is required, the Commission will, insofar as is consistent with the safety of life and property in the air, also assign painting and lighting specifications listed in this subpart.

(c) However, where antenna installations are of such a nature that their painting and lighting in accordance with these specifications are confusing or endanger rather than assist airmen or are otherwise inadequate, the Commission will specify the type of painting and lighting or other marking to be used in the individual situation.

§ 17.23 Specifications for the painting of antenna structures in accordance with § 17.21. Antenna structures shall be painted throughout their height with alternate bands of aviation surface orange and white, terminating with aviation surface orange bands at both top and bottom. The width of the bands shall be approximately one-seventh the height of the structure, provided however, that the bands shall not be more than 40 feet nor less than 1½ feet in width.

§ 17.24 Specifications for the lighting of antenna structures up to and including 150 feet in height. (a) Antenna structures up to and including 150 feet in height above the ground located in areas set forth in § 17.15 shall be lighted as follows:

(1) There shall be installed at the top of the tower at least two 100- or 111-watt lamps (#100 A21/TS or #111 A21/TS, respectively) enclosed in aviation red obstruction light globes. The two lights shall burn simultaneously from sunset to sunrise and shall be positioned so as to insure unobstructed visibility of at least one of the lights from aircraft at any angle of approach. A light sensitive control device or an astronomic dial clock and time switch may be used to control the obstruction lighting in lieu of manual control. When a light sensitive device is used, it should be adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

§ 17.25 Specifications for the lighting of antenna structures over 150 feet up to and including 300 feet in height. (a) Antenna structures over 150 feet up to and including 300 feet in height above the ground shall be lighted as follows:

(1) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500- or 620-watt lamps (PS-40, Code Beacon type), both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of not more than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon

from aircraft at any angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any angle of approach. The beacon shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute with a period of darkness equal to one-half of the luminous period.

(2) At the approximate mid point of the over-all height of the tower there shall be installed at least two 100- or 111-watt lamps (#100 A21/TS or #111 A21/TS, respectively) enclosed in aviation red obstruction light globes. Each light shall be mounted so as to insure unobstructed visibility of at least one light at each level from aircraft at any angle of approach.

(3) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

§ 17.26 Specifications for the lighting of antenna structures over 300 feet up to and including 450 feet in height. (a) Antenna structures over 300 feet up to and including 450 feet in height above the ground shall be lighted as follows:

(1) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500- or 620-watt lamps (PS-40, Code Beacon type), both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of not more than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon from aircraft at any angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any angle of approach. The beacons shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute with a period of darkness equal to one-half of the luminous period.

(2) On levels at approximately two-thirds and one-third of the over-all height of the tower, there shall be installed at least two 100- or 111-watt lamps (#100 A21/TS or #111 A21/TS, respectively) enclosed in aviation red obstruction light globes. Each light shall be mounted so as to insure unobstructed visibility of at least one light at each level from aircraft at any angle of approach.

(3) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

§ 17.27 Specifications for the lighting of antenna structures over 450 feet up to and including 600 feet in height. (a) Antenna structures over 450 feet up to and including 600 feet in height above the ground shall be lighted as follows:

(1) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500- or 620-watt lamps (PS-40, Code Beacon type), both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of not more than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon from aircraft at any angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any angle of approach. The beacons shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute with a period of darkness equal to one-half of the luminous period.

(2) At approximately one-half of the over-all height of the tower one similar flashing 300 m/m electric code beacon shall be installed in such position within the tower proper that the structural members will not impair the visibility of this beacon from aircraft at any angle of approach. In the event this beacon cannot be installed in a manner to insure unobstructed visibility of it from aircraft at any angle of approach, there shall be installed two such beacons. Each beacon shall be mounted on the outside of diagonally opposite corners or opposite sides of the tower at the prescribed height.

(3) On levels at approximately three-fourths and one-fourth of the over-all height of the tower, at least one 100- or 111-watt lamp (#100 A21/TS or #111 A21/TS, respectively) enclosed in an aviation red obstruction light globe shall be installed on each outside corner of the tower at each level.

(4) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

§ 17.28 Specifications for the lighting of antenna structures over 600 feet up to and including 750 feet in height. (a) Antenna structures over 600 feet up to and including 750 feet in height above the ground shall be lighted as follows:

(1) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500- or 620-watt lamps (PS-40, Code Beacon type), both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of not more than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon from aircraft at any angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any angle of approach. The beacon shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute with a period of darkness equal to one-half of the luminous period.

(2) At approximately two-fifths of the over-all height of the tower one similar flashing 300 m/m electric code beacon shall be installed in such position within the tower proper that the structural members will not impair the visibility of this beacon from aircraft at any angle of approach. In the event this beacon cannot be installed in a manner to insure unobstructed visibility of it from aircraft at any angle of approach, there shall be installed two such beacons. Each beacon shall be mounted on the outside of diagonally opposite corners or opposite sides of the tower at the prescribed height.

(3) On levels at approximately four-fifths, three-fifths and one-fifth of the over-all height of the tower, at least one 100- or 111-watt lamp (#100 A21/TS or #111 A21/TS, respectively) enclosed in an aviation red obstruction light globe shall be installed on each outside corner of the tower at each level.

(4) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

§ 17.29 Specifications for the lighting of antenna structures over 750 feet up to and including 900 feet in height. (a) Antenna structures over 750 feet up to and including 900 feet in height above the ground shall be lighted as follows:

(1) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500- or 620-watt lamps (PS-40, Code Beacon type), both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of not more than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon from aircraft at any angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any angle of approach. The beacons shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute with a period of darkness equal to one-half of the luminous period.

(2) On levels at approximately two-thirds and one-third of the over-all height of the tower one similar flashing 300 m/m electric code beacon shall be installed in such position within the tower proper that the structural members will not impair the visibility of this beacon from aircraft at any angle of approach. In the event these beacons cannot be installed in a manner to insure unobstructed visibility of the beacons from aircraft at any angle of approach, there shall be installed two such beacons at each level. Each beacon shall be mounted on the outside of

diagonally opposite corners or opposite sides of the tower at the prescribed height.

(3) On levels at approximately five-sixths, one-half, and one-sixth of the over-all height of the tower, at least one 100- or 111-watt lamp (#100 A21/TS or #111 A21/TS, respectively) enclosed in an aviation red obstruction light globe shall be installed on each outside corner of the tower at each level.

(4) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

§ 17.30 Specifications for the lighting of antenna structures over 900 feet up to and including 1,050 feet in height. (a) Antenna structures over 900 feet up to and including 1,050 feet in height above the ground shall be lighted as follows:

(1) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500- or 620-watt lamps (PS-40, Code Beacon type), both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of less than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon from aircraft at any angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any angle of approach. The beacons shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute, with a period of darkness equal to one-half of the luminous period.

(2) On levels at approximately four-sevenths and two-sevenths of the over-all height of the tower one similar flashing 300 m/m electric code beacon shall be installed in such position within the tower proper that the structural members will not impair the visibility of this beacon from aircraft at any angle of approach. In the event these beacons cannot be installed in a manner to insure unobstructed visibility of the beacons from aircraft at any angle of approach, there shall be installed two such beacons, at each level. Each beacon shall be mounted on the outside of diagonally opposite corners or opposite sides of the tower at the prescribed height.

(3) On levels at approximately six-sevenths, five-sevenths, three-sevenths and one-seventh of the over-all height of the tower at least one 100- or 111-watt lamp (#100 A21/TS or #111 A21/TS, respectively) enclosed in an aviation red obstruction light globe shall be installed on each outside corner of the structure.

(4) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

§ 17.31 Specifications for the lighting of antenna structures over 1,050 feet up to and including 1,200 feet in height. (a) Antenna structures over 1,050 feet up to and including 1,200 feet in height above the ground shall be lighted as follows:

(1) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500- or 620-watt lamps (PS-40, Code Beacon type), both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of not more than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon from aircraft at any angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any angle of approach. The beacon shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute with a period of darkness equal to one-half of the luminous period.

(2) On levels at approximately three-fourths, one-half and one-fourth of the over-all height of the tower one similar flashing 300 m/m electric code beacon shall be installed in such position within the tower proper that the structural members will not impair the visibility of this beacon from aircraft at any angle of approach. In the event these beacons cannot be installed in a manner to insure unobstructed visi-

bility of the beacons from aircraft at any angle of approach, there shall be installed two such beacons, at each level. Each beacon shall be mounted on the outside of diagonally opposite corners or opposite sides of the tower at the prescribed height.

(3) On levels at approximately seven-eighths, five-eighths, three-eighths, and one-eighth of the over-all height of the tower, at least one 100- or 111-watt lamp (#100 A21/TS or #111 A21/TS, respectively) enclosed in an aviation red obstruction light globe shall be installed on each outside corner of the structure.

(4) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

§ 17.32 Specifications for the lighting of antenna structures over 1,200 feet up to and including 1,350 feet in height. (a) Antenna structures over 1,200 feet up to and including 1,350 feet in height above the ground shall be lighted as follows:

(1) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500- or 620-watt lamps (PS-40, Code Beacon type), both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of not more than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon from aircraft at any angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any angle of approach. The beacons shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute with a period of darkness equal to one-half of the luminous period.

(2) On levels at approximately two-thirds, four-ninths and two-ninths of the over-all height of the tower one similar flashing 300 m/m electric code beacon shall be installed in such position within the tower proper that the structural members will not impair the visibility of this beacon from aircraft at any angle of approach. In the event these beacons cannot be installed in a manner to insure unobstructed visibility of the beacons from aircraft at any angle of approach, there shall be installed two such beacons at each level. Each beacon shall be mounted on the outside of diagonally opposite corners or opposite sides of the tower at the prescribed height.

(3) On levels at approximately eight-ninths, seven-ninths, five-ninths, one-third and one-ninth of the over-all height of the tower, at least one 100- or 111-watt lamp (#100 A21/TS or #111 A21/TS, respectively) enclosed in an aviation red obstruction light globe shall be installed on each outside corner of the tower at each level.

(4) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

§ 17.33 Specifications for the lighting of antenna structures over 1,350 feet and up to and including 1,500 feet in height. (a) Antenna structures over 1,350 feet up to and including 1,500 feet in height above the ground shall be lighted as follows:

(1) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500- or 620-watt lamps (PS-40, Code Beacon type), both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of not more than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon from aircraft at any angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any angle of approach. The beacon shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute with a period of darkness equal to one-half of the luminous period.

(2) On levels at approximately four-fifths, three-fifths, two-fifths, and one-fifth of the over-all height of the tower one similar flashing 300 m/m electric code beacon

shall be installed in such position within the tower proper that the structural members will not impair the visibility of this beacon from aircraft at any angle of approach. In the event these beacons cannot be installed in a manner to insure unobstructed visibility of the beacons from aircraft at any angle of approach, there shall be installed two such beacons at each level. Each beacon shall be mounted on the outside of diagonally opposite corners or opposite sides of the tower at the prescribed heights.

(3) On levels at approximately nine-tenths, seven-tenths, one-half, three-tenths, and one-tenth of the over-all height of the tower, at least one 100- or 111-watt lamp (#100 A21/TS or #111 A21/TS, respectively) enclosed in an aviation red obstruction light globe shall be installed on each outside corner of the tower at each level.

(4) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

§ 17.34 Specifications for the lighting of antenna structures over 1,500 feet in height. Antenna structures over 1,500 feet in height above the ground shall be lighted in accordance with specifications to be determined by the Commission after aeronautical study which will include lighting recommendations.

§ 17.35 Antenna farms and multiple structure antenna arrays. In the case of antenna structures which are so grouped as to present a common potential menace to air navigation, the foregoing requirements for painting and lighting may be modified as a result of aeronautical study.

§ 17.36 Temporary warning lights. During construction of an antenna structure, for which obstruction lighting is required, at least two 100- or 111-watt lamps (#100 A21/TS or #111 A21/TS, respectively) enclosed in aviation red obstruction light globes, shall be installed at the uppermost point of the structure. In addition, as the height of the structure exceeds each level at which permanent obstruction lights will be required, two similar lights shall be installed at each such level. These temporary warning lights shall be displayed nightly from sunset to sunrise until the permanent obstruction lights have been installed and placed in operation, and shall be positioned so as to insure unobstructed visibility of at least one of the lights at any angle of approach. In lieu of the above temporary warning lights, the permanent obstruction lighting fixtures may be installed and operated at each required level as each such level is exceeded in height during construction.

§ 17.37 Inspection of tower lights and associated control equipment. The licensee of any radio station which has an antenna structure requiring illumination pursuant to the provisions of section 303(q) of the Communications Act of 1934, as amended, as outlined elsewhere in this part:

(a) (1) Shall make an observation of the tower lights at least once each 24 hours either visually or by observing an automatic and properly maintained indicator designed to register any failure of such lights, to insure that all such lights are functioning properly as required; or alternatively;

(2) Shall provide and properly maintain an automatic alarm system designed to detect any failure of such lights and to provide indication of such failure to the licensee.

(b) Shall report immediately by telephone or telegraph to the nearest Airways Communication Station or office of Civil Aeronautics Administration any observed or otherwise known failure of a code or rotating beacon light or top light not corrected within thirty minutes, regardless of the cause of such failure. Further notification by telephone or telegraph shall be given immediately upon resumption of the required illumination.

(c) Shall inspect at intervals not to exceed 3 months all automatic or mechanical control devices, indicators and alarm systems associated with the tower lighting to insure that such apparatus is functioning properly.

§ 17.38 Recording of tower light inspections in the station record. The licensee of any radio station which has an antenna structure requiring illumination shall make the following entries in the station record of the inspections required by § 17.37:

(a) The time the tower lights are turned on and off each day if manually controlled;

(b) The time the daily check of proper operation of the tower lights was made if automatic alarm system is not provided;

(c) In the event of any observed or otherwise known failure of a tower light:

(1) Nature of such failure.

(2) Date and time the failure was observed, or otherwise noted.

(3) Date, time and nature of the adjustments, repairs, or replacements were made.

(4) Identification of Airways Communication Station (Civil Aeronautics Administration) notified of the failure of any code or rotating beacon light or top flight not corrected within 30 minutes, and the date and time such notice was given.

(5) Date and time notice was given to the Airways Communication Station (Civil Aeronautics Administration) that the required illumination was resumed.

(d) Upon completion of the periodic inspection required at least once each three months:

(1) The date of the inspection and the condition of all tower lights and associated tower lighting control devices, indicators and alarm systems.

(2) Any adjustments, replacements, or repairs made to insure compliance with the lighting requirements and the date such adjustments, replacements, or repairs were made.

§ 17.39 **Cleaning and repainting.** All towers shall be cleaned or repainted as often as necessary to maintain good visibility.

§ 17.40 **Time when lights shall be exhibited.** All lighting shall be exhibited from sunset to sunrise unless otherwise specified.

§ 17.41 **Spare lamps.** A sufficient supply of spare lamps shall be maintained for immediate replacement purposes at all times.

§ 17.42 **Lighting equipment.** The lighting equipment, color of filters, and shade of paint referred to in the specifications are further defined in the following government and/or Army-Navy Aeronautical Specifications, Bulletins, and Drawings: (Lamps are referred to by standard numbers.)

Aviation red	Army-Navy Specifications	AN-C-56.[1]
Outside white	Federal Specifications	TT-P-40, Type 1 or 2.[2]
Aviation surface orange	do	TT-P-59.[2,3]
Code beacon	CAA Specifications	446 (sec. II-d-Style 4).[4]
Obstruction light globe, prismatic.	Army-Navy Drawing	AN-L-10A [1] or CAA Specification L-810.
Obstruction light globe, Fresnel	do	
Single multiple obstruction light fitting assembly.	do	
Obstruction light fitting assembly.	do	
100-watt lamp		#100 A21/TS.[5]
111-watt lamp		#111 A21/TS (3,000 hours).
500-watt lamp		#500 PS 40/45.[5]
620-watt lamp		#620 PS 40/45 (3,000 hours).

[1] Copies of Army-Navy Specifications or drawings can be obtained by contacting Commanding General, Air Matériel Command, Wright Field, Dayton, Ohio, or the Bureau of Aeronautics, Navy Department, Washington 25, D.C. Information concerning Army-Navy Specifications or drawings can also be obtained from the Office of Federal Airways, Civil Aeronautics Administration, Department of Commerce, Washington 25, D.C.

[2] Copies of this specification can be obtained from the Government Printing Office for 5 cents.

[3] At the Air Routes and Ground Aids Division Meeting of the International Civil Aviation Organization during November 1949, the designation "Aviation Surface Orange," was adopted to replace "International Orange."

[4] Copies of this specification can be obtained from the Office of Federal Airways, Civil Aeronautics Administration, Department of Commerce.

[5] It is strongly recommended that the 111-watt and 620-watt, 3,000-hour lamps, be used instead of the 100-watt and 500-watt lamps whenever possible in view of the extended life, lower maintenance cost, and greater safety which they provide.

(c) Except as set forth in paragraphs (a) and (b) of this section, nothing in the criteria set forth in §§ 17.11 to 17.17 or this subpart concerning antenna structures or locations shall apply to painting and lighting those structures authorized prior to March 30, 1953 except where lighting and painting requirements are reduced, in which case the lesser requirements may apply.

§ 17.43 Painting and lighting existing structures. (a) All existing antenna structures required to be painted in accordance with the terms of an instrument of authorization dated prior to March 30, 1953, shall be painted in the manner set forth in § 17.23 at the time when the antenna structure is required to be repainted (see § 17.39) or in no event later than January 1, 1960.

(b) All existing antenna structures required to be lighted in accordance with the terms of an authorization requiring only the following lighting specifications shall be changed to the lighting specifications set forth below as soon as practicable or in no event later than one year from the date of the first instrument of authorization that is issued to the station after January 1, 1954:

Existing Lighting Specifications FCC Form No.	*New Lighting Specifications Rule No.*
715-1	§ 17.24(a)(1).
715-2 or B (6)-2	§§ 17.24(a)(1) and 17.26(a)(2).
715-4 or B (6)-4	§§ 17.24(a)(1) and 17.26(a)(2).

§ 17.44 Maintenance of lighting equipment. Replacing or repairing of lights, automatic indicators or automatic alarm systems shall be accomplished as soon as practicable.

§ 17.45 Report of radio transmitting antenna construction, alteration and/or removal. Any permittee or licensee who, pursuant to any instrument of authorization from the Commission to erect or make changes affecting antenna height or location of an antenna tower for which obstruction marking is required, shall, prior to start of tower construction and upon completion of such construction or changes, fill out and file with the Director, U.S. Coast and Geodetic Survey, C. & G. S. Form 844 (Report of Radio Transmitting Antenna Construction, Alteration and/or Removal) in order that antenna tower information may be provided promptly for use on Aeronautical Charts and related publications in the interest of safety of air navigation.

SPECIFIC CRITERIA TO BE USED BY RADIO/TELEVISION AND AVIATION INTERESTS RELATIVE TO HEIGHT AND LOCATION OF NEW ANTENNA STRUCTURES AND NEW AIRPORTS

A Report by the Joint Industry/Government Tall Structures Committee

Foreword

The following Report is the result of almost three years of work by the members of the JIGTSC. In its present form it is advisory and recommendatory in nature. The Report was forwarded as a recommendation to the Federal Communications Commission in regard to the amendment of Part 17 of their Rules and Regulations. The FCC has issued notices of proposed rule making in Docket 11665 (dated March 29, 1956 and November 22, 1957) in the matter of amendment of Parts 1 and 17 of the Commission's Rules to encourage the grouping of antenna towers and the multiple use of structures for supporting antennas, and amendment of Part 17 to pro-

vide new criteria for determining whether applications for antenna towers will require special aeronautical study.

As a member of the JIGTSC, the NAB was authorized by its Board of Directors to tentatively accept the Report for a one-year trial period during which time the JIGTSC would remain a standing committee. At the conclusion of this period, the JIGTSC would reconvene to re-evaluate the efficacy of the provisions of the Report. That period expired during July, 1958.[1] The above-mentioned proposed rule making in Docket 11665 is in accordance with the provisions of the Administrative Procedures Act whenever a change in the rules is proposed. These changes per Docket 11665, were proposed on the Commission's own motion. At the time this is being written, the FCC has not yet finalized their action in this docket. For final action in this regard, broadcasters are referred to this docket and subsequent revisions in Parts 1 and 17 of the FCC Rules and Regulations.

It should be pointed out that regardless of the amendments of the Commission's Rules, the Washington Airspace Panel and the Regional Airspace Subcommittees are considering broadcast tower applications coming before them on the basis of the recommendations contained in the following Report.

Preface

While it is recognized that the radio/television industry has a definite requirement for tall antenna towers in order to provide the degree of public service contemplated by the Communications Act of 1934, as amended, these tall skeletal structures and their supporting guy wires are hazardous to aviation because they are peculiarly difficult for pilots to see.

Accordingly, the Joint Industry/Government Tall Structures Committee (JIGTSC) has agreed to the following general concepts, procedures, and specific criteria as a guide to be used by both radio/television and aviation interests in their consideration of their mutual problems relating to the height and location of proposed new antenna structures and new airports.

Memorandum of Agreement

A. General

The present system of determining whether a transmitting tower constitutes an air hazard should be continued. (Ref.: Part 17, FCC Rules)

It is specifically understood that the principles subscribed to here apply only to new or modified antenna tower proposals.

B. Tower "Farms"

The adoption of the single structure multiple antenna, and/or antenna tower "farm"[2] concept for radio and television transmitting towers is necessary wherever possible in order to avoid a conflict of airspace interest between the aviation and broadcast industries.

1. Control of Transmitting Towers. The FCC has stated that it has the authority to require radio and television transmitting antennas to be placed in "farm" areas or to require the use of multiple antennas on a single supporting structure if the record shows that such action will be in the public interest, convenience, and necessity. Obviously there are some types of towers which would be excepted, as for example, standard broadcast directional antennas and towers for micro-wave transmission.

The Committee recommends that the FCC initiate a rule-making proceeding[3] to

[1] Extended to July, 1960.

[2] An antenna "farm" is an area where antenna towers having a common impact on aviation may be grouped.

[3] The FCC on March 29, 1956, issued a Notice of Proposed Rule Making concerning the antenna "farm" concept (Docket 11665) and final action on this rule making is being postponed pending action on the attached recommended criteria.

amend its rules to require that any future application for a transmitting tower in excess of 500′ in height above the ground should be reviewed by the ACC Airspace Panel to determine the aeronautical hazards involved, retaining the right of the applicant to submit evidence to the FCC as to why his tower should not be located in a "farm" area or his antenna should not be located on an existing structure. "Farm" areas should be so spaced in relation to each other as to present the least hazard to aviation.

The Committee recommends the location of all transmitting towers, government and non-government, regardless of height, in antenna "farms" wherever possible. However, this recommendation should not be interpreted as modifying FCC Part 17 or CAA TSO-N18 except as may be necessary to implement the criteria as set forth under section F of this paper.

II. Control of Receiving Antenna Towers. Since the FCC does not have authority to control the erection of receiving antenna towers, except where such receiving antenna is on the same tower as a transmitting antenna (as in a micro-wave system), legislation should be requested which would control the installation, height, and location of receiving antenna towers. Such legislation should not provide any more stringent restrictions on receiving antennas than on transmitting antennas, and should be developed and coordinated within the ACC structure.

In the event the FCC should not desire to control receiving antenna towers under such legislation, there would be no objection to a move on the part of the Federal agencies concerned to have similar authority vested in some other agency, either at Federal, or possibly State, level.

The object of such legislation would be to have the same criteria and principles apply to all tower structures. Such legislation should be sought by the FCC, with support of other interested agencies.[1]

C. Control of Unused or Abandoned Towers

FCC authority to control the lighting, marking, or removal of unused or abandoned towers is not clear except where the person involved is a licensee of another station(s). This question is presently under consideration in the Commission. Accordingly, the FCC should require the removal or appropriate marking and lighting of unused or abandoned towers if such authority exists, and if such authority does not exist, the FCC should seek appropriate legislation to attain this objective.[2]

D. Additional Lighting and Marking

Full cooperation exists between the broadcast and aviation industries toward improvement in the lighting and marking of radio and television antenna towers and experimentation is in the initial stages of implementation in the ACC structure.

E. Other Structures

Aviation authorities contend that appropriate legislation should be drafted to cover the erection, location, and height of other obstructions to aviation. Such legislation should be sought by the Department of Commerce, with the support of other interested agencies.

[1] The FCC on May 1, 1957, initiated request for legislation for the control of receiving antenna towers.

[2] The FCC on December 12, 1956, initiated a request for legislation to require that abandoned or unused radio towers continue to meet the same painting and lighting requirements that would be applicable if such towers were being used pursuant to license issued by FCC.

F. Air Hazard Criteria for Determining Height and Location (See Att. A)

At the meeting of the JIGTSC on October 3, 1955, it was agreed that criteria would be developed to serve the purpose stated in the Preface hereto, and to have the following objectives:

(*a*) To provide protection for low altitude inter-city air routes;
(*b*) To provide additional protection for high density air traffic areas, present and forecast;
(*c*) To provide increased protection for airways and much used "fly-ways";
(*d*) To provide additional protection for areas in the vicinity of airports;
(*e*) To provide areas for the erection of radio and television towers.

Specific criteria in respect to the areas described in items (*a*), (*c*), and (*d*), above are set forth in Attachment A hereto. In respect to high density air traffic areas, item (*b*), it was found that the objective was generally satisfied by the criteria developed for the other three areas. Specific criteria for this problem area could not be satisfactorily expressed in separate form as the interpretation of "high density air traffic areas" could not be precisely defined. Originally, the interpretation was held that a "high density air traffic area" was a large geographical area in which the complexity and extent of airways, controlled areas, control zones and flight operations were of a relatively higher degree than elsewhere. This concept does not lend itself to any practical approach other than the establishment of a blanket limit on structure heights.

A second interpretation of a "high density air traffic area" is that applied to the control zone of certain busy airports, such as Washington National. In such cases, the objective stated in item (*d*) would serve to satisfy the problem in this area. Accordingly, it is believed that the problem confronting aviation and radio/television interests can be resolved by application of the criteria specified for the areas described in items (*a*), (*c*) and (*d*) above.

It should be clearly understood that the criteria set forth in Attachment A are designed for the following purposes and no other:

1. As a guide for use by radio/television interests in selecting sites for antenna towers;
2. As a guide to aviation interests in conducting special aeronautical studies of applications for construction of antenna towers and in considering the effect of existing antenna towers in planning and construction of new airports;
3. To be used as a basis for recommending amendments to Part 17 of the Federal Communications Commission's Rules as it applies to the requirement for special aeronautical study of proposed towers under 500′ above ground; and
4. To be used as a basis for action by the Civil Aeronautics Administration, as appropriate, to implement paragraph 2 above.

These criteria, per se, are not intended as a rigid standard to be arbitrarily applied by the Airspace Panel in approving or disapproving applications for tower construction, and it is not intended that these criteria shall apply to existing antenna structures.

Exceptions will be made by the Airspace Panel for the purpose of establishing or adding to antenna "farm" areas, as appropriate, and where existing conditions of terrain, obstructions or other circumstances would make application of these criteria inappropriate.

It would be to the advantage of all tower applicants to consult State and local aviation officials before committing themselves to specific locations.

G. Improving Airspace Panel Procedures

If the Airspace Panel (ASP) reaches the conclusion, based solely on technical aviation considerations, that a certain tower as proposed would be a hazard, it should then determine whether or not the tower can be moved or shortened, or whether aviation adjustments should be made. At this point in its deliberations it will obviously be necessary for ASP to consider the direct cost of some physical relocation either on the part of television or aviation, in order that it may determine whether

the economic burden should rest with television or aviation interests. In some cases, the Airspace Panel should not limit its consideration of antenna tower proposals solely to the question of aviation hazards involved, but should continue its present practice of considering economic and other factors in reaching a compromise mutually satisfactory to both broadcasting and aviation.

It is the position of aviation that radio and television antenna towers in excess of 1000′ above the ground are, per se, considered to be unwarranted hazards (obstructions, menaces, etc.) to air navigation. On the other hand, it is the position of the broadcast industry that this determination can be made only in the light of all the facts surrounding the utilization of a particular tower. However, it is mutually agreed that under certain conditions antenna towers in excess of 1000′ above the ground may be required in the public interest, convenience, and necessity. In view of this, on all proposals considered by the Airspace Panel which would require towers in excess of 500′ above the gronnd, the applicant shall have the right to, and should, present complete justification, excluding all economic considerations except the direct costs of physical relocation. If the applicant does not submit justification to the Airspace Panel, the Panel will consider the application only from the aeronautical hazard perspective.

ACC coordination and cooperation should be maintained with State and local officials, who will be afforded opportunity to appear and present information with respect to State laws and local ordinances relating specifically to obstructions to air navigation.

In addition, the Airspace Panel may wish the applicant to cite the particular page and paragraph of any FCC rule to which he may allude as an FCC requirement.

The FCC should, insofar as practical, provide additional engineering and technical assistance at Airspace meetings.[1]

The National Association of Radio and Television Broadcasters should have associate membership on the Washington Airspace Panel.[2]

H. Booster and Satellite Stations

While the use of booster and satellite stations may in specific instances serve to resolve conflicts between the television and aviation industries, it is generally agreed that their use does not offer a satisfactory solution to the problem of broad area coverage.

Attachment A

Criteria

A. Protection for Areas in the Vicinity of Public-use Civil Airports

1. Classification of Airports. For the purpose of aeronautical study of proposed antenna structure, airports shall be classified in three categories: *large, small* and *personal* airports.[3]

a. Large airports shall be those having one or more existing or planned [4] runways of 3,500 feet in length or greater.

b. Airports with runways of 2,000 to 3,500 feet in length shall be classified as small.

c. All other airports shall be considered as personal airports.

2. Obstruction Limit Surfaces (JIGTSC). To provide for acceptable clearance between aircraft flight paths and antenna structures, such structures shall not extend

[1] This suggestion was acted upon favorably by the FCC.

[2] The NAB is now an Associate Member of the Washington Airspace Panel.

[3] All runway lengths used in the criteria are basic runway lengths for sea level sites under standard atmospheric conditions.

[4] Consideration to aeronautical facilities not in existence at the time of the filing of the application for radio facilities will be given only when reasonable notice of proposed airport construction or improvement plans are on file with the CAA as of the filing date of the application for such radio facilities.

above the imaginary surfaces defined below except where approved after aeronautical study:

(*a*) *Instrument Approach Areas (JIGTSC) (See Exhibit A).*

Instrument approach areas shall have the same definition and dimensions as set forth in FCC Part 17 as of this date, with the following exceptions:

Slope: The slope of the approach surface only along the runway center line extended shall be 50:1 and shall begin 2,000 feet outward from the end of existing or planned * runways.

NOTE: The over-all plan view length and width of the approach area remains as defined in Part 17 in that it begins 200 feet from the existing or planned * end of the runway (1,000 feet for military air bases), and extends outward for 50,000 feet. The change made herein affects only the sloping surface in that it starts at a greater distance outward from the runway.

(*b*) *Approach Areas (JIGTSC)—Other than Instrument Runway (See Exhibit A).*

(1) *Length:* Length of approach area shall be as presently defined in FCC Part 17.

(2) *Slope:* The slope of the approach area surface shall be 40:1 for Large, Small, and Personal type airports.

(3) *Width:* The width of the approach area shall be 500 feet at the end adjacent to the runway and 2,500 feet at the outward, or approach end. This shall apply to Large, Small and Personal airports.

NOTE: When application of the various criteria results in two or more surfaces intersecting, then the lower surface shall be considered as the significant surface for aeronautical study.

(*c*) *Circular Area Extending Outward from Airport Reference Point.* The surfaces established herein shall replace the horizontal and conical surfaces presently defined in FCC Part 17, and shall have the following dimensions (see Exhibit B).

(1) A *horizontal* surface, circular in shape, with its height 150 feet above the airport elevation and having a radius from the airport reference point as follows:

(*a*) For Large airports —2½ miles (13,200′)
(*b*) For Small airports —1½ miles (7,920′)
(*c*) For Personal airports—1½ miles (7,920′)

(2) An *inner* conical surface extending upward and outward from the periphery of the horizontal surface and having a slope of 40:1 for large and small airports, and 30:1 for personal airports. Measured radially outward from the periphery of the horizontal surface, the inner conical surface shall extend for a horizontal distance as follows:

(*a*) For Large airports —2½ miles (13,200′)
(*b*) For Small airports —1½ miles (7,920′)
(*c*) For Personal airports—2 miles (10,560′)

NOTE: The airport traffic pattern is considered to be within the area of 5 miles radius of large, and 3 miles for small and personal airports.

(3) An *outer conical* surface extending outward and upward from the periphery of the inner conical surface and having a slope of 100:1 for large and small airports, and 50:1 for personal airports. Measured radially outward from the periphery of the inner conical surface, the outer conical surface shall extend for a horizontal distance as follows:

(*a*) For Large airports —10 miles (52,800′)
(*b*) For Small airports — 2 miles (10,560′)
(*c*) For Personal airports— 1½ miles (7,920′)

3. **Approach and Landing Minimums.** Various criteria are employed in the establishment of initial approach altitudes, altitude over the facility on final approach, for holding and procedure turns, and landing minima. The base for the establishment of these values is the height of critical obstructions, including terrain within certain defined areas. Surfaces presently defined in FCC Part 17, together with the surfaces established or modified by the preceding criteria will serve to set the requirement for

aeronautical study of any proposed antenna structure that may have an adverse effect on the above minima.

B. Protection of Areas in the Vicinity of Military and Joint-use Airports

1. Obstructions 500 Feet and Under. That portion of the criteria in Section "A" which affects obstructions 500 feet or under applies to both public-use civil airports and military airports and is to be used as a basis for proposing amendments to Part 17 of the FCC Rules.

2. Obstructions Over 500 Feet. That portion of the criteria in Section "A" which affects obstructions over 500 feet applies only to public-use civil airports. The criteria for military and joint-use airports [1] are contained in AFR-86-3 and BUAER-11012.1. Whenever these criteria overlap due to proximity of airports, the more restrictive criteria will apply in the overlapping portion of airspace.

NOTE: Latest issues of AFR-86-3 and BUAER 11012.1 may be obtained from Departments of the Air Force and Navy.

C. Protection for Areas in the Vicinity of Heliports

Cognizance must be given to the operating characteristics of rotor-wing aircraft and to the requirements of aircraft with comparable operating characteristics with respect to the development and establishment of landing areas and routes which, insofar as civil operations are concerned, will normally be in built-up areas of dense population.

1. Heliports. A conical surface extending upward and outward to a horizontal distance of 4,000 feet from the edge of the existing or proposed heliport and having a slope of 20:1. Exceptions to the 20:1 slope may be made when proposed antenna construction is shielded by existing structures or obstructions of a permanent nature. For the purposes of these criteria, the edge of a heliport is considered to be 500 feet from its center, or the edge of the existing or planned [2] heliport, if the latter is greater than 500 feet from its center and shown on local aeronautical charts.

NOTE: Because of the early developmental stage of helicopter operations, no helicopter airways or flyways have been established. However, future needs for helicopter airways or flyways should be considered in analyzing the location and height of antenna structures.

D. Protection of Federal Airways Traffic (See Exhibit C)

1. On Airways. Unless adequately shielded by terrain or existing man-made structures, any proposal for new construction extending over 500 feet in height above ground, and located within the limits of designated civil airways or routes (5 miles each side of the center line) must be thoronghly weighed to determine whether or not such a tower would represent a hazard to air navigation.

2. Adjacent to Airways. In considering safety of flight along airways, the location and height of structures immediately adjacent to an airway are considered to offer a potential hazard to flight to a degree related to the longitudinal distance from the radio navigational aid, and lateral distance from the boundary of the airway. Structures which extend through the following-described planes adjacent to airways will be considered hazardous to air navigation, unless shielded by terrain or existing man-made structures, or approved by special aeronautical study.

a. Starting at a point 25 miles beyond the air navigation facility along the outer edges and 500 feet above the ground of an airway or route extending outward

[1] See Appendix 11 for June 1, 1957, list of Joint-Use Airports.

[2] Consideration to aeronautical facilities not in existence at the time of the filing of the application for radio facilities will be given only when reasonable notice of proposed airport construction or improvement plans are on file with the CAA as of the filing date of the application for such radio facilities.

and upward at a slope of 50:1 right angles to the airway for a horizontal distance of 5 miles each side of the airway.

b. Within 25 miles of a NAV Aid: This portion of the off-airway boundary narrows down to the width of the airway (10 miles) at a point right angles to the navigational aid.

3. In addition to the above, consideration shall be given to the following:

a. Cardinal altitudes (i.e., 1,000 feet; 2,000 feet; 3,000 feet, etc.) as presently established will not normally be modified to a non-cardinal figure (e.g., 1,200 feet; 1,500 feet; 2,400 feet; 2,900 feet).

b. Existing minimum en route altitudes, established at 1,500 feet MSL, will not normally be altered upward. (This will be particularly true in coastal dense traffic areas.)

c. Certain airways will be protected below the present established "Minimum En Route Altitude" where planning information indicates a requirement which may be satisfied by an additional VOR or through provision of DME or other aids.

d. The degree of change which may be tolerated for non-cardinal altitudes is dependent on factors, such as (a) density of en route and terminal air traffic, (b) prevailing weather conditions, (c) terrain, and a number of others. It is not believed practicable to establish a mechanical formula for application to this problem.

e. As a general rule civil airways extend on direct lines between adjacent air navigation radio aids. For air traffic control reasons, or to facilitate other operational advantages, airways are sometimes aligned to other than a direct routing. Where moving an airway could be accomplished without unreasonable penalty to aviation, to accommodate tall structures justified as a public need, such action may be taken.

E. Protection of Low-altitude Inter-city Routes

There are a few closely spaced large and medium size cities which generate a considerable amount of inter-city low-level traffic (such as Dallas-Forth Worth, San Francisco-Oakland, and Winston Salem-Raleigh) where it is necessary to keep the lower altitudes below the minimum en route airway altitude relatively free of obstructions in such areas to permit maximum flexibility in handling of air traffic. In other instances, the existence of a reasonably low MEA will often eliminate the necessity of inter-city instrument flight, by permitting flight underneath cloud levels. The following general procedures will be followed in aeronautical study of structures in these areas:

1. The minimum authorized altitude between closely spaced cities having substantial inter-city traffic will not normally be increased.

2. Structures extending over 500 feet above the ground should not be located within five miles of a direct line between two closely spaced airports where CAA has authorized or indicates plans for authorization of special low-altitude inter-city aircraft operation to expedite aircraft operations.

F. Protection of Flyways and Military Corridors

1. There are some areas, particularly in deserts, forests, large swamps, or mountainous country, where aircraft operating VFR are normally flown around large areas where emergency landings would be difficult, or down valleys, along rivers, through canyons, etc., at relatively low level to avoid hazardous terrain. Where this type of operation is relatively large, the routes flown are termed "Flyways." Airway radio aids are often utilized for weather information on these "Flyways," but not necessarily for air navigation. Where traffic on these "Flyways" is substantial and they are shown on aeronautical charts, specific aeronautical study shall be given to applications for towers over 170 feet above ground within five miles of the normal center line of these routes.

2. The general criteria for Federal Airways shall be applied to established military corridors in which low-level flight operations are required for military and Coast

Guard Air Stations. These corridors will normally be ten statute miles in width, extending from the stations to the coastal areas or between two military installations.

G. Provision of "Farm Areas" for the Erection of Radio and Television Towers

The above criteria are adopted with the understanding that "farm areas" [1] will be established in every community. In the establishment of the height of towers in these "farm areas," aviation interests will compromise their needs to the fullest extent possible in order to provide the tower heights required to deliver the maximum service to the public. To meet this objective, the above-noted criteria (JIGTSC, AFR-86-3 and BUAER 11012.1) will not apply.

[1] An antenna "farm" is an area where antenna towers having a common impact on aviation may be grouped.

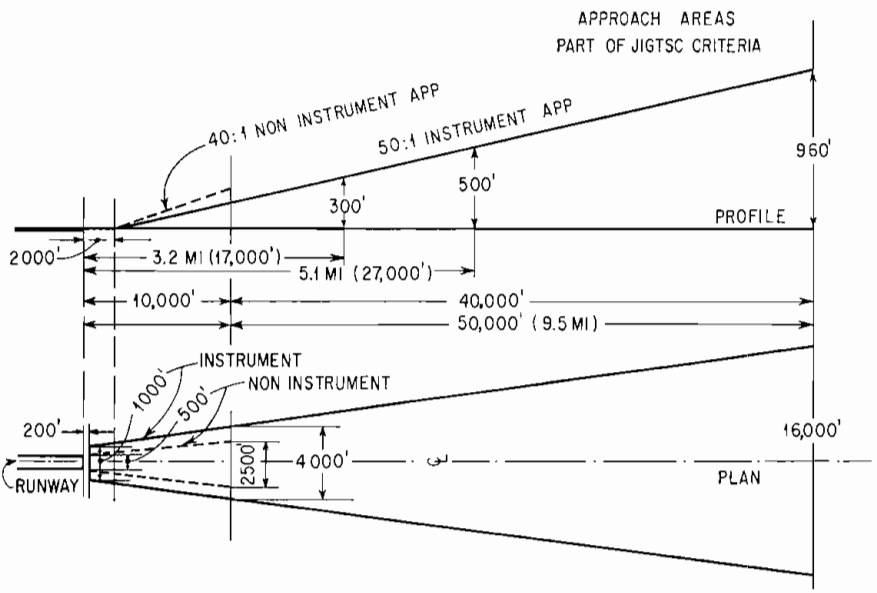
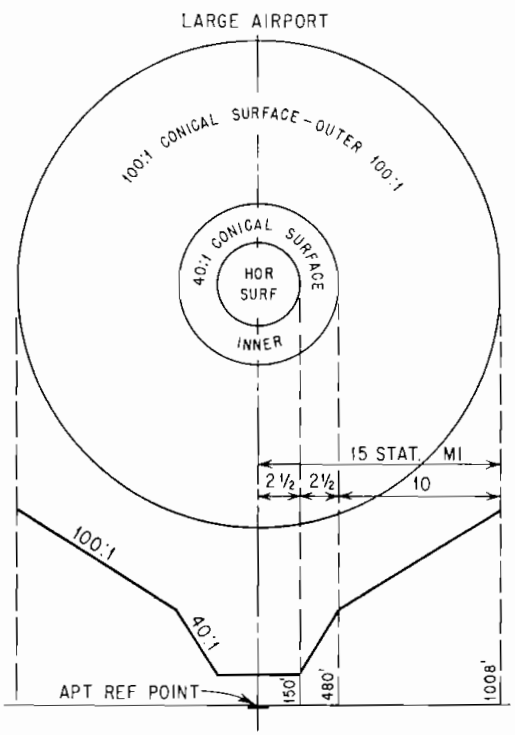


Exhibit A

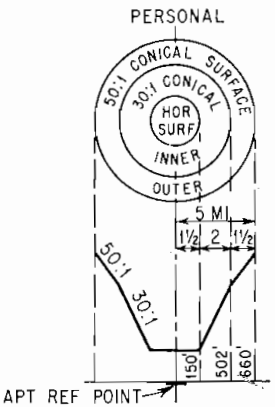


CIRCULAR AREAS
PART OF JIGTSC CRITERIA

AIRPORT CLASSIFICATION

1 PERSONAL SIZE APT. = RUNWAYS LESS THAN 2000'
2 SMALL SIZE APT. = " 2000 TO 3500
3 LARGE SIZE APT. = " 3500 & GREATER

NOTE:
ALL RUNWAY LENGTHS USED IN THE CRITERIA ARE BASIC RUNWAY LENGTHS FOR SEA LEVEL SITES UNDER STANDARD ATMOSPHERIC CONDITIONS



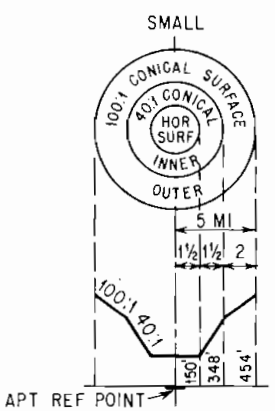


EXHIBIT B

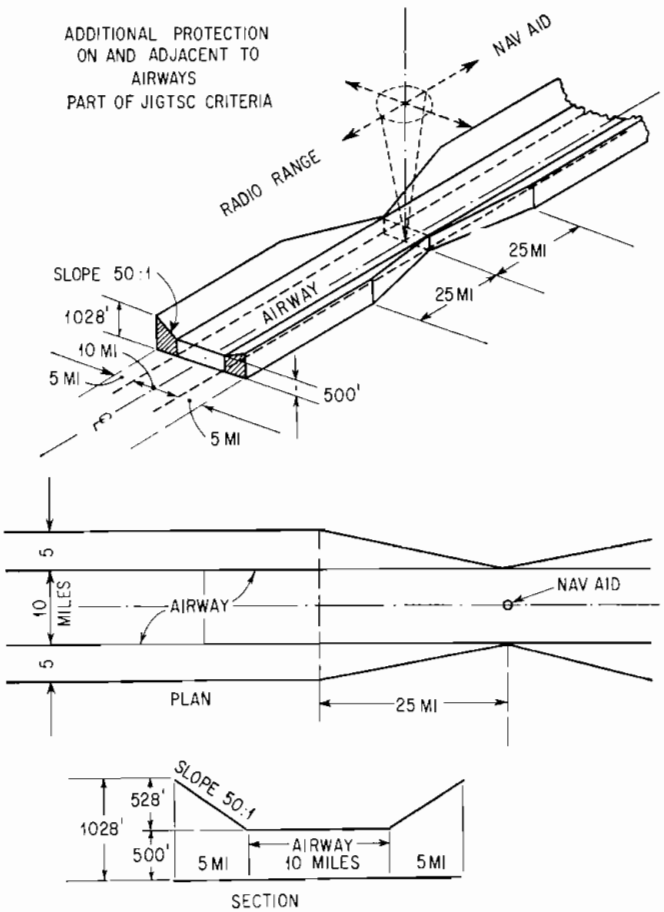

ADDITIONAL PROTECTION
ON AND ADJACENT TO
AIRWAYS
PART OF JIGTSC CRITERIA
NAV AID
RADIO RANGE
SLOPE 50:1
1028'
10 MI
5 MI
AIRWAY
25 MI
25 MI
500'
5 MI
5
10 MILES
5
AIRWAY
NAV AID
PLAN
25 MI
SLOPE 50:1
528'
1028'
500'
5 MI
AIRWAY
10 MILES
5 MI
SECTION

EXHIBIT C

Appendix I

Comparison of Part 17 and Proposed Amendments

(Sections of Part 17 not shown herein remain unchanged)

Part 17	*Proposed Amendments*
17.2(c) Approach surfaces and approach areas. The approach surface is an imaginary inclined plane through the air space located directly above the approach area. The dimensions of the approach area are measured horizontally. This inclined plane extends npward and outward from the beginning of the approach area starting at the elevation of the runway end.	17.2(c) No change.
17.2(c)(1) Length. The approach area has a length of 10,000 feet beginning 200 feet (1,000 feet for regular Department of Defense Air Bases) from the end of each runway and extending outward, ending at a point 10,200 feet (11,000 feet for regular Department of Defense Air Bases) from the end of the runway on the extended center line of the runway. In addition the approach areas of all runways which may be used for instrument operation shall extend outward an additional 40,000 feet. The approach area requirements for instrument runways shall apply to all runways which may be used for instrument operations and to both ends of such runways.	17.2(c)(1) No change.
17.2(c)(2) Width. The approach area is symmetrically located with respect to the extended runway center line, and for all instrument runways has a total width of 1,000 feet (1,500 feet for regular Department of Defense Air Bases) at the end adjacent to the runway. The approach area flares uniformly to a total width of 4,000 feet at the end of the 10,000-foot section and to a total width of 16,000 feet at the end of the additional 40,000-foot section. For all other runways not designated for instrument operation, the approach area has a total width at the end adjacent to the runway, and at the approach end, respectively, as follows: For express air carrier service and larger airports, 500 feet and 2,500 feet; for trunk line air carrier service airports, 400 feet and 2,400 feet; for feeder air carrier service airports, 300 feet and 2,300 feet; for secondary airports, 250 feet and 2,250 feet.	17.2(c)(2) Width. The approach area is symmetrically located with respect to the extended runway center line, and for all instrument runways has a total width of 1,000 feet (1,500 feet for regular Department of Defense Air Bases) at the end adjacent to the runway. The approach area flares uniformly to a total width of 4,000 feet at the end of the 10,000-foot section and to a total width of 16,000 feet at the end of the additional 40,000-foot section. For all other runways not designated for instrument operation on both large and small airports, the approach area has a total width of 500 feet at the end adjacent to the runway and 2,500 feet at the outward, or approach end.
17.2(c)(3) Slope. For instrument runways the slope of the approach surface along the runway center line extended is 50:1 (an elevation of 1 foot for each 50 feet of horizontal distance) for the inner 10,000-foot section and 40:1 (an elevation of 1 foot for each 40 feet of horizontal dis-	17.2(c)(3) Slope. For instrument runways the slope of the approach surface along the runway center line extended is 50:1 (an elevation of 1 foot for each 50 feet of horizontal distance) beginning at a point 2,000 feet from the end of each runway. For non-instrument runways the slope of the

Part 17

tance) for the outer 40,000-foot section. All other runways, not designated for instrument operation which meet or exceed the minimum runway length requirements for feeder air carrier service shall have a slope of 40:1. On airports with shorter runway lengths than those specified for feeder air carrier service, the slope of the approach surface is 20:1 (an elevation of 1 foot for each 20 feet of horizontal distance) for all runways.

17.2(d) Conical surface. The conical surface is an imaginary surface through the air space extending upward and outward from the periphery of the horizontal surface and having a slope of 20:1 measured in a vertical plane passing through the airport reference point. Measuring radially outward, from the periphery of the horizontal surface, the conical surface extends for a horizontal distance of 7,000 feet for intercontioental express airports, intercontinental airports and Department of Defense Air Bases; and 5,000 feet for continental, express, trunk line and feeder airports, and 3,000 feet for all smaller airports.

17.2(j) Horizontal surface. The horizontal surface is an imaginary plane through the airspace, circular in shape, with its height 150 feet above the established airport elevation and having a radius from the airport reference point as indicated in the following table:

Proposed Amendments

approach surface is 40:1 beginning at a point 2,000 feet from the end of each runway.

17.2(d)(1) *Inner Conical Surface.* The inner conical surface is an imaginary surface through the airspace extending upward and outward from the periphery of the horizontal surface and having a slope of 40:1 for large and small airports and 30:1 for personal airports. Measuring radially outward, from the periphery of the horizontal surface, the conical surface extends for a horizontal distance as follows:

(*a*) Large airports —2½ miles (13,200′)
(*b*) Small airports —1½ miles (7,920′)
(*c*) Personal airports—2 miles (10,560′)

17.2(d)(2) *Outer Conical Surface.* The outer conical surface is an imaginary surface through airspace extending upward and outward from the periphery of the inner conical surface and having a slope of 100:1 for large and small airports and 50:1 for personal airports. Measuring radially outward from the periphery of the inner conical surface, the outer conical surface shall extend for a horizontal distance as follows:

(*a*) Large airports —10 miles (52,800′)
(*b*) Small airports —2 miles (10,560′)
(*c*) Personal airports—1½ miles (7,920′)

17.2(d)(3) *Conical Surface for Heliports.* The conical surface for heliports is an imaginary surface through the airspace extending upward and outward from the edge of the heliport and having a slope of 20:1. Measuring radially outward from the edge of the heliport, the conical surface for heliports extends for a horizontal distance of 4,000 feet. The edge of a heliport is considered to be 500 feet from the center, or the edge of the existing or planned heliport, if the latter is greater than 500 feet from its center and shown on local aeronautical charts.

17.2(j) *Horizontal Surface.* The horizontal surface is an imaginary plane through the air space, circular in shape with its height 150 feet above the established airport elevation and having a radius from the airport reference point as follows:

Part 17

	Feet
Intercontinental express airports and Dept. of Defense Air Bases	13,000
Intercontinental airports	11,500
Continental airports	10,000
Express airports	8,500
Trunk line airports	7,000
Feeder airports	6,000
All smaller airports	5,000

The category of every airport in accordance with the above classifieation is designated by the Administrator of Civil Aeronautics.

17.2(n) Transitional surfaces. The transitional surfaces are imaginary inclined planes through the airspace having a slope of 7:1 (an elevatoin of 1 foot for each 7 feet of horizontal distance) measured upward and outward in a vertical plane at right angles to the axis of the runway. The transitional surfaces, symmetrically located on either side of the runway, extend upward and outward from a line on either side of the runway which is parallel to and level with the runway center line. These parallel lines are at a horizontal distance from the runway center line equal to one-half of the minimum width of the approach area indicated in paragraph (c)(2) of this section. Transitional surfaces extend from the edges of all approach surfaces upward and outward to the intersection with the horizontal surface or the conical surface. The approach surfaces for instrument runways projecting through and beyond the limits of the conical surface shall have 7:1 transitional surfaces extending a distance of 5,000 feet measured horizontally from the edge of the approach surfaces and at right angles to the runway axis.

NONE

NONE

NONE

Proposed Amendments

(1) Large airports —2½ miles (13,200')
(2) Small airports —1½ miles (7,920')
(3) Personal airports—1½ miles (7,920')

17.2(n) No change.

17.2(o) Low Altitude Inter-city Route. A low altitude Inter-city Route is a route authorized by CAA for air carrier operation between two closely located cities (airports) at an altitude or altitudes generally lower than the minimum enroute altitude authorized for flight on the airway joining the two cities.

17.2(p) Flyways. A flyway is a "Natural" route between two points, shown on Aeronautical charts and extensively flown in VFR operations to avoid high terrain, or to follow natural landmarks (rivers) where radio navigational facilities are not available.

17.2(q) Large Airports. For the purpose of this part, large airports are those having one or more runways of 3,500 feet in length, or greater.

Part 17	*Proposed Amendments*
NONE	17.2(r) Small Airports. For the purpose of this part, small airports are those having runways of 2,000 to 3,500 feet in length.
NONE	17.2(s) Personal Airports. For the purpose of this part, personal airports are those having all runways of less than 2,000 feet in length.
17.12(a) Where antenna structures less than 500 feet in height would necessitate the raising of the minimum flight altitude with the Civil Airways and designated air traffic control areas in the country.	17.12(a) Where antenna structures less than 500 feet in height would necessitate the raising of the minimum flight altitude within: (1) the Civil Airways, (2) designated air traffic control areas, and (3) CAA authorized low altitude inter-city routes.
17.12(b) In areas of established coastal corridors.	17.12(b) In areas of established coastal corridors (normally 10 miles in width).
17.12(c) Where the antenna structure would project above the landing area, or the limiting heights or surfaces, specified in paragraph 17.15, of all airports now in existence or provided for in approved plans.	17.12(c) No change.
NONE	17.12(d) Where the antenna structure is located within 5 miles of the center line of established and published flyways.

Appendix II

A. U.S. Air Force Bases Permitting Civil Use °

Air Force installations used by civil aircraft:

California
AF Plant No. 42, Palmdale
Colorado
Lowry AFB, Denver
Delaware
Dover AFB, Dover
Florida
Palm Beach AFB, Palm Beach
Georgia
Hunter AFB, Savannah
Kansas
McConnell AFB, Wichita
Louisiana
Lake Charles AFB, Lake Charles
Maine
Dow AFB, Bangor
Presque Isle AFB, Presque Isle
Massachusetts
Westover AFB, Chicopee Falls
Michigan
Kinross AFB, Kinross
Nebraska
Lincoln AFB, Lincoln
New Hampshire
Grenier AFB, Manchester
New Mexico
Clovis AFB, Clovis
Holloman AFB, Alamogordo
Kirtland AFB, Albuquerque
Nevada
Stead AFB, Reno
Oklahoma
Ardmore AFB, Ardmore
South Carolina
Charleston AFB, Charleston
Myrtle Beach AFB, Myrtle Beach
Texas
Amarillo AFB, Amarillo
Harlingen AFB, Harlingen
Kelly AFB, San Antonio
Laredo AFB, Laredo
Webb AFB, Big Spring
Sheppard AFB, Wichita Falls
Washington
Fairchild AFB, Spokane
McChord AFB, Tacoma
Paine AFB, Everett

° As of June 1, 1957.

B. Civil Airfields with U.S. Army, Navy, Air Force, and Air National Guard on Tenant Status *

Civil airfields on which the Department of Defense has a current requirement:

Airport Name	*Location*	*Military Activity*		
	Alabama			
Bates Field	Mobile			USA
Birmingham	Birmingham	USN †	ANG	USA
Huntsville	Huntsville			USA
Dannelly	Montgomery		ANG	
	Arizona			
Bisbee-Douglas Int.	Douglas			USA
Sky Harbor	Phoenix		ANG	USA
Tucson	Tucson		ANG	USA
	Arkansas			
Fort Smith	Fort Smith	USN	ANG	
Adams Field	Little Rock		ANG	
	California			
Chico	Chico	USAF		
Fresno Air Terminal	Fresno	USN †	ANG	
Hayward	Hayward		ANG	
Lindberg	San Diego	USN		
Long Beach	Long Beach	USAF USN		USA
Los Angeles Int.	Los Angeles	USN		
Mills	San Francisco	USN		
Monterey Peninsula	Monterey	USN		
Oakland Int.	Oakland	USN		
Ontario Int.	Ontario		ANG	
San Fernando Valley	Los Angeles/Van Nuys		ANG	USA
Sacramento	Sacramento	USN		
Stockton	Stockton			USA
Tracy	Tracy			USA
	Colorado			
Peterson Field	Colorado Springs	USAF		USA
	Connecticut			
Bridgeport	Bridgeport			USA
Brainard Field	Hartford			USA
Bradley Field	Windsor Locks	USN	ANG	USA
	Delaware			
New Castle County	Wilmington	USAF	ANG	USA
	District of Columbia			
Washington National	Washington	USAF USN		
	Florida			
Imeson Field	Jacksonville		ANG	USA
Lodwick Field	Lakeland			USA
Miami Int.	Miami	USAF		USA
Orlando	Orlando	USAF USN		
Pinellas County Int.	St. Petersburg	USAF		
Tampa Int.	Tampa			USA
Milton OLF	Milton	USN		
Pensacola OLF (Hagler)	Pensacola	USN		

* As of June 1, 1957.
† Navy use two days per month.

Georgia

Airport Name	*Location*	*Military Activity*		
Fulton County	Atlanta		USN	USA
Muscogee County	Columbus			USA
Cochran Field	Macon			USA
Travis Field	Savannah		ANG	USA

Idaho

Boise Air Terminal	Boise		ANG	USA
Caldwell	Caldwell			USA
Idaho Falls	Idaho Falls			USA
Nez Perce County	Lewiston			USA
Pocatello	Pocatello			USA
Joslin Field	Twin Falls			USA

Illinois

Chicago-Hammond	Chicago			USA
O'Hare-Chicago Int.	Chicago	USAF	ANG	
Lewis-Lockport	Lockport			USA
Greater Peoria	Peoria		ANG	
Qual City	Rock Island			USA
Capital	Springfield		USN ANG	
Midway	Chicago		ANG	
Illinois Urbana	Urbana			USA

Indiana

Dress Memorial	Evansville	USAF	USN	USA
Baer Field	Fort Wayne		USN ANG	
Stout Field	Indianapolis			USA
Weir Cook	Indianapolis		USN	
Hulman Field	Terre Haute		USN ANG	

Iowa

Atlantic	Atlantic			USA
Boone	Boone			USA
Denison	Denison			USA
Des Moines	Des Moines		USN ANG	
Fairfield	Fairfield			USA
Fort Dodge	Fort Dodge			USA
Ottumwa	Ottumwa		USN	
Sibley	Sibley			USA
Waterloo	Waterloo			USA
Sioux City	Sioux City	USAF	USN ANG	

Kansas

Dodge City	Dodge City			USA
Fort Scott	Fort Scot			USA
Great Bend	Great Bend		USN	
Hiawatha	Hiawatha			USA
Hutchinson	Hutchinson			USA
Iola	Iola			USA
Conard Field	Ottawa			USA
Philip Billard	Topeka			USA

Kentucky

Blue Grass	Lexington			USA
Bowman Field	Louisville		USN	USA
Standiford Field	Louisville		ANG	

Louisiana

Lafayette	Lafayette			USA
New Orleans	New Orleans		ANG	USA
Shreveport-Downtown	Shreveport		USN	

Maine

Airport Name	*Location*	*Military Activity*		
P & M Airfield	Fort Fairfield			USA
Port of Maine	South Portland			USA
Augusta State	Augusta			USA

Maryland

Friendship Int.	Baltimore	USAF			
Harbor Field	Baltimore		USN	ANG	USA
Hagerstown	Hagerstown		USN		

Massachusetts

Hanscom	Bedford	USAF			
Logan	Boston			ANG	
Barnes	Westfield		USN	ANG	

Michigan

Collins	Alpena			ANG	
Kellogg Field	Battle Creek		USN	ANG	
Detroit-Wayne Major	Detroit			ANG	
Willow Run	Detroit	USAF	USN		
Abrams	Grand Ledge				USA
Kent County	Grand Rapids		USN		
McNamara Field	Grayling				USA
K. I. Sawyer	Marquette	USAF			
Brooks Field	Marshall				USA

Minnesota

Bemidgi	Bemidgi		USN [a]		
Duluth	Duluth	USAF		ANG	
Minneapolis-St. Paul Int.	Minneapolis	USAF	USN		
Holman Field	St. Paul			ANG	USA

Mississippi

Hawkins Field	Jackson		USN	ANG	USA
Key Field	Meridian			ANG	
Gulfport Mun.	Gulfport			ANG [a]	

Missouri

Memorial	Cape Girardeau		USN		USA
State Line	Kansas City				USA
Southwest	St. Louis				USA
Lambert Field	St. Louis		USN	ANG	USA
Rosecrans Field	St. Joseph			ANG	
Maryville Memorial	Maryville				USA
Sky Haven	Warrensburg				USA
Mexico Memorial	Mexico				USA

Montana

Billings	Billings				USA
Gallatin Field	Bozeman				USA
Glasgow	Glasgow				USA
Great Falls	Great Falls			ANG	
Helena	Helena				USA
Flathead County	Kalispell				USA
Missoula County	Missoula				USA

Nevada

Reno	Reno			ANG	USA

New Hampshire

Manchester-Grenier	Manchester				USA

[a] Summer Cruise Station.

Airport Name	*Location*	*Military Activity*			
		New Jersey			
Atlantic City	Atlantic City		USN		
Mercer County	Trenton		USN		USA
Newark	Newark			ANG	
Linden	Linden				USA
Monmouth County	Belmar				USA
		New York			
Albany	Albany				USA
Zahns	Amityville				USA
Niagara Falls	Niagara Falls	USAF	USN	ANG	USA
Dutchess County	Poughkeepsie				USA
Monroe County	Rochester				USA
Schenectady	Schenectady		USN	ANG	
Hancock	Syracuse			ANG	USA
Westchester County	White Plains			ANG	USA
Gruman	Bethpage, L.I.		USN		
		North Carolina			
Douglas	Charlotte		USN	ANG	USA
Greensboro-High Point	Greensboro		USN		USA
Jackson	Kinston				USA
Lenoir	Lenoir				USA
Franklin	Louisburg				USA
Raleigh-Durham	Raleigh				USA
Rocky Mount	Rocky Mount				USA
Washington	Washington				USA
New Hanover County	Wilmington		USN		
		North Dakota			
Bismarck	Bismarck				USA
Hector	Fargo		USN *	ANG	
		Ohio			
Akron	Akron		USN		
Akron-Cantnn	Akron			ANG	
Cincinnati-Lunken	Cincinnati		USN		USA
Cuyahogan County	Cleveland				USA
Port Columbus	Columbus		USN		
Ohio State University	Columbus				USA
Mansfield	Mansfield			ANG	
Springfield	Springfield			ANG	
Toledo Mun.	Toledo				USA
Toledo Express	Toledo			ANG	
Youngstown	Youngstown	USAF			
Zanesville	Zanesville		USN		
		Oklahoma			
Davis Field	Muscogee	USAF			
Westheimer	Norman		USN		USA
Will Rogers	Oklahoma City		USN	ANG	
Tulsa	Tulsa		USN	ANG	
Tishomingo	Tishomingo		USN		
		Oregon			
Klamath Falls	Klamath Falls	USAF			
Portland Int.	Portland	USAF		ANG	USA
McNary	Salem		USN		

* Navy use two days per month.

Pennsylvania

Airport Name	*Location*	*Military Activity*			
Wings Field	Ambler				USA
Port Erie	Erie				USA
Harrisburg-State	Harrisburg				USA
New Castle	New Castle				USA
Taylor	New Kingstown				USA
Philadelphia Int.	Philadelphia			ANG	USA
Greater Pittsburgh	Pittsburgh	USAF	USN	ANG	
Allegheny County	Pittsburgh				USA
General Spaatz	Reading			ANG	
Mifflin County	Reedsville				USA
York	Thomasville				USA
Washington	Washington				USA
Wyoming Valley	Wilkes-Barre				USA

Rhode Island

Green	Providence			ANG	USA

South Carolina

Columbia	Columbia		USN		
Florence	Florence				USA
Memorial	Spartanburg				USA

South Dakota

Halley	Rapid City				USA
Foss Field	Sioux Falls			ANG	

Tennessee

McMinn County	Athens				USA
Lovell Field	Chattanooga				USA
Outlaw Field	Clarksville				USA
Putnam County	Cookeville				USA
McKellar Field	Jackson				USA
McGhee-Tyson	Knoxville	USAF	USN		
Gill-Dove	Martin				USA
Memphis	Memphis	USAF		ANG	USA
Murfreesboro	Murfreesboro				USA
Berry Field	Nashville			ANG	USA
Northern Field	Tullahoma	USAF			

Texas

Alice Mun.	Alice		USN		
Aransas County	Rockport		USN		
El Paso Int.	El Paso				USA
Houston Int.	Houston		USN		
Mineral Wells	Mineral Wells				USA
San Antonio Int.	San Antonio				USA
Mathis Field	San Angelo				USA

Utah

Cedar City	Cedar City				USA
Logan-Cache County	Logan				USA
Ogden	Ogden				USA
Provo	Provo				USA
Salt Lake City #1	Salt Lake City		USN	ANG	USA

Vermont

Burlington	Burlington	USAF		ANG	USA

Virginia

Covington	Covington				USA
Danville	Danville				USA

Airport Name	*Location*	*Military Activity*		
Norfolk	Norfolk			USA
Byrd Field	Richmond	USAF	ANG	USA
Woodrum Field	Roanoke	USN		USA
	Washington			
Bellevue	Bellevue			USA
Chehalis County-City	Chehalis			USA
Felts Field	Spokane			USA
Geiger	Spokane	USAF	USN ANG	
Kitsap County	Bremerton	USN		
Pearson Airpark	Vancouver			USA
	West Virginia			
Kanawha County	Charleston	USN	ANG	USA
Tri-State	Huntington			USA
Martinsburg	Martinsburg		ANG	
Morgantown	Morgantown			USA
Wheeling-Ohio County	Wheeling			USA
	Wisconsin			
Ean Claire	Eau Claire			USA
Kenosha	Kenosha			USA
Truax Field	Madison	USAF	ANG	
General Mitchell	Milwaukee	USAF	USN ANG	
Curtiss Wright	Milwaukee			USA
Phillips	Phillips			USA
Stevens Point	Stevens Point			USA
Richard Bong	Superior			USA
	Wyoming			
Casper Air Terminal	Casper		ANG	USA
Cheyenne	Cheyenne		ANG	USA
Douglas	Douglas			USA
Brees	Laramie			USA
Sheridan County	Sheridan			USA

C. U.S. Navy Bases Permitting Civilian Use *

Location	*Airlines Landing Regularly*	*NOy(R)*	
Adak, Alaska	Northwest Airlines, Inc	49144	
	Reeve Aleutian Airways, Inc.	45787	43266
	Northwest Orient Airlines	Process	
Agana, Guam	Pacific Overseas Airlines	43383	
	Transocean Air Lines	43324	
	Pan American Airways, Inc.	43380	
	Seaboard and Western Airlines, Inc.	48368	
Kodiak, Alaska	Alaska Air Lines, Inc.	43371	
	Reeve Aleutian Airways, Inc.	43265	
	Pacific Northern Airlines	43335	43336
	Aviation Corp. of Seattle	45473	
	Northern Consolidated Airlines, Inc.	43379	44873
	Transocean Air Lines	45166	
	Pan American World Airways	44770	
Green Cove Springs, Florida	Airway Service of Florida, Inc.		
San Clemente, Cal.	Avalon Air Transport (to 1 November 1957)		
Honolulu, T.H.	South Pacific Air Lines	49384	
Iwakuni, Japan	Civil Air Transport, Inc.	Process	

* Current as of 1 June 1957. Authorized under SECNAV Instruction 3770.1 of 20 May 1952.

NAVAL AIRFIELDS WHERE CIVIL USE IS PERMITTED *

Active Navy owned and/or controlled airfields where civil use is permitted under joint-use agreements:

NAS Atlantic City, N.J.	City of Atlantic City	49190
OLF North Perry, Florida	Broward County, Florida	60237
NAAS Chase Field, Beeville, Texas	City of Beeville	48949

Inactive Navy owned or controlled airfields where civilian use is permitted by contract:

Arlington, Washington	Town of Arlington	44857
	Town of Arlington	45179
Cuddihy Field, Texas	City of Corpus Christi	60302
Ottumwa, Iowa	City of Ottumwa	42997
Shelton, Washington	Mason County	44787
Tillamook, Oregon	Tillamook County	36691
	Tillamook County	42821
Richmond, Florida	University of Miami	60127
Martha's Vineyard, Mass.	Transferred in fee to Dukes County	46432

Appendix III

AFR 86–3 †

AIR FORCE REGULATION
NO. 86–3

DEPARTMENT OF THE AIR FORCE
WASHINGTON, *14 AUGUST 1956*

Installation Planning and Development

Criteria for Determining Obstructions to Air Navigation

Purpose: This regulation establishes the criteria for determining if an object or structure is an obstruction to air navigation. (Airfield zoning is described in AFR 86–11.)

1. RESPONSIBILITY FOR COMPLIANCE. Echelons of command responsible for the use of navigable airspace, airfield clearances, and airfield planning will comply with this regulation.

2. DEFINITIONS. Any natural object or man-made structure that protrudes above the planes or surfaces defined below and in paragraph 3 is considered an obstruction to air navigation. The attachments to this regulation illustrate the following definitions. If conflict exists between the definition and the illustration, the definition will govern.

a. Air Force Airfield—An area on the ground designated and used to accommodate take-offs, landings, servicing, and parking for Air Force aircraft.

b. Airfield Reference Point—A designated point on an Air Force airfield from which distances relating to specific criteria referred to in this regulation are measured. For the purpose of this regulation, the airfield reference point will be the existing control tower or a point upon which such a tower normally would be erected. (See attachment 1.)

c. Established Airfield Elevation—The elevation, in feet above mean sea level, of the highest point on the landing area which is used or intended to be used for takeoff and landing operations.

d. Landing Area—A specially prepared surface within the boundaries of an airfield designed for aircraft takeoff and landing operations. It includes the paved surface (runway and shoulders) and the safety zones immediately adjacent thereto which have been cleared of all above-ground obstructions. In no case will the width of the landing area be less than the width of the approach area at the end of the runway. (See attachments 2 and 3.)

e. Clear Zone—The areas immediately adjacent to ends of a runway which have been cleared of all above-ground obstructions and graded to prevent damage to aircraft which undershoot or overrun the runway. The standard clear zone dimensions are 1,000 feet long

* Current as of 1 June 1957.

† This regulation supersedes AFR 86–3, 9 May 1956.

(measured along the extended runway center line) and 2,000 feet wide (1,000 feet on each side of the extended runway center line). (See attachments 2 and 3.)

f. Approach Zone—An area beyond each clear zone, extending on the ground for a distance of 25,000 feet along and symmetrical about the exteuded center line of the runway. The width of the approach zone at the end of the clear zone is 2,000 feet; it flares to 4,000 feet at 10,000 feet from the end of the clear zone; and it remains 4,000 feet wide for the additional 15,000 feet. (See attachments 2 and 3.)

g. Approach Surface—An imagiuary plane above the approach zone, beginning at the end of the clear zone at the elevation of the end of the runway and rising over the approach zone on a slope of 50 to 1 (known as the glide angle) for a horizontal distance of 10,000 feet (200 feet above elevation of end of runway). From this point the controlling elevation of the approach surface will remain at 200 feet until the end of the approach zone (25,000 feet from the end of the clear zone). (See surfaces lettered A and B.)

h. Approach Area—The clear zone and the approach zone combined. The standard approach area is symmetrical about the extended center line of the runway.

i. Inner Horizontal Surface—An imaginary plane located 150 feet above the established airfield elevation. The extent of this surface will be limited to an area included within a circle having a radius of 10,000 feet measured from the airfield reference point. (See surfaces lettered D.)

j. Transitional Surface—Joins the landing area, the clear zone, and the approach surface to the inner and outer horizontal surfaces and the inner conical surface. The slope of the transitional surfaces is 7 to 1 outward and upward measured at right angles to the axis of the runway except at the extreme end of the approach surface where this slope is measured parallel to the runway axis. To determine the elevation for the beginning of the transitional surface slope at any point along the lateral boundary of the landing area including the clear zone, draw a line from the point to the runway center line. This line will be at right angles to the runway axis. The elevation at the runway center line is the elevation for the beginning of the 7 to 1 slope. (See surfaces lettered C and E.)

k. Inner Conical Surface—An imaginary surface extending outward and upward from the periphery of the horizontal surface for a distance of 7,000 feet. The slope of the conical surface will be 20 to 1. (See surfaces lettered F.)

l. Outer Horizontal Surface—An imaginary plane located 500 feet above the established airfield elevation. The extent of this surface will be limited to an area included between a circle having a radius of 17,000 feet, the upper and outer periphery of the inuer conical surface, and a circle having a radius of 50,000 feet from the airfield reference point. (See areas lettered G.)

m. Outer Conical Surface—An imaginary surface extending outward and upward from the periphery of the outer horizontal surface for a distance of 100,000 feet, measured horizontally from the airfield reference point. The slope of the outer conical surface will be 100 to 1. (See surfaces lettered H.)

3. Objects or Structures Beyond 100,000 Feet. Objects or structures which are, or are proposed to be, located at a distance greater than 100,000 feet from the airfield reference point are considered obstructions to air navigation if:

a. The top protrudes above the 100 to 1 slope of the outer conical surface (see paragraph 2*m*) extended and, for man-made structures, the top elevation is more than 500 feet above the grounnd elevation at the site; or

b. The top elevation is more than 1,000 feet above the ground elevation at the site.

4. Removal of Obstructions. Natural and man-made obstructions will be removed where removal is both feasible and economical. Where such removal is not feasible or economical, obstructions will be lighted and marked in accordance with AFR 91–14 and AFR 91–19.

5. Waivers on Air Force Controlled Property:

a. Permanent. Deviations of a permanent nature from the provisions of this regulation for obstructions, including the granting of a waiver, will not be permitted without the written permission of Headqnarters USAF. Requests for such deviations will be submitted through channels to the Director of Real Property, Headquarters USAF, Washington 25, D.C.

b. Temporary. Temporary deferment of the enforcement of this regulation for obstructions may be approved by the major air command concerned in the following instances and after the request for waiver has been concurred in by the interested operational, safety, and maintenance officer and the installations engineer at both base and command level.

(1) Enforcement of the criteria is to be deferred pending construction of a new facility which has been authorized and funded by the Congress.

(2) Enforcement of the criteria is to be deferred pending minor new construction or rehabilitatiou of a facility which has been approved and funded at the appropriate Air Force level.

(3) Waivers to permit use of experimental equipment will be limited to 1 years' duration.
(4) Deferment of enforcement of the criteria required by circumstances not covered above will be limited to 1 year's duration.

c. Major Air Command Authority for Temporary Waiver. The major air commands in exercising the authority herein granted will:

(1) Insure that the spirit and intent of this regulation are observed to the maximum extent to maintain hazard-free airfields, and
(2) Stipulate and require conformance with all reasonable safeguards to maintain a high degree of safety, and
(3) Maintain for record purposes a copy of all correspondence, maps, drawings, and other pertinent information concerning the granting of the waiver. Such records will include the certification of appropriate staff coordination of the action taken at base and each level of command.

6. WAIVERS ON OTHER PROPERTY. The control of the erection of structures which are or will be obstructions on land not under the jurisdiction of the Air Force will be governed by the provisions of AFRs 55–103, 86–2, and 86–11.

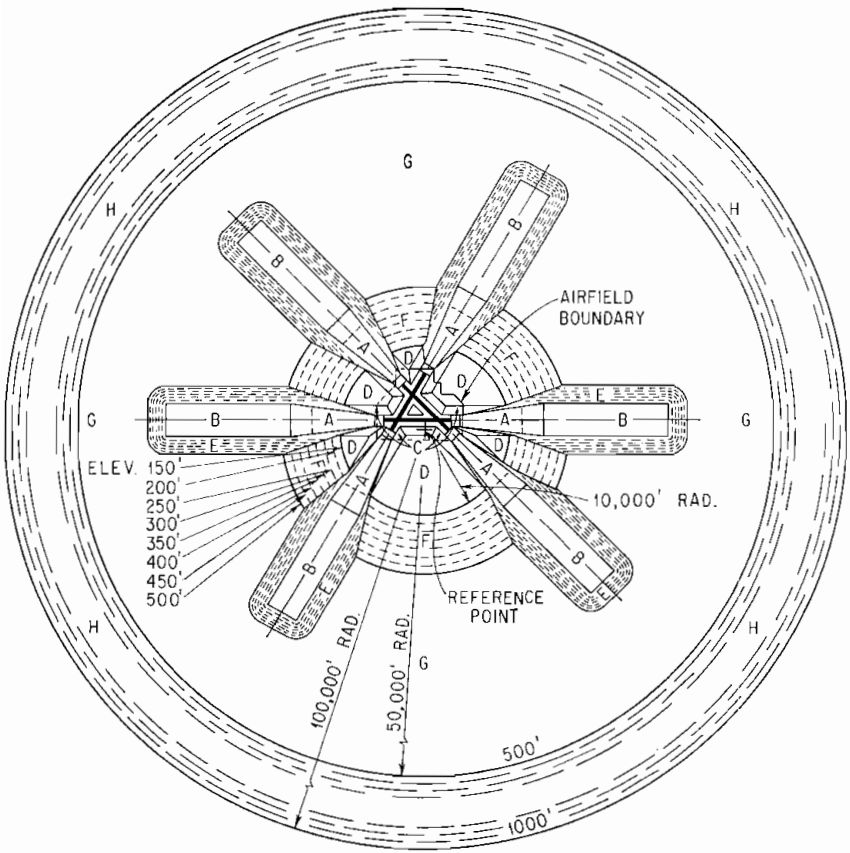
BY ORDER OF THE SECRETARY OF THE AIR FORCE:

OFFICIAL:

N. F. TWINING
Chief of Staff, United States Air Force

E. E. TORO
Colonel, USAF
Air Adjutant General

4 Attachments:
1. Airspace Control Surfaces—Plan
2. Standard Runway Approach Zone—Plan
3. Standard Runway Approach Zone—Transverse Elevation
4. Airspace Control Surfaces—Sectional Perspective



PLAN

FIGURE 1. Airspace control surfaces.

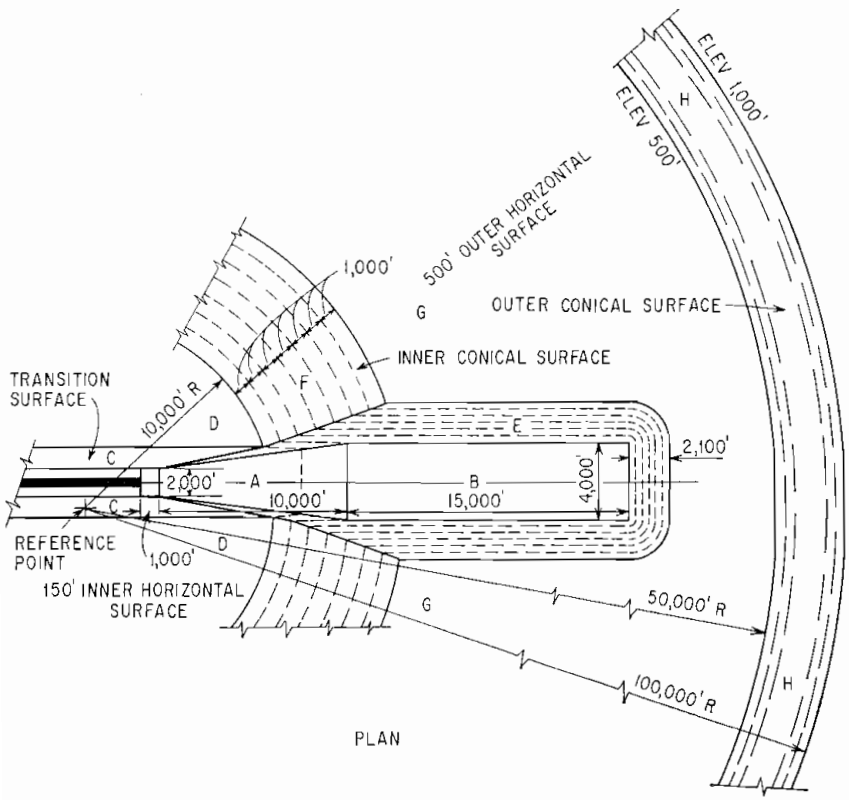


FIGURE 2. Standard runway approach zone.

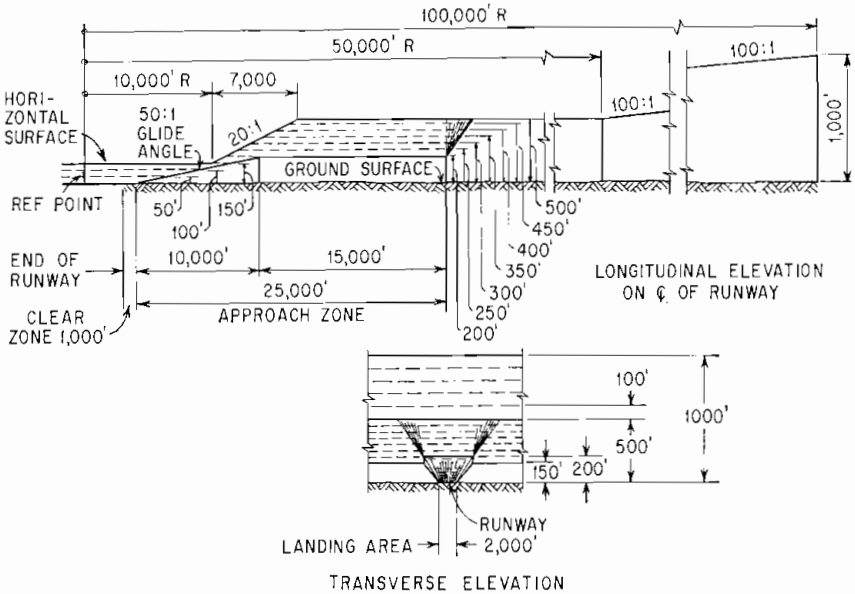


FIGURE 3. Standard runway approach zone.

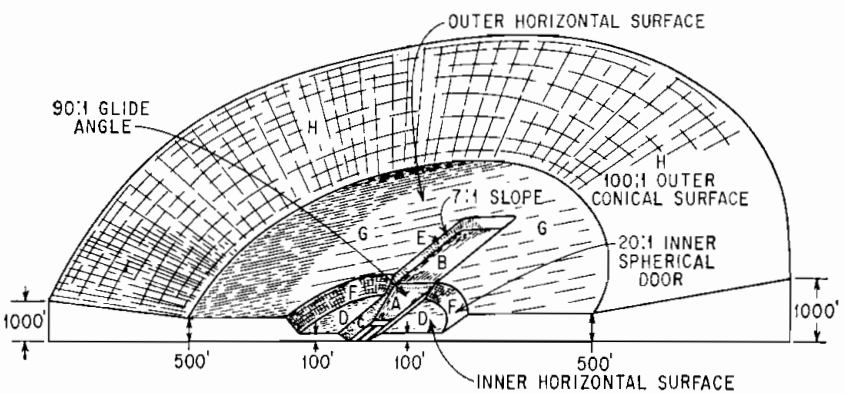
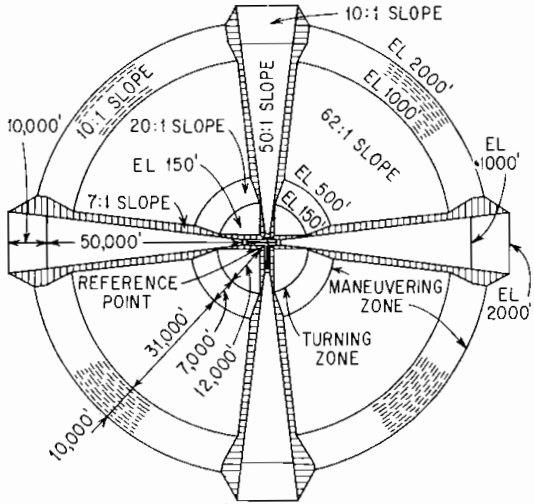
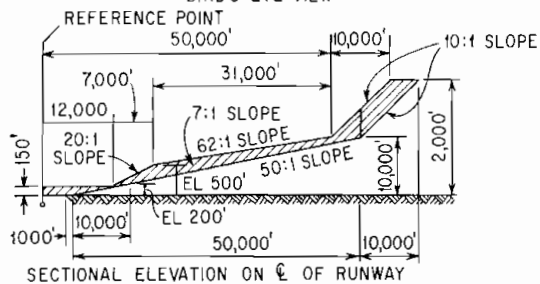


FIGURE 4. Airspace control surfaces (sectional perspective).



BIRD'S EYE VIEW

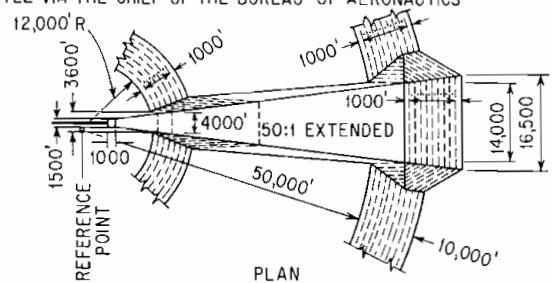


SECTIONAL ELEVATION ON ℄ OF RUNWAY

NOTES

1. TERRAIN OR STRUCTURES WHICH PROJECT ABOVE ANY OF THE IMAGINARY SURFACES SHALL BE CONSIDERED AS OBSTRUCTIONS TO AIR NAVIGATION
2. MAN MADE STRUCTURES OTHER THAN PROVIDED FOR IN SPECIAL NOTE BELOW WHICH ARE LOCATED FURTHER THAN 19,000 FEET FROM THE AIRFIELD REFERENCE POINT AND OUTSIDE OF THE APPROACH ZONES AND PROJECT ABOVE THE 62:1 OR 10:1 IMAGINARY SURFACES SHALL BE SUBJECT TO LOCAL AERONAUTICAL STUDY TO DETERMINE IF THEY ARE HAZARDOUS TO LOCAL OPERATIONS INCLUDING INSTRUMENT PROCEDURES
3. THE AIRFIELD REFERENCE POINT IS A POINT SELECTED AND MARKED AS THE APPROXIMATE CENTER OF THE USABLE LANDING AREA WHICH IS FORMED BY JOINING RUNWAY ENDS
4. SEE SPECIAL NOTE BELOW FOR SITING OF LOW VISIBILITY OBSTRUCTIONS

SPECIAL NOTE: IN ADDITION TO THE RESTRICTIONS NOTED ABOVE AND SHOWN ON THIS DRAWING, OTHER MAN MADE STRUCTURES WHICH BY THEIR NATURE ARE DIFFICULT TO SEE (SUCH AS ANTENNA TOWERS), AND ARE LOCATED WITHIN 80,000 FT OF THE AIRFIELD REFERENCE POINT SO AS TO PROJECT ABOVE IMAGINARY SURFACES BEGINING AT A 12,000 FT RADIUS FROM THE AIRFIELD REFERENCE POINT AT 150 FT ABOVE AIR STATION ELEVATION, AND RISING AT A 50:1 SLOPE FOR AN ADDITIONAL 18,000 FT AND BEYOND THAT AT A 100:1 SLOPE FOR AN ADDITIONAL 50,000 FT SHALL BE CONSIDERED AS UNACCEPTABLE HAZARDS TO AIR NAVIGATION UNLESS A SPECIFIC AERONAUTICAL STUDY DETERMINES OTHERWISE. SUCH A STRUCTURE, BEYOND THE 80,000 FT RADIUS, WHICH IS IN EXCEES OF 1000 FT ABOVE THE TERRAIN, WILL ALSO BE CONSIDERED TO BE AN UNACCEPTABLE HAZARD TO AIR NAVIGATION UNLESS A SPECIFIC AERONAUTICAL STUDY DETERMINES OTHERWISE. WHERE AN AERONAUTICAL STUDY IS INDICATED, FULL PARTICULARS WILL BE FORWARDED TO THE AIRSPACE PANEL OF THE AIR COORDINATING COMMITTEE VIA THE CHIEF OF THE BUREAU OF AERONAUTICS



PLAN

Guide for determining obstructions to air navigation.

ACC/AGA RECOMMENDATIONS FOR MARKING AND LIGHTING *

Foreword

Most problems arising between the Broadcast and Aviation Industries in the joint use of airspace (towers vs aircraft) stem fundamentally from the great difficulty of detecting and identifying the broadcast tower while flying at aircraft velocities during both day and night conditions. This is particularly acute in areas of high density air traffic and in the vicinity of airports. During marginal conditions, such as at daybreak, dusk, and during conditions of poor visibility, the ability to detect and identify such structures is made more difficult.

The following report was the recommendation of the committee composed of experts in the field of marking and lighting, camouflage, identifiability of objects, psychological and physiological factors involved. It was the desire of some of the Committee members to immediately amend the National Standards AGA-NS3 and AGA-NS4 incorporating the pertinent provisions of this report. However, it was agreed that first a field evaluation program should be conducted to make a practical assessment of these recommendations which were recognized to be based upon sound theoretical considerations. Such a program is in progress, although it is moving very slowly because of the requisite developmental and installation work involved which costs many thousands of dollars.

Any broadcaster interested in furthering the evaluation program should contact the NAB Department of Engineering for information concerning authorization to mark and/or light broadcast towers in accordance with the provisions of this report.

Problem

In the interest of safety, regularity and efficiency of aircraft operations, and in compliance with applicable directives of the ACC/AGA Subcommittee: (1) To organize a detailed plan for the development, installation, assessment and operational evaluation of the special lighting and marking systems for tall towers recommended as changes in National Standards AGA-NS3 and AGA-NS4; and (2) To transmit to the Subcommittee a description of the detailed plan and the specific recommendations of the Ad Hoc Group regarding the conduct of the evaluation program.

Recommendations

The Ad Hoc Group recommends to the AGA Subcommittee that:

1. The program of development, assessment and evaluation as described in the present report be approved and initiated under the auspices of the Subcommittee, with administratively appropriate modifications as required;
2. The Subcommittee approve that the towers listed in section *1* of the program plan be requested by AFCCE and NAB to cooperate in the program in the manner described in sections *2, 3,* and *4;*
3. The questionnaire forms described in section 5 and presented in Attachment G be distributed by the agency designated in accordance with recommendation 4 to ATA, ALPA, AOPA, NBAA, and military organizations including their reserve components, and that these questionnaires be accompanied by appropriate instructions for their use and return;
4. The Subcommittee recommend the assignment to an appropriate agency, having aircraft and statistical analysis facilities available to it, of the responsibilities for conducting the controlled test observations described in section 6 and the complete evaluation of the questionnaire data in accordance with section 7;

* Program for operational and field evaluation of special lighting and marking techniques for tall towers, presented by Ad Hoc Group studying special requirements for lighting and marking of obstructions to air navigation, Air Coordinating Committee, Technical Division, Subcommittee on Aerodromes, Air Routes and Ground Aids.

5. The Subcommittee consider this report to be the final report of the Ad Hoc Group and the work of the Ad Hoc Group completed in accordance with its original terms of reference and objectives.

Background and Procedures

In its report AGA/AHG 54-1B, dated August 25, 1954, the Ad Hoc Group conveyed to the Subcommittee its finding that the present standards AGA-NS3 and AGA-NS4 are not adequate to assure detectability of tall towers on the part of aircraft in their vicinities. In its report AGA/AHG 55-1A, dated May 3, 1955, the Ad Hoc Group presented detailed recommendations for immediate changes in the standards and also a series of marking and lighting features which it recommended be subjected to operational evaluation as a means of verifying the Ad Hoc Group's judgment that these features would aid significantly in increasing the detectability and conspicuity of tall towers. In the latter report, the Ad Hoc Group also recommended that it be directed to prepare the specifications for a complete development and operational evaluation program for the approval of the Subcommittee.

It is the understanding of the Ad Hoc Group that the Subcommittee and the Technical Division of ACC desire that no changes be made in the present standards AGA-NS3 and AGA-NS4 without corroborative field evidence regarding the efficacy of the proposed changes. It is further understood that the Ad Hoc Group is charged with the responsibility of designing a program of development and evaluation. On the basis of the results from this program, the Subcommittee should be able to make appropriate decisions regarding the acceptability for implementation of the particular changes in the National Standards that are operationally demonstrated to afford sufficiently increased detectability and conspicuity of tall towers to significantly decrease their hazard to air navigation.

In accordance with the above mentioned objectives, the Ad Hoc Group met on October 13, 1955, to discuss alternative ways of organizing the required program. The Group discussed in detail the requirements for evaluation, sources of financial and development aid, and means of further formulation of the specifications for the program.

It was indicated that the radio and TV tower owners would make certain of their towers available for experimental lighting and marking and would defray the costs of development of the required systems and their installation. The responsibility for the costs and activities of the operational evaluations, including controlled tests and analyses data, must be assigned elsewhere.

It was realized by the Ad Hoc Group that the process of field evaluation could take the form of a rigorously controlled and long range experimental investigation, the costs of which would be great and the time required for which would be more extensive than the problem warrants in terms of the confidence held in the technical recommendations previously made. The writing committee was instructed to plan a program which would require a minimum of time consistent with the adequacy of the results for the process of decision by the Subcommittee.

Program of Development, Assessment, and Evaluation

As a general and summary description of the program, it is proposed that a certain few tall towers be chosen for the appropriate characteristics of background, prevailing visibility conditions and administrative feasibility. These towers will have their current systems of lighting and marking modified to include those features previously recommended in AGA/AHG 55-1A. These additions will be arranged in a manner sufficiently flexible to allow variations of the devices to be made during the testing procedures. Assessment in terms of feasibility will be made by the tower owners and engineers with respect to costs, materiel procurement and system maintenance. Evaluations will be made by observations taken in controlled tests at various specified altitudes and under various visibility conditions and also by observations taken in uncontrolled tests (in normal and routine flying) in the areas of the experimental

towers. Records will be designed for recording the primary check data from these flights. Analyses of the accumulated records will be made to determine the nature and degree of increments in detectability and conspicuity of the towers afforded by the individual features of the additional lighting aud marking systems.

1. Tower Selection

The towers will be chosen for their altitudes, terrain background, and prevailing visibility conditions, as being appropriate for the evaluation program. The owners of the selected towers will be requested to aid in the program by defraying the costs of necessary development and by adding the required lighting and marking features to their towers.

2. Development and Installation of Marking Systems

The particular marking systems that are recommended for inclusion in the program of development, assessment and evaluation are presented in detail in Attachment A. It is these modifications that are recommended as possibilities for the National Standards AGA-NS3 and AGA-NS4.

3. Development and Installation of Lighting Systems

There are two lighting systems involved in the program: identification lighting system and obstruction lighting system. The purpose, requirements and installation instructions for the identification lighting system are presented in Attachment B. The procurement specifications for this system are presented in Attachment C. The purpose, requirements and installation instructions for the obstruction lighting system are presented in Attachment D. The procurement specifications for an improved hazard beacon are presented in Attachment E.

The steady-burning obstruction lights shall conform to all requirements of specification L-810 of the Civil Aeronautics Administration except that they shall meet the following candlepower distribution requirements:

Angle of Elevation (Degrees)	*Minimum Candlepower (Red)*
−5 to −2	5
−2 to 1	25
1 to 5	40
5 to 8	25
8 to 15	5
15 to 30	5
30 to 90	2

4. Assessment by Tower Owners and Engineers

This assessment will be made by detailed questionnaires submitted to the owners and engineers of the towers cooperating in the investigation. The interest in these assessments has to do with the judgments of practicality and financial burden occasioned by the new techniques of marking and lighting. Sample questionnaire is presented as Attachment F.

5. Assessment by Pilots in Uncontrolled Tests

This assessment will be made by detailed questionnaires submitted through the Army, Navy, Air Force, ALPA, ATA, AOPA and NBAA to pilots who fly in the areas of the towers subjected to experimental treatment. Sample questionnaire is presented as Attachment G.

In designing the questionnaires for pilots in uncontrolled and in controlled tests several factors were considered as sources of variation in the data and thus were

included as specific questions in order to fractionate the final data to assess the influence of these factors and sources of contamination.

The factors *external* to the aircraft are specifically as follows:

a. Weather-visibility: miles visibility, ceiling, clouds, smoke, haze, fog;
b. Time of day and position of sun with respect to aircraft attitude;
c. Background of tower: terrain, confusion lights and objects;
d. Altitude of tower;
e. Marking and lighting of tower: by prior standards, additional marking, additional lighting, combined additional lighting and marking viewed under daylight and early twilight conditions.

The factors *internal* to the aircraft or flight observation are specifically as follows:

f. Altitude of flight;
g. Type of aircraft;
h. Ground speed of aircraft;
i. Level of experience of observer;
j. Active vs. passive observation (seeking vs. "happen to see");
k. Concurrent activity of observer (pilot or copilot at control, pilot or copilot not at control, passenger);
l. Type and condition of windscreen;
m. Attitude of observer, prior to flight, regarding adequacy of current standards for marking and lighting tall towers.

6. Assessment by Pilots in Controlled Tests

It is necessary that an adequate number of observations be recorded throughout a wide range of visibility conditions, altitudes of flights, and diurnal conditions. It is therefore required that controlled tests be undertaken in which the ranges of these factors are assessed in a more systematic manner than can be done by depending upon the more haphazard conditions of the uncontrolled test observations. In order to meet this objective, a series of controlled tests is planned to take place under the complete variety of these interacting factors. The primary questionnaire form to be used for the controlled tests is the same as that for the uncontrolled tests, shown in Attachment C, with the exception of the descriptive material presented at the beginning of the questionnaire.

7. Evaluation of the Questionnaire Data

The questionnaires obtained from tower owners and engineers will be analyzed to determine opinions and facts regarding feasibility and practicality of development, procurement, installation and maintenance of the proposed items of modification for AGA-NS3 and AGA-NS4.

It is obvious in the design of the investigation that the primary relationship to be evaluated is the dependence of the recorded "distance at which tower is detected" (dependent variable) upon the marking and lighting of the tower (factor *e* in section 5 above). Because this dependence is contaminated with the several other factors listed in section 5, these factors are also to be evaluated as determiners of the dependent variable.

The questionnaires from the uncontrolled and from the controlled tests will be analyzed with respect to the relationships (contingencies) among these factors. The prediction offered by the Ad Hoc Group is that the features recommended as changes in the National Standards AGA-NS3 and AGA-NS4, and presented as features for development and installation in sections 2 and 3 of the program plan above, will increase the detectability and conspicuity of tall towers. The evidence upon which this hypothesis will be tested will be taken as a statistically significant increment in the "distance at which tower is detected" for the experimentally treated towers in comparison with their untreated condition, when the other determining factors are controlled or statistically minimized.

Evidence regarding *acceptance* of the proposed changes in the National Standards will be evaluated from the appropriate recorded material in the questionnaires from the tower owners and the pilots.

A. Development and Installation of Marking System

1. Purpose

The purpose of the marking system is to identify the space surrounding the tower within the confines of the guy cables as a hazardous area by markers and by color coding on the ground and tower as indicated below.

2. Operational Requirements

During daylight conditions when the north horizon sky brightness exceeds 100 foot lamberts and the reported visibility exceeds 5 miles, the marking system shall be visible and indentifiable (except where the line of sight is blocked by a hill or other obstruction not under the control of the tower management) throughout a zone having a minimum radius (measured horizontally from the vertical axis of the tower) of 3 miles and extending from the ground to an altitude of 1500 feet higher thau the tower.

3. Technical Requirements

3.1 The tower structure, antenna, and other appendages shall be marked in alternate bands of aviation surface white, aviation surface orange, and black as described below.

3.1.1 The lowest segment of the structure shall be colored in three major bands of color in the order of orange, white, and orange; each 40 feet in vertical dimension.

3.1.2 The top segment of the tower for a band between 40 and 100 feet shall be colored orange. The antenna and other projections from the top of the tower shall be colored orange. The exact dimension of the band will be determined by the requirements of 3.1.3 and 3.1.4 below.

3.1.3 The intermediate segment of the structure shall be colored in alternate major bands of orange and white beginning and ending with white. Each band shall have a minimum of 100 feet and a maximum of 150 feet vertical dimension.

3.1.4 A band of black color of 2 feet vertical dimension shall be placed between the major color bands specified above.

3.2 The ground area beneath the structures within the guyed area shall be marked as described below.

3.2.1 The ground area at the base of the structure, consisting of a circular area of 150-foot radius extending from the center of the structure for structures 500 to 1000 feet in height and of 200-foot radius for structures over 1000 feet in height, shall be treated to provide a textured surface such as would be obtained by harrowing and be colored white.

3.2.3 The ground area forming a 75-foot wide annulns for towers of 500 to 1000 feet in height and a 100-foot wide annulus for towers over 1000 feet, concentric to the center of the structure and with an outside radius equal to the distance from the structure center to the outermost guy cable anchor point, shall be treated to provide a textured surface as above and be colored in 16 alternate equal areas of aviation surface orange and white.

3.3 Rotating ground markers shall be installed on the outer perimeter and at the center of each orange section of the annulus ring and possess the following features:

3.3.1 A main support pole, in each instance of a height greater than any nearby obstruction to line of sight.

3.3.2 A mechanism for horizontally rotating a disk of 8 feet maximum diameter to be affixed to the top or near the top of the main support pole (an acceptable alternate in lieu of a rotating mechanism is a wobble plate system) the objective of

which is to present a target which is continuously changing in angular relationship between a distant observer and the zenith sky. Such mechanism to be adjustable so as to permit rotational speeds to be varied between 10 and 40 revolutions per minute.

3.3.3 A means for altering in one direction the angular pitch of the rotating disk from horizontal (normal to the main support pole length) to 45°.

3.3.4 A means of readily changing disk reflectors to permit disks of different size and type to be tested.

3.3.5 An initial series of four test disks shall be available; 2 of polished (mirrored) metal surface and 2 of sprayed metallic paint surface. One each of both types shall be 4 feet in diameter and the other two 8 feet in diameter.

3.4 All coatings utilized for coloration purposes on the structure shall be of a lusterless nature (semigloss or lower) to minimize glare and to permit the color to be effective at greater angles of observation.

4. Engineering Notes

4.1 The following procedure for controlling weed growth has been found practical for pretreatment of center and annulus-ring ground marking areas.

4.1.1 Disk harrow the area to be treated.

4.1.2 Treat with fire to kill seeds and drive out nitrogen from the soil. The use of road or snow melters now commercially available to burn the soil is thought to be a practical method.

4.1.3 Place on the treated area a layer of crushed rock salt or calcium chloride.

4.1.4 Place surface layer of crushed stone or gravel over salt layer and apply coloration as required.

4.2 The following *ground* coloring agents are offered for consideration in order of their estimated cost from least to most expensive.

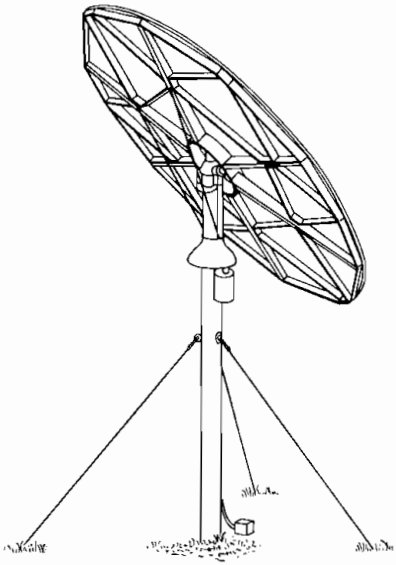
4.2.1 White only—(Whitewash)—Lime, salt (NaCl) and water.

4.2.2 Sodium silicate colored with earth pigments and precipitated upon application with calcium chloride to form an insoluble coating. (Applicable to damp surface.)

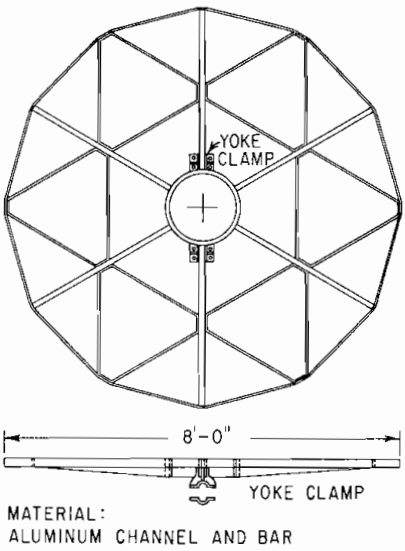
4.2.3 Rubber base paints. (Some types applicable to damp surfaces.)

4.2.4 Oleoresinous emulsifiable paints. (Applicable to damp surfaces.)

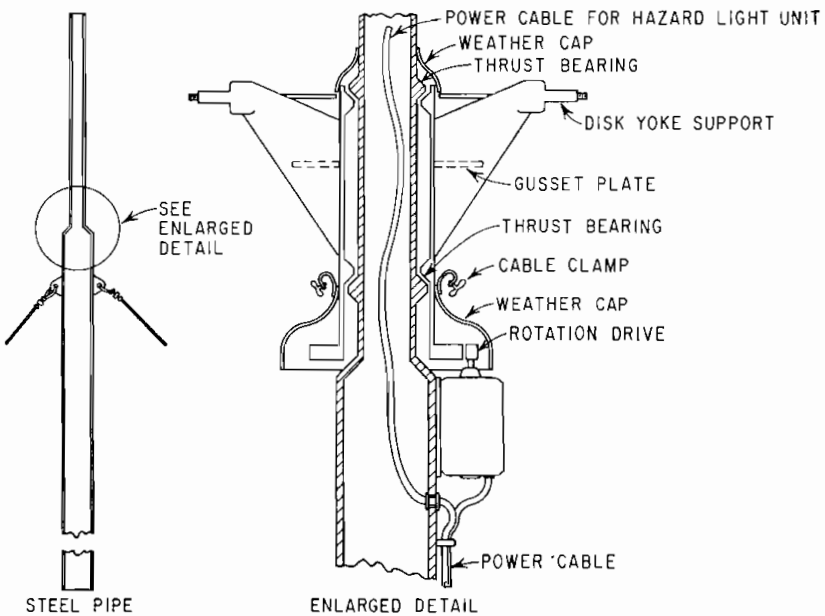
4.3 The following is a sketch in 3 parts of a rotating ground marker included for the purpose of pictorially presenting the features outlined in Paragraph 3.3 above.



Rotating disk—hazard marker.



Substructure for disk.



Rotating sleeve and disk support.

B. Purpose, Requirements, and Installation Instructions for the Identification Lighting System for Tall Towers

1. Purpose

The purpose of the identification lighting system is to identify the space surrounding the tower and guy wires as a hazardous area by the color coding and flashing characteristics of this lighting system.

2. Operational Requirements

2.1 By day and by night when the reported visibility is within the interval 1 to 3 miles, inclusive, the identification lighting system shall be visible from every point (except where the line of sight is blocked by a hill or other obstruction not under the control of the tower management) throughout a warning zone having a minimum radius (measured from the tower) of 1 mile and a maximum radius equal to the reported visibility, and extending from the tower to an altitude given by the following equation:

$$A = H + 400D + 300$$

where A = altitude of warning zone in feet
H = height of tower in feet
D = distance from tower in miles
(D does not exceed the reported visibility and is not less than 1.)

3. Detail Requirements

3.1 Identification beacons conforming to the specifications in Attachment C shall be used. The color coding of the identification beacon shall be alternate white and red flashes and the flash frequency shall be 60 (30 white and 30 red) flashes per minute.

4. Installation Requirements

4.1 One or more identification beacons shall be placed on or near the tower and near the ground level but at a height greater than that of any nearby structures, buildings, trees, etc. One or more identification beacons shall be placed at a height of 700 feet when the height of the total structure of the tower exceeds 800 feet and at a height of 700 and 1400 feet when the height of the total structure of the tower exceeds 1500 feet. One identification beacon may be used at each level when the shadows caused by the tower structural components will not reduce the effective intensity of the beacon in any direction to an effective candlepower less than 80% of the effective candlepower specified in Table 1, Paragraph 3.6 of Attachment C. If shadows caused by the structure of the tower will reduce the effective candlepower of the identification beacon in any direction to an effective candlepower less than 80% of the effective candlepower specified in Table 1 of the specification in Attachment C, two identification beacons placed on opposite sides of the tower shall be installed at each level. In order to provide satisfactory output by the identification beacons, the rated voltage of the lamps used shall correspond to or be within three percent higher than the average voltage across the lamp as measured at the lamp socket during the hours of daylight operation.

5. Operation

5.1 Day Operation. The identification beacons shall be operated with the lamps at their rated voltage whenever the north sky brightness is more than 1.0 footlambert and not more than 100 footlamberts and also when the north sky brightness is more than 100 footlamberts but the reported visibility is less than 5 miles.

5.2 Night Operation. The identification beacons shall be operated with the lamps at a voltage which will produce effective candlepowers at least one-tenth the effective candlepowers specified for daylight use whenever the north sky brightness is less than 1.0 footlambert.

C. Procurement Specifications for Identification Beacons for Tall Towers

1. Applicable Documents

1.1 The following specifications and publication, of the issue in effect on the date of invitation for bids, form a part of this specification and may be obtained upon application to the Commanding General, Air Matériel Command, Wright-Patterson Air Force Base, Dayton, Ohio; or the Commanding Officer, U.S. Naval Air Station, Johnsville, Pennsylvania.

Specifications:

MIL-E-5272	Environmental Testing, Aeronautical and Associated Eqnipment (General Specification For)
MIL-C-25050	Colors, Aeronautical Lights aud Lighting Equipment, General Requirements For

Publications:

Air Force-Navy Aeronautical Bulletin
143 Specifications and Standards, Use of

2. General Requirements

2.1 Objective. The intent of this specification is the development of a beacon suitable for marking and identifying tall towers and other hazards during daylight and bright twilight conditions. The design requirements given herein shall be complied with except that alternate designs and details of construction will be acceptable if they will produce a beacon more satisfactory for the intended application. The design of any beacon shall be approved by the procuring activity prior to fabrication of the beacon.

2.2 Component Parts. The beacon shall consist of the following major components: two or more separate optical systems, a rotating mechanism and a base.

2.3 Selection of Specifications and Standards. Specifications and standards for all materials, parts, and Government certification and approval of processes and equipment, which are not specifically designated herein and which are necessary for the execution of this specification, shall be selected in accordance with Bulletin 143, except as provided in the following paragraph:

2.3.1 Standard Parts. AN or MIL standard parts shall be used wherever they are suitable for the purpose and shall be identified by their part numbers. Commercial utility parts, such as screws, bolts, nuts, cotter pins, et cetera, may be used, provided they have suitable properties and are replaceable by the AN or MIL standard parts without alteration and provided the corresponding AN or MIL parts numbers are referenced on the drawings and in the parts lists. In applications for which no suitable corresponding AN or MIL part is in effect on date of invitation for bids, commercial parts may be used provided they conform to the requirements of this specification.

2.4 Material

2.4.1 Protective Treatment. When materials are used in the construction of the beacon that are subject to corrosion in salt air or other atmospheric conditions likely to occur during service usage, they shall be protected against such corrosion in a manner that will in no way prevent compliance with the performance requirements of this specification. Protective coating that will crack, chip, or scale with age or extremes of atmospheric conditions shall not be used.

2.4.2 Metals. Metals shall be of the corrosion-resistant type, unless suitably protected to resist corrosion during normal service life.

2.5 **Design**

2.5.1 **Operating Conditions.** The beacon shall be designed for continuous outdoor operation under all weather conditions, at altitudes not exceeding 10,000 feet. It shall be capable of operating satisfactorily under the following conditions:

a. Temperature ranging from −54° C to +55° C

b. Relative humidity up to 100% including conditions wherein condensation takes place in the form of both water and frost

c. Wind speeds ranging from 0 to 100 mph

2.5.2 **Installation and Servicing.** The design shall be such as to facilitate installation and servicing when the beacon is mounted on a tall, guyed tower.

2.5.3 **Power.** The beacon shall be designed to operate from a two-wire, 120-volt, single phase, 60-cycle, or a three-wire, 240-volt, single phase, 60-cycle power supply. If other voltages are required for lamp and motor operation, the necessary transformers or ballasts shall be provided with the beacon.

2.5.4 **Beams.** The beacon shall provide alternate separate and readily distinguishable beams of white and red light. The beams shall rotate in a horizontal plane about a central axis at a speed which will produce 60 flashes (30 white and 30 red) per minute.

2.6 **Construction.** The beacon shall be constructed so that no parts will work loose in service. It shall be built to withstand the strains, jars, vibrations, and other conditions incident to shipping, storage, installation and service.

3. Optical Systems

3.1 The optical systems shall be identical except for differences incident to the color of the beam produced. Each of the optical systems shall include all lamps, sockets, reflectors, lenses, and minor components required to produce one of the specified beams.

3.2 The optical systems shall be of the fixed, prefocus type, requiring no adjustments during installation, relamping or routine maintenance.

3.3 At least four operating lamps shall be used in each beacon, or lamp changers and spare lamps shall be provided so that the failure of a single lamp does not render the beacon ineffective. Since simultaneous burnout of the 2 or more operating lamps is very unlikely, automatic lamp changers shall not be provided when four or more operating lamps are used. Lamp life shall be not less than 1000 hours, at 5 hours operating time per start. The lamp or combination of lamps in each optical system shall be such that each system will emit at least 5 percent of the specified candlepower within 5 seconds after the power is turned on, and within 5 seconds after power is restored after a momentary failure, at any ambient temperature down to −54° C. Each system shall emit 100 percent of the specified candlepower within 10 minutes, at any ambient temperature down to −54° C. Each optical system may contain either incandescent or arc lamps alone or in combination, provided the above requirements are met.

3.3.1 Any auxiliary equipment required for lamps, such as sockets, ballast, heaters, et cetera, shall be incorporated in the design of the beacon. All such equipment shall be in accordance with high-grade commercial practice and shall be satisfactory for use in the beacon.

3.3.2 Unless otherwise specified, 6 sets of lamps shall be furnished for each of the optical systems.

3.4 The optical systems shall be enclosed in a common housing, or in separate housings mounted upon a single rotating mechanism. The housing and cover glass assembly shall be weatherproof and of such design that driving rain, snow, or sleet cannot be blown inside. If forced ventilation is utilized, adequate baffles and screening shall be provided to keep out moisture, dirt, insects, et cetera. The design shall be such that no condensate or water leaking can drip on the lamps. The housing or housings shall be fabricated from aluminum.

3.4.1 Adequate provisions shall be provided for expansion without breakage of the glass components. All gaskets, caulking compounds, separators, and cements shall be satisfactory for the intended application.

3.4.2 Means shall be provided for readily replacing burned out lamps even under icing conditions. Suitable hinges, door stops, chains, and clamps shall be provided so there will be no danger of any parts being dropped or being damaged during relamping or servicing.

3.5 Alternate optical systems shall be provided with red cover glasses or lenses and with white (clear) cover glasses or lenses.

3.5.1 All cover glasses or lenses shall be in accordance with requirements for non-diffusing ware, type 1 Aviation Colors conforming to Specification MIL-C-25050. The covers and lenses shall have transmission ratios as high as practicable. Design goals are to obtain a transmission ratio of at least 0.17 for red and 0.95 for white (clear).

3.6 The candlepower distribution of each optical system shall be as specified in Table 1 when the lamp or lamps are operated at rated voltage or lnmens.

Table 1

Angle of elevation, degrees	Minimum effective candlepower *	
	White	Red
−2 to −1	25,000	3,500
−1 to 0	100,000	15,000
0 to 8	220,000	33,000
8 to 10	100,000	15,000
10 to 15	25,000	3,500

* The effective candlepower of each flash shall be determined by the followiug formula:

$$I_E = \frac{\int_0^t I dt}{0.2 + t}$$

where I_E = effective candlepower
I = instantaneous candlepower
t = flash duration, in seconds (chosen so that I_E is the maximum)

3.7 The optical systems shall be mounted upon a turntable so that alternate flashes of white and red light are produced as the turntable rotates in the horizontal plane. The centers of the beams shall be equally spaced.

4. Mechanical Construction

4.1 The rotating mechanism shall rotate the optical systems in a horizontal plane at a fixed constant speed which will produce a flash rate of 60 ± 1 flashes per minute. (The speed tolerance is for the initial design only; all units fabricated shall have exactly the same speed.)

4.1.1 The rotating mechanism shall be designed so that the beam stops in the same position each time the unit is de-energized. Thus, all units which are properly aimed will operate in synchronism if simultaneously energized.

4.1.2 The rotating mechanism shall be of the sealed, permanently lubricated type, and shall be designed for at least 5 years operation without need for lubrication or servicing.

4.1.3 A standard, commercial type motor shall be utilized. The motor shall have ample power to operate the mechanism at any ambient temperature from −54° C to +55° C. The motor shall be properly fused so it will not be damaged in the event the rotating mechanism should become jammed.

4.1.4 If all rotating parts are not completely enclosed, a suitable clutch assembly shall be provided to permit the gear train to rotate without injury in case the turntable is prevented from rotating by an ice lock or other obstruction. The clutch design

shall be such that no damage will result to any beacon component if the beacon is operated continuously for 12 hours at rated voltage with the turntable held to prevent rotation.

4.1.5 The collector ring and brush assembly shall be of adequate design and capacity to insure trouble-free operation. The brushes shall be of copper-graphite composition and the collector rings of bronze. Adjustable springs shall be provided so the brushes are held in proper contact pressure against the collector rings.

4.1.6 All bearings shall be high quality, sealed, permanently lubricated commercial bearings.

4.2 The base shall be designed to house components of the rotating mechanism, terminal boards, and any other necessary auxiliary components in a compact manner. It shall be fabricated from aluminum.

4.2.1 The base shall be designed for platform mounting.

4.2.2 The base shall be provided with projections or surfaces upon which a carpenter's level can be placed in order that the beacon light can be accurately leveled at installation.

4.2.3 The base shall be provided with a side entrance and a waterproof fitting for the power supply wires.

4.2.4 The base shall have a removable pan or an access door to permit inspection and servicing of the components.

4.3 Suitable terminal blocks, properly marked or labeled, shall be provided in accessible locations to facilitate making any connections required at installations or during replacement of components.

4.4 The beacon shall be completely wired and connected so that only the power supply wires need be attached at installation. Flexible cord and cables shall be utilized wherever applicable. Suitable insulation shall be utilized on wires which may be exposed to high temperatures.

4.5 Size and weight shall be held to a minimum consistent with performance and reliability requirements. In order that the beacons may be mounted within the structure of tall guyed towers, the maximum horizontal dimension of the light shall not exceed 60 inches. All components shall be rugged and reliable, in order to withstand wind loading and vibration, rough handling during installation, and 5 years operation without any servicing except cleaning and relamping.

4.6 Instruction Plate. A wiring diagram and instruction plate shall be securely attached to the outside of the beacon light. The instruction plate shall contain abbreviated installation, operation, and maintenance instructions.

4.7 Nameplate. A nameplate, permanently and legibly filled in with the following information, shall be securely attached to the beacon:

Light, Rotating Beacon, Tower Identification
Specification
Mfr's Part No.
Mfr's Name or Trademark
Contract or Order No.

5. *Quality Assurance Provisions*

The hazard beacons shall be subject to the following tests:

a. Design Approval Tests
b. Inspection Tests

5.1 Design Approval Tests. The contractor shall conduct tests as necessary to determine that the design of the equipment as proposed by the contractor shall meet the requirements of all applicable specifications. The data obtained by the contractor in conducting these tests shall be included with the design data submitted to the procuring activity. These tests shall include all tests specified under Inspection Tests and, in addition, the tests described below.

5.1.1 Environmental Tests. One light shall be subjected to the following tests in accordance with the specified procedures of Specification MIL-E-5272 to determine

proper operation and lack of damage. No damage which would affect proper operation of the light shall result from these tests.

a. High Temperature: Procedure I except a temperature of 55° C ± 2° C and a period of 7 hours shall be used.

b. Low Temperature: Procedure I.

c. Rain Tests: Procedure I except that the light shall be operated at rated voltage for 2 hours before the rain is started. Operation at rated voltage with rain falling shall be continued for 3 hours.

5.1.2 Photometric Tests. One light shall be subjected to complete photometric tests to determine compliance with Section 3.

5.1.3 One light shall be bolted in place as if in service. A lateral thrust of 500 pounds shall be applied horizontally on any line through the center of the optical system by means of a calibrated spring balance. There shall be no evidence of damage.

5.1.4 The electrical characteristics, speed of rotation, and synchronism of two lights shall be checked to determine compliance with Section 4.

5.2 Inspection Tests. Each light shall be subjected to the following tests. The contractor shall be responsible for conducting the required tests.

5.2.1 Examination of Product. The light assembly and filters shall be examined to determine compliance with this specification with respect to materials and workmanship.

5.2.2 Operation. Each light shall be completely assembled and operated. It shall be inspected to determine proper operation.

5.2.3 Photometric Tests. Sufficient photometric tests shall be conducted on each light to determine whether the light is properly adjusted and focussed.

D. Purpose, Requirements, and Installation Instructions for the Obstruction Lighting System for Tall Towers

1. Purpose

The purpose of the obstruction lighting system is to identify the structure as a tower by the configuration, the color and the flashing characteristics of this lighting system, and to mark the extremities of the guy-wire system.

2. Operational Requirements

2.1 At night or twilight (sky brightness 17.5 footlamberts and lower) when the reported visibility is 3 miles, the obstruction lighting system shall be visible from every point (except where the line of sight is blocked by a hill or other obstruction not under the control of the tower management) throughout a warning zone having a radius of 3 miles (measured from the tower) and extending to an altitude 1500 feet higher than the top of the total structure.

3. General Requirements

3.1 The obstruction lighting system shall consist of two types of lighting units, steady-burning obstruction lights and flashing hazard beacons conforming to the specifications of Attachment E. The color of both types of lights shall be aviation red. The hazard beacons shall appear to flash approximately 40 times per minute.

4. Installation Requirements

4.1 One or more flashing hazard beacons shall be placed at the top of the total structure, and at approximately equal intervals not exceeding 300 feet along the structure.

4.1.1 One hazard beacon may be used at each level when the shadows caused by the tower structural components will not reduce the effective intensity of the

beacon in any direction to an effective candlepower less than 80% of the effective candlepower specified in Table 1, Paragraph 3.6 of Attachment E. If shadows caused by the structure of the tower will reduce the effective candlepower of the hazard beacon in any direction to an effective candlepower less than 80% of the effective candlepower specified in Table 1 of Attachment E, two or more hazard beacons placed on opposite sides of the tower shall be installed at each level.

4.1.2 The number and arrangement of the hazard beacons at each level shall be such that in event of failure of the lamp(s) in a hazard beacon, the effective candlepower of at least one other hazard beacon at that level in any direction is not reduced by shadows caused by the tower structural components to less than 80% of the effective candlepower specified in Table 1 of Attachment E; or a lamp changer and spare lamps shall be provided for each hazard beacon.

4.2 One or more hazard beacons shall be placed at the base of each guy wire high enough to clear surrounding trees, buildings, etc.

4.3 One steady-burning obstruction light shall be installed at each outside corner of the vertical members of the structure, at each level which is midway between the hazard beacon levels.

4.4 Hazard beacons and obstruction lights may be omitted from any level which is within 75 feet of the level at which an identification beacon (see Attachments B and C) is mounted.

4.5 In order to provide satisfactory output by the obstruction lighting system, the rated voltage of the lamps used shall correspond to or be within three percent higher than the average voltage across the lamp, measured at the lamp socket, during the hours of operation.

5. *Operation*

5.1 The hazard beacon shall be operated with the lamps at design voltage whenever the north sky brightness is less than 100 footlamberts.

E. Procurement Specifications for Hazard Beacons for Tall Towers

1. *Applicable Documents*

1.1 The following specifications and publication, of the issue in effect on the date of invitation for bids, form a part of this specification and may be obtained upon application to the Commanding General, Air Matériel Command, Wright-Patterson Air Force Base, Dayton, Ohio; or the Commanding Officer, U.S. Naval Air Station, Johnsville, Pennsylvania.

Specifications:

MIL-E-5272	Environmental Testing, Aeronautical and Associated Equipment (General Specification For)
MIL-C-25050	Colors, Aeronautical Lights and Lighting Equipment, General Requirements For

Publications:

Air Force-Navy Aeronautical Bulletin
143 Specifications and Standards, Use of

2. *General Requirements*

2.1 Objective. The intent of this specification is the development of a hazard beacon suitable for marking and identifying tall towers and other hazards during twilight and night conditions. The design requirements given herein shall be complied with except that alternate designs and details of construction will be acceptable if they will produce a hazard beacon more satisfactory for the intended application. The design of any beacon shall be approved by the procuring activity prior to fabrication of the beacon.

2.2 **Component Parts.** The beacon shall consist of the following major components: One or more separate optical systems, a rotating mechanism, and a base.

2.3 **Selection of Specifications and Standards.** Specifications and standards for all materials, parts, and Government certification and approval of processes and equipment, which are not specifically designated herein and which are necessary for the execution of this specification, shall be selected in accordance with ANA Bulletin 143, except as provided in the following paragraph:

2.3.1 **Standard Parts.** AN or MIL standard parts shall be used wherever they are suitable for the purpose and shall be identified by their part numbers. Commercial ntility parts, such as screws, bolts, nuts, cotter pins, et cetera, may be used, provided they have suitable properties and are replaceable by the AN or MIL standard parts without alteration and provided the corresponding AN or MIL part numbers are referenced on the drawings and in the parts lists. In applications for which no suitable corresponding AN or MIL part is in effect on date of invitation for bids, commercial parts may be used provided they conform to the requirements of this specification.

2.4 **Material**

2.4.1 **Protective Treatment.** When materials are used in the construction of the beacon that are subject to corrosion in salt air or other atmospheric conditions likely to occur during service usage, they shall be protected against such corrosion in a manner that will in no way prevent compliance with the performance requirements of this specification. Protective coatings that will crack, chip, or scale with age or extremes of atmospheric conditions shall not be used.

2.4.2 **Metals.** Metals shall be of the corrosion-resistant type, unless suitably protected to resist corrosion during normal service life.

2.5 **Design**

2.5.1 **Operating Conditions.** The hazard beacon shall be designed for continuous outdoor operation under all weather conditions, at altitudes not exceeding 10,000 feet. It shall be capable of operating satisfactorily under the following conditions:

a. Temperature ranging from −54° C to +55° C

b. Relative humidity up to 100 per cent including conditions wherein condensation takes place in the form of both water and frost

c. Wind speeds ranging from 0 to 100 mph

2.5.2 **Installation and Servicing.** The design shall be such as to facilitate installation and servicing when the beacon is mounted on a tall, guyed tower.

2.5.3 **Power.** The beacon shall be designed to operate from a two-wire, 120-volt, single phase, 60-cycle power supply. If other voltages are required for lamp and motor operation, the necessary transformers or ballasts shall be provided with the beacon.

2.5.4 **Flash Characteristics.** The hazard beacon shall produce separate and readily distinguishable flashes of red light by rotating the beam(s) of the beacon in a horizontal plane about a central axis at a speed which will produce 40 flashes per minute.

2.6 **Construction.** The beacon shall be constructed so that no parts will work loose in service. It shall be built to withstand the strains, jars, vibrations, and other conditions incident to shipping, storage, installation, and service.

3. *Optical Systems*

3.1 If more than one optical system is used, the optical systems shall be identical and each optical system shall include all lamps, sockets, reflectors, lenses and minor components required to produce one of the beams.

3.2 The optical systems shall be of the fixed, prefocus type, requiring no adjustments during installation, relamping or routine maintenance.

3.3 Lamp life shall be not less than 2,000 hours, at 5 hours operating time per start. The lamp or combination of lamps in each optical system shall be such that each system will emit at least five per cent of the specified candlepower within five seconds after the power is turned on, and within five seconds after power is restored

after a momentary failure, at any ambient temperature down to −54° C. Each system shall emit 100 per cent of the specified candlepower within 10 minutes, at any ambient temperature down to −54° C. Each optical system may contain either incandescent or arc lamps alone or in combination, provided the above requirements are met.

3.3.1 Any auxiliary equipment required for lamps, such as sockets, ballast, heaters, et cetera, shall be incorporated in the design of the beacon. All such equipment shall be in accordance with high-grade commercial practice and shall be satisfactory for use in the beacon.

3.3.2 Unless otherwise specified, six sets of lamps shall be furnished for each of the optical systems.

3.4 The optical systems shall be enclosed in a common housing, or in separate housings mounted upon a single rotating mechanism. The housing and cover glass assembly shall be weatherproof and of such design that driving rain, snow, or sleet cannot be blown inside. If forced ventilation is utilized, adequate baffles and screening shall be provided to keep out moisture, dirt, insects, et cetera. The design shall be such that no condensate or water leaking can drip on the lamps. The housing or housings shall be fabricated from aluminum.

3.4.1 Adequate provision shall be made for expansion without breakage of the glass components. All gaskets, caulking compounds, separators, and cements shall be satisfactory for the intended application.

3.4.2 Means shall be provided for readily replacing burned out lamps even under icing conditions. Suitable hinges, door stops, chains, and clamps shall be provided so there will be no danger of any parts being dropped or being damaged during relamping or servicing.

3.5 The optical systems shall be provided with aviation red cover glasses or lenses.

3.5.1 All cover glasses or lenses shall be in accordance with requirements for nondiffusing ware, type 1 Aviation Colors conforming to Specification MIL-C-25050. The covers and lenses shall have transmission ratios as high as practicable. The design goal is to obtain a transmission ratio of at least 0.17 after the light has been on operation and temperatures have become stabilized.

3.6 The candlepower distribution of each optical system shall be as specified in Table 1 when the lamp or lamps are operated at rated voltages or lumens.

Table 1

Angle of Elevation, Degrees	*Minimum Effective Candlepower (Red) Flashing Light* *
−5 to −2	100
−2 to 1	250
1 to 5	625
5 to 8	250
8 to 15	100
15 to 30	50
30 to 90	. . .

* The effective candlepower of each flash shall be determined by the following formula:

$$I_E = \frac{\int_0^t I dt}{0.2 + t}$$

where I_E = effective candlepower
I = instantaneous candlepower
t = flash duration, in seconds (chosen so that I_E is the maximum)

3.7 The optical system(s) shall be mounted upon a turntable so that flashes of red light are produced as the turntable rotates in the horizontal plane. The centers of the beams shall be equally spaced.

4. Mechanical Construction

4.1 The rotating mechanism shall rotate the optical system(s) in a horizontal plane at a fixed constant speed which will produce a flash rate of 40 ± 1 flashes per minute. (The speed tolerance is for the initial design only; all units fabricated shall have exactly the same speed.)

4.1.1 The rotating mechanism shall be designed so that the beam stops in the same position each time the unit is de-energized. Thus, all units which are properly aimed will operate in synchronism if simultaneously energized.

4.1.2 The rotating mechanism shall be of the sealed, permanently lubricated type, and shall be designed for at least 10 years operation without need for lubrication or servicing.

4.1.3 A standard, commercial-type motor shall be utilized. The motor shall have ample power to operate the mechanism at any ambient temperature from −54° C to +55° C at any input voltage from 105 to 130 volts. The motor shall be properly fused so it will not be damaged in the event the rotating mechanism should become jammed.

4.1.4 If all rotating parts are not completely enclosed, a suitable clutch assembly shall be provided to permit the gear train to rotate without injury in case the turntable is prevented from rotating by an ice lock or other obstructions. The clutch design shall be such that no damage will result to any beacon component if the beacon is operated continuously for 12 hours at rated voltage with the turntable held to prevent rotation.

4.1.5 The collector ring and brush assembly shall be of adequate design and capacity to insure trouble-free operation. The brushes shall be of copper-graphite composition and the collector rings of bronze. Adjustable springs shall be provided so the brushes are held in proper contact pressure against the collector rings.

4.1.6 All bearings shall be high quality, sealed, permanently lubricated commercial bearings.

4.2 The base shall be designed to house components of the rotating mechanism, terminal boards, and any other necessary auxiliary components in a compact manner. It shall be fabricated from aluminum.

4.2.1 The base shall be designed for platform mounting.

4.2.2 The base shall be provided with projections or surfaces upon which a carpenter's level can be placed in order that the hazard beacon can be accurately leveled at installation.

4.2.3 The base shall have a removable pan or an access door to permit inspection and servicing of the components.

4.3 Suitable terminal blocks, properly marked or labeled, shall be provided in accessible locations to facilitate making any connections required at installations or during replacement of components.

4.4 The hazard beacon shall be completely wired and connected so that only the power supply wires need be attached at installation. Flexible cord and cables shall be utilized wherever applicable. Suitable insulation shall be utilized on wires which may be exposed to high temperatures.

4.5 Size and weight shall be held to a minimum consistent with performance and reliability requirements. All components shall be rugged and reliable, in order to withstand wind loading and vibration, rough handling during installation, and 10 years operation without any servicing except cleaning and relamping.

4.6 Instruction Plate. A wiring diagram and instruction plate shall be securely attached to the outside of the hazard beacon. The instruction plate shall contain abbreviated installation, operation and maintenance instructions.

4.7 Nameplate. A nameplate, permanently and legibly filled in with the following information shall be securely attached to the beacon:

Light, Beacon, Hazard
Specification
Manufacturer's Part Number

Manufacturer's Name or Trademark
Contract or Order Number

5. *Quality Assurance Provision*

The hazard beacons shall be subject to the following tests:
a. Design Approval Tests
b. Inspection Tests

5.1 Design Approval Tests. The contractor shall conduct tests as necessary to determine that the design of the equipment as proposed by the contractor shall meet the requirements of all applicable specifications. The data obtained by the contractor in conducting these tests shall be included with the design data submitted to the procuring activity. These tests shall include all tests specified under Inspection Tests, and, in addition, the tests described below.

5.1.1 Environmental Tests. One light shall be subjected to the following tests in accordance with the specified procedures of Specification MIL-E-5272 to determine proper operation and lack of damage. No damage which would affect proper operation of the light shall result from these tests.

a. High Temperature: Procedure I except a temperature of 55° C ± 2° C and a period of seven hours shall be used.
b. Low Temperature: Procedure I.
c. Rain Tests: Procedure I except that the light shall be operated at rated voltage for two hours before the rain is started. Operation at rated voltage with rain falling shall be continued for three hours.

5.1.2 Photometric Tests. One light shall be subjected to complete photometric tests to determine compliance with Section 3.

5.1.3 One light shall be bolted in place as if in service. A lateral thrust of 50 pounds shall be applied horizontally on any line through the center of the optical system by means of a calibrated spring balance. There shall be no evidence of damage.

5.1.4 The electrical characteristics, speed of rotation, and synchronism of two lights shall be checked to determine compliance with Section 4.

5.2 Inspection Tests. Each light shall be subjected to the following tests. The contractor shall be responsible for conducting the required tests.

5.2.1 Examination of Product. The light assembly and filters shall be examined to determine compliance with this specification with respect to materials and workmanship.

5.2.2 Operation. Each light shall be completely assembled and operated. It shall be inspected to determine proper operation.

5.2.3 Photometric Tests. Sufficient photometric tests shall be conducted on each light to determine whether the light is properly adjusted and focussed.

Questionnaire on Development, Installation, and Maintenance of Special Marking and Lighting Techniques

The Air Coordinating Committee appreciates the cooperation and aid given by your broadcasting station in arranging for the development and installation of the special marking and lighting techniques that are being studied. As one of the means of assessing certain factors related to the efficacy of these new techniques, the Committee desires to obtain information from tower owners and engineers cooperating in the investigation. This information is being gathered on the questionnaire presented below, which we ask be completed by your staff and returned to_____ _____.

/s/_____
for the Committee

Station _____. Tower location _____.
Tower height: _____ above ground. _____ above MSL.
(The following table to be presented as attachment and detailed as desired.)

Item (Please list)	Development and Procurement Cost	Installation Cost	Est. Maintenance Cost per Annum

From ground observations and air observations (if possible) of your tower *before* and *after* installation of the special techniques, please offer your judgments as to whether the new factors appear significantly to increase the detectability and conspicuity of the tower.

_____

_____

_____

_____

_____.

It is hoped that the above judgment can be based on observations at varying distances and under a variety of conditions of reported visibility and times of day and night. Please describe the general nature of the conditions of observation upon which the above judgment was made. (Use space below, or attach report.)

If the majority of the new techniques were established as additional requirements in the National Standards AGA-NS3 and AGA-NS4, is it the feeling of your company that the costs of procurement, installation and maintenance of the new factors would place an excessive burden on tower owners, or would the additional assurance of minimizing hazards to air navigation and to the towers appear to you to warrant these expenditures in ultimate revision of the tower? (Use space below, or attach report.)

Questionnaire for Flights in Areas of Specially Marked and Lighted Tall Towers

Please complete Section I of this questionnaire before making tower observation flight.

Section I

Name (Optional):_____. Date of observation flight_____.
Origin and destination of flight during which tower was observed:_____

_____

What is your attitude regarding the adequacy of present lighting and marking techniques for tall towers which may be hazards to air navigation? (Check appropriately below.)

___ Have responded on previous questionnaire.
___ Believe present techniques adequate for purpose.
___ Believe present techniques need some slight changes to make visibility of towers adequate.

___ Believe present techniques need complete revision to produce adequate visibility of towers.

___ Believe present techniques now so inadequate as to be dangerous.

Experience of pilot-observer: Number of hours_____; Type of license/rating held_____

_____.

READ THE FOLLOWING SECTION CAREFULLY BEFORE OBSERVATION FLIGHT.

Section II

Tower Observed (*Check*)	*Height above MSL*	*Bearing and Distance from* [1] (*Named Airport*)
___ WTVH, Peoria, Ill.	1283′	_____ _____ _____
___ WFBM, Indianapolis, Ind.	1849′	_____ _____ _____
___ WJBK, Detroit, Mich.	1730′	_____ _____ _____
___ WNBK, Cleveland, O.	1945′	_____ _____ _____
___ WFMJ, Youngstown, O.	2048′	_____ _____ _____
___ WHAS, Louisville, Ky.	1440′	_____ _____ _____

[1] Information to be included in final questionnaire prepared by agency of jurisdiction. It may be desirable, in cases where two or more tall towers are in close proximity, to include additional geographic data in order to insure positive identification of the tower under study.

Type of aircraft:_____.

Miles reported visibility at weather station nearest tower: _____.

Reported ceiling:_____.

Pilot's estimate of visibility:_____.

Pilot's estimate of ceiling:_____.

Type of cloud cover: clear (_____)
scattered (_____)
broken (_____)
thin overcast (_____)
thick overcast (_____)

For daytime observation, pilot's estimate of general brightness level: ___ very bright day
___ bright day
___ average day
___ dull day
___ very dark day.

Special weather, visibility, and atmospheric conditions; e.g., smoke, industrial haze:_____

_____

Distance at which obstruction was detected_____.

Distance at which obstruction was identified as a tower_____.

Distance at which total hazard area was defined (i.e., structure of tower and area encompassed by ground anchorage of guy wires):_____.

(Please obtain as accurate an estimate of these distances as possible from ground cues, chart details, and time-speed computations.)

Altitude of flight at time of tower detection:_____ feet above MSL.

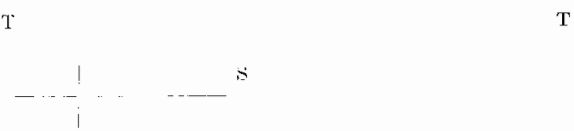
Ground speed at time of tower detection:_____ MPH, or_____ knots.

Time tower was observed:_____.

Direction (compass heading) of flight at time of tower detection:_____.

Relative compass bearing of tower from aircraft at time of detection:_____.

Diagram position of sun, tower, plane heading, and line of vision, at time of tower detection, as indicated in sample on left in which plane is flying west.



What feature of the tower or its marking or lighting was seen first? (Check with numeral 1.) What feature produced first identification of the object as a possible hazard? (Check with numeral 2.)

___ marking (paint) on tower
___ general structure of tower
___ ground marking at base of tower: (circle___, annulus___, "HAZ" signs___) and buildings___
___ reflectors on outside ground ring
___ total marking and structural configuration of tower
___ lights at base of tower
___ lights on tower
___ total lighting configuration of tower

Comments: _____

Tower observed by (check one): ___ pilot or co-pilot at controls
___ pilot or co-pilot not at controls
___ passenger-observer

Was observer of tower seeking to observe tower (_____) or did he merely happen to see the tower in course of routine flight (_____)?

Tower observed through windscreen of: ___ plate glass
___ plexiglass
___ other, specify: _____.

Condition of windscreen: dirty or scarred_____; clean and clear_____; rain_____.

What is your judgment about the adequacy of the experimental lighting and/or marking of the tower you have observed and reported on above?

___ believe no better or more visible than regular techniques
___ believe a little better than regular techniques
___ believe considerably better than regular techniques
___ believe adequate for *new* standards.

Comments or remarks: _____

Part 7

STANDARDS OF INTEREST TO BROADCAST ENGINEERS

FOREWORD

Standards relating to various areas of communication engineering and equipment are sponsored and developed through the efforts of many organizations. Among these are the National Association of Broadcasters (NAB), the International Radio Consultative Committee (CCIR), American Standards Association (ASA), the Institute of Radio Engineers (IRE), Electronic Industries Association (EIA, formerly RETMA), and Society of Motion Picture and Television Engineers (SMPTE).

In general, standards are developed by committees consisting of members representing manufacturers, consumers, technical bodies and government agencies. Included in this section are the complete Recording and Reproducing Standards of the National Association of Broadcasters and the International Radio Consultative Committee. Also included are pertinent standards from other organizations such as ASA, IRE, EIA and SMPTE.

NAB RECORDING AND REPRODUCING STANDARDS

For Mechanical, Magnetic, and Optical Recording and Reproducing Including a Glossary of Terms and Definitions

The NAB Recording and Reproducing Standards Committee was originally organized in 1941. Standards proposals issuing from the Committee have been adopted by the Board of Directors in 1942, 1949, and 1950. Standards as contained herein were adopted by the Board on June 19, 1953.

These standards and recommended good engineering practices are for the benefit and welfare of the broadcasting industry, and represent the contributions of more than 100 of the nation's authorities on the various phases of recording as used by the industry. The NAB Recording and Reproducing Standards Committee has also benefitted by contributions made by the administrations belonging to the International Radio Consultative Committee (Study Group X). The approach taken to many of the problems in the development of these standards was suggested by the work of CCIR Study Group X, particularly in the case of the methods of measuring the magnetization of a tape. The committee is open to participation by any interested individual or organization and consists of representatives from the manufacturers, broadcasters and producers. Close liaison has been maintained with other organizations (as well as foreign countries) to insure the maximum degree of coordinated understanding and recommended standardization, to permit interchangeability and, at the same time, to embrace the latest technological advances of the art.

Nothing in these standards prohibits or discourages continued progress or advancement of the art. On the contrary, the standards are so molded as to provide a stimulus for continued scientific exploration in the field of recording. It is anticipated that when necessary the NAB Recording and Reproducing Standards Committee will review its work of the past decade, looking toward any needed amendments and additions to keep pace with the art as it affects all forms of broadcasting—AM, FM, and Television.

Section 1

Mechanical Recording and Reproducing Standards *

NOTE: For the purpose of distinguishing between those recordings using a 2 mil or larger reproducing stylus and those requiring a 1 mil or smaller reproducing stylus, all Standards specifically relating to those recordings requiring the smaller stylus will use the term "fine groove."

Turntable Speed (RPM)

1.05 It shall be standard that the average speed of the turntable be either 33⅓, 45 or 78.26 RPM ± 0.3%.

1.05.01 Method of Measurement: This measurement shall be made by means of a stroboscopic disk illumined by a neon lamp or equivalent operated from the same power source as the turntable. The stroboscopic disk for 33⅓ RPM speed measurement shall have 216 spots in 360°; for 45 RPM speed it shall have 160 spots in 360°; and for 78.26 RPM speed it shall have 92 spots in 360°.

At either 33⅓, 45 or 78.26 RPM, not more than 21 dots per minute in either direction may pass or "drift" by a reference point.

Turntable and Disk Rotation

1.06 It shall be standard that disk records intended for broadcasting application be rotated in a clockwise direction as viewed from the side being reproduced.

WOW Factor (Recording)

1.10 It shall be standard that the instantaneous peak deviation from the mean speed of the recording turntable, when making the recording, shall not exceed +0.1% of the mean speed.

WOW Factor (Reproducing)

1.11 It shall be standard that the instantaneous peak deviation from the mean speed of the reproducing turntable when reproducing shall not exceed ±0.2% of the mean speed.

Disk Reproducing System Rumble

1.12 It shall be a good engineering practice that the low-frequency noise output of a turntable, its associated pickup and equalizer, when playing an essentially rumble-free silent groove, shall be more than 35 db below a reference level of 1.4 centimeters per second peak velocity at 100 cycles per second.

A record shall be considered rumble free if its rumble content is at least 8 db below

* For clarification in the use of these standards, the term "transcription" is deemed to mean those disk recordings made primarily for broadcast transmissions; the term "record" is deemed to mean those disk recordings which by virtue of their size, electrical and mechanical characteristics may be used for broadcast transmissions, but may not primarily be manufactured for this purpose.

that of the system being measured. The response of the pickup and equalizer shall conform to the NAB standard reproducing curve; the amplifier and indicating meter shall have uniform response, within ±1 db, between 10 and 250 cycles per second, with 500 cycle response 3 db below the 100 cycle response, an attenuation at the rate of at least 12 db per octave at frequencies above 500 cycles. Amplifier and indicating meter response shall decrease at the rate of at least 6 db per octave below 10 cycles per second. The meter used shall have the same ballistic characteristics as the standard VU meter. If the meter reading fluctuates, both average and maximum values shall conform to this requirement.

1.12.01 This measurement is intended to give a measure of the electrical effect of the low-frequency noise output of a turntable-pickup combination. Since the result depends on the equalizer and pickup characteristics as much as on the turntable itself, it is not feasible to standardize the turntable alone.

The measurement reflects the electrical effects, not the aural annoyance value, of low-frequency noise. It has been found that strong low-frequency noise at a frequency and intensity below audibility will create severe intermodulation distortion in an audio system, and that in modern systems with extended low-frequency response, this is more serious than the audibility of the low frequency.

The reference level of 1.4 centimeters per second at 100 cps corresponds in amplitude to 7 centimeters per second at 500 cps, since we are then operating on the constant amplitude portion of the recording characteristic. It is suggested that such noise data be taken periodically for each turntable in a broadcast system, with a change in the indication reflecting a need for maintenance work.

Turntable Recovery Time (Reproducing)

1.15 It shall be standard that the maximum turntable recovery time be 0.3 seconds.

1.15.01 Recovery time shall be defined as the time required after release of a record which has been restrained from rotation until the wows have fallen to 120% of the permissible steady state level.

Turntable Height (Reproducing)

1.20 It shall be good engineering practice that the height of the turntable be 28 inches.

1.20.01 The height of a turntable of the console type is defined as "the vertical distance from the surface on which the turntable rests to the top of the platen."

Turntable Platen (Reproducing)

1.21 It shall be good engineering practice that the diameter of the transcription reproducing turntable platen be substantially the same as that of the largest diameter records for which the turntable is intended.

1.21.01 Turntables for 45 RPM shall be recessed a minimum of 0.030″ to a diameter of $3\frac{7}{8} \pm \frac{1}{32}$″.

Turntable Center Pin Diameter

1.25 It shall be standard that the diameter of the center pin of a transcription turntable be 0.2835″ ± 0.0005″ for $33\frac{1}{3}$ and 78.26 RPM transcriptions. The diameter of the center pin for 45 RPM records shall be 1.500 + 0 − 0.002″.

Outer Record Diameters

1.30 It shall be standard that the outer record diameter fall within the limits specified in the following table:

Nominal	*Finished Records (Pressings or Instantaneous)*
16″	15 5/16″ ± 3/32″
12″	11 7/8″ ± 1/32″
10″	9 7/8″ ± 1/32″
7″	6 7/8″ ± 1/32″

Record Center Hole Diameter

1.35 It shall be standard that the record center hole diameter be 0.286″ ± 0.001″ for 33⅓ and 78.26 RPM records and transcriptions, and 1.504″ ± 0.002″ for 45 RPM records.

Concentricity of Center Hole

1.36 It shall be good engineering practice that the record center hole be concentric with the recorded groove spiral within 0.002 inches.

Record Warp

1.40 It shall be standard that the maximum departure of the surface of a record from a true plane because of warping shall not be in excess of 1/16″.

Frequency Characteristics for Vertical Recordings [1]

1.50 It shall be standard that the recorded frequency characteristics on vertically recorded records be as shown in attached Figure 1.

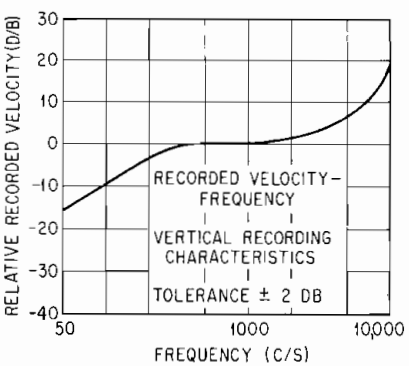


FIGURE 1. Relative recorded velocity (D/B).

Frequency Characteristics for Lateral Recordings [2]

a. A parallel L/R network having a time constant of 3180 microseconds.
b. A series RC network having a time constant of 318 microseconds.
c. A parallel RC network having a time constant of 75 microseconds.

1.55 It shall be standard that the recorded frequency characteristics on laterally recorded records be as shown in attached Figure 2.

[1] The recording characteristics for vertical transcriptions remain as specified in the standards adopted in March 1942, except that in place of "stylus velocity" the words "recorded velocity" should be substituted.

[2] This curve is defined as the algebraic sum of the ordinates of three individual curves which conform to the admittances of the following three networks expressed in db:

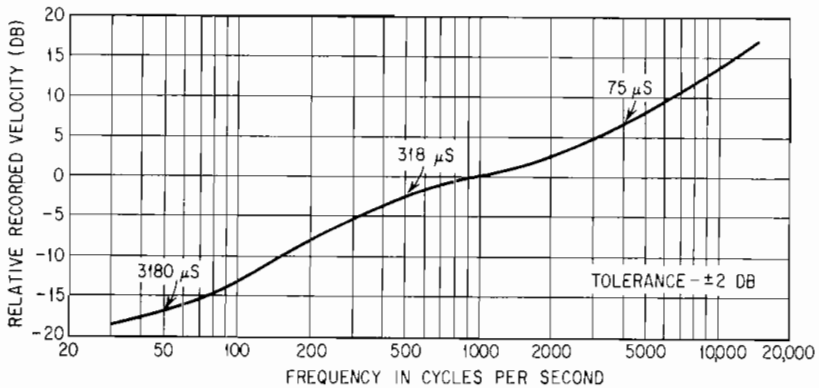


FIGURE 2. NAB lateral disk standard recording characteristic.

Record Groove Shape [1]

1.60 Lateral: It shall be standard that the groove shape for finished lateral records and transcriptions shall have an included angle of 88° ± 5°, and a top width of not less than 4.0 mils for records to be reproduced with a 2.3 mil stylus and not less than 2.0 mils for records to be reproduced with a 1.0 mil stylus.

1.60.01 It shall be good engineering practice on records and transcriptions with less than 136 lines per inch that the groove have a bottom radius of 1.5 mils; for records and transcriptions having more than 136 lines per inch, the groove shall have a bottom radius not less than 0.25 mils.

1.65 Vertical: It shall be standard that the groove shape for finished vertical records shall have an included angle of 88° ± 5°; a radius of 2.0 to 2.3 mils; and a top width of not less than 4.0 mils.

Reproducer Stylus Contour

1.70 33⅓ and 78.26 RPM lateral or vertical transcriptions (other than fine groove): It shall be the primary standard that the stylus for reproducing lateral or vertical transcriptions shall have an included angle of 40° to 55° and a bottom radius of 2.3 ± 0.2 mils.

1.70.01 45 RPM records and fine groove records and transcriptions: It shall be the primary standard that the stylus have an included angle of 40° to 55° and a bottom radius of $1.0 \begin{smallmatrix} +0.1 \\ -0.2 \end{smallmatrix}$ mils.

1.75 Lateral 78 RPM phonograph records and transcriptions: It shall be the secondary standard that the stylus for reproducing lateral 78 RPM phonograph records and transcriptions shall have an included angle of 40° to 55° and a bottom radius of 2.5 ± 0.1 mils.

Recorded Level (Lateral and Vertical) [2]

1.80 It shall be standard that the recorded program level shall produce the same reference deflection on a standard volume indicator (ASA Standard C16.5-1942)

[1] It has been concluded that groove shape standards should apply to the finished record rather than to the recording stylus. It is recognized that in some cases record groove dimensions depart slightly from those of the recording stylus, but such deviations should be anticipated in the recording operation and controlled in the processing plant. In actual practice standards covering reproducer stylus contour have no significance unless the groove standards refer to the finished record.

[2] It is well established that at least a 10 db margin is required between the sine wave load handling capacity of a system and the level of program material measured by a stand-

as that produced by a 1,000-cycle tone recorded at a peak velocity of 7 cm. per second.

Signal-to-noise Ratio [1]

1.85 It shall be standard that the noise level measured with a standard volume indicator (ASA Standard C16.5-1942) when reproducing a record on a flat velocity basis over a frequency range between 500 and 10,000 cycles per second shall be at least 40 db below the level obtained under the same conditions of reproduction using a tone record of 1,000 cycles per second having a peak velocity of 7 centimeters per second. Response of the system at 500 cycles per second shall be 3 db below the response at 1,000 cycles per second, and the response shall fall at the rate of at least 12 db per octave below 500 cycles per second. Response of the system at 10,000 cycles per second shall be 3 db below the response at 1,000 cycles per second, and the response shall fall at the rate of at least 12 db per octave above 10,000 cycles per second.

Outermost Groove Diameter

1.90 It shall be standard that the diameter of the outermost groove be within the limits specified in the following table:

16"—outside start—15½"	± 1/16"
16"—inside start —15 9/16"	maximum
12"—outside start—11½"	± 0.020"
10"—outside start— 9½"	± 0.020"
7"—outside start— 6⅝"	+ 0 — 5/64"

Number of Blank Grooves

1.100 It shall be standard for transcriptions that the number of blank grooves, before and after modulation occurs, shall be not less than two complete revolutions.

Stopping Groove

1.110 For transcriptions, it shall be standard that at the termination of the recording groove spiral a locked concentric stopping groove shall be provided.

Innermost Groove Diameter

1.115 It shall be standard that the diameter of the innermost groove shall be not less than 7½" in the case of 33⅓ RPM transcriptions recorded to be reproduced with a 2.3 mils radius styln, and not less than 4¾" for recordings to be reproduced with a 1 mil stylus. It shall be standard that the diameter be not less than 3¾" for 78.26 RPM recordings and not less than 4¼" for 45 RPM recordings.

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ard volume indicator. This standard would then contemplate program peaks running as high as a velocity of 21 centimeters per second. This is believed to be approximately the maximum velocity which can be traced without excessive distortion at groove speeds encountered at the inner radius of a 33⅓ rpm disk. This has also been substantiated by practical experience. This standard of course applies to both lateral and vertical recording.

[1] This measurement is intended to give a measure of noise in terms of a fixed reference. In this way it becomes a true figure of merit for comparisons of variations in surface noise of disks. It does not, however, take into account the program level which may happen to be recorded on a particular disk nor the dynamic range of the program material. NAB preemphasis will improve the signal to noise ratio by approximately 8 db, thus resulting in an effective signal to noise ratio under minimum conditions of 48 db. It should be remembered that the peak signal to noise ratio will be at least 10 db better than the figure given above when NAB standard of recorded level is used, with normal program material.

Minimum Label Information

1.120 It shall be standard for the label of a recording to contain at least the following technical information:

a. Type of recording—vertical or lateral
b. Speed—78.26, 45, or 33⅓ RPM
c. Direction of feed (start)—outside-in or inside-out
d. Recording frequency characteristic (Example: NAB 1953 Standard.)
e. Recommended type of playback stylus

Section 2

Magnetic Recording and Reproducing Standards

Magnetic Tape Dimensions

2.05 Thickness: It shall be standard that the thickness of magnetic tape shall not exceed 0.0022 inches.

2.10 Width: It shall be standard that the width of magnetic tape shall not exceed 0.250 inches nor shall it be less than 0.244 inches.

Magnetic Tape Speed

Definition: Magnetic tape speed for recording and reproducing is the velocity of the magnetic tape recording medium with respect to the recording or reproducing device.

2.15 Primary standard: It shall be standard that the primary standard magnetic tape speed shall be 15 inches per second.

2.20 Secondary standard: It shall be standard that the secondary magnetic tape speed shall be 7.5 inches per second.

2.25 Supplementary standard: It shall be standard that the supplementary magnetic tape speed shall be 30 inches per second.

Frequency Response Limits

2.30 Primary Frequency Response Limits: It shall be standard that the primary frequency response shall lie between two limits. (See Figure 3-A.) The upper of these limits shall be uniform from 50 to 15,000 cps. The lower shall be uniform from 100 to 7500 cps and 2 db below the upper limit. In addition, the lower limit shall be an additional amount down at 50 and 15,000 cps determined by decrease at a uniform rate of 3 db per octave below 100 cps and above 7500 cps.

2.35 Secondary Frequency Response Limits: (For applications where a restricted frequency response may be tolerated). It shall be standard that the secondary frequency response shall lie between two limits. (See Figure 3-B.) The upper of these limits shall be uniform from 50 to 7500 cps. The lower shall be uniform from 100 to 5000 cps and 2 db below the upper limit. In addition, the lower limit shall be an additional amount down at 50 and 7500 cps determined by a uniform 3 db decrease from 100 to 50 cycles and from 5000 to 7500 cycles.

Flutter and WOW

2.40 It shall be standard that the instantaneous peak flutter and wow shall not exceed 0.2% (peak to peak 0.4%) when recording and reproducing on the same equipment.

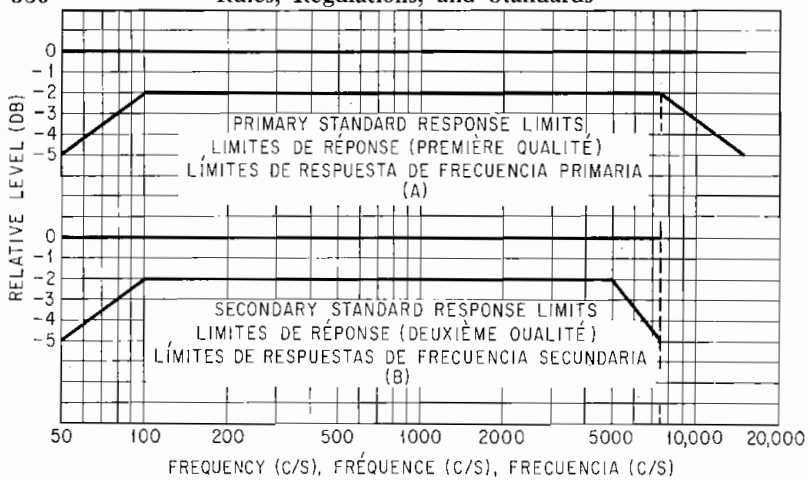


FIGURE 3. Frequency response limits for magnetic tape recording and reproducing systems.

Magnetic Tape Reel

2.45 It shall be standard that the hub carrying magnetic tape shall be in accordance with Figure 4.

Tape Wind

2.46 It shall be standard that magnetic tape, when supplied on reels ready for use, shall be wound with the active magnetic surface on each layer facing toward the center of the reels.

2.50 Primary Standard: It shall be standard where flanges are used that the primary standard flange shall be in accordance with Figure 5.

2.50.01 The primary standard flange provides for the accommodation of sufficient magnetic tape of standard thickness for a nominal 30 minutes of recording.

Erasing Function

2.55 It shall be standard that the erasing function shall be applied to the entire width of the tape.

Magnetic Tape Length

2.60 Length-Primary Standard: It shall be standard that the primary standard length of magnetic tape shall be 2,400 feet, +50 feet −0 feet.

2.60.01 The primary standard length of magnetic tape provides the nominal amount of maximum thickness magnetic tape for the primary standard flange as well as a nominal recording time of 30 minutes (plus a starting and stopping margin) when recording with the primary standard magnetic tape speed.

2.65 Length-Secondary Standard: It shall be standard that the secondary standard length of magnetic tape shall be 1,200 feet, +25 feet −0 feet.

2.65.01 The secondary standard length of magnetic tape provides a nominal recording time of 30 minutes (plns a starting and stopping margin) when recording with the secondary standard magnetic tape speed.

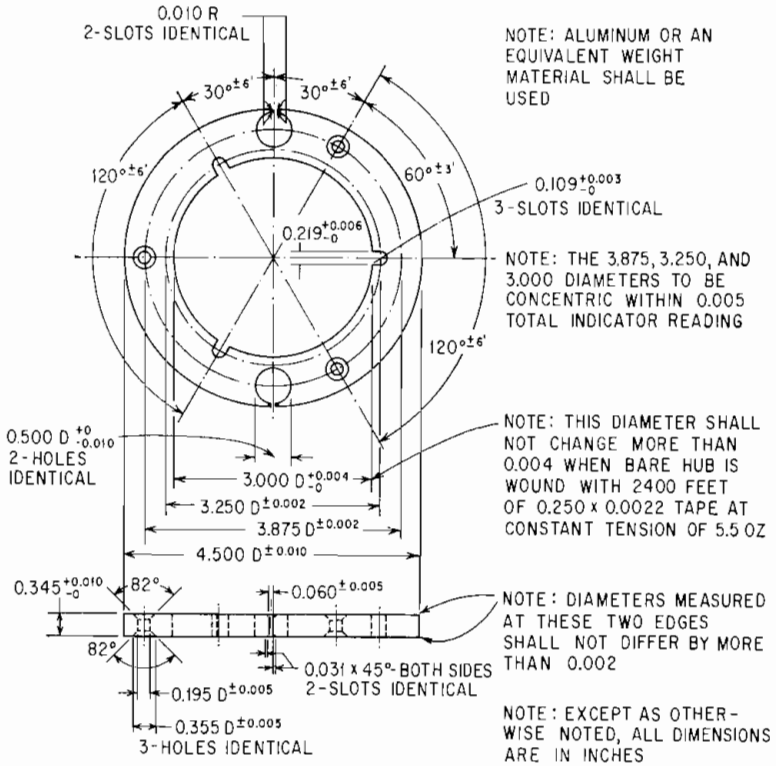


FIGURE 4. NAB standard hub for magnetic tape reel.

Magnetic Sound Track Position

2.75 It shall be standard that the magnetic sound track shall be symmetrically located with respect to the center line of the tape.

Standard Reproducing Characteristic

2.80 It shall be standard that a Standard Reproducing System is one having an "ideal" reproducing head,[1] the EMF of which is amplified in an amplifier with a response curve having the following characteristic:

At a tape speed of 15"/second: The response curve shall be that which results from the superposition of three curves; one that falls with increase of frequency at the rate of 6 db per octave; this curve to be modified at low audio frequencies by a curve that falls with decrease of frequency in conformity with the admittance of a series combination of a capacity and a resistance having a time constant of 3180 microseconds; and this same curve to be modified at high audio frequencies by a curve that rises with increase of frequency in conformity with the admittance of a

[1] An "ideal" reproducing head is defined as a reproducing head the losses of which are negligible. With a normal ferromagnetic head this means that the gap is short and the arc of contact with the tape is long compared to the relevant wavelengths, and the losses in the material of the head are small. With the reproducing heads used in practice, an equalization to compensate for the head losses must be added to the replay amplifier.

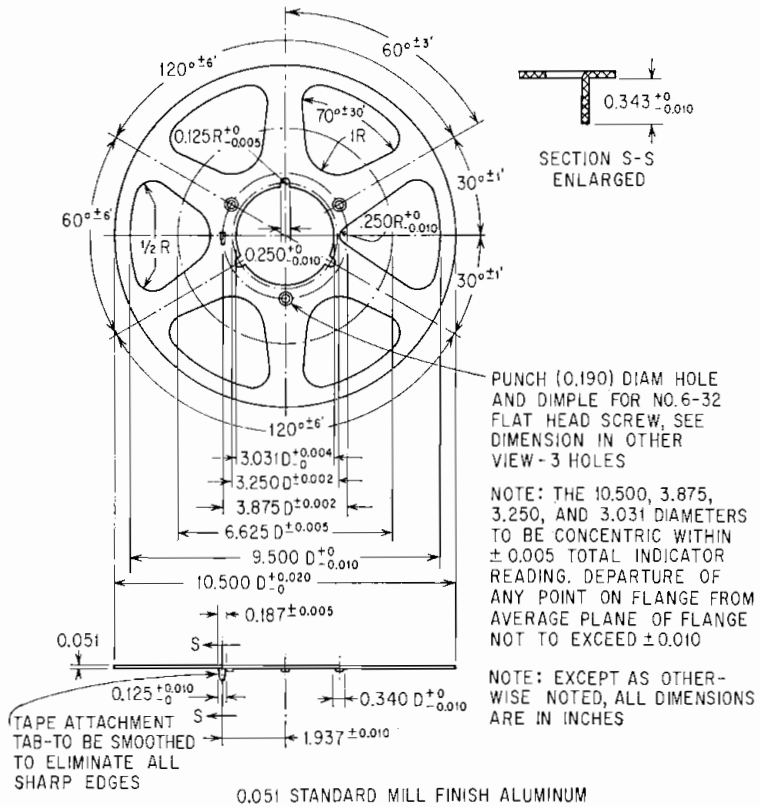


FIGURE 5. NAB standard flange for magnetic tape reel.

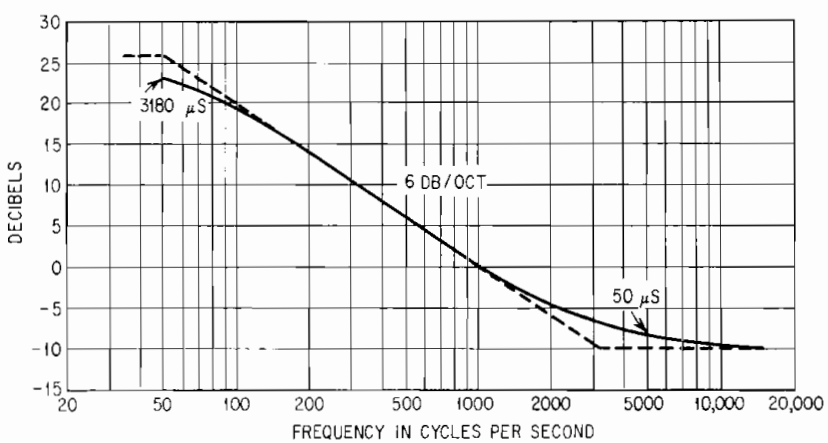


FIGURE 6. NAB magnetic tape standard reproducing characteristic, 15 inches per second.

parallel combination of a capacitance and a resistance having a time constant of 50 microseconds. The combined curve is shown in Figure 6.

Methods of Establishing the Standard Reproducing System

2.85 The relative surface inductions at different frequencies on a tape can be measured by at least three methods that are described in the attached Annex. From such measurements the departure of the response of a reproducing head from the "ideal" can be deduced and consequently a Standard Reproducing System can be established as a primary standard. Test tapes can then be made which can serve as secondary standards for use in normal operation.

Signal-to-noise Ratio

2.90 It shall be standard that the signal-to-noise ratio of a recording system shall be at least 55 db referred to the Standard Reference Level. All frequencies between 50 and 15,000 cycles are to be included in the measurement of the noise. (The standard reference level for signal-to-noise measurements shall be the output level obtained by reproducing tape, produced by a recording system operating under normal conditions, at which two percent total harmonic distortion of the recorded 400 cycle tone occurs using tape that is normally available.)

Annex

Methods of Measuring the Magnetization of a Tape [1]

There are two general ways in which the surface induction [2] vs. frequency characteristic of a tape may be determined:

1. By means which do not affect the surface induction. This implies the use of a non-magnetic reproducing device. For example, reproduction by means of a simple non-magnetic conductor placed in the field at the surface of the moving tape appears to be practicable as a laboratory method and might therefore be used to establish a primary standard which could be used to determine the relative change of surface induction with wavelength created by the presence of a magnetic head.
2. By means of a magnetic reproducing device, which necessarily affects the surface induction of the tape in a manner dependent on recorded wavelength. In this category there are two ways in which conventional magnetic heads have been used, one method involving heads with a short gap, the other involving heads with a long gap. In both cases the gap in the reproducing head must be sufficiently accurate, magnetically, to give well-defined minima of reproduced level, one in the short gap method or several in the long gap method.

(a) **The "Short Gap" Head Method.** The longest wavelength at which a minimum of reproduced level occurs is the effective gap length (d). The necessary correction for the gap length is calculated on the assumption that output is proportional to

$$\frac{\sin \frac{\pi d}{\lambda}}{\frac{\pi d}{\lambda}}$$

[1] These methods resulted from experiments undertaken by members of the NAB Recording and Reproducing Standards Committee following the original work in C.C.I.R. Study Group X on the subject.

[2] In general terms, surface induction is the flux density (B) at right angles to the surface of the tape. It depends not only on the magnetization of the tape but also on the properties of the reproducing device. In the following, surface induction means the surface induction of the tape in space and not in contact with a reproducing device.

This correction must not exceed 5 db at the shortest wavelength considered. Any necessary correction for eddy current losses must also be determined, for example, by comparing output at various tape speeds or by the use of an inducing loop.

It appears that if the correction for gap length does not exceed 5 db, then the surface induction is altered, due to the presence of the head, by an approximately constant factor over the whole range of wavelengths and may therefore be neglected.

Once these corrections are known and applied, the head may be used as an "ideal" head to measure relative surface inductions on the tape over the wavelength range considered. Since surface induction is a measure of flux density, it is proportional to the open circuit induced voltage of an "ideal" short gap head.

(b) The "Long Gap" Method. In this method a head is used with a gap some 50 times as long as that of the normal reproducing head. In practice an erase head can usnally be adapted for the purpose. The response of such a head should show a series of well defined maxima and minima as shown in Figure 7.

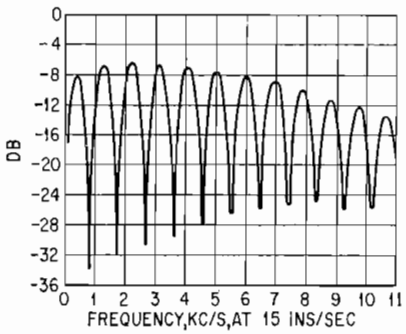


FIGURE 7. Frequency characteristic standardization in magnetic recording.

A curve through the successive maxima is a measure of the surface induction on the tape when the necessary corrections for eddy current losses of the head have been made. This curve falls at approximately 4 db per octave compared with the curve of surface induction vs. frequency in air as determined by a non-magnetic reproducing device, or by a "sharp-gap" head. This correction must be explored further before this method can be applied.

NOTE 1. The "Long Gap" method is included here because of its use in other countries and its possible future use in the U.S.A. The uncertainty of the correction factor makes it unusable as a standard method of measurement at present.

The precise steps by which the procedures of (2) (*a*) and (*b*) may be applied in practice are outlined in the following.

Standardization by the "Short Gap" Magnetic Head

Using the "Short Gap" Method a recording equipment is set to the standard condition in the following way:

1. A "gliding tone" is recorded on a tape and reproduced by means of the head to be used for the measurements. The longest wavelength at which the output disappears is noted. This wavelength will be equal to the effective gap length, from which the necessary gap correction may be deduced. If this correction exceeds 5 db, the head is unsuitable for this measurement.

Since the measurement must take place at a very short recorded wavelength, a high coercivity tape should be used, and a certain amount of pre-emphasis will be found useful. In order to avoid making the measurements at an unnecessarily high frequency, the lowest tape speed available should be used.

2. The tape with the gliding tone is reproduced at two different speeds and the output curves compared. If the curve can be brought to coincidence by displacing

one frequency scale so that equal wavelengths coincide it may be assumed that frequency-dependent losses are negligible. If not, these losses may be deduced from the two curves mentioned or, alternatively, from a measurement with an inducing loop.

3. The frequency response of the reproducing amplifier is now adjusted to consist of the sum of the following:

a. Compensation for the gap loss noted in (1) above.

b. Any compensation for the frequency-dependent losses noted in (2) that may be required.

c. The response curve specified for a Standard Reproducing System with an "ideal" reproducing head and shown in Figure 6.

4. The recording equalization is then adjusted so that a flat overall response is obtained.

Standardization by the "Long Gap" Magnetic Head

Using the "Long Gap" Method a recording equipment is set to the standard condition in the following way:

1. The reproducing head used has a well defined gap long enough to give successive maxima of response at intervals of 1 kc/s or less in the audio frequency range. (With a tape speed of 30 in/sec the gap length required would be about 800 microns.) If the successive minima in the response curve are not equally well defined, the head is not suitable for this measurement.

A short preliminary experiment is carried out to determine the exact frequencies at which the successive maxima occur at the standard tape speed.

2. A "gliding tone" test tape of the audio frequencies of maximum level is then recorded with constant voltage input to the recording chain and the tape is reproduced using the long gap head. The open circuit voltage of the head around these frequencies is then plotted against frequency, and a smooth curve is drawn through the successive maxima.

3. The tape with the gliding tone is reproduced at two different speeds using the long gap head and the output curves compared. If the curves can be brought to coincide by displacing one frequency scale so that equal wavelengths coincide it may be assumed that frequency-dependent losses are negligible. If not, these losses may be deduced from the two curves mentioned or, alternatively, from a measurement with an inducing loop.

4. When the curve drawn in (2) has been corrected by a 6 db/octave rise with increase in frequency, together with the compensation for frequency-dependent losses and a correction of 1 to 2 db/octave falling with increase of frequency, the result defines the surface induction of the tape.

5. The equalization of the recording amplifier is now altered to obtain a characteristic of surface induction vs. frequency that is the inverse of the equalization specified for the reproducing system (without allowance for the reproducing head losses).

6. The reproducing amplifier equalization is then adjusted so that a flat over-all response is obtained when using a normal reproducing head.

Section 4

Glossary of Mechanical, Magnetic, and Optical Terms and Definitions

4.005 Acetate Disks. Acetate disks are mechanical recording disks, either solid or laminated which are made mostly from cellulose nitrate lacquer plus a lubricant.

4.010 Advance Ball. An advance ball is a rounded support (often sapphire) attached to a cutter which rides on the surface of the recording medium so as to maintain a uniform mean depth of cut and correct for small irregularities of the disk surface.

4.015 Aeolight. An aeolight is a glow lamp employing a cold cathode and a

mixture of permanent gases in which the intensity of illumination varies with the applied signal voltage.

4.020 Background Noise. Background noise is the total system noise independent of whether or not a signal is present. The signal is not to be included as part of the noise.

4.025 Bilateral-area Track. A bilateral-area track is a sound track having the two edges of the central area modulated according to the signal.

4.030 Binder. A binder is a resinous material which causes the various materials of a record compound to adhere to one another.

Biscuit—see Preform (Biscuit).

4.035 Burnishing Surface. A burnishing surface, in mechanical recording, is the portion of the cutting stylus directly behind the cutting edge which smooths the groove.

Cathode Sputtering—see Sputtering.
Cellulose Nitrate Disks—see Lacquer Disks.

4.040 Chip. The chip, in mechanical recording, is the material removed from the recording medium by the recording stylus while cutting the groove.

Christmas Tree Pattern—see Optical Pattern.
Coated Tape—see Magnetic Powder-coated Tape.
Concentric Groove—see Groove, Locked.

4.041 Compression Molding. Compression molding is molding a record or transcription by means of compressing a preform of plastic.

4.042 Cold Cutting Stylus. A cold cutting stylus is a stylus having its cutting edge burnished at a plane substantially different from the cutting face for the purpose of cutting and polishing the groove in an acetate disk at normal room temperature.

4.045 Constant-amplitude Recording. Constant-amplitude recording indicates a mechanical recording characteristic wherein, for a fixed amplitude of a sinusoidal signal, the resulting recorded amplitude is independent of frequency.

4.050 Constant-velocity Recording. Constant-velocity recording indicates a mechanical recording characteristic wherein, for a fixed amplitude of a sinusoidal signal, the resulting recorded amplitude is inversely proportional to the frequency.

4.052 Constant Velocity Recorder or Reproducer. Consists of a recording or reproducing machine designed so that the turntable rotates in such a manner that constant velocity is effected at the recording stylus or reproducer stylus irrespective of diameter.

4.055 Control Track. A control track is a supplementary sound track, usually placed on the same film with the sound track carrying the program material. Its purpose is to control, in some respect, the reproduction of the sound track. Ordinarily, it contains one or more tones, each of which may be modulated either as to amplitude or frequency.

4.060 Core. A core, in mechanical recording, is the center layer or basic support of certain types of laminated media.

Crossover Frequency—see Transition Frequency.
Crosstalk—see Magnetic Printing.

4.065 Crystal Cutter. A crystal cutter is a cutter in which the mechanical displacements of the recording stylus are derived from the deformations of a crystal having piezoelectric properties.

4.070 Cutter (Mechanical Recording Head). A cutter is an electromechanical transducer which transforms an electric input into a mechanical output, typified by mechanical motions which may be inscribed into a recording medium by a cutting stylus.

De-emphasis—see Postemphasis.

4.075 Densitometer. A densitometer is an instrument for the measurement of optical density (photographic transmission, photographic reflection, visual transmission, etc.) of a material.

4.080 Disk Recorder. A disk recorder is a mechanical recorder in which the recording medium has the geometry of a disk.

Drift—see Flutter.

4.085 Drive Pin. A drive pin, in disk recording, is a pin similar to the center pin, but located to one side thereof, which is used to prevent a disk record from slipping on the turntable.

4.090 Drive-pin Hole. A drive-pin hole, in disk recording, is a hole in a disk recording which accommodates the turntable drive pin.

4.095 Dubbing. Dubbing is a term used to describe the combining of two or more sources of sound into a complete recording, at least one of the sources being a recording. (See Re-recording)

Dynamic Reproducer—see Pickup, Moving Coil.
Eccentric Circle—see Groove, Eccentric.

4.100 Eccentricity. Eccentricity, in disk recording, is the displacement of the center of the recording groove spiral, with respect to the record center hole.

4.105 Equalization (Corrective Equalization). Equalization is the effect of all corrective means employed in the recording and reproducing process to obtain a desired over-all frequency response.

4.106 Equalization (Diameter). Diameter equalization is the increasing of the high frequency response with respect to decreasing diameter of the recording.

4.110 Erasing Head. An erasing head is a device for obliterating any previous recordings. It may be used for preconditioning the magnetic media for recording purposes.

4.115 Erasing Head, A-C. An a-c erasing head is a magnetic head which uses alternating current to produce the magnetic field necessary for erasing.

NOTE: A-c erasing is achieved by subjecting the medium to a number of cycles of a magnetic field of a decreasing magnitude. The medium is, therefore, essentially magnetically neutralized.

4.120 Erasing Head, D-C. A d-c erasing head is a magnetic head which utilizes direct current to produce the magnetic field necessary for erasing.

NOTE: D-c erasing is achieved by subjecting the medium to a unidirectional field. Such a medium is, therefore, in a different magnetic state than one erased by a-c.

4.125 Erasing Head, P-M. A p-m erasing head uses the fields of one or more permanent magnets for erasing.

4.130 Fast Groove (Fast Spiral). A fast groove, in disk recording, is an unmodulated spiral groove having a pitch that is much greater than that of the recorded grooves.

4.132 Feed Back Cutter. A feed back cutter is an electromechanical transducer which performs the same as a "cutter" except that it is equipped with an auxiliary feed back coil in the magnetic field. Signals exciting the "cutter" are induced into the feed back coil which in turn is fed back to the input of the cutter amplifier resulting in a substantially uniform frequency response.

4.135 Filler. Filler, in mechanical recording, is the insert material of a record compound as distinguished from the binder.

4.140 Film Reproducer. A film reproducer is an instrument in which film is the medium from which a recording is reproduced.

NOTE: In many cases, the term "film reproducer" is erroneously used synonymously with optical sound reproducer.

4.145 Film Sound Recorder. A film sound recorder is equipment which uses film as the recording medium.

NOTE: In many cases, the term "film sound recorder" is erroneously used synonymously with optical sound recorder.

4.147 Flash. Flash is the excess material generated at the edge of a record or transcription after the molding is completed.

4.150 Flutter (WOW) (Drift). In recording and reproducing, flutter is the deviation of frequency which results in general from irregular motion during recording, duplication, or reproduction.

NOTE: The term "flutter" usually refers to cyclic deviations occurring at a relatively high rate, as for example, 10 cycles per second. The term "wow" usually refers to cyclic deviations occurring at a relatively low rate, as for example, a once-per-revolution speed variation of a phonograph turntable. The term "drift" usually refers to a random rate close to zero cycles per second.

4.155 Flutter Rate. Flutter rate is the number of cyclical variations per second of the flutter.

Frequency—Crossover-Transition-Turnover—see Transition, Frequency.

4.157 Forty-five Record. A "45 RPM" record is a record recorded and reproduced at 45 revolutions per minute having a center hole of 1.5 inches.

4.160 Frequency Record. A frequency record is a recording of various known frequencies at known amplitudes, usually for the purposes of testing or measuring.

4.165 Galvanometer Recorder (for Photographic Recording). A galvanometer recorder for photographic recording is a combination of mirror and coil suspended in a magnetic field. The application of a signal voltage to the coil causes a reflected light beam from the mirror to pass across a slit in front of a moving photographic film, thus providing a photographic record of the signal.

4.170 Gamma. The gamma of a photographic material is the slope of the straight line portion of the H and D curve. It represents the rate of change of photographic density with the logarithm of exposure. Gamma is a measure of the contrast properties of the film. Both gamma and density specifications are commonly used as controls in the processing of photographic film.

4.175 Gap Length. In longitudinal magnetic recording, the gap length is the physical distance between adjacent surfaces of the poles of a magnetic head. (See Magnetic Head.)

NOTE: The effective gap length is usually greater than the physical length and can be experimentally determined in some cases.

4.180 Grain. A grain of photographic material is a small particle of metallic silver remaining in a photographic emulsion after development and fixing. In the agglomerate, these grains form the dark area of a photographic image.

4.185 Graininess. Graininess of a photographic material is the visible coarseness under specified conditions due to silver grains in a developed photographic film.

4.190 Groove. A groove, in mechanical recording, is the track inscribed in the record by the cutting or embossing stylus, including undulations or modulations caused by the vibration of the stylus.

4.195 Groove Angle. Groove angle, in disk recording, is the angle between the two walls of an unmodulated groove in a radial plane perpendicular to the surface of the recording medium.

4.200 Groove, Eccentric (Eccentric Circle). An eccentric groove, in disk recording, is an unmodulated locked groove whose center is other than that of the disk record (generally used in connection with mechanical control of phonographs).

4.205 Groove, Fast (Fast Spiral). A fast groove, in disk recording, is an unmodulated spiral groove having a pitch that is much greater than that of the recorded grooves.

4.210 Groove, Lead-in (Lead-in Spiral). A lead-in groove, in disk recording, is a blank spiral groove at the beginning of a record generally having a pitch that is much greater than that of the recorded grooves.

4.215 Groove, Lead-over, Crossover Spiral). A lead-over groove, in disk recording, is a groove cut between recordings of small durations which enables the pickup stylus to travel from one cut to the next.

4.220 Groove, Lead-out (Throw-out Spiral). A lead-out groove, in disk recording, is a blank spiral groove at the end of a recording generally of a pitch that is much greater than that of the recorded grooves and which is connected to either the locked or eccentric groove.

4.225 Groove, Locked (Concentric Groove). A locked groove, in disk recording, is a blank and continuous groove at the end of modulated grooves whose function is to prevent further travel of the pickup.

4.230 Groove Shape. Groove shape, in disk recording, is the contour of the groove in a radial plane perpendicular to the surface of the recording medium.

4.235 Groove Speed. Groove speed, in disk recording, is the linear speed of the groove with respect to the stylus.

4.240 Groove, Unmodulated. An unmodulated groove, in mechanical recording, is a groove made in the medium with no signal applied to the cutter.

4.245 Ground Noise. Ground noise is the residual system noise in the absence of the signal. It is usually caused by inhomogeneity in the recording and reproducing media, but may also include amplifier noise such as tube noise or noise generated in resistive elements in the input of the reproducer amplifier system.

4.250 Grouping. Grouping is nonuniform spacing between the grooves of a disk recording.

4.255 Guard Circle. A guard circle is an inner concentric groove inscribed, on disk records, to prevent the pickup from being damaged by being thrown to the center of the record.

4.260 H and D Curve (Hurter and Driffield Curve). An H and D Curve is a characteristic curve of a photographic emulsion which is a plot of density against the logarithm of exposure. It is used for the control of photographic processing, and for defining the response characteristics to light of photographic emulsions.

Impregnated Tape—see Magnetic Powder-Impregnated Tape.

4.262 Injection Molding. Injection molding is the process of molding a record or transcription by means of injecting into a die cavity a plastic liquified by heat.

4.265 Instantaneous Recording. An instantaneous recording is a recording which is intended for direct reproduction without further processing.

4.270 Lacquer Disks (Cellulose Nitrate Disks). Lacquer disks are mechanical recording disks usually made of metal, glass, or paper, and coated with a lacquer compound (often containing cellulose nitrate).

4.275 Lacquer Original (Lacquer Master °). A lacquer original is an original recording on a lacquer surface for the purpose of making a master.

4.280 Lacquer Recording. A lacquer recording is any recording made on a lacquer recording medium.

4.285 Laminated Record. A laminated record is a mechanical recording medium composed of several layers of material. Normally, it is made with a thin face of surface material on each side of a core.

4.290 Land. The land is the record surface between two adjacent grooves of a mechanical recording.

4.295 Lateral Recording. A lateral recording is a mechanical recording in which the groove modulation is perpendicular to the motion of the recording medium and parallel to the surface of the recording medium.

4.300 Light Modulator. A light modulator is the combination of a source of light, an appropriate optical system, and a means for varying the resulting light beam, so that a sound track may be produced (such as a galvanometer or light valve).

4.305 Light Valve. A light valve is a device in which the light passes through one or more slits, the width of which changes in accordance with the signal supplied.

° Deprecated.

4.307 Long-playing. Long-playing refers to a transcription or record having substantially longer playing time by reason of more lines per inch.

4.310 Magnetic Biasing. Magnetic biasing is the simultaneous conditioning of the magnetic recording medium during recording by superposing an additional magnetic field upon the signal magnetic field.

NOTE: In general, magnetic biasing is used to obtain a substantially linear relationship between the amplitude of the signal and the remanent flux density in the recording medium.

4.315 Magnetic Biasing, A-C. A-c magnetic biasing is magnetic biasing accomplished by the use of an alternating current, usually well above the signal frequency range.

4.320 Magnetic Biasing, D-C. D-c magnetic biasing is magnetic biasing accomplished by the use of direct current.

4.325 Magnetic Cutter. A magnetic cutter is a cutter in which the mechanical displacements of the recording stylus are produced by the action of magnetic fields.

4.330 Magnetic Head. In magnetic recording, a magnetic head is a transducer for converting electric variations into magnetic variations for storage on magnetic media, for reconverting energy so stored into electric energy, or for erasing such stored energy.

4.335 Magnetic Head, Double Pole-piece. A double pole-piece magnetic head is a magnetic head having two separate pole pieces in which pole faces of opposite polarity contact the medium on opposite sides. Either both or only one of these pole pieces may be provided with an energizing winding.

4.340 Magnetic Head, Single Pole-piece. A single pole-piece magnetic head is a magnetic head having a single pole piece which contacts the recording medium on oue side.

4.345 Magnetic Plated Wire. Magnetic plated wire is a magnetic wire having a core of nonmagnetic material and a plated surface of ferromagnetic material.

4.350 Magnetic Powder-coated Tape (Coated Tape). Magnetic powder-coated tape is a tape consisting of a coating of uniformly dispersed, powdered ferromagnetic material on a nonmagnetic hase.

4.355 Magnetic Powder-impregnated Tape (Impregnated Tape) (Dispersed Magnetic Powder Tape). Magnetic powder-impregnated tape is a magnetic tape which consists of magnetic particles uniformly dispersed in a nonmagnetic material.

4.360 Magnetic Printing (Crosstalk °). Magnetic printing is the permanent transfer of a recorded signal from a section of a magnetic recording medium to another section of the same or a different medium when these sections are brought in proximity.

4.365 Magnetic Recorder. A magnetic recorder is equipment incorporating an electromagnetic transducer and means for moving a ferromagnetic recording medium relative to the transducer for recording electric signals as magnetic variations in the medium.

NOTE: The generic term "magnetic recorder" can also be applied to an instrument which has not only facilities for recording electric signals as magnetic variations, but also for converting such magnetic variations back into electric variations.

4.370 Magnetic Recording Head. In magnetic recording, a magnetic recording head is a magnetic head for transforming electric variations into magnetic variations for storage on magnetic media.

4.375 Magnetic Recording Medium. A magnetic recording medium is a magnetizable material used in a magnetic recorder for retaining the magnetic variations imparted during the recording process. It may have the form of a wire, tape, cylinder, disk, etc.

4.380 Magnetic Recording Reproducer. A magnetic recording reproducer is equipment for converting magnetic variations on magnetic recording media into electric variations.

° Deprecated.

4.385 Magnetic Reproducing Head. In magnetic recording, a magnetic reproducing head is a magnetic head for converting magnetic variations on magnetic media into electric variations.

4.390 Magnetic Tape. Magnetic tape is a magnetic recording medium having a width greater than approximately 10 times the thickness. This tape may be homogeneous or coated.

4.395 Magnetic Wire. Magnetic wire is a magnetic recording medium, approximately circular in cross section.

4.400 Magnetization, Longitudinal. Longitudinal magnetization in magnetic recording is magnetization of the recording medium in a direction essentially parallel to the line of travel.

4.405 Magnetization, Perpendicular. Perpendicular magnetization in magnetic recording is magnetization of the recording medium in a direction perpendicular to the line of travel, and parallel to the smallest cross-sectional dimension of the medium.

NOTE: In this type of magnetization, either single pole-piece or double pole-piece magnetic heads may be used.

4.410 Magnetization, Transverse. Transverse magnetization in magnetic recording is magnetization of the recording medium in a direction perpendicular to the line of travel and parallel to the greatest cross-sectional dimension.

4.415 Master. A master is a metal part, normally derived from a disk recording by electroforming, which is a negative of the recording, i.e., a master which has ridges instead of grooves and thus cannot be played with a pointed stylus.

Master, Lacquer—see Lacquer Original.
Master, Metal—see Master, Original.

4.420 Master No. 2, No. 3, Etc. A No. 2, No. 3 master, etc. is a master produced by electroforming from a No. 1, No. 2, etc. mold.

4.425 Master, Original (Metal Master) (Metal Negative) (No. 1 Master). An original master, in disk recording, is the master produced by electroforming from the face of a wax or lacquer recording.

4.430 Mechanical Recorder. A mechanical recorder is an equipment for transforming electric or acoustical signals into mechanical motion of approximately like form and inscribing such motion in an appropriate medium by cutting or embossing.

Mechanical Recording Head—see Cutter.
Mechanical Reproducer—see Pickup.
Metal Master; Metal Negative—see Master, Original.
Metal Positive—see Mold, No. 1.

4.432 Micro-groove. Micro-groove refers to a transcription or record having substantially longer playing time by reason of more lines per inch.

4.433 Mini-groove. Mini-groove is a recording having more lines per inch than the average 78 RPM phonograph record and yet not enough lines per inch to be called "Extended play," "Long playing" or "Micro-groove."

4.435 Mixer. A mixer, in a sound recording or reproducing system, is a device having two or more inputs, usually adjustable, and a common output, which operates to combine linearly the separate input signals to produce an output signal.

NOTE: The term is also sometimes applied to the operator of the above device.

4.440 Modulation Noise. (Noise behind the Signal.) The modulation noise is the noise caused by the signal. The signal is not to be included as part of the noise.

NOTE: The term is used where the noise level is a function of the strength of the signal.

4.445 Mold. In disk recording, a mold is a metal part derived from a master by electroforming which is a positive of the recording, i.e., it has grooves similar to a recording and thus can be played in a manner similar to a record.

4.450 Mold, No. 1 (Mother) (Metal Positive). A No. 1 mold is a mold derived by electroforming from the original master.

4.455 Mold, No. 2, No. 3, Etc. A No. 2, No. 3, etc. mold is a mold derived by electroforming from a No. 2, No. 3, etc. master.

Mother—see Mold, No. 1.

4.460 Multitrack Magnetic Recording System. A multitrack magnetic recording system is a recording system which provides; on a medium such as magnetic tape, two or more recording paths which are parallel to each other, and which may carry either related or unrelated program material in common time relationship.

Needle Drag—see Stylus Drag.
Needle Force—see Stylus Force.
Noise behind the Signal—see Modulation Noise.

4.465 Noise Reduction. Noise reduction is a process whereby the average transmission of the sound track of the print (averaged across the track) is decreased for signals of low level and increased for signals of high level.

NOTE: Since the background noise introduced by the sound track is less at low transmission, this process reduces film noise during soft passages. The effect is normally accomplished automatically.

4.470 Offset Angle. In lateral disk recording reproduction, the offset angle is the smaller of the two angles between the projections into the plane of the disk of the vibration axis of the pickup stylus and the line connecting the vertical pivot (assuming a horizontal disk) of the pickup arm with the stylus point.

4.475 Opacity. Opacity of an optical path is the reciprocal of transmission. (See Transmission.)

Optical Density—see Transmission Density.

4.480 Optical Pattern (Christmas Tree Pattern). In mechanical recording, an optical pattern is a pattern which is observed when the surface of a record is illuminated by a light beam.

4.485 Optical Sound Recorder (Photographic Sound Recorder). An optical sound recorder is equipment incorporating a light modulator and means for moving a light-sensitive medium relative to the modulator for recording electric signals derived from sound signals.

4.490 Optical Sound Reproducer. An optical sound reproducer is a combination of light source, optical system, photoelectrical cell, and a mechanism for moving a photoelectric medium (usually film), by means of which recorded variations on a sound track may be converted into electric signals of approximately like form.

4.495 Overcutting. In disk recording, overcutting is the effect of excessive level characterized by one groove cutting through into an adjacent one.

4.500 Photographic Emulsion. Photographic emulsion is the light-sensitive coating on photographic film consisting usually of a gelatine containing silver halide.

4.505 Pickup, Acoustical. An acoustical pickup is a device which transforms groove modulation directly into acoustical radiation.

4.510 Pickup Arm (Tone Arm). A pickup arm is a pivoted arm arranged to hold a pickup.

4.515 Pickup, Capacitor. A capacitor pickup is a reproducer which depends for its operation upon the variation of its electrical capacitance.

4.520 Pickup Cartridge. A pickup cartridge is the removable portion of a pickup containing the electromechanical translating elements and the reproducing stylus.

4.525 Pickup, Crystal. A crystal pickup is a reproducer which depends for its operation on the piezoelectric effect of crystals.

4.530 Pickup, Light-beam. A light-beam pickup is a reproducer in which a light beam is a coupling element of the transducer.

4.535 Pickup, Magnetic (Variable-reluctance Pickup). A magnetic pickup is a reproducer which depends for its operation on the variations in the reluctance of a magnetic circuit.

4.540 Pickup (Mechanical Reproducer). A pickup is a mechanoelectrical transducer which is actuated by modulations present in the groove of the recording medium and which transforms this mechanical input into an electric output.

4.545 Pickup, Moving-coil (Dynamic Reproducer). A moving-coil pickup is a reproducer, the electric output of which results from the motion of a coil in a magnetic field.

4.550 Pick-up, Variable-inductance. A variable-inductance pickup is a reproducer which depends for its operation on the variation of its inductance.

4.555 Pickup, Variable-resistance. A variable-resistance pickup is a reproducer which depends for its operation upon the variation of a resistance.

4.560 Pinch Effect. In disk recording, the pinch effect is a pinching of the reproducing stylus tip twice each cycle in the reproduction of lateral recordings, due to a decrease of the groove angle cut by the recording stylus when it is moving across the record as it swings from a negative to a positive peak.

4.565 Playback. A playback is an expression used to denote reproduction of a recording.

Playback Loss—see Translation Loss.

4.570 Poid. A poid is the curve traced by the center of a sphere when it rolls or slides over a surface having a sinusoidal profile.

4.575 Post-emphasis (De-emphasis) (Post Equalization). Post-emphasis is usually a form of equalization complementary to pre-emphasis.

4.580 Pre-emphasis (Pre-equalization). In recording, pre-emphasis is an arbitrary change in the frequency response of a recording system from its basic response (such as constant velocity or amplitude) for the purpose of improvement in signal-to-noise ratio, or the reduction of distortion.

4.585 Preform (Biscuit *). In disk recording, a preform is a small slab of record stock material as it is prepared for use in the record presses.

4.590 Pressing. In disk recording, a pressing is a record produced in a record-molding press from a master or stamper.

4.595 Recording Channel. The term "recording channel" refers to one of a number of independent recorders in a recording system or to independent recording tracks on a recording medium.

NOTE: One or more channels may be used at the same time for covering different ranges of the transmitted frequency band, for multichannel recording, or for control purposes.

4.600 Recording Loss. Recording loss, mechanical recording, is the loss in recording level whereby the amplitude of the wave in the recorded medium differs from the amplitude executed by the recording stylus.

4.605 Re-recording. Re-recording is the process of making a recording by reproducing a recorded sound source and recording this reproduction. (See Dubbing.)

4.610 Re-recording System. A re-recording system is an association of reproducers, mixers, amplifiers, and recorders capable of being used for combining or modifying various sound recordings to provide a final sound record. Recording of speech, music, and sound effects may be so combined.

4.615 Ring Head. A ring head is a magnetic head in which the magnetic material forms an enclosure with one or more air gaps. The magnetic recording medium bridges one of these gaps and is contacted by the pole pieces on one side only.

4.620 Rumble (Turntable Rumble). Rumble is low-frequency vibration mechanically transmitted to the recording or reproducing turntable and super-imposed on the reproduction.

4.625 Scoring System. A scoring system for motion picture production is a recording system used for recording music to be reproduced in timed relationship with a motion picture.

4.630 Sensitometry. Sensitometry is the measurement of the light response characteristics of photographic film under specified conditions of exposure and development.

* Deprecated.

4.635 Shaving. In mechanical recording, shaving is the process of removing material from the surface of a recording medium for the purpose of obtaining a new recording surface.

4.640 Side Thrust. Side thrust, in disk recording, is the radial component of force on a pickup arm caused by the stylus drag.

4.645 Single Track (Standard Track). A single track is a variable-density or variable-area sound track in which both positive and negative halves of the signal are linearly recorded.

4.650 Sound Recording System. A sound recording system is a combination of transducing devices and associated equipment suitable for storing sound in a form capable of subsequent reproduction.

4.655 Sound Reproducing System. A sound reproducing system is a combination of transducing devices and associated equipment for reproducing recorded sound.

4.660 Sound Track. A sound track is a narrow band, usually along the margin of a sound film, which carries the sound record. In some cases, a plurality of such bands may be used.

4.665 Sound Track, Multiple. A multiple sound track consists of a group of sound tracks, printed adjacently on a common base, independent in character but in a common time relationship, e.g., two or more have been used for stereophonic sound recording.

4.670 Sound Track, Push-Pull, Class-A. A class-A push-pull sound track consists of two single tracks, side by side, the transmission of one being 180 degrees out of phase with the transmission of the other. Both positive and negative halves of the sound wave are linearly recorded on each of the two tracks.

4.675 Sound Track, Push-Pull, Class-B. A class-B push-pull sound track consists of two tracks, side by side, one of which carries the positive half of the signal only, and the other the negative half. During the inoperative half-cycle each track transmits little or no light.

Spiral, Crossover—see Groove, Leadover.
Spiral, Fast—see Groove, Fast.
Spiral, Lead-in—see Groove, Lead-in.
Spiral, Throw-out—see Groove, Thow-out.

4.677 Silvering. Silvering is a process wherein the surface of the original recorded master is metallized by precipitating on to this surface, the metallic silver in ammoniated silver nitrate.

4.678 Silver Spraying. Silver spraying is metallizing the surface of the original recorded master using a dual spray nozzle wherein the ammoniated silver nitrate and reducer are combined in anatomized spray to precipitate the metallic silver.

4.680 Sputtering (Cathode Sputtering). Sputtering is a process sometimes used in the production of the metal master wherein the original is coated with an electric conducting layer by means of an electric discharge in a vacuum.

NOTE: This is done prior to electroplating a heavier deposit.

4.685 Squeeze Track. A squeeze track is a variable-density sound track wherein, by means of adjustable masking, the width is varied by the recording operator, thus providing an overriding control on the amplitude of the reproduced signal.

4.690 Stamper. A stamper is a negative (generally made of metal by electroforming) from which finished pressings are molded.

4.695 Stamper, Backed. A backed stamper is a thin metal stamper which is attached to a backing material, generally a metal disk of desired thickness.

Standard Track—see Single Track.

4.700 Stylus, Cutting. A cutting stylus is a recording stylus with a sharpened tip which, by removing material, cuts a groove into the recording medium.

4.705 Stylus Drag (Needle Drag). Stylus drag is an expression used to denote the force resulting from friction between the surface of the recording medium and the reproducing stylus.

4.710 Stylus, Embossing. An embossing stylus is a recording stylus with a rounded tip which displaces the material in the recording medium to form a groove.

4.715 Stylus Force (Static Stylus Force) (Vertical Stylus Force) (Needle Force) (Stylus Pressure °). The stylus force is the vertical force exerted on a stationary recording medium by the stylus when in its operating position.

4.720 Stylus, Recording. A recording stylus is a tool which inscribes the grooves into the recording medium. There is the unmounted type used by cementing to the mounting; mounted, affixed to a metal shank and held in place by a set screw; morse taper which is held in place by friction. The latter two methods are necessary for "hot stylus" technique.

4.725 Stylus, Reproducing. A reproducing stylus is a mechanical element adapted to following the modulations of a record groove and transmitting the mechanical motion thus derived to the pickup mechanism.

NOTE: Stylus is a term defining a pickup needle or a holder furnished with a jewel or other abrasive-resistant tip. A stylus may or may not be arranged for convenient replacement.

4.730 Surface Noise. In mechanical recording surface noise is the noise component in the electric output of a pickup due to irregularities in the contact surface of groove. (See Ground Noise.)

Throw-out Spiral—see Groove, Lead-out.

4.735 Toe and Shoulder (of an H and D Curve). Toe and shoulder are the terms applied to the nonlinear portions of the H and D curve which lie respectively below and above the straight portion of this curve.

Tone Arm—see Pickup Arm.

4.740 Tracing Distortion. Tracing distortion is the nonlinear distortion introduced in the reproduction of mechanical recording because the curve traced by the motion of the reproducing stylus is not an exact replica of the modulated groove. For example, in the case of a sine-wave modulation in vertical recording the curve traced by the center of the tip of a stylus is a poid.

4.745 Tracking Error. Tracking error, in lateral mechanical recording, is the angle between the vibration axis of the mechanical system of the pickup and a plane containing the tangent to the unmodulated record groove and being perpendicular to the surface of the recording medium at the point of needle contact.

4.750 Transition Frequency (Crossover Frequency) (Turnover Frequency). The transition frequency, of a disk recording system, is the frequency corresponding to the point of intersection of the asymptotes to the constant amplitude and the constant velocity portions of its frequency response curve. This curve is plotted with output voltage ratio in decibels as the ordinate and the logarithm of the frequency as the abscissa.

4.755 Translation Loss (Playback Loss). Translation loss is the loss in the reproduction of a mechanical recording whereby the amplitude of motion of the reproducing stylus differs from the recorded amplitude in the medium.

4.760 Transmission. Transmission, as applied to optical recording, is the ratio of the light flux transmitted by a medium to the light flux incident upon it. Transmission may be either diffuse or specular.

4.765 Transmission Density, Diffuse.° Diffuse transmission density is the value of the photographic transmission density obtained when the light flux impinges normally on the sample and all the transmitted flux is collected and measured.

4.770 Transmission Density, Photographic † (Optical Density). Photographic transmission density is the common logarithm of opacity. Hence, film transmitting

° Deprecated.

† For details of measurement and specifications see American Standard Diffuse Transmission Density, Z38.2.5–1946, or the latest edition thereof approved by the American Standards Association.

100 percent of the light has a density of zero; transmitting 10 percent a density of 1, etc. Density may be diffused, specular, or intermediate. Conditions must be specified.

4.775 Transmission Density, Specular. Specular transmission density is the value of the photographic density obtained when the light flux impinges normally on the sample and only the normal component of the transmitted flux is collected and measured.

Turnover Frequency—see Transition Frequency.

4.780 Unilateral-area Track. A unilateral-area track is a sound track in which one edge only of the opaque area is modulated in accordance with the recorded signal. There may, however, be a second edge modulated by a noise reduction device.

4.782 Vacuum Chuck. A vacuum chuck is a chuck constructed with vacuum seals in such a manner that stampers may be held by vacuum for the purpose of machining.

4.785 Variable-area Track. A variable-area track is a sound track divided laterally into opaque and transparent areas, a sharp line of demarcation between these areas forming an oscillographic trace of the wave shape of the recorded signal.

4.790 Variable-density Track. A variable-density track is a sound track of constant width and of uniform light transmission on any instantaneous transverse axis and of which the average light transmission varies along the longitudinal axis in proportion to some characteristic of the applied signal.

4.795 Vertical Recording (Hill and Dale Recording). A vertical recording is a mechanical recording in which the groove modulation is in a direction perpendicular to the surface of the recording medium.

4.800 Wax. In mechanical recording, wax refers to a blend of waxes with metallic soaps. (See also Wax, Cake.)

4.805 Wax, Cake. Cake wax is a thick disk of wax upon which an original mechanical disk recording may be inscribed.

4.810 Wax, Flowed. Flowed wax is a mechanical recording medium, in disk form, prepared by melting and flowing wax onto a metal base.

4.815 Wax Original (Wax Master [*]). A wax original is an original recording on a wax surface for the purpose of making a master.

Wow—see Flutter.

C.C.I.R. STANDARDS OF SOUND RECORDING FOR THE INTERNATIONAL EXCHANGE OF PROGRAMS

Foreword

The International Radio Consultative Committee is a technical body functioning under the auspices of the United Nations. Its broad responsibilities are to make technical recommendations to the International Telecommunications Union (ITU) to facilitate and modernize the art of radio communication throughout the world. The C.C.I.R. has a permanent staff in Geneva, Switzerland, with a Director and a Vice-Director.

The work of the C.C.I.R. is divided among 14 Study Groups. One of these Groups is Study Group X, Broadcasting. Its terms of reference were defined at the VIIIth Plenary Assembly in Warsaw, Poland, 1956, and further amended at the IXth Plenary in Los Angeles, 1959, to include the study of the technical aspects of transmission and reception in the sound broadcasting service (except for tropical broadcasting), including standards of sound recording and sound reproduction to facilitate the international exchange of programmes, as well as standards for video tape.

The following Standards and Recommendations of the C.C.I.R. are included in

[*] Deprecated.

Volume I of the Documents of the VIIIth Plenary Assembly of the C.C.I.R., held in Warsaw, Poland, 1956, and will be included in the IXth Plenary documents when published. This volume may be purchased in its entirety from the International Telecommunications Union, Geneva, Switzerland. The entire volume contains Recommendations, Reports, Resolutions, Questions, and Study Programmes of all the 14 Study Groups of C.C.I.R.

Recommendation No. 207 *

Standards of Sound Recording for the International Exchange of Programmes

(Questions Nos. 42 and 63)
(Geneva, 1951–London, 1953–Warsaw, 1956)

The C.C.I.R. recommends that the international exchange of recorded sound programmes between broadcasting organisations should be by means of lateral-cut recording on disc and single-track magnetic recording on tape, conforming to the technical standards given in

Recommendation No. 208 for disc,
Recommendation No. 209 for tape.

Recommendation No. 208 †

Standards of Sound Recording for the International Exchange of Programmes

Lateral-cut Recording on Discs

(Questions Nos. 42 and 63–Recommendation No. 207)
(London, 1953–Warsaw, 1956)

The C.C.I.R. recommends that lateral-cut recording on disc should be in accordance with the following technical standards:

1. *Type of groove:*
   (*a*) Coarse groove
   –Minimum top width: 0.004″ (0.1 mm),
   –Maximum bottom radius: 0.0015″ (0.038 mm),
   –Included angle: 80° to 90°;
   (*b*) Fine groove
   –Minimum top width: 0.002″ (0.05 mm),
   –Maximum bottom radius: 0.0003″ (0.0076 mm),
   –Included angle: 80° to 90°.
2. *Speed of rotation:*
   33⅓ r.p.m. ± 0.5%,
   78 r.p.m. ± 0.7%.
3. *Direction of rotation:*
   Clockwise.
4. *Direction of cut:*
   Outside to inside.
5. *Type of disc:*
   Lacquer coated or processed.
6. *Maximum diameter of disc:*
   –for 33⅓ r.p.m. 16$\frac{1}{16}$″ (408 mm),
   –for 78 r.p.m. 12$\frac{1}{32}$″ (306 mm).
7. *Centre hole diameter:*

$$0.285'' \begin{cases} +0.002'' \\ -0'' \end{cases} \left(7.24 \text{ mm} \begin{cases} +0.05 \text{ mm} \\ -0 \text{ mm} \end{cases} \right)$$

* This Recommendation replaces Recommendation No. 133.
† This Recommendation replaces Recommendation No. 134.

8. *Minimum diameter of recorded surface:*
   —For 33⅓ r.p.m. coarse groove: 7½″ (190 mm),
   fine groove: 4¾″ (120 mm),
   —For 78 r.p.m. 3¾″ (95 mm).
9. *Number of plain grooves:*
   At start: minimum 2, maximum 4,
   At finish: minimum 2, maximum 4.
10. *Minimum information to be stated on label:*
   —Broadcasting organisation,
   —Programme title,
   —Side number,
   —Total number of sides,
   —Reference number,
   —Total playing time of programme,
   —Speed of rotation in r.p.m.
   —Type of groove.
   (The last two items should be marked as prominently as possible.)
11. *Recording characteristic* (fine and coarse groove discs):
   (*a*) Nominal characteristic
   With constant voltage applied to that point in the recording chain where the normal signal has the frequency characteristic that it is desired subsequently to reproduce, the curve of recorded velocity ° versus frequency shall be that which results from the combination of three curves as follows:
   —One rising with frequency in conformity with the admittance of a parallel combination of a capacitance and a resistance having a time constant of t_1;
   —One rising with frequency in conformity with the admittance of a series combination of a capacitance and a resistance having a time constant of t_2;
   —One falling with rise of frequency in conformity with the impedance of a series combination of a capacitance and a resistance having a time constant of t_3.
   The combined curve is defined by:

$$N\ (\text{db}) = 10 \log (1 + 4\pi^2 f^2 t_1^2) - 10 \log \left(1 + \frac{1}{4\pi^2 f^2 t_2^2}\right) + 10 \log \left(1 + \frac{1}{4\pi^2 f^2 t_3^2}\right)$$

where f = frequency in c/s
$t_1 = 50 \times 10^{-6}$ seconds
$t_2 = 318 \times 10^{-6}$ seconds
$t_3 = 3180 \times 10^{-6}$ seconds

This curve is shown in the figure.

NOTE: This paragraph defines the relative velocities to be recorded on a disc; but to ensure that the proper response is obtained on reproduction it is necessary to use a pickup with a suitable stylus and with working pressures low enough to avoid any appreciable deformation of the disc material.

   (*b*) Tolerance
   Discs for international interchange of programmes should be recorded within ±2 db of the nominal characteristic, taking as reference point the value at 1000 c/s.
   Any variation, for example that which results from the application of radius compensation, should be within the stated tolerance.

NOTE ON USE OF RECORDING CHARACTERISTIC: Within the U.S.A. a different characteristic will be used for the interchange of programmes between broadcasting organisations

° "Recorded velocity" is here defined as that determined by the Buchmann-Meyer light-band method.

but the C.C.I.R. characteristic will be used by the broadcasting companies of the U.S.A. for international exchange.

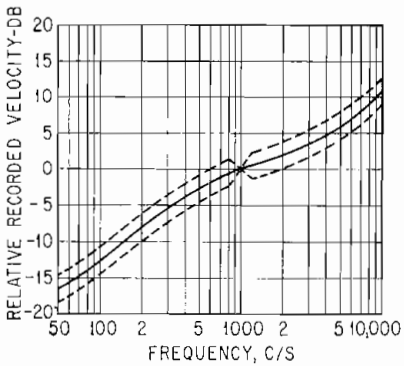


FIGURE 1. I.E.C. nominal recording characteristic for lateral-cut discs of fine groove and the tolerance within which discs should be recorded.

Recommendation No. 209 *

Standards of Sound Recording for the International Exchange of Programmes

Single Track Recording on Magnetic Tape

(Questions Nos. 42 and 63–Recommendation No. 133)
(London, 1953–Warsaw, 1956)

The C.C.I.R. unanimously recommends that single track recording on magnetic tape should be in accordance with the following technical standards:

1. *Speed of tape*

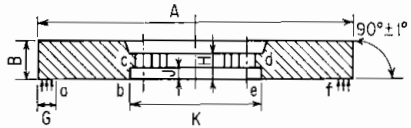
Primary speed:	15 inches/s ± 0.5%	(38.1	cm/s ± 0.5%),
Secondary speeds: †	30 inches/s ± 0.5%	(76.2	cm/s ± 0.5%),
	7½ inches/s ± 0.5%	(19.05	cm/s ± 0.5%).

2. *Width of tape*

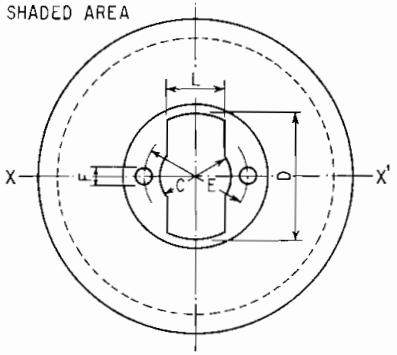
$$0.250 \text{ inches} \begin{cases} +0 \\ -0.006 \text{ inches} \end{cases} \left(6.35 \text{ mm} \begin{cases} +0 \\ -0.15 \text{ mm} \end{cases} \right)$$

3. *Strength of tape*
   The tape should be suitable for use on a machine exerting a maximum (transient) stress of 2.2 pounds (1 kg).
4. *Direction of winding*
   The tape should be wound in such a way that it may be unwound in an anti-clockwise direction during playing.
5. *Tape spools*
   Two types of hub are accepted for international programme exchange:
   Figure 1 gives the principal dimensions of the type more generally used in Europe;
   Figure 2 gives the dimensions of the hub more generally used in the United States and of the accompanying flange;
   Figure 3 gives the main dimensions of a typical machine fitting to receive the hub of Figure 1.
   Figure 4 gives the main dimensions of an adapter to enable the machine fitting of Figure 3 to receive the hub of Figure 2.

* This Recommendation replaces Recommendation No. 135.
† The secondary speeds should only be used by prior agreement.



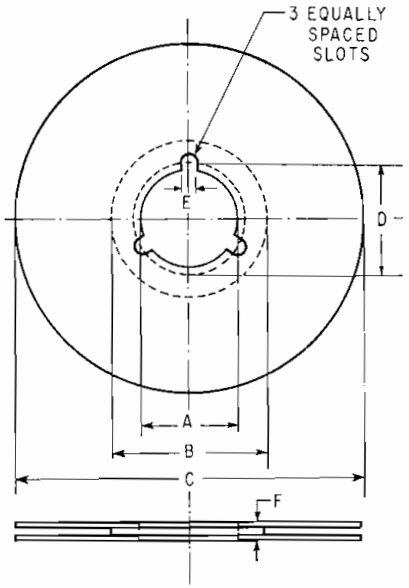
NOTE: THE CROSS-SECTION OF THE INNER SURFACE abcdef MUST FALL WITHIN THE SHADED AREA



THE HUB MAY CARRY A LABEL AND A FIXING DEVICE FOR THE TAPE, WHICH ARE NOT SHOWN

DIMENSIONS	MILLIMETERS	INCHES
A	58 a 100	2.28 to 3.95
B	11 $^{+0}_{-0.2}$	0.433 $^{+0}_{-0.008}$
C	20.1 $^{+0.1}_{-0}$	0.791 $^{+0.004}_{-0}$
D	35 $^{+0.2}_{-0}$	1.378 $^{+0.008}_{-0}$
E	28 $^{+0.2}_{-0}$	1.102 $^{+0.008}_{-0}$
F	5 $^{+0.2}_{-0}$	0.197 $^{+0.008}_{-0}$
G	4	0.157
H	7 $^{+0}_{-0}$	0.275 $^{+0}_{-0.04}$
J	3.5 MIN	0.138 MIN
K	36 MIN	1.417 MIN
L	16 $^{+0.2}_{-0}$	0.63 $^{+0.008}_{-0}$

FIGURE 1. European standards—spool hub for magnetic tape recording.



DIMENSION	INCHES		MILLIMETRES	
	MIN	MAX	MIN	MAX
A	3.000	3.004	76.20	76.30
B	4.490	4.510	114.05	114.55
C	10.50	10.52	267.0	267.5
D	3.248	3.252	82.45	82.55
E	0.219	0.225	5.60	5.75
F	0.447	0.457	11.35	11.60

FIGURE 2. U.S.A. type of spool for magnetic tape recording.

Whenever the exchange of recorded programmes has to be effected with cine-type flanged spools, the spools must conform to the standards established by the International Electrotechnical Commission.

6. *Maximum outside diameter of the reel of tape*
   For hub of Fig. 1: 11.4 inches (290 mm),
   For hub of Fig. 2: 10.5 inches (267 mm).
7. *Tape leader*
   A non-magnetic identification strip at least one meter long should be placed at the beginning of the tape giving at least the number of the spool and the reference number (see § 8 below). This information should be given on the side of the leader continuous with the unrecorded side of the tape.

NOTE: It is recommended that whenever possible the unrecorded side of the tape should be identified by some form of marking continuous throughout the length of the tape.

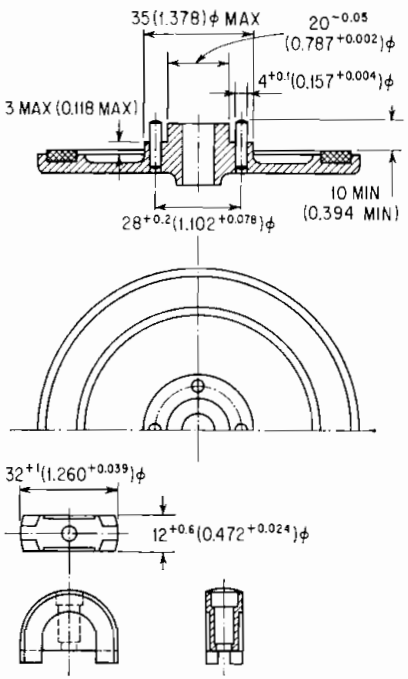


FIGURE 3. European standards—machine fitting to receive spool hub. NOTE: Unless otherwise indicated, all dimensions are in millimetres, with corresponding figures in inches in parenthesis.

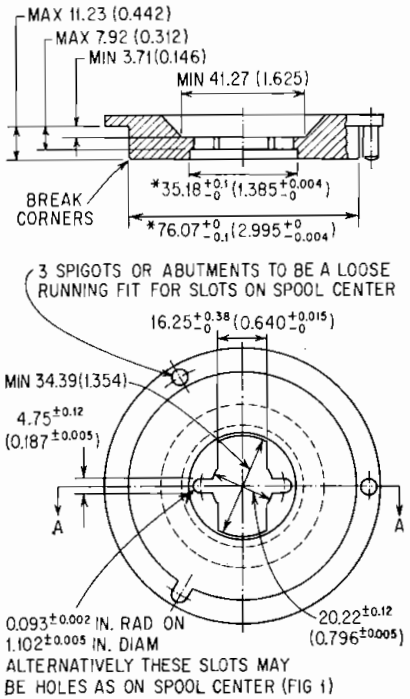


FIGURE 4. Typical adaptor to enable the European type of machine fitting to receive hub of Fig. 2. NOTE: Diameters marked thus * to be concentric within 0.003". Unless otherwise indicated, all dimensions are in millimetres, with corresponding figures in inches in parenthesis.

8. *Programme identification*

A label giving the following information should accompany each reel:
- —Broadcasting organisation,
- —Programme title,
- —Reel number,
- —Total number of reels,
- —Reference number,
- —Total playing time of programme,
- —Speed of tape (marked as prominently as possible).

9. *Reproducing characteristics*

A Standard Replay Chain is specified and recordings for programme interchange should give a response within the tolerances stated below when reproduced on this Standard Replay Chain:

(*a*) Nominal characteristic

The Standard Replay Chain is defined as one having the same response as that of an "ideal" reproducing head, the open-circuit voltage of which is amplified in an amplifier with a response curve as specified below:

For tape speeds of 15 in/s (38.1 cm/s) and 30 in/s (76.2 cm/s), the specified frequency response curve falls with increasing frequency in conformity

with the impedance of a series combination of a capacitance and a resistance having a time constant of 35 μs. This curve is shown in Figure 5;
For a tape speed of 7½ in/s (19.05 cm/s) the specified frequency response curve falls with increasing frequency in conformity with the impedance of a series combination of a capacitance and a resistance having a time constant of 100 μs. This curve is shown in Figure 6.

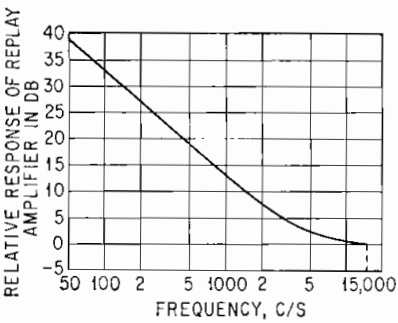


FIGURE 5. Nominal reproducing characteristic for magnetic tape at 15 in/s and 30 in/s.

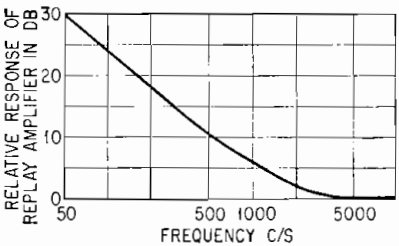


FIGURE 6. Nominal reproducing characteristic for magnetic tape at 7½ in/s.

(*b*) Tolerances

Tapes for international programme interchange should be recorded so that, when reproduced on a Standard Replay Chain the response falls between upper and lower limits defined as follows for tape speeds of 15 in/s (38.1 cm/s) and 30 in/s (76.2 cm/s):

Upper limit
—From 50 c/s to 100 c/s falling regularly by 1 db,
—From 100 c/s to 5 000 c/s flat,
—From 5 000 c/s to 10 000 c/s rising regularly by 1 db,
—From 10 000 c/s to 15 000 c/s flat;

Lower limit
—From 50 c/s to 100 c/s rising regularly by 3 db,
—From 100 c/s to 7 500 c/s flat,
—From 7 500 c/s to 15 000 c/s falling regularly by 3 db.

From 100 to 5 000 c/s the flat portions of the upper and lower limits are 2 db apart. These limits are shown in Figure 7;
For a tape speed of 7½ in/s (19.05 cm/s), the response should fall within limits defined as follows:

Upper limit
—From 50 c/s to 10 000 c/s flat;

Lower limit
—From 50 c/s to 100 c/s rising regularly by 3 db,
—From 100 c/s to 5 000 c/s flat,
—From 5 000 c/s to 10 000 c/s falling regularly by 3 db;

From 100 to 5 000 c/s the flat portions of the upper and lower limits are 2 db apart. These limits are shown in Figure 8.

NOTES:

1. An "ideal" reproducing head is defined as a ferromagnetic reproducing head, the losses of which are negligible. Normally this means that the gap is short, that the arc of contact with the tape is long compared with the relevant wavelengths on the tape and that the losses in the material of the head are small. With the reproducing heads used in practice, compensation for the head losses must be added to the replay amplifier. With good replay heads a mean value of this equalisation may be used for the two higher speeds and even for the three speeds.

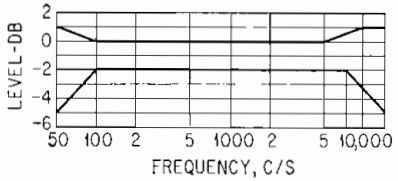


FIGURE 7. Recording tolerance for the speed of 15 and 30 in/s. Limits within which the response should lie when reproduction is carried out on the Standard Replay Chain.

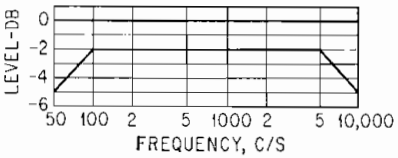


FIGURE 8. Recording tolerance for the speed of 7½ in/s. Limits which the response should lie when reproduction is carried out on the Standard Replay Chain.

2. The open circuit voltage developed in a ferromagnetic reproducing head depends on the surface induction * on the tape while it is in contact with the head. It has been found that, provided a coated high-coercivity tape is used, the surface induction in free space will be altered, when the tape is placed in contact with the head, by an approximately constant factor over the whole range of wavelengths. Under these circumstances the relative surface inductions at different frequencies can be measured by at least three methods that are described in the Annex. From such measurements the departure of the response of a reproducing head from the "ideal" can be defined, and consequently a Standard Replay Chain can be established as a primary standard. Test tapes can then be made which can serve as secondary standards for use in normal operation.

NOTE ON USE OF REPRODUCING CHARACTERISTICS: A different Standard Replay Chain has been adopted in the U.S.A. for 15 in/s (38.1 cm/s). The difference between the nominal characteristics of the Standard Replay Chain of the U.S.A. and that of the C.C.I.R. is less than the tolerance in § 9. Furthermore a different characteristic is used in France for 30 in/s (76.2 cm/s).

Annex

Methods of Measuring the Magnetisation of a Tape

There are two general ways in which the surface induction/frequency characteristic of a tape may be determined:

1. By means which do not affect the surface induction. This implies the use of a non-magnetic reproducing device. For example, reproduction by means of a simple non-magnetic conductor placed in the field at the surface of the moving tape is practicable as a laboratory method and may therefore be used to establish a primary standard. This can be used to determine the relative change of surface induction with wavelength created by the presence of a magnetic head;
2. By means of a magnetic reproducing device, which necessarily affects the surface induction of the tape in a manner dependent on recorded wavelength. In this category there are two ways in which conventional magnetic heads have been used, one method involving heads with a short gap, the other involving heads with a long gap. In both cases the gap in the reproducing head must be sufficiently accurate, magnetically, to give well-defined minima of reproduced level, one in the short gap method or several in the long gap method. In order to ensure that the same results will be obtained with both magnetic and non-magnetic reproducing devices, a coated high-coercivity tape must be used.

Steps must be taken to ensure that the arc of the tape in contact with the head is long enough in relation to the longest wavelengths recorded. If this is not so, it may be found that output level at the lower frequencies is slightly higher than that given by an ideal head and that the deviation increases as the frequency decreases while remaining as a general rule within the tolerances defined above. The

* In this Recommendation and in the Annex the term surface induction means the normal surface induction, that is to say, the flux density at right angles to the surface of the tape.

error may be reduced by using bigger reproducing heads for the very low frequencies.*

(a) **The "Short Gap" Method.** The longest wavelength at which a minimum of reproduced level occurs is called the effective gap length: d. The necessary correction for the gap length is calculated on the assumption that output is proportional to

$$\frac{\sin \frac{\pi d}{\lambda}}{\frac{\pi d}{\lambda}}$$

This correction must not exceed 5 db at the shortest wavelength considered. Any necessary correction for eddy current losses must also be determined, for example, by comparing outputs at various tape speeds or by the use of an inducing loop. Once these corrections are known and applied, the head may be used as an "ideal" head to measure relative surface inductions on the tape over the wavelength range considered.

(b) **The "Long Gap" Method.** In this method a head is used with a gap some 50 times longer than that of the normal reproducing head. In practice an erase head can usually be adapted for the purpose. The response of such a head should show a series of well defined maxima and minima as shown in Figure 9.

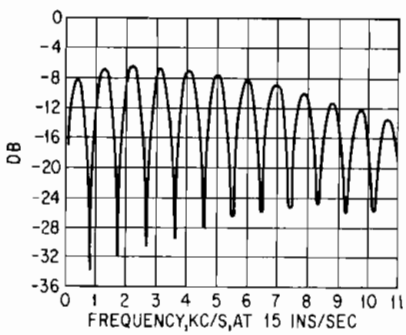


FIGURE 9. Typical response curve of a "long gap" reproducing head.

A curve through the successive maxima is a measure of the relative surface induction on the tape, when the necessary correction for the eddy current losses of the head has been made. This curve falls approximately 4 db/octave compared with the curve of surface induction/frequency in air as determined by a non-magnetic reproducing device, or by a "short gap" head. This correction must therefore be applied.

The precise steps by which the procedures of 2(a) and (b) may be applied in practice are outlined in the following.

Standardisation by the Short Gap Magnetic Head

Using the short gap method a recording equipment is set to the standard condition in the following way:

1. A "gliding tone" is recorded on a tape and reproduced by means of the head to be used for the measurements. The longest wavelength at which the output disappears is noted. This wavelength will be equal to the effective gap length, from which the gap correction may be deduced. If this correction exceeds 5 db the head is unsuitable for this measurement.

Since the measurement must take place at a very short recorded wavelength, a high-coercivity tape should be used, and a certain amount of pre-emphasis will be found useful. In order to avoid making the measurements at an unnecessarily high frequency the lowest tape speed available should be used.

* See Report No. 79.

2. The tape with the gliding tone is reproduced at two different speeds and the output curves are compared. If the curves can be brought to coincidence by displacing one frequency scale so that equal wavelengths coincide, it may be assumed that frequency-dependent losses are negligible. If not, these losses may be deduced from the two curves mentioned or, alternatively, from a measurement with an inducing loop.

3. The frequency response of the reproducing chain is now adjusted to be that specified in § 9(*a*) of this Recommendation together with the gap correction noted in 1. above and the compensation for frequency dependent losses noted in 2. above.

4. The recording equalisation is then adjusted so that a flat overall response is obtained.

Standardisation by the Long Gap Magnetic Head

Using the long gap method a recording equipment is set to the standard condition in the following way:

1. The reproducing head used has a well-defined gap long enough to give successive maxima of response at intervals of 1 kc/s, or less, in the audio-frequency range (with a tape speed of 30 in/sec (76.2 cms/sec) the gap length required would be about 800 microns). If the successive minima in the response curve are not equally well defined the head is not suitable for this measurement. A short preliminary experiment is carried out to determine the exact frequencies at which successive maxima occur at the relevant tape speed.

2. A "gliding tone" test tape of the audio frequencies of maximum level is then recorded with constant voltage input to the recording chain and the tape is reproduced using the long gap head. The open circuit voltage of the head around these frequencies is then plotted against frequency, and a smooth curve is drawn through the successive maxima.

3. The tape with the gliding tone is reproduced at two different speeds using the long gap head and the output curves are compared. If the curves can be brought to coincidence by displacing one frequency scale so that equal wavelengths coincide it may be assumed that frequency-dependent losses are negligible. If not, these losses may be deduced from the two curves mentioned or, alternatively, from a measurement with an inducing loop.

4. When the curve drawn in § 2 has been corrected by a 6 db/octave rise with increasing frequency together with the correction for frequency-dependent losses and a correction of 2 db/octave falling with increase of frequency, the result defines the relative surface inductions on the tape.

5. The equalisation of the recording amplifier is now altered to obtain a characteristic of surface induction/frequency that is the inverse of the equalisation specified for the reproducing chain (without allowance for the replay head losses).

6. The reproducing amplifier equalisation is then adjusted so that a flat overall response is obtained when using a normal reproducing head.

Recommendation No. 210

Measurement of Wow and Flutter in Equipment for Sound Recording and Reproduction

(Study Programme No. 74 (X))
(Warsaw, 1956)

The C.C.I.R. unanimously recommends:

1. That the tone to be recorded for the measurement of wow and flutter measurement should preferably be 3000 c/s;

2. That the equipment used should measure wow and flutter within a minimum frequency range of 0–200 c/s.

Recommendation No. 211

Sound Recording on Film for the International Exchange of Television Programmes

(Question No. 100)
(Warsaw, 1956)

The C.C.I.R. unanimously recommends that in the exchange of television programmes on film the recording of the sound should be carried out:

1. By conventional optical means on 35 mm perforated film with dimensions according to the ASA specifications:

PH 22.36 PH 22.58
PH 22.59 PH 22.40

2. By conventional optical means on 16 mm perforated film with dimensions according to the ASA specifications:

PH 22.12 Z 22.8
Z 22.7 Z 22.41

3. By conventional magnetic means on 16 mm perforated film with a single perforation and with the magnetic sound stripe towards the edge of the film remote from the perforations, and conforming to the following standards:

3.1 The dimension and position of the magnetic stripe should be as given in Figure 1;

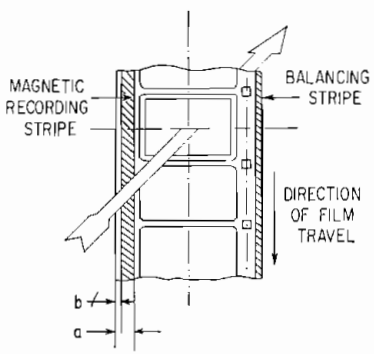


FIGURE 1. Sound recording on film Type 16 COMMAG.

SIZE OF MAGNETIC RECORDING STRIPE

(a) $2.5\ ^{+0.1}_{-0}$ MM ($0.1\ ^{+0.004}_{-0}$ IN.)
(b) $0.125\ ^{+0}_{-0.125}$ MM ($0.005\ ^{+0}_{-0.005}$ IN.)

3.2 Safety film should be used ;
3.3 The film should normally be photographic positive;
3.4 The film should be on reels as specified in ASA standard PH 22.11;*
3.5 Splicing of the film should be carried out according to the ASA standard PH 22.24;
3.6 The picture frequency should be either 25 frames or 24 frames (perforations) per second and should always be indicated;
3.7 The sound record should be in advance of the picture by 28 ± 0.5 frames;

NOTE: The figure of 26 ± 0.5 frames has been previously proposed by certain organisations. This figure is the same as that used in optical sound recording. At a meeting in Stockholm of an I.S.O. commission, the delegates agreed on a spacing of 28 ± 0.5 frames

* A different hub is used in France.

between picture and magnetic sound record. To facilitate the construction of machines with reproducing heads for both types of sound, the spacing between the picture and the magnetic and the optical sound recording should be different for the two systems. A difference of the order of 2 frames is considered desirable.

3.8 The magnetic stripe should be on the side of the film that faces the light source of a projector arranged for direct projection on a reflecting type screen;
3.9 The maximum additional thickness due to the magnetic stripe should be 0.0008 inch (20 microns);
3.10 If a balancing magnetic stripe is used outside the sprocket holes it should have the same composition and thickness as the main magnetic strip;
3.11 The recording characteristic should be that defined in Recommendation No. 209, § 9 for a tape speed of 7½ inches (19.05 cm) per second;
4. In certain cases by conventional magnetic means on 16 mm perforated film separate from the picture film, carrying magnetic sound stripes only and running at the same mean speed as the picture film.
Until standards for the second film can be agreed, reference should be made to Report No. 81.

STANDARDS OF THE AMERICAN STANDARDS ASSOCIATION

Because of the large number of standards available from the ASA, it is suggested that those who are interested request a list directly from the American Standards Association, Inc., 70 East 45th Street, New York 17, N.Y. ASA standards are divided into the following principal categories:

Automotive	D
Chemical	K
Civil Engineering and Construction	A
Commercial	DS
Drawings, Symbols, and Abbreviations	Y
Electrical Engineering	C
Ferrous Materials and Metallurgy	G
Mechanical Engineering	B
Mining	M
Miscellaneous	Z
Nonferrous Materials	H
Nuclear	N
Office Equipment and Supplies	X
Photography and Motion Pictures	PH
Pulp and Paper	P
Rubber	J
Textile	L
Wood	O

INSTITUTE OF RADIO ENGINEERS CURRENT STANDARDIZATION REPORTS

The following standards pertain and are of interest to the broadcast industry. For additional standards and information please contact IRE, 1 East 79th Street, New York 21, N.Y.:

48 IRE 2., 11., 15.S1	Standards on Antennas, Modulation Systems, and Transmitters: Definitions of Terms, 1948.
53 IRE 2.S1	Standards on Antennas and Waveguides: Definitions of Terms, 1953. Adopted by ASA (ASA C16.21-1954).
55 IRE 2.S1	Standards on Antennas and Waveguides: Definitions for Waveguide Components, 1955.
48 IRE 2.S2	Standards on Antennas: Methods of Testing, 1948. Adopted by ASA (ASA C16.11-1949).

54 IRE 3.S1	Standards on Audio Techniques: Definitions of Terms, 1954.
56 IRE 3.S1	Standards on Audio Systems and Components: Methods of Measurement of Gain, Amplification, Loss, Attenuation, and Amplitude-frequency-response, 1956. Adopted by ASA (ASA C16.29-1957).
53 IRE 3.S2	Standards on American Recommended Practice for Volume Measurement of Electrical Speech and Program Waves, 1953. Adopted by ASA (ASA C16.5-1954).
53 IRE 7.S1	Standards on Electron Devices: Methods of Measuring Noise, 1953. Adopted by ASA (ASA C60.13-1954).
50 IRE 7.S2	Standards on Electron Tubes: Methods of Testing, 1950.
57 IRE 7.82	Standards on Electron Tubes: Definitions of Terms, 1957.
53 IRE 11.S1	Standards on Modulation Systems: Definitions of Terms, 1953.
49 IRE 14.S1	Standards on Piezoelectric Crystals, 1949. Adopted by ASA (ASA C83.3-1951, R 1954).
53 IRE 19.S1	Standards on Sound Recording and Reproducing: Methods of Measurement of Noise, 1953.
53 IRE 19.S2	Standards on Sound Recording and Reproducing: Methods for Determining Flutter Content, 1953. Adopted by ASA (ASA Z57.1-1954).
55 IRE 22.S1	Standards on Television: Definitions of Color Terms, 1955.
50 IRE 23.S1	Standards on Television: Methods of Measurement of Television Signal Levels, Resolution, and Timing of Video Switching Systems, 1950.
54 IRE 23.S1	Standards on Television: Methods of Measurement of Aspect Ratio and Geometric Distortion, 1954. Adopted by ASA (ASA C16.23-1954).
55 IRE 23.S1	Standards on Television: Definitions of Television Signal Measurement Terms, 1955.
50 IRE 23.S2	Standards on Television: Methods of Measurement of Time of Rise, Pulse Width, and Pulse Timing of Video Pulses in Television, 1950.
50 IRE 23.S3	Standards on Television: Methods of Measurement of Electronically Regulated Power Supplies, 1950.
45 IRE 24.S1	Standards on Radio Wave Propagation: Definition of Terms Relating to Guided Waves, 1945.
50 IRE 24.S1	Standards on Wave Propagation: Definitions of Terms, 1950.
56 IRE 27.S1	Standards on Methods of Measurement of the Conducted Interference Output of Broadcast and Television Receivers in the Range of 300 Kc to 25 Mc, 1956. Adopted by ASA (ASA C16.25a-1957).

STANDARDS OF THE NATIONAL ASSOCIATION OF BROADCASTERS

Additional copies of the NAB Recording and Reproducing Standards with a Glossary of Terms and Definitions may be obtained by addressing a request to the NAB; Department of Engineering. These standards are set forth in this section.

RECOMMENDED STANDARDS OF THE ELECTRONIC INDUSTRIES ASSOCIATION

EIA has available and for sale numerous recommended standards and engineering publications. Advance payment is required except when a company purchase order is furnished and all remittances and orders should be forwarded directly to EIA Engineering Office, Room 650, 11 West 42nd Street, New York 36, N.Y. The following standards pertain and are of interest to the broadcast industry. For additional standards and information, please contact EIA.

GEN-101-A	Color Codes
REC-108-A	Color Codes
REC-128	Standard Frequency Test Record
REC-134	Magnetic Recorders, Conditions for Measurement and Definitions

REC-138	Recording Tapes
REC-143	Standards for Universal Television Broadcasting
REC-146	Lateral Disc Recording Characteristics
TR-101-A	Electrical Performance Standards for Standard Broadcast Transmitters
TR-102-B	Power Transformers for Radio Transmitters
TR-103-A	Transmission lines for FM Broadcast Transmitters (88–108 Mc)
TR-104-B	Electrical Performance Standards for Monochrome Television Broadcast Transmitters Channels 2–13
TR-105-B	Audio Facilities for Radio Broadcast Systems
TR-106	Electrical Performance Standards for Television Relay Facilities
TR-107	Electrical Performance Standards for FM Broadcast Transmitters (88–108 Mc)
TR-108-A	Rectangular Wave Guides
TR-110-B	Power Filter Reactors for Radio Transmitters
TR-111-A	Socket and Accessories for Electron Tubes for Use in Transmitters
TR-112-A	Definitions and Dimensional Characteristics of Quartz Crystal Units
TR-114	Frequency Modulation Broadcast Transmission Pre-emphasis and Polarization
TR-115	Symbols and Designations for Single Line Diagrams for Audio Facilities
TR-116	Radio Transmitting Antennas and Supporting Towers for Radio Transmitting Antennas
TR-117	Antennas and Combinations of Antennas and Transmission Lines for FM Broadcast Stations
TR-118	Cable Connectors for Audio Facilities for Radio Broadcasting
TR-119-A	Minimum Standards for Land-mobile Communication FM Receivers
TR-135	Electrical Performance Standards—Television Studio Facilities
TR-136	Television Picture Area—35 mm Motion Picture Film
TR-137	Television Picture Area—16 mm Motion Picture Film
TR-138	Slides and Opaques for Television Film Camera Chains
TR-139	Audio Transmitter Input Impedances
TR-142	Microwave Housing Facilities
TR-144	Color Television Test Signal to Accompany Monochrome Transmission
RS-152	Land Mobile Transmitters, FM (25–470 Mc)

EIA Television Test Charts

Resolution Chart (18" x 24" Heavy Paper)

The Resolution Chart is used to help measure the resolving power of a television system or of a part of it, such as a television camera chain. The chart is televised by the studio facility, under test, and reproduced on a suitable picture monitor; 10 gray steps aid in setting monitor bias and gain. Horizontal and vertical resolution wedges cover the range from 200 to 600 lines.

Gray Scale Overlay Strips for Resolution Chart (10" x 1" Cardboard Strips—Set of 4)

The Gray Scale overlay strips are intended to be pasted over the corresponding sections of the Resolution Chart (18" x 24"). These highly accurate gray scales will then provide the correct logarithmic reflections relationship for the scales on the chart.

Linearity ("Ball") Chart (18" x 24" Heavy Paper)

The Linearity Chart is used to help test geometric distortion of a television camera chain. This is done by comparing on a suitable picture monitor two superimposed patterns; one generated by an electrical pattern generator, the other by television a chart with the equipment to be checked. The electrical pattern grating generator frequencies required to match the chart pattern are 315 kc for horizontal, 900 cycles for vertical linearity tests.

Color Registration Chart (18" x 24" Heavy Paper)

The Color Registration Chart is used to aid in the alignment and test of the accuracy of registration of triple-pickup color television cameras. The fine black horizontal and vertical lines on a white background permit accurate alignment of the optical and electrical systems of three-pickup cameras.

Linear Reflectance Chart (18" x 24" Cardboard Mounted)

The Linear Reflectance Chart is used in the alignment and measurement of the transfer characteristic of television camera systems. This is of particular importance in color television, where departures from the correct characteristics may result in color error.

Logarithmic Reflectance Chart (18" x 24" Cardboard Mounted)

This chart is similar to the Linear Reflectance Chart with the exception that the steps of reflectance difference follows a logarithmic, instead of a linear, relationship. This chart is also highly useful in the alignment and measurement of the transfer characteristic of television camera systems, particularly those for color.

Color Registration Slide Transparency (2" x 2")

Metal and glass mounted, highly accurate slide of Color Registration Chart (see above).

IRE Facsimile Test Chart (8½" x 11")

This chart was prepared as an engineering test to show limitations of facsimile equipment, transmission circuits, recording paper, and over-all systems. Sections of this chart are specifically intended for checking modulation characteristics, power-supply regulation, halftone characteristics, definition, index of cooperation, paper-feed error, readability, jitter, and other factors affecting facsimile reproduction.

STANDARDS OF THE SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS (SMPTE)

SMPTE has available numerous test films which are widely used by the television industry as yardsticks for setting performance objectives of new and operational equipment. The test films are planned by the technical committee of the Society after considerable research and consultation. When ordering test films, you must specify the name, the code number, and, where priced on a footage basis, the length of the film desired. All other films are supplied only in the lengths shown. When requested, pro forma invoices will be supplied in advance. All films are sold on a cash basis only and no discounts are given and facilities for extending credit are not available.

35-mm Television Test Film

Code No.: TV35. Length: 945 ft.

Alignment and Resolution Section: Code No.: TV35-AS. Length: 100 ft.

The Television Test Film is a print which indicates the operating condition of those portions of the television film reproducing system which depend upon the relation between the projector and the electrical equipment. Six test sections and several representative scenes make up the complete test reel. The film is silent, being used for picture tests only. The test sections are a series of geometric patterns that check the factors most likely to be degraded in television reproduction. Each target selects some particular failing of the average system and produces a signal intended to exaggerate and thus clearly define any deviation from normal.

The Alignment Section of the alignment and resolution target defines the portion of the projected film frame which is to be reproduced by the television system and permits accurate alignment of the motion picture projector with the television camera. Resolution patterns are of calibrated wedge design and range from 200 to 500 television lines.

The Low Frequency Response Section is made in two parts, each consisting of a half-black, half-white frame, with the dividing line horizontal. When viewed on the waveform monitor set for field rate deflection, serious tilting or bowing of a square wave indicates incorrect low-frequency phase and amplitude response. The section of the target which is black at the bottom also permits a check on the amount of flare encountered in iconoscope operation.

The Medium Frequency Response of the system is checked by a test target having horizontal bars equal in length to the distance of scanning beam travel at 2, 5, 12½, and 32 microseconds. These correspond to half-wave pulses covering an approximate fundamental frequency range from 15 to 250 kc.

The Storage Test Section provides an indication of the storage characteristics of pickup tubes. This chart is made up to vertical black and white stripes on a gray background and is viewed on the waveform monitor set at field rate.

The Transfer Characteristics target provides a measure of the television system's ability to reproduce shades of gray. The target consists of two strips of seven density tablets each. In the upper strip the shades are from white to black and in the lower they are reversed.

An Automatic Brightness Control test consists of a black frame in which a white disc enlarges slowly until the entire frame is white. The ability of the automatic brightness control to hold constant black level is clearly demonstrated.

To provide a qualitative check on the over-all results to be expected from good motion picture film, several scenes taken from pictures made specifically for television are included.

Separate lengths of the Alignment and Resolution Section of this film are required for extended testing during installation or servicing of television film projectors.

16-mm Television Test Film

Code No.: TV16. Length: 367 ft.

Alignment and Resolution Section: Code No.: TV16-AS. Length: 100 ft.

This print is a 16-mm version of the 25-mm Television Test Film. To assure the best possible test of picture resolution, the Alignment and Resolution Section is made on original camera film which is spliced into the reel and is also available as a separate section.

35-mm Color Television Test Film

Code No.: TV-35-Color. Length: 700 ft.

The Color Television Test Film includes prints which represent the quality of material obtainable from Ansco, Technicolor, and Eastman prints. Each color print material contains five scenes.

At the beginning of the first scene is a section including a gray scale which can be used in setup or for adjusting the signal-generating equipment so that the chrominance subcarrier vanishes on this setup.

All scenes were illuminated with a lighting ratio of approximately 2:1; that is, the key light was twice the fill light, as measured in foot-candles.

The film is silent, being used for picture tests only.

16-mm Color Television Test Film

Code No.: TV-16-Color. Length: 280 ft.

This print is a 16-mm version of the 35-mm Color Television Test Film.

Color Television Test Slides Size 2″ x 2″

Code No.: Slides TV Color. Set of 10.

The slides contain the same high-quality color picture material used in the television test films.

35-mm Television Leader

Code No.: L35. Length: 90 ft.

Leaders are produced as fine-grain master positive prints. The film is one strip of three complete leaders. The leader is intended for general release print use and is designed to have a main body pattern to be used in television to permit checking system operation before switching into the first picture frame. Footage and sound threading marks have been clearly indicated for easier reading.

16-mm Television Leader

Code No.: L16. Length: 25 ft.

Fine-grain master positive prints are a 16-mm version of the 35-mm leader. The film is one strip of three complete leaders.

35-mm Magnetic Four-track CinemaScope Test Films

NOTE: Items 3 and 4 are f.o.b. Hollywood.

1. Level Balance Test Film. Code No.: SL-1. Length: 50 ft. 1,000 cps; four tracks simultaneously; sound only.

2. Multifrequency Test Reel. Code No.: MF-1. Length: 425 ft. Various frequencies; four tracks simultaneously; sound only.

3. Loudspeaker Balance Reel. Code No.: LB-1. Length: 300 ft. Recording of identical speech and music on all four tracks, progressively in this order: 2, 1, 3, and 4.

4. Stereophonic Test Reel. Code No.: ST-1. Length: 330 ft. Picture with stereophonic sound and 12-kc control signal.

5. Flutter Test Film. Code No.: FL-1. Length: 50 ft. 3,000 cps; four tracks simultaneously; sound only.

6. Loudspeaker Phasing Test Film. Code No.: LP-1. Length: 50 ft. Warble frequency; tracks—1, 2, and 3 simultaneously; sound only; crossover 400 or 500 cps. Specify which frequency desired.

7. Constant Level Test Film. Code No.: AZ-1. Length: 50 ft. 8,000 cps; azimuth check; four tracks simultaneously; sound only.

8. Channel-Four Test Film. Code No.: CH-4. Length: 50 ft. 12,000 cycles/1,000 cycles; sound only.

9. Projector Alignment Chart. Code No.: PR-1. Length: 100 ft. Picture only. For aligning projectors using a four-track aperture 0.912 x 0.715 in., aspect ratio of 2.55 to 1.

10. Projector Alignment Chart (Optical Track) Standard Sprocket Holes. Code No.: CSOS. Length: 50 ft per min or multiples thereof. Picture only.

35-mm Visual Test Film

Code No.: VTF. Length: 450 ft.

Focus-and-alignment Section. Code No.: VTF-FAS. Length: 100 ft.

Travel-ghost Target Section. Code No.: VTF-TGS. Length 100 ft.

Jump-and-weave Target Section. Code No.: VTF-JWS. Length: 100 ft.

The Visual Test Film is a special type of print, picture only, containing four targets to check focus and alignment, travel ghost, jump and weave, and lens aberrations. This test film is used when installing new projectors and screens or performing maintenance operations on existing equipment.

The Focus-and-alignment target shows whether or not picture size and screen masking are correct and whether the projected picture is centered properly on the screen.

The Travel-ghost target shows improper timing of the shutter quite readily and gives a clear indication of the correct adjustment as the timing is being corrected.

The Jump-and-weave target gives an accurate indication of the unsteadiness of the projected picture. Picture jump is measured in per cent of picture height, and picture weave is measured in per cent of picture width.

The Lens-aberration target shows picture distortion and gives an indication of the lack of sharpness that will be present in pictures shown on any particular projector.

Explanatory titles precede each section and an instruction booklet is furnished giving complete details on its proper use.

Because some users prefer loops or continuous lengths of the separate target sections for adjusting machines, one at a time or in pairs, separate sections of the first three targets have been made available.

16-mm Magnetic Azimuth Alignment Test Film

Code No.: MATF. Length: 100 ft.

A 200-mil sound recording of 7,000 cycles is placed on full-width coated 16-mm film. The sound record is in the same position as that shown on American Standard PH22.87 with the exception of the recorded width being 200 mils instead of the 100-mil width specified. Azimuth is correct to ±3 min of arc.

16-mm Magnetic Multifrequency Test Film

Code No.: M16MF. Length: 200 ft.

The Magnetic Multifrequency Test Film has a recorded track 200 mils wide, the edge of which is 5 mils in from the nonperforated side of the film.

The sequence of recorded material is as follows ±7,000 cycles—approx. 30 ft azimuth adjustment.

Each of the following frequencies is preceded by a spoken announcement:

1,000	300	3,000	7,000
50	500	4,000	1,000
100	1,000	5,000	
200	2,000	6,000	

16-mm Sound-service Test Film

Code No.: SPSA. Length: 320 ft.

The 16-mm Sound-service Test Film is a special type of print, both picture and sound, developed for users of 16-mm projectors and films, as well as for television stations and projector service shops. This film includes wide-frequency-range title music, followed by sections of buzz-track, which is a 14-ft section of original negative spliced in, sound-focusing test, constant frequencies from 50 to 6,000 cycles, dialogue, piano music, and orchestral music. The buzz, focus, and frequency sections will show whether mechanical or electrical adjustments are correct, while the one dialogue and three music sections, which were specially prepared for this film and are consistent with the best quality obtainable today, will indicate over-all reproducer sound quality.

Accompanying titles explain the purpose of each section, while the instruction book supplied with the film explains in detail why the various tests are made and how the results of those tests should be evaluated. This combination test film will show whether poor sound quality is the fault of the projector or of the print being projected. It will indicate when projector overhaul is necessary and the nature of the repairs required.

16-mm "Jiffy" Test Film

Code No.: Jiffy. Length: 135 ft.

A short, inexpensive test film for rapid checking and demonstrating of 16-mm projector system performance developed in collaboration with the U.S. Navy. This high-quality film will prove a boon to projector manufacturers, educational organizations, repair shops, and camera stores.

It requires no test instruments, yet provides checks for faithful reproduction of wide-range music, picture steadiness, uniform picture brightness, flutter, correct sound-track guide adjustment, normal volume, sound focusing in both standard and non-standard emulsion positions, frequency response from 50 to 5,000 cycles, and dialogue intelligibility.

16-mm 3,000-cycle Flutter Test Film

Code No.: PH22.43. Length: 380 ft.
Code No.: PH22.43. Length: 100 ft.

The 3,000-cycle Flutter Test Film is a direct-positive original recording and carries a 3,000-cycle tone having extremely low flutter content for use in measuring the flutter introduced by 16-mm sound reproducers. A flutter meter is required to make this measurement. The recorded frequency is within 25 cycles of the 3,000-cycle frequency, the output level is constant within 0.25 db, and the total flutter content of the film at the time of shipment is less than 0.1 per cent.

16-mm Multifrequency Test Film

Code No.: PH22.44. Length: 150 ft.

The Multifrequency Test Film is a direct-positive original recording and is used to obtain the electrical-frequency response at the output of the power amplifier. Each film is individually calibrated on equipment correct with ±0.5 db above 3,000 and through 7,000 cycles. The deviation from the intended flat-response characteristic (assuming negligible reproducing light-beam width) is stated as a correction for each frequency which will give the true level when it is added algebraically to the output-level measurement obtained when using the film.

This test film contains the following series of frequencies, each preceded by a spoken announcement:

400	300	2,000	5,000
50	500	3,000	6,000
100	1,000	4,000	7,000
			400

16-mm Scanning-beam Illumination Test Film

Laboratory Type: Code No.: PH22.80-L. Length: 102 ft.
Service Type: Code No.: PH22.81-S. Length: 100 ft.

The Scanning-beam Illumination Test Film is a print and carries a narrow sound track (0.005 in. wide) modulated at constant level by a 1,000-cycle tone. The location of this sound track changes at a uniform rate along the length of the film from a position just inside one edge of the scanned area to a position just inside the opposite edge of the scanned area. The narrow 1,000-cycle sound track sweeps across the scanning-light beam from one end to the other at a uniform rate, the position of the sound track relative to the ends of the light beam at any instant being shown by an animated diagram appearing in the picture area.

If the scanning-beam illumination were absolutely uniform across the width of the scanned area, the output level of the 1,000-cycle tone would be constant. In practice, however, some variation of an output-meter reading will always be observed. By running a loop of the film continuously and observing the indications of the

output meter while adjustments are made, it is usually possible to correct unevenness of illumination and bring the variation of output within a limit of ±1.5 db.

The Laboratory Type is shipped in one length of film to make three 34-ft loops and the Service Type in one length of twenty-four 3½-ft loops.

16-mm Buzz-track Test Film

Code No.: PH22.57. Length: 100 ft.

The Buzz-track Test Film is an original negative and is used for checking scanning-beam placement. The track consists of an 0.076-in. opaque center with a frequency of 300 cycles on the picture side and a frequency of 1,000 cycles on the side nearest the film edge. These tracks are accurately located on the film so that when the film is run on a projector in correct adjustment and free from weave, no sound should be heard or equal loudness of both buzz sounds.

16-mm Sound-focusing Test Film

Laboratory Type: Code No.: PH22.42-7000. Length 100 ft.

Service Type: Code No.: PH22.42-5000. Length: 100 ft.

The Sound-focusing Test Film is an original negative and carries a special "square-wave" track, chosen because its output changes more rapidly with changes in the focus of the sound optical system of the projector than the output from the usual "sine-wave" high-frequency track. The "square-wave" track also gives a more sensitive indication of the errors of the "azimuth" adjustment of the sound-reproducing light beam.

The Sound-focusing Test Film is made in two types: Laboratory Type, a 7,000-cycle record for manufacturing and precision adjustments of the focus and azimuth of the sound optical system, and Service Type, a 5,000-cycle record for quick service adjustment.

16-mm 400-cycle Signal-level Test Film

Code No.: PH22.45. Length: 100 ft.

The 400-cycle Signal-level Test Film is a direct-positive original recording designed to furnish as nearly as is practicable an absolute standard of recorded signal level for use in measuring the effective amplification and sound output of 16-mm sound motion picture projectors, taking into account the sound optical system and phototube, as well as the amplifier and loudspeaker.

A definite output level is determined by specifying the amplitude of the recorded signal, the density of the image, and the combined base and fog density of the clear part of the sound track within narrow limits. The specified level is approximately 2 db below the maximum level possible and is about equal to the highest level that is to be expected in most recording, since in commercial practice the image density is usually not so great and the fog density not so low as the values specified for this film.

16-mm Steadiness Test Film

Code No.: ST16. Length: 100 ft.

This film permits the unsteadiness of a projected film image to be measured. As a steadiness reference there are three round holes punched in the picture area. The center and lower holes are produced by a single punch stroke that is indexed from the adjacent standard film perforation, the one that locates that particular frame in the aperture on many projectors. The upper hole is produced by the succeeding stroke. Motion of the center hole can be measured by using the gauge supplied with the film. Residual unsteadiness of films approved for sale is no greater than 0.05 per cent of picture width.

16-mm Travel-ghost Test Film (Block Target)

Code No.: TG16. Length: 100 ft.

This print is a 16-mm version of the Travel-ghost Target Section of the 35-mm Visual Test Film. The target shows improper timing of the shutter quite readily and gives a clear indication of correct performance as the timing is being adjusted.

16-mm Projector Lens Resolution Target

Code No.: PH22.53.

This is a glass slide, approximately 1 x 2 in. with 19 resolution test patterns photographed within the standard 16-mm projector aperture area. This slide is intended for use in determining the resolving power of projector lenses in terms of the number of lines per millimeter which are resolved.

A special test projector designed to hold the glass test plate in proper relation to the lens axis, which may be very simply designed, is required as auxiliary equipment. This test is normally used by development laboratories and lens and projector manufacturers.

Part 8

NAB SAMPLE TRANSMITTER OPERATING LOGS AND PERTINENT FCC RULES AND REGULATIONS

INTRODUCTION

The Rules and Regulations of the Federal Communications Commission require that operating logs be maintained by all broadcasting stations. These requirements are set forth in Part 3 of the FCC Rules and Regulations and in some instances in the instrument of authorization, i.e., license, construction permit, temporary authorization, etc. The following article consolidates the FCC Rules, Regulations and Standards of Good Engineering Practice pertaining to AM, FM, and TV broadcast station logs, and, in addition, presents an up-to-date version of the NAB Sample Logs.

The material presented herewith is divided into two sections:

Part I contains pertinent facts about the format and use of transmitter operating logs and discusses each part of the log requirements. It also makes suggestions with respect to the NAB Sample Logs appearing in Part II.

Part II contains explanations and illustrations of Sample Logs.

Maintenance logs are not considered in this material, since the requirements for such logs are somewhat peculiar to each transmitter installation. In most instances, maintenance logs are found to be kept separately from the operating log. This procedure, while generally desirable, is not, however, mandatory. The logs may be combined. Also combination (basic) logs may be used in such instances where one operator is in charge of the actual operation of an AM transmitter and an FM transmitter.

The FCC does not place its official approval on any particular log as compared with another; its only interest is that the required entries be made in a neat and orderly fashion in accordance with the Rules and Regulations. The Sample Logs attached have been examined by Commission Engineering personnel and are believed to meet all their requirements.

We hereby acknowledge our thanks and appreciation to them for their help and criticism.

PART I

PERTINENT FACTS ABOUT THE FORMAT AND USE OF TRANSMITTER OPERATING LOGS

Sections 3.111(b) and (c), 3.281(b) and (c), 3.663(b) and (c), 17.37, and 17.38 set forth the basic requirements as to entries which must be made in the transmitter logs of AM, FM, and TV Stations.

To comply with paragraph (b)(1), the time (to the nearest minute) any amount of carrier is applied to the radiating systems [1] should be entered in Column 1 of the

[1] Includes video and audio transmitters of TV stations.

sample logs, with an appropriate phrase in the "Remarks" column such as "Carrier on." If the carrier is applied in steps, entries of voltage and currents may be made for each step or an entry in the "Remarks" column may be made as to the approximate power. The time the carrier is removed from the radiating system should be entered in Column 1 and in the "Remarks" column the words "Carrier off" may be inserted.

To comply with (b)(2) the time the program is applied to the carrier(s) [1] and the time the program is removed from the carrier(s) [1] should be entered in Column 1. Since the rule requires only two entries for each broadcast period appropriate entries may be made in the "Remarks" column such as "Program on" and "Program off" or "Program begins" and "Program ends." "Program on" and "Program off" times may be entered in the "Remarks" column if desired instead of in Column 1. This is often done when the time at half-hour intervals is printed on the log.

To comply with (b)(3) the time of each carrier interruption must be entered in Column 1, and a statement as to the cause and duration of the interruption must be placed on the log, preferably in the "Remarks" column. Upon resumption of transmission, the time the carrier is placed on the air and the time the program is resumed must be entered in Column 1 with appropriate remarks in the "Remarks" column.

This part (b)(4) requires that certain operating constants of the transmitter(s) [1] be entered in the log every 30 minutes during the time the carrier is on the air. The times that the readings are taken should be entered in Column 1 and the proper entries should be made in Columns 2-6 and 2-5 of the basic logs for either AM or FM or TV stations respectively (Figures 1, 4, and 5).

To comply with (b)(4)(i), enter in Column 2 of the sample log the total plate current of the final radio-frequency stage in the transmitter. In Column 3 should be entered the plate voltage applied to the final radio-frequency stage.

(NOTE: FOR AM STATIONS) Column 4 of the basic AM log is provided to comply with (b)(4)(ii) for the entry of the reading of the actual antenna current meter, remote antenna meter, or transmission line current meter, whichever method is elected by the station in accordance with Commission Rules. Column 4 may be labeled I_A for actual antenna current, I_R for remote antenna meter reading, or I_T for transmission line current. If remote reading meters are utilized, calibration must be checked against the actual antenna current meter at least once weekly for each authorized power.[1] The time of the calibration check should be entered in Column 1 and the check data in the "Remarks" column.

Under Section 3.51, the indirect method of determining power may be used under certain conditions on a temporary basis. When this method is used with a series feed antenna, the transmission line current may be logged in lieu of the antenna current, provided that the ratio between transmission line current and the antenna current is logged every 30 minutes. Further, the actual antenna current must be checked for each operating power at least once daily and logged by entering the time of the check in Column 1 and the check data in the "Remarks" column. In such instances, a column headed, for example, $I_T I_A$ should be used. Since the indirect measurement method can be used only on a temporary basis, a permanent column for this purpose is not necessary.

In the case of a shunt excited antenna the transmission line current meter at the transmitter may be considered as a remote antenna ammeter, provided that the antenna termination of the transmission line is made directly into a series circuit without parallel tuning components. The transmission feed line meter (meter in slant wire feed line or equivalent) may be logged for each authorized power. The time of this observation should be entered in Column 1 and appropriate remarks made in the "Remarks" column.

For installations using directional antenna systems, 3.111(b)(4)(ii), which states that merely "antenna current" should be logged, must be considered with an inter-

[1] Where convenient, it is often advisable to check the calibration daily so that in the event of failure time will permit repair or replacement.

pretation of requirements appearing in the instrument of authorization (DA Specs) to operate with a directional antenna system. Following are steps of consideration:

1. The antenna current meter reading at the common point of feed must be logged each half hour, since this is the point where power is determined. This may be identified as I_{cr}.

2. In reference to the ratio of antenna currents as determined from the indications of the phase monitor, these indications must be the current flowing in each phase monitor sampling loop circuit with no other shunt circuits of any nature employed. Although no specific rule states that current ratios must be logged, such ratios are included in the instrument of authorization and, for the protection of the licensee, logging of it appears advisable. If loop currents are logged, base currents must be read and logged once each day for each authorized power. The time of these observations should be entered in Column 1 and data in the "Remarks" column. In the event remote reading meters are used in a directional antenna system to read base currents, a calibration check between meters must be made at least once each week. It is, however, general practice at most stations to make this calibration check once daily.

3. If a phase monitor is employed, relative phase indications between the elements must be logged at least once each hour. This requirement appears only on certain instruments of authorization.

4. In the interest of consistency and to prevent confusion, it is suggested that each station select a definite system of identifying elements in a DA system such that each tower can be easily and readily associated with the element identification given in the instrument of authorization. In preparing the log format, this identification should appear at the top of the column used for that tower.

(NOTE: FOR FM AND TV STATIONS) On FM and TV installations (b)(4)(ii) requires that transmission line voltage or current be logged each half hour. Figure 5 (TV Log) indicates the use of "Reflectometer Unit" as found in one particular make of television transmitter. If transmission line voltmeters or ammeters are used, Columns 5-6 and 8-9 may be deleted and one column under both audio and video transmitters added for transmission line voltage or current.

In compliance with (b)(4)(iii), the frequency monitor reading should be entered in Column 5 of the AM and FM logs. Columns 4 and 7 of Figure 5 (TV Log) must be filled in with the frequency deviation in cps of the audio and video carriers respectively.

PART II

EXPLANATIONS AND ILLUSTRATIONS OF SAMPLE LOGS

Figure 1. Basic AM Log. The columns set forth in this form cover the basic AM requirements, the form being suitable for stations having no special log requirements occasioned by the use of directional antennas.

Figure 2. This figure consists of three sections to be added to the Basic AM Log if directional antennas are employed. The number of columns to be employed would be equal to the number of antennas used in the directional array.

(*1*) *Antenna Current.* This is as may be read on remote reading meters. If this method is elected by the station, calibration checks must be made at least once weekly. Most stations, however, provide this calibration check daily.

(*2*) *Current Ratios.* Ratios are not required to be logged. It is the usual practice to log only currents in the sampling loops, from which ratios may be determined when needed. However, if it appears desirable that operators compute ratios, this column may be used. If sampling loop currents are used, tower base currents must be read daily for each power used. The common point current must also be checked in the normal manner.

(*3*) *Phasing Relation.* This group of columns must be used if a phase monitor is employed. The readings should follow those values set forth in the instrument of authorization and should show degrees of lead or lag with respect to the reference tower.

AM STATION CALL LETTERS
TRANSMITTER OPERATING LOG
12 — KILOCYCLES: 5 KW — DAY 1 KW — NIGHT

DATE _____ 19__

CITY AND STATE

① TIME	② PLATE CURRENT FINAL STAGE	③ PLATE VOLTAGE FINAL STAGE	④ ANTENNA CURRENT AMPS	⑤ FREQUENCY DEVIATION ± CYCLES	REMARKS:

FIGURE 1. Basic AM log.

COLUMNS ① TO ⑤ OF BASIC AM LOG

	1				2			3			
	ANTENNA CURRENT					CURRENT RATIO			PHASING RELATION			REMARKS
	COMMON POINT	1	2	3	4	2/1	3/1	4/1	2/1	3/1	4/1	

FIGURE 2

If monitoring point readings are required, add additional columns. The "Remarks" column would follow the final column on the chart.

Figure 3. This is a sample log for a standard station using a three-element directive array at night and non-directional operation daytime.

Figure 4. Basic FM Log. The columns set forth in this sample log cover the basic FM requirements.

Figure 5. Basic TV Log. This is a sample log for a television station. Although the rules are somewhat ambiguous as to the frequency monitor reading, the frequency deviation of both carriers must be checked and logged every 30 minutes.

Important Points of Consideration in Designing an Operating Log Format

(Sample abbreviations shown in brackets)

1. Be sure the log is properly identified as to station location and frequency. It is sometimes convenient to print the transmitter latitude and longitude in the log.
2. Put the date in a convenient place in the event reference must be made to a specific day.
3. If abbreviations of any nature are used, be certain that each abbreviation is fully explained on the log and as a permanent part of the log. This is generally done at the bottom or on the back of each page when the logs are printed.
4. Where directive arrays are used, identify each tower in a manner consistent with the instrument of authorization.
5. Keep the log neat, precise, simple, and free of extraneous remarks.

TRANSMITTER OPERATION LOG
CALL LETTERS DATE _____ 19___
LOCATION
FREQUENCY – POWER – TIME OF OPERATION

TIME	E_p	I_p	F_d	ANTENNA CURRENTS				PHASE RELATION		REMARKS:
				I_{cp}	I_1	I_2	I_3	T_1/T_2	T_1/T_3	

ABBREVIATIONS:
E_p - FINAL STAGE PLATE VOLTAGE - KILOVOLTS
I_p - FINAL STAGE PLATE CURRENT - AMPERES
F_d - FREQUENCY DEVIATION - CYCLES PER SECOND
I_{cp} - COMMON POINT ANTENNA CURRENT - AMPS - REMOTE
I_1, I_2, I_3 - PHASE MONITOR SAMPLING LOOP CURRENTS. I_1 LOOP CURRENT USED IN LIEU OF ANTENNA CURRENT ON NON-DA OPERATION
T_1/T_2 - PHASE DIFFERENCE BETWEEN TOWER # 1 AND TOWER # 2
T_1/T_3 - PHASE DIFFERENCE BETWEEN TOWER # 1 AND TOWER # 3

FIGURE 3

FM STATION CALL LETTERS
TRANSMITTER OPERATING LOG
CHANNEL 269 — 101.7 MC — POWER 1KW

① TIME	② PLATE CURRENT FINAL STAGE	③ PLATE VOLTAGE FINAL STAGE	④ TRANSMISSION LINE * CURRENT	⑤ FREQUENCY DEVIATION ± CYCLES	REMARKS:

* OR VOLTAGE

FIGURE 4. Basic FM sample.

TV STATION CALL LETTERS
TRANSMITTER OPERATING LOG

CHANNEL _____ DATE _____
VIDEO FREQUENCY _____ CITY AND STATE _____
AUDIO FREQUENCY _____

TIME (1)	AUDIO TRANSMITTER (I)					VIDEO TRANSMITTER (II)			REMARKS
	I_p	E_p	F_d	REFLECTOMETER INCI.	REFL.	F_d	REFLECTOMETER INCI.	REFL.	
	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	

ABBREVIATIONS
E_p – PLATE VOLTAGE FINAL STAGE
I_p – PLATE CURRENT FINAL STAGE
F_d – FREQUENCY DEVIATION IN CYCLES PER SECOND

(I) AUDIO: ___ MICROAMPERES INCIDENT IS EQUAL TO ___ WATTS.
(II) VIDEO: ___ MICROAMPERES INCIDENT IS EQUAL TO ___ WATTS.
(I) AND (II) CALIBRATED USING DUMMY LOAD BEYOND SIDE BAND FILTER.

FIGURE 5. Basic TV sample.

6. Provide sufficient room for a "Remarks" column, which may be used for the following:

a. Operator's signature (not initials) when going on and off duty, if not placed in separate box.
b. Notation "Carrier On" and "Carrier Off." [CON] [COF]
c. Notation "Program On" and "Program Off." [PON] [POF]
d. Remarks as to cause of carrier interruption.
e. Calibration checks on remote-reading meters, etc. [CRRM]
f. Observation of tower lights and remarks as to steps taken if tower lights fail.
g. Remarks as to any unusual occurrences affecting transmissions.
h. Notations and initialing in the case of corrections in log entries.
i. Time of power change if required.

7. Stations utilizing remote control should make provisions in the operating log for the weekly calibration of the remote control metering system. The Commission also requires that the indications at the transmitter, if remote control of a directional antenna is utilized, of the common point current, base currents, phase monitor sample loop currents, and phase indications shall be read and entered in the operating log once each day for each pattern. These readings must be made within 2 hours after the commencement of operation of each pattern.

Part 9

NATIONAL BUREAU OF STANDARDS STANDARD FREQUENCY TRANSMISSIONS

STANDARD FREQUENCIES AND TIME SIGNALS WWV AND WWVH

The National Bureau of Standards' Radio Stations WWV (in operation since 1923) and WWVH (since 1949) broadcast six widely used technical services: 1. STANDARD RADIO FREQUENCIES, 2. STANDARD AUDIO FREQUENCIES, 3. STANDARD TIME INTERVALS, 4. STANDARD MUSICAL PITCH, 5. TIME SIGNALS, 6. RADIO PROPAGATION FORECASTS.

All inquiries concerning the technical radio broadcast services should be addressed to: National Bureau of Standards Boulder Laboratories, Boulder, Colorado.

The radio bands in which the foregoing services are broadcast are: 2500 ± 5 kc (2500 ± 2 kc in Region 1); 5000 ± 5 kc; 10,000 ± 5 kc; 15,000 ± 10 kc; 20,000 ± 10 kc; 25,000 ± kc. These bands were allotted by international agreement, in 1947, for exclusive standard-frequency-broadcast use.

The National Bureau of Standards' radio stations are located as follows: WWV, Beltsville, Maryland (Box 182, Route 2, Lanham, Maryland); WWVH, Maui, Hawaii (Box 901), Puunene, Maui, Hawaii). Coordinates of the stations are: WWV (lat. 38°59′33″ N., long. 76°50′52″ W.); WWVH (lat. 20°46′02″ N., long. 156°27′42″ W.).

The WWV-WWVH broadcasts are a convenient means of transferring the national standard of frequency and time interval and making it readily available throughout the United States and over much of the world. The broadcast program is shown schematically in Figure 1.

1. Standard Radio Frequencies

Station WWV broadcasts on standard radio frequencies of 2.5, 5, 10, 15, 20, and 25 Mc. The broadcasts are continuous, night and day, except WWV is off the air for approximately 4 minutes each hour. The silent period commences at 45 minutes, plus 0 to 15 seconds, after each hour.

Station WWVH broadcasts on standard radio frequencies of 5, 10, and 15 Mc. The WWVH broadcast is interrupted for 4 minutes following each hour and half hour and for periods of 34 minutes each day beginning at 1900 UT (Universal Time, UT is the same as GMT and GCT).

The standard radio frequencies are widely used, e.g., by the communications and electronics industry, research laboratories, and government. A local oscillator may be set versus the received frequency, and any desired radio frequency, including microwave frequencies, may be accurately measured in terms of the standard. The beat frequency method, or variations of it, is generally used. With a very narrow band receiver the standard radio frequency can be used when the received field strength is too low for audibility on ordinary radio receivers.

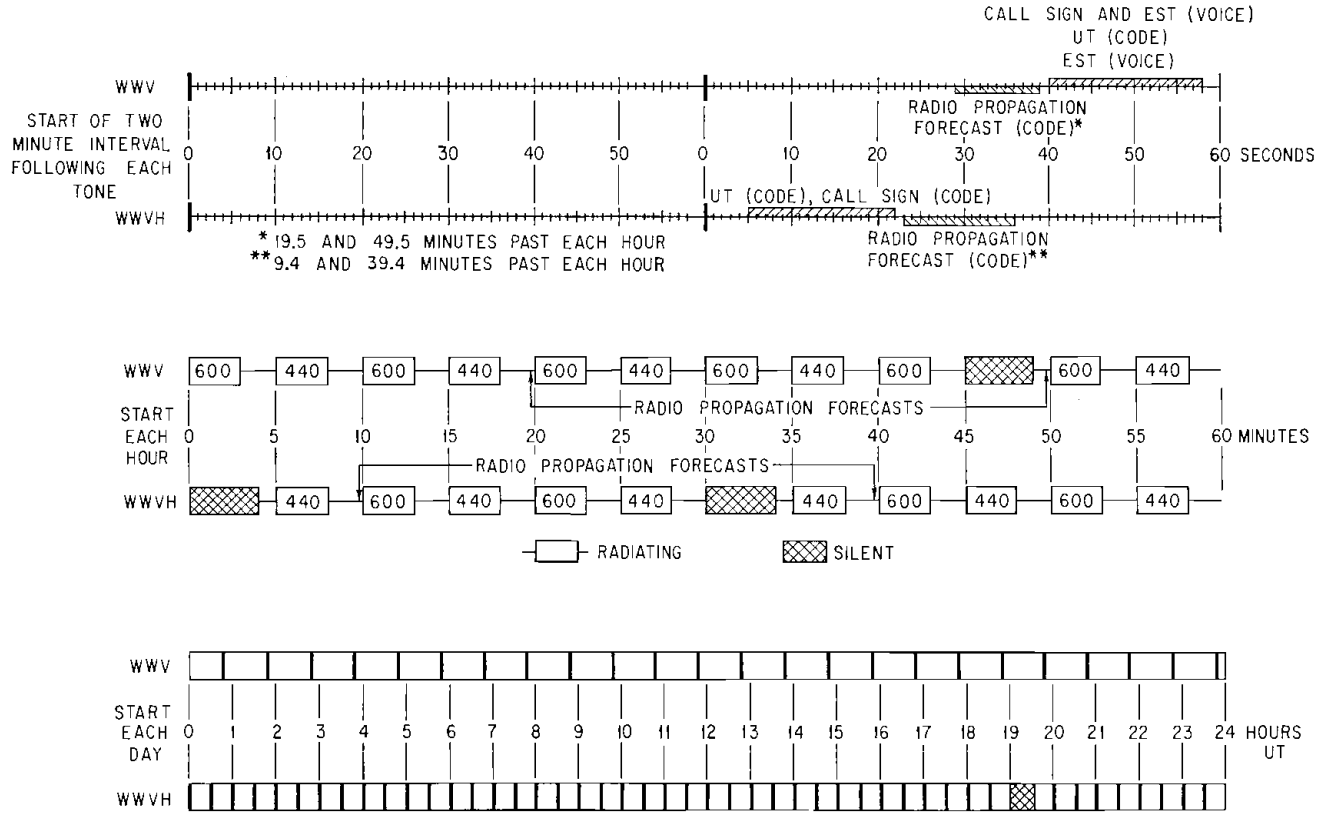

CALL SIGN AND EST (VOICE)
UT (CODE)
EST (VOICE)
WWV
START OF TWO MINUTE INTERVAL FOLLOWING EACH TONE
RADIO PROPAGATION FORECAST (CODE)*
0 10 20 30 40 50 0 10 20 30 40 50 60 SECONDS
UT (CODE), CALL SIGN (CODE)
WWVH
*19.5 AND 49.5 MINUTES PAST EACH HOUR
**9.4 AND 39.4 MINUTES PAST EACH HOUR
RADIO PROPAGATION FORECAST (CODE)**
WWV
600 440 600 440 600 440 600 440 600 440 600 440
START EACH HOUR
RADIO PROPAGATION FORECASTS
0 5 10 15 20 25 30 35 40 45 50 55 60 MINUTES
RADIO PROPAGATION FORECASTS
WWVH
440 600 440 600 440 440 440 600 440 600 440
RADIATING
SILENT
WWV
START EACH DAY
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 HOURS UT
WWVH

FIGURE 1

The accuracy of each of the radio frequencies as transmitted is better than 1 part in 100,000,000. The stability (quality of remaining fixed or unvarying) at the transmitter is normally within 1 part in 10^9 at WWV and 5 parts in 10^9 at WWVH. Deviations at WWV are about 2 in 10^{10} each day; frequency adjustments are made each day if necessary at 1900 UT. Deviations at WWVH are about 4 in 10^{10} each day; frequency adjustments are made each day if necessary during the interval 1900 to 1935 UT. If received accuracies better than 3 parts in 10^7 are desired it is necessary to make measurements over a long interval, e.g., 24 hours to obtain an accuracy of 1 part in 10^8. Such long-interval measurements should preferably be of the type that result in a strip chart record of frequency or phase changes (local oscillator vs WWV or WWVH) during the measurement interval. During intervals of about 10 hours or less, one may obtain highest accuracy when ionospheric conditions are normal and when measurements are made at the optimum time of day which is when sunrise or sunset does not occur over the radio propagation path.

Final corrections to the broadcast frequencies are available on a quarterly basis from the National Bureau of Standards Boulder Laboratories, Boulder, Colorado.

2. *Standard Audio Frequencies*

Two standard audio frequencies, 440 cycles per second and 600 cycles per second, are broadcast on each radio carrier frequency. The audio frequencies are given alternately starting with 600c on the hour for three minutes, interrupted two minutes, followed by 440c for three minutes and interrupted two minutes. Each 10-minute period is the same except for transmitter interruptions mentioned under 1 above.

The two standard audio frequencies are useful for accurate measurement or calibration of instruments operating in the audio or ultrasonic regions of the frequency spectrum. The frequencies broadcast were chosen because 440c is the standard musical pitch and 600c has the maximum number of integral multiples and submultiples; also, 600c is conveniently used with the standard power-frequency 60c.

Electronic circuits may be associated with radio receivers which automatically convert 600c to 1000c, 100c, etc.

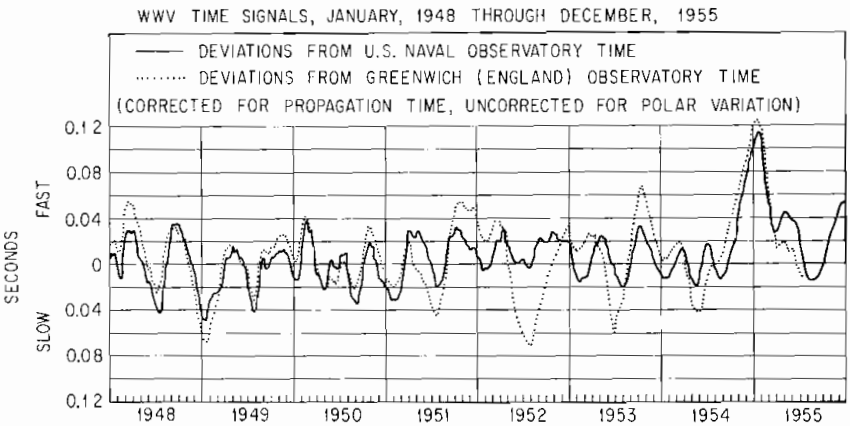
The accuracy of the audio frequencies, as transmitted is better than one part in 100,000,000. Changes in the transmitting medium (Doppler effect, etc.) result at times in fluctuations in the audio frequencies as received.

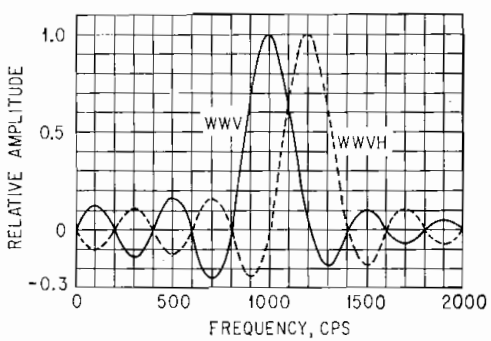
3. *Standard Time Intervals*

Seconds pulses at intervals of precisely one second are given as double sideband amplitude modulation on each radio carrier frequency. The pulse duration is 0.005 second. The pulse wave form is shown in Figure 2. At WWV each pulse consists of five cycles of a 1000c frequency. At WWVH each pulse consists of six cycles of a 1200c frequency. The pulse spectrum is composed of discrete frequency components at intervals of 1.0c. The components have maximum amplitudes at approximately 995c and 1194c for the WWV and WWVH pulses respectively.

The seconds pulses provide a useful standard time interval for quick and accurate measurement or calibration of time and frequency standards and timing devices. For example, a watch rate recorder may be checked by recording the seconds pulses. Intervals of one minute are marked by omitting the pulse at the beginning of the last second of every minute and by commencing each minute with two pulses spaced by 0.1 second. The two-minute, three-minute and five-minute intervals are synchronized with the seconds pulses and are marked by the beginning or ending of the periods when the audio frequencies are off.

A time interval as broadcast from WWV is accurate to 1 part in 10^8 plus or minus 1 microsecond. Received pulses have random phase shifts or jitter because of changes in the propagating medium. The magnitudes of these changes range from practically zero for the direct or ground wave to about 1000 microseconds when received via a changing ionosphere. Multiple pulses and echos are sometimes received because of propagation around the world and reflection from objects on the earth's





THE FREQUENCY SPECTRUM
OF THE
WWV AND WWVH SECONDS PULSES

THE SPECTRUM IS COMPOSED OF DISCRETE FREQUENCY COMPONENTS AT INTERVALS OF 1.0 CPS. THE COMPONENTS AT THE SPECTRAL MAXIMA HAVE AMPLITUDES OF 0.005 VOLT. FOR A PULSE AMPLITUDE OF 1.0 VOLT. THE WWV PULSE CONSISTS OF FIVE CYCLES OF 1000 CPS. THE WWVH PULSE CONSISTS OF SIX CYCLES OF 1200 CPS.

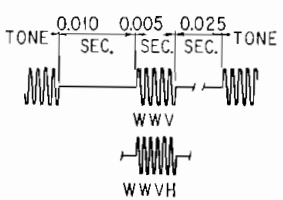


FIGURE 2

surface. The beginning of the first pulse received, i.e., the part having least delay, is most accurate and should be used. When ionospheric conditions are normal and the correct time of day is chosen, a frequency standard can be checked in a few hours versus WWV with a precision of about 1 part in 10^9; however, it is best to use intervals of 24 hours when comparing with this precision.

In using the time interval markers for high precision work it is necessary to remember that step adjustments of precisely ±20 milliseconds may be made at the transmitter on Wednesdays at 1900 UT; this is explained under paragraph 5, Time Signals.

The seconds pulses from WWVH are adjusted if necessary each day during the interval 1900 to 1935 UT so as to commence simultaneously with these from WWV, within plus or minus 500 microseconds.

4. Standard Musical Pitch

The frequency 440 cycles per second for note A above middle C has been the standard in the music industry in the United States since 1925. The radio broadcast of this standard was commenced by the National Bureau of Standards in 1937. It is now given six times per hour, 18 minutes per hour, from WWV and WWVH as shown in Figure 1. With this broadcast the standard pitch is maintained and musical instruments are manufactured and adjusted versus an unvarying standard. Listeners of music are benefited because there are fewer instruments not in tune and practically no instruments are manufactured which cannot be tuned to 440c.

A high frequency or short-wave radio receiver is the only equipment needed to effectively use the musical pitch standard.

5. Time Signals

The audio frequencies are interrupted at precisely two minutes before each hour. They are resumed precisely on the hour and each five minutes thereafter; they mark accurately the hour and the successive 5-minute periods (see Figure 1).

Time signals from WWV are maintained in close agreement with uniform time, called U. T. 2, determined by the U. S. Naval Observatory. This is done by occasional step adjustments in time, when necessary, of precisely plus or minus twenty milliseconds. These adjustments may be necessary several times per year. When required, they are made on Wednesdays at 1900 UT simultaneously at WWV and WWVH.

Universal Time is announced in telegraphic code each five minutes from WWV and WWVH. This provides a quick reference to correct time where a timepiece may be in error by a few minutes. The zero- to twenty-four-hour system is used starting with 0000 at midnight. The first two figures give the hour and the last two figures give the number of minutes past the hour when the tone returns. For example, at 1655 UT, or 11:55 a.m., Eastern Standard Time, four figures (1, 6, 5, and 5) are broadcast in code. The time announcement refers to the end of an announcement interval, i.e., when the audio frequencies are resumed.

At Station WWV a voice announcement of *Eastern* Standard Time is given before and after each telegraphic code announcement. For example, at 9:10 a.m., EST, the voice announcement in English is: "National Bureau of Standards, WWV; when the tone returns, Eastern Standard Time is 9:10 a.m."

Final corrections to the time signals, as broadcast, are determined and published, on a weekly basis, by the U.S. Naval Observatory, Washington 25, D.C.

6. Radio Propagation Forecasts

A forecast of radio propagation conditions is broadcast in telegraphic code on each of the standard radio carrier frequencies; from WWV at approximately 19.5 and 49.5 minutes past each hour, and from WWVH at approximately 9.4 and 39.4 minutes past each hour, as shown in Figure 1. Propagation notices were first broadcast from WWV in 1946; the present type of announcement has been broadcast from WWV since July 1952, and from WWVH since January 1954.

The forecast announcement tells users the condition of the ionosphere at the regular time the forecast is made and how good or bad communications conditions are expected to be in the succeeding 6 or more hours. The NBS forecasts are based on information obtained from a world-wide network of geophysical and solar observatories, including radio soundings of the upper atmosphere, short-wave reception data, and similar information. Trained forecasters digest the information and formulate the predictions.

From WWV the forecasts refer only to North Atlantic radio paths, such as Washington to London or New York to Berlin. The times of issue are 0500, 1200 (1100 in summer), 1700, 2300 UT. These are the short-term forecasts prepared by NBS-CRPL North Atlantic Radio Warning Service, Box 178, Ft. Belvoir, Virginia.

From *WWVH* the forecasts are for North Pacific radio paths, such as Seattle to Tokyo or Anchorage to San Francisco. The times of issue are 0200 and 1800 UT, with these forecasts first broadcast at 0239 and 1839 UT respectively. These are short-term forecasts prepared by NBS-CRPL North Pacific Radio Warning Service, Box 1119, Anchorage, Alaska. (Another short-term forecast at 0900 UT may be broadcast at a later date.)

The forecasters assume that the most suitable radio frequencies for communications are available and in use for the typical paths. Because of this assumption, their notices must be interpreted on a relative scale in terms of experience on each radio circuit in use. It is impossible to rate conditions on an absolute scale since the varied effects of transmitter power, type of communications traffic and procedure, antennas and receivers, prevent an evaluation which will be valid for all circuits. One purpose of broadcasting both a description and a forecast is to show more clearly whether propagation conditions are expected to deteriorate or improve in the coming period. The forecasts broadcast by WWV and WWVH apply only to short-wave radio transmissions over paths which are near the auroral zone for a considerable part of their length. In this zone the ionospheric layers are very likely to be disturbed, and because short-wave, long-range radio transmissions are dependent on the condition of the ionosphere, communications may be disrupted. Often the ionospheric disturbance accompanies intense magnetic field variations and a brilliant aurora. The resulting propagation effects range from severe fading to a complete break in the communications link.

The forecast is broadcast as a letter and a digit. The letter portion of the announcement identifies the radio quality at the time the forecast is made. The letters denoting qnality are "N," "U," and "W," signifying that radio propagation conditions are normal, unsettled, and disturbed. The digit portion is the forecast of the radio propagation quality on a typical North Atlantic (from WWV) or a typical North Pacific (from WWVH) transmission path during the 6 or more hours after the forecast is made. Quality is graded in steps ranging from 1 (useless) to 9 (excellent) as follows:

Disturbed Grades (W)	*Unsettled Grade (U)*	*Normal Grades (N)*
1–useless	5–fair	6–fair-to-good
2–very poor		7–good
3–poor		8–very good
4–poor-to-fair		9–excellent

If, for example, propagation conditions at the time the forecast is made are normal but are expected to be only "poor-to-fair" within the next 6 or more hours, the announcement would be broadcast as N4 in international Morse code.

7. *Radiated Power, Transmitting Antennas, Modulation*

Radiated power is shown in the table below:

Frequency, Mc	*Power, Kw WWV*	*Power, Kw WWVH*
2.5	1	
5	8	2
10	9	2
15	9	2
20	1	
25	0.1	

The broadcast on 2.5 Mc is from a vertical quarter-wave antenna. The broadcasts on all other frequencies are from vertical half-wave dipoles. The radiation is omnidirectional.

The percent amplitude modulation, double sideband, is:

Audio frequencies 440 or 600 c/s	75%
Voice and seconds pulses, peak	100%

At WWV, the tone frequency 440 or 600 c/s, except on 25 Mc, is experimentally operated as a single upper sideband with full carrier. Power output from the sideband transmitter is about one-third the carrier power. Single sideband tone on 25 Mc may be added at a later date. Other signals (announcements and seconds pulses) are double sideband, 100 percent amplitude modulation.

8. *Accuracy*

Frequencies from WWV and WWVH are accurate to within 1 part in 10^8 as broadcast; this is with reference to the U.S. Naval Observatory time and is limited by uncertainties in the immediate determination of astronomical time.

The radio frequencies may be consistently received with accuracies equal to those transmitted for several hours per day during total light or total darkness over the transmission path at locations in the service range. This was described under 1. Standard Radio Frequencies.

Large errors are caused by motion of the radio receiver relative to the transmitting stations or by motions of the reflecting ionospheric layers on which long-distance radio propagation depends. For example, on a vehicle moving 60 miles per hour relative to a fixed station, the received frequency would be in error by about 1 part in 10^7. Measurements made at NBS Boulder Laboratories and at WWVH have shown that during the course of the day errors in the received frequencies vary approximately -3 to $+3$ parts in 10^7.

Daily deviations in frequency and time of stations WWV and WWVH are tabulated on a quarterly basis. These data are available on request. In Figure 2 are plotted time signal deviations extending back 7 years. The deviations may be considerably less commencing in 1956.

9. *Distance Range of Reception*

Of the standard radio frequencies (2.5, 5, 10, 15, 20 and 25 Mc), the lowest provide service to short distances, and the highest to great distances. Reliable reception is in general possible throughout the United States and the North Atlantic and Pacific Oceans, and reception at times throughout the world. One should select the frequency that gives best reception at any particular place and time. This can be done by two methods:

a. By tuning to the different frequencies and selecting the one most suitable at that time.

b. By making use of techniques of prediction of usable frequencies. NBS publications useful for this purpose are the reports of the CRPL-D series, "Basic Radio Propagation Predictions," which are issued monthly, three months in advance of the month of prediction, and Circular 465 of the National Bureau of Standards, "Instructions for the Use of Basic Radio Propagation Predictions." These two publications may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., price in U.S. $1.00 per year (12 issues) and 30 cents per copy, respectively (foreign, $1.25, and 40 cents).

10. *Other Standard Frequency and Radio Time Signal Services*

The U.S. Naval Observatory, Department of the Navy, broadcasts time signals at regular intervals from NSS (Annapolis, Maryland), NPG (Mare Island, California), NPM (Pearl Harbor, Hawaii), NBA (Balboa, Canal Zone). Detailed information may be obtained from the U.S. Naval Observatory, Washington 25, D.C.

The Dominion Observatory, Ottawa, Canada, broadcasts time signals continuously over Station CHU on frequencies of 3330, 7335 and 14670 kc. Information may be obtained by writing the Dominion Observatory.

A comprehensive list of United States and foreign radio time signals is given in chapter 3 of "Radio Navigational Aids," Hydrographic Office publication No. 205,

for sale by the Hydrographic Office, Washington 25, D.C., price $2.00, U.S. or foreign.

Standard frequencies and time signals are broadcast by other stations as indicated in the following table.

Call Sign	*Location*	*Carrier Frequency Mc*	*Modulation c/s*	*Carrier Power Kw*
LOL	Buenos Aires, Argentina	2.5, 5, 10, 15, 20 and 25	1, 440, 1000	2
ZUO	Johannesburg, South Africa	5	I – –	0.1
ZLFS	Lower Hutt, New Zealand	2.5	– – –	0.035
–	Moscow, USSR	10 and 15	I – –	–
MSF	Rugby, England	2.5, 5 and 10	1, 1000 –	0.5
JJY	Tokyo, Japan	2.5, 5, 10 and 15	1, 1000 –	1
IBF	Torino, Italy	5	1, 440, 1000	0.3
–	Uccle, Belgium	2.5	– – –	0.02

FEDERAL COMMUNICATIONS COMMISSION 20103
Washington 25, D.C.

(Revised as of
May 17, 1955)

February 16, 1954

NOTICE TO ALL BROADCAST STATION LICENSEES:

SUBJECT: Rebroadcasts of Time Signals
(This supersedes all notices on this subject of earlier dates)

A. Naval Observatory Time Signals
Any broadcasting station desiring to rebroadcast Naval Observatory Time Signals is hereby authorized to do so, without further permission by the Commission, subject to the following conditions:
1) The time signal rebroadcast must be obtained by direct reception from a Naval radio station.
2) Announcement of the time signal must be made without reference to any commercial activity.
3) Identification of the Naval Observatory as the source of the time signal must be made by an announcement, substantially as follows: "With the signal, the time will be _____, courtesy of the United States Naval Observatory."
Schedules of time signal broadcasts may be obtained upon request from the superintendent, United States Naval Observatory, Washington 25, D.C.

B. Time Signals from National Bureau of Standards Stations
Any broadcasting station desiring to rebroadcast the time signals from stations WWV or WWVH is hereby authorized to do so, without further permission by the Commission, subject to the following conditions:
1) The use of receiving and rebroadcasting equipment which does not delay the signals by more than 0.05 second.
2) Voice of code announcements on WWV or WWVH are not to be rebroadcast.
3) Announcement that the signal is a rebroadcast of a continuous service given by the National Bureau of Standards.

A circular describing the Bureau's radio broadcast services is available on request from the National Bureau of Standards, Boulder, Colorado

Mary Jane Morris
Secretary

Section 2

ANTENNAS, TOWERS, AND WAVE PROPAGATION

Part 1

WAVE PROPAGATION, RADIATION, AND ABSORPTION *

EDWARD W. ALLEN, JR.

Chief Engineer
Federal Communications Commission
Washington, D.C.

THE NATURE OF RADIO-WAVE PROPAGATION

Radio waves are a part of a larger spectrum of electromagnetic radiation or wave motion extending from the very low frequencies which are now employed in servomechanisms, up through the extremely high frequencies and short wavelengths found in cosmic rays. Between these two extremes lie several ranges of frequencies which are related by reason of their being portions of a common spectrum but which exhibit such different characteristics under normal experience that their kinship may not be readily recognized. However, under certain conditions, analogies are useful for describing the characteristics of one range in terms of another. These other ranges include the frequencies used for electric-power systems; the audio frequencies used in systems for the transmission, amplification, or recording of audible sounds; the radio frequencies; radiant heat; light; and the X rays.

The portions of the spectrum occupied by these frequency ranges are shown in Fig. 1-1*a*. The limits of each frequency range are not defined sharply, but each range overlaps slightly into the ranges above and below. The frequency ranges are marked in terms of the frequency F in cycles per second and are also marked in terms of the wavelength λ in space in centimeters. The wavelength λ is related to the frequency F by the formula $C = F\lambda$, where C is the velocity of light and other electromagnetic radiation in space and is approximately equal to 3×10^{10} cm/sec ($2.99795 \pm 0.00003 \times 10^{10}$).

The range comprising the presently recognized limits of the radio spectrum has been expanded in Fig. 1-1*b*. The portions of the radio spectrum to which television broadcasting and television relay stations are allocated have been further expanded in Fig. 1-1*c*. The following discussion and methods apply particularly to these portions of the spectrum. †

The television broadcast allocations in the United States are: Channels 2 to 4 and 54 to 72 Mc, Channels 5 to 6 and 76 and 88 Mc, Channels 7 to 13 and 174 to 216 Mc, Channels 14 to 83 and 470 to 890 Mc. The television relay allocations are: 1,990 to 2,110 Mc, 6,875 to 7,125 Mc, and 12,700 to 13,200 Mc. The allocations for common carrier channels over which television programs are carried between cities are 3,700 to 4,200 Mc, 5,925 to 6,425 Mc, and 10,700 to 11,700 Mc. These allocations may change from time to time as the relative needs of various services for radio frequencies change, so that the allocations included herein should be considered to be merely illustrative. Current information should be obtained, when necessary, by consulting the Rules of the FCC.

* Reprinted from "Television Engineering Handbook," edited by Donald G. Fink, McGraw-Hill Book Company, Inc., 1957.

† The recently concluded Administrative Radio Conference (ITU, Geneva, 1959) extended their consideration of the radio spectrum to 40,000 Mc.

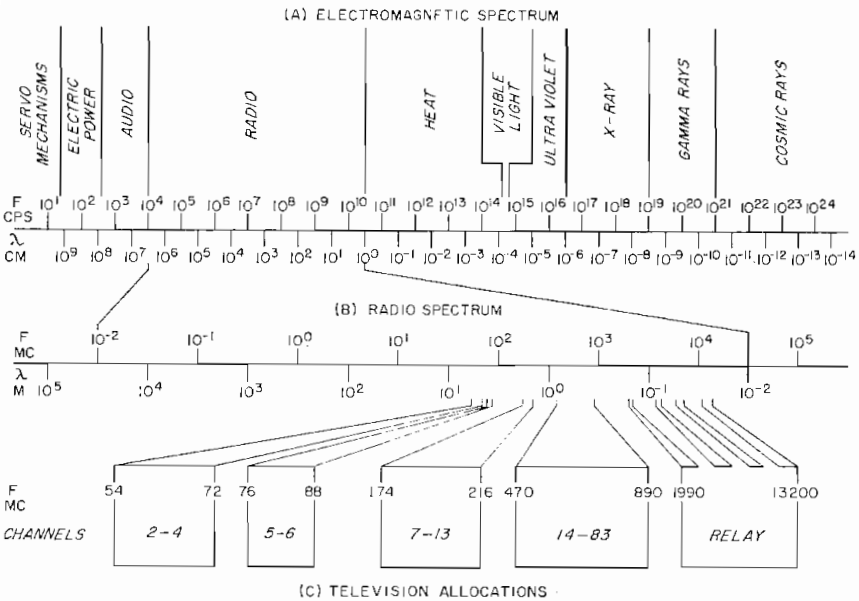


FIG. 1-1. (*a*) Electromagnetic spectrum; (*b*) radio spectrum; (*c*) television allocations.

PROPAGATION IN FREE SPACE

For simplicity and ease of explanation, propagation in space and under certain conditions involving simple geometry, in which the wavefronts remain coherent, may be treated as ray propagation. It should be kept in mind that this assumption may not hold in the presence of obstructions, surface roughness, and other conditions which may be encountered in practice.

For the simplest case of propagation in space, namely that of uniform radiation in all directions from a point source, or isotropic radiator, it is useful to consider the analogy to a point source of light. The radiant energy passes with uniform intensity through all portions of an imaginary spherical surface located at a radius r from the source. The area of such a surface is $4\pi r^2$, and the power flow per unit area $W = P_t/4\pi r^2$, where P_t is the total power radiated by the source. In the engineering of broadcasting and of some other radio services, it is conventional to measure the intensity of radiation in terms of the strength of the electric field E_o rather than in terms of power density W. The power density is equal to the square of the field strength divided by the impedance of the medium, so for free space $W = E_o^2/120\pi$, and $P_t = 4\pi r^2 E_o^2/120\pi$, or

$$P_t = \frac{r^2 E_o^2}{30} \tag{1-1}$$

where P_t is in watts radiated, W is in watts per square meter, E_o is the free-space field in volts per meter, and r is the radius in meters. A more conventional and useful form of this equation, which applies also to antennas other than isotropic radiators, is

$$E_o = \frac{\sqrt{30 g_t P_t}}{r} \tag{1-2}$$

where g_t is the power gain of the antenna in the pertinent direction compared with an isotropic radiator.

An isotropic antenna is useful as a reference for specifying the radiation patterns for more complex antennas but does not in fact exist. The simplest forms of practical antennas are the electric doublet and the magnetic doublet, the former a straight conductor which is short compared with the wavelength and the latter a conducting loop of short radius compared with the wavelength. For the doublet radiator the gain is 1.5 and the field strength in the equatorial plane is

$$E_o = \frac{\sqrt{45P_t}}{r} \tag{1-2a}$$

For a half-wave dipole, namely, a straight conductor one-half wave in length, the power gain is 1.64 and

$$E_o = \frac{7\sqrt{P_t}}{r} \tag{1-2b}$$

From the above formulas it can be seen that for free space (1) the radiation intensity in watts per square meter is proportional to the radiated power and inversely proportional to the square of the radius or distance from the radiator, (2) the electric field strength is proportional to the square root of the radiated power and inversely proportional to the distance from the radiator.

Typical Antennas in Free Space

The formulas for the free-space patterns, power gains, and effective areas of the fundamental doublet antennas and of a few typical antennas which are used frequently in television broadcast and relay systems are shown in Fig. 1-2. For purposes of pattern calculation, the element spacings S are measured in electrical angles $S^\circ = 2\pi S/\lambda$. For the turnstile and loop arrays the length $L = nS$, and for $S = \lambda/2$, $n = 2L/\lambda$.

The effective area B is related to the power gain g by the formula $B = g\lambda^2/4\pi$. The physical dimensions of the antennas, their effective areas, the wavelength, etc., should be expressed in the same units. The values given for power gain and effective area are for optimum conditions, and departures will result in lesser values of power gain and effective area.[1,2,*]

Transmission Loss between Antennas in Free Space [9]

The maximum useful power P_r that can be delivered to a matched receiver is given by

$$P_r = \left(\frac{E\lambda}{2\pi}\right)^2 \frac{g_r}{120} \text{ watts} \tag{1-3}$$

where E = received field strength in volts per meter
λ = wavelength in meters, $300/F$
F = frequency in megacycles per second
g_r = receiving antenna power gain over an isotropic radiator

This relation between received power and the received field strength is shown by scales 2, 3, and 4 in Fig. 1-3 for a half-wave dipole. For example, the maximum useful power at 100 mc that can be delivered by a half-wave dipole in a field of 50 db above 1 μv per meter is 95 db below 1 watt. A general relation for the ratio of the received power to the radiated power obtained from Eqs. (1-2) and (1-3) is

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi r}\right)^2 g_t g_r \left(\frac{E}{E_o}\right)^2 \tag{1-4}$$

* Superscript numbers refer to References at end of part.

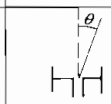
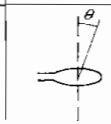
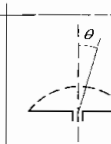
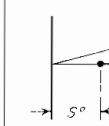
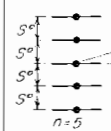
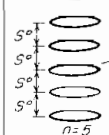
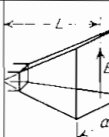
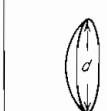
TYPE	CONFIGURATION	PATTERN	POWER GAIN OVER ISOTROPIC	EFFECTIVE AREA
ELECTRIC DOUBLET		$\cos\theta$	1.5	$1.5\frac{\lambda^2}{4\pi}$
MAGNETIC DOUBLET OR LOOP		$\sin\theta$	1.5	$1.5\frac{\lambda^2}{4\pi}$
HALF WAVE DIPOLE		$\frac{\cos(\frac{\pi}{2}\sin\theta)}{\cos\theta}$	1.64	$1.64\frac{\lambda^2}{4\pi}$
HALF WAVE DIPOLE AND SCREEN		$2\sin(S°\cos\beta)$	6.5	$1.64\ \lambda^2/\pi$
TURNSTILE ARRAY		$\frac{\sin(n\frac{S°}{2}\sin\beta)}{n\sin(\frac{S°}{2}\sin\beta)}$	n OR $2L/\lambda$	$n\lambda^2/4\pi$ OR $L\lambda/2\pi$
LOOP ARRAY		$\frac{\cos\beta\sin(n\frac{S°}{2}\sin\beta)}{n\sin(\frac{S°}{2}\sin\beta)}$	n OR $2L/\lambda$	$n\lambda^2/4\pi$ OR $L\lambda/2\pi$
OPTIMUM HORN $L \geq a^2/\lambda$		HALF POWER WIDTH $70\lambda/a$ DEGREES (H PLANE) $51\lambda/b$ DEGREES (E PLANE)	$10\,ab/\lambda^2$	$0.81\,ab$
PARABOLA		HALF POWER WIDTH $70\lambda/d$ DEGREES	$2\pi d^2/\lambda^2$	$d^2/2$

FIG. 1-2. Patterns, gains, and areas of typical antennas.

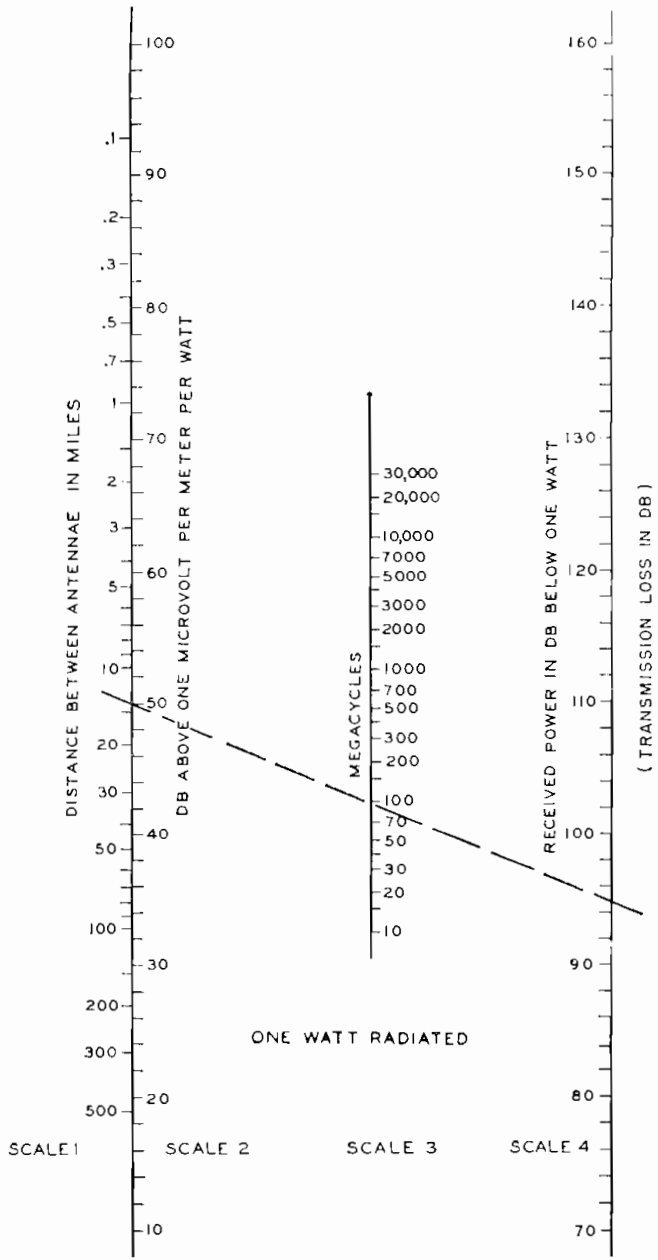


FIG. 1-3. Free-space field intensity and received power between half-wave dipoles.

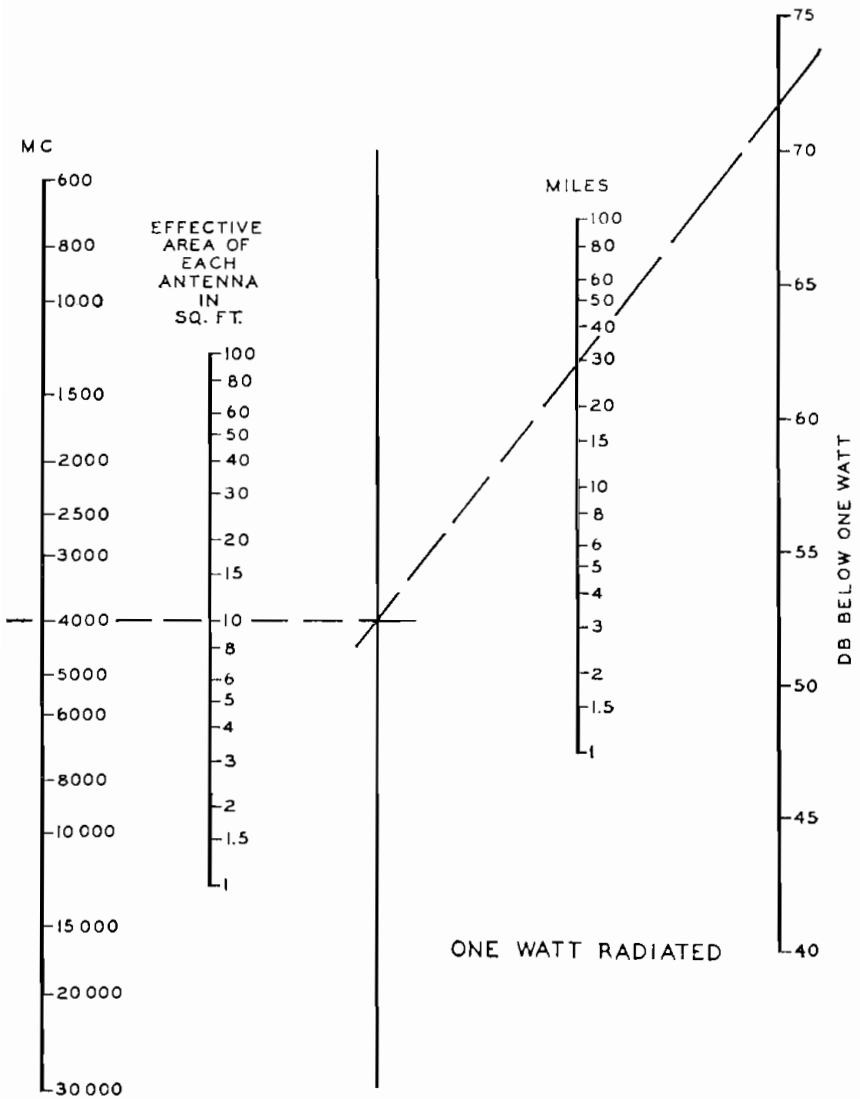


Fig. 1-4. Received power in free space between two antennas of equal effective areas.

When both antennas are half-wave dipoles, the power-transfer ratio is

$$\frac{P_r}{P_t} = \left(\frac{1.64\lambda}{4\pi r}\right)^2 \left(\frac{E}{E_o}\right)^2 = \left(\frac{0.13\lambda}{r}\right)^2 \left(\frac{E}{E_o}\right)^2 \tag{1-4a}$$

and is shown on scales 1 to 4 of Fig. 1-3. For free-space transmission $E/E_o = 1$.

When the antennas are horns, paraboloids, or multielement arrays, a more convenient expression for the ratio of the received power to the radiated power is given by

$$\frac{P_r}{P_t} = \frac{B_t B_r}{(\lambda r)^2} \left(\frac{E}{E_o}\right)^2 \tag{1-4b}$$

where B_t and B_r are the effective areas of the transmitting and receiving antennas, respectively. This relation is obtained from Eq. (1-4) by substituting $g = 4\pi B/\lambda^2$, and is shown in Fig. 1-4 for free-space transmission when $B_t = B_r$. For example, the free-space loss at 4,000 Mc between two antennas of 10 sq ft effective area is about 72 db for a distance of 30 miles.

PROPAGATION OVER PLANE EARTH [3,7]

The presence of the ground modifies the generation and the propagation of the radio waves so that the received field strength is ordinarily different than would be expected in free space. The ground acts as a partial reflector and as a partial absorber, and both of these properties affect the distribution of energy in the region above the earth.

Field Strengths Over Plane Earth

The geometry of the simple case of propagation between two antennas each placed several wavelengths above a plane earth is shown in Fig. 1-5. For isotropic antennas, for simple magnetic-doublet antennas with vertical polarization, or for simple electric-doublet antennas with horizontal polarization the resultant received field is [5,7]

$$E = \frac{E_o d}{r_1} + \frac{E_o d R e^{j\Delta}}{r_2} = E_o(\cos\theta_1 + R\cos\theta_2 e^{j\Delta}) \tag{1-5}$$

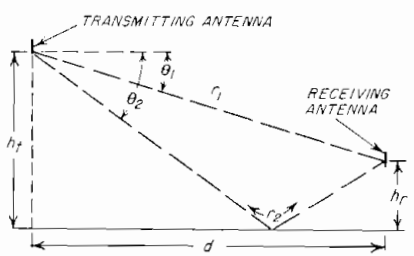


FIG. 1-5. Ray paths for antennas above plane earth.

For simple magnetic-doublet antennas with horizontal polarization or electric-doublet antennas with vertical polarization at both transmitter and receiver, it is necessary to correct for the cosine radiation and absorption patterns in the plane of propagation. The received field is

$$E = E_o(\cos^3\theta_1 + R\cos^3\theta_2 e^{j\Delta}) \tag{1-5a}$$

where E_o is the free-space field at distance d in the equatorial plane of the doublet, R is the complex reflection coefficient of the earth, $j = \sqrt{-1}$; $e^{j\Delta} = \cos\Delta + j\sin\Delta$, and Δ is the phase difference between the direct wave received over path r_1 and the ground-reflected wave received over path r_2, which is due to the difference in path lengths.

For distances such that θ is small and the differences between d and r_1 and r_2 can be neglected, Eqs. (1-5) and (1-5a) become

$$E = E_o(1 + Re^{j\Delta}) \tag{1-6}$$

When the angle θ is very small, R is approximately equal to -1. For the case of two antennas, one or both of which may be relatively close to the earth, a surface-wave term must be added [3,4] and Eq. (1-6) becomes

$$E = E_o[1 + Re^{j\Delta} + (1 - R)Ae^{j\Delta}] \tag{1-7}$$

The quantity A is the surface-wave attenuation factor which depends upon the frequency, ground constants, and type of polarization. It is never greater than unity and decreases with increasing distance and frequency, as indicated by the following approximate equation: [9]

$$A \simeq \frac{-1}{1 + j(2\pi d/\lambda)(\sin\theta + z)^2} \tag{1-7a}$$

This approximate expression is sufficiently accurate as long as $A < 0.1$, and it gives the magnitude of A within about 2 db for all values of A. However, as A approaches unity, the error in phase approaches 180°. More accurate values are given by Norton [7] where, in his nomenclature, $A = f(P,B)e^{i\phi}$.

The equation (1-7) for the absolute value of field strength has been developed from the successive consideration of the various components which make up the ground wave, but the following equivalent expressions may be found more convenient for rapid calculation:

$$E = E_o \left\{ 2 \sin \frac{\Delta}{2} + j[(1 + R) + (1 - R)A]e^{j\Delta/2} \right\} \tag{1-8}$$

When the distance d between antennas is greater than about five times the sum of the two antenna heights h_t and h_r, the phase difference angle Δ is equal to $4\pi h_t h_r/\lambda d$ radians. Also when the angle Δ is greater than about 0.5 radian the terms inside the brackets, which include the surface wave, are usually negligible, and a sufficiently accurate expression is given by

$$E = E_o \left(2 \sin \frac{2\pi h_t h_r}{\lambda d} \right) \tag{1-8a}$$

In this case the principal effect of the ground is to produce interference fringes or lobes, so that the field strength oscillates about the free-space field as the distance between antennas or the height of either antenna is varied.

When the angle Δ is less than about 0.5 radian, there is a region in which the surface wave may be important but not controlling. In this region sin $\Delta/2$ is approximately equal to $\Delta/2$ and

$$E = E_o \frac{4\pi h_t' h_r'}{\lambda d} \tag{1-8b}$$

In this equation $h' = h + jh_o$, where h is the actual antenna height and $h_o = \lambda/2\pi z$ has been designated as the minimum effective antenna height. The magnitude of the minimum effective height h_o is shown in Fig. 1-6 for sea water and for "good" and "poor" soil. "Good" soil corresponds roughly to clay, loam, marsh, or swamp, while "poor" soil means rocky or sandy ground.[9]

The surface wave is controlling for antenna heights less than the minimum effective height, and in this region the received field or power is not affected appreciably by changes in the antenna height. For antenna heights that are greater than the minimum effective height, the received field or power is increased approximately 6 db every time the antenna height is doubled, until free-space transmission is reached. It is ordinarily sufficiently accurate to assume that h' is equal to the actual antenna height or the minimum effective antenna height, whichever is the larger.

When translated into terms of antenna heights in feet, distance in miles, effective power in kilowatts radiated from a half-wave dipole, and frequency F in megacycles per second, Eq. (1-8b) becomes the following very useful formula for the rapid calculation of approximate values of field strength for purposes of prediction or for comparison with measured values:

$$E \simeq F \frac{h_t' h_r' \sqrt{P_t}}{3d^2} \tag{1-8c}$$

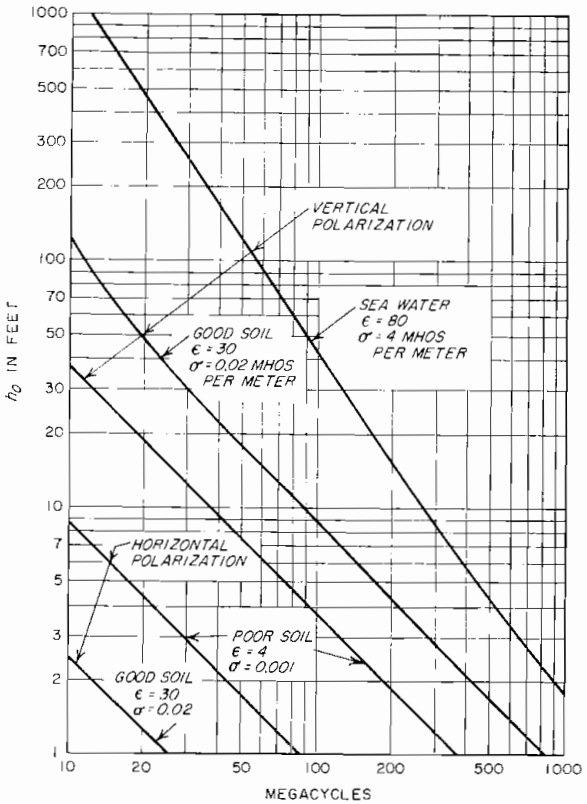


FIG. 1-6. Minimum effective antenna height.

Transmission Loss between Antennas Over Plane Earth

The ratio of the received power to the radiated power for transmission over plane earth is obtained by substituting Eq. (1-8*b*) into (1-4), resulting in

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi d}\right)^2 g_t g_r \left(\frac{4\pi h_t' h_r'}{\lambda d}\right)^2 = \left(\frac{h_t' h_r'}{d^2}\right)^2 g_t g_r \tag{1-9}$$

This relation is independent of frequency, and is shown on Fig. 1-7 for half-wave dipoles ($g_t = g_r = 1.64$). A line through the two scales of antenna height determines a point on the unlabeled scale between them, and a second line through this point and the distance scale determines the received power for 1 watt radiated. When the received field strength is desired, the power indicated on Fig. 1-7 can be transferred to scale 4 of Fig. 1-3, and a line through the frequency on scale 3 indicates the received field strength on scale 2. The results shown on Fig. 1-7 are valid as long as the value of received power indicated is lower than that shown on Fig. 1-3 for free-space transmission. When this condition is not met, it means that the angle Δ is too large for Eq. (1-8*b*) to be accurate and that the received field strength or power oscillates around the free-spaee value as indicated by Eq. (1-8*a*).[9]

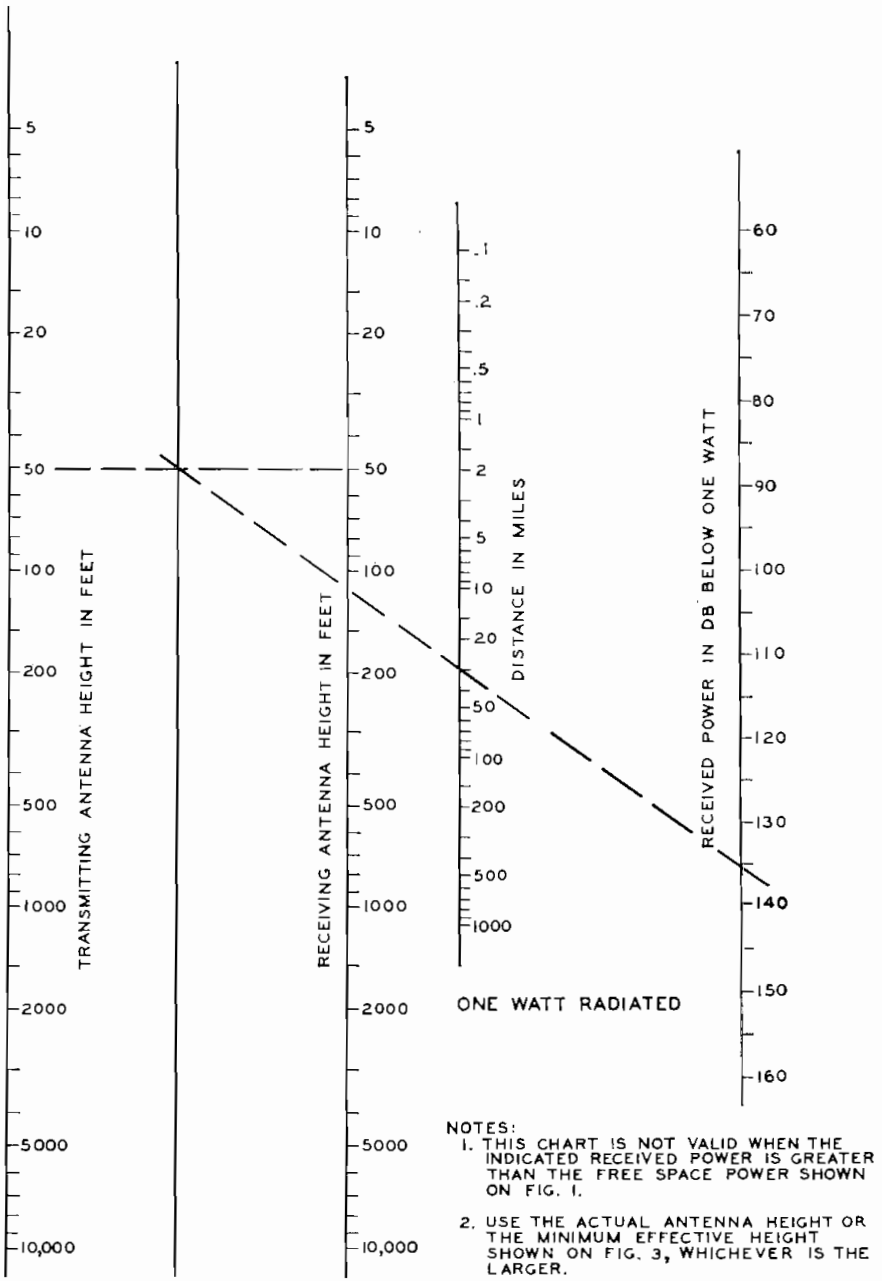


FIG. 1-7. Received power over plane earth between half-wave dipoles.

PROPAGATION OVER SMOOTH SPHERICAL EARTH

Propagation within the Line of Sight

The curvature of the earth has three effects on the propagation of radio waves at points within the line of sight. First, the reflection coefficient of the ground-reflected wave differs for the curved surface of the earth from that for a plane surface. This effect is of little importance, however, under the circumstances normally encountered in practice. Second, since the ground-reflected wave is reflected against the curved surface of the earth, its energy diverges more than would be indicated by the inverse distance-squared law and the ground-reflected wave must be multiplied by a divergence factor D. Finally, the heights of the transmitting and receiving antennas h_t' and h_r', above the plane which is tangent to the surface of the earth at the point of reflection of the ground-reflected wave, are less than the antenna heights h_t and h_r, above the surface of the earth, as shown in Fig. 1-8.

Under these conditions Eq. (1-6), which applies to larger distances within the line of sight and to antennas of sufficient height that the surface component can be neglected, becomes

$$E = E_o(1 + DR'e^{j\Delta}) \tag{1-10}$$

Similar substitutions of the values which correspond in Figs. 1-5 and 1-8 may be made in Eqs. (1-7) through (1-9). However, under practical conditions, it is generally

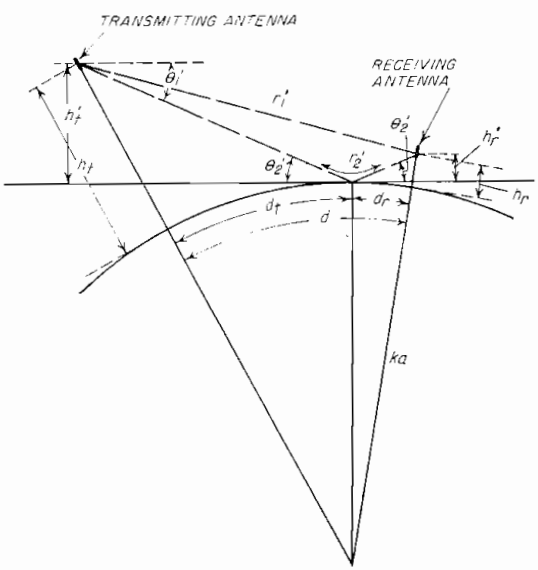


FIG. 1-8. Ray paths for antennas above spherical earth.

satisfactory to use the plane-earth formulas for the purpose of calculating smooth-earth values. An exception to this is usually made in the preparation of standard reference curves, which are generally calculated by the use of the more exact formulas.[4–10]

Propagation beyond the Line of Sight

Radio waves are bent around the earth by the phenomenon of diffraction, with the ease of bending decreasing as the frequency increases. Diffraction is a fundamental property of wave motion, and in optics it is the correction to apply to geometrical optics

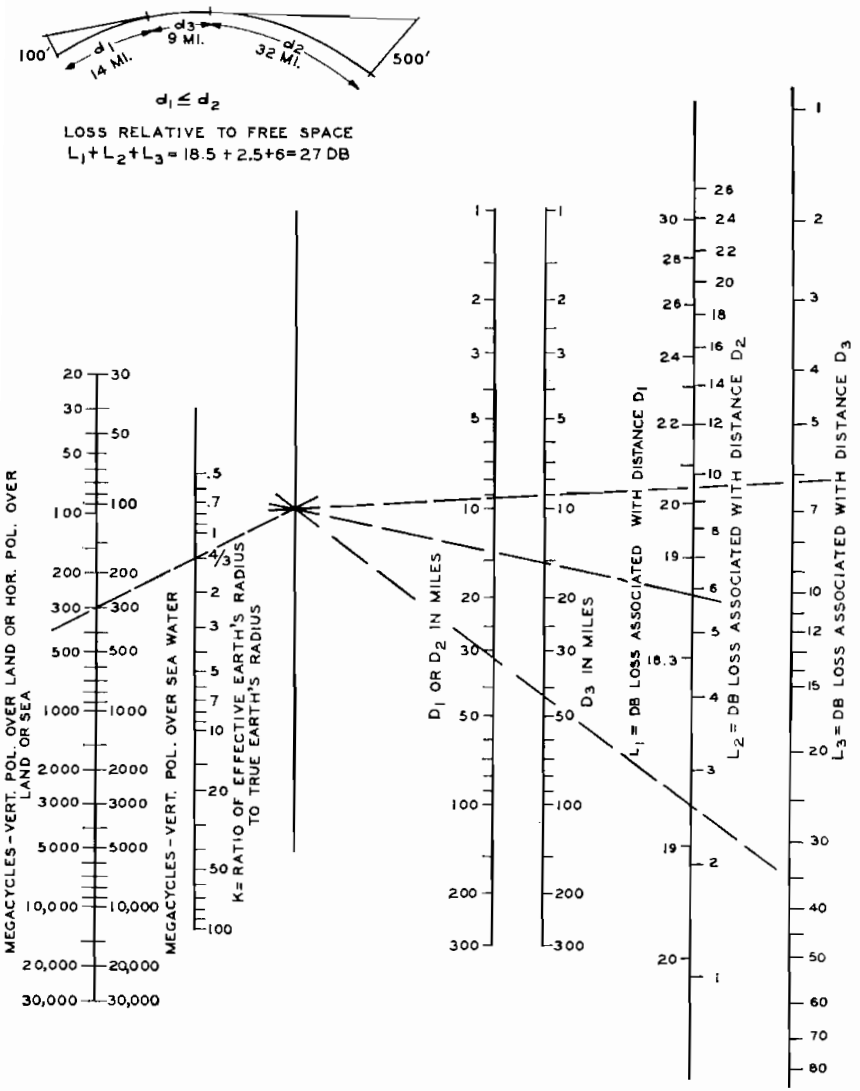


FIG. 1-9. Decibel loss beyond line of sight.

(ray theory) to obtain the more accurate wave optics. In wave optics, each point on the wavefront is considered to act as a radiating source. When the wavefront is coherent or undisturbed, the resultant is a progression of the front in a direction perpendicular thereto, along a path which constitutes the ray. When the front is disturbed, the resultant front may be changed in both magnitude and direction with resulting attenuation and bending of the ray. Thus all shadows are somewhat "fuzzy" on the edges and the transition from "light" to "dark" areas is gradual, rather than infinitely sharp.

The effect of diffraction around the earth's curvature is to make possible transmission beyond the line of sight, with somewhat greater loss than is incurred in free space or

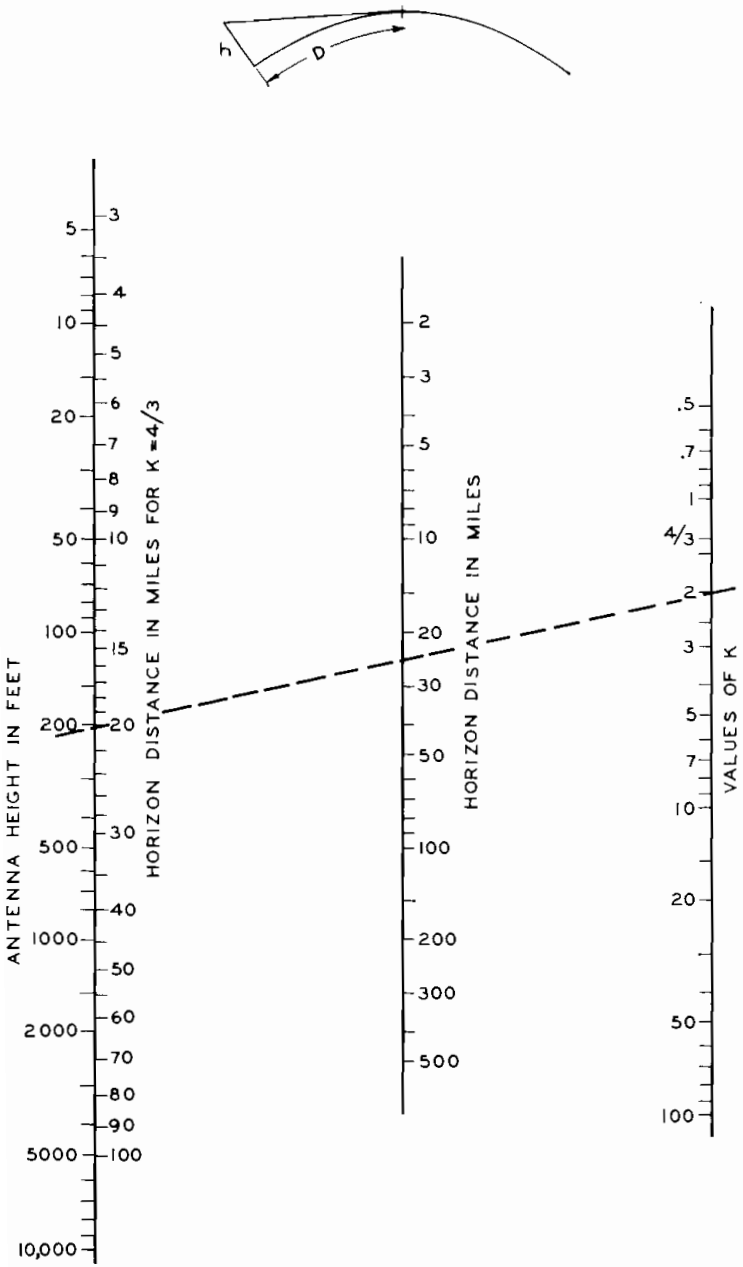


FIG. 1-10. Distance to horizon.

over plane earth. The magnitude of this loss increases as either the distance or the frequency is increased, and it depends to some extent on the antenna height.

The calculation of the field strength to be expected at any particular point in space beyond the line of sight around a spherical earth is rather complex, so that individual calculations are seldom made. Rather, nomograms or families of curves are usually prepared for general application to large numbers of cases. The original wave equations of Van der Pol and Bremmer [4] have been modified by Burrows [6] and by Norton [5,7] so as to make them more readily usable and particularly adaptable to the production of families of curves. Such curves have been prepared. These curves have not been included herein, in view of the large number of curves which are required to satisfy the possible variations in frequency, electrical characteristics of the earth, polarization, and antenna height. Also, the values of field strength indicated by smooth-earth curves are subject to considerable modification under actual conditions found in practice. For VHF and UHF broadcast purposes, the smooth-earth curves have been to a great extent superseded by curves modified to reflect average conditions of terrain.

Figure 1-9 is a nomogram to determine the additional loss caused by the curvature of the earth.[9] This loss must be added to the free-space loss found from Fig. 1-3. A scale is included to provide for the effect of changes in the effective radius of the earth, caused by atmospheric refraction. Figure 1-9 gives the loss relative to free space as a function of three distances; d_1 is the distance to the horizon from the lower antenna, d_2 is the distance to the horizon from the higher antenna, and d_3 is the distance between the horizons. The total distance between antennas is $d = d_1 + d_2 + d_3$.

The horizon distances d_1 and d_2 for the respective antenna heights h_1 and h_2 and for any assumed value of the earth's radius factor k can be determined from Fig. 1-10.

EFFECTS OF HILLS, BUILDINGS, VEGETATION, AND THE ATMOSPHERE

The preceding discussion assumes that the earth is a perfectly smooth sphere with a uniform or a simple atmosphere, for which condition calculations of expected field strengths or transmission losses can be computed for the regions within the line of sight and regions well beyond the line of sight, and interpolations can be made for intermediate distances. The presence of hills, buildings, and trees has such complex effects on propagation that it is impossible to compute in detail the field strengths to be expected at discrete points in the immediate vicinity of such obstructions or even the median values over very small areas. However, by the examination of the earth profile over the path of propagation and by the use of certain simplifying assumptions, predictions which are more accurate than smooth-earth calculations can be made of the median values to be expected over areas representative of the gross features of terrain.

Effects of Hills

The profile of the earth between the transmitting and receiving points is taken from available topographic maps * and is plotted on a special chart which provides for average air refraction by the use of a four-thirds earth radius, as shown in Fig. 1-11. The vertical scale is greatly exaggerated for convenience in displaying significant angles and path differences. Under these conditions vertical dimensions are measured along vertical parallel lines rather than along radii normal to the curved surface, and the propagation paths appear as straight lines. The field to be expected at a low receiving antenna at A from a high transmitting antenna at B can be predicted by plane-earth methods, by drawing a tangent to the profile at the point at which reflection appears to occur with equal incident and reflection angles. The heights of the transmitting and receiving antennas above the tangent are used in conjunction with Fig. 1-7 to compute the transmission loss or with Eq. (1-8c) to compute the field strength. A similar procedure can be used for more distantly spaced high antennas when the line of sight does not clear the profile by at least the first Fresnel zone.[11]

* Available from the U.S. Geological Survey, Department of the Interior, Washington, D.C.

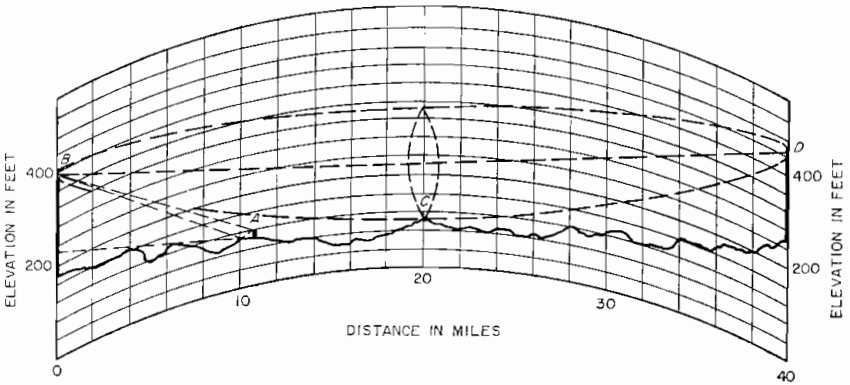


FIG. 1-11. Ray paths for antennas over rough terrain.

Propagation over a sharp ridge or over a hill when both the transmitting and receiving antenna locations are distant from the hill may be treated as diffraction over a knife edge, shown schematically in Fig. 1-12*a*.[9–15] The height of the obstruction H is measured from the line joining the centers of the two antennas to the top of the ridge. As shown in Fig. 1-13, the shadow loss approaches 6 db as H approaches 0, grazing incidence, and it increases with increasing positive values of H. When the direct ray clears the obstruction, H is negative, and the shadow loss approaches 0 db in an oscillatory manner as the clearance is increased. Thus, a substantial clearance is required over line-of-sight paths in order to obtain free-space transmission. There is an optimum clearance, called the first Fresnel-zone clearance, for which the transmission is theoretically 1.2 db better than in free space. Physically, this clearance is of such magnitude that the phase shift along a line from the antenna to the top of the obstruction and from there to the second antenna is about one-half wavelength greater than the phase shift of the direct path between antennas.

The locations of the first three Fresnel zones are indicated on the right-hand scale on Fig. 1-13, and by means of this chart the required clearances can be obtained. At 3,000 Mc, for example, the direct ray should clear all obstructions in the center of a 40-mile path by about 120 ft, to obtain full first-zone clearance, as shown at C in Fig. 1-11. The corresponding clearance for a ridge 100 ft in front of either antenna is 4 ft. The locus of all points which satisfy this condition for all distances is an ellipsoid of revolution with foci at the two antennas.

When there are two or more knife-edge obstructions or hills between the transmitting and receiving antennas, an equivalent knife edge may be represented by drawing a line from each antenna through the top of the peak that blocks the line of sight, as in Fig. 1-12*b*.

Alternatively, the transmission loss may be computed by adding the losses incurred when passing over each of the successive hills, as in Fig. 1-12*c*. The height H_1 is measured from the top of hill 1 to the line connecting antenna 1 and the top of hill 2. Similarly, H_2 is measured from the top of hill 2 to the line connecting antenna 2 and the top of hill 1. The nomogram in Fig. 1-13 is used for calculating the losses for terrain conditions represented by Fig. 1-12*a*, *b*, and *c*.

The above procedure applies to conditions for which the earth-reflected wave can be neglected, such as the presence of rough earth, trees, or structures at locations along the profile at points where earth reflection would otherwise take place at the frequency under consideration or where first Fresnel-zone clearance is obtained in the foreground of each antenna and the geometry is such that reflected components do not contribute to the field within the first Fresnel zone above the obstruction. If conditions are favorable to earth reflection, the base line of the diffraction triangle should not be drawn through the antennas, but through the points of earth reflection, as in Fig. 1-12*d*. H is

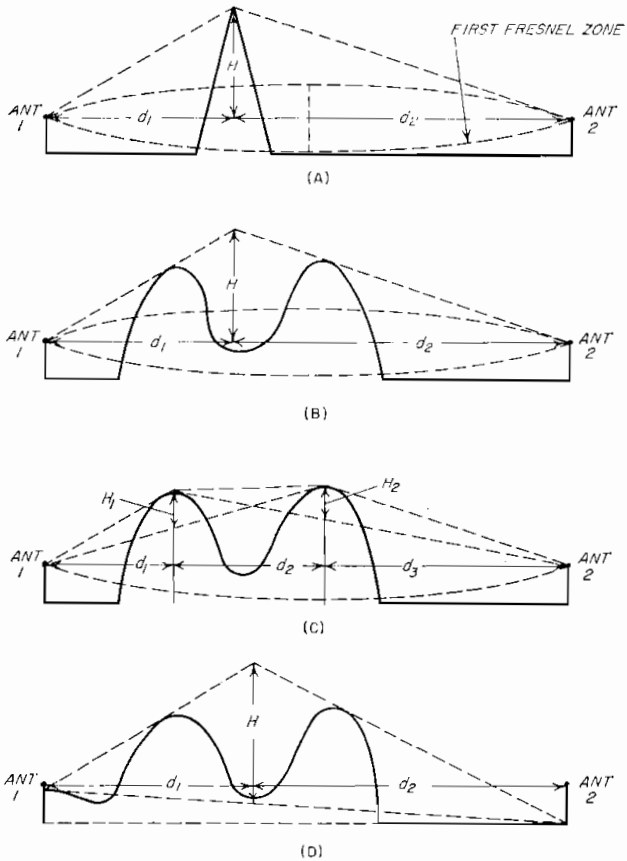


FIG. 1-12. Ray path for antennas behind hills.

measured vertically from this base line to the top of the hill, while d_1 and d_2 are measured to the antennas as before. In this case Fig. 1-14 is used to estimate the shadow loss to be added to the plane-earth attenuation.[9]

Under conditions where the earth-reflected components reinforce the direct components at the transmitting and receiving antenna locations, paths may be found for which the transmission loss over an obstacle is less than the loss over spherical earth. This effect may be useful in establishing VHF relay circuits where line-of-sight operation is not practical. Little utility may be expected for mobile or broadcast services.[15]

An alternate method for predicting the median value for all measurements in a completely shadowed area is as follows:[16] (1) The roughness of the terrain is assumed to be represented by height H, shown on the profile at the top of Fig. 1-15. (2) This height is the difference in elevation between the bottom of the valley and the elevation necessary to obtain line of sight with the transmitting antenna. (3) The difference between the measured value of field intensity and the value to be expected over plane earth is computed for each point of measurement within the shadowed area. (4) The median value for each of several such locations is plotted as a function of $\sqrt{H/\lambda}$.

These empirical relationships are summarized in the nomogram shown in Fig. 1-15. The scales on the right-hand line indicate the median value of shadow loss, compared

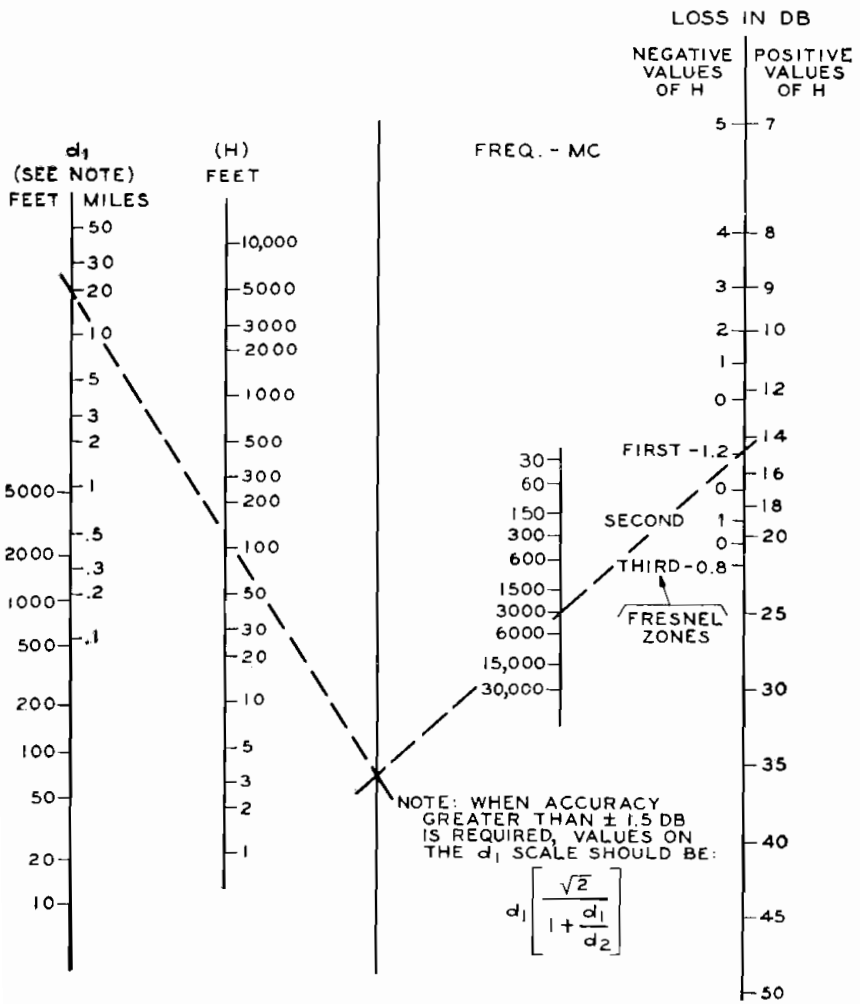


FIG. 1-13. Shadow loss relative to free space.

with plane-earth values, and the difference in shadow loss to be expected between the median and the 90 per cent values. For example, with variations in terrain of 500 ft, the estimated median shadow loss at 4,500 Mc is about 20 db and the shadow loss exceeded in 90 per cent of the possible locations is about 20 + 15 = 35 db. This analysis is based on large-scale variations in field intensity and does not include the standing-wave effects which sometimes cause the field intensity to vary considerably in a matter of a few feet.

Effects of Buildings

Built-up areas have little effect on radio transmission at frequencies below a few megacycles, since the size of any obstruction is usually small compared with the wavelength and the shadows caused by steel buildings and bridges are not noticeable except

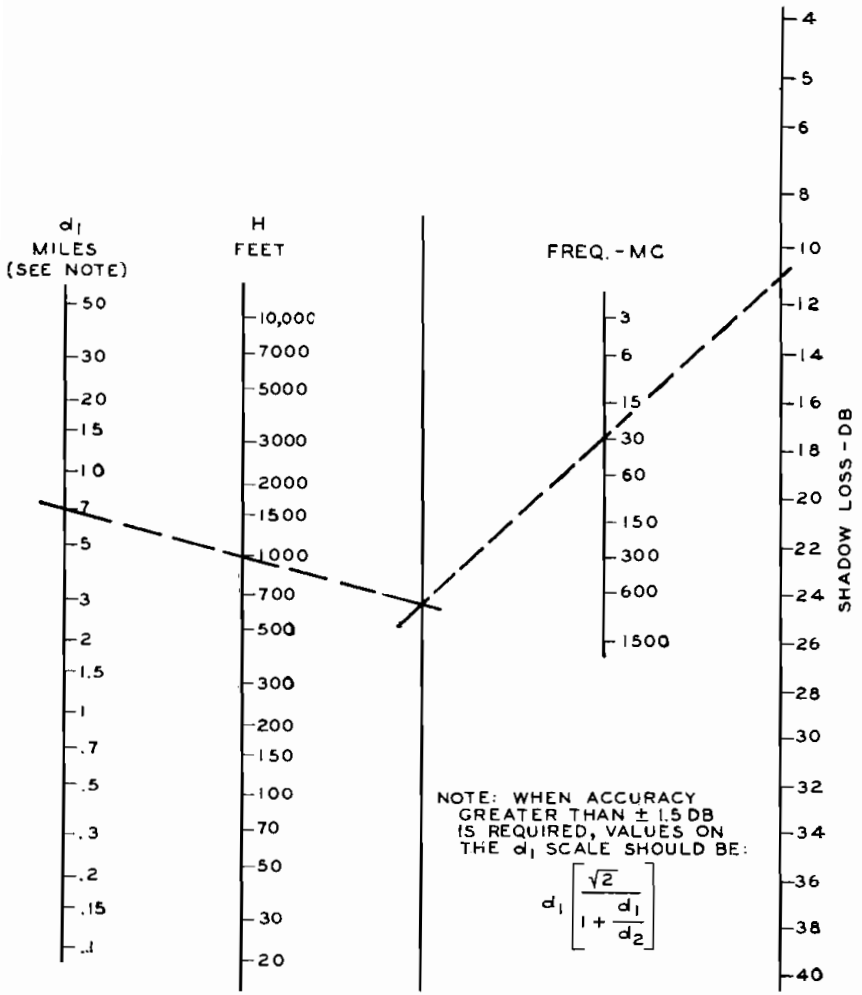


FIG. 1-14. Shadow loss relative to plane earth.

immediately behind these obstructions. However, at 30 Mc and above, the absorption of a radio wave in going through an obstruction and the shadow loss in going over it are not negligible, and both types of losses tend to increase as the frequency increases. The attenuation through a brick wall, for example, may vary from 2 to 5 db at 30 Mc and from 10 to 40 db at 3,000 Mc, depending on whether the wall is dry or wet. Consequently, most building are rather opaque at frequencies of the order of thousands of megacycles.

For radio-relay purposes, it is the usual practice to select clear sites, but where this is not feasible the expected fields behind large buildings may be predicted by the preceding diffraction methods. In the engineering of mobile- and broadcast-radio systems it has not been found practical in general to relate measurements made in built-up areas to the particular geometry of buildings, so that it is conventional to treat them statistically. However, measurements have been divided according to general categories into

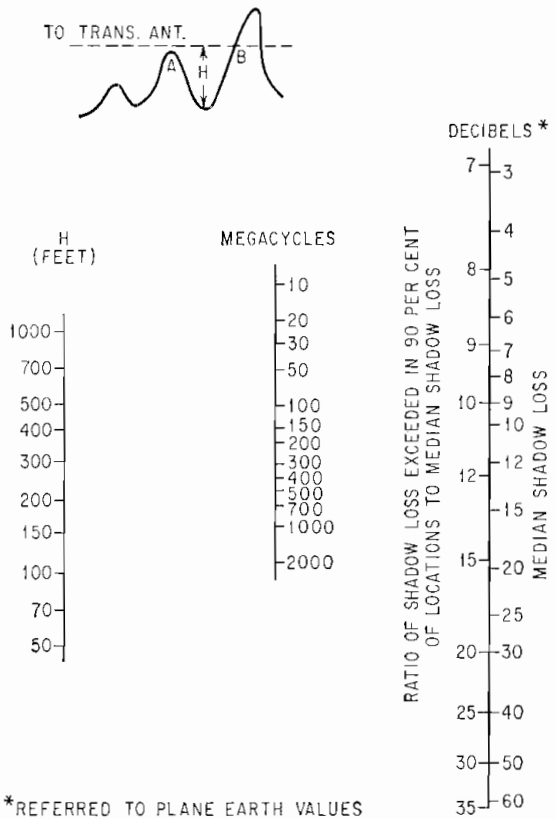


FIG. 1-15. Estimated distribution of shadow loss for random locations.

which buildings can readily be classified, namely, the tall buildings typical of the centers of cities on the one hand, and typical two-story residential areas on the other.

Buildings are more transparent to radio waves than the solid earth, and there is ordinarily much more back scatter in the city than in the open country. Both of these factors tend to reduce the shadow losses caused by the buildings. On the other hand, the angles of diffraction over or around the buildings are usually greater than for natural terrain, and this factor tends to increase the loss resulting from the presence of buildings. The quantitative data on the effects of buildings indicate that in the range of 40 to 450 Mc there is no significant change with frequency, or at least the variation with frequency is somewhat less than the square-root relationship noted in the case of hills. The median field strength at street level for random locations in Manhattan (New York City) is about 25 db below the corresponding plane-earth value. The corresponding values for the 10 and 90 per cent points are about -15 and -35 db, respectively.[9,15]

Measurements in congested residential areas indicate somewhat less attenuation than among large buildings. In the Report of the Ad Hoc Committee[19] measurements between 4 and 10 miles from the transmitter, which include some large building areas and some open areas but are made up principally of residential areas, shown median values of 4 to 6 db below plane earth for frequencies below 100 Mc and about 10 db for frequencies near 200 Mc. More recent measurements at 850 Mc[20] show values of 15 to 26 db below free space, which appear to be about 10 to 15 db below plane earth. These measurements were not random, however, but were the maximum values of field between 10

and 30 ft above the earth. The average effects for measurements taken in built-up areas have been accounted for in the preparation of the modified propagation curves of Figs. 1-19 and 1-20.

Effects of Trees and Other Vegetation

When an antenna is surrounded by moderately thick trees and below treetop level, the average loss at 30 Mc resulting from the trees is usually 2 or 3 db for vertical polarization and negligible with horizontal polarization. However, large and rapid variations in the received field strength may exist within a small area, resulting from the standing-wave pattern set up by reflections from trees located at a distance of as much as 100 ft or more from the antenna. Consequently, several nearby locations should be investigated for best results. At 100 Mc the average loss from surrounding trees may be 5 to 10 db for vertical polarization and 2 or 3 db for horizontal polarization. The tree losses continue to increase as the frequency increases, and above 300 to 500 Mc they tend to be independent of the type of polarization. Above 1,000 Mc trees that are thick enough to block vision present an almost solid obstruction, and the diffraction loss over or around these obstructions can be obtained from Fig. 1-13 or 1-14.[9,10]

There is a pronounced seasonal effect in the case of deciduous trees, with less shadowing and absorption in the winter months when the leaves have fallen. However, when the path of travel through the trees is sufficiently long that it is obscured, losses of the above magnitudes may be incurred, and the principal mode of propagation may be by diffraction over the trees.

When the antenna is raised above trees and other forms of vegetation, the prediction of field strengths again depends upon the proper estimation of the height of the antenna above the areas of reflection and of the applicable reflection coefficients. For growth of fairly uniform height and for angles near grazing incidence, reflection coefficients will approach -1 at frequencies near 30 Mc. As indicated by Rayleigh's criterion of roughness, the apparent roughness for given conditions of geometry increases with frequency so that near 1,000 Mc even such low and relatively uniform growth as farm crops or tall grass may have reflection coefficients of about -0.3 for small angles of reflection.[20]

The distribution of losses in the immediate vicinity of trees does not follow normal probability law but is more accurately represented by Rayleigh's law, which is the distribution of the sum of a large number of equal vectors having random phases. This distribution is shown by the graph R of Fig. 1-23.

Effects of the Lower Atmosphere, or Troposphere

The dielectric constant of the air is slightly greater than 1 and is variable. It depends on the pressure and temperature of the air and on the amount of water vapor present, so that it varies with weather conditions and with the height above the earth. Whenever the dielectric constant varies with height, a horizontally traveling wave will be refracted and the path deviated from a straight line. A general solution of the problem for any possible distribution of dielectric constant with the height at any point along the radio path is virtually impossible because of a large number of variables involved, so some simplifying assumptions are needed in order to obtain an engineering solution which will permit the calculation of radio field strengths under known meterological conditions. The complexity of this problem, together with the facts that detailed meteorological data which would permit calculation are no more readily available than radio data and that meteorological conditions are not readily predictable over long periods of time, has led to the statistical treatment of radio data, for the purpose of predicting long-distance effects and for the calculation of television service and interference, as in Statistical Evaluation of Propagation.

Stratification and Ducts

In the earlier work in this field the assumption was made that the air was horizontally stratified.[22,23] A simple engineering solution for average conditions can be obtained by

making the additional assumption that the dielectric constant is a linear function of the height. On this basis, the effect of atmospheric refraction can be included in the expression of diffraction around the smooth earth, without discarding the useful concept of straight-line propagation, by multiplying the actual earth's radius by k, to obtain an effective earth's radius, where

$$k = \frac{1}{1 + a/2(\Delta\epsilon/\Delta h)} \tag{1-11}$$

where a is the radius of the earth and $\Delta\epsilon$ is the change in dielectric constant in going from height h to $h + \Delta h$.[9]

Meteorological measurements indicate that the actual curve of dielectric constant vs. the height above the ground is frequently complex with one or more sharp bends, rather than a straight line as required in using the concept of an effective earth's radius. Theoretical considerations indicate that this curve can be approximated with reasonable accuracy by a series of straight lines as long as each individual line corresponds to a change in height of not more than 20 to 50 wavelengths. At 30 Mc height intervals of 600 to 1,500 ft can be assumed. Since most of the radio energy transmitted between two ground stations travels in the first of these height intervals, the concept of effective earth radius is a useful one and is sufficiently accurate at 30 Mc. However, as the frequency increases, the straight-line approximation is valid over smaller and smaller height intervals. At 3,000 Mc, for example, this interval is only 6 to 15 ft, and the concept of effective earth radius becomes inadequate for analytical use. The rate of decrease of time-median measurements with distance is relatively consistent with theoretical propagation over an equivalent knife edge rather than with values calculated from assumed earth-radius factors.[16]

The dielectric constant normally decreases with increasing height, k is greater than unity, and the radio waves are bent toward the earth. Since the earth's radius is about 2.1×10^7 ft, a decrease in dielectric constant of only 2.4×10^{-8} per foot of height results in a value of $k = \frac{4}{3}$, which is commonly assumed to be a good average value. When the dielectric constant decreases about four times as rapidly (or by about 10^{-7} per foot of height), the value of k becomes infinite. This means that, as far as radio propagation is concerned, the earth can be considered flat, since any ray that starts parallel to the earth will remain parallel.

When the dielectric constant decreases more rapidly than 10^{-7} per foot of height, radio waves that are radiated parallel to or at an angle above the earth's surface may be bent downward sufficiently to be reflected from the earth, after which the ray is again bent toward the earth, and so on.[8,9,24] The radio energy is thus trapped in a duct or wavegnide between the earth and the maximum height of the radio path. For low-layer heights, this phenomenon is variously known as trapping, duct transmission, anomalous propagation, or guided propagation. Elevated layers of this type at heights up to several thousand feet are believed to be responsible for the occurrence of high field strengths at distances somewhat beyond the horizon from the transmitter. Theoretical studies indicate that attainable values of dielectric variation could produce the field strengths which are usually observed at such distances for small percentages of the time.[23] Confirmation has also been obtained through simultaneous observations of radio field strengths and of meteorological conditions.[22] In addition to the simple form of a duct where the earth is the lower boundary, trapping may also occur in an elevated duct. For example, in the lower segment of the duct the dielectric constant may decrease very slowly or may even increase, so that the waves travel upward into an upper segment in which the dielectric constant decreases more rapidly than 10^{-7} per foot and in which the waves are again refracted in a downward direction to encounter the lower segment again, after which the process is repeated. In the case of either of the two foregoing forms of ducts, if there were no losses of energy involved, the field strengths at any given distance would exceed the free-space fields, since the spread of energy is restrained in the vertical dimension. However, experience indicates that over land paths the losses are such that the received field strengths are seldom greater than the plane-earth values.[9]

Tropospheric Scatter

More recently a theory has been developed by Booker and Gordon [25,26] attributing the distant tropospheric fields to the scattering of the radio waves by atmospheric turbulence rather than by reflection from horizontal stratification. There is considerable activity, both theoretical and experimental, to determine whether elevated stratified layers, turbulence, residual effects from the normal gradients of dielectric constant, or contributions from all three, are responsible for the high field strengths beyond the line of sight, which are of concern in estimating the interference between television broadcast stations. In addition to these higher field strengths, which occur for small percentages of the time, there are rather consistent fields of about 80 db below free space, which are largely independent of frequency. The rate of decrease for the median values of these fields is consistent with the theory of scatter from random turbulence.[22,28]

Atmospheric Fading

Variations in the received field strengths around the median value are caused by changes in atmospheric conditions. Field strengths tend to be higher in summer than in winter and higher at night than during the day for paths over land beyond the line of sight. As a first approximation, the distribution of long-term variations in field strength in decibels follows a normal probability law, as shown by graph N of Fig. 1–23.

Measurements indicate that the fading range reaches a maximum somewhat beyond the horizon and then decreases slowly with distance out to several hundred miles. Also the fading range at the distance of maximum fading increases with frequency, while at the greater distances where the fading range decreases, the range is also less dependent on frequency. Thus the slope of the graph N must be adjusted for both distance and frequency. This behavior does not lend itself to treatment as a function of the earth's radius factor k, since calculations based on the same range of k produce families of curves in which the fading range increases systematically with increasing distance and with increasing frequency. Methods for the statistical treatment of fading are described in Statistical Evaluation of Propagation.

Effects of the Upper Atmosphere, or Ionosphere

At the present time four principal layers or regions in the ionosphere are recognized. These are the E layer, the $F1$ layer, and the $F2$ layer, centered at heights of about 100, 200, and 300 km, respectively, and the D region, which is less clearly defined but lies below the E layer. These "regular" layers are produced by radiation from the sun, so that the ion density, and hence the frequency of the radio waves which can be reflected thereby, is higher in the day than at night. The characteristics of the layers are different for different geographic locations, and the geographic effects are not the same for all layers. The characteristics also differ with the seasons and with the intensity of the sun's radiation, as evidenced by the sunspot numbers, and the differences are generally more pronounced upon the $F2$ than upon the $F1$ and E layers. There are also certain random effects which are not fully explained. Some of these are associated with solar and magnetic disturbances. Other effects which occur at or just below the E layer have been established as being caused by meteors.[30]

Briefly the presently recognized ionospheric effects can be grouped into seven major categories as follows: (1) D region, (2) regular E layer, (3) regular $F1$ layer, (4) regular $F2$ layer, (5) sporadic E layer, (6) meteoric, and (7) anomalous and irregular ionization. The effects of the first three categories are either negligible or nonexistent at frequencies above 30 Mc and will not be referred to in detail. Categories (4), (5), and (6) will be discussed briefly as to their probable impact upon television service. The impact of (7) on television service is expected to be negligible.

F2 Layer

Data taken mainly during the years 1946 to 1948, when solar activity was high, indicate that during certain seasons of the year long-distance propagation by way of the regular *F*2-layer ionization can occur in temperate latitudes on frequencies up to about 50 Mc. The percentage of the total time during which it is possible is small, being, for example, of the order of 4.5 per cent on 50 Mc over the London–New York circuit, during the most favorable month of the year at sunspot maximum. In the tropics, however, such propagation can occur up to 60 Mc, with almost regular propagation on waves of 30 to 40 Mc. The field strengths observed are very variable, ranging from values exceeding the free-space value to those near or below the receiver noise level, over very short periods of time. However, since the radio noise fields are also very low, reception is often continuous for long periods of time and serious interference may result to services which are designed to provide communication at relatively low field strengths.

For several years around the solar maximum, on a widely occupied channel, intolerable long-range interference may be expected on frequencies below about 50 Mc during daylight hours in the equinox and winter seasons. The lowest frequency at which such interference becomes so infrequent as to be inappreciable is about 50 Mc for stations in temperate latitudes and about 60 Mc for stations in the tropics.[31, 32]

Worldwide predictions of *F*2-layer maximum usable frequencies (MUF) are given in monthly charts published by the Central Radio Propagation Laboratory of the National Bureau of Standards (CRPL).[33] Because of the variability of the *F*2 layer, precise predictions cannot be given for individual days, but statistically in one case out of ten the critical frequency at a given location will vary from the running average by more than 15 per cent. In other words, for the estimation of interference from this cause between television stations, it may be assumed that the daily MUF will exceed the monthly median MUF by more than 15 per cent on an average of 1 to 2 days per month. The occurrence in percentage of the time and in numbers of hours during the 1933-to-1944 sunspot cycle, as a function of the frequency and of the skip distance, is shown in Fig. 1-16, as estimated from the vertical incidence measurements made by the CRPL.[34]

Sporadic E

About five different forms of E_s are presently recognized and their occurrence varies in different latitudes. The form most prevalent in the United States and of interest to television can occur at any time of day but has a broad peak around midday and a subsidiary peak around sunset. It exhibits a marked seasonal variation and is especially prevalent during the months of May to September inclusive and of relatively small importance during the remaining months. Transmission by way of it is ordinarily confined to a single hop, at distances between about 400 and 1,400 miles. No definite correlation with the sunspot cycle has as yet been established.

The nature and causes of E_s are not well understood, but the most widely accepted explanation is that the typical E_s of the temperate latitudes consists of turbulent and rapidly moving clouds of ionization. When the clouds are large, steady and intense fields may be received for periods ranging from a few minutes to several hours. When the clouds are small and numerous, interference between the several reflected wavefronts produces very rapid fading. Superposed on the rapid fading are changes in the average field strength over longer periods of time, resulting from changes in the sizes, shapes, and positions of the clouds. These characteristics make difficult the estimation of time of occurrence and the probable interference therefrom. Figure 1-17 shows the number of hours and the percentage of the total time of occurrence of E_s from September, 1943, through August, 1944, as a function of frequency and of skip distance, estimated from vertical incidence measurements made by the CRPL. In Fig. 1-18, the curve $N = 1$ represents estimated field strengths exceeded for the times indicated in Fig. 1-17. Curves $N = 0.25$, $N = 0.5$, $N = 2$, and $N = 4$ represent the estimated field strengths to be expected for the corresponding multiples of the percentages of time shown in Fig. 1-17. For example, from Fig. 1-17, at a frequency of 40 Mc and at 1,000 miles, E_s field strengths occur for 1 per cent of the time. Referring to Fig. 1-18, at 1,000 miles, a field strength

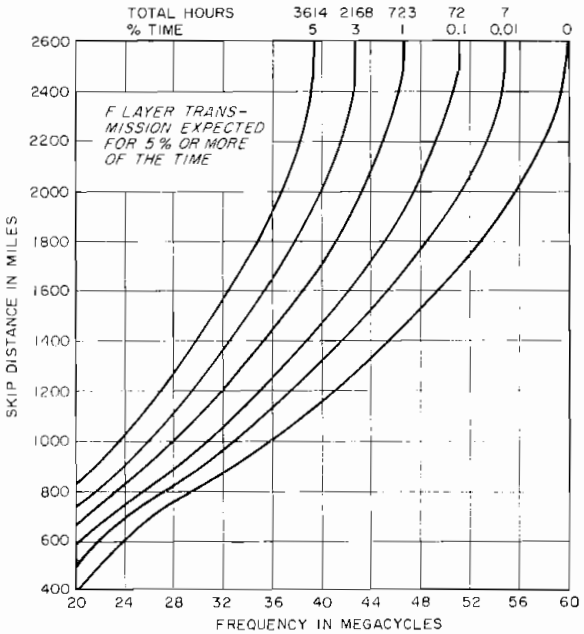


FIG. 1-16. Occurrence of F2-layer propagation.

of 27 db below free space was exceeded for 1 per cent of the time (curve $N = 1$), or 21.5 db for 0.25 per cent of the time (curve $N = 0.25$). At 81 Mc these fields would be exceeded for 0.01 and 0.0025 per cent of the time respectively. The rate of increase in the expected times of interference due to additional transmitters is not known. It is probably a function of the frequency, since the apparent size of the E_s clouds will decrease with increasing frequency. Thus for frequencies above 54 Mc, the lowest of the television channels, there is likely to be little correlation between the times of interference received from transmitters separated by a few hundred miles.[34,35]

The above information is based on a relatively small amount of data taken over a 1-year period. It is known that there are significant variations in E_s from year to year. Predictions of E_s for 3 months in advance are given in CRPL Series *D* and measured data in Series *F*, publications of the National Bureau of Standards.[33] The values given are monthly median values, and for short periods of time fluctuations about the median may result in the propagation of frequencies well above the values shown. Until more is known of the nature and causes of E_s, more detailed predictions cannot be given. For the same reasons, the above information is to be considered more as a guide as to the order of magnitude of these effects than as the basis for reliable estimates of interference from E_s.

Meteoric Ionization

Radio waves are reflected from the ionized trails produced by meteors at the height of the *E* layer and somewhat below. Because of the transitory nature of such ionization, the waves are usually received in short bursts of signal lasting for a fraction of a second. However, long bursts of from several seconds to several minutes' duration will be received at infrequent intervals. Measurements made at a frequency of 44 Mc and over distances of 300 to 700 miles indicate that during the diurnal maximum, which occurs in early morning hours, about 100 bursts exceeding a field strength of 70 db below free space may occur per hour. The peak amplitudes for distances between 300 and 1,100 miles lie between 40 and 50 db below free space.[36]

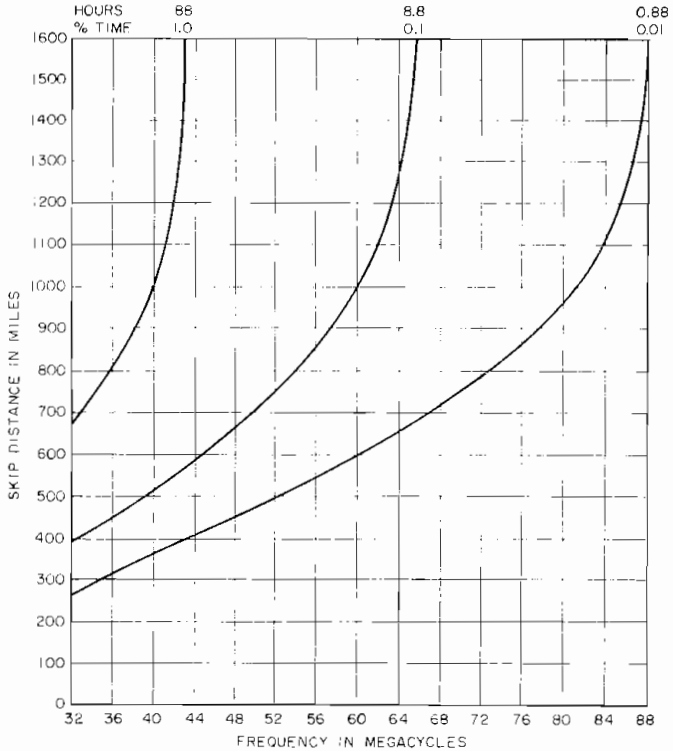


FIG. 1-17. Occurrence of E_s-layer propagation.

STATISTICAL EVALUATION OF PROPAGATION

In previous sections a partial statistical description has been given of the separate effects of terrain and of the variation of field strengths with time. Methods have been given for the prediction of the median field strengths to be expected for areas of size comparable to the gross features of the terrain, to which correction factors may be applied for the presence of buildings and vegetation and within which the fields may be described in terms of the strengths which are expected to be exceeded at a given percentage of locations. Alternatively, the distribution of field strengths as a function of the percentage of locations may be regarded as the probability, in per cent, that a given field strength will be exceeded at a particular location within the area in question.

For the purpose of formulating a national plan for the assignment of television channels, it was felt to be impractical to consider in detail even the gross features of terrain, so that a statistical approach has been adopted to prepare families of propagation curves reflecting the median values found from all available data. Figures 1-19 and 1-20 show the field strengths in decibels relative to 1 μv/m for 1 kw of effective radiated power to be expected at the best 50 per cent of receiving locations for at least 50 per cent of the time, for antenna heights from 100 to 10,000 ft. These field strengths are referred to as $F(50,50)$. The field strengths are based on an effective power of 1 kw radiated from a half-wave dipole in free space, which produces an unattenuated field strength at 1 mile of about 103 db above 1 μv/m (103 dbμ). The antenna height to be used with these charts in any particular case is the height of the center of the radiating element above the average height of the profile between 2 and 10 miles from the transmitter along the desired radial. Figures 1-21 and 1-22 show the corresponding field strengths

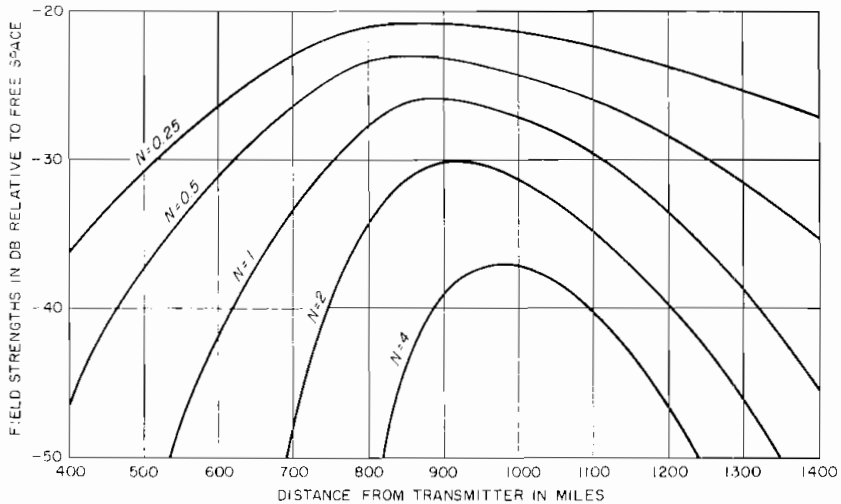


FIG. 1-18. E_s field strengths.

for 50 per cent of the locations and 10 per cent of the time $F(50,10)$. These families of curves, in conjunction with curve N of Fig. 1-23, may be used to estimate the service provided by television stations, in accordance with the following procedures.

Prediction of Field Strengths for Television Service [19]

The field strengths required to provide television service are derived in the following manner: Test receivers of known characteristics as to sensitivity, selectivity, etc., are set up under typical home lighting and viewing conditions. Viewers then rate the relative acceptability of pictures at varying levels of input signals as obtained from a calibrated source, such as a television signal generator. The ratings are then analyzed statistically in terms of the percentages of viewers who rate the pictures as of a given quality, such as satisfactory, at each level of signal input. These results follow the normal probability law of curve N. It is impractical to satisfy 100 per cent of viewers and values satisfying 50 to 70 per cent are usually adopted for broadcast purposes. From the signal level thus selected and the known bandwidth and noise characteristics of the receiver, a required signal-to-noise ratio is determined. The required instantaneous fields F' to provide service of this quality are then derived by applying the proper values for the receiver-noise figure and the antenna and transmission line characteristics of the typical receiver installation. Similar procedures are used for deriving the desired to undesired ratio for various types of interfering signals. For this purpose the undesired signal is also fed into the receiver input in various ratios and at various frequencies in relation to the desired signal.[39]

The service at a particular location is said to be satisfactory if the minimum required field F', as above determined, is exceeded for some agreed percentage of the time T, such as 90 per cent. This may be expressed as a T per cent field strength $F'(T)$. The required time median field $F'(T = 50)$ to provide the minimum field for the desired percentage of time $F'(T)$ is given by the equation

$$F'(T) = F'(T = 50) + N'(T) \tag{1-12}$$

$N'(T)$ is the time distribution factor in decibels for T per cent of the time. This factor is assumed to be independent of location so that Eq. (1-12) can also be written

$$F'(L,T) = F(L,50) + N'(T) \tag{1-12a}$$

and

$$F'(50,10) = F(50,50) + N'(T = 10) \tag{1-12b}$$

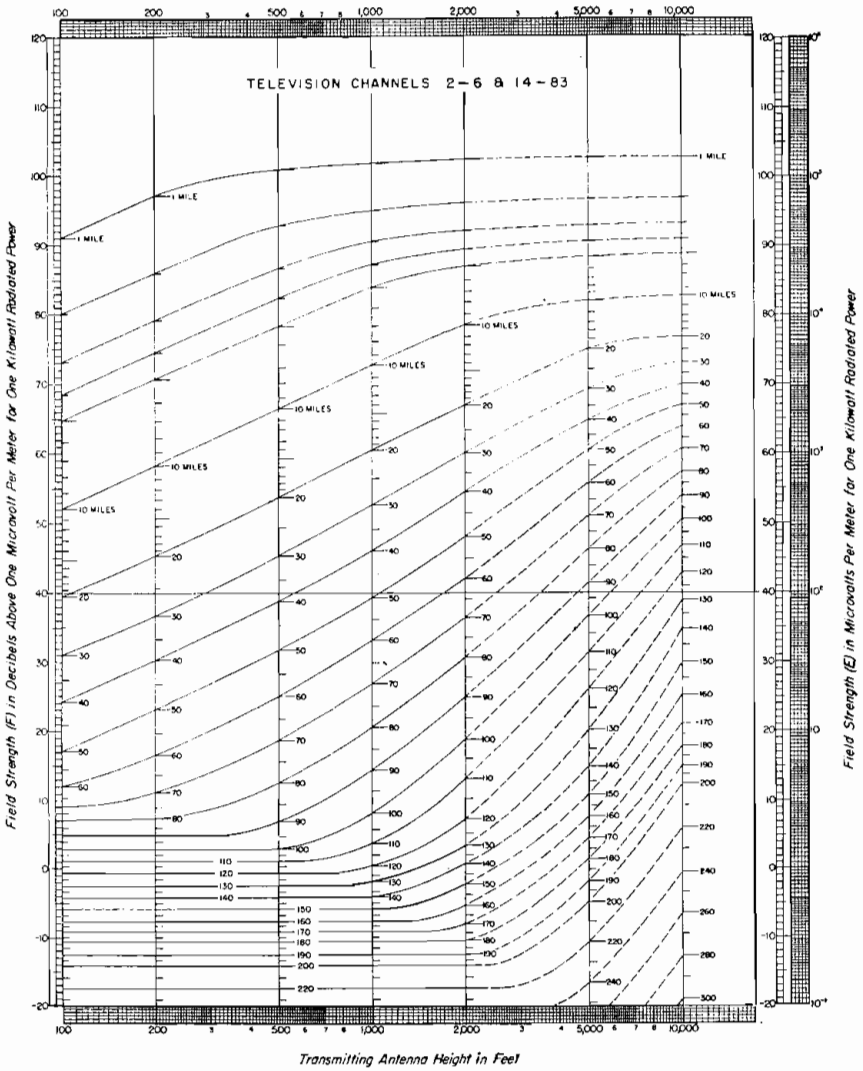


FIG. 1-19. $F(50,50)$ for television channels 2 to 6, 14 to 83.

Thus $N'(T = 10)$ can be determined for various frequencies, distances, and antenna heights, using the appropriate values of $F(50,10)$ shown in Figs. 1-21 and 1-22 and of $F(50,50)$ shown in Figs. 1-19 and 1-20. The distributions of field strengths for waves propagated via the troposphere are highly variable. For short periods of time during which the characteristics of the troposphere do not vary materially and the variation is due mainly to wave interference, the distribution may approach the Rayleigh distribution shown in curve R of Fig. 1-23. For longer periods of time the distributions of instantaneous values and of hourly median values assume complex forms of which the curve T of Fig. 1-23 is characteristic. Since the field strengths from which the curve was constructed have contributions from various modes of propagation and since the shape of the curve varies with such parameters as frequency, distance, transmitting

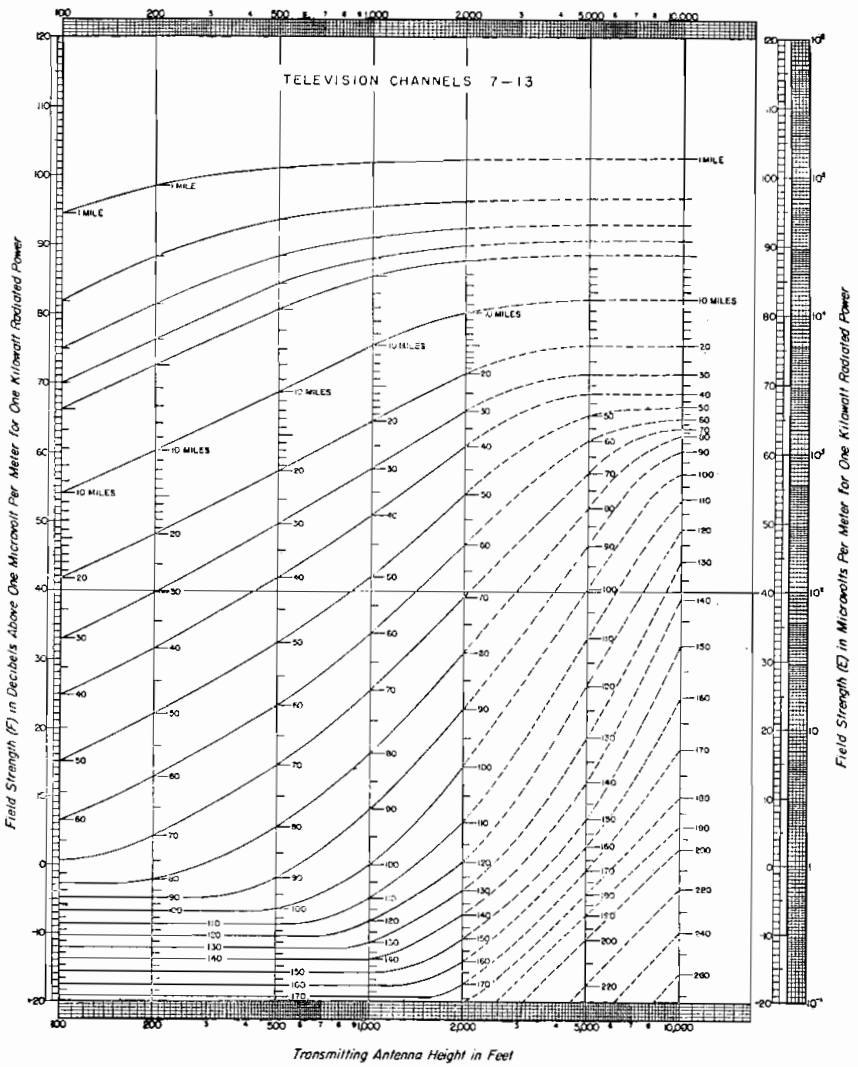


FIG. 1-20. $F(50,50)$ for television channels 7 to 13.

antenna height, receiver location, etc., an exact expression is not possible. However, the curve is sufficiently close to the log normal curve N, so that with attention to the proper slope as determined by the appropriate value of $N'(T = 10)$, a log normal distribution can be used for the purposes of estimating service and interference. Thus $N'(T)$ for values of T other than 10 per cent can be approximated by the formula

$$N'(T) = N'(T = 10) \frac{N(T)}{N(T = 10)} \tag{1-13}$$

The percentage of locations L or the percentage probability L that the received fields $F'(L,T)$ will exceed the required T per cent fields $F'(T)$ at a particular location within the area may be determined by the formula

$$N'(L) = F'(L,T) - P' - F(50,50) - N'(T) \tag{1-14}$$

where $N'(L)$ is the location distribution factor in decibels for L per cent of locations or L per cent probability at a particular location. For VHF television Channels 2 to 13, $N'(L)$ is equal to 0.53 times the values given by the normal probability curve N of Fig. 1-23, or $N'(L) = 0.53\ N(L)$. For UHF Channels 14 to 83

$$N'(L) = 0.75\ N(L)$$

$F'(L,T)$ is the minimum field strength, in dbμ, to be expected at the best L per cent of locations for at least T per cent of the time. P' is the effective radiated power in

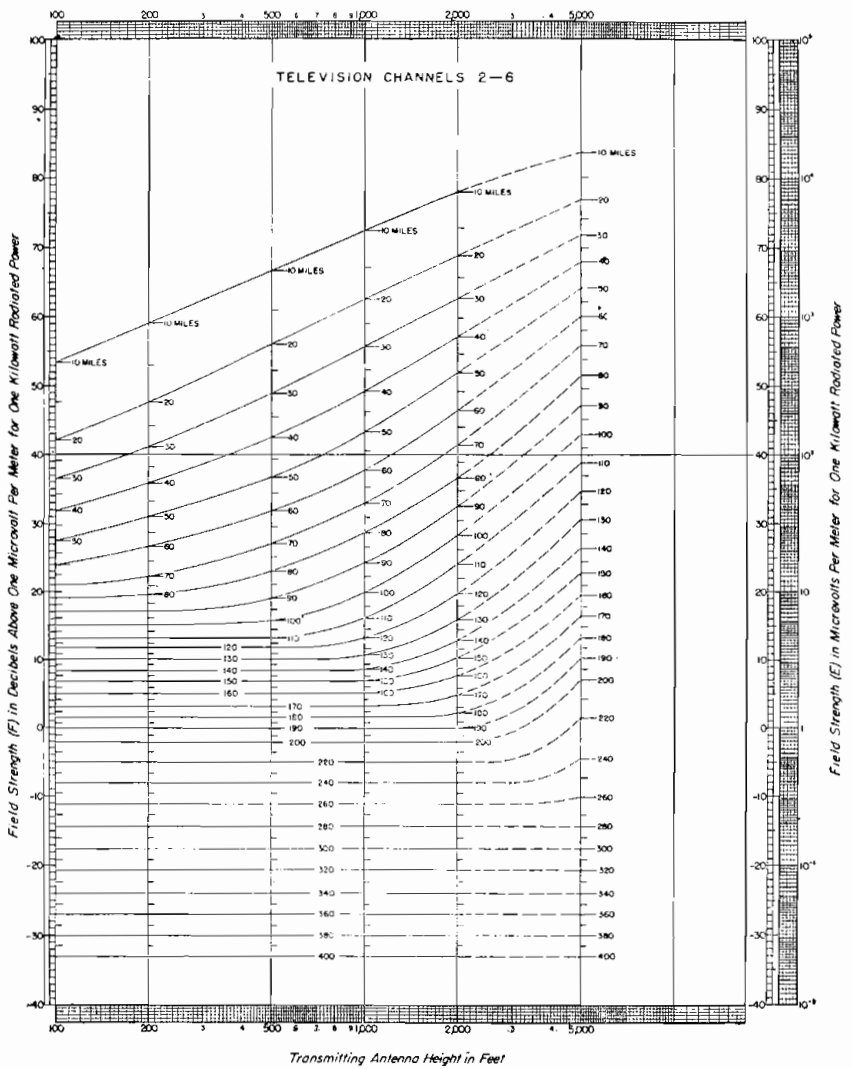


FIG. 1-21. $F(50,10)$ for television channels 2 to 6.

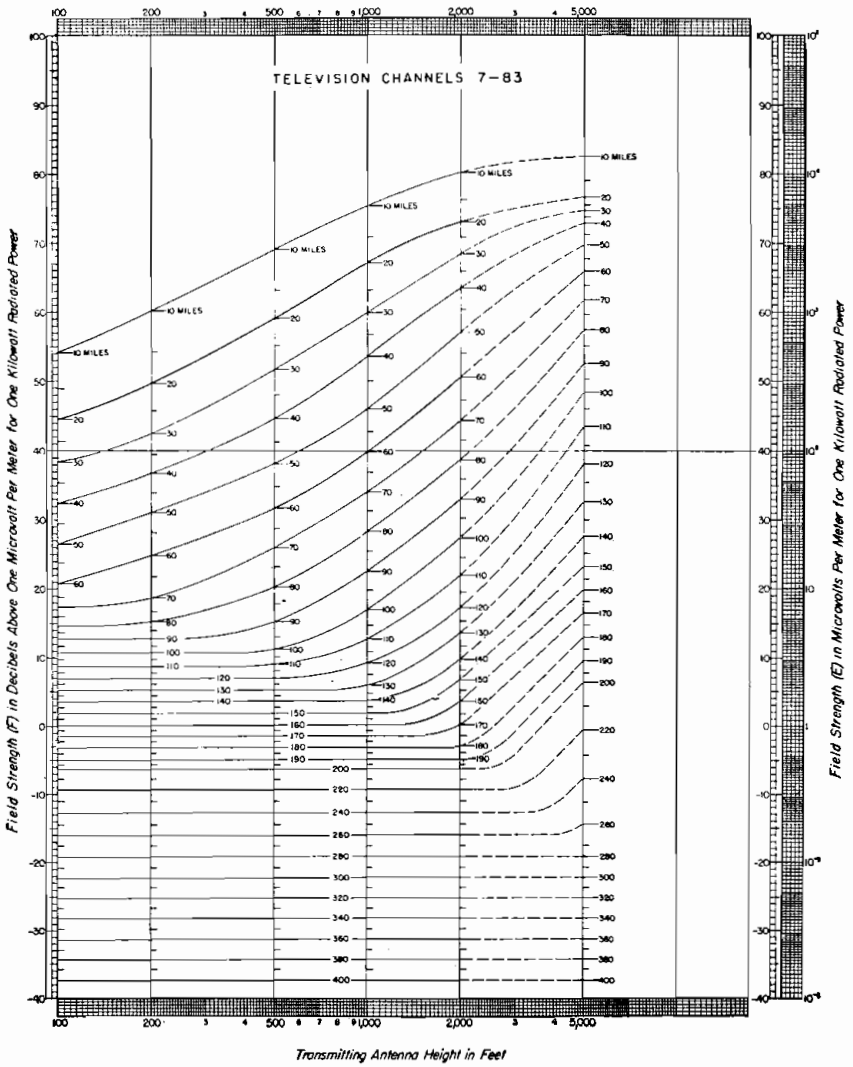


FIG. 1-22. $F(50,10)$ for television channels 7 to 83.

decibels relative to 1 kw (dbk) radiated from a half-wave dipole. $F(50,50)$ is the median value of field strength in dbμ for an effective radiated power of 0 dbk for the area in question, as taken from Fig. 1-19 or 1-20, for the appropriate frequency, distance, and transmitting antenna height.

Example: For a television station operating on Channel 2, with an effective radiated power of 100 kw (20 dbk) and an average transmitting antenna height of 500 ft for 2 to 10 miles along the radial, what percentage of locations in an area 20 miles from the transmitter may be expected to have field strengths exceeding 74 dbμ for at least 90 per cent of the time?

$$F'(L,90) = 74 \text{ db}\mu$$
$$P' = 20 \text{ dbk}$$
$$F(50,50) = 54 \text{ db}\mu \text{ (from Fig. 1-19)}$$
$$F(50,10) = 56 \text{ db}\mu \text{ (from Fig. 1-21)}$$
$$N'(T = 10) = 56 - 54 = 2 \text{ db [from Eq. (1-12}b\text{)]}$$
$$N'(T = 90) = \frac{2(-20)}{20} = -2 \text{ db [from Fig. 1-23 and Eq. (1-13)]}$$

Substituting in Eq. (1-14)

$$N'(L) = 74 - 20 - 54 - (-2) = +2$$
$$N(L) = \frac{N'(L)}{0.53} = 3.8$$
$$L = 41 \text{ per cent (from Fig. 1-23)}$$

Several points at various distances along each radial can be calculated in the above manner and the distance at which desired percentages of locations, or desired probabilities, such as 50, 70, 90 per cent, etc., occur may be determined by interpolation. Iso-service contours may be drawn by connecting the points having the same probability on each of the several radials.

Some analyses have been made of this problem using different characteristic slopes for values of T above and below 50 per cent. Since values of T between 10 and 90 per cent are usually of principal interest for broadcast purposes, a closer fit to the curve T can be made by this method within the range of interest.

Prediction of Service in the Presence of Interference from One Undesired Station [19]

The percentage of receiving locations, or the probability in per cent L, at any given distance from a desired station and one undesired station (for which an acceptable ratio

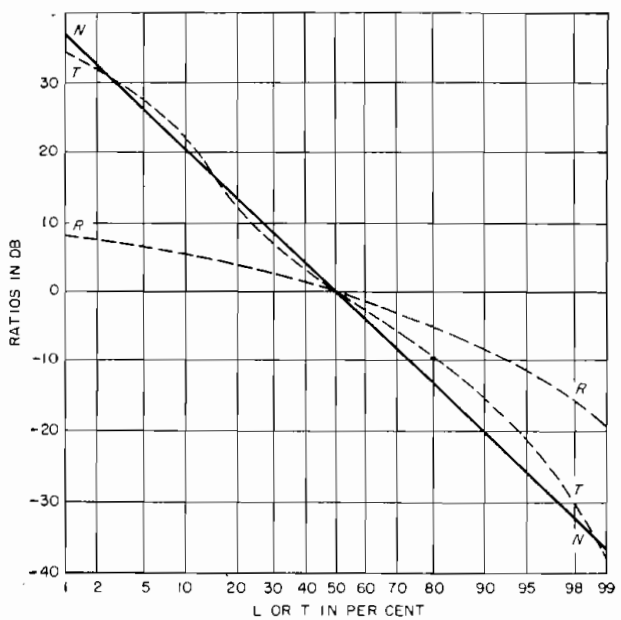


Fig. 1-23. Time and location distributions.

A, in decibels, of desired-to-undesired signals is exceeded for at least T per cent of the time at the receiver input) can be determined from the following equation

$$n'(L) = A + P_u' - P_d' + g_{ru} - g_{rd} + F_u(50,50) - F_d(50,50) + \sqrt{N_d'(T)^2 + N_u'(T)^2} \quad (1\text{-}15)$$

The subscript d denotes values applicable to the desired signal, and the subscript u denotes values applicable to the undesired signal. As above, the effective radiated powers of the desired and undesired station in P_d' and P_u' are expressed in decibels above 1 kw radiated from a half-wave dipole. g_{ru} and g_{rd} are, respectively, the gains of the receiving antenna in the directions of the undesired and the desired transmitters. $F_u(50,50)$ and $F_d(50,50)$ are the indicated field strengths from the undesired and desired transmitters taken from the appropriate curves of Fig. 1-19 or 1-20. $N_d'(T)$ and $N_u'(T)$ are the time-distribution factors for the desired and the undesired field strengths, respectively. The factors for 90 per cent of the time can be determined by subtracting the (50,10) field strength from the (50,50) field strength for each station at the proper distances on the appropriate curves of Figs. 1-19 to 1-22, in accordance with Eq. (1-12*b*). The factors for any other desired percentage of time may be found by the use of Eq. (1-13) and curve N of Fig. 1-23.

The answer for the factor $n'(L)$ is obtained in decibels. For Channels 2 through 13, $n'(L) = 0.75\ N(L)$ and the percentage of locations at which the ratio A is exceeded may be read from the probability distribution, $N(L)$, as a function of L in Fig. 1-23. For Channels 14 through 83, $n'(L) = 1.05N(L)$.

It will be seen from Eq. (1-15) that the time-distribution factor applicable to two fading signals combines as the square roots of the individual factors. When the fading of the undesired signal is three or more times the fading of the desired, the latter fading may be neglected with negligible error. Thus, the charts for the desired signal $F(50,50)$ and the tropospheric charts $F(50,10)$ for the undesired, with appropriate corrections for the effective radiated powers of the two stations and the directional patterns of the receiving antennas, can be used to determine directly the isoservice contours for 90 per cent of the time and 50 per cent of the locations.

The approximate method, in which the fading of the desired signal is neglected, can be expressed in the following formula:

$$n'(L) = A + P_u' - P_d' + g_{ru} - g_{rd} + F_u(50,10) - F_d(50,50) \quad (1\text{-}16)$$

This formula permits the approximate method to be applied to the case where it is desired to locate the contour at which an acceptable ratio is exceeded for a percentage of the locations other than 50 per cent.

Prediction of Service in the Presence of Interference from Several Sources

This problem was studied by the Ad Hoc Committee and four methods of calculating the combined effects of several interfering signals were reported in vol. 2 of the report of the Committee.[11] The methods involve somewhat different assumptions as to the subjective effects of interference and as to the time and space correlations of the various signals. Reference should be made to that report for details as to the assumptions made and the limitations involved in each method. The application of three of these methods is somewhat tedious, and since the results obtained by all four methods are reasonably consistent, just one relatively simple method will be described in detail.

This method involves the conclusion that the probability of a receiving location receiving satisfactory service for a particular percentage of time in the presence of a plurality of interfering signals is equal to the product of the probabilities that satisfactory service will be received for the same percentage of time in the presence of each of the interfering signals alone. Thus the values of $n'(L)$ for the desired signal and each of the interfering signals are computed individually from Eq. (1-15) or (1-16), and the resulting probability found by multiplying the individual values together. Take as an example the case of two interfering signals, the first of which yields a location probability of 0.90 (90 per cent of locations), and the second of which yields a location probability of 0.70, at a

given point. The probability of receiving satisfactory service of the same time availability at the same point is $0.90 \times 0.70 = 0.63$, or 63 per cent.

Distribution and Summation of Service

The method of describing service areas by isoservice contours, while relatively simple and useful for some purposes, is in fact a rather incomplete method which may lead to erroneous conclusions unless applied with understanding. Contours are frequently used to describe the outer limits of recognized grades of service for administrative purposes. The treatment of an isoservice contour as a limit of service, rather than as a contour of equal service availability, leads to errors in estimating service availability as well as the number of people who are expected to receive service. The foregoing analysis shows that in any small area only a percentage of the residents is expected to have service of a given quality available, so that this percentage of the population, rather than the total population of the area, should be included in a population count. Also, the percentage varies from area to area within the contour, increasing generally with decreasing distance from the desired transmitter, so that to obtain a fairly reliable count, variable percentages should be used for different areas.

As the distance from the desired transmitter increases, the quality of service does not change abruptly as might be inferred from the drawing of service contours but shades gradually from service of generally high quality to service of low quality. Thus it is proper to represent the expected quality of service as a continuous function of distance. Figure 1-24 shows the percentages of locations at various radii from a television station, at 63 Mc, with 100 kw ($P' = 20$ dbk) radiated from a 500-ft antenna, which would be expected to receive service for at least 90 per cent of the time in the presence of receiver and cosmic noise only. In Fig. 1-25 the percentages of locations in each annular ring at the radius r from the transmitter have been multiplied by the area of the ring, to produce service distributions in terms of integrated service area Y, as a function of distance from the transmitter. The thickness of each ring has been taken as $\frac{1}{2}\pi$ so that the ring area is equal to the radius in each case. The curve labeled $P' = 20$ dbk corresponds to the conditions of Fig. 1-24. Curves for powers of $P' = 0$ dbk, $P' = 10$ dbk, and $P' = 30$ dbk are also shown to illustrate how the service varies with changes in the effective radiated power. In order to estimate the equivalent service area provided by the station, the area under the curve is integrated by the use of a planimeter or in accordance with the formula

$$\text{Service area} = 2\pi \int_0^\infty Yr\, dr$$

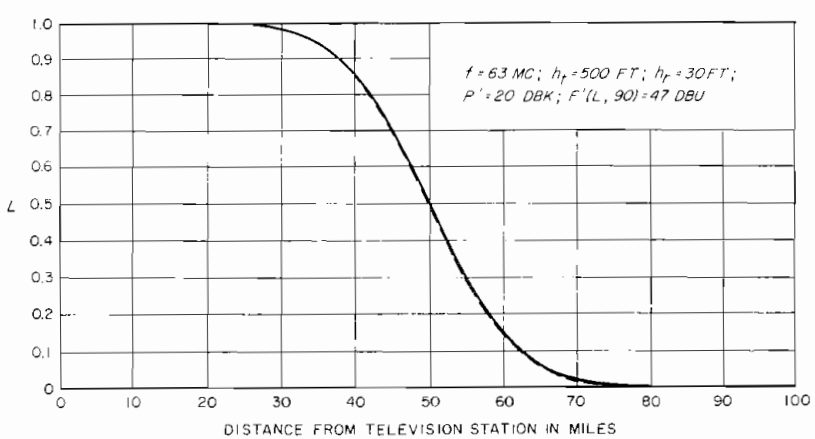


FIG. 1-24. Distribution of noise-limited-service probability.

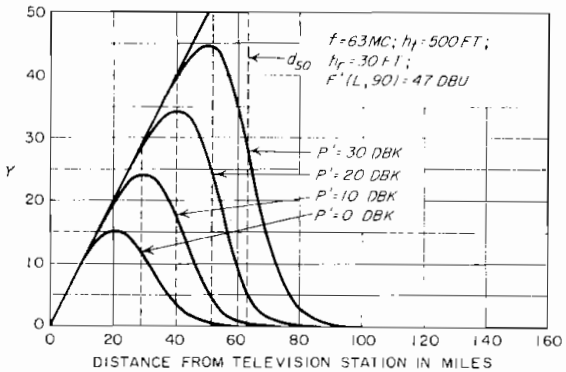


FIG. 1-25. Distribution of noise-limited service.

As an additional step, the integrated service area may be represented graphically by a circle of equivalent radius. These radii are indicated for each power on Fig. 1-25 by the dashed lines labeled d_{50}.

A similar approach can be used for cases in which it is desired to estimate the resulting service areas in the presence of interference from other television stations and other sources. Needless to say, the procedure becomes exceedingly complex in particular cases where there is a lack of symmetry between the sources of interference and the various radials along which service is to be estimated. In addition, as stated above, the available propagation data are subject to large probable errors when used to estimate service for any particular station. For these reasons, application of the procedures has so far been limited to broad studies of channel utilization, which are useful in developing station assignment plans and rules.

As illustrative of the methods of estimating service in the presence of several sources of interference, assume a case in which co-channel and adjacent-channel stations are assigned in a saturated triangular lattice, as shown in the inset of Fig. 1-26. The proba-

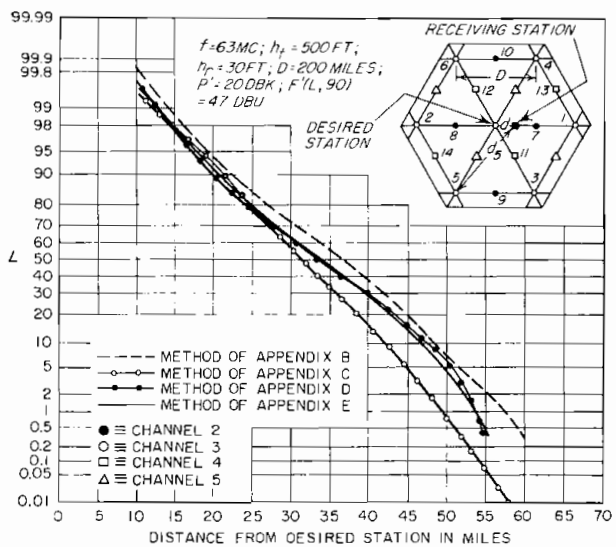


FIG. 1-26. Distribution of service probability limited by interference.

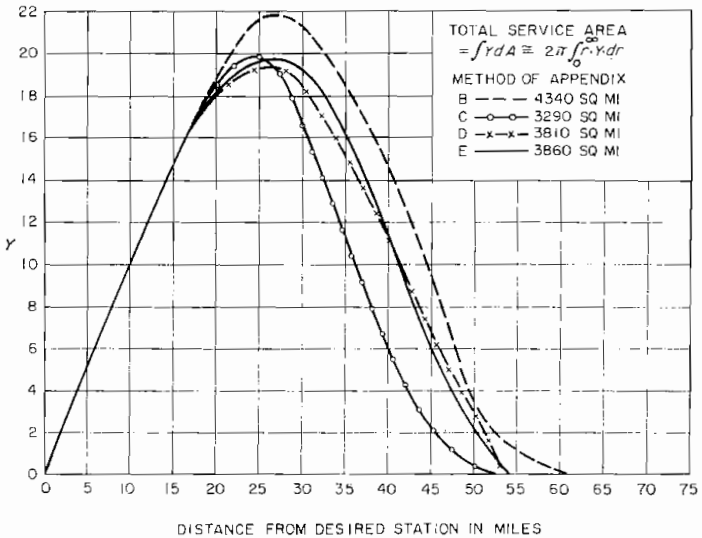


FIG. 1-27. Distribution of service limited by interference.

bility of receiving service of a given quality for a specified percentage of time from the desired station in the presence of the several sources of interference can be calculated for particular receiving locations along a radial in accordance with the four methods. The resulting distributions are shown in Fig. 1-26. Figure 1-27 shows the corresponding area probability and total areas for the four methods. It can be seen that the simple method described in Appendix C of vol. 2 of the Ad Hoc Report, and described previously herein, yields smaller estimates of service than do the other three methods.

Using this concept of total area it is possible to estimate the probable efficiency of utilization of the available television channels for various combinations of station power, antenna heights, and station spacings. While it is known that as a practical matter the station assignment pattern will follow the pattern of cities rather than the idealized and somewhat more efficient lattice, from the standpoint of area coverage, useful conclusions as to station-spacing requirements have been drawn from such studies.[19]

SELECTION OF STATION SITES

The sites for the antennas of permanent relay stations and for television broadcast stations should be selected carefully, as the success of the operation depends to a great extent upon the care and foresight used in selecting the sites. In previous sections, quantitative information has been given which will assist in estimating the transmission loss incurred over television relay links under specified conditions and in estimating the probable service obtained from a television broadcast station. The purpose of this section is to give a few guides which engineers have found to be of assistance in selecting sites which will yield optimum results for the area in question.

Selection of Sites for Radio Relay Stations

A large amount of preliminary work is necessary in laying out a radio relay system. For microwave systems it is usual that adjacent sites have a clear line-of-sight path between their antennas. To determine station locations, the best available topographical maps should be used. These, however, usually will not be adequate for final station location, particularly since for some areas no maps are available and for others existing

maps may be found to be inaccurate. In some cases, aerial surveys have been used. Before finally selecting a site, radio transmission tests should be made with the adjacent sites. For these tests, portable towers with parabolic antennas and transmitters mounted on carriages which can be moved up and down the towers are used.

If the intervening terrain is rough and the intermediate clearances satisfactory, no large change in received signal will be found as the antennas are raised and lowered on the towers, until the antennas are lowered so far that clearance of the first Fresnel zone no longer exists.

In some cases, however, substantial earth reflection may be encountered, and this will be evidenced by substantial variations in received signal strength as the antennas travel up and down. It is desirable that transmission be largely confined to a single ray arriving from the distant station. If one or more additional rays are present, owing to reflection from the earth at some intervening point or points, the resultant signal will be that due to the combination of rays and will depend on their relative phase relations. Sites showing such earth reflection are not desirable, as substantial amounts of fading may be expected at times when changes in the atmosphere cause the amount of bending of the waves to change with consequent changes in phase relation of the arriving rays. If such variations are observed in these path tests, the intervening terrain should be inspected with a view to determining whether by moving one or both sites a short distance the reflecting earth surface can be avoided.

It is usually difficult to recognize the areas which are responsible for earth reflection, but a few guides can be given to assist in inspection at the site. If the suspected area is fairly flat, areas of a size equivalent to an ellipse capable of reflecting the wavefront over the first Fresnel zone should be inspected. Smaller areas are capable of supporting a reflection, but in general the strength of the reflected component will be decreased. When the intervening area is rolling or irregular, the determination of the location and size of the responsible area is still more difficult. It will also be necessary to decide whether the surface roughness is too great to support reflection at the frequency of interest. For this purpose, Rayleigh's criterion of roughness is used. The surface is considered to be smooth if $h \sin \theta < \lambda/8$, where h is the average height of the features of roughness, θ is the angle of incidence of the wave to the reflecting surface, and λ is the wavelength expressed in the same units as h.

In one case where transmission was to take place over extensive salt flats which are smooth and of high conductivity, it was not possible to avoid earth reflection by any reasonable change in the station locations. The fading due to such reflection was minimized in this case by employing very low antennas at one end of the section and high mountain-top antennas at the adjacent station. With this arrangement, the earth-reflection point was close to one of the stations thereby minimizing the change in phase relations between the direct and reflected rays during periods of varying transmission conditions.[17]

Selection of Sites for Television Broadcast Stations

Sites for the antennas of television broadcast stations should be so chosen that at least first Fresnel-zone clearance is obtained over all near obstructions in the directions of the areas to be served. Thus hills with gentle slopes or with foothills which prevent such clearance should be avoided. Not only will the field strengths be reduced in the shadows of foothills and along the slope of the hill, owing to the low height of the antenna above the effective plane of reflection, but also nonuniform fields and ghosts may occur in distant areas which are within the line of sight of the transmitting antenna. Similarly, sites in the midst of tall buildings should be avoided unless the antenna can be placed well above them.

If relief maps of the proposed site are available or can be made, small grain-of-wheat lamps placed at the antenna location will assist in locating shadowed areas. Both theory and experience indicate that the radio shadows are of lesser length than the optical shadows.[37]

Profiles, taken from topographic maps, should be drawn for at least eight radials from the antenna site, and for any additional radials which from inspection appear to present

particular problems, in the manner shown in Fig. 1-11. Estimates of the areas of service should be made, both by the methods provided by the Rules of the FCC.[40]

In doubtful areas, actual measurements should be made over these radials, either from existing transmitters at or near the chosen site which have frequencies near the chosen frequency or from test transmitters installed for the purpose. If test transmitters are pulsed and mobile measurements are to be made, the pulse repetition rate should be sufficiently rapid so that the peak detector of the field-strength meter can distinguish between the pulse peaks and the peaks caused by standing-wave patterns through which the meter will pass. Otherwise the meter will indicate the peaks of such standing-wave patterns rather than the desired average value which is indicative of the strength of the incident fields.

There is as yet no unanimity among engineers as to the preferred method of making field-strength surveys for television broadcast stations. Because of the relative ease and dispatch with which the area may be covered, some prefer the taking of mobile measurements with a simple nondirectional antenna mounted on the vehicle at about 10 ft above ground. Because of the difficulty of estimating height gain and antenna gain of the typical receiving antenna in a typical location as compared with the simple mobile measuring antenna under the nonideal conditions to be found in all service areas, many engineers prefer to obtain relatively fewer measurements under conditions which they consider to be more nearly typical for broadcast receiving installations. For this purpose a collapsible mast carrying a typical antenna is mounted on a vehicle and measurements are made at various accessible locations along each of the radials. Several techniques have been employed with this type of measuring equipment: (1) maintaining the antenna at a fixed height during a short run,[37] (2) clusters of spot-sampling measurements with the antenna at a fixed height,[38] or (3) moving the antenna vertically at a fixed location.[39] All three techniques have specific advantages and disadvantages. Spot sampling, which is most nearly analogous to the typical receiver situation, also presents the most difficulty in obtaining a significant sampling of the existing fields. All measurements should be made in accordance with the standards of the Institute of Radio Engineers.[41]

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Part 2

DESIGN, ERECTION, AND MAINTENANCE OF ANTENNA STRUCTURES

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INTRODUCTION

This is not intended to be a treatise on tower design. The object of this discussion is to give the average broadcaster, owner, manager, or engineer a practical understanding of tower structures. General problems concerning tall structures are discussed in order to aid the broadcast people who are responsible for buying and maintaining towers. Electrical problems will not be discussed.

TOWER COST

The approximate cost of a tower installation is of prime importance for planning purposes. The accompanying curves show approximate costs of typical installations. These curves are intended to show the scale or range of dollars involved. The cheapest tower structure is the simplest one, such as an AM tower. This tower merely holds itself up, with a set of lights. Obviously, anything you add to the tower such as coaxial lines, signs, and so on, will increase the wind load, which in turn increases the weight and cost. It is impossible to show all the different conditions which arise. For example, only a few of the items which will increase cost are:

Winter erection
Inaccessible sites
Foundations in swamps, rock, sand, tide water, or any water
Heavier wind-design load
Top hats
Special insulators
Electric signs
Large high-gain antennas
Large amount of coaxial
Elevators
Multiple antennas

Towers over 1,000 ft usually involve special engineering for the particular conditions required. Hence, the cost of towers over 1,000 ft is very approximate. People often inquire about the tallest tower which can be built. At the present time, there

is no particular engineering reason why towers can not be built up to 3,000 or 4,000 ft with present-day materials and equipment.

Self-supporting Towers vs. Guyed Towers

The obvious advantage of a self-supporting tower is that it requires less ground area at the base of the tower. This often is necessitated because of crowded conditions, such as putting up a tower in the center of a city block, on a roof top, or on a small mountain top. The area required for a typical self-supporting tower will be roughly a square or a triangle somewhere between 7½ and 20 per cent of the over-all height of the structure, depending on the designer. AM towers tend to be a little more slender than the TV towers. The disadvantage of a self-supporting tower is that, as a general rule, it is more expensive. An additional disadvantage of a self-supporting tower is that the designer does not usually investigate whip or inertia forces. These whip forces tend to be larger in a tall, slender self-supporting tower with a heavy weight on top (such as an antenna) than in a guyed tower.

The obvious advantage of a guyed tower is its cheaper (installed) cost. Most guyed towers today are built with a uniform cross section and, in many instances, a constant weight in cross section. This makes for cheaper fabricating and easier and cheaper stacking during erection. A guyed tower is lighter than a self-supporting tower. The guys, in effect, form a very large base. A guyed tower having less steel

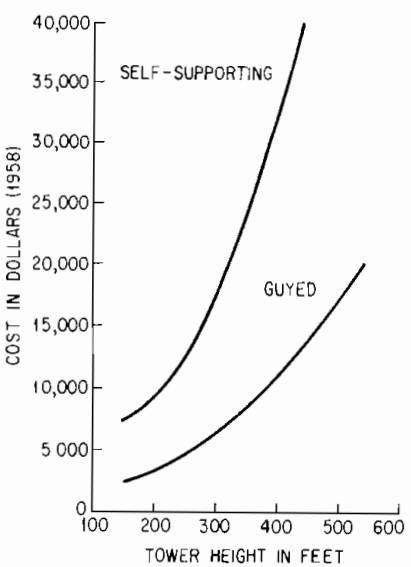


FIG. 2-1. Approximate installed cost of 30-lb insulated AM towers. Cost includes tower, foundations, FAA lights, and erection.

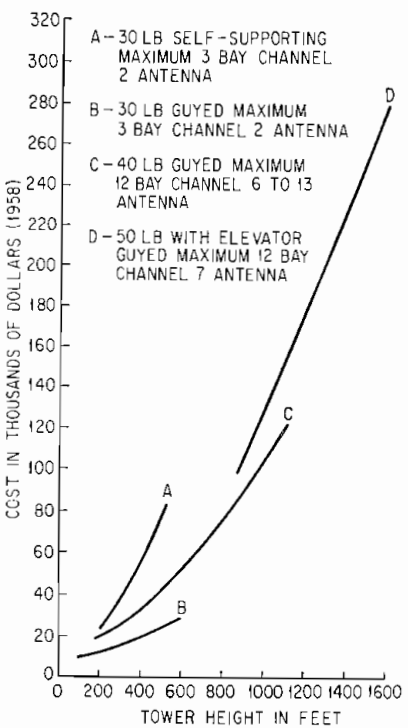


FIG. 2-2. Approximate installed cost of TV towers. Cost includes tower, foundation, erection, FAA lights, erection of coaxial and antenna.

is usually cheaper to paint and to maintain, since it has fewer members and the members are easier to reach on the way up and down the tower.

The area required for a guyed tower varies with the designer. Current practice is to place the guy anchors out from the base pier a distance equal to 50 to 100 per cent of tower height. The tower designer knows that as he pulls in his guy anchor distance, he increases the down load on the tower and so runs up the size of guys and the size of vertical members. This tends to run up the cost of the tower.

It is not always necessary to buy all the land enclosed by the outline connecting the anchors. Many towers have guys crossing a public road. There are many tower installations where it was necessary to buy or long-lease a small plot at each guy anchor and at the base of the tower.

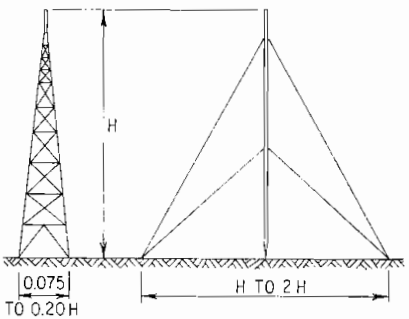


FIG. 2-3. Relative space requirements for self-supporting and guyed towers.

Tower Material

Most towers today are built from steel for the simple reason that steel is more economical than any other material available at the present time. It is possible to build towers from wood, any number of aluminum alloys, and a number of other materials. Wood is usually uneconomical over 80 or 90 ft, and the broadcast range begins at 150 ft. Aluminum alloys tend to give a lighter but a more expensive tower. The broadcaster usually is more interested in the cost than the weight of the tower. There may be a day when the basic cost of some of these aluminum alloys will come down and steel will go up, so that it may be economical to use these aluminum alloys.

Probably the most commonly used steel is structural carbon steel which comes under ASTM A-7 specifications. The yield of this material is 33,000 psi. It has good elongation and very good working and welding properties. Its base price is relatively cheap.

Pipe is used by some manufacturers. Pipe comes under ASTM A-120. This pipe has a yield of 25,000 to 35,000 psi, depending upon the grade. Pipe is fairly easy to work as a rule and is suitable for welding. Its popularity is due to the fact that it has a low base price. The disadvantage is it comes only in certain specific sizes.

Mechanical steel tubing, both welded and seamless is used in various grades and alloys to meet specific requirements. Exacting properties such as tensile strength, ductility, and weldability can be produced. A big advantage of tubing is that both the outside dimensions and the wall thickness can be varied at will by the buyer. The disadvantage of tubing is its relatively high base price.

Some designers of the taller towers like to use one of the so-called low alloys. There are a number of these alloys on the market in a number of forms. The most popular form is the solid round bar, although tubes are available as well. The advantage of these low alloys is an approximate 50,000-psi minimum yield strength. These alloys have good working and welding properties, and they seem to have a somewhat higher corrosion resistance than mild steel. The advantage of these materials is that they save wind load and weight of structure. One of these new alloys is T-1, a 90,000-psi-yield steel. The virtue of this material is its high yield and its low carbon content, making it weldable in the shop with no heat treating after welding being required by the fabricator. The base price of this material is several times that of structural steel, and it has proved economical to date only on tall towers. T-1 does not lend itself to galvanizing.

There have been some towers using high carbon strip rolled into Vs. Towers using this material very seldom have welding connections because of the previously mentioned difficulty encountered in welding.

High yields up to 110,000 psi are obtainable from stainless steel in the 17-7 or 18-8 varieties which have good working and welding properties. Although an excellent material, its high cost prohibits its use in commercial tower construction at the present time. It has been used by the U.S. Navy for masts on seagoing ships.

Commercial machine parts usually get high strength by heat-treating higher carbon steel. The higher carbon steel is more difficult to weld. Also, heat treating large, bulky tower columns is uneconomical. For this reason, high-carbon heat-treated steel is very rarely used in tower work.

SHAPE OF MATERIAL

There is no particular magic in any one structural shape. All shapes have their advantages and their disadvantages. The different tower designers have different shape preferences. Different tower manufacturers have different shape-fabricating facilities. It might be interesting to review some of the more commonly used steel shapes.

Steel Angle

The most easily available shape and the one used in great amounts is the structural steel angle. The advantages of a steel angle are its universal availability, low initial cost, ease in fabricating, ease in shipping, ease of galvanizing, and ease of assembly. Because these structural angles make 90° angles, most towers which use angles are four sided. Three-sided towers using angles are possible. The largest single disadvantage of a structural angle shape is that the angle runs up the wind load and, consequently, the weight of the tower, particularly as the height of the tower increases. Almost all towers were made of angles, at one time, when the heights were low. Today most tall towers make use of cylindrical shapes.

A much-used shape is a steel strip which is rolled into a V or some shape approximating a V. The main advantage of a rolled strip is that it is possible to form an approximate 60° angle. This makes it relatively simple to fabricate a triangular cross-sectional tower. The advantages and disadvantages of formed strips are about the same as those of structural angles.

Cylindrical

A solid round steel bar has become popular, particularly in the taller towers. The advantage of a solid bar is that it has low wind resistance for a given cross-sectional area. Its base price is also relatively inexpensive. The solid bar tower tends to run the tower weight up if the designer is not careful.

The advantage of a tube to a tower designer is that it has a circular shape which keeps the wind load down and it gives the tower designer the most efficient material distribution to carry a column load. Tubular towers are usually more efficient and lighter, have fewer parts, and are cleaner looking than those of other shapes. The greatest disadvantage of a tube is its relatively high initial base price for the material.

To sum up shapes, it must be borne in mind there is no particular magic in any of the shapes used. It always amazes people to see different companies using different designs, different types of facilities, and different shapes and coming out with approximately the same tower cost.

TOWER ASSEMBLY

The three principal methods of putting a tower together in the field are bolting, riveting, and welding. The latter two methods are seldom used. Since bolts are used almost universally in tower erection, a discussion of the various types of bolts and bolting practices is in order.

We may also note at this time the advantage of the prefabricated tower section where most of the assembly work is done in the shop. The expensive erection bolting is then kept to a minimum with a resultant saving in time and cost.

Bolts

The most commonly used bolt is the square-head machine bolt and nut. Hex-head bolts and nuts are available at slight extra cost.

High-strength bolts are becoming more popular with the tower designer. They allow the designer to use a smaller and hence a lighter bolt with the same strength for the same load. The high-strength bolt incurs additional advantages by allowing the designer to cut down the size of the connecting parts. A high-strength bolt, properly tightened, is self-locking and requires no additional locking nut or device.

The properly tightened high-strength bolt exerts a high clamping force, thereby creating a stiffer connection. It is desirable that the high-strength bolts be tightened to at least the minimum tension specified by the manufacturer. The following are the most commonly used methods for torquing high-strength bolts.

1. Torque wrench. An indicator which registers torque is a component part of this wrench.
2. Pneumatic impact wrench. Air pressure is controlled so that the wrench stalls at desired torque.
3. Pneumatic impact wrench with internal automatic cutoff which shuts off air supply when proper torque is reached.
4. The nut is turned to an initial tightness. Then the nut is given prescribed amount of visual turn with the wrench.

Ribbed or Dardelet bolts are sometimes used. These bolts have ribs along the body of the bolt. These ribs dig into the bolted material, providing the holes are undersize. If properly used, they make a rigid connection. They are not popular with erectors because of the extra work involved in driving the bolts into undersized holes. Their effectiveness is lost if holes are not undersized. These bolts require locking devices.

It is mandatory that all bolts and nuts be drawn tight. All nuts (except on high-strength bolts) should be locked in some manner to prevent them from working loose. This can be accomplished in many ways. A simple way is to stake the nuts by upsetting the thread on the bolt after bolt is on. A great variety of patented lock nuts, washers, and devices are available. They all seem to be fairly effective providing they are put on and put on tightly.

Number of Faces on a Tower

The number of faces a tower has is usually dictated by the economy of fabrication and erection. The simplest tower is one which has a circular cross section, which, in effect, has no face at all. Wooden poles would make such a tower, and tall radio towers have been designed out of large-diameter steel or aluminum tubes. An extreme case of the number of faces on a tower would be a tower made up of eight, ten, or even twelve faces. There is no reason why good towers with that number of faces could not be built, and they sometimes are. It should be pointed out that a poorly designed tower is a poorly designed tower and a well-designed tower is a well-designed tower irrespective of the number of faces the tower has. At the present time, most towers are built using either a triangular or a rectangular cross section.

Preassembly by Welding

Some towers are preassembled by welding in the shop. These prefabricated sections may be anywhere from 5 to 30 ft in length. The length of the section preassembled in the shop is dictated usually by handling, shipping, and erection facilities. The advantage of prefabrication is that it takes some work from the erector in the field and puts it into a better equipped and organized shop. These preassembled sections may be made from material of any shape. The welding gives a stiffer, lighter, and cleaner subassembly as a general rule.

Erectors like prefabricated sections because they save money by merely stacking sections, having fewer bolts to contend with, and fewer joints to check. The biggest

disadvantage of the prefabricated tower is its bulk and resultant increased freight cost. For this reason, prefabricated sections are used in shorter towers. For example, shipping a 1,000-ft tower in sections 1,000 miles would incur a total freight bill far in exeess of the savings in erection. It is not correct to state that a prefabricated or preassembled tower is better than a knocked-down one, or vice versa. Total cost is the measure.

TOWER CONFIGURATION

The Uniform-cross-section Radiator

Most people are under the erroneous impression that the uniform cross section in radio towers was dictated by the radiation properties of an AM tower. It is true that the radiator of uniform cross section from top to bottom has radiating properties which an electrical engineer says are easier to predict. But note that self-supporting towers are tapered, although it is possible to build them with a uniform cross section. The electrical engineer simply has to contend with the radiating properties of a tapered structure.

Tapered guyed towers and nontapered self-supporting towers are built but not as a general rule. Most guyed towers are built with constant cross section and most self-supporting towers are tapered because of one simple reason—it is cheaper to build them that way.

Straight Base vs. Pivot on a Guyed Tower

A guyed tower may be designed to come straight down at the base pier or to a pivot. Either method is satisfactory providing the conditions encountered are properly engineered. The advantage of a pivot base is that the pivot relieves a large bending moment at the pivot. In Fig. 2-4 this is graphically illustrated by comparing the moment curves of the two types of towers. The pivot saves steel and takes bending off the base insulator, if there is an insulator. The load on a pier is pure down load and the pier is a bit easier to design. The advantage of a straight fixed base is ease in fabrication. The erector can start erecting without using temporary guys. However, the bending moment tends to increase weight, the size of insulators (if any), and the size of the base pier. Also, the pier top must be perfectly level to distribute the load evenly from each tower leg.

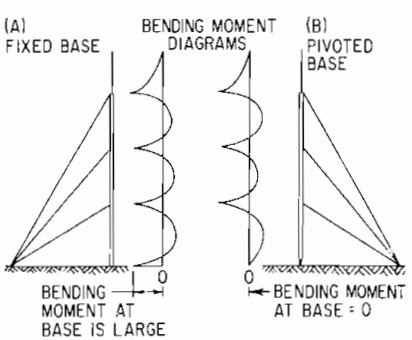


FIG. 2-4. Effect of a fixed base on a guyed tower.

Tower Weight

The weight of a tower is quite important. The weight comes into the calculations of the strength of the tower in a very simple manner. The heavier the tower, the greater is the total down load; consequently, more steel is needed and the sizes of the base insulator and base pier go up. In the 200-ft AM guyed tower range, the weight is relatively a small percentage of the total design load, usually somewhere between 10 and 20 per cent. This percentage increases with the height of the tower. In the 1,000-ft tower range, the weight becomes an appreciable item. Skillful designers of steel towers recognize this fact and make some effort to keep down the dead weight. It is possible to have two towers equally strong and yet with entirely different weights. For example, as a general rule a four-sided tower made up of structural angles will weigh more than a triangular tower using round members and yet the design strength will be about the same in either case. The statement that tower *A* is stronger than tower *B* because it is

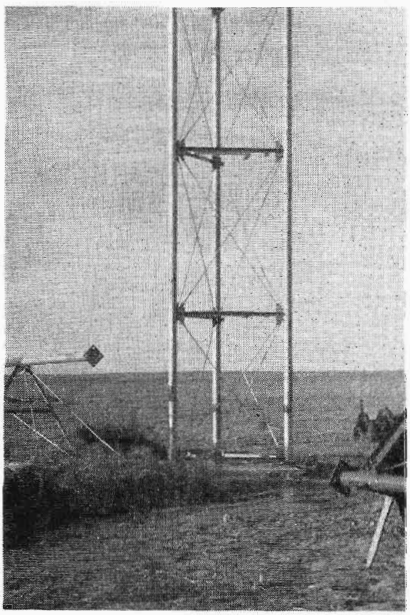


FIG. 2-5. Photograph showing fixed-base tower.

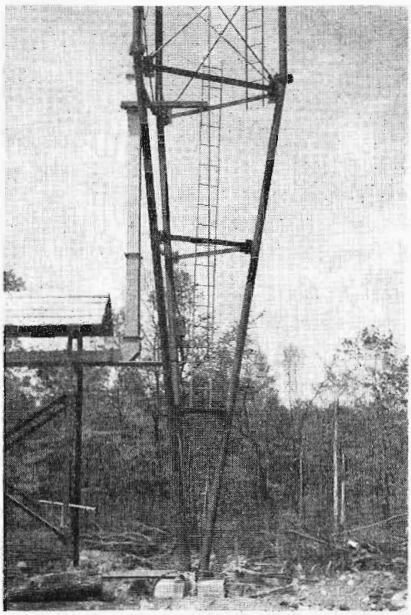


FIG. 2-6. Photograph showing tapered-base-type tower.

heavier or vice versa is simply not true if both towers are designed to the same specifications.

A heavier tower will generally tend to have larger inertia or whip forces than a lighter tower. Usually these forces are not serious, but they may well be. For example, in a tall, self-supporting tower with a slender ratio and with a heavy antenna on top, whip forces are appreciable.

There is one practical minimum limit to the weight of a tower. The size of the members should not be so small that they are susceptible to damage in transit, during erection, or during maintenance climbing operations later on. Tower members should be rugged enough so that they can be handled as structures and not as fragile china. The average erector with heavy boots should be able to climb the tower without rolling over edges, bending thin members, or kinking small rods. Most towers used in the broadcast range today have members which are sturdy enough for ordinary usage.

Rigid-frame Trusses

Towers are designed as trusses, either the conventional type X or diagonal bracing or the rigid-frame type. The joints of a rigid-frame type of truss are moment-resisting and are usually welded. Conventional-type trusses are usually bolted at joints, and the joints are considered to be hinged. In rigid-frame trusses, the members have bending stresses as well as axial stresses. Standard methods of analysis can be used for determining the stresses. Rigid-frame trusses tend to be very clean aerodynamically and offer a minimum re-

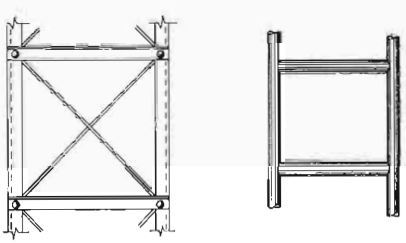


FIG. 2-7. Conventional X-type and rigid-frame bracing.

sistance to wind. They have also proved themselves quite economical for towers, particularly in the short heights.

TOWER ATTACHMENTS

Antenna

The prime purpose of a TV tower is to support the TV antenna and its feed system. The attachment of the antenna to the tower is a problem, especially when the antenna is large.

Antennas have been mounted on towers in three different methods. One method is to side-mount the antenna onto the tower. In general, when this method is used, the radiating elements are clamped onto the vertical tower members. This method of mounting the antenna has the advantage that the loads caused by the antenna are kept to a minimum and also the antenna loads can be distributed over the tower easily.

A second method of mounting an antenna on a tower is with the telescoping-pole type of mount. The pole telescopes down the center of the tower, the distance depending upon the size of the antenna. At the top of the tower, the pole has some sort of adjustable guide so that it can be plumbed. The bottom of the pole fits into the pole socket. Usually the pole socket is a fixed position and is not adjustable.

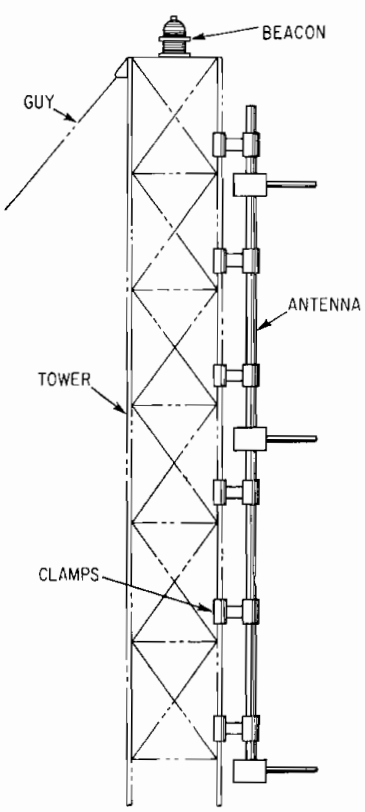


Fig. 2-8. Side antenna attachment.

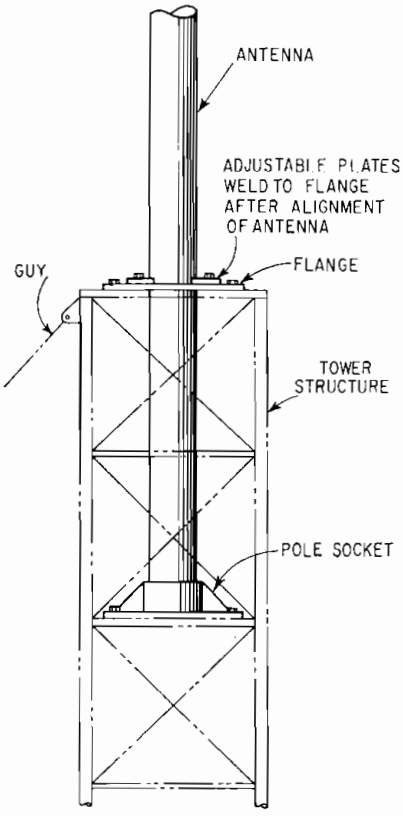


Fig. 2-9. Telescopic antenna mast attachment.

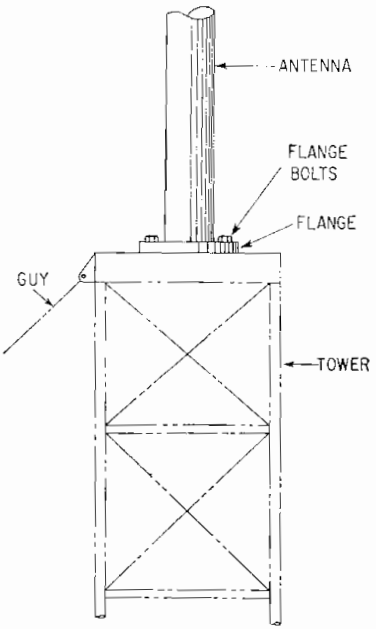


FIG. 2-10. Flange antenna attachment.

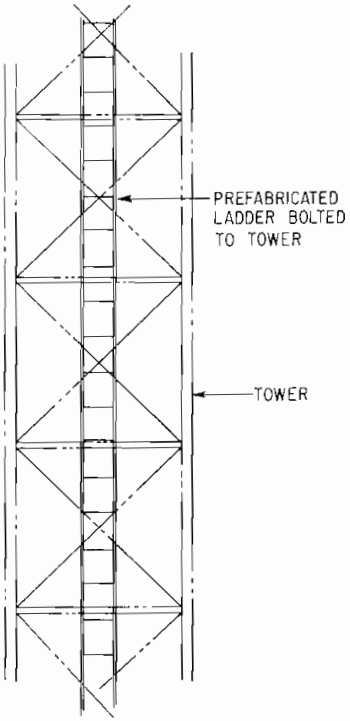


FIG. 2-11. Ladder mounted on tower face.

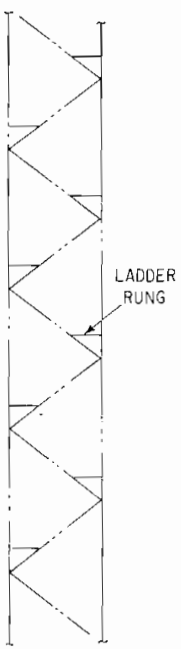


FIG. 2-12. Ladder steps welded to tower structure.

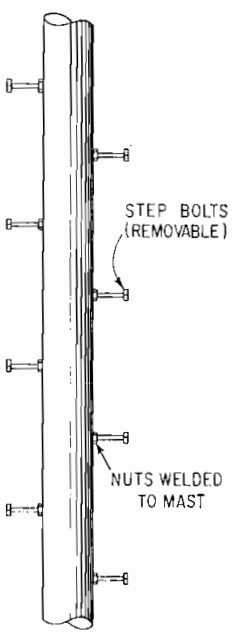


FIG. 2-13. Step bolts on cylindrical mount.

The third common type of antenna mount is the flange mount. A flange-type antenna mount suddenly dumps a large overturning moment into the tower. If the moment is large relative to the capacity of the tower as with some TV antennas, the problem can become quite nasty structurally.

Usually it is necessary to install the antenna in a vertical position. The top of the tower or the leveling plates as furnished by some manufacturers should be checked to make sure they are level before actual installation of the antenna.

Climbing Facilities

A tower must have some climbing facilities in order to maintain it and its equipment. Sometimes short towers have the tower members themselves arranged in such a manner that they act as step bars. Various climbing facilities are illustrated in Figs. 2-11, 2-12, and 2-13. When towers are short, step bolts similar to the ones seen on

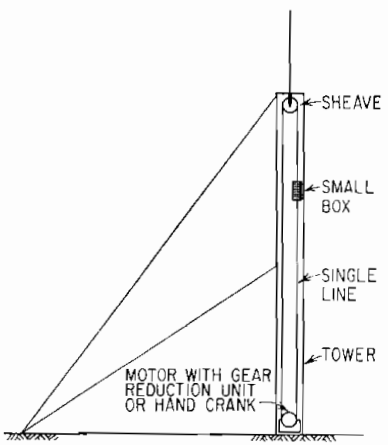


FIG. 2-14. Dumb-waiter type of lift.

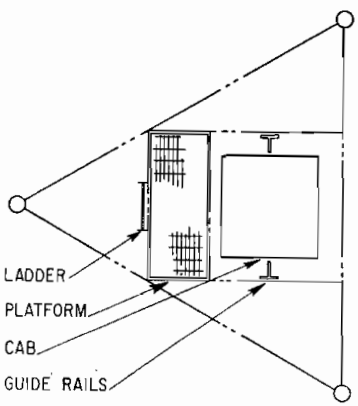


FIG. 2-15. Typical section through elevator.

telephone poles are occasionally used. As the tower height increases, these step bolts do not give a feeling of security to the person climbing. As a general rule, ladders are provided on tall towers. Erectors themselves usually prefer a ladder on the face of the tower, since the erector likes to climb on the outside of the tower where he has fewer encumbrances. Most engineers and station people, however, who climb the tower occasionally to check antennas or lights feel safer if the ladder is within the confines of the tower cross section so that the outside of the tower forms, in effect, a natural safety cage. A safety cage is sometimes provided so that it is practically impossible to fall out. Usually, safety cages are not called for, since they add wind load to the tower and, consequently, increase the cost.

On taller towers, some form of hoist or elevator is occasionally used. The simplest arrangement, shown in Fig. 2-14 is, in effect, a form of dumb waiter.

Tower Elevators

It may take a man ¾ hr to climb the full length of a 1,000-ft tower. If there is any equipment to be lugged up, this adds quite a burden to the climber. For this reason, it is often desirable to install an elevator in towers over 1,000 ft.

The elevator adds to the wind and dead loads, and so, the tower has to be designed originally to carry the elevator. A well-designed elevator embodies the elements noted in Fig. 2-16. There are many variations of the details required.

An elevator suitable for use in a tower consists of a driving mechanism, car, guide rails, hoisting cables, counterweights, integral and auxiliary cab controls, and two-way communication system. The guide rails should be machined to provide a smooth, steady ride. The T shape is commonly used, but rounds are used to cut wind loads. The driving mechanism should be a traction type with a high starting torque and low starting current. Rope guards are necessary to prevent entanglement of the hoisting rope in the tower structure during severe wind storms.

Different people prefer cages of different sizes. The tower designer leans toward a small cage; the owner would rather have a large cage. Elevators have a relatively slow rate of climb, simply because it keeps the power requirements and the cost down. The commonly used rate of ascent for elevators today is 100 fpm. Elevators are available with electronic controls and two-way communication systems in cab and tower base so that the operator is able to stop the cage at any height.

Considerable attention is given to safety devices in the design of a tower elevator. For example, in case of hoisting-cable failure, spring-loaded cams automatically are brought into play to freeze the car against the guide rails. Limit switches stop the car motion past either the upper or lower landing platforms should the operator fail to do so. The brakes on the driving mechanism are spring applied, electrically released, and designed to be automatically applied in the event of interruption of power from any cause. A tension device is supplied, limited by moistureproof switches which will cut off power in the event of cable stretch or excessive cable motion. Finally an access ladder is supplied for the full height of the tower to be used as an emergency descent.

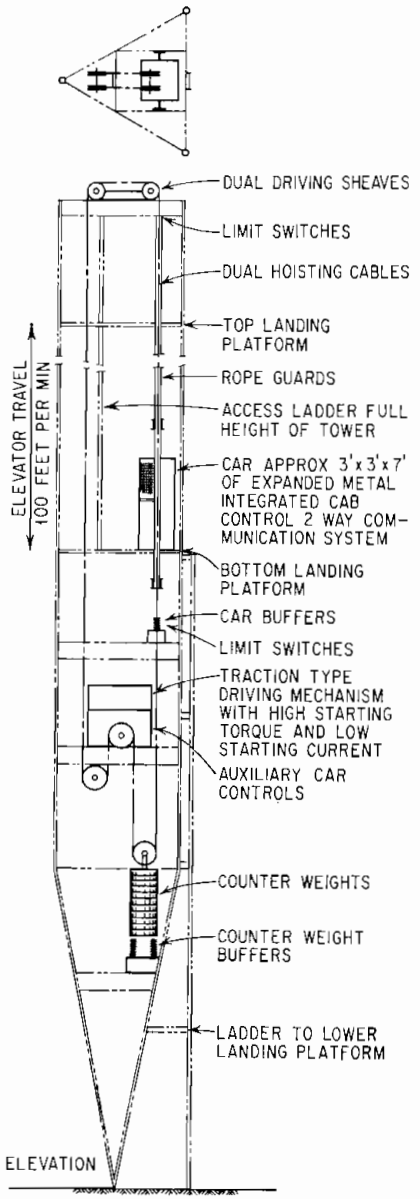


Fig. 2-16. Typical elevator installation.

TOWER PROTECTION

Galvanizing

Galvanizing is the process of coating metals, usually steel and iron, with zinc. One of the peculiarities of the zinc trade is that this coat is expressed in ounces of zinc for a square foot of surface. Most galvanizing is done via the "hot-dip" method. That is, steel is dunked into a zinc bath and then pulled out. The excess zinc drips off, and a certain thickness of zinc stays on the steel. If a thick coat is desired, the steel is dunked a second or even a third time. This is termed a double or triple hot dip. How does this zinc

help? Zinc is higher than steel in the electrochemical series. It means that the zinc tends to be eaten away over an area before the steel does, even if the zinc surface is scratched to expose bare steel. Corrosion of steel is delayed until the adjacent blob of zinc is depleted.

Obviously, the life of the coat depends on the thickness or weight of the zinc coating and the atmosphere. For years, the American Society of Testing Materials has been testing miscellaneous weights of zinc on steel structures in different parts of the country. There are available estimated life curves of zinc coats in various atmospheres, expressed in years vs. the coat thickness, in such locations as Pittsburgh, Pa.; Sandy Hook, N.J.; and Ames, Iowa.

Almost all guy strand and wire rope are zinc-coated for the simple reason that the individual wires making up the guy are small and usually run in diameter from 1/16 to 3/16 in., so that corrosion is a critical factor.

Since the zinc coat will impose an additional cost, should one galvanize? This will depend upon conditions. First of all, it is impossible for steel to corrode if the paint is properly kept up. However, there may be installations in certain highly corrosive atmospheres where maintaining the paint will present quite a problem. Those installations are not too frequent. If the broadcaster properly maintains his paint, then this should be adequate. On small, unattended towers where inspection may not be too regular, there is some merit in galvanizing. It is also possible in large, unusual towers where a special dispensation has been obtained to paint only a portion of the tower that it may be worth galvanizing only those portions of the tower which are never painted.

Tubular members, if galvanized, should be galvanized both inside and outside or else the drain holes should be plugged up. Care should be taken to seal the ends of tubes on tubular structures if they are not galvanized. Moisture or oxygen cannot get inside a properly sealed tubular member, and therefore there is no possibility of corrosion on the inside surface.

Painting

FCC Requirements

The Federal Communications Commission has prescribed a set of standards to provide an effective means of indicating the presence of obstructions to air commerce. Radio and TV towers, because of their height, are considered as possible obstructions to air navigation by the Federal Communications Commission and, therefore, must be marked and lighted accordingly.[1]

To comply with these regulations, the towers are painted in contrasting colors of white and international orange in alternate bands for maximum visibility during daylight hours. The exact spacing of these bands is spelled out on the face of the construction permit. The FCC also requires that towers be painted as often as necessary to maintain good visibility. Obviously the painting becomes quite a maintenance problem, and if it were not for this paint regulation, probably the cheapest finish would be a coat of zinc.

Surface Treatment

Paint will not stick to brand-new galvanized surfaces. The erector should treat the surfaces of the galvanized parts. Some fabricators give galvanized parts a special treatment prior to shipment so that the surface is prepared for painting. Any number of solutions have been made to etch this smooth zinc coat. The simplest and most commonly used treatment is plain vinegar or a weak acetic acid solution which is applied to the surfaces in the field prior to painting. A better solution is as follows:

2 oz copper chloride
2 oz copper nitrate
2 oz sal ammoniac

[1] Federal Communications Commissions Rules and Regulations, Part 17.

2 oz muriatic acid
1 gal water

Apply with rag or brush to the tower, and allow to dry for 10 hours before applying paint. Galvanizing will first turn black and then a dull gray. Such a treated galvanized surface requires no primer. Another way to treat galvanized sections is to let them weather a period of three months to a year depending on whether the tower is located in a dry or a salty and moist atmosphere.

Application

Paint usually consists of two coats. The outside coat is a hard enamel, either orange or white and sometimes black. The enamel has wearing qualities and is relatively tough. However, enamel does not stick very well to plain steel. For this reason, towers usually have a primer coat. The purpose of the primer coat is to effect a bond between the steel and enamel.

Primer will not stick to a surface which has scaled rust, mud, dirt, oil, or grease. For that reason, the surface has to be fairly clean. If the rust is scaly, it should be wire-brushed off. If the surface is dirty or oily, it should be wiped with a thinner, alcohol, gasoline, or any number of cleaners or detergents. There are many good primers—red lead, iron oxide, zinc cromate, and combinations thereof. The primer should be on the thin side, since a thick primer has a tendency to peel. The primer has no staying qualities; that is, it will not weather very long.

Tests show that international orange and white enamels from most reliable companies are good. The life of the orange and white paint depends upon the location. In the dry desert parts of the United States towers do not require repainting for 10-year stretches. Towers along the seacoast, which are constantly subjected to salt spray and sunshine, require a new coat of paint approximately once a year. There is no fixed rule in the length of the life of the outside coat.

Broadcasters should be cautioned about getting unusually cheap prices for painting or repainting a tower from unknown erectors who happen to be passing through town. These "fast prices" sometimes leave one with a tower where only the bottom 100 ft are painted beautifully and the rest of the tower is painted on the bottom surfaces only.

On paint maintenance contracts, broadcasters should make sure that the painter has public liability and property damage insurance coverage, since it is very difficult to keep the paint from flying, even in a very small wind. This is a very definite hazard, since neighboring buildings and cars are constantly being covered by flying paint.

TOWER GUYS

Steel Guy Material

Rope and Strand

Tower guys are usually made out of steel rope or steel strand. Both rope and strand are made up of high-strength steel wires. A number of wires spun as a single group is called a strand. A number of strands spun to form a group is called a rope.

The advantage of steel rope is that it is flexible. That is, it is capable of being run over sheaves or pulleys continuously. The disadvantage of rope is that it has a low modulus of elasticity (it is more stretchable than strand) and, as a general rule, it is more expensive than strand. Strand as a rule is preferred in towers because it has a high modulus of elasticity, does not stretch so much as wire rope, and is cheaper per foot for a given strength.

Catalogue value for strand modulus of elasticity is 24 million. This 24 million is a minimum figure. The 24-million figure is fairly consistent and constant. Coiling and uncoiling strand decrease this figure less than 1 per cent, but it comes back to the 24 million.

It is the considered opinion of most engineers that there is no such thing as a yield point for strand. The curve falls off gently to a breaking strength. The catalogue values of the ultimate strength or breaking strength of strands are always minimum. The range of breaking strength is usually 2 to 10 per cent above catalogue values.

Strand is made from high-carbon cold-worked wire. It is very rugged and very insensitive to notch defect. It will take quite a beating. A good approximation of estimating the percentage of reduction in strength of strand is to note how much wire is cut. For example, if you have 19 wires in a strand and one wire is nicked halfway through, then that strand is subject to a reduction in breaking strength of approximately $\frac{1}{38}$ of the catalogue value.

Fig. 2-17. Composition of typical guy material.

As a rough rule of thumb, it takes 2 per cent of the breaking strength of a 19-wire strand to stretch that strand or cable out to its true length. A 1 by 7 strand will require approximately 5 per cent of breaking strength.

Prestressing

When a prestressed cable is wound up on a reel and then unwound in the field, there is a negligible amount of length lost. This has been proved many times by checking on long cables for 1,000-ft towers and on suspension-bridge cables.

Prestressing the guys at a strand manufacturer's plant takes out some of the structural stretch. Most wire manufacturers will pull the guy to 50 per cent of ultimate and hold for approximately ½ hr. Prestressing will stretch the strand somewhere from $\frac{1}{10}$ to ¼ of 1 per cent of the length.

Bird Caging

Bird caging can occur in both manufacturing and in handling in the field. Bird caging prior to shipping is rare. Bird caging in the field is caused by a kink in the strand, unreeling improperly, allowing a large reel to get away, getting a loop in the strand, dropping a guy, or anything that puts wires in compression. Since most strands (19 wires and over) have lays going both ways, there is no method of really fixing a true bird cage. There is no tendency for wires to unravel and bird-cage by themselves. That is, all strands are basically very stable.

Fatigue

We have never heard of a fatigue failure of wire where it enters a socket on a guyed tower. However, such failures have occurred in sockets which come out on highly loaded shovels where there is continuous large vibration on strands which are constantly highly loaded in tension.

This question arises every now and then when the tower guy has been stretched in a wind storm and you take up the slack: Is the guy breaking strength reduced? The answer is No. For example, strand in preloaded concrete slabs have initial tensions up to 70 per cent of the breaking strength, and the working tension of the strand is 50 per cent of the breaking strength. Notice that you can take strand and load it to 70, 80, or 90 per cent of the breaking strength; unload the strand; and still get 100 per cent breaking strength.

Zinc Coat

The usefulness of a zinc coat on a guy comes from the fact that the zinc coat wastes away instead of the load-carrying steel. The zinc does not protect the strand wire indefinitely. The fact that zinc wastes away rather than steel is good. It should be pointed out that the smaller the wire diameter, the thinner is the zinc coat. Using a galvanized socket instead of a black one on the end of a guy will not appreciably increase the life of the guy. It is also for this reason that when you have a corroded clip, the best thing to do is to leave it alone. Corrosion usually starts at the threads where the zinc is stripped, and there is usually enough "meat" in the rest of the clip and in the guys to take care of itself.

AM Guys

Guys on AM towers have to be made nonradiating. The currently accepted method is to break the guys up with insulators into lengths approximately one-seventh of the wavelength on the radiator. Obviously, this breaking up of the guys is a necessary nuisance. People constantly are looking for guy materials which would be nonradiating. To date, such materials as nylon and dacron have too much stretch to be of any practical value. However, in the foreseeable future, it is possible that some such material may be usable. A new polyester film material Mylar bears watching. At the moment it is expensive, but it does not have the great stretch which nylon has.

Guying Arrangement

A three-way guying arrangement where the guys are laid out 120° apart in plan form shown on accompanying sketch *A* of Fig. 2-18 gives the simplest possible guying arrangement which will support a tower in a wind from any direction. This gives the smallest number of guys and usually tends to give you cheaper foundations and a smaller number of insulators.

A much-used guying arrangement is shown on sketch *B* of Fig. 2-18. A four-sided tower has four sets of guys spaced 90° apart in platform.

A guying arrangement such as shown in plan form *C* (Fig. 2-18) has been used in tall towers. The disadvantage is the need for more anchors. The advantage is that it tends to save in the column load on the tower and some weight.

A guying arrangement as shown on plan form *D* (Fig. 2-18) shows double guys coming off each face. The advantage of this system is that it gives the tower some torsional resistance until the tower has twisted. The disadvantage of plan form *D* is extra handling by the erector. Most erectors prefer single rather than double guys.

Guy Connections

Clips

The most commonly used guy connections at the insulators are steel clips. These clips are relatively cheap, and they are easily available. They are used by the millions. The efficiency of the clip depends upon drawing the clip up tight. In Fig. 2-22 showing a properly drawn up clip, you will notice that the yoke must make a definite dent on the surface of the strand. It is also a known fact that after you put load on a guy, you can pull the clip up a little more. Since this is very difficult to do in a guy with many insulators in it (which are made in the field), clip efficiency should not be rated over 80 per cent. It is possible to get clip efficiencies in a laboratory over 95 per cent. The greatest danger in a clip is that the erector may forget to draw up all clips securely. The best visual inspection that we know of is to check whether the yoke of U part of the clip puts a definite dent in the guy. These clips come in many shapes and forms such as shown. All clips rust sooner or later. When a clip is drawn up, some of the zinc strips off the threads and you have

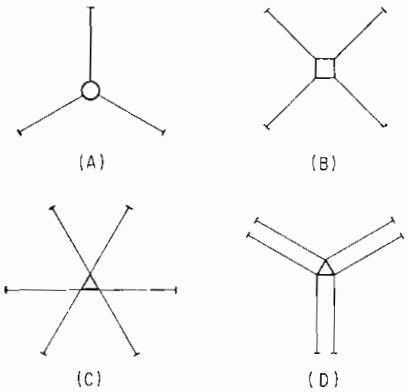


FIG. 2-18. Commonly used guying arrangements.

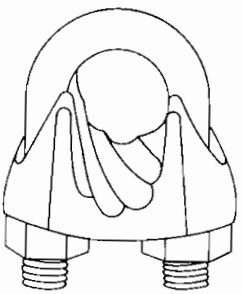


FIG. 2-19. Wire-rope clip.

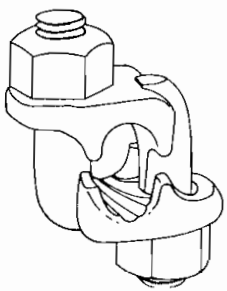


FIG. 2-20. Laughlin safety clip.

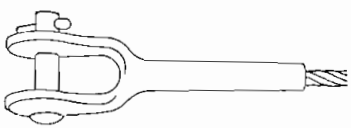


FIG. 2-21. Swage fitting.

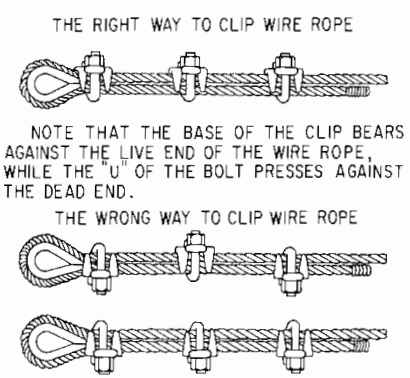


FIG. 2-22. Proper method of applying rope clips.

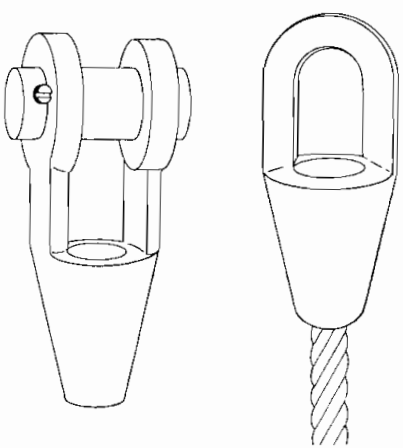
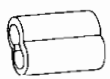


FIG. 2-23. Wire-rope sockets.

a focal point of corrosion. Most clips are sturdy and have enough "meat" in them to last for many years. This corrosion depends on the atmosphere in which the tower is sitting. Some erectors have lately been spraying their clips with clear plastic lacquers which come in pressurized cans.

Serving

A neat and clean-looking connection which is very simple to apply has been developed by the power companies in their work. It is the so-called "serving." The several wires are unraveled, then each individual wire is rolled back on the strand. The efficiency of this method is usually in the high 90 per cents. It makes a clean connection. It is a safer connection than a clip connection, since you do not run the risk of forgetting to run up the clips tightly. It also does away with the problem of corrosion of the clips.



Sleeves and Sockets

There are several makes of sleeves which are press fittings. This again was developed by power companies. They are good-looking and neat on smaller sized guys.

Large guys usually make use of zinc sockets. On most towers today, the sockets are supplied on the strand by the guy fabricator, since their application takes a certain amount of skill and technique. These sockets are usually made of cast or forged steel.

FIG. 2-24. Nicopress sleeve-type fitting.

Guy Tension

The proper initial tension in guys is an integral part of tower design and should be determined by the tower manufacturer. Proper guy tension is necessary in order to control the deflection of the tower so that certain specified limits are not exceeded and in order that deflection of the tower does not weaken it.

Common values of initial tension in guys vary between 5 and 25 per cent of the breaking strength of the guy, depending on the design and requirements. In general, a low initial tension tends to give a more flexible and lighter tower. A high initial tension tends to give a stiffer and heavier tower. Initial guy tension in a properly designed tower seems to have little effect on the ultimate strength of the tower.

During erection and in maintenance, there is danger of putting too much tension in guys. This overloads the tower as a column and literally pulls the tower down to failure.

Initial tension is seldom specified on small AM and communication towers up to heights of 200 or 300 ft. In these cases where the exact initial tension in guys is not critical from the deflection point of view but is critical in that overload can cause tower failure, tower manufacturers should specify an initial tension and the erector or the maintenance men should check the guy tension by some convenient method such as with a dynamometer.

It is common practice on taller towers with a pivot base that guy tensions are adjusted either so that the tower deflects as a straight line from its base to its top when loaded with the design load or so that the differential deflection at guy points is taken into account in calculating the stresses in the tower members. On these large towers, the erection drawings always specify guy tension and some method of checking it. A number of methods commonly used to measure initial tension in the field are described.

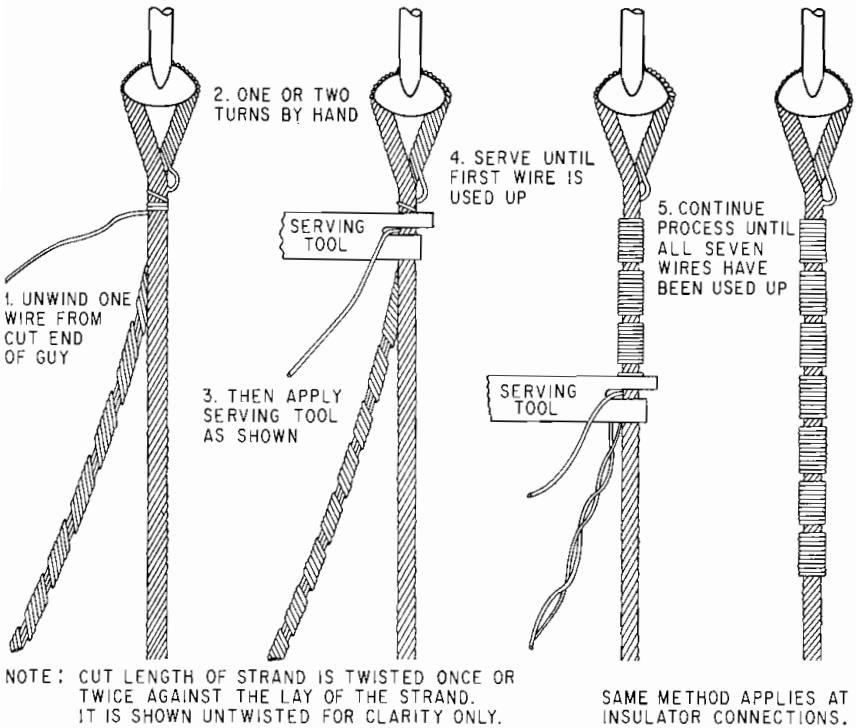


FIG. 2-25. Serving guy connections.

Methods for Determining Guy Tension

Calibrated-rule Method. In the calibrated-rule method, two buttons are attached approximately 8 ft apart to the lower end of the guys. During fabrication of the guys, the required initial tension is applied to the guy. While this load is on the guy, a rule is marked exactly the same as the buttons. In erection, the guy is tightened up until the marks on the buttons line up with the marks on the rule.

Although various stable metals are used to fabricate the rule, this system is subject to errors from several sources. The most likely source of error is the fact that the gauge length (approximately 8 ft) is relatively small and therefore the change in length of the guy in the 8-ft length will be very small. The eye cannot see much closer than 0.01 in., and an error of this magnitude would result in a 10 to 20 per cent error in the initial guy tension. It is doubtful that the erector in the field would take the trouble to read these calibrations with any great precision.

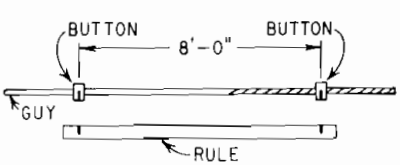


FIG. 2-26. Calibrated-rule method.

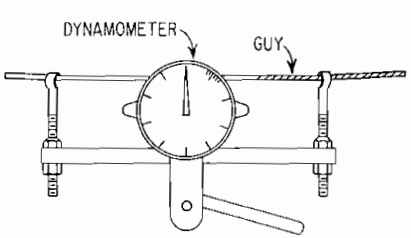


FIG. 2-27. Shunt-type dynamometer.

Temperature is another factor that must be compensated for, particularly when the linear coefficient of expansion of the guy differs from the rule.

Shunt-type Dynamometer. This type of dynamometer or tensiometer is used in determining and maintaining the proper sag or tension in guys. It can be used without breaking-in on the guy to be tested and can be left on the guy until the dial shows the desired reading.

The principle of the shunt dynamometer is based on the relation of the tension in the strand to the force necessary to displace it in a direction perpendicular to the axis of tension.

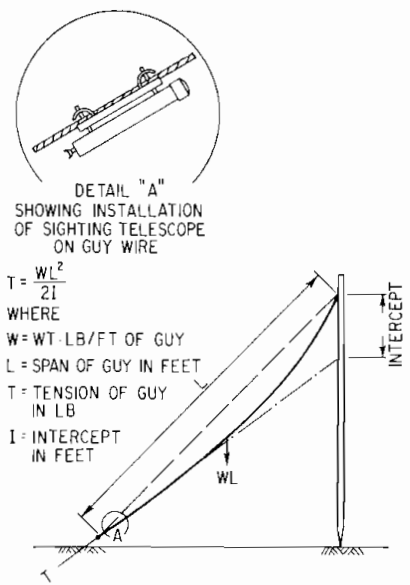


FIG. 2-28. Use of "sight bar" for determining guy tensions.

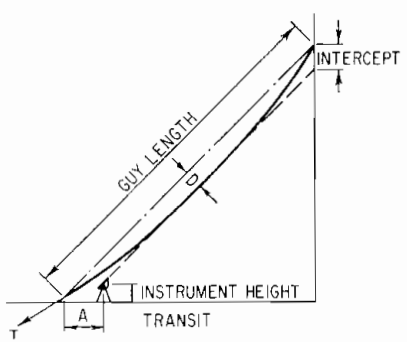


FIG. 2-29. Transit-intercept method for tensioning guys.

The dial is graduated from 0 to 100 units and does not read directly in pounds. Tension is determined from graphs specially prepared for each size and type of wire or cable on which the dial reading is plotted against tension in pounds. The manufacturer guarantees the accuracy to within plus or minus 2 per cent of the dial reading.

On relatively short towers with small guys, use of a mechanical tensiometer is probably the most practical method to measure guy tensions. On tall towers with large guys, the sag of the guys becomes appreciable and can be used as a measure of guy tension. The guy-sag method is a relatively simple and very practical way to check the guy tension.

Guy sag can be checked with a transit or with a sight bar. We shall briefly describe the sight-bar method. A straight bar made of steel or wood with two hooks is used to make the line of sight parallel to the guy. If the unaided eye cannot see clearly to set the intercept, a telescope can be used as shown in Fig. 2-28. It is important in making up this sight bar that the line of sight of the bar be parallel to the guy at its point of attachment. This method is quite accurate in setting initial tension when the guys and intercepts are large. For example, a 100-ft intercept read with 2 ft has an approximate error of 2 per cent. Tension is given by the following formula:

$$T = \frac{WL^2}{2I}$$

The values of the weight of the guy per foot, the span of the guy, and the recommended tension of the guy should be readily available from the tower manufacturer.

Example: 1,000-ft tower with 1-in. guy strand

$$L = 1{,}220 \text{ ft}$$
$$W = 2.14 \text{ lb/ft}$$
$$I = 160 \text{ ft}$$
$$T = \frac{(2.14)(1{,}220)^2}{(2)(160)} = 9{,}950 \text{ lb}$$

Transit-intercept Method for Tensioning Guys. With guy length and desired tension T known, the sag D is calculated from standard formulas. Again with known instrument height a sight line is established tangent to the guy and ground distance A and tower intercept determined. At erection a transit is set up using these intercepts to establish the line of sight. The guy is then tightened until it becomes tangent to the line of sight.

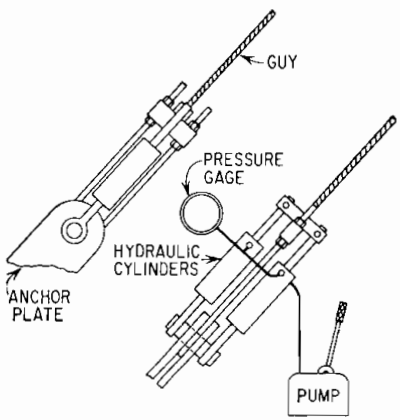


FIG. 2-30. Hydraulic-cylinder method for measuring guy tensions.

Hydraulic-cylinder Method for Measuring Guy Tensions. The guy is put under the required tension with two push-pull hydraulic cylinders which are usually pumped up by hand. The required tension is read on the pressure gauge. The nuts are pulled up on the U bolt or turnbuckles to hold this tension in the guys. Hydraulic units are then removed. It is recommended that the hydraulic cylinders and gauge be checked accurately prior to use, since there is a tendency for errors to creep into the gauge.

Spring Method of Tensioning Guys. A spring with known deflection characteristics is selected and installed in the guy anchor connection. The guy is tightened until the spring has deflected the desired amount, thereby obtaining the required tension in the guy. A combination tubular spring cover and spacer of predetermined length is normally used to obtain the correct deflection. Caution: Do not continue to tighten the guy after the spacer has bottomed; otherwise, excessive tension will be applied to the guy.

Vibration Method of Measuring Guy Tensions. The guy is set properly vibrating by pulling the guy back and forth sideways with the hands. Vibrations are timed with a stop watch. This reading is then substituted in the following formula and the initial tension is calculated.

$$\text{Cycles/min} = \frac{1707}{L \times (\text{wt/ft of guy})}$$

where L = length of guy, ft
T = guy tension, lb

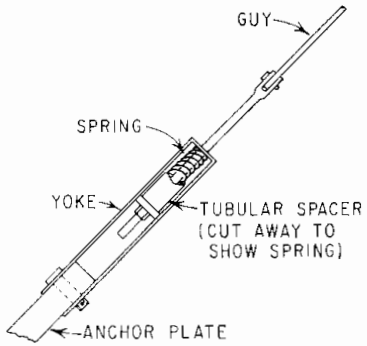


FIG. 2-31. Spring method of tensioning guys.

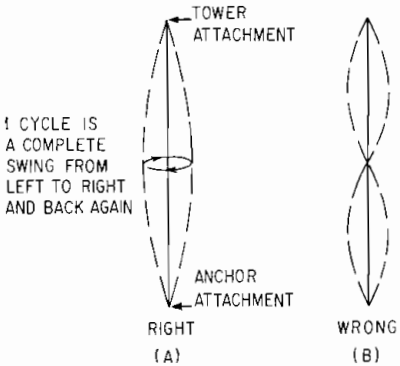


FIG. 2-32. Vibration method of measuring guy tensions.

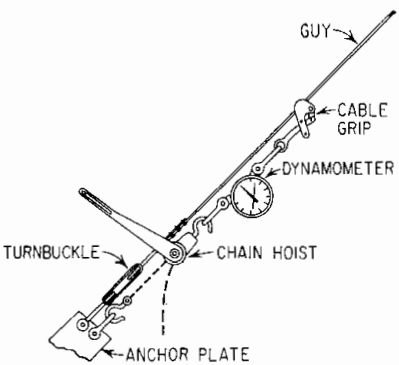


FIG. 2-33. Dynamometer method.

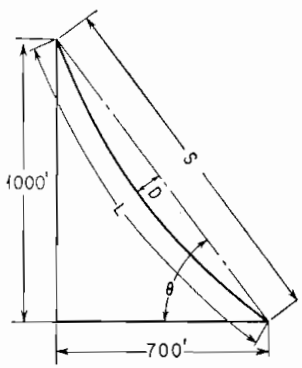


FIG. 2-34. Method of calculating guy lengths.

The vibration method applies to guys of uniform weight and is not applicable to guys with insulators or other concentrated weights. It must be pointed out that this system is only as accurate as the measurement of the frequency of the guys.

Dynamometer Method. As shown in Fig. 2-33, a tension-type dynamometer is mounted between a cable grip and usually a chain hoist. A load is applied to the dynamometer, and when the desired reading is reached, the guy turnbuckle is tightened accordingly. The dynamometer equipment is then removed.

$$S = \sqrt{1{,}000^2 + 700^2} = 1{,}220.6555 \text{ ft}$$

Given: $W = 2.073$ lb/ft—1-in.-diam guy
$T = 10{,}000$ lb—initial tension

Sag in guy wire with 10,000-lb tension

$$D = \frac{WS^2 \cos\theta}{8T}$$

$$= \frac{2.073 \times (1{,}220.6555)^2 \times 0.57346}{80{,}000}$$

$$= 22.1411 \text{ ft}$$

Assume that the guy takes the shape of a parabola

$$L = S + \frac{8D^2}{3S}$$

$$= 1{,}220.6555 + \frac{8(490.2283)}{3{,}661.9665} = 1{,}221.7265 \text{ ft}$$

Length of guy at 10,000-lb tension

Guy Vibration

Although guy vibration is not, as a rule, a serious problem, it may be well to note its effect. Tower guys have been known to vibrate in a few isolated instances. The natural frequency of any tower guy is a function of:

1. The length of the guy
2. The tension in the guy
3. The weight distribution of the guy

A change in any of these constants will change the frequency of the guy. The natural frequency of a guy without ice is different from that with ice simply because the weight of the ice changes the weight distribution of the guy and automatically increases the tension in the guy. Obviously, if a guy begins to vibrate, changing any of these constants, namely, knocking ice off the guy, adding weights to it, shortening its effective length by a bridle, increasing or decreasing its tension, should kick the guy out of the vibrating frequency. If long guys are provided with weights which are attached to the guys at irregular intervals, the probability of vibration is theoretically reduced. Insulated towers have these weights already on them in the form of guy insulators. Some towers come with some form of cast-iron weights which are clamped around guys to form the guy dampener. Most tower designers feel that a guy dampener is easy enough to install should you get vibration where no dampeners were specified.

WINDS, WEATHER, AND HAZARDS

Wind Velocity

The Weather Bureau aims to get true wind velocities at a height of approximately 10 m (33 ft) in open exposure and ten times as far from any obstruction as it is high. The Bureau tries to approach this ideal, but it should be obvious that sometimes it is virtually impossible to find such an exposure for all wind directions in a well-built-up city and even in some airports. The Weather Bureau's figure for true wind is measured over a 1-min time interval. Some countries use up to 10 min. The Weather Bureau also gives the fastest mile as maximum gust velocity or the peak indication of a pressure tube anemometer. A cup anemometer tends to overregister in a gusty wind. However, this overregistration is very small and never more than a few per cent.

Indicated vs. True

There is misunderstanding about indicated and true wind velocity. Any figure obtained from a Weather Bureau today or in the last quarter century is a true wind velocity. This true wind velocity is also the indicated velocity. This is because anemometers have been calibrated and the indicated and the true are practically the same. However, in about 1898, the Weather Bureau discovered that the anemometers were registering approximately 25 per cent too high. In order to avoid throwing away at least a quarter century of Weather Bureau records already obtained, the Bureau decided to keep on with the figures which were 25 per cent high. This continued until about 1924. This means that records prior to 1924 may show an indi-

cated and a true wind velocity differing by approximately 25 per cent. Any wind velocities given by a Weather Bureau since that time are true wind velocities.

Since air is a viscous fluid, the ground has a certain amount of "slowing-up" effect on the wind velocity. Another way of putting it, wind velocity tends to increase as height above the ground is increased. Obviously this velocity gradient is not a constant, nor is it easy to express. The Weather Bureau gives the formula shown in Fig. 2-35 for velocity ratios as expressed in terms of height. The constant N is somewhere between 2 and 7. Although we do not know how much faster it is actually blowing

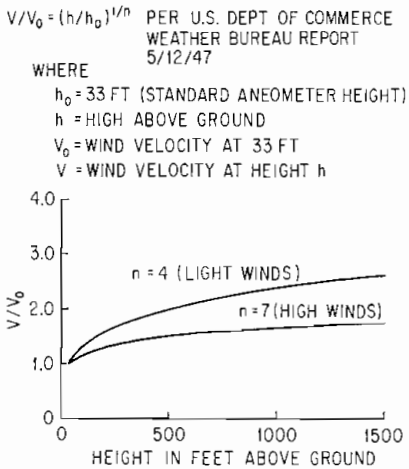


FIG. 2-35. Variation of wind velocity with height.

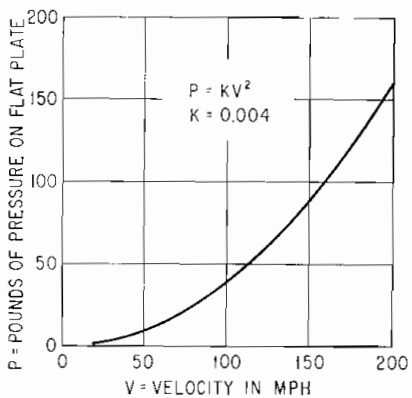


FIG. 2-36. Wind pressure vs. velocity curve.

at 1,000 ft as compared with ground, we are sure that it is blowing faster. For that reason, taller towers should be designed to a slightly higher wind load.

In addition to this wind gradient, there is what the Weather Bureau calls a velocity gradient. This means that in addition to the average maximum wind velocity, there may be superimposed gust velocities for short durations. Much work has been done studying these gusts, and there are some empirical estimates. There is no sure prediction of gusts. It is reasonable to assume that gusts are possible which exceed the maximum wind velocity by a factor between 10 and 30 per cent.

Hurricanes

Hurricanes are large-diameter tropical storms. These hurricanes usually start out in the Gulf of Mexico or the Caribbean Sea or in the Atlantic Ocean east of the Caribbean. The plotted tracks of past hurricanes cover practically every part of the Gulf of Mexico and the Caribbean Sea and much of the North Atlantic Ocean. They are apt to strike most of the Gulf ports and most of Florida. A good many veer off the southeastern coast of the United States and swing out to sea. However, many of them cruise up through Georgia, the Carolinas, and New England. Hurricanes have a counterclockwise wind system. The strongest winds are somewhere between 75 and 100 mph. Occasionally, they may get up to 150 mph. The eye, or the dead portion of the storm, usually runs about 10 miles in diameter. The outside dimensions of a hurricane which covers the width of the destructive winds could be anywhere from 25 to 400 miles. In the United States, hurricanes reach a peak frequency in August, September, and October. It is possible to design hurricaneproof towers at slight additional cost. The EIA Tower Standard RS-222 shows recommended tower strengths for different heights and locations.

Some hurricanes are accompanied by a strong tide which in some cases can be 10 or 12 ft high when it reaches the seacoast. In certain bays where there is a narrow channel, this rise may be as high as 50 ft. These waves are certainly unusual, and although towers have been known to be washed away, no attempt has been made to design towers to withstand such tides.

Tornadoes

Tornadoes, or twisters, occur in most parts of the United States. The highest probability of their occurrence seems to be the Mississippi Valley, but one can expect them in the Southwest, Middle West, or Southeast parts of the country. The highest frequency occurs during the months of April, May, and June. A typical tornado starts in the late afternoon, usually moves from the southwest to the northeast, and cuts a path of destruction somewhere between several hundred yards and a mile wide. The winds inside this twister are very high and are believed to exceed 500 mph at times. No attempt is made to design towers to withstand these high wind velocities, but because of the narrow path involved, the probability of a tornado hitting a tower is not too high.

Wind Pressure

The commonly accepted formula for wind pressure is $P = KV^2$. P is wind pressure in pounds per square foot of projected area; K is the wind conversion factor depending on the shape; V is the actual wind velocity in miles per hour. The nominal value for K pressure on flat surfaces is 0.004. Notice that the pressure is proportional to the square of the velocity. If we plot this, we get the curve in Fig. 2-36. The commonly accepted practice is to use 0.004 for flats and angles and shapes and two-thirds of this value for cylindrical shapes.

Specifications

The EIA specifications for towers were drawn up by representatives of various tower manufacturers. These specifications cover very broadly, but very adequately, all important points in designing steel towers. It is best if broadcasters keep this in mind. There are other specifications probably as good, but they tend only to confuse things. For example, the American Institute of Steel Construction has a set of specifications which were drawn up primarily for large buildings and bridges. It is possible to misuse specifications. For example, AISC reads, "members subject to stresses produced by wind forces may be proportioned for unit stresses 33⅓ per cent greater than those specified for dead and live stresses." The intent of that paragraph was secondary wind bracing for structures with heavy live loads. A tower is not such a structure. This paragraph should not be used in radio-tower design, for if it is carried out to its literal conclusion, it is possible for broadcasters to specify a 30-lb wind-load AISC tower and obtain approximately a 20-lb EIA tower.

EIA specifications take a practical look at the method of analysis. EIA recommends that wind loads be expressed in terms of pounds per square foot projected area. Consequently you hear the expression "the tower is a 30-, a 40-, or a 50-lb tower."

Wind vs. Tower Failure

The question often arises, at what wind velocity will a tower fall down? It is very difficult to give an honest answer to that question. Let us take an example: Assume a 40-lb tower. This means that the tower was designed for 40-lb wind pressure on flats, safety factor 1.8, so that the yield of the structure would be approximately at a wind pressure of 40 times 1.8, or 72 lb. Looking at the pressure–wind-velocity curve, 72 lb equals about 134-mph wind velocity. Theoretically, a wind of 134 mph distributed uniformly over the structure produces yield in a structure, and this usually means failure. But how do we know how fast the wind was blowing on the tower? How do we know that the wind was distributed uniformly over the structure? Probably the best record available is the Department of Commerce

Weather Bureau, miles away at a different elevation. For example, assume the anemometer 750 ft below your tower. Wind velocity at your tower could be 134 mph, but the wind velocity vs. height curve in Fig. 2-35 shows that there is approximately a 1.5 times increase in velocity, or at the anemometer, 750 ft below, the wind is blowing about 90 mph. If you throw in a 10 per cent gust factor, it is possible that the anemometer 750 ft below your tower registered 80 mph when it was 134 mph at the top of your tower. For this reason, it is very difficult to correlate wind velocities as given by the Weather Bureau miles away from the tower site with the actual wind velocity blowing through the top of the tower. We do know that from past experience, in certain locations, towers designed to certain wind pressures seem to stay up and are adequate. The best indication for any given location is past experience.

Wind Loading

It is interesting to note the effects of installing different items on a tower. By far the greatest single contributor to the load on a tower is the area exposed to the wind. This means that the less area there is exposed to the wind, the less tower is needed

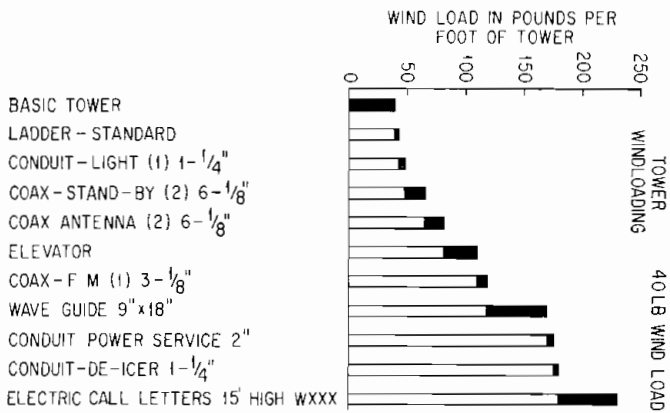


FIG. 2-37. Wind load in pounds per foot of tower.

to support itself. The simplest tower is a small AM radiator whose function is to support itself, with possibly one small lighting line. The other extreme is where signs, elevators, spare coaxial lines, antennas, and other equipment are installed on the tower. The accompanying graph (Fig. 2-37) is made in an attempt to show vividly the effect of various items "hanging" on a tower. The tower is a typical clean tower in the 500- to 600-ft height range with various items being added on, one at a time. Obviously, it is not very difficult to double or even triple the side load on a tower by adding these items. The addition of any single item or article to the tower increases the wind load on it. This, in turn, means that the tower has to be stronger, heavier, and possibly a little bigger in cross section. This additional cross section increases the wind load, which increases the weight and the cost of the tower. Obviously, you cannot hang all these components on the tower without increasing the weight and cost.

Icing

Ice tends to form on all structures exposed to the elements under certain conditions of humidity and temperature. The temperature is usually a little below freezing, and the air is superladen with moisture. Icing is spotty both in location and in frequency. You usually do not get much ice in dry climates, in very cold weather, or in very

warm weather. There has been ice as far south as Atlanta, Ga. To find out how icing conditions are in your locality, ask the engineers at your local power company. Utilities constantly have trouble with ice. Tall towers, around 1,000 ft, tend to get layers of ice farther up the tower. You usually find more ice on mountain tops.

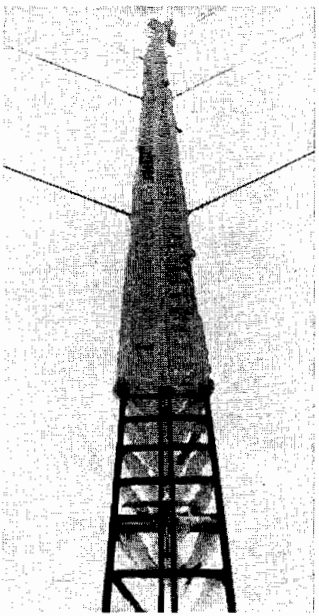


FIG. 2-38. Ice formation on a tower.

It is the feeling of the people who drew up the EIA specifications for towers that, since ice and wind do not occur simultaneously as a rule, the tower should be designed for wind pressure alone. If you are in a location where icing exists, specify a tower somewhat stronger, say a 40- instead of a 30-lb tower.

Prevention of Icing

A number of ideas on preventing ice formation on towers and guys have been advanced. Heating elements have never been tried to deice the tower as far as we know. Heating elements are used on the antennas, not to prevent damage to the antenna, but rather to prevent damage to the radiating properties. The most practical solution seems to be to make the tower strong enough to carry the ice.

Falling Ice

Ice falling off the structure presents a hazard. A chunk of ice 4 or 5 in. thick falling several hundred feet carries quite a "wollup." Automobiles parked at the base of the tower or even some distance from the base of the tower can be damaged. Ice has been known to break beacons, lights, and microwave gear on the way down. It is certainly a hazard to horizontal runs of coaxial lines. A simple corrugated-iron or wooden shield to deflect the flying ice is adequate. Icing over 1 in. in thickness, except in isolated cases, is rare. Pictures of ice 1 and 2 ft thick taken on Mount Washington should not be used as a guide in designing a tower.

Earthquake Loading

Towers on the West Coast are usually required to meet the Pacific Coast Uniform Building Code for earthquake loadings. This code says as follows:

In determining the horizontal force to be resisted, the following formula shall be used:

$$F = CW$$

where F = horizontal force, lb
W = total load tributary to the point under consideration
C = 0.05 for towers which are connected to a building
= 0.025 for radio towers which are not supported by a building

This horizontal force F is added directly to the wind load. In a short, light tower, say 200 ft, this does not add an appreciable amount of load to the tower. In a tall, heavy tower, this factor may be considerable.

Atomic Blasts

One of the atomic blasts out in the Nevada flats was made to test a number of civilian defense items. The bomb was set off on a 500-ft steel tower. Two small

cities were built, the first approximately a mile from the blast, the second approximately 2 miles from the blast. Depending on the size of the bomb, all steel within a certain radius is immediately atomized and, for all practical purposes, simply vanishes. So it is impossible to build an atomic bombproof tower. One practical observation was that in the test city, alongside brick and wooden homes which were badly mangled, a guyed 150-ft AM tower designed as a 30-lb EIA tower at 250 ft survived undamaged, although there was evidence of the tower having moved a great deal during the blast. A 100-ft self-supporting tower, noninsulated, loaded with two-way radio antennas, designed to approximately 20-lb EIA load, failed at the same site. A very rough conclusion may be that a short guyed 40-ft EIA tower is approximately a little better than average small buildings. Since the blast gave the tower a violent "jerking about," as it were, the whip or inertia forces must have been high. Consequently, the above conclusion may not be the same for towers which have larger inertia or whip forces. Inertia forces are greater in the case of self-supporting towers and guyed towers with heavy top loads from antenna.

INSULATORS

Base Insulators

Current practice for AM radiators is to have the base of the tower insulated, although there still are some shunt-fed installations.

Most insulators today are made of porcelain. There is no reason why other materials could not be used, such as wood, glass, or fiberglass and other new plastics.

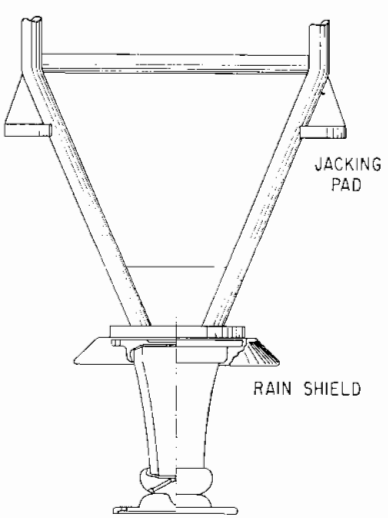


FIG. 2-39. Typical base insulator for guyed towers.

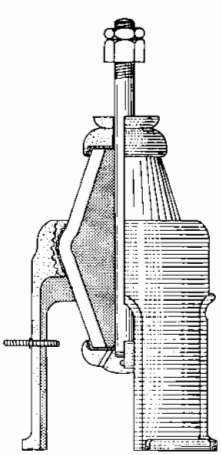


FIG. 2-40. Push-pull type of insulator for self-supporting towers.

Since current practice is to use porcelain, this discussion will concern porcelain insulators. A designer of porcelain insulators always keeps in mind that porcelain is strong in compression but weak in tension. Therefore, the insulators are always designed so that the load pushes on either a mass of solid porcelain or a cone of porcelain. The designer tries to make sure that there is no bending or tension induced into the porcelain portion of the insulator. Most guyed towers come down to a

single-point pivot, and the insulator will have a rounded surface so that the tower can pivot. This is to prevent any bending being induced back into the porcelain, and most of the load is pure compression. Figure 2-39 shows a typical installation. Sometimes a rain shield is put over the top of the insulator in an attempt to keep the insulator dry, since the flashover value of dry porcelain is better than that of wet porcelain. However, most rain shields are very ineffective in a driving rain unless they form a complete shroud down and around the porcelain. Since porcelain is fragile and subject to cracking, some care should be exercised in handling it. There have been instances where water has got into the cone, the drain hole has plugged up with dirt, and the water froze and shattered the insulator. This is quite unusual. The cost of base insulators with leakage paths greater than 10 ft increases rapidly.

The self-supporting tower presents a unique problem in that the base insulator has to transmit either compression or tension from the leg member. The accompanying cross section of a typical push-pull insulator in Fig. 2-40 shows how this is accomplished. This insulator works in such a way that the upper cone works when the load is down (compression on the pier) and the bottom cone works in compression when the load is an upload on the leg member. These insulators are usually very bulky and expensive, and except for the smaller sizes, delivery and availability are not too good.

FIG. 2-41. Example of raising base insulator for flood-water conditions.

It is perfectly possible to have a three-legged or four-legged guyed tower which is shaped so that it sits on all three or four legs on the pier, in which case, three or four insulators will be required at the base of the tower. Some designers prefer this form, and there is nothing wrong with it providing the insulators are capable of transmitting a certain amount of tension and the foundation pier is absolutely level.

Large special insulators are sometimes used, but they are not typical.

Once in a great while, the porcelain on a base insulator will crack. The crack may be due to an old flaw, an external blow, a lightning hit, or water getting inside the porcelain and freezing. In order to change the base insulator, the tower must be raised slightly. This is not a particularly difficult operation, but it is very critical. Sometimes, on tall towers, jack pads are incorporated into corner legs to facilitate raising the tower.

Raising Base Insulator above Ground

The base insulator of an AM tower is located so that unusual weather will not ground the insulator. Sometimes, 1 or 2 ft above the ground is adequate. The insulator is usually placed in a concrete pier 3 to 5 ft tall. Occasionally, insulating may be as much as 25 ft above the ground as is shown in the accompanying photograph, Fig. 2-41. Sometimes, in an array of four towers on a sloping piece of ground, it may be desirable to locate all insulators in the same horizontal line. Each tower

sits on a pier of a different height. Concrete is generally used up to about 5 to 10 ft. Over that height, some sort of steel pier is probably the most economical.

Guy Insulators

Typical guy insulators and guy-insulator assemblies are shown.

The most commonly used guy insulator for AM work is the so-called strain insulator. Since most AM towers are under 300 ft, most towers use these insulators. The insulators were developed by the power companies and are made in large quantities so that they are easily available and the cost per unit is very low. They come with multifins to increase leakage path and are used with strand up to ½ in. Another advantage of a strain insulator is that if an insulator cracks, the tower fails safe; that is, the interlocking loops of strand keep the guy intact.

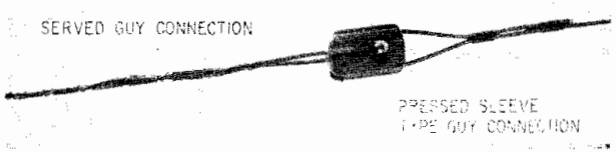


FIG. 2-42. Typical strain insulator.

Where it is desired to have the insulators capable of being inserted after erection, the open-type insulator is sometimes used. A strand over ½ in. is very stiff, and it is very difficult to pull around the insulator. Great care must be taken to make sure that the strand hugs the loop all around its periphery. In other words, the strand must be forced around the grooves on the insulator. If this is not a snug fit at both sides of this insulator, the insulator will tend to cock, the insulators will be loaded at a point rather than over a surface, and the desired mechanical strength will not be obtained.

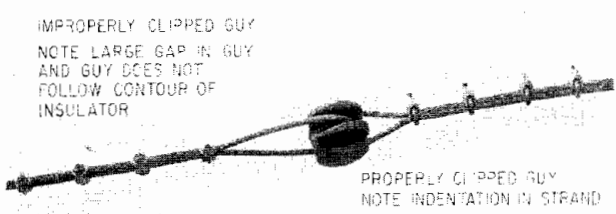


FIG. 2-43. Improperly and properly clipped guy.

On large guys and when the leakage path is greater than that obtained by strain insulators, the so-called cone insulators are used. This cone insulator is nothing more than a base insulator with a basket around it. You will notice that the load is transmitted through a cone of porcelain in compression. It is interesting to trace the load transmitted through one of these insulators. The load comes down the guy, through the top socket, then around the insulator, through a steel yoke and to the bottom of the cone. All this load so far is tension. The load is transmitted through the porcelain to the top of the cone in compression. The top of the cone has a pivot with a gonglike piece hanging down to pick up the bottom socket. These insulators are large, clumsy, expensive, and not easily available. Also, they do not fail safe.

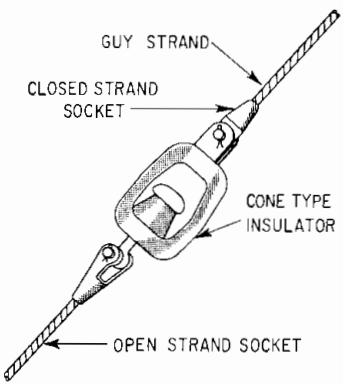


FIG. 2-44. Cone-type guy insulator.

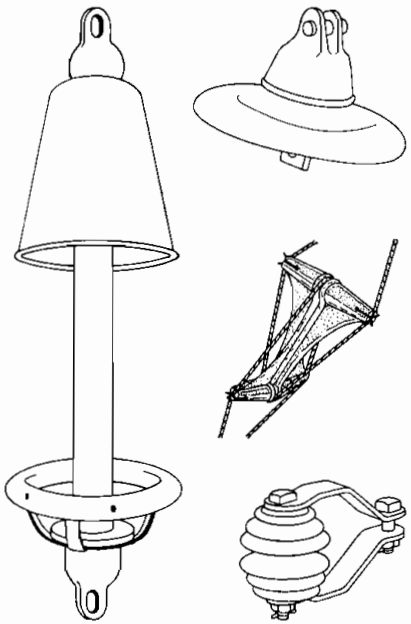


FIG. 2-45. Miscellaneous guy insulators.

Several other types of guy insulators which have been used are shown. Porcelain insulators have a very good life. Replacement of cracked strain insulators is not common. For replacement, the guy is dropped or an erector slides down the guy to the point in question.

Sectional Tower Insulators

There are some installations where by sectionalizing a tower it can be used for more than one function. A sectionalized tower can be used to control the AM radiating characteristics of a tall tower. This allows a tall TV tower to be used as an AM tower. This is possible by insulating portions of the tower from one another. As shown in the illustration (Fig. 2-46), either the pivot type or the push-pull type of insulator can be used to sectionalize a tower. It is desirable to taper the tower for the pivot-type insulator. The push-pull type of insulator is used at each leg member as is used in a self-supporting design. In either case it is necessary to check the shear transfer across the insulator.

With a sectionalized tower, periodic inspections of the insulators are mandatory. A failure in a sectionalizing insulator very likely will cause the tower to fail.

BONDING

An AM tower is a radiator. Hence, it is important that the steel tower acts as one continuous electrical unit. Faying surfaces on a galvanized tower are not painted and as a rule are considered sufficiently bonded through the zinc contact. Two methods of bonding steel towers are shown below.

The weld type of bond is positive, but extreme care must be taken when welding near guys. It is possible to damage guy strand with the molten weld slag. The copper-jumper type of bonding is a bit more troublesome. The holes must be abso-

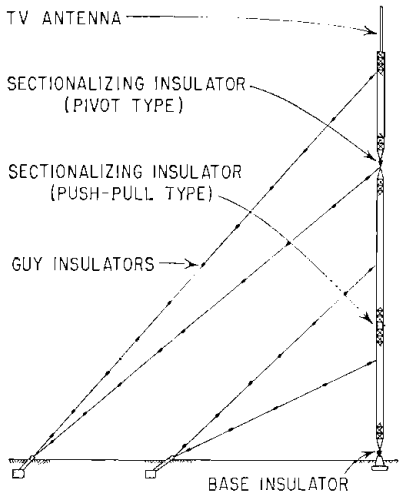


FIG. 2-46. Example of a sectionalized tower shown with two types of sectionalizing insulators.

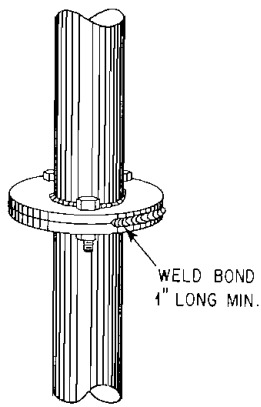


FIG. 2-47. Weld-type bonding.

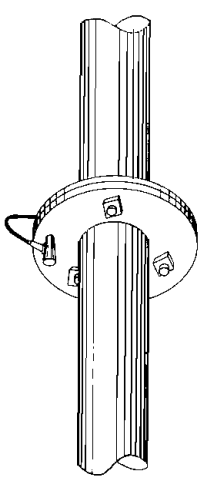


FIG. 2-48. Jumper-type bonding.

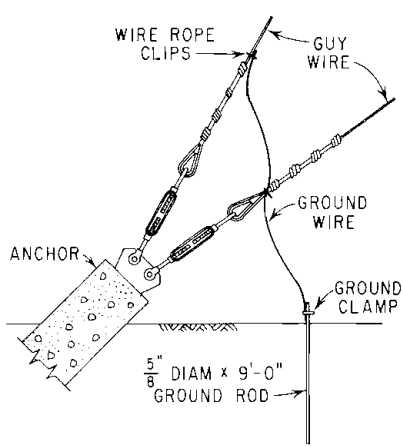


FIG. 2-49. Grounding at guy anchor.

lutely clean and free from rust and paint. The wedges should be driven in tightly to make good contact and exclude any moisture to preclude any electrolytic action.

LIGHTNING

Since the steel tower is usually the tallest object in its vicinity, it is always the first to be hit by lightning. As a matter of fact, the tower itself forms an electrical umbrella, as it were, for adjacent structures. Since steel is a very good conductor, lightning does not damage the tower or its guys. Although there have been many rumors about lightning shattering concrete foundations, we have never been able to find a record of such an incident. An AM tower, with its screen and radials, automatically makes a very good ground for dissipation of lightning. TV and other towers

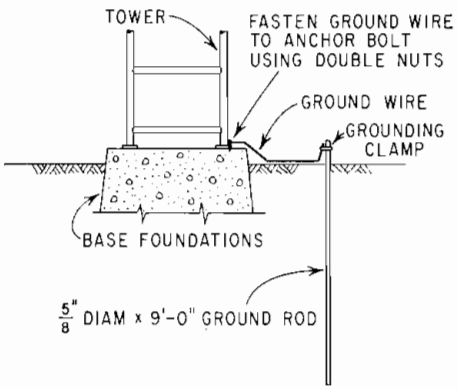


FIG. 2-50. Grounding at tower.

should be adequately grounded simply as a precaution to keep the lightning path away from the transmitter house. A typical guy cable grounding system is shown in Fig. 2-49 (see page 2-71). Lightning, however, can and has done damage to any and all kinds of electrical equipment on the tower. It seems almost impossible to build a tower where the manufacturer can guarantee that lightning will not knock out pieces of electrical wiring, lamps, junction boxes, etc.

SOILS, ANCHORS, AND FOUNDATIONS

Soil Exploration

On small towers such as a 200-ft guyed AM tower, the magnitude of loads is not large enough as a rule to warrant soil exploration, unless, of course, the soil is very sandy or swampy. If the condition of the ground is in doubt and on tall TV installations where the magnitude of load is appreciable, a thorough soil exploration is certainly advisable. In most parts of the country, there are soil engineers who are familiar with the type of soil in a particular location. Test bores are usually made at the tower base and at the anchor foundation locations. At the base of the tower, test bores should be approximately 25 or 35 ft deep, whereas at the guy anchors, test bores should be a little deeper than the anchor depth.

The purpose of the test bore is to help determine the allowable unit bearing pressure for design. Sometimes, local building codes set their own values for local conditions. There are any number of methods used to study the subsurface conditions. A simple test which permits classification of the soil may or may not be adequate to tell the bearing capacity. For that reason, a test boring log should be turned over to competent soil engineers, who will then convert the data to allowable

bearing capacities of the soil. Soil engineers are usually more familiar with local conditions, codes, and geology than others far removed. For purposes of approximation, the allowable bearing values of foundation soils are given in Table 2-1.

Table 2-1. Approximate Allowable Bearing Value of Foundation Soils

	Bearing Capacity, Tons per Sq Ft	
Soils	*Approximate Depth 3 Ft*	*Approximate Depth 6 to 10 Ft*
Soft silt and mud	0.1–0.2	0.2–0.5
Silt (wet but confined)	1–2	1.5–2
Soft clay	1–1.5	1–1.5
Dense firm clay	2–2.5	2.5–3
Clay and sand mixed firm	2–3	2.5–3.5
Fine sand (wet but confined)	2	2–3
Coarse sand	3	3–4
Gravel and coarse sand	4–5	5–6
Cemented gravel and coarse sand	5–6	6–8
Poor rock	7–10	7–10
Sound bedrock	20–40	20–40

A typical log of a boring is shown in Fig. 2-51. This log is in turn analyzed by a competent soil engineer who will recommend allowable unit bearing pressure for design.

Anchors and Piers

Tower base foundations are usually made of reinforced concrete and are designed to carry the total column load of a tower. The area of the footing should be of sufficient size to prevent detrimental settling of the tower structure.

Anchor foundations, on the other hand, exert little down loads. The vertical component from a guy is resisted by the weight of the concrete and earth overburden. The horizontal component is resisted by friction on the anchor base and by the lateral resistance of soil on the face of the anchor.

At some installations the allowable bearing pressure of the soil is very low or an underlying stratum is exceptionally poor. Serious settling of the foundation may occur under these conditions, and it is advisable to drive piles under the footing.

Figures 2-52 to 2-62 show the many types of base pier and anchor designs for radio and TV towers. Many metal-type anchors for small tower installations are available for different soil conditions, and the illustrations are self-explanatory. The screw-type swamp anchor has a pipe for its shank. The length of the shank is increased by coupling additional pieces of pipe until the screw has been driven into hard soil. Various types of guy anchors are shown.

The photograph in Fig. 2-63 shows an anchor installation at KOA-TV, Denver. Usually, the small flats on top of hills make a self-supporting tower a must. However, it is possible to install tall guyed towers in rough, mountainous terrain. Naturally, this usually brings about installation problems. Probably the costliest item is making the tower base and each anchor point physically accessible to trucks and erection equipment. Tower designers like to choose sites so that each anchor falls off approximately the same. However, this is not always possible or absolutely necessary.

Concrete Foundations

Reinforcing

Most foundations are made of reinforced concrete (see Fig. 2-52). Since the concrete is in a wet plastic state when it is poured, it must be confined until it hardens. Usually, these forms are made of wood. Sometimes in small towers, forms are dispensed with at the anchors simply by digging a hole of rectangular shape and allowing

the sides of the earth to give the concrete its shape. On a large tower, the wooden forms run into a considerable amount of money.

Except for tiny foundations, concrete piers and anchors are always reinforced with reinforcing bars of the deformed type of steel. The purpose of these bars is to help

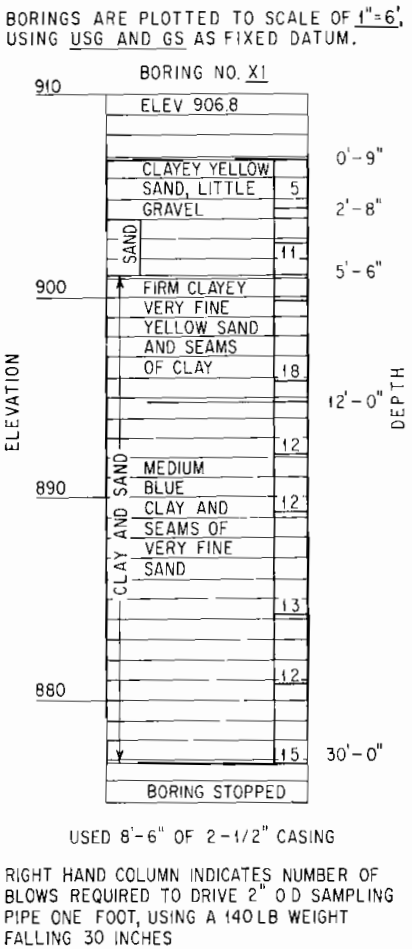


FIG. 2-51. Typical boring log.

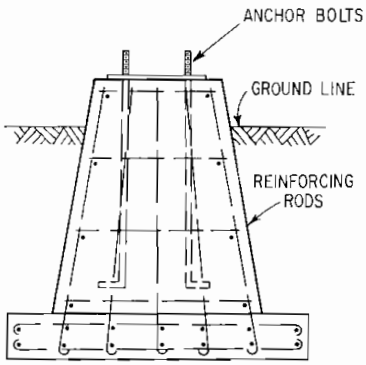


FIG. 2-52. Typical reinforced-concrete base pier.

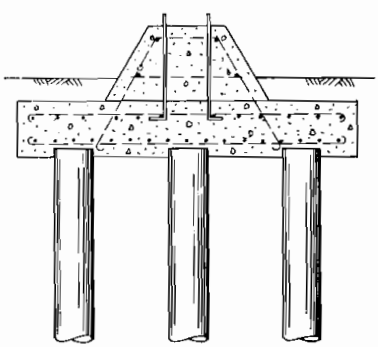


FIG. 2-53. Base pier of reinforced concrete on piles for use in poor soils.

carry any tensile stresses in the concrete block, since concrete is essentially a compressive load-carrying material. Deformed steel is used, since the deformed surfaces give a better mechanical bond to the concrete. Since reinforcing bars are universally obtainable, the steel is usually procured locally. The reinforcing bars should be carefully wired and placed together as called for on the foundation drawing prior to pouring the concrete. Sometimes these bars are welded together into a subassembly.

Mix

The concrete is usually obtainable from a local ready-mix plant. The foundation designer always specifies the proportions of the mix and the water-cement ratio or strength of concrete. These items should be relayed to the supplier of the concrete. A typical mix is 1-2-4, where the numbers 1-2-4 represent the proportions of cement, sand, and gravel. The water-cement ratio is often expressed by specifying approximate compression strength of the concrete after 28 days. A typical strength is 2,500 psi.

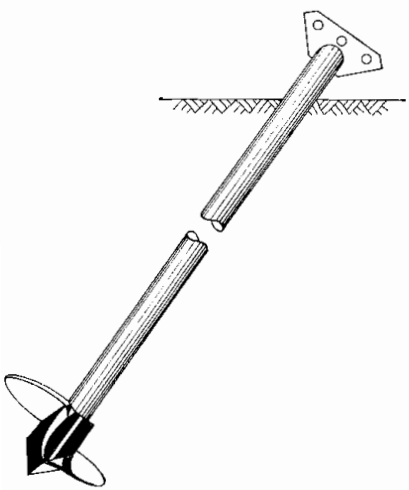


FIG. 2-54. Screw-type swamp anchor.

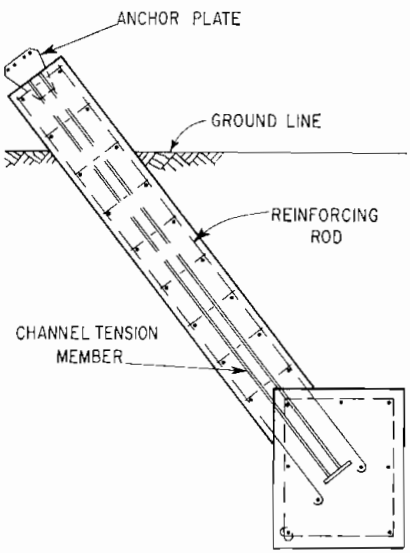


FIG. 2-55. Typical reinforced-concrete guy anchor.

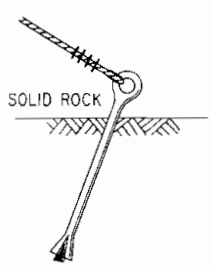


FIG. 2-56. Wedge-type rock anchor.

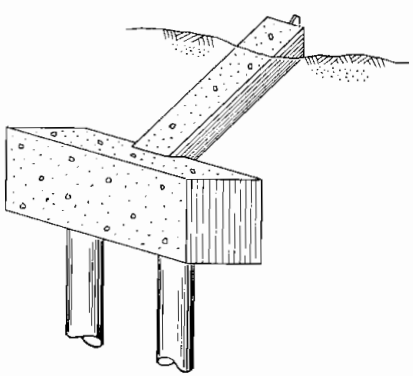


FIG. 2-57. Reinforced-concrete guy anchor on piles for use in poor soils.

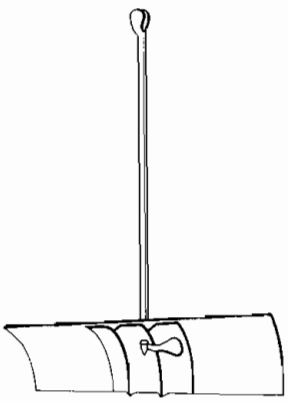


FIG. 2-58. Two-piece metal anchor for clay or loam.

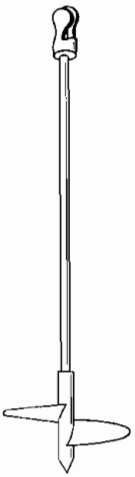


FIG. 2-59. Screw-type earth anchor.

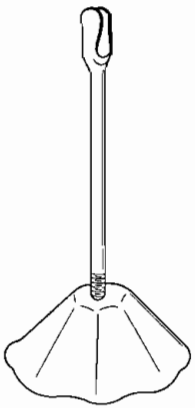


FIG. 2-60. Cone-type anchor for rocky soils.

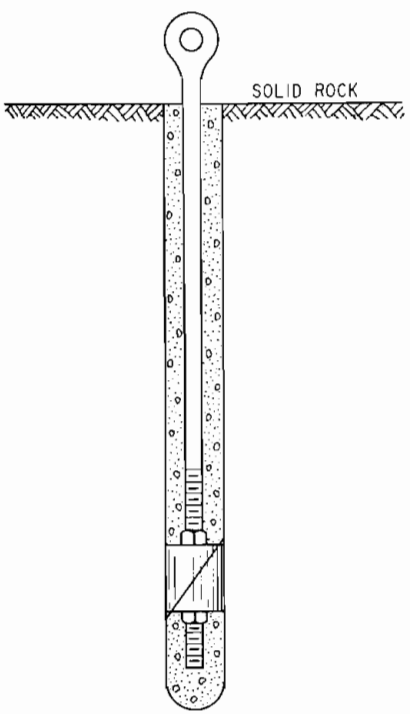


FIG. 2-61. Expanding rock anchor.

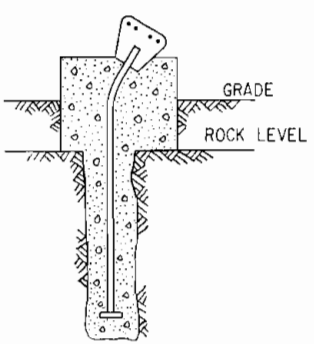


FIG. 2-62. Concrete-type rock anchor.

Pouring

As the concrete is being poured, precautions should be taken to see that the forms are filled completely. The usual method is simply to poke or churn the concrete with a pole or shovel, especially along the edges of the forms. Care should be taken to see that the steel arms which protrude from the forms are not moved or disturbed by the pouring of the concrete.

On towers where the guys are supplied with fixed lengths, it is most important to know the exact dimensions from the working points at each guy anchor. These are

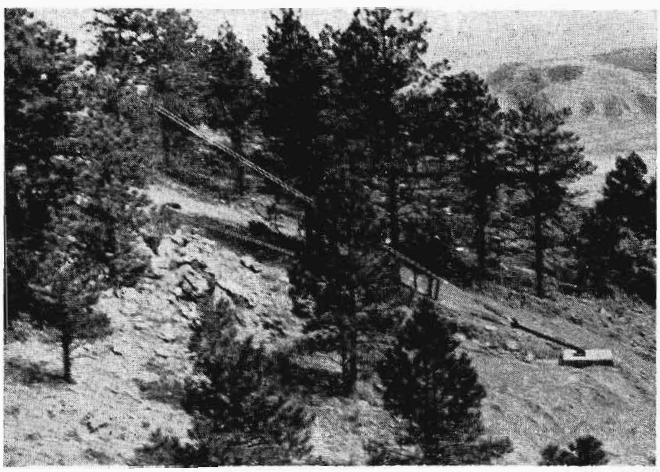


FIG. 2-63. Guy anchor installation at KOA-TV, Denver, Colo.

surveyed and determined prior to pouring the concrete. Since the concrete may disturb the steel anchor arms, it is advisable to survey the installed anchors and get a new set of readings locating these work points.

When concrete is poured under water, proper forms and a comparatively dry mix will aid procedure. Where the simple method of depositing the concrete under water directly is not possible, a cofferdam can be built. A cofferdam is a temporary wall structure out of which water is pumped so that work can be carried on in a comparatively dry area.

Freezing

Frozen concrete may not suffer any visible deterioration, but its strength is greatly decreased. Some precautions must be taken during freezing weather. Fresh concrete, when frozen, is easily recognized by its white color, whereas ordinary concrete will remain a slate color. One precaution is to heat the ingredients and water prior to mixing and then cover the poured concrete with layers of hay or straw. Sometimes heat is introduced from a portable heater. Another precaution is adding calcium chloride to the mixture. This generates heat during the setting period.

Strength

There are occasions where high strength in concrete foundations at an early age is desired so that the erection of steel can begin at the earliest possible moment or to

make possible early reuse of forms. In cold-weather construction, high early strength reduces the time of protection required. High strength at early ages can be achieved by using a type III portland cement usually designated as high-early-strength portland cement or by using richer mixtures of other types of portland cement. The type III cements cost more than the normal portland cement.

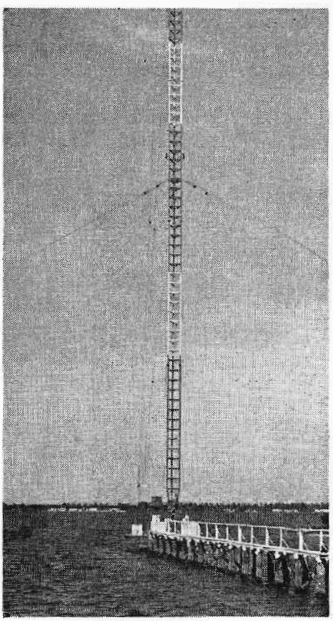


FIG. 2-64. Photograph of a water installation. The erection costs rise very rapidly. Cofferdams are built prior to pouring the foundations, and the erector must invent ingenious devices to get his material to the base of the tower in the water. The photograph is Station WMMB, Melbourne, Fla.

Since the important factors which govern the strength of portland cement concrete are the relative proportions of cement and mixing water and conditions during curing, great latitude in obtaining desired strengths at a given period can be obtained by adjusting these factors. Sometimes, calcium chloride is used as an accelerating admixture to increase the rate at which concrete develops its early strength. The calcium chloride is particularly effective in increasing strengths at 1 to 3 days. On the other hand, for a given water content, high-early-strength cements give higher strengths than normal portland cement either with or without the accelerator at the later ages up to about one year.

TOWER ACCEPTANCE

Inspection

Most towers are very simple structures physically. Assuming that the tower was designed by a competent engineer to EIA standards and that the number and size of members called for by the manufacturer are adequate, the job of checking should not be too complicated. The following is a suggested checkoff list:

Tower Inspection Checkoff List

1. Has the site been cleaned of all debris, paint cans, reels, and miscellaneous erection junk?
2. Is the tower plumb?
3. Is the tower painted properly—international orange and white—per construction permit?
4. Are the bolts pulled up tight?
5. Are all the nuts secured and locked as called for by the manufacturer?
6. Are the turnbuckles safety-wired to prevent back turning?
7. Is the service entrance cable or conduit attached securely?
8. Check anchor distances against tower drawing.
9. Were holes for the foundations dug deep enough as per drawing?
10. Are the anchor holes backfilled? If not, the first rain will make a sizable depression over the anchor.
11. Is the coaxial system tight?
12. Does the lighting system work?
13. Are all the junction boxes secured with watertight gaskets in them?
14. Look at the face of the tower. Is there any appreciable twist in one face?

15. On large towers, check the guy tensions by the method given to you by the manufacturer.

16. Look at all the members from the ground. Are any of them visibly damaged or bent during the course of construction?

17. Did the erector leave any unpaid bills around town that you know of?

Three chronic complaints about erectors are:

1. Shorting in the lighting system
2. Sloppy paint job
3. Leaks and dents in the coaxial system

General Erection Notes

There is a tendency for the broadcaster to take a long time to decide what tower to buy and then expect an erector on the site before the material has arrived. These boys do not get paid for days they do not work. If they are held up because of lack of material, they resent it! Very often, the broadcaster, with no ill intent, tells the erector that most of the material is on the site and the balance is in transit. This may be true, but unless the last bolt and every piece of coaxial, anchor, and tower is on the site, one can never be sure when it will get there! Less-than-carload shipments are very slow. The erector will cry for extras, and bad feeling begins. You can't blame the erector. Bear in mind that the average erector many times works under adverse conditions and is away from home.

Tower-erection business is very competitive. Most bids are based on the erector's being able to get to the site. He does not necessarily need a four-lane highway, but he should be able to drive the truck to the base of the tower and drive to each anchor. The fact that you can walk on the site does not necessarily mean that it will hold up a truck. He also needs a cleared piece of land to assemble his material.

It is not the erector's responsibility to get a building permit. It is customary for the tower buyer to get all permits simply because they are usually obtained under local conditions which change from town to town all over the country. Sometimes it is a matter of a two-dollar license. In other cases, political intervention or an expensive engineering analysis and approval are required.

Erectors bid on the understanding that they will work regular hours. Overtime is expensive, and one should expect some resentment from the erector when he is asked to work overtime at no extra cost.

It would be wise to allow a somewhat longer time for erection than promised by the erector. He usually thinks in terms of elapsed working days and does not count Sundays, Saturdays, holidays, opening day for fishing, opening days for hunting season, or days or rain, sleet, and high winds. Often winds are 10 mph on the ground but 30 mph aloft at 700 ft (see Fig. 2-35).

Erection work is usually risky work simply because it is off the ground. The more you push the workmen, the more prone to accidents they become. The erector is not going to get paid until he finishes the job, so he, too, is anxious to complete it.

The erector expects electrical power at the base of the tower prior to starting the job. Otherwise, he has trouble getting temporary lights and he will complain.

Erection work is usually thankless and dangerous. Working conditions, because of cold, rain, mud, swamps, rocks, snow, wind, and weather, in general are never so good as those in an air-conditioned factory. The men have to be of a tougher breed. Understanding their problems helps everyone.

Insurance

If a station decides to hire its own erector to install the tower, it is recommended that the following evidence of insurance from the erector (in the form of certificates) be obtained. The following different insurance certificates are customary today:

1. Workmen's compensation and occupation diseases, including employer's liability insurance. *Limits:* This insurance should be checked with the statutory requirements

as applicable in the state in which the work is being performed. Employer's liability should be at least $25,000.

2. Contractor's public liability insurance which covers damage and injury to objects and people not under the care and custody of the contractor. *Limits:* Bodily injury, $15,000/100,000; property damage, $15,000/100,000.

3. Contractor's protective liability insurance protects the contractor with his subcontractors. For example, the contractor may sublet the foundations or sublet the electrical work or paint because of union problems. *Limits:* bodily injnry, $15,000/100,000; property damage, $15,000/100,000.

4. Automobile liability insurance. This covers all motor vehicles owned or leased, including nonownership liability covering contractors' employees' personal cars and trucks. *Limits:* Bodily injury, $100,000; property damage, $100,000.

5. Direct damage insurance. This insurance provides for protection against all risk of the tower, antenna, lines, and the equipment which the erector is working on or material which is in his (erector's) custody until completion of the job. *Limits:* Should be set to cover the value of the tower, lights, coaxial lines, antenna, and any other equipment he is installing, plus erection labor involved.

The owner should have an insurance policy covering any loss to the tower once the tower erection is completed and the customer has accepted the tower. Values are set for replacement values, namely, the price which he has paid for the tower and equipment on the tower plus the cost of erection.

TOWER LIGHTING

Since a tower is a hazard to air navigation, the government prescribes certain warning lights to be installed on the broadcast towers. In general the lighting requirements are spelled out in a pamphlet put out by the FAA called "Standards for Marking and Lighting Obstructions to Air Navigations, November 1, 1953." However, the exact lighting requirements are given very specifically in detail in the construction permit from the FCC for every station. These specific instructions may differ from the general specifications. Since the maintenance of the tower lights is a never-ending problem, it behooves the station management to see what can be done to keep the lighting requirements down. For example, any tower in the shadow of a taller obstruction, such as a taller building, a taller tower, or a taller hill, can usually be installed without any lighting.

The electrical system is essentially very simple. It consists of a number of lamps which are fed by one or more circuits either 110 or 220 60 cycles alternating current. On AM towers, the RF must be isolated from the 60-cycle current. Circuits are made and broken intermittently by a flasher. A photocell is used to turn the lights on and off automatically at certain light levels.

Maintenance of lighting systems as a rule is fairly simple. Lamps burn out and must be replaced. It is possible to double the lamp-replacement period by installing two lamps at every light requirement and connecting these two lamps with a small relay which turns on lamp 2 upon failure of lamp 1.

The most chronic tower-lighting complaint is water getting into the system and causing shorts. Here again, it is a matter of making sure that all connectors and covers are installed neatly and made watertight. It seems that about as many leaks occur in the conduit system as in the system which uses flexible cable.

Some stations with tall towers have experienced broken glass on beacons due to falling ice and have installed small ice shields over the beacons. Most flashers today use a mercury switch to make and break the circuit. These mercury switches are relatively trouble-free. Flashers which use contactors for making and breaking a circuit tend to give trouble because contact points burn and pit.

Tall towers requiring several beacons and side lamps are usually fed with several circuits of color-coded TW wire in rigid conduit. Most short AM towers make use of service entrance cable or any number of flexible cables, since this system is cheaper.

Since the beacon is the uppermost point on a tower, it is usually protected with a

lightning rod, which reaches a couple of feet above the beacon. Most TV antennas have a lightning rod built into the antenna. As a conservative precaution, it is wise to ground physically in the junction boxes the neutral or ground wire in the lighting system at several levels on the tower.

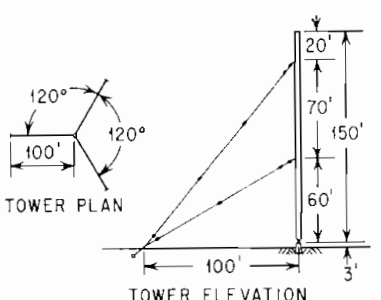
SIMPLIFIED TOWER DESIGN

Calculating Wind Load

The method of calculating wind load on a tower is given in Sec. 2 of EIA Standard RS-222. On triangular tower structures, wind pressure is applied to 1.5 of the projected area of all members in one face. Pressure is applied to the projected area of lighting lines. Calculations below are for 30 psf on flat members and 20 psf on round members.

1. Tower:

Member	External Diameter, in.	Length, in.	Number of pieces	Projected area, ft²
Cross member				
¾ in. I.P.S.	1.05	16.34	8	0.95
Diagonals				
¾ in. I.P.S.	1.05	39	7	1.99
Verticals				
1¼ in. I.P.S.	1.66	240	2	5.53
Total projected area				8.47



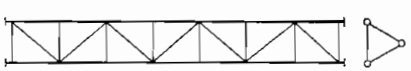


Fig. 2-65. Typical triangular tower section.

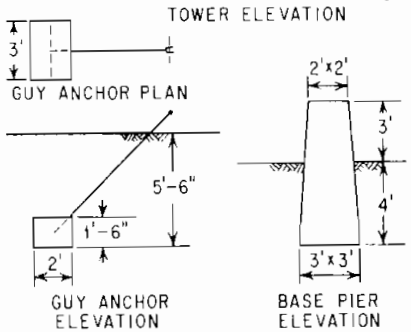


Fig. 2-66. Tower sample analysis.

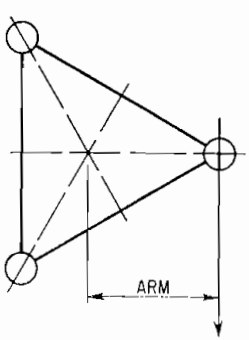


Fig. 2-67. Shear and moment analysis.

Wind load:

$$\frac{\text{Projected area} \times 1.5 \times \text{wind pressure}}{20 \text{ ft}} = \frac{8.47 \times 1.5 \times 20}{20} = 12.71 \text{ psf}$$

2. Lights:

$$\text{Total projected area} = \frac{1 \times 20}{12} = 1.67 \text{ sq ft}$$

$$\text{Wind load} = \frac{\text{projected area} \times \text{wind pressure}}{20 \text{ ft}} = \frac{1.67 \times 20}{20} = 1.67 \text{ psf}$$

3. Total wind load = 12.71 lb/ft + 1.67 lb/ft = 14.38 lb/ft

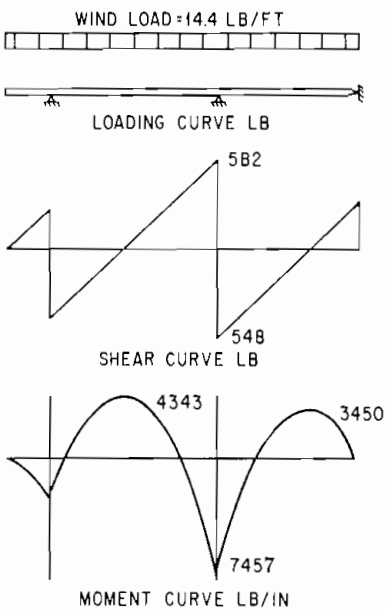


FIG. 2-68. Loading, shear, and moment curves.

Shear, Moment, and Loading

Obtain shears and moments, considering the tower as a continuous beam. Assume that the points of support deflect as a straight line. Use the moment-distribution or similar method. Allow for eccentric application of the load by the guy. The eccentric moment is the vertical component of the load in the guy multiplied by its distance from the center of the tower.

Diagonal Struts

Diagonal struts resist tower shear. Assume that two-thirds of the shear is carried by one face of the tower.

Maximum shear = 582 lb

$$\text{Load} = \tfrac{2}{3} \times 582 \times \frac{34.1}{18} = 735 \text{ lb}$$

Check the strength of the member for compression and for tension using allowable stresses (see RS-222 Par. 3.1.1).

Horizontal Struts

The load in horizontal members is equal to the horizontal component of the load in diagonal members.

$$\text{Load} = 735 \times \frac{18}{34.1} = 388 \text{ lb}$$

Check the strength as for diagonal strut.

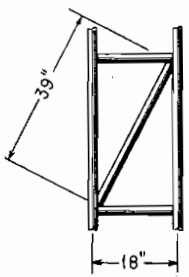


FIG. 2-69. Diagonal and horizontal struts.

Column Load on Tower

The wind direction shown is critical for the column load on the tower. Two guys are on the windward side of the tower and apply a vertical load. Assume that the tension in the leeward guy is negligible, then the load in each guy is

$$\text{Tension} = \text{reaction} \times \frac{\text{length}}{\text{guy radius}}$$

The column load is the sum of the weight plus the vertical components of the guys.

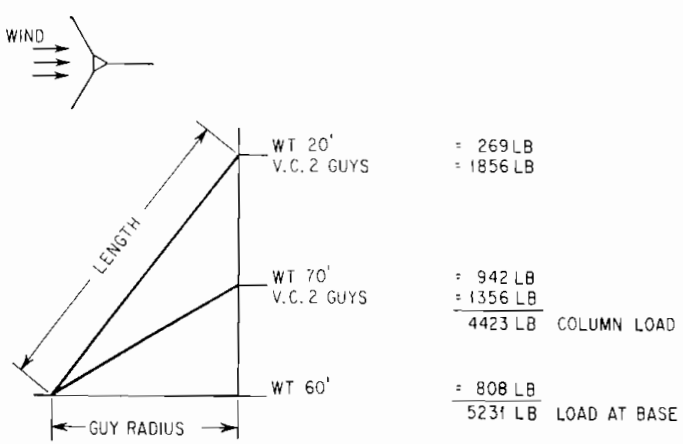


FIG. 2-70. Column-load analysis.

Load in Vertical Member

The vertical members of the tower must be designed for combined compression and bending. The load in a vertical member is equal to the column load divided by 3 plus the chord load due to bending M/d where d is depth. The tower must

be checked for tension in the vertical members and for compression. At the point of maximum moment in the first bay, the member is checked as follows:

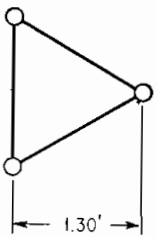


Fig. 2-71. Vertical-member load.

$$\text{Column load} = 4{,}423 \text{ lb}$$

$$\text{Moment} = 3{,}450 \text{ ft-lb}$$

$$\text{Load} = \frac{4{,}423}{3} \pm \frac{3{,}450}{1.30}$$

$$= 1{,}474 \pm 2{,}650$$

$$= 4{,}124 \text{ lb compression}$$

$$= 1{,}176 \text{ lb tension}$$

Check the strength of the member for compression and for tension, using allowable stresses in RS-222 (Par. 3.1.1).

The tower acting as a column between guys may be critical if the slenderness ratio becomes large. In general, if the ratio of the span between guys divided by the face width of the tower is 40 or less for triangular towers and 50 or less for square towers, column action of the tower is not critical.

Guy Load

The load in guys depends on the guying arrangement and on the direction of the wind. For any number of equally spaced guys, there is a critical wind direction, and this direction must be used to obtain the maximum guy load. Critical loads for three-way guying are shown in Fig. 2-72.

By statics

$$\text{Horizontal component (guy } A) = \frac{\text{tower reaction}}{\cos 30°}$$

$$\text{Horizontal component} = \frac{R}{0.866} = 1.154R$$

and

$$\text{guy tension} = T = 1.154R \times \frac{L}{d}$$

In practice, especially on tall towers, an allowance is made for wind loads on guys and for erection tension or initial tension in guys. EIA Standard RS-222 (Par. 8.2)

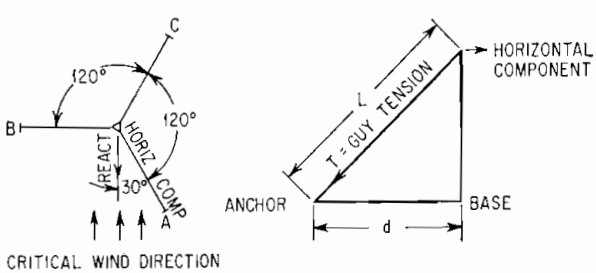


Fig. 2-72. Critical loads for three-way guying.

requires a factor of safety of 2.5, based on the ultimate strength of the guy strand.

For a sample tower, guy loads are as follows:

Guy No.	R, lb	L, ft	d, ft	Crit. guy load, lb	Guy size, in.	Ultimate strength, lb	Factor of safety
1	1,130	117	100	1,526	1 × 7 × 1/4 E.H.S.*	6,650	4.36
2	714	164	100	1,350	1 × 7 × 1/4 E.H.S.*	6,650	4.93

* Extruded Hardened Steel.

Foundation Loading

1. Base foundations must be proportioned so that the area of the base is greater than the total column load plus the weight of the concrete pier divided by the allowable soil bearing pressure.
2. By EIA, RS-222, bearing pressure for normal soil is 4,000 psf.
3. Applied column load = 5,230 lb
   Weight of concrete pier 44.3 cu ft at 140 lb/cu ft = 6,200 lb
   Total load on base = 11,430 lb
   Bearing pressure = $\frac{11{,}430}{3 \times 3}$ = 1,270 psf
4. Bearing pressure is considerably less than 4,000 psf, and the pier has a large factor of safety.

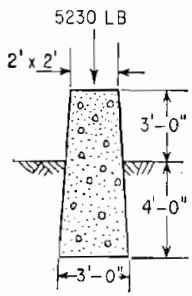


FIG. 2-73. Base-foundation analysis.

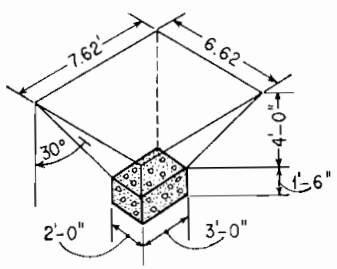


FIG. 2-74. Guy-anchor analysis.

Guy Anchors

1. Guy anchors are designed for the resultant load of guys when the wind is blowing in the critical direction.
2. Vertical load is resisted by weight of concrete and earth overburden. EIA specifies in uplift that the foundations shall be designed to resist two times more than the applied load assuming that the pier engages a 30° frustrum as an earth overburden. Resistance to horizontal load is provided by friction on the base of the anchor and by lateral resistance of soil on the face of the anchor. Friction on the base is usually small and is neglected. Lateral resistance can be obtained by Rankine's formula for passive resistance:

$$P = wh \frac{1 - \sin \phi}{1 + \sin \phi}$$

where P = resistance, psf
w = unit weight of earth — 100 lb/cu ft
h = depth to point considered — 4.75 ft
ϕ = angle of internal friction of soil assumed to be 30°

$$P = 100h \frac{1 + 0.5}{1 - 0.5} = 300h = 300(4.75) = 1{,}425 \text{ psf}$$

3. Allowable uplift on anchors:

$$\text{For weight of earth: } \tfrac{1}{3}(6 + 50.4 + \sqrt{302.4}) = 98.5 \text{ cu ft}$$
$$98.5 \text{ cu ft} \times 100 \text{ lb/cu ft} = 9{,}850 \text{ lb of earth}$$
$$\text{For weight of concrete: } 2 \text{ ft} \times 3 \text{ ft} \times 1.5 \text{ ft} = 9 \text{ cu ft}$$
$$9 \text{ cu ft} \times 140 \text{ lb/cu ft} = 1{,}260 \text{ lb of concrete}$$
$$\frac{9{,}850 \text{ lb}}{11{,}110 \text{ lb}} \text{ of earth} \times \tfrac{1}{2} = 5{,}555 \text{ lb allowable uplift}$$

4. Allowable horizontal load on anchor

$$= \text{resistance psf} \times \text{frontal area}$$
$$= 1{,}425 \text{ psf} \times 3 \text{ ft} \times 1.5 \text{ ft}$$
$$= 6{,}420 \text{ lb}$$

Part 3

STANDARD BROADCAST ANTENNA SYSTEMS

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PREFACE

The purpose of this section is to furnish useful information to the engineer, technician, and operator in a broadcasting station. The material is divided into text and handbook types of presentation. An effort has been made to approach each new subject gradually in the text, while in the appendices, design equations and data have been presented in handbook style with the aim of making them most useful to the technician and operating engineer.

First, the single tower is analyzed. It is then used as elements in a two-tower directional-antenna array before going to the more complicated arrays.

Antennas form the dominant theme supported by other items such as coupling networks and monitoring circuits. The topics of adjustments and field measurements are treated in a way thought to be most useful to a man in the field.

INTRODUCTION

The chief purpose of a radio-broadcasting antenna is to radiate the energy supplied by the transmitter efficiently. A simple antenna can do this job quite well. It is usually a vertical tower that radiates the energy equally in all directions along the ground.

A secondary purpose of the antenna system may be to concentrate the amount of radiation in the directions that it is wanted and to restrict the radiation in the directions it is not wanted. This may require a very complicated directional-antenna system if the requirements are great.

The antenna is the last point in the system under the control of the radio-broadcasting station. Radio waves radiated from the transmitting antenna are propagated through space to the receiving antenna. The only control over these propagated waves is in the selection of the antenna site, the polarizations, and the strength of the signals leaving

the transmitting antenna. The selection of the antenna site is determined by many considerations, such as ground constants, terrain, distance and direction to populated areas to be served, distance and direction to the areas to be protected, and last but not least the availability of a suitable land area to install the necessary towers and ground system.

For standard broadcast stations, vertical polarization is used because of its superior ground-wave-propagation characteristics and the simplicity of antenna design. The strength of the signal from the transmitting antenna, in any given direction, depends upon the output power of the transmitter and the antenna design. Since the output power is regulated by the Federal Communications Commission for the class of stations involved, the only factors remaining under the engineer's control are the antenna location and design. These factors go hand in hand when designing directional antennas for broadcast purposes.

THE SINGLE-TOWER NONDIRECTIONAL ANTENNA

Current and Voltage Distribution

The vast majority of radio-broadcasting stations have single-tower antennas that are neither top-loaded nor sectionalized. Most of them have an insulator near the ground. Such towers all have a current distribution with a zero value at the top as shown in Fig. 3-1. The maximum value of current is 90° down from the top on a theoretical

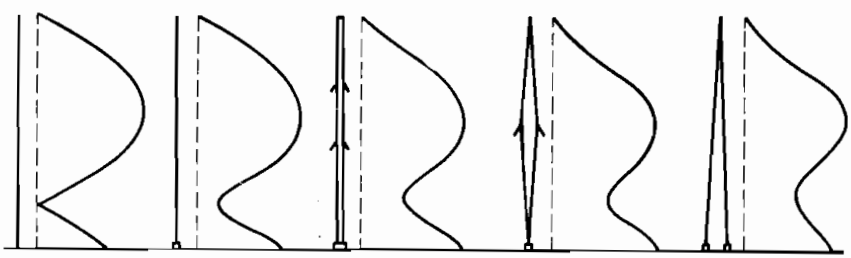

FIG. 3-1. Practical compared with theoretical current distribution on vertical radiator.

antenna, while on all practical antennas it is less than 90° down from the top. This is owing to the fact that the velocity of propagation slows down as the cross section of the tower is increased. For the average uniform-cross-section tower the current maximum is about 84° down from the top.*,[1]

The general shape of the current distribution on a tower is that of a sine wave given by

$$i_a = I_a \sin (G - y) \tag{3-1}$$

where i_a = current amplitude at distance y above the ground as shown in Fig. 3-2*a*, amp
I_a = maximum current amplitude, amp
G = height of antenna, deg
y = height of current element i_a, deg

For most purposes it is entirely satisfactory to consider the current distribution as an exact sine wave through this equation. This is practically true for a vertical wire as shown in Fig. 3-1*b*. It is also a good approximation for a uniform-cross-section tower as illustrated in Fig. 3-1*c*. For the diamond and tapered types as shown in Fig. 1*d* and *e*, the approximation may not be satisfactory.

* Superscript numbers refer to References on page 2-110.

The general shape of the voltage distribution is very nearly that of a cosine wave as shown in Fig. 3-2 for the theoretical case and is expressed by the equation

$$e_a = E_a \cos (G - y) \tag{3-2}$$

where e_a = voltage amplitude at distance y above the ground as shown in Fig. 3-2*b*, volts
E_a = maximum voltage amplitude, volts
and G and y are as defined in Eq. (3-1). If the tower is not tall enough for the current distribution to have a minimum below the top of the tower, then the maximum value of voltage will be at the top of the tower. It is necessary to visualize the shape of the

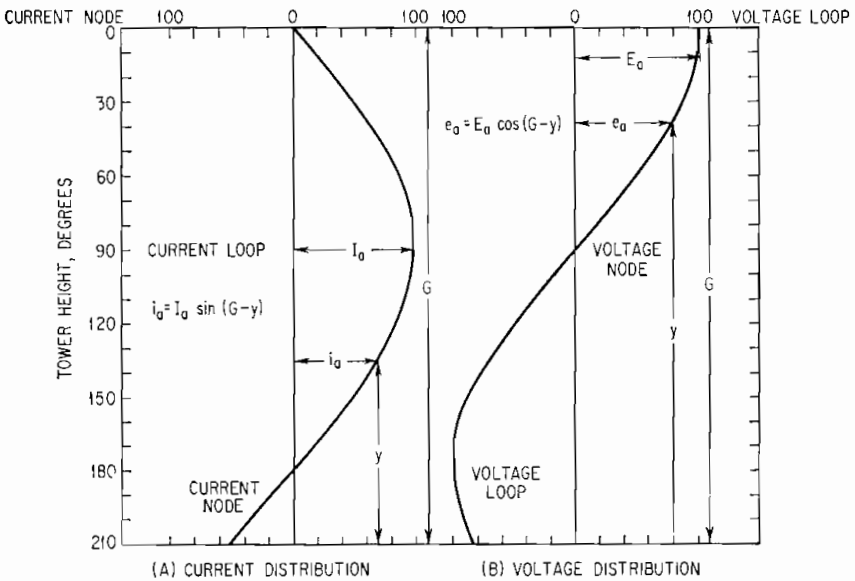

FIG. 3-2. Theoretical current and voltage distribution on a vertical radiator.

voltage distribution along the tower because of the need of good insulators at the high-voltage points. If sufficient insulation is not provided in the guy cables or at the tower base, the current may arc-over at these points and disrupt the broadcasting service. If the initial design has poor insulation, then redesign with adequate insulation should be considered.

Some towers are not insulated at the base. Such towers are shunt-fed at some point above the base. This type of tower is less expensive, has no dangerous base voltage, and is less vulnerable to lightning. The feed line can be used to some extent as the matching network to couple the transmitter or transmission line to the tower. The current distribution above the feed point is essentially the same as for a base-insulated tower.[1] The current below the feed point deviates materially from a sine wave as shown in Fig. 3-3. This is of little consequence in nondirectional operations. It cannot be tolerated in critical directional-antenna systems because of its effect on deep minima of the radiation pattern.

By proper design the coupling can consist of a slant feed cable with a series capacitor to couple into the transmission line. In general, as the height of the feed point on the tower is raised, the resistance and positive reactance increases. When the horizontal distance to the feed point from the tower base is increased, the resistance and positive

reactance decreases. The exact position of the shunt feed line can best be determined by experiment.

The slant cable can consist of two parallel cables properly insulated and having the proper physical dimensions. Such an arrangement can be adjusted to couple directly into a transmission line.

Another method which eliminates the undesirable radiation effects of the slant line is to connect several cables to the tower one-quarter wave ($\lambda/4$) from the base and stretch them down to the ground with insulators at the lower end. These cables form a short-circuited one-quarter-wave ($\lambda/4$) transmission line which is open-circuited at the base, thus making it possible to feed the tower through these cables connected in parallel.

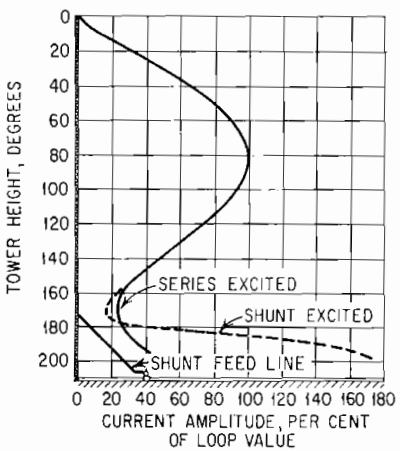

FIG. 3-3. Experimental current distribution on shunt- and series-fed tower. (*Morrison and Smith, Proc. IRE, June, 1937.*)

Sectionalized towers have been used for some time and have taken on added importance with the advent of FM and TV broadcasting. A sectionalized tower, in addition to the ordinary base insulator, has one or more insulators in the tower above the base. Very tall towers are often used to support FM and TV antennas in order to achieve the desired height above average terrain for maximum coverage of the FM or TV station. If this is the sole objective, the tower does not have to be sectionalized with insulators.

In some cases a tall tower is sectionalized for the purpose of preventing undesired reradiation when in the vicinity of AM towers, particularly if the other towers are elements of a directional-antenna array. In other cases it is desired to use part or all of the sectionalized tower as active AM radiating elements. This may not be so easy to accomplish as one would expect. Moreover, it requires considerable effort and planning to design the system properly. The Federal Communications Commission will require proof that the antenna system is operating properly, especially if the sectionalized tower is near or part of a directional-antenna array.

Sometimes a tall sectionalized tower is constructed for the purpose of obtaining greater AM broadcast coverage by properly controlling the current distribution on the tower.[2,3] When towers are sectionalized for this purpose, considerable attention is given to the current distributions on the various sections of the tower. This is necessary because the radiation from the current elements on each section must add properly to produce the greatest or optimum field-strength effects. It is well worthwhile to look seriously into these possibilities, even if the tower is to be used for FM and TV operations in addition to AM operation.

Vertical-radiation Characteristic

A nondirectional tower, whether series- or shunt-fed, sectionalized or nonsectionalized, top-loaded or without top loading, has its own vertical-radiation pattern sometimes called its vertical-radiation characteristic. This is simply the amount of signal radiated at all elevation angles above the horizontal plane with respect to the horizontal-plane radiation. Its calculation is usually made using the assumption of sinusoidal current distribution on the radiating portion of the tower.

The current distribution can be controlled by the height and shape of the tower. On a sectionalized tower the magnitude and phase of the current on the lower sections can be controlled with respect to the current on the top section. This permits such a tower to possess a family of vertical-radiation characteristics.[2,3]

The vertical-radiation characteristic of a vertical nonsectionalized, base-insulated tower is given by

$$f(\theta) = \frac{\cos(G \sin\theta) - \cos G}{(1 - \cos G)\sin\theta} \tag{3-3}$$

where $f(\theta)$ = vertical radiation characteristic
G = electrical height of antenna, deg
θ = elevation of observation point, deg

The derivation of Eq. (3-3) is given in Appendix A as a special case for a sectionalized tower when the top section is zero. The curves showing $f(\theta)$ as a function of height were published in several forms in the 4th edition of the "NAB Engineering Handbook."[4] The most useful form is reproduced in Appendix A.

Self-impedance

A radio tower has a different impedance at every point along its height. Two points are of special interest. One is at the current loop which is the current maximum approximately 90° down from the top of the tower if it is not top-loaded, and the other is at the point where the tower is fed at the base.

Much effort has been made in recent years to find a reliable means of calculating the base impedance of a tower. The average characteristic impedance, usually called Z_0 of the tower appears to play an important role in such calculations.[4]

Assuming a sinusoidal current distribution and the conservation of power between the loop and the base for a simple tower without top loading, the base and loop radiation resistances can be related by the simple equation

$$R_{\text{base}} = \frac{R_{\text{loop}}}{\sin^2 G} \tag{3-4}$$

where R_{base} = base radiation resistance, ohms
R_{loop} = loop radiation resistance, ohms
G = height of tower, deg

This equation for base resistance is quite reliable for antenna heights up to 120°. The loop and base radiation resistance along with the theoretical field strength, assuming a perfect ground, are shown in Appendix A.

It should be remembered that any set of calculations may not and usually will not agree with the actual values determined from measurement after the tower has been constructed. For this reason about the best that one can hope for is to make as intelligent an estimate as possible. The base impedance is affected by stray capacity and inductance effects and may be considerably different from the approximate theory when the tower is of the order of a half wave ($\lambda/2$) high.

The loop impedance of a single tower serves an important role by virtue of the fact that the calculated base impedance usually disagrees with the measured value and also because some towers are fed at or near the loop point. For example, a 90° tower fed at its base is also approximately fed at its loop; thus

$$Z_{\text{base}} = Z_{\text{loop}} = 36.6 + j21.3 \tag{3-5}$$

where Z_{base} = base impedance, ohms
Z_{loop} = loop impedance, ohms
$j = \sqrt{-1}$, making the second term an inductive reactance

This means that the antenna is series resonant, without reactance, when the height G is slightly less than 90°.

Ground System

A single AM tower is not complete without a ground system. To feed power into such a tower it is common practice to couple the output of the transmitter across the base insulator. The tower base forms one terminal, and the ground system forms the other terminal. Simple antenna theory assumes the ground plane to be a perfect conductor which acts like a mirror plane to the radio waves. In practice it is not a perfect

conductor and may introduce a series-ground-loss resistance from a fraction of an ohm to several ohms.

A rather common rule of thumb is to use 2 ohms' loss resistance for the copper-wire ground system consisting of 120 radials 90° long. This ground-loss resistance can be

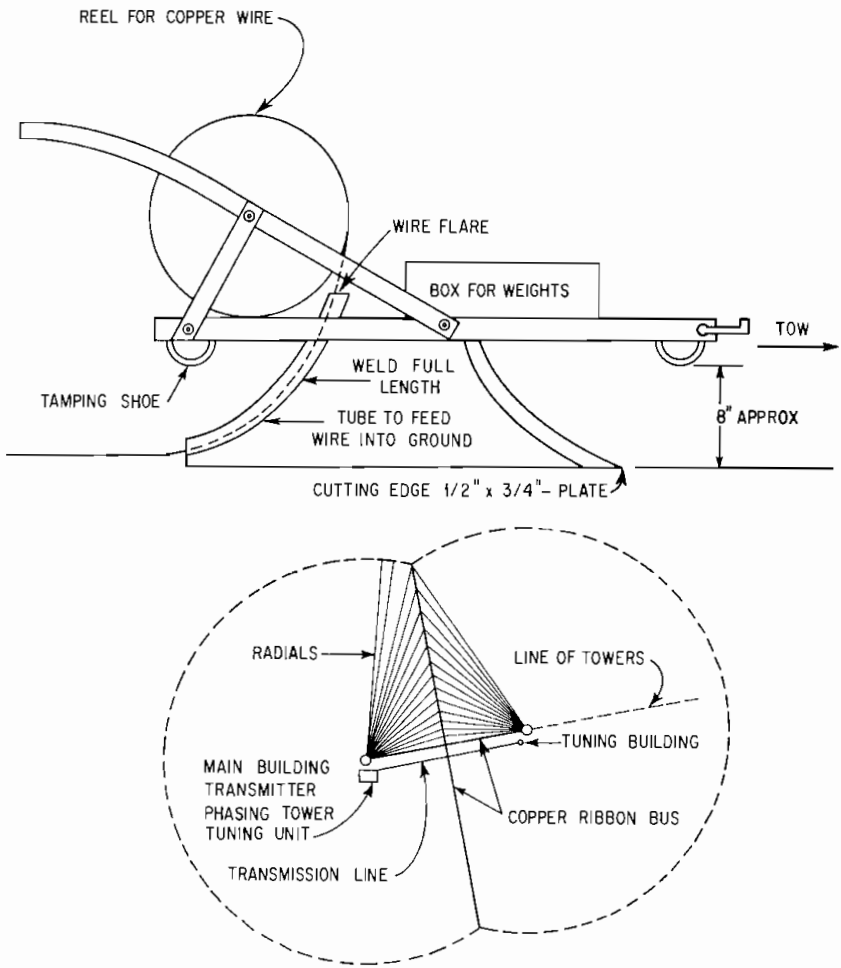

FIG. 3-4. Design of plow for laying ground wires and typical two-tower ground system.

decreased by reducing the E loss due to the electric field and the H loss due to the magnetic field.

When the tower is near a half wavelength in height, there is a voltage maximum at the base with a resulting strong electric field that results in high E losses owing to the displacement current passing from the antenna through the earth to the radial ground wires. This loss can be materially reduced by using an expanded copper screen around the antenna base or increasing the number of radial conductors and placing them very near the surface or under a layer of asphalt pavement which has very low loss for the electric displacement current.

The H loss due to the magnetic field extends out a considerable distance. This loss

is due to the radial current which divides between the ground conductors and the earth. It can be decreased by increasing the number of conductors and extending their length. This will cause a larger portion of the current to be in the copper radials where the resistance is very low.

A typical ground system may consist of No. 10 copper wire buried 4 to 12 in. deep. Usually this area is made into meadow or grassland that is mowed often enough to prevent tall grass that may cause considerable E loss under certain conditions. If it is necessary to till the soil, the wires must be buried deep enough to avoid mechanical injury.

It is common practice to use a wire plow, as shown in Fig. 3-4, to lay the ground system. The wire plow consists of a thin vertical steel blade to cut a slit in the ground. At the rear edge of the blade there is a small tube through which the copper wire passes from a wire reel into the ground. The depth of the ground wire can be controlled by the adjustment of the vertical blade with respect to horizontal sled runners or wheels which support the plow mechanism. Soft- or medium-hard-drawn copper wire is easier to handle in the field than hard-drawn copper wire. It can also stand more mechanical stretching before breakage occurs.

The radial wires are usually plowed in, starting from the tower, and driving a tractor pulling the plow toward a guidepost at the edge of the ground system. It is convenient to provide a copper wire or cable ring around the tower base to which each radial ground wire can be mechanically fastened while the radial is being installed. The radial wires must then be soldered or brazed to this ring to provide a good electrical connection. Copper ribbon can then be bonded to the copper ring and run to the ground-system terminal of the antenna. Copper-clad stakes are commonly used to hold the copper ring in place and act as a lightning ground. These stakes are driven down level with the copper ring, and the two are brazed together to form a good electrical connection.

Expanded copper mesh is commonly used inside the copper tie ring or square. Its primary purpose is to terminate the E field. Its secondary job is to carry the radial ground-system current. However, if the amount of copper in the mesh is inadequate, then radial copper straps can be added in this area and bonded to the expanded copper mesh.

Tower Lighting and Painting

The Federal Communications Commission has rules for suitably lighting and painting radio towers so they can be seen from aircraft, thus minimizing their hazard. They are also marked on the aeronautical charts used by aircraft pilots. Part 17, Construction, Lighting and Marking of Antenna Structures, of the FCC Rules and Regulations covers this subject thoroughly.

In brief, it is necessary to provide warning lights at the top and fractional elevation levels of the tower. For tall towers flasher beacons are required at the top and some intermediate levels. For base-insulated towers it is necessary to transfer the a-c power across the base insulator. This is commonly done by RF choke coils, Austin-type power transformers, or the use of quarter-wave ($\lambda/4$) isolating stubs.

Radio towers must be painted with alternate strips of international orange and white paint. The number and width of the strip are covered in the above regulations.

Lightning Protection

Radio towers are vulnerable to lightning; hence it is very important to provide the necessary protection. Lightning rods should be provided at the top of the tower to protect the flasher beacon. Choke coils, large values of resistance, oil-filled insulators, or isolation stubs should be used to drain the static charges across the sectionalizing and base insulators. Ball gaps or horn gaps should be placed across the insulators to carry the high current surges.

The ground system around the tower base should have nonfusible cable or conductor. It is good practice to terminate these cables in copper-clad ground rods not far from the tower base. In some cases the radial ground system itself may be adequate to handle the lightning surges.

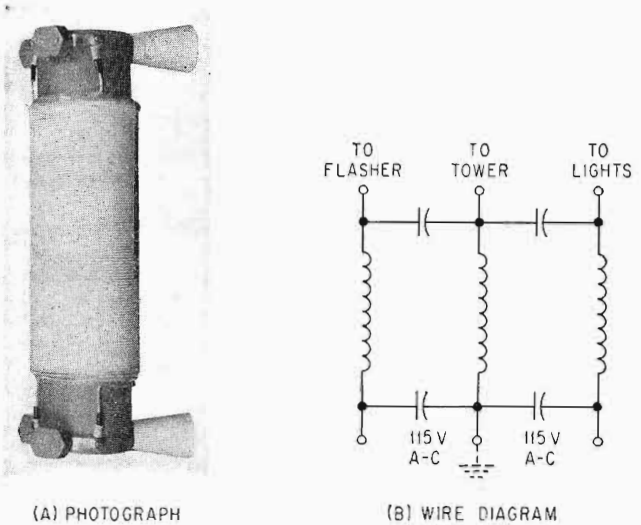

Fig. 3-5. Antenna-lighting choke coil.

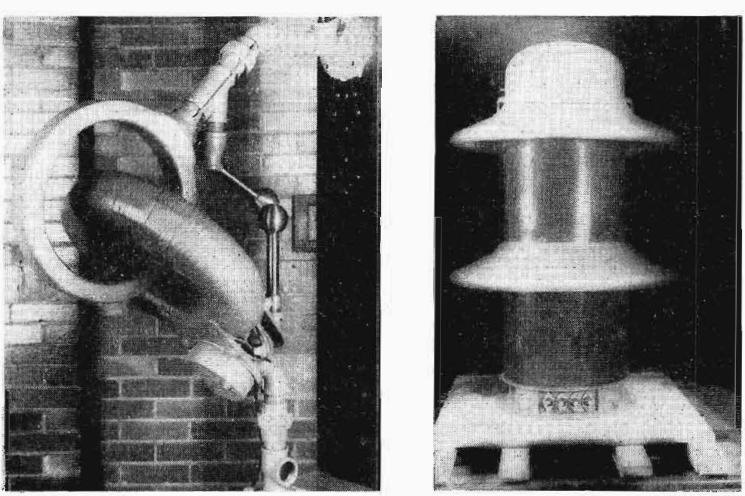

Fig. 3-6. Austin-type transformers: (*a*) Air-insulated. (*b*) Oil-insulated.

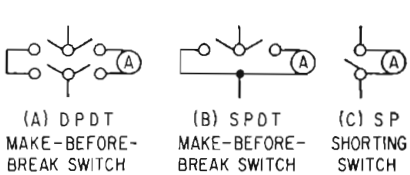

Fig. 3-7. Typical antenna meter switching circuits.

An important consideration is the protection of the base current antenna meter and the RF coupling equipment. It is good practice to provide a tower-grounding disconnection switch on the antenna side of the RF coupling equipment for the protection of technical personnel that must maintain it. During operation the antenna terminal of the RF coupling equipment should have a horn-gap path so lightning discharges can be bypassed directly to ground. The lightning paths should be as direct and short as possible to ground

With regard to the RF antenna meter the best practice is to connect it into the circuit with a double-pole-double-throw (DPDT), make-before-break switch, as shown in Fig. 3-7*a*. The meter can then be inserted or removed completely from the circuit during operation. When removed from the circuit, there is very little chance for lightning to injure it because there are no metallic connections to it. The meter is always removed from the circuit except when it is necessary to make a reading. It is sometimes necessary to adjust the length of the shorting loop so it will have the same inductance as the meter loop.

A less expensive and less desirable method is to use a single-pole-double-throw (SPDT), make-before-break switch as shown in Fig. 3-7*b*. The least expensive and least desirable method is to use a single-pole (SP) shorting switch as shown in Fig. 3-7*c*. The shorting switch shunts most of the current around the RF meter; however, a lightning surge may be sufficient to injure it.

It is difficult to predict what a lightning stroke will do, particularly if it is a direct hit on the tower. The stroke may jump to the transmission-line side of the coupling network; hence it is advisable to provide lightning-protection gaps at the tower end of the transmission line.

Adjustments

A transmission line can usually be coupled into a tower by the use of a series and shunt element. If the tower is in a directional-antenna array, then three tuning components are usually employed so the phase can also be controlled at this point.

Usually it is necessary to design and order the coupling network components before the tower and ground system are installed. In this case sufficient latitude must be allowed for variations of the inductive and capacitive components to match into the tower impedance from the transmitter or transmission line. If the tower and ground system are already installed, antenna input impedance measurements can be made at the operating frequency. It is therefore possible to determine, quite accurately, the value of the components required, but even in this case it is advisable to provide a reasonable tolerance for adjustment in the field.

The problem of coupling a transmission line to a sectionalized tower is usually much more involved. The sectionalized tower is, in effect, a collinear vertical directional-antenna system and therefore should be provided with both magnitude and phase control for each of the several elements. For this type of antenna it is usually desired to obtain the optimum vertical-radiation characteristic. If this is done, the results should be checked by field-strength measurements. In this type of antenna it is desirable to provide considerable latitude in variations of the adjustment components.[2,3]

The design information necessary for matching from the transmission line into the antenna is covered in Appendix B.

Inverse Field Strength at 1 Mile

The inverse field strength at 1 mile, sometimes referred to as the unattenuated field strength at 1 mile, is the field strength at 1 mile when the only attenuation is that of distance. It is a theoretical value and is considered primarily for comparison purposes. This concept removes the frequency and ground attenuation effects. Nondirectional- and directional-antenna patterns can be compared on this basis.

The vertical-radiation characteristic, for example, is merely a comparison of the inverse field strength at 1 mile at all elevation angles above the horizontal plane with the inverse field strength at 1 mile in the horizontal plane. When it is necessary to express the radiation from an antenna the value is usually given as the horizontal-plane

inverse field strength at 1 mile. It can be expressed either with or without the inherent losses of the antenna system.

When submitting inverse-field-strength information to the Federal Communications Commission it is common practice to include the antenna-system losses. Nondirectional antennas produce but one such value, since the input power is determined by direct input-power measurements. In other words, the input power is determined by multiplying the measured input resistance by the square of the antenna current measured at the same point. In equation form,

$$P_a = I_a^2 R_a \tag{3-6}$$

where P_a = antenna power input, watts
I_a = antenna current, amp
R_a = antenna resistance, ohms

A nondirectional antenna theoretically produces only one value of inverse field strength at 1 mile, which is the same at all horizontal bearings from the antenna. Nondirectional-antenna patterns are graphically described by a circle, the radius of which is the inverse field strength at 1 mile. The pattern of a single-tower radiator is usually considered to be nondirectional. If the feeder is nonsymmetrical, such as in the case of a shunt-fed antenna, or if there are objects which reradiate in the vicinity of the tower, the horizontal pattern will not be circular or nondirectional but will have some directivity.

If the horizontal pattern is directional or nondirectional, its equivalent nondirectional effectiveness can be expressed as the root-mean-square (rms) inverse field strength at 1 mile, or simply its rms value. The rms value is the radius of a circle which has the same area as the pattern formed by all the inverse-field-strength values at 1 mile in all horizontal directions.

A directional-antenna pattern can be quite well described by plotting the inverse-field-strength values at 1 mile at intervals of 10° on polar graph paper. The rms value of the pattern can be obtained by taking the square root of the sum of the squares divided by the number of squared values, thus

$$E_0 = \sqrt{\frac{E_{10}^2 + E_{20}^2 + E_{30}^2 + \cdots + E_{360}^2}{36}} \tag{3-7}$$

where E_0 = rms field strength, mv/m
E_{10} = inverse field strength at azimuth angle of 10°, mv/m
E_{20} = inverse field strength at azimuth angle of 20°, mv/m, etc.

The rms value can also be obtained by using a polar planimeter to measure the area and determining the radius of the circle having the same area. This radius is the rms value of the pattern in the same units used to plot the directional pattern. It is common practice to measure the field strength and plot patterns in millivolts per meter, abbreviated mv/m.

The Federal Communications Commission does not normally require proof of performance measurements on single-tower nondirectional antennas. Therefore measured values of inverse field strength of nondirectional antennas are not in general available to the public at the reference room of the FCC, Washington, D.C. The description of existing towers of nondirectional radio stations is usually not complete except as to height and type. In most directional-antenna proof-of-performance reports it is required to show nondirectional measurements on a single tower in the array either before the other towers are erected or when the other towers are detuned so they will contribute a minimum of reradiation. This information is available at the reference room of the FCC.

Attenuated Field Strength

The attenuated field strength is the amount of signal left after it has been diminished by distance, ground conductivity, ground inductivity, and all other effects encountered by the signal between the antenna and the point of measurement. The field strength

is also a function of the operating frequency and unattenuated field strength at 1 mile in the direction from the antenna toward the measuring point.

Only after a tower is constructed is it possible to determine the actual attenuated field strength at any point. Sometimes a test antenna and transmitter are installed at a proposed site to determine more precisely the coverage or interference to be expected. The attenuated field strength is determined by measurement with a field-strength meter properly calibrated and operated.

When the unattenuated rms field strength is needed to prove compliance with minimum requirements, it is necessary to make proof-of-performance measurements on a nondirectional antenna. This consists of a set of attenuated field strength measurements made on each of eight or more radials. The attenuated measurements are then used to determine the unattenuated field strength at 1 mile in the direction of each radial. The manner of taking measurements and the means of analysis are fully described in the Technical Standards of Part 3, Radio Broadcast Services, of the FCC Rules and Regulations.

TWO-TOWER DIRECTIONAL ANTENNA

Radiation-pattern Shape

One purpose of a directional antenna is that of producing a greater radiation in one or more directions than a nondirectional antenna would produce with the same power. Another purpose is to produce a small radiation in one or more directions. The latter consideration is more often required than the former because it is the rule rather than the exception that when a directional antenna is required, its radiation pattern must be so designed that it will not cause interference in any area, thereby depriving that area of one or more existing services. Or if this is not possible, the interference that is created must be limited to population that would feel the impact of losing service least. In other words if interference must be caused to some population, it is more desirable that it be caused to population that already has plenty of service rather than to population that has a meager amount of service or no service at all.

An existing radio station is faced with the same type of interference problem if it desires to change its directional-antenna pattern or if its directional antenna gets out of adjustment. A careful theoretical study of the two-tower directional antenna provides the owner and operator with a very useful tool for maintaining the correct operation.

The two-tower directional antenna, besides being the simplest of directional antennas, if often a basic unit of a three-tower or more array. It may be compared with a single tower in the following respects: The signals produced are but one signal as far as the receiver is concerned. Each tower produces a pattern having an rms value that must be above a specified minimum value according to the FCC rules. The current and voltage distributions on the towers in a directional-antenna array are usually assumed to be sinusoidal and cosinusoidal, respectively, just as they are on a nondirectional antenna. The vertical-radiation characteristic of each tower is defined in exactly the same way. The two-tower operation converges to a single-tower operation if the tower heights are equal, the phasing of the currents in the towers are the same, and the spacing of the two-tower array approaches zero.

This is as far as one can go in comparing the single- and two-tower operations. The two-tower operations are different in the following respects: The spacing of the towers in the two-tower array makes the instantaneous signal of one tower out of phase with the corresponding instantaneous signal for the other tower. This means that the towers can be spaced so that the signal can be made to add or subtract as desired. This, of course, cannot be done with a single tower. Also by means of phasing circuits it is possible to control the instantaneous signals from each of the towers in the two-tower array. Usually the phasing circuit is placed in only one of the tower circuits, since the object of interest is to control the phase of the current in one tower with respect to the phase of the current in the other tower. Furthermore, the magnitude of the current in one tower can be controlled with respect to the magnitude of the current in the other tower. This

permits the control of minima depth in the directional antenna pattern. Thus, the spacing, phase, and current ratio controls available in the two-tower array are not available in the single tower, which must have a circular pattern.

To understand better the two-tower directional antenna, consider the following description. Let one tower, say tower 1, be the reference tower and fixed in location. Let the other tower 2 be free to move on a straight line, say due north from tower 1. Let us also by means of the phasing and coupling circuits maintain the same electrical phasing and current magnitude in the two towers. Let us further assume that a person P_n is due north of tower 1 and that another person P_s is due south of tower 1. Now, if tower 2 is gradually moved north, P_n will note that the signal from tower 1 is being received at the same time as before but that the signal from tower 2 is being received sooner. The person P_s will note that the signal from tower 1 is being received at the same time as before but that the signal from tower 2 is being received later. The person P_n might say that the signal from tower 2 leads the signal from tower 1, while the person P_s will say that the signal from tower 2 lags the signal from tower 1.

Actually the persons P_n and P_s can observe only the combination signal from towers 1 and 2. When tower 2 is moved 180° north of tower 1, the person P_n will note an absence of signal. This means that the signal from tower 2 leads the signal from tower 1 by 180°, and since the signals are the same magnitude, they cancel and produce a null effect. The person P_s will also note a null effect which is due to the signal from tower 2 lagging the signal from tower 1 by 180°.

Now, consider person P_e due east and person P_w due west from tower 1 and observing the resulting signal in these directions. They will both note at all times, regardless of the location of tower 2, that both signals arrive at the same time. Hence, the signals are always in phase and add completely. When the towers are spaced 180° and are in phase, it is therefore seen that the pattern has the shape of a figure eight with the lobes east and west and the nulls north and south. This case is illustrated in column 1 of Figs. B-3 and B-9.

One other pattern will be similarly described. Let all the above assumptions hold except that tower 2 is now always phased by means of the electrical phasing circuits to be 90° ahead of tower 1. Now when tower 2 is 90° north of tower 1, the person at P_n will note that the signal from tower 2 leads the signal from tower 1 by 180° and therefore complete cancellation occurs, with the result of a null. The person P_s will note that the signal from tower 2 is exactly in phase with the signal from tower 1 and therefore they completely add to form a lobe. The persons P_e and P_w will receive a signal 41 per cent greater than the individual signal from tower 1 or 2 because these signals are 90° out of phase. This pattern has the shape of a cardioid with the lobe to the south and the null to the north. This fact can be further explored by referring to column 3, Fig. B-3, or column 2, Fig. B-8.

The above two patterns just described serve to illustrate the effect of both spacing and phasing. From this it is seen that the pattern shape is affected both by the spacing and phasing. The above discussion pertains only to the pattern shape in the horizontal plane. For the more general case see Appendix B, Two-tower Directional Antennas.

Radiation-pattern Size

The Federal Communications Commission provides specific amounts of power for the various classes of radio-broadcasting stations. The rules permit the following amounts of power; 100, 250, 500, 1,000, 5,000, 10,000, 25,000, and 50,000 watts. It is therefore necessary to select the value of power to be used and make sure the individual towers will produce enough inverse field strength at 1 mile so the rms of the directional-antenna array will meet minimum radiation requirements of the rules. The pattern used for rms size consideration is the one in the horizontal plane. If the directional antenna is inefficient, the rms pattern may be too small. It is therefore important to be able to determine pattern size.

There are many factors involved in determining the pattern size of a directional-antenna array. The principal ones are phasing, spacing, and height of the towers and the ground-system resistance losses. The pattern size can first be determined assuming no loss in the directional-antenna system. This value is computed from a formula which is

based on one tower operating alone, the self-resistance of both towers, the mutual impedance between the two towers, the current ratio, and the relative current phase. The total resistance losses of the directional-antenna system are commonly computed by assigning a series loss resistance to each tower.

The mutual impedance between two towers can be calculated from cumbersome formulas, or it can be found more quickly by graphical means. The mutual impedance between equal-height towers for various spacings is given in Fig. B-14. The mutual impedance is referred to the loop, or maximum current position. It is convenient to use the loop values for computation but necessary to use the base mutual-impedance values when tuning up a directional-antenna array.

The procedure for determining pattern size is to use the above factors in the formula, as given in Appendix B, page 2-118, to calculate the field strength of the reference tower when operating in the directional-antenna array. The field strength from the other tower can then be obtained by applying the field ratio that was used to determine the pattern shape in the horizontal plane. The use of these values of E_1 and E_2 in the horizontal-pattern formula results in the correct-sized pattern.

RMS Field Strength at 1 Mile

It is now possible to calculate the rms field strength of the directional-antenna pattern in the horizontal plane. The appropriate formula in Eq. (B-14) is easy to apply, and the results are accurate. Moreover, these calculations serve as an excellent check on the rms of the plotted pattern which can be measured by using a polar planimeter or Eq. (3-7).

Monitoring System

Practically all directional antennas have monitoring systems consisting of individual antenna current meters, a common-point input current meter, and a phase monitor to give the relative phase between the towers. Most directional antennas have antenna meters at each tower base and corresponding remote meters in the transmitter operating room. This makes it possible for the operator on duty to observe the operating conditions continually and make the necessary log entries.

Usually, when the directional antenna is installed, all the antenna meters are calibrated against a meter of known accuracy. Sometimes RF meters are injured in shipment or for some other reason will not give accurate readings. It is good practice to retain an accurate meter so the calibration of all the RF meters can be checked from time to time as needed. The antenna meters at the towers are read daily or weekly, and the remote meters checked for accuracy. Most remote meters are provided with an adjustment so their reading can be made to correspond exactly to the antenna meter.

The calibration of the phase monitor at the time of the antenna installation is as a rule adequate as long as the monitoring loops and phase-monitoring lines stay in good physical and electrical condition. It is important to have a phase-monitoring system that is more reliable than the directional-antenna system. If the phase readings vary from the licensed value and there is no noticeable change in the antenna current readings, it is advisable to question the phase monitor before making any readjustments on the directional-antenna system. In such cases the field strength at the monitoring points should be checked. If these readings are normal, the trouble is probably in the phase-monitor system.

Feeder System

All that is required for a single tower is to match the antenna to the transmission line, and in turn the transmission line must be matched to the transmitter. In most cases the transmitter will match directly into the transmission line, and if the tower is next to the transmitter building, a transmission line is not required. In some cases it is possible to excite the antenna directly from the transmitter output without a transmission line or coupling circuits.

In a directional-antenna feeder system, power-dividing and -phasing networks are required in addition to transmission lines and matching networks. A typical two-tower directional-antenna feeder system is shown in Fig. 3-8. At least one tower of a two-

tower array must have its driving-point impedance transformed to match into a transmission line. The other tower, if not located close to the transmitter, must also be excited through a transmission line.

In a two-tower directional antenna it is necessary to have the required total phase shift from the common point at the transmitter output to each of the towers. The phase shift must be such that the phase of the tower currents meets the design requirements. When a phasing network is employed, it should operate over a favorable control range so the current in tower 2 with respect to the current in tower 1 can be adjusted and maintained at the proper value. In Fig. 3-8 the current ratio of tower 2 to tower 1 can be adjusted and maintained by the power-dividing network.

It should be pointed out that the phase- and power-division controls are usually not independent because of the mutual-impedance coupling effects between the towers. In other words a change in the phase control may have more effect on the current ratio

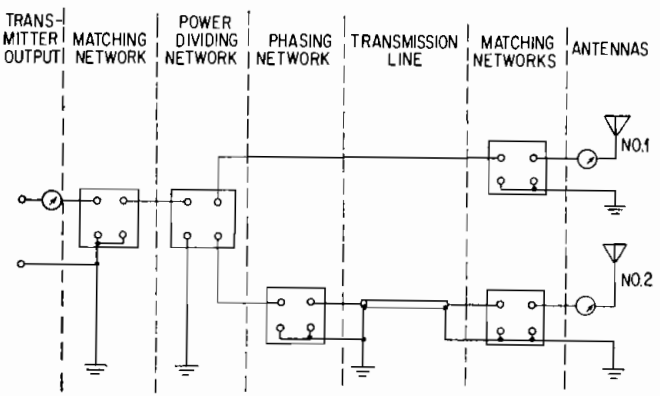

FIG. 3-8. Block diagram of a directional-antenna feeder system.

than on the phase-monitor reading. The person that must keep the directional-antenna system in adjustment should therefore operate the various controls and obtain a feel of how the system reacts. Before moving any controls, however, the settings should be noted and recorded so it is possible to return to the original operating condition. Here it is assumed that the feeder system is already operating properly. Only persons with the responsibility of operating and maintaining the directional-antenna system need to have this experience.

If the feeder system has been designed and the antenna system is to be tuned up, it is desirable first to determine the feed-point driving-point impedance values. This can be done by following the procedure in Appendix B. It is then necessary to set up the tower coupling networks so they will match into the driving-point impedances determined above. In addition they should have the correct value of phase so the phasing control will be near the center of its range for proper phase of tower 2 with respect to tower 1. The power-dividing network can then be set up to give the approximate division of power, and if there is a matching network between the transmitter and the power divider, it can be set up to give the proper impedance for the transmitter.

A small amount of RF power can now be fed in at the common point, and adjustments made to approximate the required current ratio and phasing between the two towers. If the driving-point impedances at the towers were computed correctly and the tower matching networks were set up properly, it should not be necessary to make any further adjustments at this point other than to add or subtract phase shift.

It should be observed that the driving-point impedances at the towers will not have their correct values until the feeder system is in final adjustment. Therefore, improper meter readings and standing waves on the transmission lines are to be expected until the final adjustment is approached.

When a directional-antenna array has been correctly adjusted, complete measurement data should be taken before it is turned over to the new user. These data should include not only RF bridge measurements of all components but similar static measurements at several points in the feeder system. These measurements should be made, for example, at the input to each tower impedance-matching network by opening up the transmission line and connecting the RF bridge at this point. Also record open- and short-circuit measurements of all transmission lines.

These measurements can be further supplemented by making dynamic RF voltage readings to ground at a number of points in the feeder system. Also RF current readings should be taken in all network branches.

Then in the event there is a departure from normal performance, the above static and dynamic measurements can be duplicated to assist in the restoration of the feeder system to normal service. This information is particularly helpful if a component becomes defective or is destroyed by lightning.

It is also good practice to make a record of all capacitor and inductor adjustments. It is advisable to mark all coil taps and capacitor settings with lacquer paint. Fingernail polish can be used for this purpose.

Particular attention should be given to make sure that the phase-monitoring system is in good condition and properly installed. If the phase-monitor lines are of equal length and some of the line must be coiled up, this should be done so that, as nearly as possible, equal lengths are outside the building and will therefore be equally affected by temperature variations. Otherwise, phase variations may occur owing to unequal temperatures of the phase-monitoring lines.

The feeder system should be inspected and cleaned regularly. It is advisable to use insectproof screens over any openings in the housing of feeder system networks. If pressure gauges are used on capacitors or coaxial transmission lines, they should be checked occasionally. These components may be injured if operated without pressure even though the gauge reading appears to be satisfactory.

In the day-to-day operation of a directional-antenna system it should not be necessary to move any controls or make any adjustments. Sometimes temperature and weather conditions will cause slight excursions of the phase and current ratio values. If the tolerance limits are exceeded, then the problem should be analyzed and appropriate corrective measures taken.

DIRECTIONAL ANTENNAS HAVING MORE THAN TWO TOWERS

Comparison with Two-tower Array

Many directional antennas consist of more than two towers because a two-tower array cannot produce the pattern shape required. It often happens that a two-tower pattern could be used, or it may even be that a nondirectional pattern could be employed if the pattern size were small. Such patterns may be ruled out by the owner because of prestige as to power statements and lack of good service over the urban and rural areas to be covered.

General Case

A general treatment of directional antennas of more than two towers can be limited to an explanation of one tower with respect to a reference point because all other towers are treated in exactly the same manner, since no specific information can be given to distinguish one tower from another. The only facts that need be known about a tower are that it has height, it is sectionalized or not, top-loaded or not, that it has a certain cross-sectional shape and size for each distance above the ground, and that it has a ground system of a specified efficiency. Most of these items have already been discussed.

The important considerations for a general tower in a directional-antenna system are its spacing, phasing, current, and height with respect to the other towers in the array. These four items define its contribution to the radiation characteristics of the array once its individual or single tower characteristics are defined. Hence this general treatment must conclude with an expression that describes the radiation of any tower of a multielement array. This expression is called a vector and is written

$$\dot{E}_k = E_k f_k(\theta) \angle S_k \cos \phi_k \cos \theta + \Psi_k \tag{3-8}$$

where $\dot{E}_k$ = vector unattenuated inverse field strength at 1 mile for the kth tower while in operation, mv/m
E_k = magnitude of horizontal field strength of kth tower, mv/m
$f_k(\theta)$ = vertical-radiation characteristics of kth tower—always unity // along ground
$\angle$ = vector angle terms are placed in this position. Vector magnitude terms are placed ahead of this angle sign
S_k = spacing of kth tower, deg
ϕ_k = azimuth angle measured clockwise from reference through kth tower, deg
θ = elevation angle from ground or horizontal plane, deg
Ψ_k = electrical phase of current in kth tower, deg

The subscript k was used in this equation to distinguish the radiated field strength of this tower from the other towers in the array. The sum of the vector fields from all the towers gives the total field strength in any direction from the array.

Dropping the subscripts in the above equation for simplicity, the product $Ef(\theta)$ is the magnitude of the vector and $S \cos \phi \cos \theta + \Psi$ is the phase of the vector. The only real value of this general treatment is the meaning it lends to the over-all theory. In fact its understanding is so vital that a clear concept of directional antennas must come from its meaning. As a matter of fact one can treat the whole matter of pattern shape from the vector concept directly without other mathematical complications. If this is done, it is, of course, necessary to know how to add, subtract, multiply, and divide vectors. On the other hand if the mechanism of vectors is not known, one is at a great disadvantage from the start in acquiring a thorough understanding of directional antennas. It is therefore recommended that at least the rudiments of vector analysis be learned by anyone desiring really to understand directional antennas.

Before leaving the general case attention is called to the fact that any directional antenna must be treated as a unit such that the whole operation is considered when any part of the antenna system is changed. For example, it is very important to know how a change in the magnitude or phase of each tower current affects the shape of the pattern, but at the same time it cannot be forgotten that the efficiency is also a factor that must be considered.

The perfect pattern shape and the most efficient operation are seldom attained at the same time. Theoretically this may be possible, but actually the number of towers may be limited or the coverage and protection requirements may have changed after the directional-antenna system was put into operation. Suffice it to say that it is the rule rather than the exception that one or more compromises are necessary before the final operation is attained, and it is best to understand the peculiarities of any particular array so that these compromises can be recognized and dealt with in the most intelligent manner.

Special Cases

Two-tower Pattern

The simplest equation for a two-tower pattern is

$$E = 2E_2 \cos\left(\frac{S_2}{2} \cos \phi + \frac{\Psi_2}{2}\right) \tag{3-9}$$

where E = inverse field strength at 1 mile, mv/m
E_2 = inverse field strength at 1 mile for each tower acting alone, mv/m
$S_2/2$ = spacing from a reference point midway between the two towers, deg
ϕ = azimuth angle measured clockwise from line of towers, deg
$\Psi_2/2$ = electrical time phase of tower 2 and the negative electrical time phase of tower 1, deg

This equation is for the horizontal plane only, and the terms are especially defined to make the equation simple. The tower heights and current values are assumed to be equal or such that $E_1 = E_2$ along the ground. The spacing S_2 is from tower 1 to tower 2, and the phase Ψ_2 is the phase of the current in tower 2 taken with respect to tower 1 (see Fig. 3-9).

Since a two-tower pattern is symmetrical with respect to the line of towers, it is necessary to compute the values for only one side of the line of towers, that is, ϕ from 0 to 180°, and these same values can be used on the other side of the line of towers. For example, cos 10° = cos 350°, and hence the value of E will be the same in these two directions.

The shape of the pattern is controlled by proper selection of spacing S_2 and phasing Ψ_2, while the pattern size is controlled by E_2. For null filling or to determine the radiation above the ground plane, it is necessary to use a more general formula.

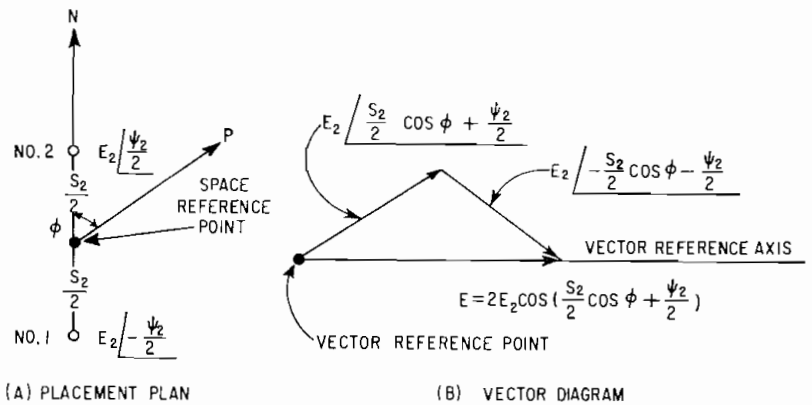

FIG. 3-9. Simple two-tower case.

Three Towers in Line

A three-tower array will be considered from the simultaneous points of view of theory and practical operation. Three towers are either in line or not in line. If they are in line, as in the case of all two-tower patterns, the three-tower pattern must be symmetrical about the line of towers. Consequently, the pattern shape needs to be computed only on one side of the line of towers.

The three towers may be equally spaced or not equally spaced. If vectors alone are used to analyze the operation, it makes little difference where the towers are located, especially if the current values are not chosen for mathematical simplicity. If simplicity is desired, as it often is, the tower spacings should be made equal. This is covered more thoroughly in Appendix C, Fig. C-1.

To relate theory and practice consider an array of three towers in line. The field strength produced by each tower can be represented by a vector at any point in space. The sum of the three vectors at the point is the total field strength produced by the entire array. This sum, or resultant field strength, is itself a vector and can be determined mathematically when all the parameters of the three-tower array are known. The size, or magnitude, of the resultant vector is the all-important part of the resultant field strength as far as the radio receiver is concerned. This is because the receiver does not detect the phase angle; it simply responds to the magnitude of the resultant vector and detects the information on it. The magnitude of the resultant vector at the receiver depends upon the magnitude and phase of the current on each of the three towers, which amounts to a total of six parameters.

The observation that there are six parameters in a three-tower array, which can vary independently of one another, makes it clear that it is necessary to understand which ones are being changed when the array is being adjusted. Otherwise, the possibility of making the wrong adjustment is very great. On the other hand when a desired correction is made by changing the appropriate parameter, the result cannot be wrong. This view is somewhat optimistic because theory does not hold exactly in practice

where actual conditions involve the necessity of making compromises. For example, it is not difficult to change a parameter to get a certain field strength at a given point but in so doing the field strength may be adversely affected elsewhere.

An understanding of the directional antenna is quite easily acquired through vector analysis, but in actual field practice it is almost always more efficient to convert the vectors to an ordinary algebraic expression of the field strength at 1 mile. When this is done, the theoretical effects of a change in any one parameter can be quickly determined. The algebraic equations for a three-tower-in-line array are given in Appendix C, Fig. C-3.

Three Towers Not in Line

The above treatment of three towers in a straight line should and did receive first consideration because of the number of such directional-antenna arrays in existence. Three towers not in line, sometimes referred to as a dog-leg array, deserves serious consideration because of the number of such arrays that are in existence and because such three-tower patterns naturally fit the predominately unsymmetrical requirements.

There are a number of ways to select the reference point and the reference line in the three-tower array. Only one will be treated here for the sake of clarity and briefness. It is believed to have more significance than other choices because it can be related to the two-tower treatment already covered and to the four-tower paralellogram array.

Further discussion of three towers not in line follows the treatment of the four-tower parallelogram array; hence it is treated as a corollary in Appendix C, Fig. C-4.

Four-tower Parallelogram

Many directional-antenna systems have four towers located at the corners of a parallelogram. The chief reason for the popularity of this type of array is the ease with which the pattern shape can be designed to meet complicated requirements. The design procedure is straightforward, and the computations are relatively easy. Because of these advantages it is surmised that some four-tower arrays have been designed and constructed where three-tower arrays would do the job. This does not necessarily imply that the three-tower array would do a better job. The four-tower array may have better stability in operation and make it possible to modify the pattern without change in tower location, and the efficiency may be better.

When the multiplication form of the four-tower array is used, it can be designed piecemeal by first selecting one two-tower design that will provide the necessary protection in two directions. Then another two-tower array can be selected to protect in two other directions. If the parallelogram design is used, these patterns can be multiplied together and achieve the necessary protection in all four specified directions. The design details are given in Appendix C, Fig. C-2.

Arrays of More than Four Towers

It is not believed advisable to go further into the discussion of special cases where more than four towers are involved. If an owner or operator of a multielement array desires to adjust or understand a specific directional-antenna system, it is anticipated that he will take one of two courses: employ a competent consultant to do the work or become sufficiently proficient himself to do the job.

Suffice it to say here that in general the adding of more towers in an array permits protection in more directions or greater protection over wider angles and may in some cases be used to increase the field strength in some directions. The more complicated arrays are usually made up of combinations of two-tower units, and in some cases three-tower units are used. For example, an eight-tower array may be made up of four two-tower units, or a nine-tower array may be made up of three three-tower units.

GENERAL CONDITIONS AND PLANT LAYOUT

The entire plant should be considered from a number of points of view prior to detail study if an existing broadcast station is in need of adjustments or if the broadcast plant is to be built from its beginning.

The location of the transmitter building with respect to the towers is important from the standpoint of access to the transmitter from the road, and if the common point of the directional-antenna system is in the transmitter building, the building should be close to the towers to minimize RF transmission-line losses. If the transmitter building must be located some distance from the towers, it is advisable to feed the RF power over a transmission line to a common point located so that the RF lines from this point to the towers will have a minimum of loss.

The ground-system design for a new directional-antenna array should be laid out such that the copper will be used to best advantage to minimize E and H losses. This does not necessarily mean that a radial system under each tower is the best layout. A study of the H field or ground-current direction at a number of points will help decide how the copper wire should be placed. If the ground system has been installed for some time, it may have deteriorated somewhat. In such cases it is advisable to check for corrosion and mechanical failure of the conductors. The extent of the ground system should be checked against the original construction permit for completeness.

The transmission line, if above the ground, should have a ground strap buried in the ground below it, and this strap should be tied into the ground conductor system. This buried ground strap should be bonded to the ground side of the transmission line at regular intervals.

A general survey of the feeder system in an existing plant will involve not only the location of the matching, phasing, and power-division networks but obtaining information concerning possible inefficiencies and inconveniences in operating arrangements and adjustment controls.

The phase monitor should be the most reliable indicator of the current of the various towers. If this is not the case, steps should be taken to improve its operation. The location of remote indicating meters should be checked along with their calibration against the antenna ammeters. If any question exists about the current magnitudes, then all the antenna and common-point meters should be calibrated against a meter of known accuracy.

It is good practice to become familiar with the procedure for warming up the transmitter, including starting and stopping operations. This will protect the equipment. Safety precautions, especially when high power is involved, should be obeyed rigorously. It is much better to spend a little more time than to have someone injured or killed.

All tuning controls, including variable capacitors and inductors, should be noted. All taps and settings should be recorded. A complete set of meter and phase-monitor readings should be recorded before any adjustments are made on an existing system.

The tower lighting, tower insulation, lighting-control circuits, or the phase-monitoring system may require preliminary alterations before tower-impedance or common-point-impedance measurements are made.

The number of transmitters available for regular, auxiliary, or emergency operation should be inspected with regard to switching circuits and studied with regard to the possibility of improvements in convenience and efficiency.

REQUIRED PREADJUSTMENT INFORMATION

Preliminary Computations

Base Driving-point Impedance

The loop impedance values can be computed or estimated, and from this information the base driving-point impedances of all towers can be estimated as outlined in Appendix B.

Base Driving-point Currents

Knowing the power and driving-point impedances it is possible to estimate the base driving-point currents. Consideration should be given to the conservation of power principle between the loop and base values as discussed in Appendix B.

Characteristic Impedance of Transmission Lines

In a new or old system it is good practice to measure the characteristic impedance of all transmission lines. This can sometimes be done by measuring the open- and short-circuit impedances and determining the characteristic impedance from the equation

$$Z_0 = \sqrt{Z_{oc}Z_{sc}} \tag{3-10}$$

where Z_0 = characteristic impedance, ohms
Z_{oc} = open-circuit impedance, ohms
Z_{sc} = short-circuit impedance, ohms

These values may all contain resistance terms when measured with an RF bridge. When the transmission line is near 90° in length, this method gives very good results. However, when the line is near 180° in length, the open-circuit values will be very large and the short-circuit values will be very small, with the result that Z_0 from the above equation may not be very accurate.

Another method, quite good and acceptable in practice, is to use a decade resistance box at one end of the line and measure the impedance looking in at the other end of the line. Then plot the decade box resistance along the x axis of graph paper and the measured RF bridge input impedance magnitude along the y axis. Where this curve intersects a 45° diagonal line in the first quadrant is located the characteristic impedance magnitude.

This method works quite well for any length of line. Of course, as the line becomes very long, the variation of resistance at the far end will have less and less effect, because if the line is of infinite length, the input impedance will look like the characteristic impedance regardless of the value of load resistance.

This method can be refined in accuracy by first measuring with the RF bridge the values of the decade box resistance. Usually decade resistance boxes have an inductive reactance component that may vary with resistance-value settings. In such cases it may be desirable to parallel the decade resistance box with a small variable capacitor that is adjusted to make the load terminals of the decade box look like a pure resistance. With such refinements it is usually possible to obtain very good results in the field.

Matching Networks

With the above information at hand the transmission line to tower matching networks can be adjusted to transfer the transmission-line-impedance to the driving-point-impedance value. An L section is usually adequate unless the design requires a different amount of phase shift.

The system should be designed for the least amount of phase shift possible consistent with good operating practice because in this way the system efficiency can be maximized.

If it is not convenient to set up dummy driving-point impedances and measure the network from the transmission-line end, then a resistor equal to the characteristic impedance of the transmission line can be connected across the line side of the matching network. The network can then be adjusted until the RF bridge looking in at the tower terminals sees the conjugate value of the driving-point impedance. This means that when the network is connected at this point in a normal fashion, the reactance of the driving-point impedance will be resonated with the reactance of its conjugate value. The resistance of the conjugate impedance is equal to the resistance of the driving-point impedance. Hence the condition for maximum power transfer is achieved.

Probably the only other matching network will be between the power divider and the

transmitter. This is the last network to be adjusted. It may be either before or after the common point where the power input to the directional antenna is measured. Usually it is after the common point in order that the common-point input will be a pure resistance at the operating frequency. The loss in this network is then charged against the directional-antenna system, since it is beyond the common point of power measurement.

Phase-shifting Networks

Usually the phase-shifting networks are designed to operate into the characteristic impedance of the transmission line. Hence, they can be connected directly and maintain an impedance match. It is rather common practice to place the phase-shifting networks in the lines that handle the least amount of RF power, thus minimizing the RF power loss of the feeder system. The transmission line or tower that takes the most power can be run directly to the power-dividing network.

It is usually easier to vary the phase by ganging the rollers of coils rather than using variable capacitors. For this condition a T section would be chosen for a $90° \pm 10°$ phase-retarding network and a π section would be chosen for a $90° \pm 10°$ phase-advancing network as shown in Appendix B, Fig. B-26.

If it is necessary to vary a capacity element, it is sometimes more convenient to place a small fixed capacitor in series with a variable coil so that the series combination will have the correct value at the operating frequency. If the filtering or harmonic properties also have to be considered, this combination may not be satisfactory.

It is important to make sure that the rotating wiping contacts on the phase shifters are in good mechanical condition to wipe smoothly and make good electrical contact continuously. The contacts should feel nearly as cool as the other parts after the equipment has been in operation; otherwise there is too much resistance at the contacts.

Power-dividing Networks

The power-dividing network usually accepts power from the transmitter output and feeds the proper amounts into transmission lines and phase-shifting networks. For maximum efficiency it is good practice to feed the largest amount of power directly into the transmission line, thus avoiding the power loss in the phase-shifting network.

If power-handling dummy driving-point-impedance loads are used the power divider can be adjusted approximately before connecting to the towers. If this procedure is followed, the approximate value of phase can be inserted if the phase sampling is done at the input to the dummy loads. For L sections in parallel the resistance input to the individual L sections must have the value of resistance needed to absorb the correct ratio of the total power delivered from the common point.

For example, in a two-tower array, the L section resistance inputs can be written

$$R_1 = \frac{V^2}{P_1} \tag{3-11}$$

$$R_2 = \frac{V^2}{P_2} \tag{3-12}$$

where R_1 = resistance into L section leading to tower 1, ohms
R_2 = resistance into L section leading to tower 2, ohms
V = voltage between common point and ground, volts
P_1 = power to tower 1, watts
P_2 = power to tower 2, watts

The common-point resistance can be written

$$R = \frac{R_1 R_2}{R_1 + R_2} \tag{3-13}$$

where R is the common-point resistance in ohms

Component Ratings

The current through and the voltage across each component in the feeder system should be computed to determine the required rating. This information provides a means of choosing the most economically sized component in a new installation. These computations will show up components in an existing system which are underrated and should be changed.

The current rating of capacitors are given by the manufacturer and should not be exceeded during operation for the most adverse temperature and poor adjustment conditions. The voltage ratings are also given by the manufacturer and should be high enough to comply with any surges that may arise, including lightning. The lightning-protection devices should be good enough to allow for reasonable economy in deciding the maximum voltage rating.

The current and voltage rating of coils are related to the voltage gradient between turns of the coil. The distance between conductor centers in adjacent turns should be roughly twice the diameter of the conductor, and the conductor diameter must comply with good engineering standards as to coil losses.

Coarse Adjustments

Meter Calibrations

All meters should be checked for accuracy against meters which are of known accuracy. Calibration charts should be made up for meters that do not register correctly. The current-sampling system on each tower should be checked for accuracy.

Phase-monitor System

The phase monitor should be checked for accuracy. The tower-sampling loops can be placed in parallel and checked for zero phase when the same field is sampled. If tower input currents are sampled, the same current can be sampled by two sampling units to check for accuracy.

Another method is to establish a null off the end of two towers and read the phase which is known quite accurately by theory for this condition. This can be done by setting up a field strength set at some distance and walk the two-tower phase and power-division controls to give a deep null. This also gives an excellent check on unity field-strength ratio. It is helpful to have two-way communication to expedite these measurements.

Common-point Impedance

After the array is approximately adjusted, it is advisable to measure the common-point input impedance. It may be desired at this time to make input matching network adjustments so a pure resistance load will be presented to the transmitter at the operating frequency.

After final adjustment of the array the common-point input impedance must be measured across a band of frequencies to meet FCC requirements and check on characteristics that may cause objectionable distortion. It is desirable to have a relatively constant value of resistance over the modulation-frequency range.

Low-power Operation

After the common-point impedance has been adjusted properly, low power can be fed into the system and all meters checked for predicted readings. If errors have been made in the computations, the adjustment will probably be incorrect.

Field-strength Check

After the array is in reasonable adjustment, it is timely to check the field strength. Usually a nondirectional proof is made by running at least eight radials to determine the rms value and the attenuation in the various directions and establish suitable monitoring points in critical directions.

These measurements will probably indicate what changes are necessary to meet the requirements in the construction permit. Any change in adjustment should be followed by appropriate field-strength measurements properly logged so that further adjustments are always in the correct direction.

As the desired pattern is approached and the feeder system comes into proper adjustment, the full input power can be used.

Fine Adjustments

These adjustments are simply a continuation of the tuning to arrive at the final values. More exact and extensive information is gathered with regard to how the controls affect the field-strength measurements, particularly along radials in the direction of the various minima.

The final adjustment of the array is decided upon after enough information is gathered to show what adjustment of the array gives the desired over-all results. The final adjustment may involve compromises in optimum field strength between the various minima and critical bearings concerned with protection.

During this phase the monitoring points are usually selected. The value of monitoring-point readings should be recorded along with the other meter readings of the system.

When the final pattern adjustments have been made, careful attention is given to establishing the exact power at the common point. The resistance and reactance vs. frequency measurements are then run for the common point.

Final Operating Adjustment

With the antenna system operating properly, all meter readings are recorded and maintained while the field-strength measurements are made to prove the shape and size of the horizontal pattern.

The monitoring points have to be photographed in order to provide a reliable means of finding their exact location in the future. The field strength at the monitoring points should be checked at least daily while making the proof of performance field-strength measurements.

The field-strength radial measurements are plotted on FCC logarithmic paper and analyzed to determine the unattenuated field strength at 1 mile. These values are then plotted on polar coordinate paper, and a planimeter can then be used to determine the rms value. This should agree closely with the predicted value.

If only a skeleton or partial proof is required, sufficient directional measurements must be made at points used in the original proof to show by means of ratios between the two measurements at each location that the pattern is basically unchanged. If the average of the ratios for each radial, usually about 5, is between 0.8 and 1.2, it is considered that the pattern is unchanged. If the average deviates outside this range on two or more radials, the array probably needs further adjustment.

MULTIPURPOSE ANTENNA SYSTEMS

Two-pattern Arrays

Many directional-antenna systems have a different day and night pattern. Usually the nighttime pattern requires deeper minima and in many cases different locations of the towers or more towers in the array.

In the layout and design of such a system the problem should be carefully analyzed and the simplest layout used consistent with good engineering practice. Many times the same matching networks can be used with a day-night transfer relay to change coil turns and capacity values as required for the two conditions of operation.

It is good practice to provide pilot-light circuits to indicate when all RF relays are in their correct positions. If power is applied to a system with the relays not in proper positions, some components may be injured and the transmitter may not be working into a matched load.

Two Transmitters Using Same Towers

There are a number of cases where an antenna system is used by more than one station. If, for example, two radio transmitters use the same towers, it is necessary to add RF filter circuits so energy will not be fed from the output of one transmitter back to the output of the other transmitter and produce cross-modulation products. If this happens, the program of the other radio station will be heard in the background.

In the feeder-system design for two transmitters using the same towers it is usually possible to design the networks such that the T, π, or L sections perform the necessary filtering action in addition to the required impedance transformation and phase-shift functions.

The metering circuits must also be filtered so they will not respond to the undesired frequency. If a meter has two RF currents of different frequencies, it will give an rms response providing it is not frequency-sensitive.

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APPENDIX A. SINGLE-TOWER ANTENNAS

Theoretical Vertical-radiation Characteristics

Formulas

Sectionalized Top-loaded Tower. The current distribution on the bottom section of the tower as shown in Fig. A-1 is given by

$$i_a = I_a \sin (G - y) \tag{A-1}$$

The current distribution on the top section is given by

$$i_c = I_c \sin (H - y) \tag{A-2}$$

At the insulator height $y = A$, $I_c = i_a$, $G - A = B$, and

$$I_c \sin (H - A) = I_a \sin B \tag{A-3}$$

or

$$I_c = \frac{\sin B}{\sin (H - A)} I_a \tag{A-4}$$

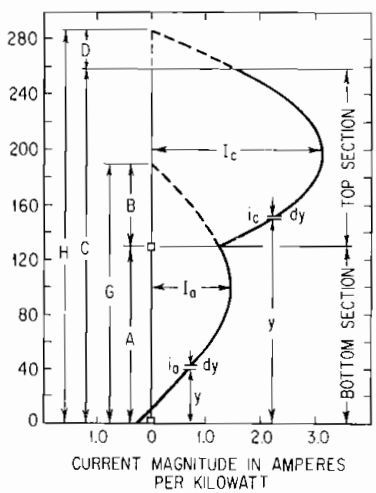


FIG. A-1. Theoretical current distribution on a top-loaded sectionalized tower.

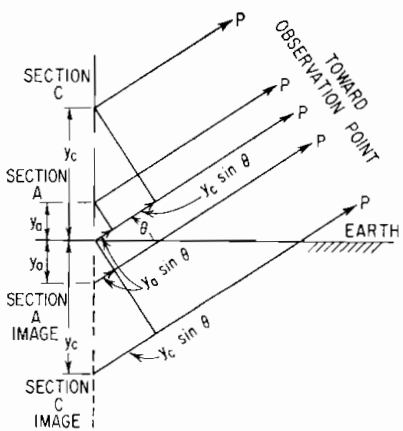


FIG. A-2. Geometry to determine field from sectionalized tower with images.

The inverse field or unattenuated field strength toward 1 mile at the observation point P at an elevation angle θ produced by a vertical element dy at the base of the antenna would be $dy \cos \theta$. The field from any other similar element of the antenna or its image would have a phase different from zero as depicted in Fig. A-2. The addition of these vector fields from an element and its image on sections A and C is shown in Fig. A-3*a* and *b*, respectively. It is noted that the sine components cancel. The total field at the point P is, therefore,

$$E_\theta = K 2 I_a \cos \theta \left[\int_0^A i_a \cos (y \sin \theta)\, dy + \int_A^C i_c \cos (y \sin \theta)\, dy \right] \tag{A-5}$$

where K is a constant such that E_θ will be in the units desired. K cancels out in $f(\theta)$. Substituting from Eqs. (A-1), (A-2) and (A-4), performing the indicated integration, and dividing the result by itself when $\theta = 0$ give

$$f(\theta) = \frac{\cos B \cos (A \sin \theta) - \cos G + \dfrac{\sin B \cos (H - C) \cos (C \sin \theta)}{\sin (H - A)} - \dfrac{\sin B \sin \theta \sin (H - C) \sin (C \sin \theta)}{\sin (H - A)} - \dfrac{\sin B \cos (H - A) \cos (A \sin \theta)}{\sin (H - A)}}{\cos \theta \{\cos B - \cos G + [\sin B / \sin (H - A)](\cos \overline{H - C} - \cos \overline{H - A})\}} \tag{A-6}$$

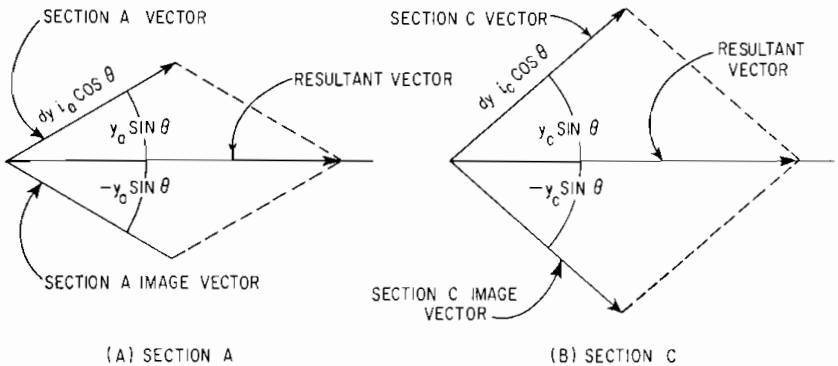


FIG. A-3. Vector diagrams of field strength at point P.

This is the vertical-radiation-characteristic equation for a two-section sectionalized tower. The same procedure can be applied if more than two sections are involved.

Top-loaded Tower. Referring to Fig. A-1 it is noted that the sectionalized antenna can be reduced to a nonsectionalized top-loaded antenna by making the top section of zero length but at the same time arranging for top loading such that B is unchanged. This can be done by letting $C = A$ and $H = C$ in Eq. (A-6), which then reduces to

$$f(\theta) = \frac{\cos B \cos (A \cos \theta) - \cos G - \sin B \sin \theta \sin (A \sin \theta)}{\cos \theta (\cos B - \cos G)} \tag{A-7}$$

This is the vertical-radiation characteristic for a top-loaded tower of height A and top-loaded to a height of $C = A + B$.

Ordinary Vertical Tower. The ordinary tower without top loading can be obtained from Eq. (A-6) by letting $C = A$, $H = C$, and $B = 0$ or in Eq. (A-7) by letting $A = G$ and $B = 0$ to obtain

$$f(\theta) = \frac{\cos (G \sin \theta) - \cos G}{\cos \theta (1 - \cos G)} \tag{A-8}$$

This is the same as Eq. (3-3) in the text. Table A-1 gives values of $f(\theta)$ for a useful range of tower heights, and Fig. A-4 gives this information in graphical form.

Theoretical Self-impedance and Radiation

It is useful to know the theoretical loop and base resistance of a vertical radiator. This information is presented graphically in Fig. A-5 along with the theoretical inverse field strength at 1 mile.

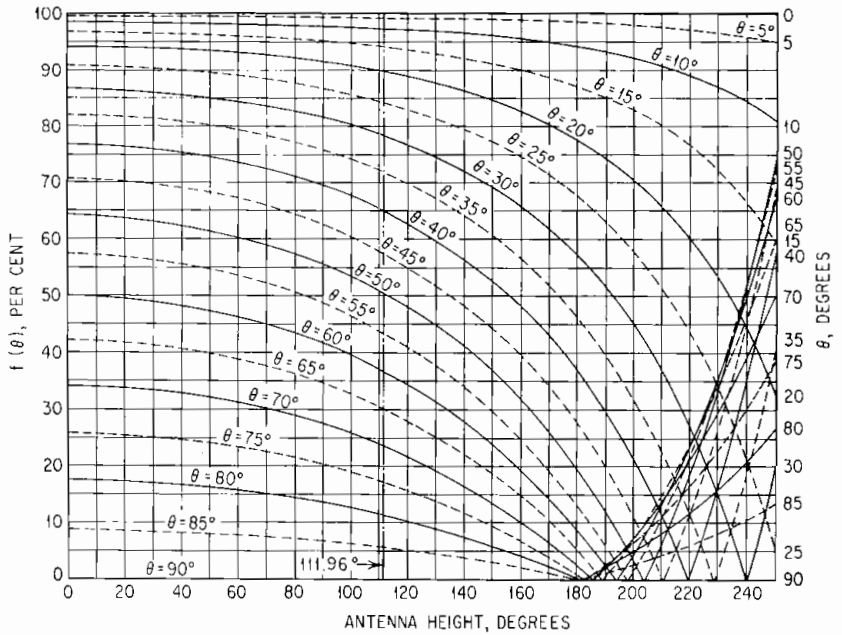


FIG. A-4. Vertical-radiation characteristic as a function of electrical tower height for various values of elevation angle.

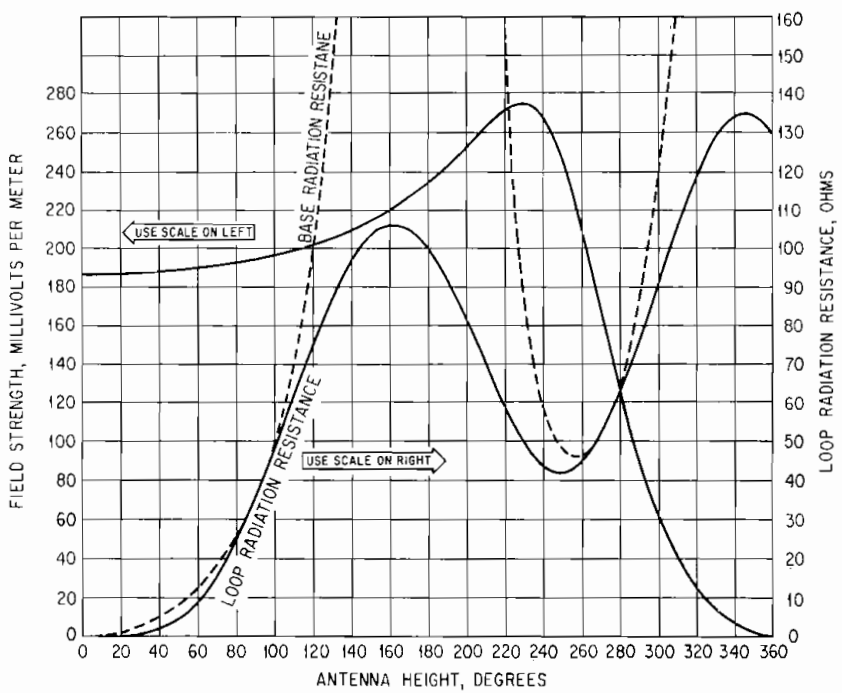


FIG. A-5. Inverse field strength at 1 mile for 1 kw, loop and base radiation resistance as a function of tower height over a perfectly conducting earth.

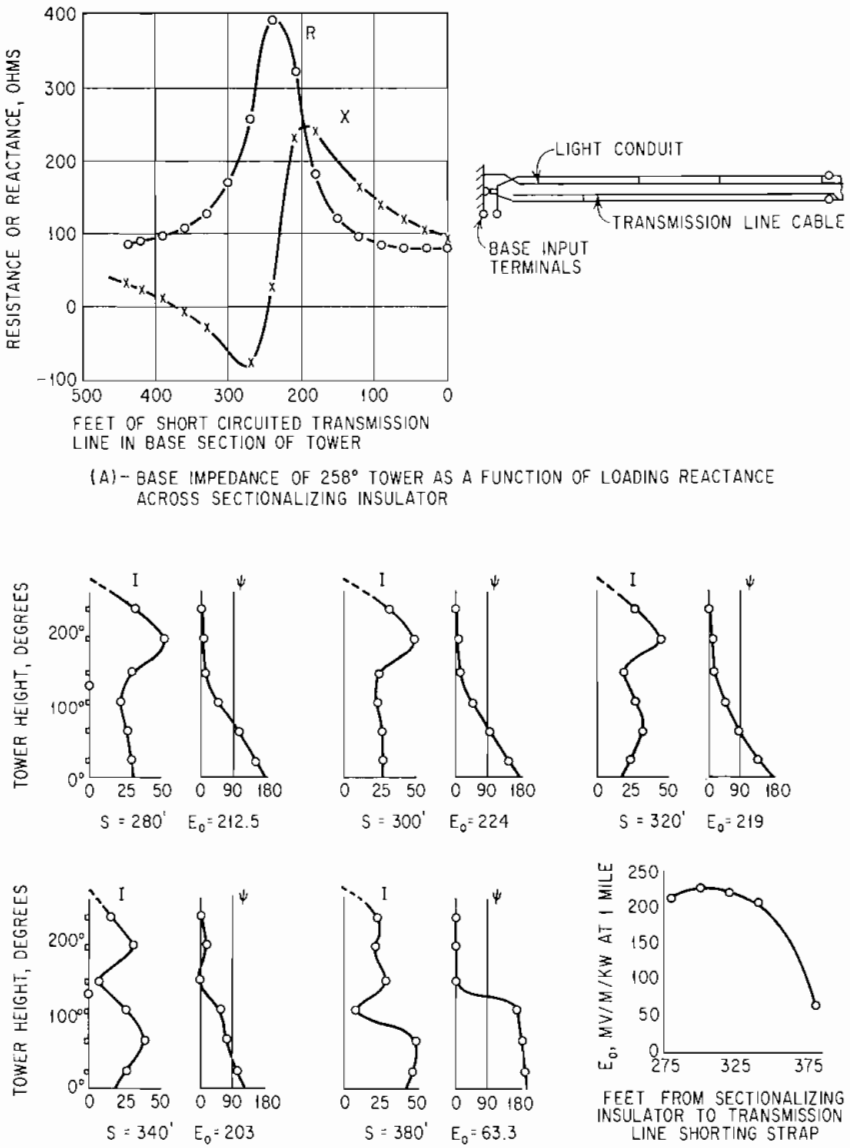
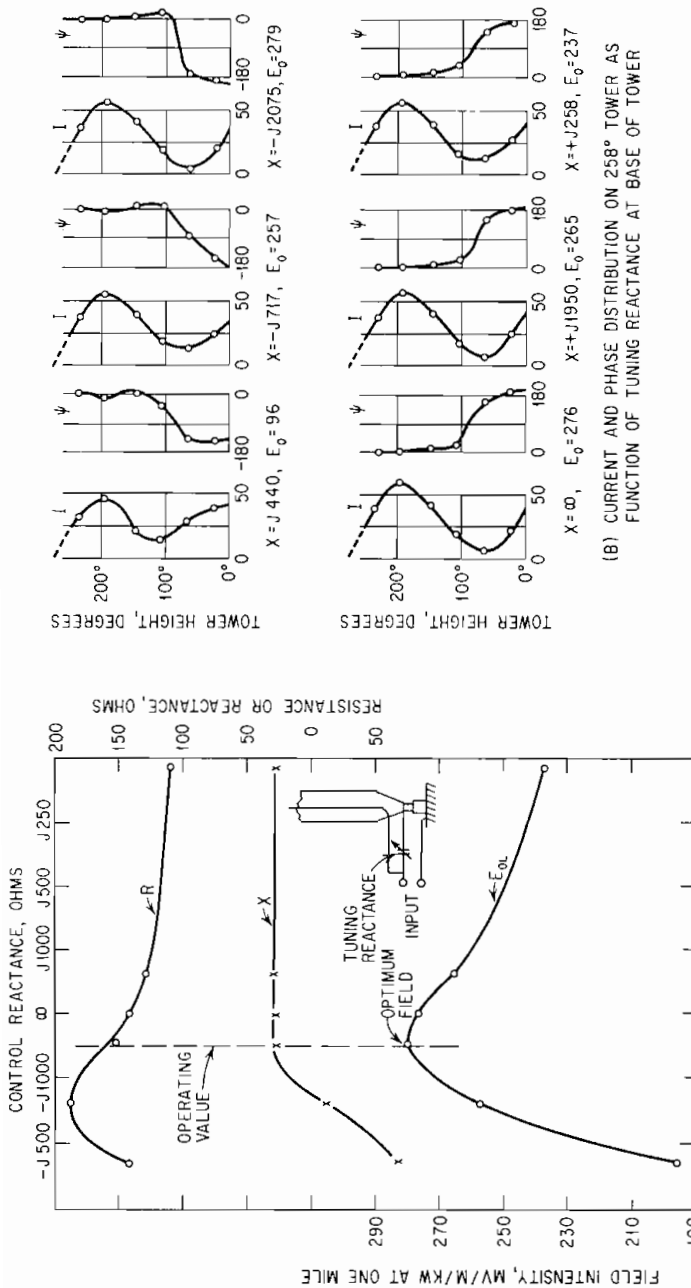


FIG. A-6. Performance of sectionalized tower with top section excited through reactance element from bottom section.



(A) INPUT IMPEDANCE AND FIELD STRENGTH OF TOP LOADED SECTIONALIZED 258° TOWER AS FUNCTION OF TUNING REACTANCE

(B) CURRENT AND PHASE DISTRIBUTION ON 258° TOWER AS FUNCTION OF TUNING REACTANCE AT BASE OF TOWER

FIG. A-7. Performance of sectionalized tower with top and bottom sections excited independently.

Table A-1. Vertical-radiation Characteristic $f(\theta)$

$\theta°$	Tower height, $G°$								
	0	5	10	15	20	25	30	35	40
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9962	0.9962	0.9962	0.9961	0.9961	0.9961	0.9960	0.9960	0.9959
10	0.9848	0.9848	0.9847	0.9846	0.9845	0.9843	0.9841	0.9839	0.9836
15	0.9659	0.9659	0.9657	0.9655	0.9653	0.9649	0.9644	0.9639	0.9632
20	0.9397	0.9394	0.9393	0.9390	0.9386	0.9379	0.9372	0.9362	0.9351
25	0.9063	0.9062	0.9058	0.9054	0.9047	0.9037	0.9026	0.9012	0.8996
30	0.8660	0.8658	0.8654	0.8648	0.8638	0.8626	0.8610	0.8592	0.8571
35	0.8192	0.8188	0.8186	0.8176	0.8164	0.8148	0.8129	0.8106	0.8080
40	0.7660	0.7658	0.7653	0.7642	0.7628	0.7610	0.7587	0.7561	0.7530
45	0.7071	0.7069	0.7062	0.7051	0.7035	0.7014	0.6989	0.6960	0.6925
50	0.6428	0.6423	0.6418	0.6406	0.6390	0.6368	0.6341	0.6309	0.6272
55	0.5736	0.5732	0.5726	0.5714	0.5697	0.5674	0.5647	0.5615	0.5577
60	0.5000	0.4947	0.4990	0.4979	0.4961	0.4940	0.4914	0.4882	0.4846
65	0.4226	0.4222	0.4217	0.4203	0.4191	0.4171	0.4143	0.4117	0.4084
70	0.3420	0.3412	0.3412	0.3404	0.3390	0.3372	0.3351	0.3325	0.3297
75	0.2588	0.2579	0.2584	0.2575	0.2564	0.2550	0.2533	0.2513	0.2490
80	0.1736	0.1695	0.1732	0.1727	0.1720	0.1710	0.1697	0.1684	0.1668
85	0.0871	0.0844	0.0869	0.0869	0.0864	0.0858	0.0852	0.0844	0.0836

$\theta°$	45	50	55	60	65	70	75	80	85
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9958	0.9957	0.9956	0.9955	0.9953	0.9952	0.9950	0.9948	0.9946
10	0.9832	0.9830	0.9824	0.9819	0.9815	0.9809	0.9804	0.9795	0.9788
15	0.9625	0.9617	0.9607	0.9597	0.9585	0.9573	0.9559	0.9544	0.9527
20	0.9339	0.9325	0.9309	0.9289	0.9272	0.9251	0.9227	0.9200	0.9173
25	0.8978	0.8957	0.8934	0.8908	0.8879	0.8848	0.8813	0.8776	0.8735
30	0.8546	0.8519	0.8487	0.8453	0.8416	0.8375	0.8328	0.8278	0.8224
35	0.8050	0.8015	0.7977	0.7934	0.7887	0.7836	0.7779	0.7718	0.7651
40	0.7485	0.7449	0.7410	0.7358	0.7305	0.7244	0.7180	0.7109	0.7103
45	0.6886	0.6769	0.6791	0.6735	0.6675	0.6608	0.6536	0.6457	0.6372
50	0.6230	0.6186	0.6130	0.6073	0.6009	0.5936	0.5862	0.5777	0.5686
55	0.5535	0.5486	0.5427	0.5373	0.5308	0.5236	0.5159	0.5075	0.4984
60	0.4804	0.4759	0.4705	0.4648	0.4587	0.4518	0.4441	0.4361	0.4271
65	0.4042	0.4002	0.3954	0.3898	0.3843	0.3779	0.3710	0.3630	0.3556
70	0.3263	0.3216	0.3190	0.3141	0.3089	0.3031	0.2970	0.2906	0.2842
75	0.2463	0.2433	0.2400	0.2363	0.2323	0.2279	0.2232	0.2181	0.2127
80	0.1649	0.1629	0.1622	0.1576	0.1557	0.1515	0.1492	0.1457	0.1408
85	0.0826	0.0816	0.0804	0.0791	0.0777	0.0761	0.0739	0.0726	0.0707

$\theta°$	90	95	100	105	110	115	120	125	130
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9944	0.9942	0.9939	0.9937	0.9934	0.9931	0.9927	0.9923	0.9919
10	0.9781	0.9770	0.9760	0.9749	0.9738	0.9725	0.9712	0.9697	0.9681
15	0.9509	0.9489	0.9468	0.9445	0.9420	0.9393	0.9363	0.9337	0.9297
20	0.9143	0.9110	0.9074	0.9035	0.8993	0.8947	0.8898	0.8845	0.8788
25	0.8691	0.8642	0.8590	0.8534	0.8473	0.8407	0.8336	0.8259	0.8175
30	0.8165	0.8102	0.8033	0.7959	0.7878	0.7791	0.7698	0.7597	0.7489
35	0.7579	0.7501	0.7417	0.7320	0.7228	0.7122	0.7000	0.6886	0.6754
40	0.6946	0.6855	0.6759	0.6656	0.6541	0.6420	0.6288	0.6157	0.5999
45	0.6279	0.6180	0.6073	0.5958	0.5834	0.5702	0.5560	0.5408	0.5245
50	0.5591	0.5487	0.5373	0.5253	0.5124	0.4987	0.4838	0.4689	0.4511
55	0.4886	0.4781	0.4669	0.4548	0.4419	0.4281	0.4134	0.3977	0.3809
60	0.4178	0.4078	0.3969	0.3854	0.3730	0.3600	0.3460	0.3310	0.3151
65	0.3470	0.3378	0.3279	0.3174	0.3061	0.2942	0.2813	0.2680	0.2536
70	0.2766	0.2687	0.2598	0.2509	0.2413	0.2311	0.2203	0.2091	0.1969
75	0.2067	0.2007	0.1937	0.1866	0.1790	0.1709	0.1623	0.1533	0.1437
80	0.1377	0.1331	0.1281	0.1237	0.1180	0.1130	0.1064	0.1005	0.0941
85	0.0686	0.0664	0.0640	0.0614	0.0588	0.0559	0.0529	0.0497	0.0464

Table A-1. Vertical-radiation Characteristic $f(\theta)$ (*Continued*)

$\theta°$	Tower height, $G°$							
	135	140	145	150	155	160	165	170
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9915	0.9910	0.9905	0.9899	0.9893	0.9886	0.9878	0.9870
10	0.9663	0.9645	0.9624	0.9602	0.9577	0.9551	0.9522	0.9491
15	0.9259	0.9219	0.9175	0.9127	0.9075	0.9019	0.8956	0.8889
20	0.8725	0.8657	0.8584	0.8504	0.8418	0.8324	0.8222	0.8110
25	0.9085	0.7988	0.7883	0.7769	0.7645	0.7511	0.7366	0.7207
30	0.7372	0.7245	0.7108	0.6961	0.6801	0.6628	0.6440	0.6237
35	0.6612	0.6460	0.6293	0.6118	0.5926	0.5720	0.5496	0.5254
40	0.5837	0.5664	0.5477	0.5276	0.5060	0.4828	0.4577	0.4305
45	0.5070	0.4882	0.4681	0.4466	0.4235	0.3979	0.3719	0.3432
50	0.4330	0.4137	0.3932	0.3710	0.3473	0.3219	0.2948	0.2657
55	0.3631	0.3440	0.3237	0.3020	0.2786	0.2542	0.2278	0.1996
60	0.2981	0.2802	0.2611	0.2407	0.2190	0.1960	0.1713	0.1451
65	0.2382	0.2222	0.2051	0.1867	0.1675	0.1469	0.1256	0.1019
70	0.1838	0.1716	0.1555	0.1399	0.1237	0.1065	0.0881	0.0687
75	0.1335	0.1227	0.1114	0.0994	0.0866	0.0732	0.0590	0.0439
80	0.0868	0.0796	0.0719	0.0634	0.0547	0.0458	0.0359	0.0256
85	0.0428	0.0390	0.0351	0.0309	0.0265	0.0218	0.0169	0.0117

$\theta°$	175	180	185	190	195	200	205	210
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9861	0.9851	0.9840	0.9828	0.9815	0.9801	0.9784	0.9766
10	0.9455	0.9418	0.9375	0.9330	0.9278	0.9222	0.9159	0.9089
15	0.8815	0.8733	0.8645	0.8547	0.8438	0.8319	0.8186	0.8038
20	0.7988	0.7855	0.7708	0.7548	0.7370	0.7175	0.6958	0.6718
25	0.7034	0.8845	0.6638	0.6412	0.6168	0.5888	0.5585	0.5250
30	0.6015	0.5774	0.5510	0.5222	0.4907	0.4561	0.4179	0.3757
35	0.4991	0.4706	0.4395	0.4057	0.3687	0.3283	0.2839	0.2350
40	0.4013	0.3696	0.3353	0.2979	0.2573	0.2129	0.1645	0.1112
45	0.3122	0.2788	0.2427	0.2036	0.1612	0.1152	0.0650	0.0103
50	0.2344	0.2008	0.1646	0.1256	0.0834	0.0378	−0.0118	−0.0657
55	0.1658	0.1370	0.1022	0.0649	0.0247	−0.0186	−0.0655	−0.1161
60	0.1171	0.0873	0.0553	0.0211	−0.0155	−0.0550	−0.0973	−0.1431
65	0.0772	0.0509	0.0228	−0.0071	−0.0391	−0.0733	−0.1100	−0.1494
70	0.0481	0.0261	0.0029	−0.0220	−0.0483	−0.0765	−0.1065	−0.1388
75	0.0280	0.0111	−0.0069	−0.0259	−0.0461	−0.0676	−0.0905	−0.1150
80	0.0148	0.0033	−0.0089	−0.0218	−0.0354	−0.0499	−0.0633	−0.0818
85	0.0062	0.0004	−0.0057	−0.0122	−0.0191	−0.0264	−0.0341	−0.0424

$\theta°$	215	220	225	230	235	240	245	250
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9746	0.9723	0.9697	0.9668	0.9635	0.9597	0.9551	0.9504
10	0.9011	0.8925	0.8826	0.8580	0.8586	0.8442	0.8275	0.8084
15	0.7873	0.7689	0.7481	0.7247	0.6981	0.6679	0.6333	0.5935
20	0.6450	0.6151	0.5815	0.5438	0.5010	0.4525	0.3970	0.3334
25	0.4877	0.4462	0.3997	0.3475	0.2887	0.2220	0.1462	0.0593
30	0.3291	0.2772	0.2188	0.1548	0.0821	0.0000	−0.0931	−0.1992
35	0.1810	0.1214	0.0551	−0.0188	−0.1016	−0.1946	−0.2997	−0.4191
40	0.0529	−0.0117	−0.0814	−0.1620	−0.2501	−0.3489	−0.4599	−0.5853
45	−0.0498	−0.1156	−0.1881	−0.2683	−0.3572	−0.4562	−0.5671	−0.6917
50	−0.1243	−0.1885	−0.2588	−0.3363	−0.4216	−0.5163	−0.6216	−0.7394
55	−0.1711	−0.2310	−0.2962	−0.3677	−0.4462	−0.5327	−0.6285	−0.7351
60	−0.1924	−0.2461	−0.3040	−0.3674	−0.4364	−0.5125	−0.5958	−0.6882
65	−0.1918	−0.2375	−0.2880	−0.3406	−0.3989	−0.4625	−0.5322	−0.6089
70	−0.1733	−0.2107	−0.2503	−0.2935	−0.3402	−0.3909	−0.4463	−0.5069
75	−0.1411	−0.1691	−0.1992	−0.2315	−0.2664	−0.3042	−0.3452	−0.3899
80	−0.0992	−0.1182	−0.1380	−0.1600	−0.1826	−0.2079	−0.2346	−0.2639
85	−0.0511	−0.0605	−0.0705	−0.0812	−0.0927	−0.1051	−0.1185	−0.1330

Sectionalized Tower Measurements

Two cases of interest are presented in Figs. A-6 and A-7. In Fig. A-6, it will be noted that the maximum field strength is 224 mv/m for 1-kw input when the tower is driven at the base and an inductive reactance in the form of a short-circuited transmission line is connected across the sectionalizing insulator. The current and phase distribution are of particular interest for this condition. A standing wave of varying amplitude exists on the top section with very little phase shift, while on the lower section a traveling wave characterized by a constant amplitude and progressive phase shift is evident.

When both the upper and lower tower sections are driven as shown in Fig. A-7, the maximum inverse field strength for 1-kw input is 279 mv/m. In this case there is a very rapid phase shift of 180° and the current drops to a very low value. At the bottom of the tower there is a build-up of current that is approximately 180° out of phase with the current on the top section. It is this combination that reduces high angle radiation and is responsible for the strong ground-wave field strength.

APPENDIX B. TWO-TOWER DIRECTIONAL ANTENNAS

Pattern Formulas

General Equation

The inverse field strength from a two-tower directional antenna as shown in Fig. B-1 is given by

$$E = E_1 f_1(\theta) \sqrt{2F} \sqrt{\frac{1 + F^2}{2F} + \cos (S \cos \phi \cos \theta + \Psi)} \tag{B-1}$$

where E = inverse field strength at 1 mile, mv/m
E_1 = inverse field strength at 1 mile from tower 1 when operating in array, mv/m
$f_1(\theta)$ = vertical-radiation characteristic of tower 1

$$F = \frac{E_2 f_2(\theta)}{E_1 f_1(\theta)} \tag{B-2}$$

= ratio of field strength from tower 2 to tower 1

where E_2 = inverse field strength at 1 mile from tower 2 when operating in array, mv/m
$f_2(\theta)$ = vertical-radiation characteristic of tower 2
S = spacing between tower 2 and tower 1, deg
ϕ = azimuth angle from line of towers, deg
θ = elevation angle, deg
Ψ = electrical phase angle of current in tower 2 with respect to tower 1, deg

The above terms as shown in Fig. B-2 are written without subscripts where possible for a simple two-tower array. When more than two towers are involved, the term F in Eq. (B-2) is written F_{21} to designate the ratio between tower 2 and tower 1. Similarly, the spacing would be marked S_{21}, which is the distance from tower 2 to tower 1 that is located at the space reference point. The electrical phase in general is written Ψ_{21} to designate the phase of the current in tower 2 with respect to tower 1.

Minimum-depth Term

The minimum-depth term by definition is

$$\frac{1 + F^2}{2F} \tag{B-3}$$

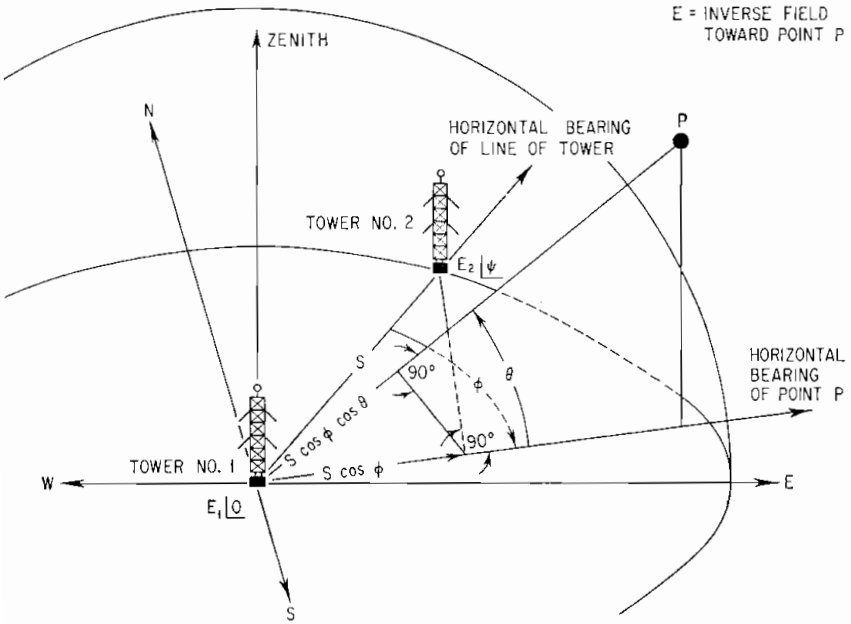


Fig. B-1. Space view of two-tower directional antenna.

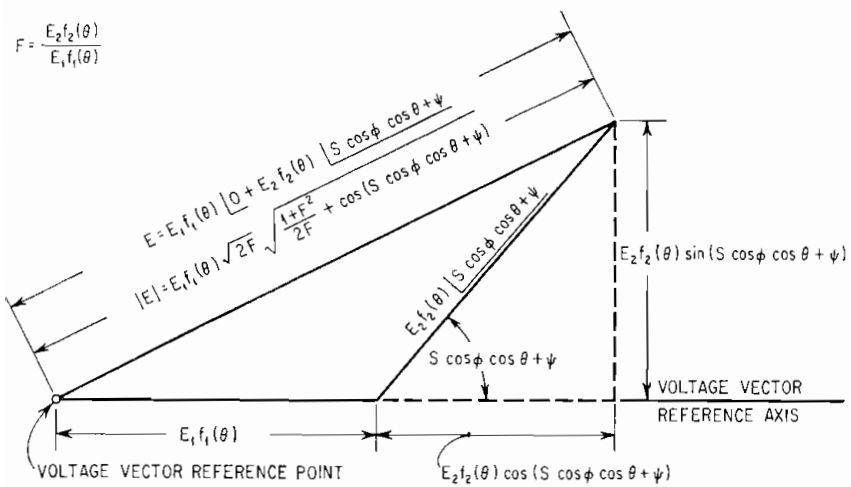


Fig. B-2. Voltage vector diagram for two-tower directional antenna.

Because of its significance in Eq. (B-1), Table B-1 has been prepared. This table lists the values of F, $1/F$, F^2, and the minimum-depth term. The minimum-depth term is unchanged if $1/F$ is used in the place of F.

An inspection of the radicand in Eq. (B-1) shows that E in the minima can be made larger than zero providing the minimum-depth term is not completely canceled by the cosine term. The exact size of E in the minima can be fixed by choice of the value of the minimum-depth term. Conversely, if the equation for E is in the form of Eq. (B-1) and if F is also given, then Table B-1 can be used to check the accuracy of the formula quickly. If F is not given, it can be found from the table.

General Value of Field Ratio

The general form of F is given in Eq. (B-2). The values of $f(\theta)$ for various tower heights are given in Fig. A-4 and Table A-1. Hence, in the design of a two-tower directional antenna, it is convenient first to select the value of the minimum-depth term. The corresponding value of F can be found in Table B-1, and by Eq. (B-2) the ratio of E_2 over E_1 can be determined. This procedure can be reversed to check a given equation.

For pattern computations, it is convenient to fix θ and vary ϕ; thus the information can be used to meet the requirement in Paragraph 3.150 of Part 3, FCC Rules. The data required are field strength E as a function of azimuth angle ϕ for 5° intervals of elevation angle θ from 0 to 60°.

Horizontal-plane Equation

In the ground plane Eq. (B-1) reduces to

$$E = E_1\sqrt{2F}\sqrt{\frac{1 + F^2}{2F} + \cos(S\cos\phi + \Psi)} \qquad \text{(B-4)}$$

where F is the ratio of E_2 over E_1 for equal or unequal height towers. Thus Eq. (B-4) can be used for $\theta = 0$ and Eq. (B-1) can be used at elevation angles up to 60° as required by the above rules.

If the ratio of E_2 over E_1 is given but E has not been expressed in the form of Eq. (B-1) or (B-4), it is convenient to use Table B-1 to obtain the values to be used in the above equations.

The minimum-depth term usually appears more than once in directional-antenna-pattern equations for arrays having more than two towers. Three towers in line and parallelogram arrays can use two or more of the multiplication radicands given in Eq. (B-1).

Systematization of Two-tower Patterns

The systematization has been divided into relatively large steps of 45° for phasing and spacing in Figs. B-3 to B-6. The spacing extends to four wavelengths or 1,440°. The more useful range of spacing up to one wavelength is given in small steps of 15° for both spacing and phasing in Figs. B-7 to B-12.

Pattern Size

Field Strength of Reference Tower

In order to determine the pattern size, it is rather common practice to compute the value of field strength that the reference tower will radiate when operating in the directional-antenna array. This value can then be used in Eq. (B-1) to determine the pattern shape at the correct size. The value of E_1 can be computed from the following

(*Continued on page 2-131.*)

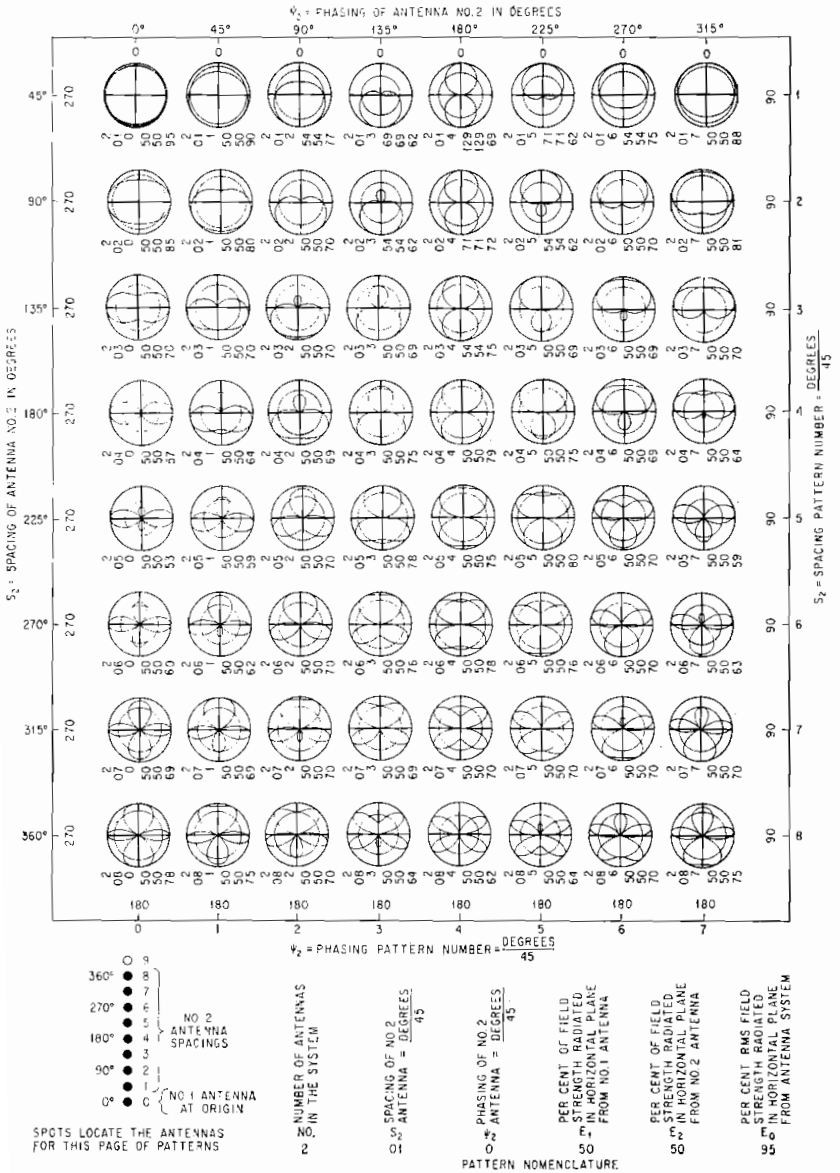


FIG. B-3

FIGS. B-3 to B-6. Systematization of two-tower patterns in steps of 45 to 1,440°.

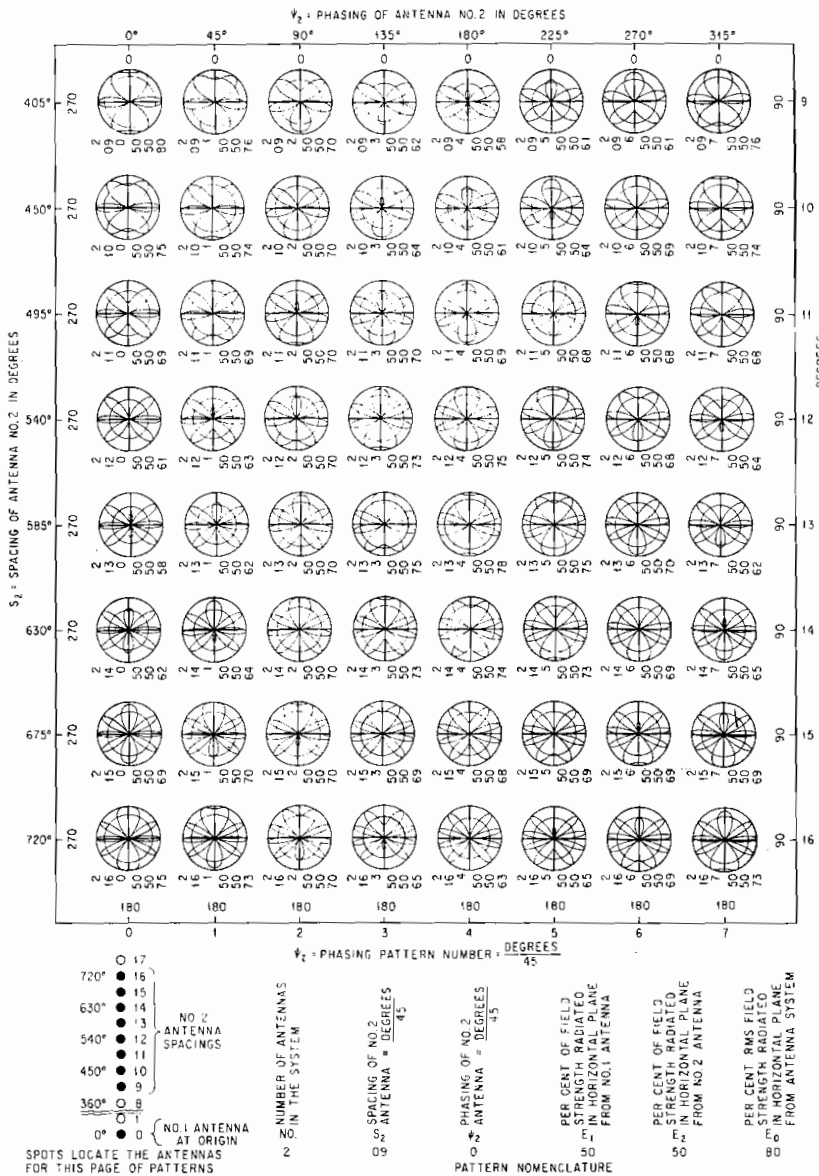

ψ2 = PHASING OF ANTENNA NO.2 IN DEGREES
0° 45° 90° 135° 180° 225° 270° 315°
S2 = SPACING OF ANTENNA NO.2 IN DEGREES
405° 450° 495° 540° 585° 630° 675° 720°
S2 = SPACING PATTERN NUMBER = DEGREES / 45
ψ2 = PHASING PATTERN NUMBER = DEGREES / 45
0 1 2 3 4 5 6 7
720° 630° 540° 450° 360° 0°
NO. 2 ANTENNA SPACINGS
NO.1 ANTENNA AT ORIGIN
SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS
NUMBER OF ANTENNAS IN THE SYSTEM
SPACING OF NO.2 ANTENNA = DEGREES / 45
PHASING OF NO.2 ANTENNA = DEGREES / 45
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.1 ANTENNA
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.2 ANTENNA
PER CENT RMS FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM
NO.
S2
ψ2
E1
E2
Eo
2
09
0
50
50
80
PATTERN NOMENCLATURE

FIG. B-4

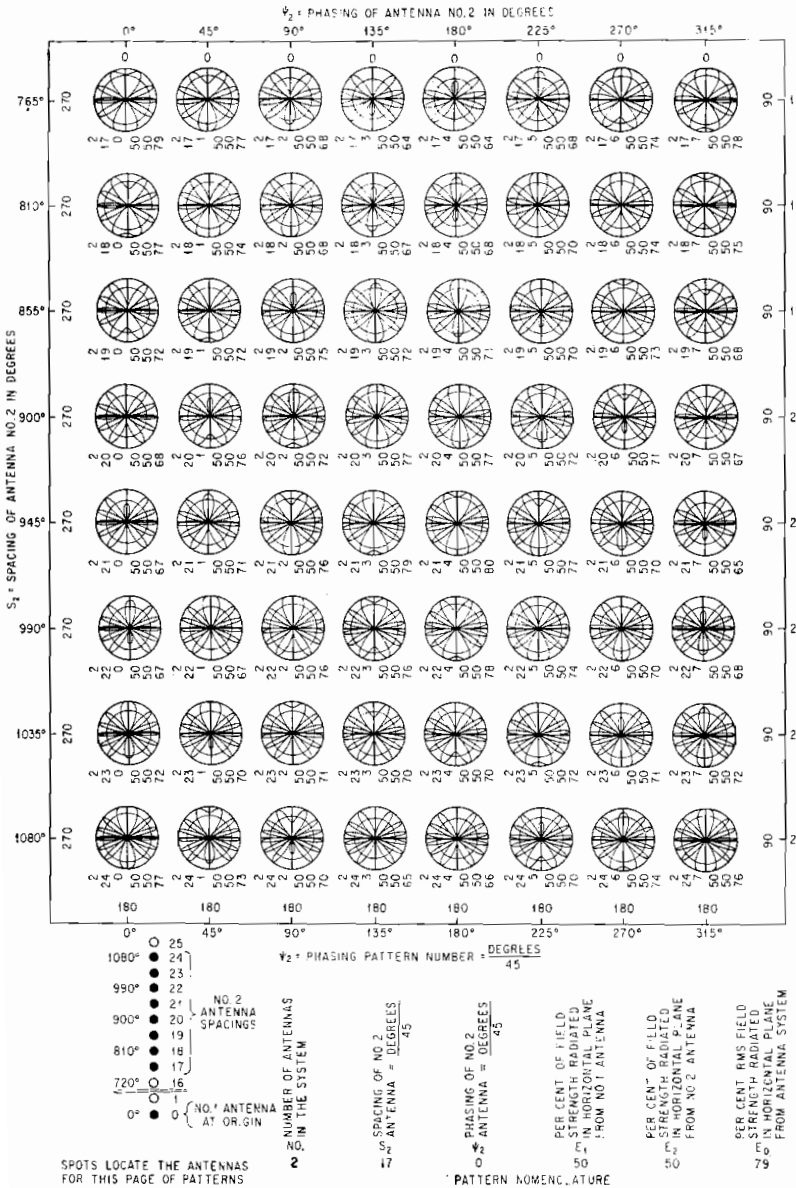

Ψ2 = PHASING OF ANTENNA NO.2 IN DEGREES
0° 45° 90° 135° 180° 225° 270° 315°
S2 = SPACING OF ANTENNA NO.2 IN DEGREES
765° 810° 855° 900° 945° 990° 1035° 1080°
S2 = SPACING PATTERN NUMBER = DEGREES / 45
Ψ2 = PHASING PATTERN NUMBER = DEGREES / 45
NO. 2 ANTENNA SPACINGS
NO.1 ANTENNA AT ORIGIN
NUMBER OF ANTENNAS IN THE SYSTEM
SPACING OF NO.2 ANTENNA = DEGREES / 45
PHASING OF NO.2 ANTENNA = DEGREES / 45
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.1 ANTENNA
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.2 ANTENNA
PER CENT RMS FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM
SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS
PATTERN NOMENCLATURE
NO. 2 17 0 50 50 79

FIG. B-5

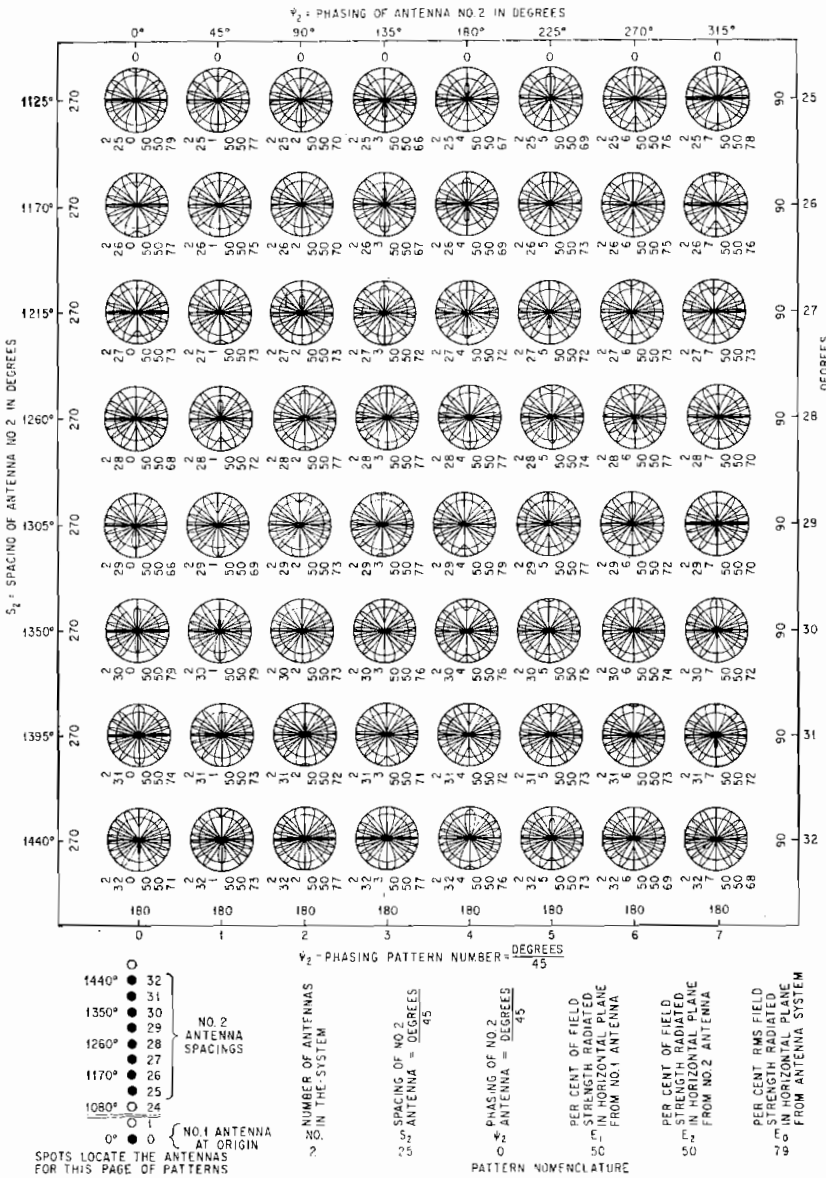

ψ2 = PHASING OF ANTENNA NO.2 IN DEGREES
0° 45° 90° 135° 180° 225° 270° 315°
S2 = SPACING OF ANTENNA NO 2 IN DEGREES
1125° 1170° 1215° 1260° 1305° 1350° 1395° 1440°
S2 = SPACING PATTERN NUMBER = DEGREES / 45
ψ2 = PHASING PATTERN NUMBER = DEGREES / 45
1440° 32
1395° 31
1350° 30
1260° 29
1260° 28
1215° 27
1170° 26
1125° 25
1080° 24
NO. 2 ANTENNA SPACINGS
0° 0
NO.1 ANTENNA AT ORIGIN
SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS
NUMBER OF ANTENNAS IN THE SYSTEM
NO. 2
SPACING OF NO.2 ANTENNA = DEGREES / 45
S2
25
PHASING OF NO.2 ANTENNA = DEGREES / 45
ψ2
0
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.1 ANTENNA
E1
50
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.2 ANTENNA
E2
50
PER CENT RMS FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM
E0
79
PATTERN NOMENCLATURE

FIG. B-6

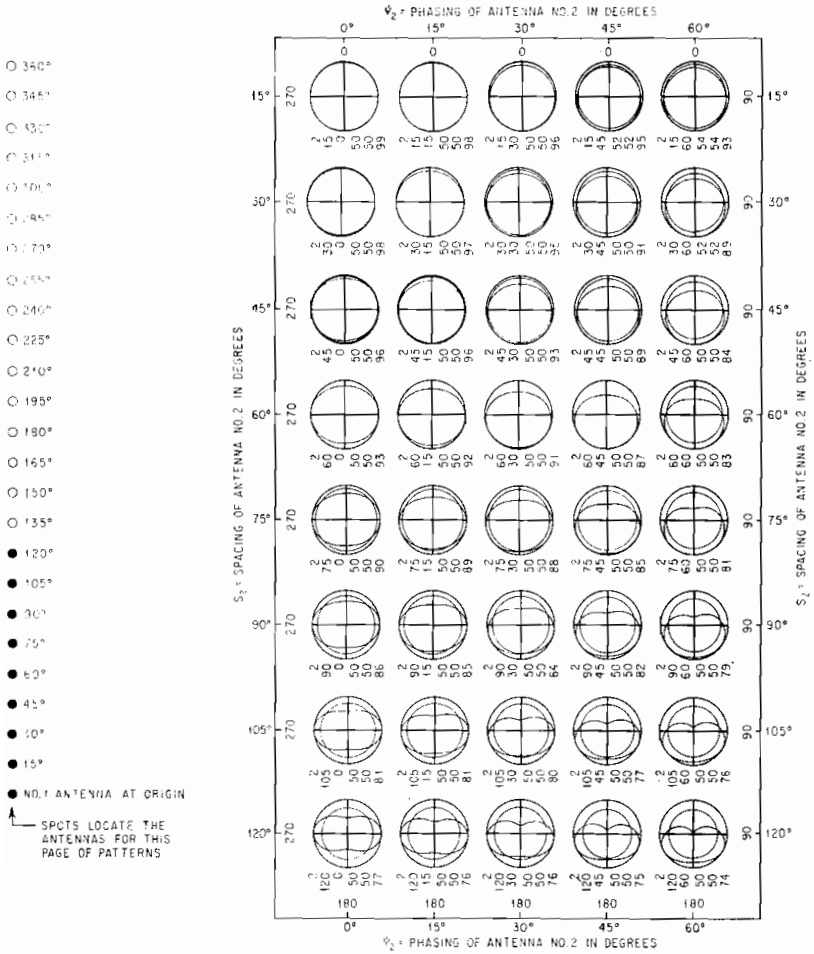


FIG. B-7

FIGS. B-7 to B-12. Systematization of two-tower patterns in steps of 15 to 360°.

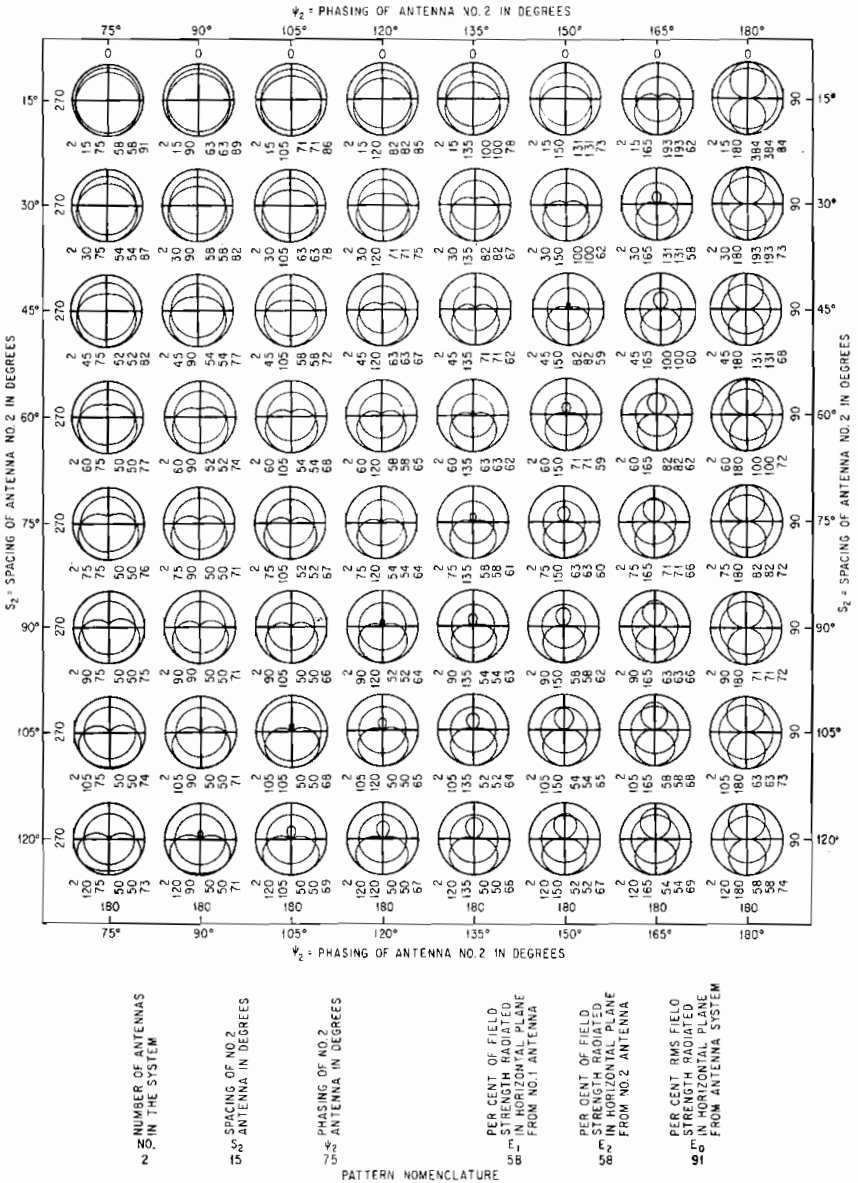

Ψ2 = PHASING OF ANTENNA NO.2 IN DEGREES
75° 90° 105° 120° 135° 150° 165° 180°
S2 = SPACING OF ANTENNA NO.2 IN DEGREES
15° 30° 45° 60° 75° 90° 105° 120°
NUMBER OF ANTENNAS IN THE SYSTEM
NO. 2
SPACING OF NO.2 ANTENNA IN DEGREES
S2 15
PHASING OF NO.2 ANTENNA IN DEGREES
Ψ2 75
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.1 ANTENNA
m 58
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.2 ANTENNA
n 58
PER CENT RMS FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM
o 91
PATTERN NOMENCLATURE

FIG. B-8

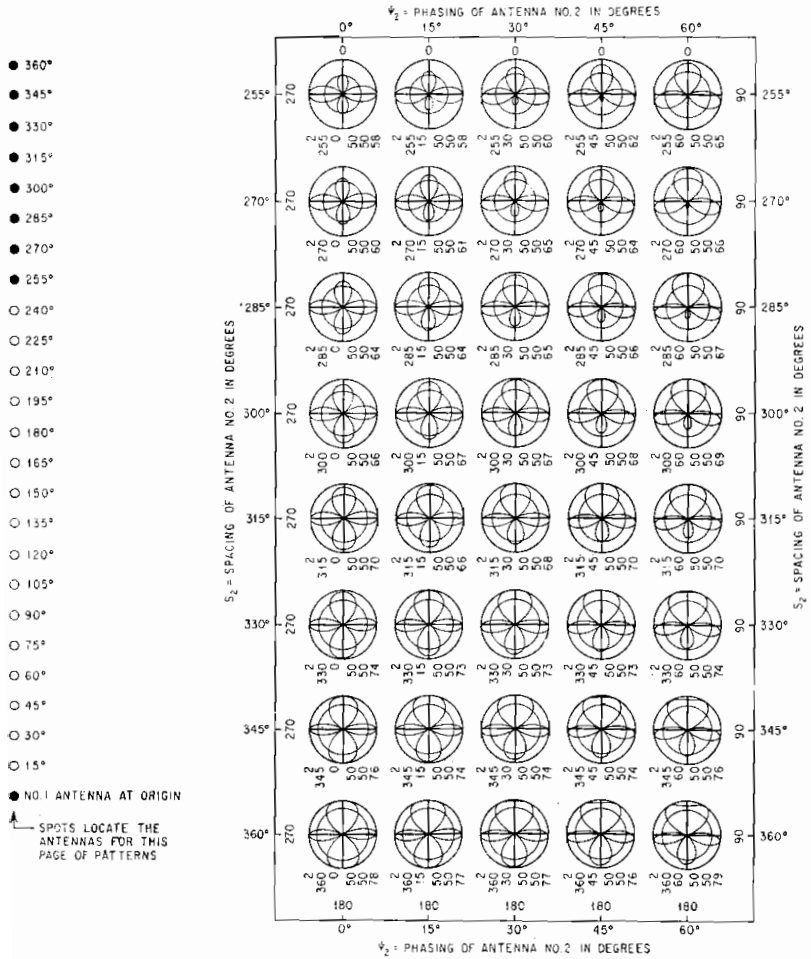

● 360°
● 345°
● 330°
● 315°
● 300°
● 285°
● 270°
● 255°
○ 240°
○ 225°
○ 210°
○ 195°
○ 180°
○ 165°
○ 150°
○ 135°
○ 120°
○ 105°
○ 90°
○ 75°
○ 60°
○ 45°
○ 30°
○ 15°
● NO.1 ANTENNA AT ORIGIN
SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS
Ψ2 = PHASING OF ANTENNA NO.2 IN DEGREES
0° 15° 30° 45° 60°
S2 = SPACING OF ANTENNA NO.2 IN DEGREES
255° 270° 285° 300° 315° 330° 345° 360°
180 180 180 180 180
Ψ2 = PHASING OF ANTENNA NO.2 IN DEGREES

FIG. B-9

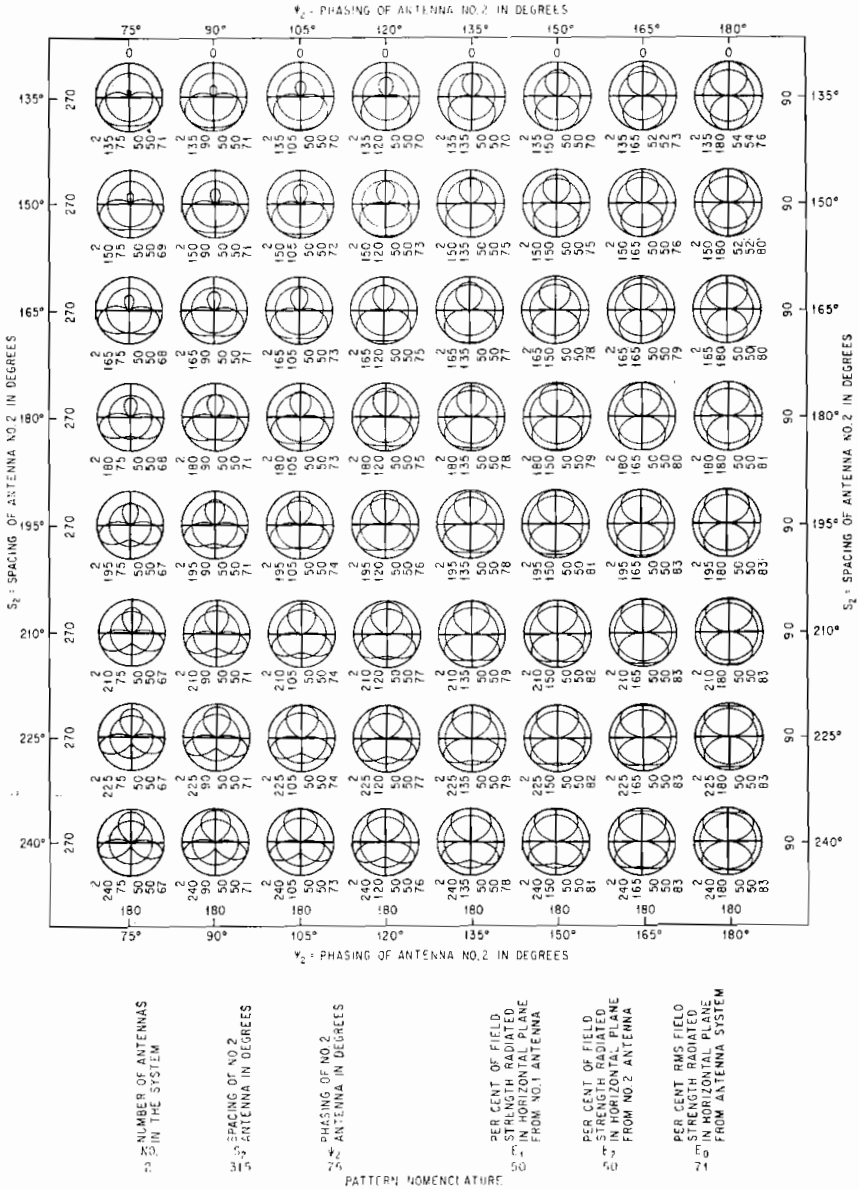

Ψ_2 = PHASING OF ANTENNA NO.2 IN DEGREES
75° 90° 105° 120° 135° 150° 165° 180°
S_2 = SPACING OF ANTENNA NO.2 IN DEGREES
135° 150° 165° 180° 195° 210° 225° 240°
0 90 180 270
NUMBER OF ANTENNAS IN THE SYSTEM
SPACING OF NO.2 ANTENNA IN DEGREES
PHASING OF NO.2 ANTENNA IN DEGREES
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.1 ANTENNA
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.2 ANTENNA
PER CENT RMS FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM
PATTERN NOMENCLATURE

FIG. B-10

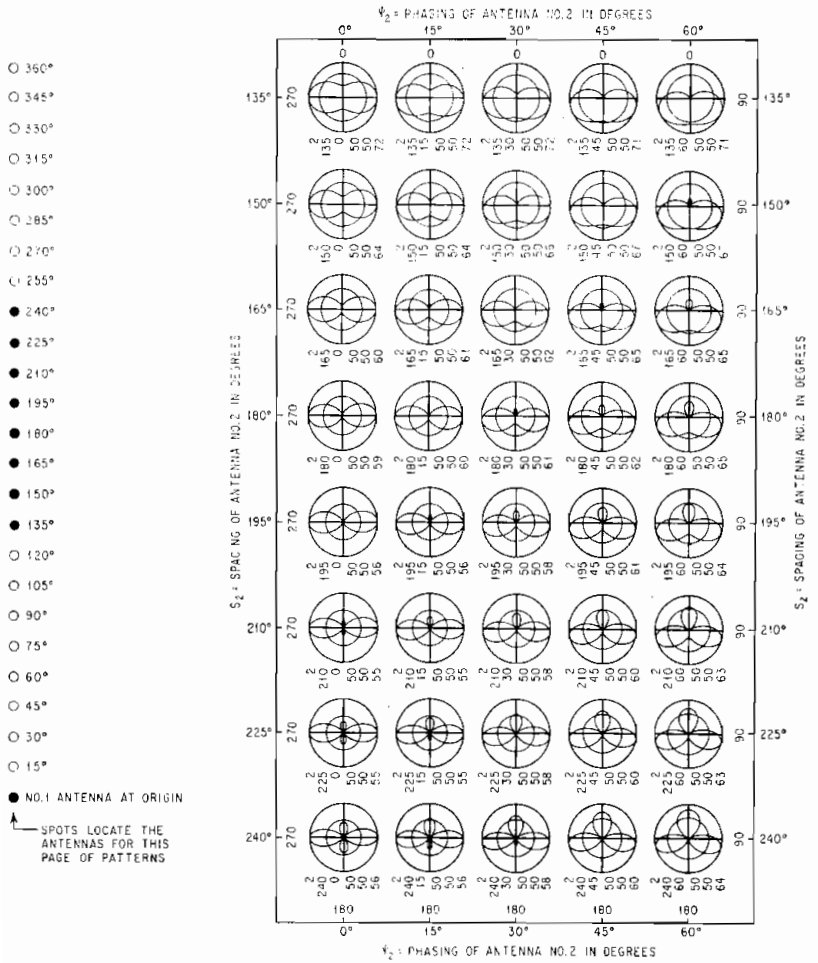

Ψ_2 = PHASING OF ANTENNA NO.2 IN DEGREES
0°
15°
30°
45°
60°
S_2 = SPACING OF ANTENNA NO.2 IN DEGREES
135°
150°
165°
180°
195°
210°
225°
240°
270°
90°
180
360°
345°
330°
315°
300°
285°
270°
255°
240°
225°
210°
195°
180°
165°
150°
135°
120°
105°
90°
75°
60°
45°
30°
15°
NO.1 ANTENNA AT ORIGIN
SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS

FIG. B-11

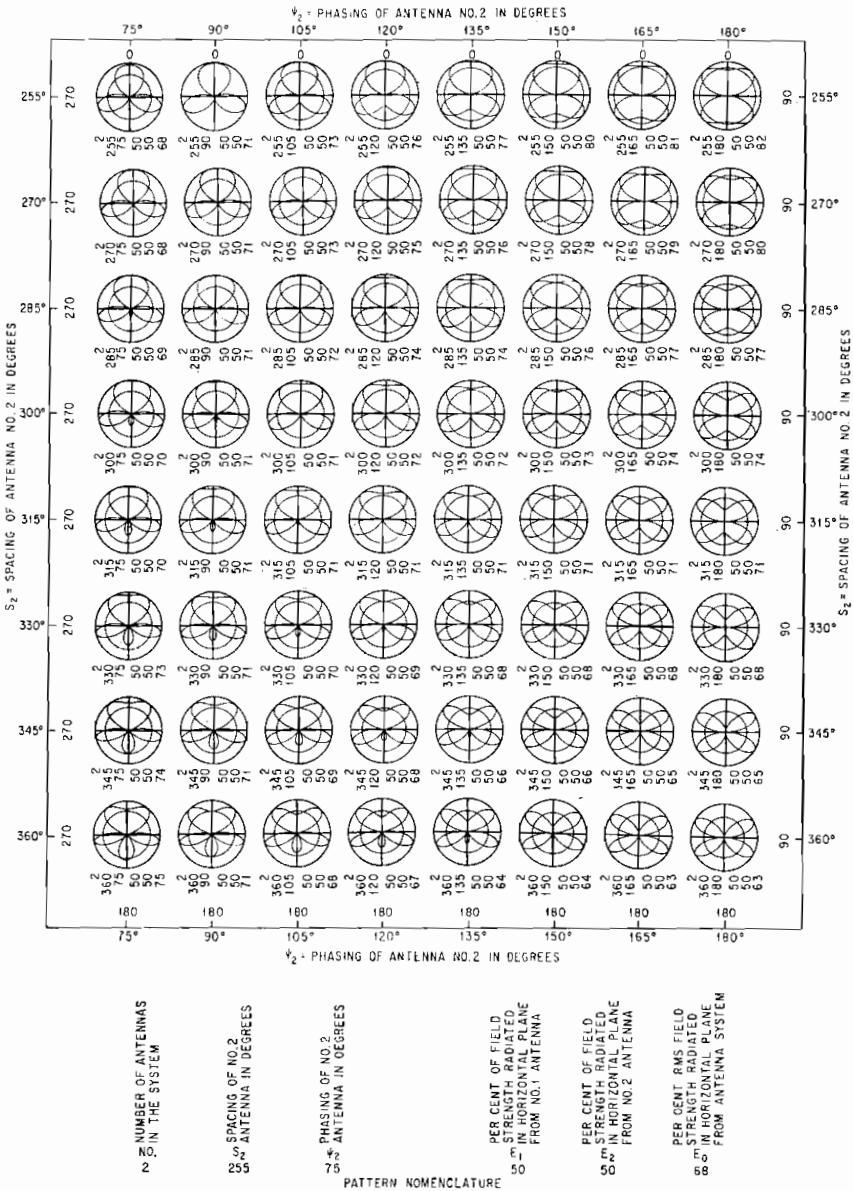

ψ2 = PHASING OF ANTENNA NO.2 IN DEGREES
75° 90° 105° 120° 135° 150° 165° 180°
S2 = SPACING OF ANTENNA NO.2 IN DEGREES
255° 270° 285° 300° 315° 330° 345° 360°
NUMBER OF ANTENNAS NO. IN THE SYSTEM
SPACING OF NO.2 ANTENNA IN DEGREES S2
PHASING OF NO.2 ANTENNA IN DEGREES ψ2
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.1 ANTENNA E1
PER CENT OF FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM NO.2 ANTENNA E2
PER CENT RMS FIELD STRENGTH RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM Eo
PATTERN NOMENCLATURE

FIG. B-12

equation, sometimes called the loop impedance formula, thus

$$E_1 = E_{1s}\sqrt{\frac{R_{11}}{R_1 + M^2R_2}}$$

$$= E_{1s}\sqrt{\frac{R_{11}}{(R_{11} + R_{L1} + R_{C1}) + M^2(R_{22} + R_{L2} + R_{C2})}} \qquad \text{(B-5)}$$

where E_1 = inverse field strength at 1 mile for tower 1 while operating in the array, mv/m
E_{1s} = inverse field strength at 1 mile for tower 1 operating alone as a standard reference antenna, mv/m
R_{11} = loop self-resistance of tower 1, ohms
R_{L1} = loss resistance assumed at loop of tower 1, ohms
R_{C1} = coupled resistance at loop of tower 1 from other towers while array is in operation, ohms
R_{22} = loop self-resistance of tower 2, ohms
R_{L2} = loss resistance assumed at loop of tower 2, ohms
R_{C2} = coupled resistance at loop of tower 2 from other towers while array is in operation, ohms
M = ratio of current at loop of tower 2 divided by current at loop of tower 1

The values of E_{1s}, R_{11}, and R_{22} can be obtained from Fig. A-5 for simple towers that are not sectionalized or top-loaded. For other types of towers these values must be assumed or calculated. The values of R_{L1} and R_{L2} are usually assumed to be 2 ohms each.

Coupled-resistance Formula

The values of coupled resistance from the other towers are given by

$$R_{C1} = MZ\cos(\Psi + \gamma) \qquad \text{(B-6)}$$

$$R_{C2} = \frac{Z}{M}\cos(-\Psi + \gamma) \qquad \text{(B-7)}$$

where Z = magnitude of loop impedance between the two towers, ohms
M = magnitude of current ratio of loop current in tower 2 divided by tower 1
γ = angle of loop mutual impedance, deg
Ψ = electrical phase angle of current in tower 2 with respect to tower 1, deg

These equations can be used with reasonable accuracy for simple nonloaded towers.

The above equations are written without the use of magnitude signs and subscripts for the sake of simplicity. The exact vector expressions are

$$Z_{21} = |Z_{21}|\,\underline{\gamma_{21}} \qquad \text{(B-8)}$$

and

$$M_{21} = \frac{I_2}{I_1} = |M_{21}|\,\underline{\Psi_{21}} \qquad \text{(B-9)}$$

where the currents are vector values having magnitude and phase angle. The current values in this equation are determined when the directional antenna is designed.

Mutual-impedance Curves

The value of mutual impedance for most tower heights and spacing is given in Fig. B-13. The loop mutual impedance between quarter-wave towers is shown in Fig. B-14. These values can be used in the above equations for coupled resistance. For towers of unequal height the mutual impedance can be computed or reference can be made to curves already computed.[4]

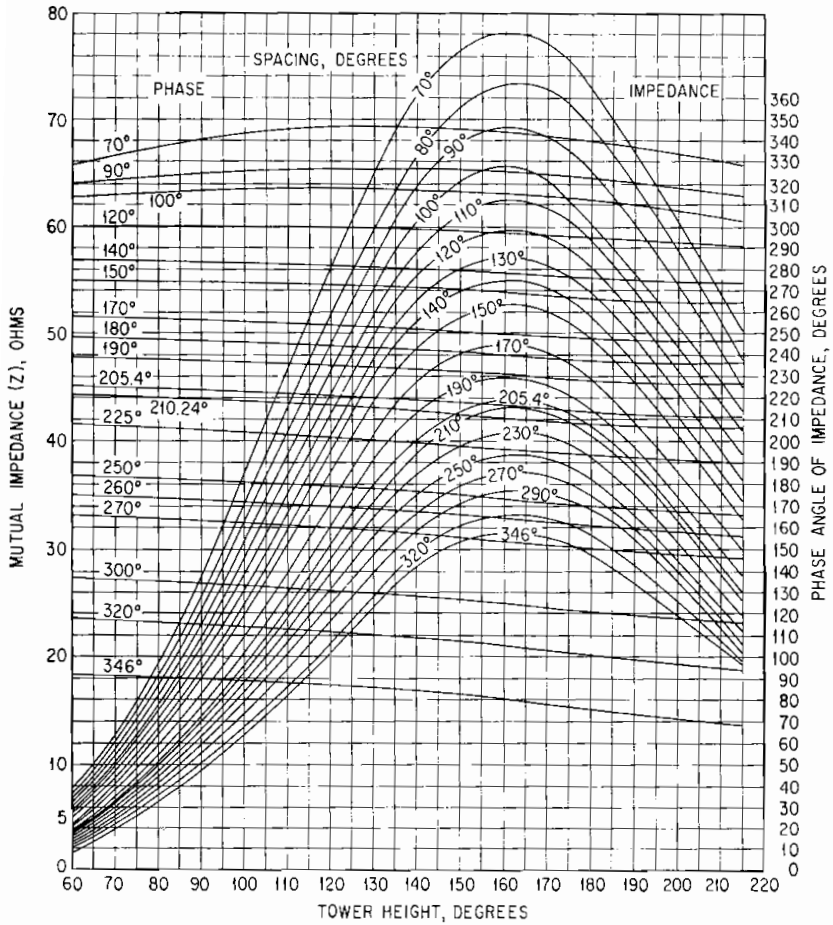


FIG. B-13. Loop mutual impedance and phase angle between two towers of equal height.

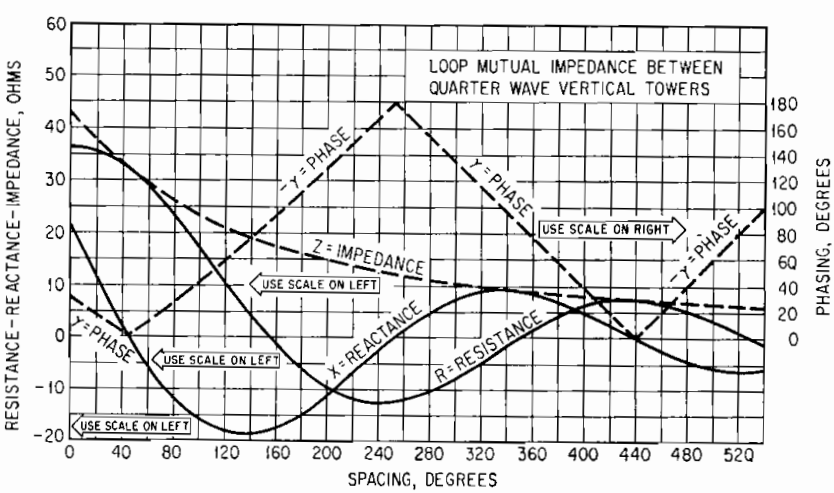


FIG. B-14. Loop mutual impedance between quarter-wave vertical towers.

Top-loaded and Sectionalized Towers

The preceding equations can be applied to top-loaded and sectionalized towers but with considerable complication. The field strength E_{1s} and the self-resistance R_{11} are in general not available. They can be found in the literature for a few special cases.[3] The mutual impedance between sectionalized towers likewise is not readily available. It must be calculated for any special case if it is to be determined accurately. It is easier to determine the mutual effects by graphical solutions to the necessary accuracy.

Horizontal-plane RMS Field Strength

The rms field strength for a two-tower array can be determined from

$$E_0 = E_1\sqrt{1 + F^2 + 2F \cos \Psi J_0(S)} \tag{B-10}$$

where E_0 = rms inverse field strength at 1 mile, mv/m
E_1 = inverse field strength at 1 mile for reference tower 1 while operating in array, mv/m
F = ratio of magnitude of field strength from tower 2 divided by tower 1
Ψ = electrical phase of field from tower 2 with respect to tower 1, deg
$J_0(S)$ = Bessel function of first order for tower spacing S

Usually the terms F and M are identical. However, with unequal-height towers and top-loading or sectionalized towers these ratios may have different values. Table B-2 can be used to obtain the desired Bessel-function values. Interpolation can be used if necessary.

Horizontal RMS Field-strength and Power Gain

The field-strength gain of any directional-antenna array can be written

$$\sqrt{g_0} = \frac{E_0}{E_{1s}} \tag{B-11}$$

where $\sqrt{g_0}$ = field-strength gain by definition in the horizontal plane
E_0 = rms inverse field strength at 1 mile, mv/m
E_{1s} = inverse field strength at 1 mile for tower 1 operating alone as a standard reference antenna, mv/m

The power gain for a two-tower array is given by

$$g_0 = \frac{1 + F^2 + 2F \cos \Psi J_0(S)}{1 + F^2 + 2F \cos \Psi (R_{12}/R_{11})} \tag{B-12}$$

where g_0 = directivity or power gain
F = ratio of magnitude of field strength from tower 2 divided by tower 1
Ψ = electrical phase of field from tower 2 with respect to tower 1, deg
$J_0(S)$ = Bessel function of first kind and zero order for tower spacing S
R_{12} = mutual loop resistance between towers, ohms
R_{11} = loop-radiation self-resistance of tower 1, ohms

It is of interest to know whether a particular antenna system is a gainer or a loser as compared with a standard reference antenna. This can be determined by the following:

$$E_0 = E_{1s}\sqrt{g_0} \tag{B-13}$$

Now, if 90° towers are used and the field ratio $F = 1$, Eq. (B-12) substituted in Eq. (B-13) gives

$$E_0 = 195\sqrt{\frac{1 + \cos \Psi J_0(S)}{1 + \cos \Psi (R_{12}/36.6)}} \tag{B-14}$$

The solution of this equation is shown in Fig. B-15 for various values of tower current phasing and tower spacing. It gives the theoretical field without loss for 1-kw operation.

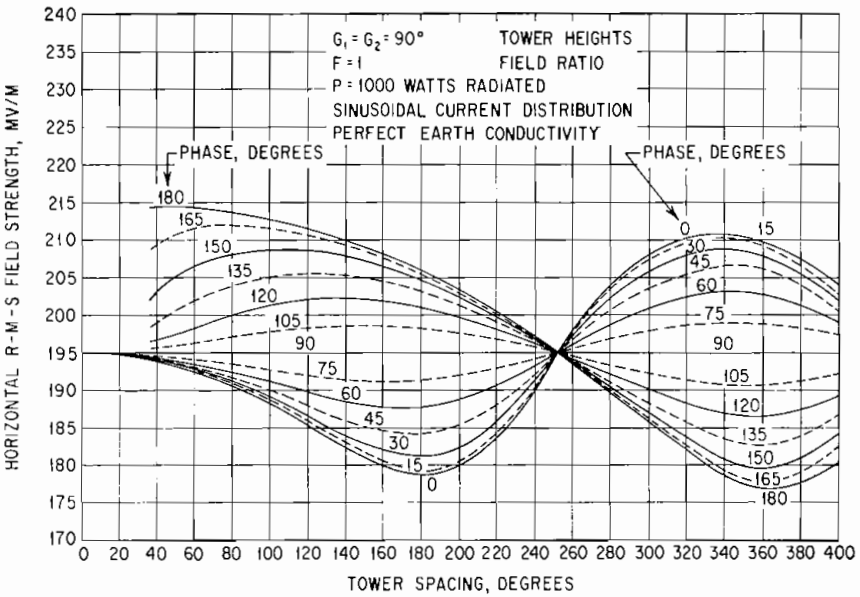


FIG. B-15. Horizontal rms field strength of two-tower directional antenna.

Power to Provide System Losses

Because of losses in the transmission lines and matching, phasing, and power-division networks, plus other losses in the system such as resistance losses in the tower and ground system and dielectric losses in the insulators, an overfeeding of power is allowed by FCC at the common point.

The calculation of the amount of overfeeding of power at the common point is made as follows:

For stations with directional antennas authorized to radiate 5 kw of power or less, the measured common-point resistance is assumed to be 92.5 per cent of its measured value, and for all other directional antennas, it is assumed to be 95 per cent. This arbitrary reduction in resistance amounts to increasing the current at the common point by $1/\sqrt{0.925} = 1.0389$, or approximately a 4 per cent increase for values of transmitter power up to and including 5 kw. For transmitters with power above 5 kw the antenna current can be increased $1/\sqrt{0.95} = 1.0252$, or approximately a 2.5 per cent increase.

Another way of saying this is that for a 1-kw station 1,081 watts can be fed in at the common point, while for a 50-kw station 52,105 watts can be fed in at the common point. For the 1-kw station there is 81 watts available for feeder-system loss, and in the 50-kw station there is 2,105 watts available for feeder-system loss.

Feeder System

Loop and Base, Impedance and Current

The first approximation of the base resistance of an ordinary base-insulated tower that is not top-loaded or sectionalized is given by

$$R_b = \frac{R_a}{\sin^2 G} \tag{B-15}$$

where R_b = base resistance of tower, ohms
R_a = loop resistance of tower, ohms
G = electrical height of tower, deg
The first approximation of the base current for the above tower is

$$I_b = I_a \sin G \tag{B-16}$$

where I_b = base current of tower, amp
I_a = loop current of tower, amp
These equations are consistent with the theory that the power at the loop is equal to the power at the base; that is,

$$I_b^2 R_b = I_a^2 R_a \tag{B-17}$$

These equations are most accurate for single towers operating alone where the cross section is small and uniform so the current distribution will be approximately sinusoidal.

A second approximation of the base impedance depends upon the tower acting like a transmission line from the loop to the base and is given by

$$Z_b = Z_0 \frac{Z_a \cos (G - 90) + jZ_0 \sin (G - 90)}{Z_0 \cos (G - 90) + jZ_a \sin (G - 90)} \tag{B-18}$$

where Z_b = base impedance of tower, ohms
Z_a = loop impedance of tower, ohms
Z_0 = average characteristic impedance of tower, ohms
G = electrical height of tower, deg

A second approximation for the base current also depends upon the tower acting like a transmission line and is written

$$I_b = |I_a| \left[\sin G + j \frac{R_a}{2Z_0} (1 - \cos G) \right] \tag{B-19}$$

where I_b = complex value of tower base current, amp
$|I_a|$ = magnitude of tower loop current, amp
R_a = loop resistance of tower, ohms
Z_0 and G are defined following Eq. (B-18). The first term in this equation is a sinusoidal term corresponding to Eq. (B-16), which corresponds to the antenna current that causes the radiation. The second term is the feed current which supplies the radiated power from the base to the loop. It should be noted that this equation does not give the phase of the base current with respect to the loop current. This change in phase between the loop and base current is expressed by the more general equation

$$I_y = |I_a| \left[\sin (G - y) + j \frac{R_a}{2Z_0} (\cos y - \cos G) \right] \tag{B-20}$$

where Iy is the current at any height y on the tower in amperes. The other terms are defined in Eq. (B.19). Equation (B-20) reduces to Eq. (B-19) when $y = 0$. It gives the phase as well as the magnitude of the current at any point on the tower; hence at the current loop,

$$I_a = |I_a| \left[1 + j \frac{R_a}{2Z_0} (\cos y - \cos G) \right] \tag{B-21}$$

The difference in the phase of the current I_a in Eq. (B-21) and the current I_b in Eq. (B-19) is the additional phase shift that must be provided for in the feeder system.

Conservation of power between the loop and base may not exist in Eqs. (B-18) and (B-19) as it does in Eqs. (B-15) and (B-16). However, Eqs. (B-18) and (B-19) usually give a better answer for the base impedance values when the towers are operating in a directional-antenna system.

These equations can be used in the feeder-system design. However, it is advisable to provide adequate range so proper adjustments can be made when the system is put into operation.

Networks for Matching Impedances

General. A directional-antenna system usually requires impedance-matching networks at several points such as from the transmission lines to the towers and perhaps from the transmitter to the common point of the antenna feeder system. These networks are usually made up of lumped constants in the form of L, T, or π sections.

If an impedance load is not a pure resistance, it can be made to look like a pure resistance by adding a reactance element in series or parallel that will make the load either series- or parallel-resonant. If this is done, the treatment of the impedance-matching networks can be simplified. Therefore in this section networks to match between pure resistance values of R_1 and R_2 will be treated.

L Sections. An L section is the simplest way to match between two resistors R_1 and R_2. It is made up of an inductor for Z_2 and a capacitor for Z_3 with a small, fixed phase lag depending upon the ratio $r = R_1/R_2$. Or it can be constructed with a capacitor for Z_2 and an inductor for Z_3 with a small phase advance as shown in Figs. B-16 and B-17.

The phase shift in an L section is fixed by the ratio $r = R_1/R_2$. This is because there are only two reactance elements. The size of the shunt element across R_1 controls the size of R_2, while the series element is used to resonate the circuit so only resistance appears at the R_2 terminals.

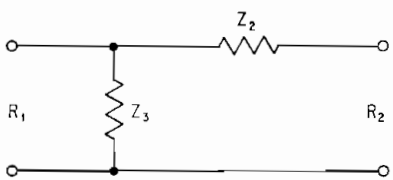


FIG. B-16. General L-section impedance-matching network.

The design equations for an L section matching between resistors R_1 and R_2 are

$$Z_2 = \pm jR_2\sqrt{r-1} = \pm j\frac{R_1}{a} \quad \text{(B-22)}$$

$$Z_3 = \mp j\frac{R_1}{\sqrt{r-1}} = \mp j\frac{R_1}{b} \quad \text{(B-23)}$$

$$\cos\beta = \frac{1}{\sqrt{r}} \quad \text{(B-24)}$$

where Z_1 = reactance of series arm, ohms
Z_2 = reactance of shunt arm, ohms
R_1 = larger terminating resistance, ohms
R_2 = smaller terminating resistance, ohms
$r = R_1/R_2$ ratio
β = phase shift, deg

The $\pm j$ in Eq. (B-22) and $\mp j$ in Eq. (B-23) means simply that if $+j$ or an inductor is used for Z_1, then $-j$ or a capacitor must be used for Z_3.

T and π Sections. T and π sections made up of reactance arms are widely used in the directional-antenna feeder systems. With the three reactance elements it is possible to control the amount of phase shift in addition to the input and output resistance values.

The efficiency of such a network is implicitly determined by the ratio $r = R_1/R_2$ and the phase shift β. There is no choice between T and π sections, whether advancing or retarding the phase, as far as efficiency is concerned. The loss increases with the ratio r and tends to increase for very small or very large phase shifts. For very high transformation ratios r of, say, 10 or more, it is advisable to use two or more sections in tandem. This will increase the stability and reduce the loss.

The design equations for a T or π section are

$$a = \frac{r\sin\beta}{\sqrt{r} - \cos\beta} \quad \text{(B-25)}$$

$$b = \sqrt{r}\sin\beta \quad \text{(B-26)}$$

$$c = \frac{\sqrt{r}\sin\beta}{1 - \sqrt{r}\cos\beta} \quad \text{(B-27)}$$

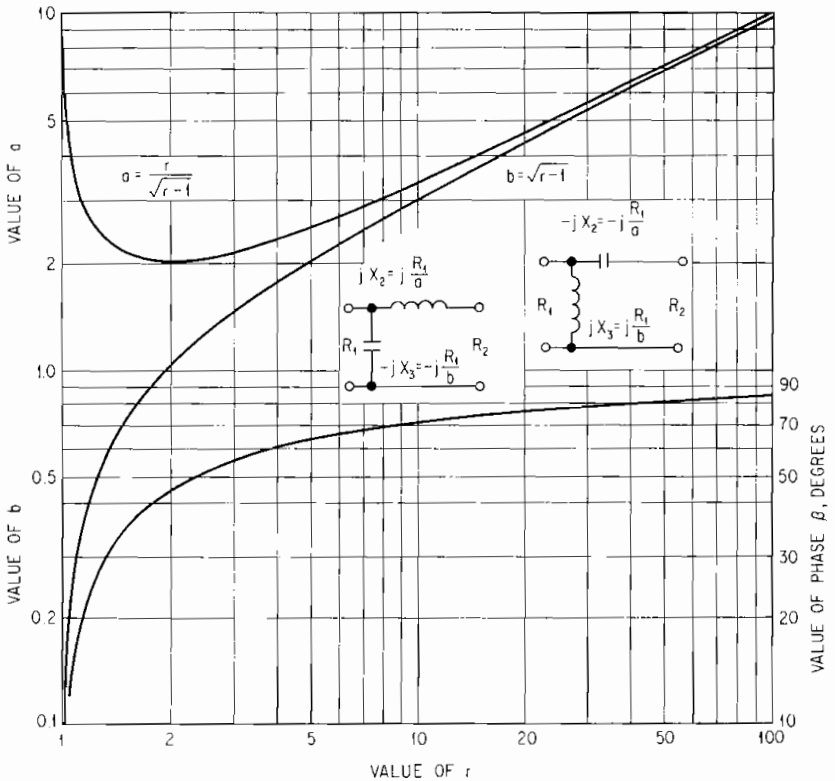


FIG. B-17. L-section design chart.

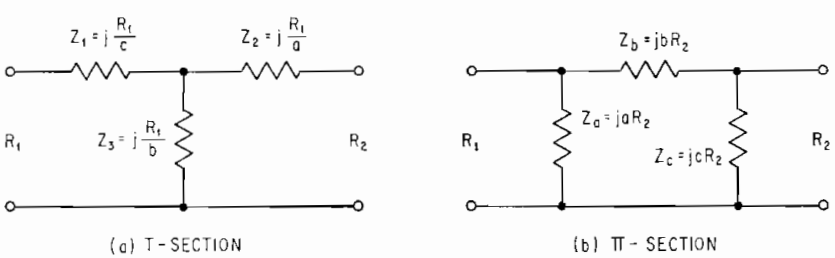


FIG. B-18. General T- and π-section impedance-matching network.

where a = design factor as shown in Figs. B-18 and B-19
b = design factor as shown in Figs. B-18 and B-19
c = design factor as shown in Figs. B-18 and B-19
$r = R_1/R_2$, ratio, greater than 1
β = phase shift, deg

The graphs of a, b, and c are shown in Figs. B-20 through B-24 where r is assumed to be equal or greater than unity. The terminals at R_1 can be placed at either the load or generator end of the section; hence the above equations can be applied to any case.

It is interesting to note that these design curves also apply for the L section where $a = r/\sqrt{r-1}$, $b = \sqrt{r-1}$, and $c = \infty$.

Transmission Lines

General. Most directional antennas require one or more RF transmission lines. They are usually operated nonresonant, which means that the load is made equal to the characteristic impedance of the transmission line. In this case the wave travels from the transmitter end to the load end and is completely absorbed by the load; therefore, there are no standing waves on the line. For this condition of operation the power loss and standing waves on the line are a minimum.

The general equations for the voltage and current at the sending and receiving end of a transmission line are

$$E_s = E_r \cosh \sqrt{ZY}\, l + I_r Z_0 \sinh \sqrt{ZY}\, l \tag{B-28}$$

$$I_s = I_r \cosh \sqrt{ZY}\, l + \frac{E_r}{Z_0} \sinh \sqrt{ZY}\, l \tag{B-29}$$

where E_s = sending end voltage, volts
E_r = receiving end voltage, volts
$Z = R + j\omega L$ = series impedance per unit length, ohms
$\gamma = G + j\omega C$ = shunt admittance per unit length, ohms
l = length of line in same units as Z and γ
$Z_0 = \sqrt{Z/Y}$ = characteristic impedance, ohms
$\gamma = \sqrt{ZY}$ = propagation constant, or hyperbolic angle per unit length, radians

Characteristic Impedance. The characteristic impedance at radio frequency can be taken as a pure resistance,

$$Z_0 = \sqrt{\frac{L}{C}} \tag{B-30}$$

where L = inductance per unit length, henrys
C = capacitance per unit length, farads

For a single coaxial transmission line this equation can be written

$$Z_0 = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{D}{d} \tag{B-31}$$

where ϵ = dielectric constant
D = inside diameter of outer conductor
d = outside diameter of inner conductor in the same units as D

For a parallel two-wire transmission line the characteristic impedance is

$$Z_0 = 120 \cosh^{-1} \frac{D}{d} \tag{B-32}$$

where D = spacing between conductor centers
d = diameter of conductors in same units as D

The characteristic impedance of coaxial and two-wire transmission lines is shown in Fig. B-25.

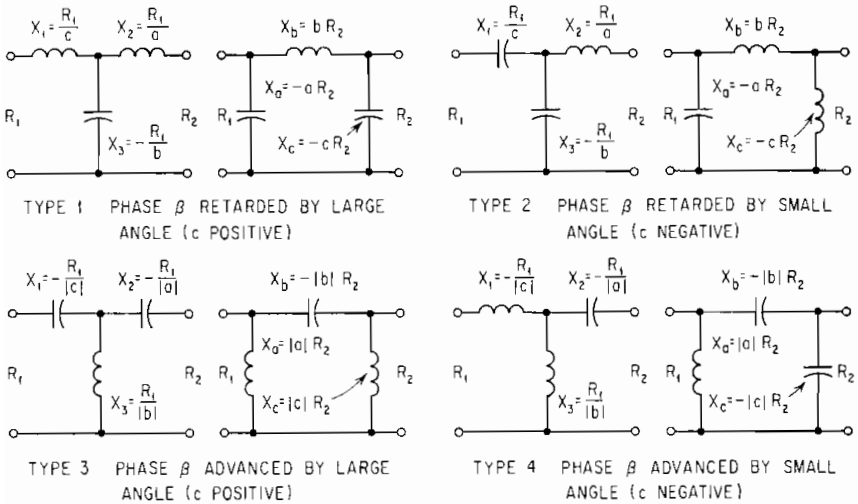


FIG. B-19. Specific three-element reactance networks.

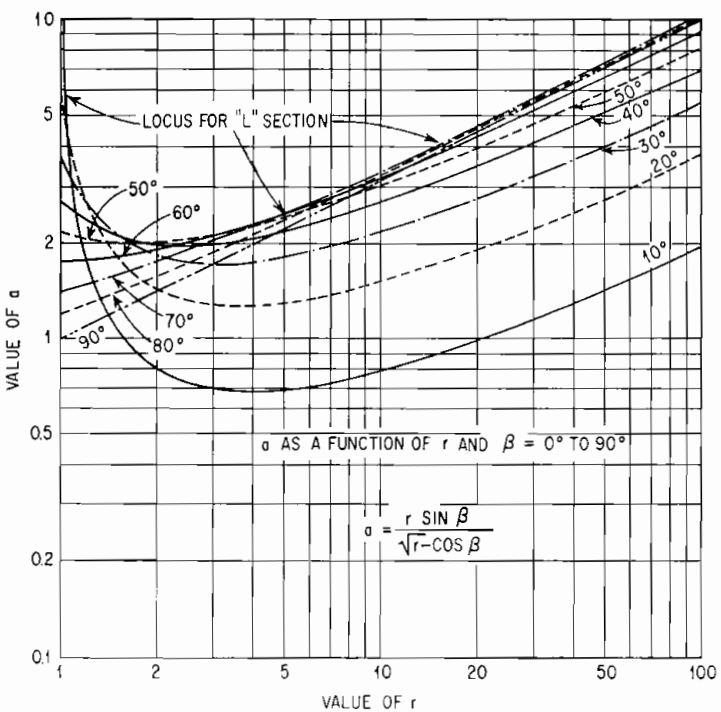


FIG. B-20. Design chart for a as function of r and β = 0 to 90°.

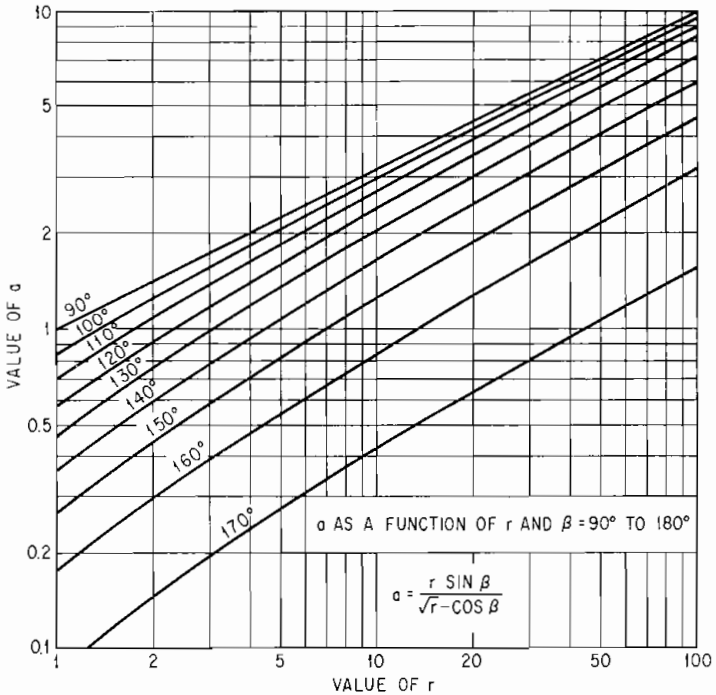


FIG. B-21. Design chart for a as function of r and β = 90 to 180°.

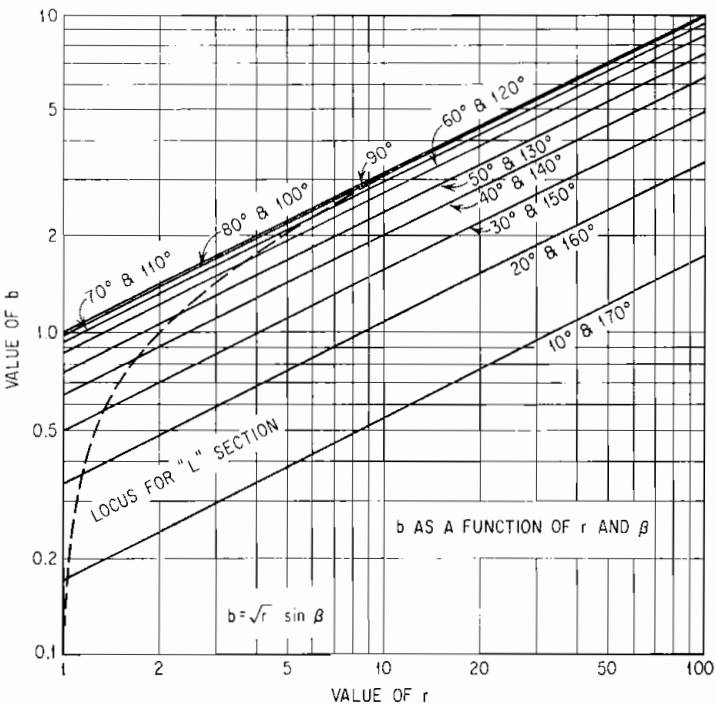


FIG. B-22. Design chart for b as function of r and β.

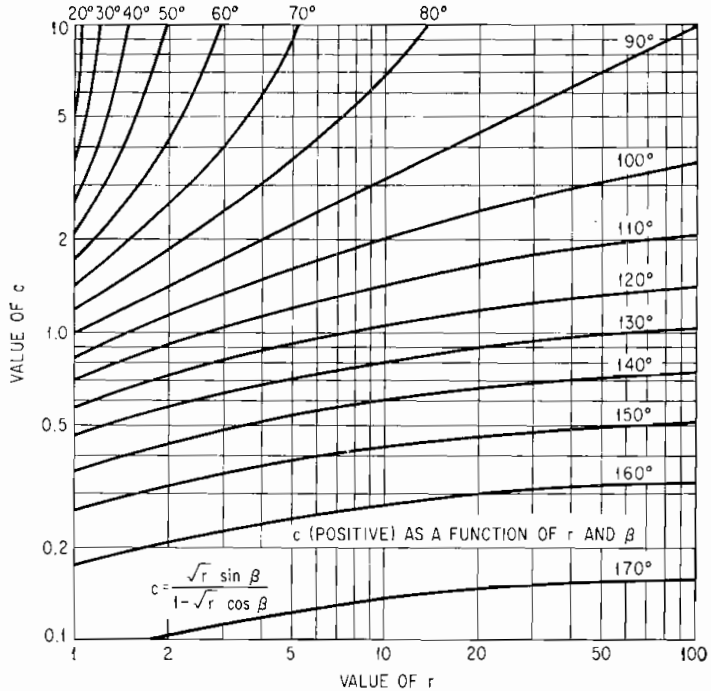


FIG. B-23. Design chart for c (positive) as function of r and β.

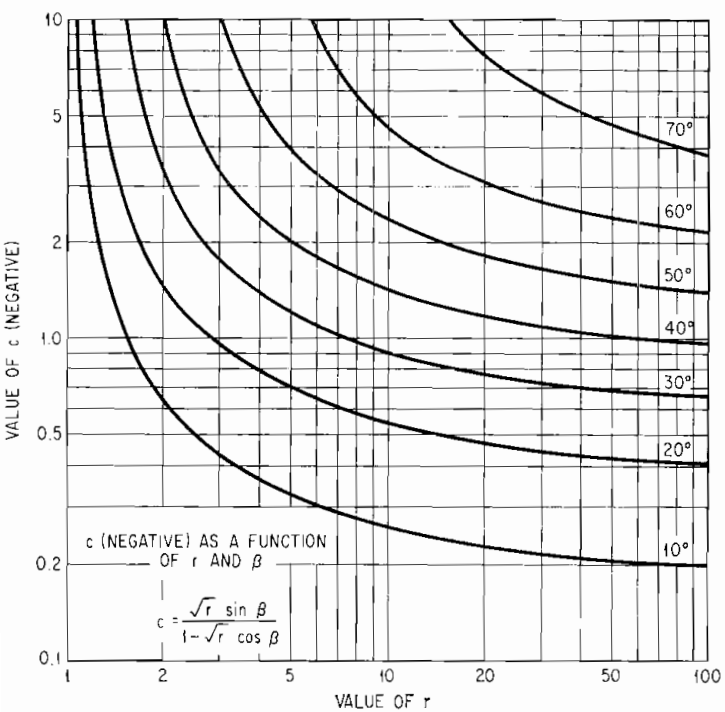


FIG. B-24. Design chart for c (negative) as function of r and β.

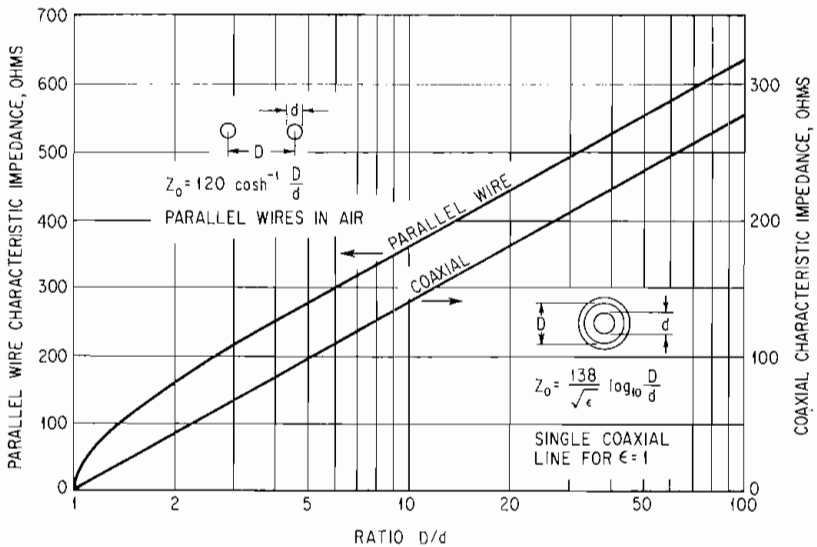
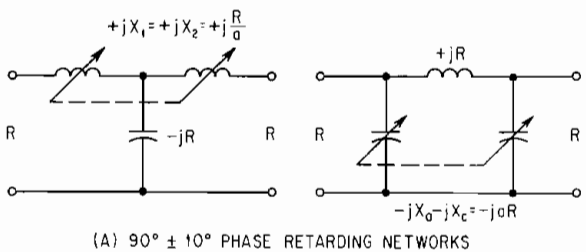
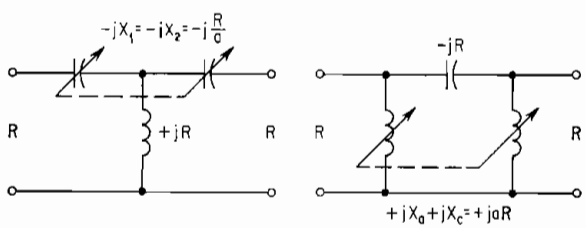


FIG. B-25. Characteristic impedance of coaxial and two-wire transmission lines.



(A) 90° ± 10° PHASE RETARDING NETWORKS



(B) 90° ± 10° PHASE ADVANCING NETWORKS

FIG. B-26. Phase-shifting networks.

Propagation Constant. The other factor of interest is the propagation constant given by

$$\sqrt{ZY} = \gamma = \alpha + j\beta \tag{B-33}$$

where γ = propagation constant, radians per unit length
α = attenuation constant, nepers per unit length
β = phase constant, radians per unit length

Usually the attenuation in the line can be neglected in the design of directional antennas, particularly if the line is designed for low loss and is operated nonresonant.

The phase shift in an air-dielectric line will be only a few per cent less than would occur in free space. For a coaxial line with ceramic beads the velocity factor is 0.85, while with solid polyethylene insulation the velocity factor is approximately 0.66. For two-wire lines insulated with ceramic spacers at intervals of a few feet the velocity factor is about 0.975. These factors must be taken into consideration when determining the phase shift in transmission lines of a directional-antenna system.

Phase-shifting Networks

In addition to the necessary phase shift in the networks and transmission lines of a feeder system, it is usually desirable to have a phase-shift network the control on which shifts the phase with little or no impedance transformation. This is readily accomplished in a 90° T or π section that has unity impedance transformation, $r = 1$, between input and output terminals.

In such a 90° T or π section the reactance arms all have the same magnitude and are equal to $R = R_1 = R_2$. The shunt arm in the T section or the series arm in the π section is held constant while the other two arms are varied in unison to shift the phase (see Figs. B-26 and B-27).

The value of the reactance in the series arms of a T section is

$$Z_1 = Z_2 = \pm jR \frac{1 - \cos\beta}{\sin\beta} = \pm j\frac{R}{a} \tag{B-34}$$

where $Z_1 = Z_2$ = series-arm reactance, ohms
$R = R_1 = R_2$ = terminating resistances, ohms
β = phase shift, deg

and the shunt arm of the T section is

$$Z_3 = \mp jR \frac{1}{\sin\beta} = \mp j\frac{R}{b} \tag{B-35}$$

where Z_3 is the shunt-arm reactance in ohms and the other values are given above.

The value of the resistance in the shunt arms of a π section is

$$Z_a = Z_c = \pm jR \frac{\sin\beta}{1 - \cos\beta} = \pm jaR \tag{B-36}$$

where $Z_a = Z_c$ = shunt-arm resistance, ohms
$R = R_1 = R_2$ = terminating resistances, ohms
β = phase shift, deg

and the series arm of the π section is

$$Z_b = \mp jR \sin\beta = \mp jbR \tag{B-37}$$

where Z_b is the series-arm reactance in ohms and the other values are defined above.

The phase shift for the approximation that $b = 1$ gives good answers for ±10° and can be written

$$\beta = \cos^{-1}\left(1 - \frac{R}{X_1}\right) = \cos^{-1}\left(1 - \frac{R}{X_a}\right) \tag{B-38}$$

where X_1 and X_a are the reactance values as shown in Fig. B-27 and the other values are defined above for the T- and π-section phase-shifting network.

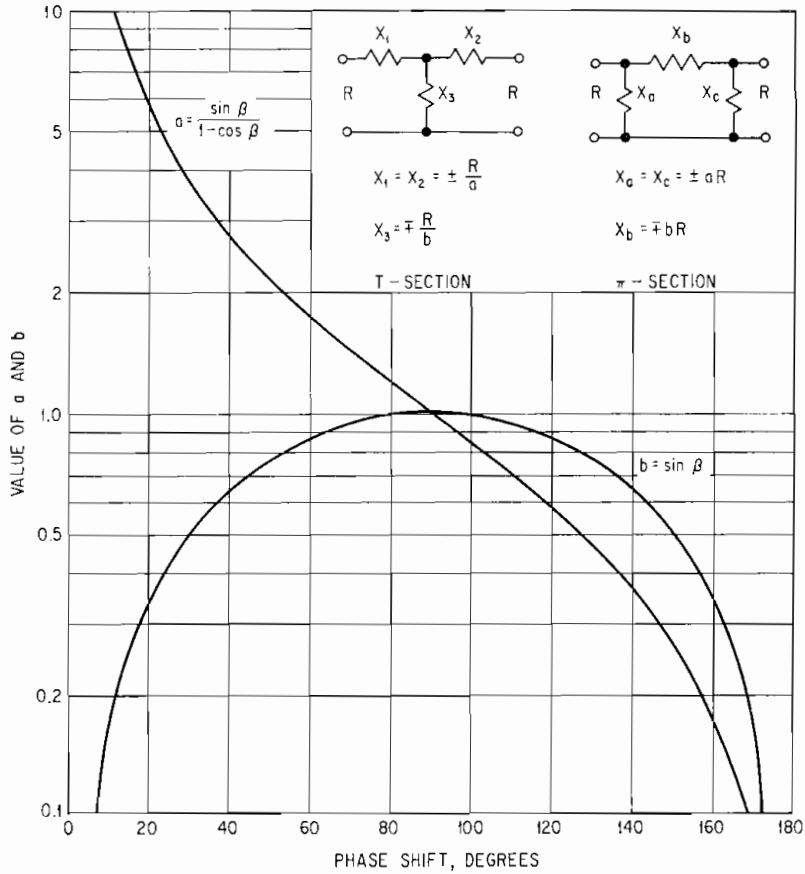


FIG. B-27. Phase-shifting-network curves.

Power-dividing Networks

The driving-point impedance at the base of each tower in a directional-antenna system must be fed the correct amount of power to make the array operate properly. The usual practice is to provide a power-dividing network near the common-point input to the feeder system as shown in Fig. 3-8.

Typical power-dividing networks are shown in Fig. B-28. Terminals 1 and 2 are the output terminals to towers 1 and 2, respectively. The transmitter is connected directly or through a matching section to the terminals marked IN. A common practice is to start with the phase at the antenna loop current and compute the phase shift back through the matching networks, transmission lines, and phase shifters to the output of the power divider. In case the power division is nearly equal and the feed lines need to be out of phase, the push-pull circuit in Fig. B-28*a* may be suitable. Where the feeder lines are in phase the series- or parallel-resonant circuits of Fig. B-28*b* or *c* are applicable. In some cases the feed lines may be in quadrature phase, so the circuit of Fig. B-28*d* can be used. If the power input to the feeder lines is known, then L sections can be designed to give the proper division as shown in Fig. B-28*e*.

Small and Large Values of Variable Reactance

The design of a feeder system should be such that adjustments can be made with ease in the field. Some ideas are given here that may be of help in new designs or modifications of existing designs to make them easier to adjust.

If a very low value of capacitive reactance is required, it can be obtained easily by placing an inductor in series with a capacitor as shown in Fig. B-29*a*. This arrangement makes it easy to obtain equivalent capacity values up to infinity when the circuit becomes series-resonant. Thus, it is possible to obtain values of inductive or capacitive reactance near zero values. This arrangement is often used in the shunt or series arms of a T or π section, so the correct value can be easily obtained. It is usually more satisfactory than providing a variable capacitor. In this arrangement care must be taken not to exceed the current rating of the capacitor. This discussion neglects the resistance component, which is usually very small.

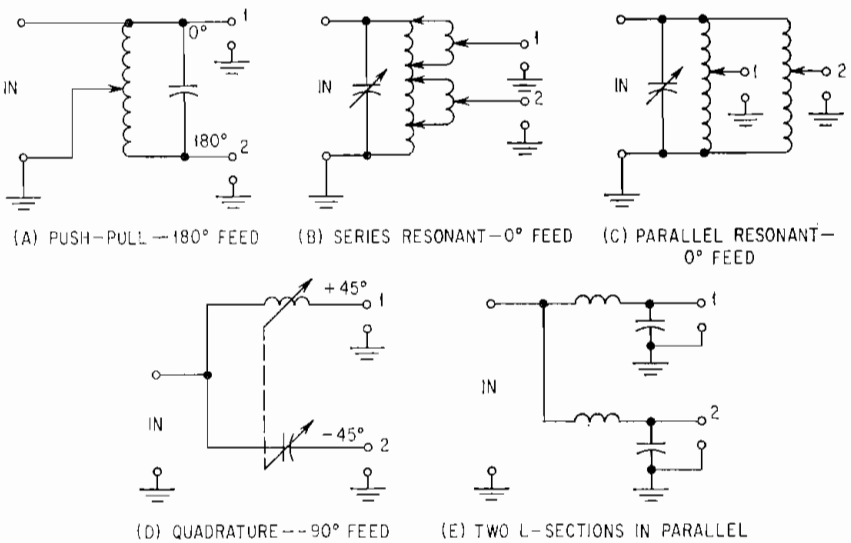


FIG. B-28. Typical power-dividing networks.

Sometimes it is necessary to obtain an inductive reactance larger than the reactance of available inductors. In such cases it is possible to parallel the coil with a very small capacitor. If the capacitor tap on the coil is moved as shown in Fig. B-29*b*, the desired value of inductive reactance can be achieved.

Adjustments

Theoretical Mesh Circuit Equation

In order to understand the operation of a directional-antenna system, it is desirable to understand how the circuit performs theoretically. With this understanding, it is easier to make the necessary adjustments. For a two-tower array the input terminals of the two towers can be considered to be a mesh circuit; hence the following simultaneous equations apply:

$$V_1 = I_1 Z_{11} + I_2 Z_{12} \tag{B-39}$$

$$V_2 = I_1 Z_{21} + I_2 Z_{22} \tag{B-40}$$

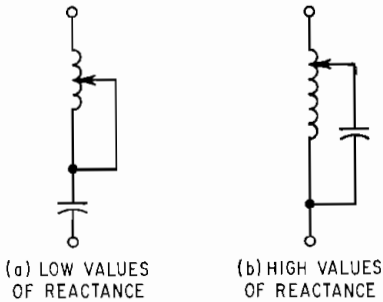


FIG. B-29. Methods of varying reactance.

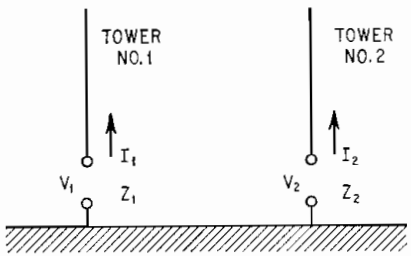


FIG. B-30. Two-tower input terminals.

where V_1 and V_2 = vector effective voltage at input terminals of towers 1 and 2 respectively, volts
I_1 and I_2 = vector effective current at input terminals of towers 1 and 2 respectively, amp
Z_{11} and Z_{22} = self-impedance of towers 1 and 2 respectively, ohms
$Z_{12} = Z_{21}$ = mutual impedance between towers 1 and 2, ohms
All the terms in the above mesh equations are complex quantities.

From this set of simultaneous equations it is possible to define the driving point impedance of each tower, thus

$$Z_1 = \frac{V_1}{I_1} = Z_{11} + \frac{I_2}{I_1} Z_{12} \tag{B-41}$$

$$Z_2 = \frac{V_2}{I_2} = \frac{I_1}{I_2} Z_{12} + Z_{22} \tag{B-42}$$

where Z_1 = driving-point impedance of tower 1 while array is in operation, ohms
Z_2 = driving-point impedance of tower 2 while array is in operation, ohms
The resistance component R_1 of Z_1 and R_2 of Z_2 is pure radiation resistance if there is no loss in the system. The directional-antenna system can be designed using this theoretical basis, and then from a knowledge of the system losses the driving-point impedances can be estimated with fair accuracy. (See Fig. B-30.)

Measured Base Self-impedance

If the towers are approximately 90° high or less and the spacing is not very close, then the self-impedance can be measured by leaving the terminals of tower 2 open while measuring the impedance of tower 1 with an RF bridge at the operating frequency. This can be seen by inspecting Eq. (B-41), where $I_2 = 0$; hence only Z_{11} will be measured for this condition.

Similarly, Z_{22} can be measured by leaving the terminals of tower 1 open while measuring at the terminals of tower 2.

Measured Base Mutual Impedance

This can be done by inserting a variable reactance in series with the terminals of tower 2 when the terminals of tower 1 are open and adjusting it so that only a pure resistance R_{22} remains. This can be done with an RF bridge. Tower 2 is now tuned to resonance at the operating frequency.

The next step is to drive tower 1 with a suitable voltage at the operating frequency and note the currents in towers 1 and 2 when tower 2 is tuned to resonance.

From these measurements the magnitude of the mutual impedance to a first approximation is

$$|Z_{12}| = -\frac{|I_2|}{|I_1|} R_{22} \tag{B-43}$$

The angle of the mutual impedance can best be approximated by using theoretical information. If the loop mutual-impedance phases are used, they must be delayed by the effective electrical distance of the loop above the tower base. If base mutual-impedance phases are used, they also must be delayed by the same effective electrical distance because they do not provide for time delay of the current to reach the loop position.

If the phase-monitoring system has been installed and is calibrated to read properly, it can be used to measure the phase of I_2 with respect to I_1 and thus provide the necessary phase angle of Z_{12}. This is a good way to check the theoretical values. It may be even a better check on the phase-monitor calibration.

The theoretical value of the magnitude of Z_{12} written $|Z_{12}|$ can be used in lieu of the above measured value. If the towers are near 180° in height, it is advisable to measure the mutual impedance. Also, if the spacing is less than 90°, the mutual-impedance values should be measured. In other words if the mutual impedance is large, it should be measured for best results.

Estimated Base Driving-point Impedance

The driving-point impedance Z_1 can now be estimated by using the above values of Z_{11} and Z_{12} along with the current ratio:

$$M_{21} = \frac{I_2}{I_1} \tag{B-44}$$

as specified in the directional-antenna design. When these values are substituted in Eq. (B-41), the driving-point impedance for tower 1 while the array is in operation results.

Similarly it is possible to obtain the driving-point impedance for tower 2.

Estimated Base Driving-point Current

Assuming no loss in the tower, insulators, or ground system, the authorized power input must be

$$P = |I_1|^2 R_1 + |I_2|^2 R_2 \tag{B-45}$$

Since the ratio of current is known, we can write

$$|I_1| = \frac{P}{R_1 + |M_{21}|^2 R_2} \tag{B-46}$$

and then,

$$|I_2| = |I_1|\,|M_{21}| \tag{B-47}$$

The above authorized power does not include the power allowed by FCC for feeder-system losses.

Feeder-system Adjustment

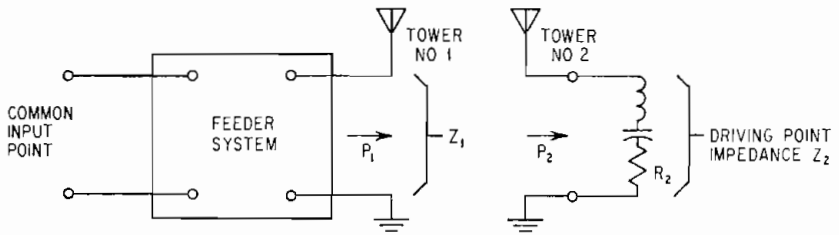
A good way to set up the feeder system is to make up dummy driving-point impedance loads with the aid of an RF bridge. If small components are available, only RF bridge measurements can be used. If larger resistors are used which will not change value when heated up with power, then the whole feeder system can be set up and adjusted for the correct power division using dummy driving-point impedance loads.

It is possible to adjust each transmission line to the tower input network using the dummy load, since the tower input impedance will not have the correct value until the whole directional-antenna system is operating properly. After these matching networks are adjusted with the RF bridge, it should not be necessary to make any further adjust-

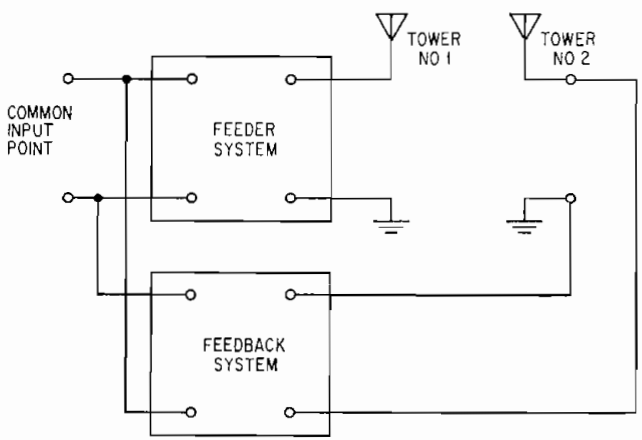
ments at this point. The networks at the towers can then be connected, and the completion of the feeder-system adjustments can usually be made at the common point where the power division and phasing controls are located.

Tower with Negative Resistance

In some directional-antenna systems a tower will have a negative resistance at the driving point. This means that power must be removed from the tower terminals. While the initial adjustments are made, this power can be dissipated, but for the final



(A) NEGATIVE TOWER CONNECTED TO DISSIPATIVE RESISTANCE R_2



(B) NEGATIVE TOWER CONNECTED THROUGH FEEDBACK SYSTEM TO COMMON POINT

FIG. B-31. Addition of power from tower with negative resistance.

operation it is usually desirable to feed this power back into the system in order to maintain high efficiency.

In Fig. B-31*a* the antenna system is properly adjusted to give the required pattern shape but the power from tower 2 is being dissipated into a driving-point impedance with a negative resistance component. If the driving-point impedance of the negative tower is matched into a transmission line, this power can be fed back to the common-point input point as shown in Fig. B-31*b*. It is necessary to adjust the phase and magnitude of the feedback voltage properly so it will equal the magnitude and phase of the voltage where the feedback system is connected at the common point. Then the two circuits can be connected in parallel. The feedback system is used to control the phase and magnitude of the feedback voltage. When the feedback voltage is connected across the common-point input terminals, the input resistance will increase because the negative

resistance in parallel with a positive resistance will have a resistance value larger than the positive resistance value alone.

In the design of the feeder system it is usually possible simply to tap on to the power-dividing network in the usual manner with the circuit to the tower having a negative resistance. In this case the phase shifts must be figured in the reverse direction owing to the reverse direction of power flow.

Table B-1. Minimum-depth Term *

F	$\frac{1}{F}$	F^2	$\frac{1+F^2}{2F}$	F	$\frac{1}{F}$	F^2	$\frac{1+F^2}{2F}$
0.995	1.0050	0.99002	1.00001	0.745	1.3422	0.55502	1.0436
0.990	1.0101	0.98010	1.00005	0.740	1.3513	0.54760	1.0457
0.985	1.0152	0.97022	1.00011	0.735	1.3605	0.54022	1.0478
0.980	1.0204	0.96040	1.00020	0.730	1.3698	0.53290	1.0499
0.975	1.0256	0.95062	1.00032	0.725	1.3793	0.52562	1.0522
0.970	1.0309	0.94090	1.00046	0.720	1.3888	0.51840	1.0544
0.965	1.0363	0.93122	1.00063	0.715	1.3986	0.51122	1.0568
0.960	1.0417	0.92160	1.00083	0.710	1.4084	0.50410	1.0592
0.955	1.0471	0.91202	1.00106	0.705	1.4184	0.49702	1.0617
0.950	1.0526	0.90250	1.00132	0.700	1.4285	0.49000	1.0643
0.945	1.0582	0.89302	1.0016	0.695	1.4388	0.48302	1.0669
0.940	1.0638	0.88360	1.0019	0.690	1.4492	0.47610	1.0696
0.935	1.0695	0.87422	1.0023	0.685	1.4598	0.46922	1.0724
0.930	1.0752	0.86490	1.0026	0.680	1.4705	0.46240	1.0753
0.925	1.0810	0.85562	1.0030	0.675	1.4814	0.45562	1.0782
0.920	1.0869	0.84640	1.0035	0.670	1.4925	0.44890	1.0812
0.915	1.0929	0.83722	1.0039	0.665	1.5037	0.44222	1.0844
0.910	1.0989	0.82810	1.0045	0.660	1.5151	0.43560	1.0875
0.905	1.1049	0.81902	1.0050	0.655	1.5267	0.42902	1.0909
0.900	1.1111	0.81000	1.0056	0.650	1.5384	0.42250	1.0942
0.895	1.1173	0.80102	1.0062	0.645	1.5503	0.41602	1.0977
0.890	1.1236	0.79210	1.0068	0.640	1.5625	0.40960	1.1012
0.885	1.1299	0.78322	1.0075	0.635	1.5748	0.40322	1.1049
0.880	1.1363	0.77440	1.0082	0.630	1.5873	0.39690	1.1086
0.875	1.1428	0.76562	1.0089	0.625	1.6000	0.39062	1.1125
0.870	1.1494	0.75690	1.0097	0.620	1.6129	0.38440	1.1164
0.865	1.1560	0.74822	1.0105	0.615	1.6260	0.37822	1.1205
0.860	1.1627	0.73960	1.0114	0.610	1.6393	0.37210	1.1246
0.855	1.1695	0.73102	1.0123	0.605	1.6528	0.36602	1.1289
0.850	1.1764	0.72250	1.0132	0.600	1.6666	0.36000	1.1333
0.845	1.1834	0.71402	1.0142	0.595	1.6806	0.35402	1.1378
0.840	1.1904	0.70560	1.0152	0.590	1.6949	0.34810	1.1425
0.835	1.1976	0.69722	1.0163	0.585	1.7094	0.34222	1.1472
0.830	1.2048	0.68890	1.0174	0.580	1.7241	0.33640	1.1521
0.825	1.2121	0.68062	1.0186	0.575	1.7391	0.33062	1.1571
0.820	1.2195	0.67240	1.0197	0.570	1.7543	0.32490	1.1621
0.815	1.2269	0.66422	1.0210	0.565	1.7699	0.31922	1.1675
0.810	1.2345	0.65610	1.0223	0.560	1.7857	0.31360	1.1728
0.805	1.2422	0.64802	1.0236	0.555	1.8018	0.30802	1.1784
0.800	1.2500	0.64000	1.0250	0.550	1.8181	0.30250	1.1841
0.795	1.2578	0.63202	1.0264	0.545	1.8348	0.29702	1.1899
0.790	1.2658	0.62410	1.0279	0.540	1.8518	0.29160	1.1959
0.785	1.2738	0.61622	1.0294	0.535	1.8691	0.28622	1.2021
0.780	1.2820	0.60840	1.0310	0.530	1.8867	0.28090	1.2084
0.775	1.2903	0.60062	1.0327	0.525	1.9047	0.27562	1.2149
0.770	1.2987	0.59290	1.0343	0.520	1.9230	0.27040	1.2215
0.765	1.3071	0.58522	1.0361	0.515	1.9417	0.26522	1.2284
0.760	1.3157	0.57760	1.0379	0.510	1.9607	0.26010	1.2354
0.755	1.3245	0.57002	1.0397	0.505	1.9802	0.25502	1.2426
0.750	1.3333	0.56250	1.0417	0.500	2.0000	0.25000	1.2500

* $(1 + F^2)/2F$ where either F or $1/F$ is the ratio of the inverse field strengths.

Table B-1. Minimum-depth Term (*Continued*)

F	$\frac{1}{F}$	F^2	$\frac{1+F^2}{2F}$	F	$\frac{1}{F}$	F^2	$\frac{1+F^2}{2F}$
0.495	2.0202	0.24502	1.2576	0.345	2.8985	0.11902	1.6218
0.490	2.0408	0.24010	1.2654	0.340	2.9411	0.11560	1.6406
0.485	2.0618	0.23522	1.2734	0.335	2.9850	0.11222	1.6600
0.480	2.0833	0.23040	1.2817	0.330	3.0303	0.10890	1.6802
0.475	2.1052	0.22562	1.2901	0.325	3.0769	0.10562	1.7010
0.470	2.1276	0.22090	1.2988	0.320	3.1250	0.10240	1.7225
0.465	2.1505	0.21622	1.3078	0.315	3.1746	0.09922	1.7448
0.460	2.1739	0.21160	1.3170	0.310	3.2258	0.09610	1.7679
0.455	2.1978	0.20702	1.3264	0.305	3.2786	0.09302	1.7918
0.450	2.2222	0.20250	1.3361	0.300	3.3333	0.09000	1.8167
0.445	2.2471	0.19802	1.3461	0.295	3.3898	0.08702	1.8424
0.440	2.2727	0.19360	1.3564	0.290	3.4482	0.08410	1.8691
0.435	2.2988	0.18922	1.3669	0.285	3.5087	0.08122	1.8969
0.430	2.3255	0.18490	1.3778	0.280	3.5714	0.07840	1.9257
0.425	2.3529	0.18062	1.3890	0.275	3.6363	0.07562	1.9557
0.420	2.3809	0.17640	1.4005	0.270	3.7037	0.07290	1.9869
0.415	2.4096	0.17222	1.4123	0.265	3.7735	0.07022	2.0193
0.410	2.4390	0.16810	1.4245	0.260	3.8461	0.06760	2.0531
0.405	2.4691	0.16402	1.4371	0.255	3.9215	0.06502	2.0883
0.400	2.5000	0.16000	1.4500	0.250	4.0000	0.06250	2.1250
0.395	2.5316	0.15602	1.4633	0.245	4.0816	0.06002	2.1633
0.390	2.5641	0.15210	1.4770	0.240	4.1666	0.05760	2.2033
0.385	2.5974	0.14822	1.4912	0.235	4.2553	0.05522	2.2451
0.380	2.6315	0.14440	1.5058	0.230	4.3478	0.05290	2.2889
0.375	2.6666	0.14062	1.5208	0.225	4.4444	0.05062	2.3347
0.370	2.7027	0.13690	1.5364	0.220	4.5454	0.04840	2.3827
0.365	2.7397	0.13322	1.5524	0.215	4.6511	0.04622	2.4331
0.360	2.7777	0.12960	1.5689	0.210	4.7619	0.04410	2.4860
0.355	2.8169	0.12602	1.5859	0.205	4.8780	0.04202	2.5415
0.350	2.8571	0.12250	1.6035	0.200	5.0000	0.04000	2.6000

Table B-2. Bessel Function, J_0 ($S \cos \theta$)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	0.999	0.999	0.999	0.999	1.000	1.000	1.000	1.000	1.000
4	0.999	0.999	0.999	0.999	0.999	0.999	1.000	1.000	1.000
5	0.998	0.998	0.998	0.999	0.999	0.999	1.000	1.000	1.000
6	0.997	0.997	0.998	0.998	0.998	0.999	0.999	1.000	1.000
7	0.996	0.996	0.997	0.997	0.998	0.998	0.999	1.000	1.000
8	0.995	0.995	0.996	0.996	0.997	0.998	0.999	0.999	1.000
9	0.994	0.994	0.995	0.995	0.996	0.997	0.998	0.999	1.000
10	0.992	0.993	0.993	0.994	0.996	0.997	0.998	0.999	1.000
11	0.991	0.991	0.992	0.993	0.995	0.996	0.998	0.999	1.000
12	0.989	0.989	0.990	0.992	0.994	0.996	0.997	0.999	1.000
13	0.987	0.988	0.989	0.990	0.992	0.995	0.997	0.998	1.000
14	0.985	0.986	0.987	0.989	0.991	0.994	0.996	0.998	1.000
15	0.983	0.983	0.985	0.987	0.990	0.993	0.996	0.998	0.999
16	0.981	0.981	0.983	0.985	0.985	0.992	0.995	0.998	0.999
17	0.978	0.979	0.981	0.984	0.987	0.991	0.994	0.997	0.999
18	0.976	0.976	0.978	0.982	0.985	0.990	0.994	0.997	0.999
19	0.973	0.974	0.976	0.980	0.986	0.989	0.993	0.997	0.999
20	0.970	0.971	0.973	0.977	0.982	0.987	0.992	0.996	0.999
21	0.967	0.968	0.971	0.975	0.980	0.986	0.992	0.996	0.999
22	0.964	0.965	0.968	0.973	0.973	0.985	0.991	0.996	0.999
23	0.960	0.961	0.965	0.970	0.977	0.983	0.970	0.975	0.999
24	0.957	0.958	0.962	0.967	0.974	0.982	0.985	0.995	0.999
25	0.953	0.954	0.958	0.965	0.972	0.980	0.988	0.994	0.999
26	0.949	0.951	0.955	0.962	0.970	0.979	0.987	0.994	0.998
27	0.945	0.947	0.953	0.959	0.968	0.977	0.986	0.994	0.998
28	0.941	0.943	0.948	0.956	0.965	0.976	0.985	0.993	0.998
29	0.937	0.939	0.944	0.953	0.963	0.974	0.984	0.993	0.998
30	0.933	0.935	0.940	0.949	0.960	0.972	0.983	0.992	0.998
31	0.928	0.930	0.936	0.946	0.958	0.970	0.982	0.992	0.998
32	0.924	0.926	0.932	0.942	0.955	0.968	0.981	0.991	0.998
33	0.919	0.921	0.928	0.939	0.952	0.966	0.979	0.990	0.998
34	0.914	0.916	0.924	0.935	0.945	0.964	0.978	0.990	0.997
35	0.905	0.912	0.919	0.931	0.941	0.962	0.977	0.985	0.997
36	0.904	0.907	0.915	0.927	0.943	0.960	0.976	0.989	0.997
37	0.899	0.901	0.910	0.923	0.940	0.957	0.974	0.986	0.997
38	0.893	0.896	0.905	0.919	0.937	0.955	0.973	0.987	0.997
39	0.888	0.891	0.900	0.915	0.933	0.953	0.971	0.987	0.997
40	0.882	0.885	0.895	0.911	0.930	0.950	0.970	0.986	0.996
41	0.876	0.880	0.890	0.906	0.926	0.948	0.968	0.985	0.996
42	0.870	0.874	0.885	0.902	0.923	0.945	0.967	0.984	0.996
43	0.864	0.868	0.880	0.897	0.919	0.943	0.965	0.984	0.996
44	0.858	0.862	0.874	0.892	0.915	0.940	0.963	0.983	0.996
45	0.852	0.856	0.868	0.888	0.913	0.937	0.962	0.982	0.995
46	0.845	0.850	0.862	0.883	0.908	0.935	0.960	0.981	0.995
47	0.839	0.843	0.857	0.878	0.904	0.932	0.958	0.980	0.995
48	0.832	0.837	0.851	0.873	0.900	0.929	0.957	0.980	0.995
49	0.825	0.830	0.845	0.868	0.896	0.926	0.955	0.979	0.994
50	0.818	0.823	0.838	0.862	0.891	0.923	0.953	0.978	0.994
51	0.812	0.817	0.832	0.857	0.887	0.920	0.951	0.977	0.994
52	0.804	0.810	0.826	0.851	0.883	0.917	0.949	0.976	0.994
53	0.797	0.803	0.820	0.846	0.878	0.913	0.947	0.975	0.994
54	0.790	0.796	0.813	0.840	0.874	0.910	0.945	0.974	0.993
55	0.783	0.789	0.807	0.835	0.869	0.907	0.943	0.973	0.993

Table B-2. Bessel Function, J_0 ($S \cos \theta$) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
56	0.775	0.782	0.800	0.829	0.865	0.904	0.941	0.972	0.993
57	0.767	0.774	0.793	0.823	0.860	0.900	0.939	0.971	0.993
58	0.760	0.767	0.786	0.817	0.855	0.897	0.937	0.970	0.992
59	0.752	0.759	0.779	0.811	0.850	0.893	0.935	0.969	0.992
60	0.744	0.751	0.772	0.805	0.845	0.890	0.933	0.968	0.992
61	0.736	0.743	0.765	0.799	0.840	0.886	0.930	0.967	0.991
62	0.728	0.735	0.758	0.792	0.835	0.883	0.928	0.966	0.991
63	0.720	0.728	0.750	0.786	0.830	0.879	0.926	0.965	0.991
64	0.712	0.720	0.743	0.780	0.825	0.875	0.923	0.964	0.991
65	0.703	0.712	0.735	0.773	0.820	0.871	0.921	0.963	0.990
66	0.695	0.703	0.728	0.766	0.815	0.867	0.919	0.962	0.990
67	0.686	0.695	0.720	0.760	0.810	0.863	0.916	0.960	0.990
68	0.678	0.686	0.712	0.753	0.804	0.860	0.914	0.959	0.989
69	0.669	0.678	0.704	0.746	0.798	0.856	0.911	0.958	0.989
70	0.660	0.669	0.696	0.739	0.792	0.851	0.909	0.957	0.989
71	0.652	0.661	0.688	0.732	0.787	0.847	0.906	0.956	0.988
72	0.642	0.652	0.680	0.725	0.781	0.843	0.904	0.954	0.988
73	0.634	0.643	0.672	0.718	0.776	0.839	0.901	0.953	0.988
74	0.625	0.635	0.664	0.711	0.770	0.835	0.898	0.952	0.987
75	0.615	0.626	0.656	0.703	0.764	0.830	0.896	0.950	0.987
76	0.606	0.617	0.648	0.697	0.758	0.826	0.893	0.949	0.987
77	0.597	0.607	0.639	0.689	0.752	0.822	0.890	0.948	0.986
78	0.588	0.599	0.631	0.682	0.746	0.818	0.887	0.947	0.986
79	0.578	0.589	0.622	0.674	0.740	0.813	0.884	0.945	0.986
80	0.569	0.580	0.613	0.667	0.734	0.808	0.882	0.944	0.985
81	0.559	0.571	0.605	0.659	0.728	0.804	0.879	0.943	0.985
82	0.550	0.561	0.596	0.652	0.722	0.799	0.876	0.941	0.985
83	0.540	0.552	0.587	0.644	0.715	0.794	0.873	0.939	0.984
84	0.531	0.543	0.579	0.636	0.709	0.790	0.870	0.938	0.984
85	0.521	0.535	0.570	0.628	0.702	0.785	0.867	0.937	0.983
86	0.511	0.524	0.561	0.620	0.696	0.780	0.864	0.935	0.983
87	0.502	0.515	0.552	0.612	0.689	0.775	0.861	0.934	0.983
88	0.492	0.505	0.543	0.604	0.683	0.770	0.858	0.933	0.982
89	0.482	0.495	0.534	0.596	0.678	0.766	0.854	0.931	0.982
90	0.472	0.486	0.525	0.588	0.670	0.761	0.851	0.929	0.981
91	0.462	0.476	0.516	0.580	0.663	0.756	0.848	0.928	0.981
92	0.452	0.466	0.506	0.572	0.656	0.751	0.845	0.926	0.981
93	0.442	0.456	0.497	0.564	0.649	0.746	0.842	0.924	0.980
94	0.432	0.447	0.488	0.556	0.643	0.741	0.839	0.923	0.980
95	0.422	0.437	0.479	0.547	0.636	0.735	0.835	0.921	0.979
96	0.412	0.427	0.470	0.539	0.629	0.730	0.832	0.920	0.979
97	0.402	0.417	0.461	0.531	0.622	0.725	0.829	0.918	0.978
98	0.392	0.407	0.451	0.522	0.615	0.720	0.825	0.916	0.978
99	0.382	0.397	0.442	0.514	0.608	0.714	0.822	0.915	0.977
100	0.372	0.387	0.432	0.506	0.601	0.709	0.818	0.913	0.977
101	0.361	0.377	0.423	0.497	0.594	0.703	0.815	0.911	0.977
102	0.352	0.367	0.414	0.489	0.587	0.698	0.812	0.909	0.976
103	0.341	0.357	0.404	0.480	0.579	0.693	0.808	0.908	0.976
104	0.331	0.347	0.395	0.471	0.572	0.687	0.804	0.906	0.975
105	0.321	0.337	0.385	0.463	0.565	0.682	0.801	0.904	0.975
106	0.311	0.327	0.375	0.454	0.558	0.676	0.797	0.902	0.974
107	0.301	0.317	0.366	0.446	0.551	0.671	0.793	0.900	0.974
108	0.290	0.307	0.356	0.437	0.543	0.665	0.790	0.899	0.973
109	0.281	0.297	0.347	0.428	0.536	0.660	0.786	0.897	0.973
110	0.270	0.287	0.337	0.419	0.528	0.654	0.783	0.895	0.972

Table B-2. Bessel Function, J_0 ($S \cos \theta$) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
111	0.260	0.277	0.328	0.411	0.521	0.648	0.779	0.893	0.972
112	0.250	0.267	0.318	0.402	0.513	0.642	0.775	0.891	0.971
113	0.240	0.257	0.309	0.393	0.506	0.636	0.771	0.890	0.971
114	0.230	0.247	0.299	0.385	0.498	0.630	0.767	0.888	0.970
115	0.220	0.237	0.290	0.376	0.491	0.625	0.763	0.886	0.970
116	0.210	0.227	0.280	0.367	0.484	0.619	0.760	0.884	0.969
117	0.200	0.217	0.271	0.359	0.476	0.613	0.756	0.882	0.969
118	0.190	0.208	0.261	0.350	0.468	0.607	0.752	0.880	0.968
119	0.180	0.198	0.252	0.341	0.461	0.601	0.748	0.878	0.968
120	0.170	0.188	0.242	0.332	0.453	0.596	0.744	0.876	0.967
121	0.160	0.178	0.233	0.323	0.445	0.590	0.740	0.874	0.967
122	0.150	0.168	0.223	0.314	0.438	0.584	0.736	0.872	0.966
123	0.140	0.158	0.214	0.306	0.430	0.578	0.732	0.870	0.965
124	0.130	0.148	0.204	0.297	0.422	0.572	0.728	0.868	0.965
125	0.120	0.139	0.195	0.288	0.415	0.565	0.724	0.866	0.964
126	0.111	0.129	0.185	0.279	0.407	0.559	0.720	0.864	0.964
127	0.101	0.120	0.176	0.270	0.400	0.553	0.716	0.861	0.963
128	0.092	0.110	0.167	0.261	0.392	0.547	0.712	0.859	0.963
129	0.082	0.101	0.158	0.253	0.384	0.541	0.707	0.857	0.962
130	0.072	0.091	0.148	0.244	0.376	0.535	0.703	0.855	0.961
131	0.063	0.082	0.139	0.235	0.368	0.529	0.699	0.853	0.961
132	0.053	0.072	0.129	0.227	0.360	0.522	0.695	0.851	0.960
133	0.044	0.063	0.120	0.218	0.353	0.516	0.690	0.848	0.960
134	0.035	0.053	0.111	0.209	0.345	0.510	0.686	0.846	0.958
135	0.026	0.044	0.102	0.201	0.337	0.503	0.682	0.844	0.958
136	0.017	0.035	0.093	0.192	0.329	0.497	0.678	0.842	0.958
137	0.007	0.026	0.094	0.183	0.321	0.491	0.673	0.840	0.957
138	−0.002	0.017	0.075	0.175	0.314	0.485	0.669	0.837	0.957
139	−0.011	0.008	0.066	0.166	0.308	0.478	0.665	0.835	0.956
140	−0.020	−0.001	0.058	0.158	0.299	0.472	0.660	0.833	0.955
141	−0.029	−0.010	0.049	0.149	0.291	0.466	0.656	0.830	0.955
142	−0.037	−0.019	0.040	0.141	0.283	0.459	0.652	0.828	0.954
143	−0.046	−0.028	0.031	0.132	0.275	0.453	0.647	0.826	0.954
144	−0.055	−0.036	0.022	0.124	0.267	0.446	0.642	0.823	0.953
145	−0.064	−0.045	0.013	0.115	0.259	0.440	0.638	0.821	0.952
146	−0.072	−0.053	0.005	0.107	0.252	0.434	0.634	0.819	0.952
147	−0.080	−0.062	−0.003	0.099	0.244	0.427	0.629	0.817	0.951
148	−0.088	−0.070	−0.012	0.090	0.236	0.420	0.625	0.814	0.950
149	−0.097	−0.078	−0.020	0.082	0.229	0.414	0.620	0.812	0.950
150	−0.105	−0.087	−0.029	0.073	0.221	0.408	0.615	0.809	0.949
151	−0.113	−0.095	−0.037	0.065	0.213	0.401	0.611	0.807	0.948
152	−0.121	−0.103	−0.045	0.057	0.205	0.395	0.606	0.805	0.947
153	−0.129	−0.111	−0.053	0.049	0.198	0.388	0.602	0.802	0.947
154	−0.137	−0.119	−0.062	0.040	0.190	0.382	0.597	0.800	0.946
155	−0.145	−0.126	−0.070	0.032	0.183	0.375	0.592	0.797	0.945
156	−0.153	−0.134	−0.078	0.024	0.175	0.368	0.587	0.795	0.945
157	−0.160	−0.142	−0.085	0.017	0.167	0.362	0.583	0.792	0.944
158	−0.167	−0.149	−0.093	0.009	0.160	0.356	0.578	0.790	0.943
159	−0.175	−0.157	−0.101	0.001	0.152	0.349	0.573	0.787	0.943
160	−0.182	−0.164	−0.108	−0.007	0.145	0.343	0.569	0.785	0.942
161	−0.189	−0.172	−0.116	−0.015	0.137	0.336	0.564	0.782	0.941
162	−0.196	−0.179	−0.123	−0.023	0.130	0.330	0.559	0.780	0.940
163	−0.203	−0.186	−0.131	−0.030	0.122	0.323	0.555	0.777	0.940
164	−0.210	−0.193	−0.138	−0.037	0.114	0.317	0.550	0.774	0.939
165	−0.217	−0.200	−0.146	−0.045	0.107	0.310	0.545	0.772	0.938

Table B-2. Bessel Function, J_0 (S cos θ) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
166	−0.223	−0.207	−0.153	−0.053	0.100	0.303	0.541	0.769	0.937
167	−0.230	−0.213	−0.159	−0.060	0.093	0.297	0.536	0.767	0.937
168	−0.236	−0.220	−0.167	−0.068	0.085	0.290	0.531	0.764	0.936
169	−0.242	−0.226	−0.173	−0.075	0.078	0.284	0.526	0.761	0.935
170	−0.249	−0.232	−0.180	−0.082	0.070	0.277	0.521	0.759	0.935
171	−0.255	−0.239	−0.187	−0.089	0.063	0.271	0.516	0.756	0.934
172	−0.261	−0.245	−0.194	−0.097	0.056	0.264	0.511	0.753	0.933
173	−0.266	−0.251	−0.200	−0.104	0.049	0.258	0.506	0.751	0.932
174	−0.272	−0.257	−0.207	−0.111	0.042	0.251	0.502	0.748	0.932
175	−0.278	−0.263	−0.213	−0.118	0.035	0.245	0.497	0.746	0.931
176	−0.283	−0.269	−0.220	−0.125	0.027	0.238	0.492	0.743	0.930
177	−0.289	−0.274	−0.226	−0.131	0.020	0.232	0.487	0.740	0.929
178	−0.294	−0.279	−0.232	−0.138	0.013	0.226	0.482	0.737	0.928
179	−0.299	−0.285	−0.238	−0.145	0.006	0.219	0.477	0.735	0.927
180	−0.304	−0.290	−0.244	−0.151	−0.001	0.212	0.472	0.732	0.927
181	−0.309	−0.295	−0.249	−0.158	−0.008	0.206	0.467	0.729	0.926
182	−0.314	−0.300	−0.255	−0.164	−0.015	0.200	0.462	0.726	0.925
183	−0.319	−0.305	−0.261	−0.171	−0.022	0.193	0.457	0.723	0.924
184	−0.323	−0.310	−0.266	−0.177	−0.028	0.187	0.452	0.721	0.923
185	−0.328	−0.315	−0.272	−0.183	−0.035	0.180	0.447	0.718	0.923
186	−0.332	−0.319	−0.277	−0.190	−0.041	0.174	0.442	0.715	0.922
187	−0.336	−0.324	−0.282	−0.196	−0.048	0.167	0.437	0.712	0.921
188	−0.340	−0.328	−0.287	−0.202	−0.055	0.161	0.432	0.709	0.920
189	−0.344	−0.332	−0.292	−0.208	−0.061	0.155	0.427	0.706	0.919
190	−0.348	−0.336	−0.297	−0.214	−0.068	0.148	0.422	0.704	0.918
191	−0.351	−0.340	−0.302	−0.219	−0.074	0.142	0.417	0.701	0.918
192	−0.355	−0.344	−0.307	−0.225	−0.081	0.136	0.412	0.698	0.917
193	−0.358	−0.348	−0.311	−0.231	−0.087	0.129	0.407	0.695	0.916
194	−0.362	−0.352	−0.316	−0.236	−0.094	0.123	0.402	0.692	0.915
195	−0.365	−0.355	−0.320	−0.242	−0.100	0.117	0.397	0.689	0.914
196	−0.368	−0.359	−0.324	−0.247	−0.106	0.110	0.392	0.686	0.913
197	−0.371	−0.362	−0.328	−0.252	−0.113	0.104	0.387	0.683	0.913
198	−0.374	−0.365	−0.332	−0.257	−0.119	0.098	0.382	0.680	0.912
199	−0.376	−0.368	−0.336	−0.262	−0.125	0.092	0.377	0.677	0.911
200	−0.379	−0.371	−0.340	−0.267	−0.131	0.086	0.372	0.674	0.910
201	−0.381	−0.374	−0.344	−0.272	−0.137	0.079	0.367	0.671	0.909
202	−0.383	−0.376	−0.347	−0.277	−0.143	0.073	0.361	0.668	0.908
203	−0.386	−0.379	−0.351	−0.282	−0.149	0.067	0.356	0.665	0.907
204	−0.388	−0.381	−0.354	−0.287	−0.154	0.061	0.351	0.662	0.906
205	−0.390	−0.383	−0.357	−0.292	−0.160	0.055	0.346	0.659	0.905
206	−0.391	−0.385	−0.360	−0.296	−0.166	0.049	0.341	0.656	0.904
207	−0.393	−0.387	−0.363	−0.301	−0.172	0.043	0.336	0.653	0.904
208	−0.394	−0.389	−0.366	−0.305	−0.177	0.037	0.331	0.650	0.903
209	−0.396	−0.391	−0.369	−0.309	−0.183	0.031	0.326	0.647	0.902
210	−0.397	−0.393	−0.372	−0.313	−0.188	0.025	0.321	0.644	0.901
211	−0.398	−0.394	−0.374	−0.317	−0.193	0.019	0.316	0.641	0.900
212	−0.399	−0.396	−0.377	−0.321	−0.199	0.013	0.311	0.638	0.899
213	−0.400	−0.397	−0.379	−0.325	−0.204	0.007	0.306	0.635	0.898
214	−0.401	−0.398	−0.382	−0.329	−0.209	0.001	0.301	0.632	0.897
215	−0.401	−0.399	−0.384	−0.333	−0.214	−0.004	0.296	0.629	0.896
216	−0.402	−0.400	−0.386	−0.336	−0.220	−0.010	0.291	0.626	0.895
217	−0.402	−0.401	−0.388	−0.340	−0.225	−0.016	0.285	0.623	0.894
218	−0.403	−0.401	−0.389	−0.343	−0.230	−0.022	0.280	0.620	0.893
219	−0.403	−0.402	−0.391	−0.346	−0.235	−0.027	0.275	0.616	0.892
220	−0.403	−0.402	−0.393	−0.350	−0.239	−0.032	0.270	0.613	0.892

Table B-2. Bessel Function, J_0 (S cos θ) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
221	−0.403	−0.403	−0.394	−0.353	−0.244	−0.038	0.265	0.610	0.891
222	−0.402	−0.403	−0.395	−0.356	−0.249	−0.044	0.260	0.607	0.890
223	−0.402	−0.403	−0.397	−0.359	−0.254	−0.049	0.255	0.604	0.889
224	−0.402	−0.403	−0.398	−0.362	−0.258	−0.055	0.250	0.601	0.888
225	−0.401	−0.403	−0.399	−0.364	−0.263	−0.061	0.245	0.597	0.887
226	−0.400	−0.402	−0.400	−0.367	−0.267	−0.066	0.240	0.594	0.886
227	−0.399	−0.402	−0.400	−0.370	−0.272	−0.072	0.235	0.591	0.885
228	−0.398	−0.401	−0.401	−0.372	−0.276	−0.077	0.230	0.588	0.884
229	−0.397	−0.401	−0.402	−0.374	−0.280	−0.083	0.225	0.585	0.883
230	−0.396	−0.400	−0.402	−0.377	−0.284	−0.088	0.220	0.581	0.882
231	−0.395	−0.399	−0.402	−0.379	−0.288	−0.093	0.215	0.578	0.881
232	−0.393	−0.398	−0.403	−0.381	−0.292	−0.099	0.210	0.575	0.880
233	−0.392	−0.397	−0.403	−0.383	−0.296	−0.104	0.205	0.572	0.879
234	−0.390	−0.396	−0.403	−0.385	−0.300	−0.109	0.200	0.568	0.878
235	−0.389	−0.395	−0.403	−0.387	−0.304	−0.114	0.195	0.565	0.877
236	−0.387	−0.393	−0.402	−0.388	−0.308	−0.119	0.190	0.562	0.876
237	−0.385	−0.391	−0.402	−0.390	−0.312	−0.124	0.185	0.559	0.875
238	−0.383	−0.389	−0.402	−0.391	−0.315	−0.129	0.180	0.555	0.874
239	−0.380	−0.388	−0.401	−0.393	−0.319	−0.134	0.175	0.552	0.873
240	−0.378	−0.386	−0.401	−0.394	−0.322	−0.139	0.170	0.549	0.871
241	−0.376	−0.384	−0.400	−0.395	−0.326	−0.144	0.165	0.546	0.870
242	−0.373	−0.382	−0.399	−0.397	−0.329	−0.149	0.160	0.543	0.869
243	−0.371	−0.380	−0.398	−0.398	−0.333	−0.154	0.155	0.540	0.868
244	−0.368	−0.377	−0.397	−0.399	−0.336	−0.159	0.150	0.536	0.867
245	−0.365	−0.375	−0.396	−0.399	−0.339	−0.164	0.145	0.533	0.866
246	−0.363	−0.372	−0.395	−0.400	−0.342	−0.168	0.140	0.530	0.865
247	−0.359	−0.370	−0.393	−0.401	−0.345	−0.173	0.135	0.526	0.864
248	−0.356	−0.367	−0.392	−0.401	−0.348	−0.178	0.130	0.523	0.863
249	−0.353	−0.364	−0.390	−0.402	−0.351	−0.183	0.125	0.520	0.862
250	−0.350	−0.361	−0.389	−0.402	−0.353	−0.187	0.120	0.516	0.861
251	−0.346	−0.358	−0.387	−0.402	−0.356	−0.192	0.116	0.513	0.860
252	−0.343	−0.355	−0.385	−0.403	−0.359	−0.196	0.111	0.510	0.859
253	−0.339	−0.352	−0.383	−0.403	−0.361	−0.201	0.106	0.506	0.858
254	−0.335	−0.349	−0.381	−0.403	−0.364	−0.205	0.101	0.503	0.857
255	−0.332	−0.346	−0.379	−0.403	−0.366	−0.209	0.097	0.500	0.856
256	−0.328	−0.342	−0.377	−0.402	−0.368	−0.214	0.092	0.496	0.855
257	−0.324	−0.339	−0.374	−0.402	−0.371	−0.218	0.087	0.493	0.854
258	−0.320	−0.335	−0.372	−0.402	−0.373	−0.222	0.082	0.489	0.852
259	−0.316	−0.331	−0.369	−0.401	−0.375	−0.226	0.077	0.486	0.851
260	−0.312	−0.327	−0.367	−0.401	−0.377	−0.231	0.072	0.483	0.850
261	−0.307	−0.324	−0.364	−0.400	−0.379	−0.235	0.067	0.479	0.849
262	−0.303	−0.320	−0.361	−0.400	−0.380	−0.239	0.063	0.476	0.848
263	−0.299	−0.316	−0.358	−0.399	−0.382	−0.243	0.058	0.472	0.847
264	−0.294	−0.312	−0.356	−0.398	−0.384	−0.247	0.053	0.469	0.846
265	−0.290	−0.307	−0.353	−0.397	−0.386	−0.251	0.049	0.466	0.844
266	−0.285	−0.303	−0.350	−0.396	−0.387	−0.255	0.044	0.462	0.843
267	−0.280	−0.299	−0.346	−0.395	−0.389	−0.259	0.039	0.459	0.842
268	−0.276	−0.294	−0.343	−0.393	−0.390	−0.262	0.035	0.455	0.841
269	−0.271	−0.290	−0.340	−0.392	−0.391	−0.266	0.030	0.452	0.840
270	−0.266	−0.285	−0.336	−0.391	−0.393	−0.270	0.026	0.449	0.839
271	−0.261	−0.281	−0.333	−0.389	−0.394	−0.274	0.021	0.446	0.838
272	−0.256	−0.276	−0.330	−0.387	−0.395	−0.277	0.017	0.442	0.837
273	−0.251	−0.271	−0.326	−0.385	−0.396	−0.281	0.012	0.439	0.835
274	−0.246	−0.267	−0.322	−0.384	−0.397	−0.284	0.007	0.435	0.834
275	−0.241	−0.262	−0.318	−0.382	−0.398	−0.288	0.003	0.432	0.833

Table B-2. Bessel Function, J_0 (S cos θ) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
276	−0.235	−0.257	−0.314	−0.380	−0.399	−0.291	−0.002	0.429	0.832
277	−0.230	−0.252	−0.310	−0.378	−0.399	−0.294	−0.006	0.425	0.831
278	−0.225	−0.247	−0.306	−0.376	−0.400	−0.298	−0.011	0.422	0.830
279	−0.219	−0.242	−0.302	−0.374	−0.401	−0.301	−0.015	0.418	0.829
280	−0.214	−0.236	−0.298	−0.372	−0.401	−0.304	−0.020	0.415	0.827
281	−0.208	−0.231	−0.294	−0.370	−0.402	−0.307	−0.024	0.411	0.826
282	−0.203	−0.226	−0.289	−0.367	−0.402	−0.311	−0.028	0.408	0.825
283	−0.197	−0.221	−0.285	−0.365	−0.402	−0.314	−0.033	0.404	0.824
284	−0.192	−0.215	−0.281	−0.362	−0.402	−0.317	−0.037	0.401	0.823
285	−0.186	−0.210	−0.276	−0.360	−0.403	−0.320	−0.042	0.397	0.822
286	−0.181	−0.205	−0.272	−0.357	−0.403	−0.323	−0.046	0.394	0.820
287	−0.175	−0.199	−0.267	−0.354	−0.403	−0.326	−0.050	0.390	0.819
288	−0.169	−0.194	−0.263	−0.351	−0.403	−0.328	−0.055	0.387	0.818
289	−0.163	−0.188	−0.258	−0.349	−0.403	−0.331	−0.059	0.384	0.817
290	−0.157	−0.182	−0.253	−0.346	−0.402	−0.334	−0.063	0.380	0.816
291	−0.151	−0.177	−0.248	−0.343	−0.402	−0.337	−0.068	0.377	0.814
292	−0.146	−0.171	−0.243	−0.340	−0.402	−0.339	−0.072	0.373	0.813
293	−0.140	−0.166	−0.238	−0.336	−0.401	−0.342	−0.076	0.370	0.812
294	−0.134	−0.160	−0.233	−0.333	−0.401	−0.344	−0.080	0.366	0.810
295	−0.128	−0.154	−0.228	−0.330	−0.400	−0.346	−0.084	0.363	0.809
296	−0.122	−0.148	−0.223	−0.326	−0.400	−0.349	−0.089	0.359	0.808
297	−0.116	−0.143	−0.218	−0.323	−0.399	−0.351	−0.093	0.356	0.807
298	−0.110	−0.137	−0.213	−0.320	−0.398	−0.354	−0.097	0.352	0.805
299	−0.104	−0.131	−0.208	−0.316	−0.397	−0.356	−0.101	0.349	0.804
300	−0.098	−0.125	−0.203	−0.313	−0.396	−0.358	−0.105	0.345	0.803
301	−0.092	−0.119	−0.198	−0.309	−0.395	−0.360	−0.109	0.342	0.802
302	−0.086	−0.113	−0.192	−0.305	−0.394	−0.362	−0.113	0.338	0.801
303	−0.080	−0.107	−0.187	−0.301	−0.393	−0.364	−0.117	0.335	0.799
304	−0.076	−0.101	−0.182	−0.298	−0.392	−0.366	−0.121	0.332	0.798
305	−0.068	−0.095	−0.176	−0.294	−0.391	−0.368	−0.125	0.328	0.797
306	−0.062	−0.090	−0.171	−0.290	−0.390	−0.370	−0.129	0.325	0.796
307	−0.056	−0.084	−0.165	−0.286	−0.388	−0.372	−0.133	0.321	0.794
308	−0.050	−0.078	−0.160	−0.282	−0.387	−0.374	−0.137	0.318	0.793
309	−0.044	−0.072	−0.155	−0.278	−0.385	−0.376	−0.141	0.314	0.792
310	−0.038	−0.066	−0.149	−0.273	−0.384	−0.377	−0.145	0.311	0.791
311	−0.032	−0.060	−0.144	−0.269	−0.382	−0.379	−0.149	0.307	0.789
312	−0.026	−0.054	−0.138	−0.265	−0.380	−0.380	−0.152	0.304	0.788
313	−0.020	−0.048	−0.133	−0.261	−0.379	−0.382	−0.156	0.300	0.787
314	−0.014	−0.042	−0.127	−0.256	−0.377	−0.383	−0.160	0.297	0.786
315	−0.008	−0.036	−0.122	−0.252	−0.375	−0.385	−0.163	0.293	0.784
316	−0.002	−0.030	−0.116	−0.248	−0.373	−0.386	−0.167	0.290	0.783
317	0.004	−0.024	−0.110	−0.243	−0.371	−0.387	−0.171	0.286	0.781
318	0.010	−0.018	−0.104	−0.239	−0.369	−0.389	−0.175	0.283	0.780
319	0.016	−0.013	−0.099	−0.234	−0.367	−0.390	−0.178	0.279	0.779
320	0.022	−0.007	−0.093	−0.229	−0.365	−0.391	−0.182	0.276	0.777
321	0.028	−0.001	−0.088	−0.225	−0.363	−0.392	−0.185	0.273	0.776
322	0.034	0.005	−0.082	−0.220	−0.360	−0.393	−0.189	0.269	0.775
323	0.039	0.011	−0.076	−0.215	−0.358	−0.394	−0.192	0.266	0.773
324	0.045	0.017	−0.071	−0.211	−0.356	−0.395	−0.196	0.262	0.772
325	0.051	0.023	−0.065	−0.206	−0.353	−0.396	−0.200	0.259	0.771
326	0.056	0.028	−0.059	−0.201	−0.351	−0.397	−0.203	0.255	0.770
327	0.062	0.034	−0.053	−0.196	−0.348	−0.397	−0.206	0.252	0.768
328	0.068	0.040	−0.048	−0.191	−0.345	−0.398	−0.210	0.248	0.767
329	0.073	0.046	−0.042	−0.186	−0.343	−0.399	−0.213	0.245	0.766
330	0.079	0.051	−0.037	−0.182	−0.340	−0.399	−0.217	0.241	0.764

Table B-2. Bessel Function, J_0 ($S \cos \theta$) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
331	0.085	0.057	−0.031	−0.177	−0.337	−0.400	−0.220	0.238	0.763
332	0.090	0.062	−0.025	−0.172	−0.334	−0.400	−0.223	0.234	0.762
333	0.095	0.068	−0.020	−0.167	−0.331	−0.401	−0.227	0.231	0.760
334	0.101	0.073	−0.014	−0.162	−0.328	−0.401	−0.230	0.227	0.759
335	0.106	0.079	−0.009	−0.157	−0.325	−0.402	−0.233	0.224	0.758
336	0.111	0.084	−0.003	−0.152	−0.322	−0.402	−0.236	0.221	0.756
337	0.116	0.090	0.003	−0.147	−0.319	−0.402	−0.239	0.218	0.755
338	0.122	0.095	0.008	−0.141	−0.316	−0.402	−0.242	0.214	0.754
339	0.127	0.100	0.014	−0.136	−0.313	−0.403	−0.245	0.211	0.752
340	0.132	0.106	0.020	−0.131	−0.310	−0.403	−0.249	0.207	0.750
341	0.137	0.111	0.025	−0.126	−0.307	−0.403	−0.252	0.204	0.749
342	0.142	0.116	0.031	−0.121	−0.303	−0.403	−0.255	0.200	0.748
343	0.147	0.121	0.036	−0.116	−0.300	−0.403	−0.258	0.197	0.746
344	0.151	0.126	0.042	−0.111	−0.297	−0.403	−0.261	0.193	0.745
345	0.156	0.131	0.047	−0.105	−0.293	−0.402	−0.263	0.190	0.744
346	0.161	0.136	0.052	−0.100	−0.290	−0.402	−0.266	0.187	0.742
347	0.166	0.141	0.058	−0.095	−0.286	−0.402	−0.269	0.183	0.741
348	0.170	0.146	0.063	−0.090	−0.282	−0.402	−0.272	0.180	0.740
349	0.175	0.151	0.068	−0.084	−0.279	−0.401	−0.275	0.176	0.738
350	0.170	0.155	0.073	−0.079	−0.275	−0.401	−0.278	0.173	0.737
351	0.184	0.160	0.079	−0.074	−0.271	−0.400	−0.281	0.169	0.735
352	0.188	0.164	0.084	−0.069	−0.268	−0.400	−0.283	0.166	0.734
353	0.192	0.169	0.089	−0.064	−0.264	−0.399	−0.286	0.163	0.732
354	0.197	0.173	0.094	−0.058	−0.260	−0.399	−0.289	0.159	0.731
355	0.201	0.178	0.099	−0.053	−0.257	−0.398	−0.291	0.156	0.730
356	0.205	0.182	0.104	−0.048	−0.253	−0.397	−0.294	0.152	0.729
357	0.209	0.187	0.109	−0.043	−0.249	−0.397	−0.297	0.149	0.727
358	0.213	0.191	0.114	−0.038	−0.245	−0.396	−0.299	0.146	0.726
359	0.216	0.194	0.119	−0.033	−0.241	−0.395	−0.302	0.142	0.724
360	0.220	0.199	0.124	−0.027	−0.237	−0.394	−0.304	0.139	0.723
361	0.224	0.203	0.128	−0.022	−0.233	−0.393	−0.307	0.136	0.722
362	0.228	0.207	0.133	−0.017	−0.228	−0.392	−0.309	0.132	0.720
363	0.231	0.211	0.138	−0.012	−0.224	−0.391	−0.312	0.129	0.719
364	0.234	0.215	0.143	−0.006	−0.220	−0.390	−0.314	0.125	0.717
365	0.238	0.218	0.147	−0.001	−0.216	−0.389	−0.316	0.122	0.716
366	0.241	0.222	0.152	0.004	−0.212	−0.388	−0.319	0.119	0.714
367	0.244	0.226	0.156	0.009	−0.208	−0.387	−0.321	0.116	0.713
368	0.247	0.229	0.161	0.014	−0.204	−0.386	−0.323	0.113	0.712
369	0.250	0.233	0.165	0.019	−0.199	−0.384	−0.325	0.109	0.710
370	0.253	0.236	0.170	0.024	−0.195	−0.383	−0.327	0.106	0.708
371	0.256	0.239	0.174	0.029	−0.191	−0.381	−0.330	0.103	0.707
372	0.259	0.242	0.178	0.034	−0.186	−0.380	−0.332	0.099	0.705
373	0.262	0.245	0.182	0.039	−0.182	−0.378	−0.334	0.096	0.704
374	0.264	0.248	0.186	0.044	−0.178	−0.377	−0.336	0.093	0.702
375	0.267	0.251	0.190	0.049	−0.173	−0.375	−0.338	0.089	0.701
376	0.269	0.254	0.194	0.054	−0.169	−0.374	−0.340	0.086	0.700
377	0.271	0.257	0.198	0.059	−0.164	−0.372	−0.342	0.083	0.698
378	0.274	0.260	0.202	0.064	−0.160	−0.370	−0.344	0.079	0.697
379	0.276	0.262	0.206	0.069	−0.156	−0.369	−0.346	0.076	0.695
380	0.278	0.265	0.210	0.074	−0.151	−0.367	−0.348	0.073	0.694
381	0.280	0.267	0.213	0.079	−0.147	−0.365	−0.349	0.070	0.692
382	0.282	0.270	0.217	0.084	−0.142	−0.363	−0.351	0.066	0.691
383	0.283	0.272	0.220	0.088	−0.138	−0.361	−0.353	0.063	0.689
384	0.285	0.274	0.224	0.093	−0.133	−0.359	−0.355	0.060	0.688
385	0.287	0.276	0.227	0.097	−0.128	−0.357	−0.357	0.057	0.686

Table B-2. Bessel Function, J_0 ($S \cos \theta$) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
386	0.288	0.278	0.230	0.102	−0.124	−0.355	−0.358	0.053	0.685
387	0.290	0.280	0.233	0.107	−0.119	−0.353	−0.360	0.050	0.684
388	0.291	0.282	0.237	0.111	−0.115	−0.351	−0.362	0.047	0.682
389	0.292	0.284	0.240	0.116	−0.110	−0.349	−0.363	0.044	0.681
390	0.293	0.285	0.243	0.120	−0.106	−0.347	−0.365	0.040	0.679
391	0.295	0.287	0.246	0.125	−0.101	−0.345	−0.366	0.037	0.678
392	0.296	0.288	0.249	0.129	−0.097	−0.342	−0.368	0.034	0.676
393	0.296	0.290	0.251	0.134	−0.092	−0.340	−0.369	0.031	0.675
394	0.297	0.291	0.254	0.138	−0.087	−0.338	−0.371	0.028	0.673
395	0.298	0.292	0.257	0.142	−0.082	−0.335	−0.372	0.025	0.671
396	0.298	0.294	0.259	0.146	−0.078	−0.333	−0.374	0.021	0.670
397	0.299	0.295	0.262	0.151	−0.073	−0.331	−0.375	0.018	0.668
398	0.299	0.296	0.264	0.155	−0.069	−0.328	−0.376	0.015	0.667
399	0.300	0.297	0.267	0.159	−0.064	−0.326	−0.378	0.012	0.665
400	0.300	0.297	0.269	0.163	−0.060	−0.323	−0.379	0.009	0.664
401	0.300	0.298	0.271	0.167	−0.055	−0.321	−0.380	0.006	0.662
402	0.300	0.298	0.273	0.171	−0.050	−0.318	−0.381	0.003	0.661
403	0.300	0.299	0.275	0.175	−0.046	−0.315	−0.382	0.000(−)	0.659
404	0.300	0.299	0.277	0.179	−0.041	−0.313	−0.383	−0.003	0.658
405	0.300	0.300	0.279	0.183	−0.036	−0.310	−0.385	−0.006	0.656
406	0.299	0.300	0.281	0.186	−0.032	−0.307	−0.386	−0.009	0.655
407	0.299	0.300	0.283	0.190	−0.027	−0.304	−0.387	−0.012	0.653
408	0.298	0.300	0.284	0.194	−0.023	−0.302	−0.388	−0.016	0.652
409	0.298	0.300	0.286	0.198	−0.018	−0.299	−0.389	−0.019	0.650
410	0.297	0.300	0.287	0.201	−0.013	−0.296	−0.390	−0.022	0.648
411	0.296	0.300	0.289	0.204	−0.009	−0.293	−0.390	−0.025	0.647
412	0.296	0.299	0.290	0.208	−0.004	−0.290	−0.391	−0.028	0.645
413	0.295	0.299	0.291	0.211	0.000(+)	−0.287	−0.392	−0.031	0.644
414	0.294	0.298	0.293	0.215	0.005	−0.284	−0.393	−0.034	0.642
415	0.292	0.298	0.294	0.218	0.009	−0.281	−0.394	−0.037	0.641
416	0.291	0.297	0.295	0.221	0.014	−0.278	−0.394	−0.040	0.639
417	0.290	0.297	0.295	0.224	0.018	−0.275	−0.395	−0.043	0.638
418	0.289	0.296	0.296	0.227	0.023	−0.272	−0.396	−0.046	0.636
419	0.287	0.295	0.297	0.230	0.027	−0.269	−0.396	−0.049	0.635
420	0.286	0.294	0.298	0.233	0.032	−0.266	−0.397	−0.052	0.633

APPENDIX C. DIRECTIONAL ANTENNAS HAVING MORE THAN TWO TOWERS

A Three-tower-in-line-array Pattern Shape

Three towers in line spaced an equal distance between adjacent towers and with the end towers having equal inverse fields and phasings that are equal but opposite in sign are shown in Fig. C-1*a*. The resultant inverse field strength at 1 mile in the direction of any point P in the horizontal plane is shown in the vector diagram of Fig. C-1*b*. The resultant vector E always lies along the vector reference axis. This simplifies the pattern computations.

The resultant inverse field strength E at 1 mile in the direction of point P in the horizontal plane is given by

$$E = E_1 \underline{|0} + E_2 \underline{|\beta_2} + E_3 \underline{|\beta_3} \qquad \text{(C-1)}$$

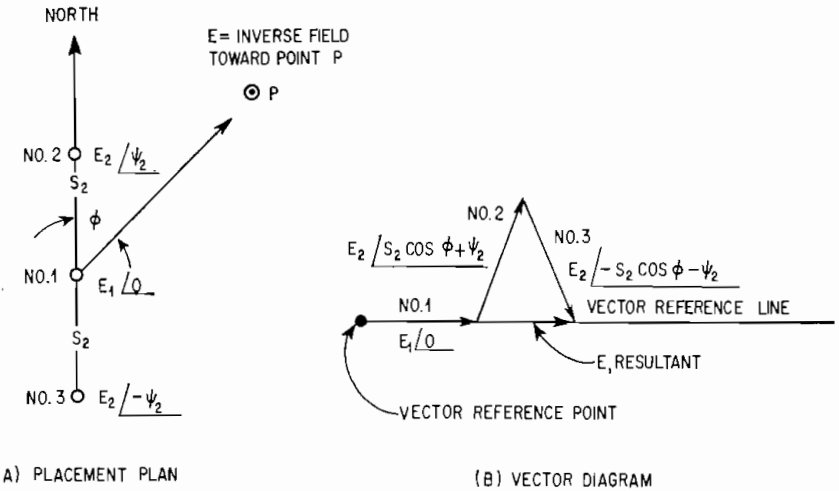


FIG. C-1. Three-tower-in-line array.

where E = resultant inverse field strength at 1 mile, mv/m
E_1 = inverse field strength from tower 1 at 1 mile while array is in operation, mv/m
E_2 = inverse field strength from towers 2 and 3 at 1 mile while array is in operation, mv/m

$$\beta_2 = -\beta_3 = S_2 \cos \phi + \Psi_2 \tag{C-2}$$

where S_2 = spacing from tower 1 to 2 and 3, deg
ϕ = azimuth angle to observation point P, deg
Ψ_2 = phase of tower 2 with respect to tower 1, deg

The magnitude of E in the above equation can be written

$$E = E_1(1 + 2F_2 \cos \beta_2) \tag{C-3}$$

where $F_2 = E_2/E_1$. This equation is in convenient form for computing the horizontal pattern. It can also be used to determine the effect of any change in the design parameters. For example, for a given spacing $S_2 = 90°$ and direction $\phi = 60°$, the equation can be written

$$E = E_1[1 + 2F_2 \cos (45 + \Psi_2)] \tag{C-4}$$

If $F_2 = 0.5$, then the equation becomes

$$E = E_1[1 + \cos (45 + \Psi_2)] \tag{C-5}$$

Now when Ψ_2 is selected properly, E can be made to have any value from 0 to $2E_1$. If E is to be zero at 60 and 300°, since the pattern is symmetrical, then $\cos (45 + \Psi_2) = -1$ or $\Psi_2 = 135°$. For this condition the horizontal-pattern equation is written:

$$E = E_1[1 + \cos (90 \cos \phi + 135)] \tag{C-6}$$

When ϕ is varied from 0 to 180°, the complete pattern can be determined because it is symmetrical around the line of towers.

In general a three-tower-in-line array will produce a pattern with four nulls. Actually the pattern of Eq. (C-6) has four nulls, but two occur at $\phi = 60°$, and two occur at $\phi = 300°$. This results in wider angles of low field strength at these two bearings than would be the case with single nulls.

The multiplication form for three towers in line is a more useful form and in the horizontal plane is written

$$E = 2E_1\sqrt{F_2F_3}\left[\left(\frac{1 + F_2^2}{2F_2} + \cos\beta_2\right)\left(\frac{1 + F_3^2}{2F_3} + \cos\beta_3\right)\right]^{1/2} \qquad \text{(C-7)}$$

where $F_2 = E_2/E_1$
$F_3 = E_3/E_1$
$\beta_2 = S_2 \cos\phi + \Psi_2$
$\beta_3 = -S_3 \cos\phi - \Psi_3$

and the other values are defined above. Each parenthesis term in Eq. (C-7) gives the pattern shape for two towers. The resulting pattern is produced by multiplying these terms together and taking the square root. With this design the direction of the nulls can be controlled for each pair of towers, the center tower in this case acting like two towers. If F_2 and F_3 are other than unity, a minimum rather than a null will result. Thus it is possible to fill in one pair of nulls independently of the other set.

Attention is directed to the minimum-depth terms

$$\frac{1 + F_2^2}{2F_2} \quad \text{and} \quad \frac{1 + F_3^2}{2F_3}$$

which can be determined from Table B-1. The actual values of F_2 and F_3 or their reciprocal values can be used to obtain the same result. If the actual reciprocal values are used to make adjustments in the field, this fact should be made clear in the report to FCC and there should be no objection on their part.

Four-tower Parallelogram-array Pattern Shape

General Case

The plan configuration of a four-tower parallelogram array is shown in Fig. C-2 along with the related vector diagram. The general equation for the pattern can be written

$$E = E_1 f_1(\theta)[1 + F_2^2 + F_3^2 + F_4^2 + 2F_2\cos\beta_2 + 2F_3\cos\beta_3 + 2F_4\cos\beta_4 + 2F_2F_4\cos(\beta_2 - \beta_4) + 2F_2F_3\cos(\beta_2 - \beta_3) + 2F_3F_4\cos(\beta_3 - \beta_4)]^{1/2} \qquad \text{(C-8)}$$

where E = inverse field strength at 1 mile in direction of point P, mv/m

$\beta_2 = S_2\cos(\phi_2 - \phi)\cos\theta + \Psi_2$
$\beta_3 = S_3\cos(\phi_3 - \phi)\cos\theta + \Psi_2$
$\beta_4 = S_4\cos(\phi_4 - \phi)\cos\theta + \Psi_2$

$$F_2 = \frac{E_2 f_2(\theta)}{E_1 f_1(\theta)}$$

$$F_3 = \frac{E_3 f_3(\theta)}{E_1 f_1(\theta)}$$

$$F_4 = \frac{E_4 f_4(\theta)}{E_1 f_1(\theta)}$$

E_1, E_2, E_3, and E_4 = inverse field strength at 1 mile produced by towers 1 to 4, respectively when, the array is in operation, mv/m

$f_1(\theta)$, $f_2(\theta)$, $f_3(\theta)$, and $f_4(\theta)$ = vertical radiation characteristic of towers 1 to 4, respectively

This equation is valid for towers of unequal height but is of a form seldom used. If the restriction $\beta_4 = \beta_2 + \beta_3$ and $F_4 = F_2F_3$ is applied, Eq. (C-8) can be written

$$E = 2E_1 f_1(\theta)\sqrt{F_2F_3}\left[\left(\frac{1 + F_2^2}{2F_2} + \cos\beta_2\right)\left(\frac{1 + F_3^2}{2F_3} + \cos\beta_3\right)\right]^{1/2} \qquad \text{(C-9)}$$

where the terms are defined above.

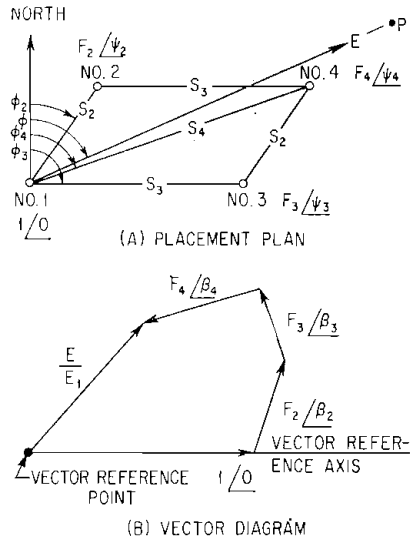


FIG. C-2. General parallelogram array.

It is noted that tower 4 must have the following field ratio:

$$F_4 = F_2F_3 = \frac{E_2f_2(\theta)E_3f_3(\theta)}{E_1^2f_1^2(\theta)} \tag{C-10}$$

If $E_1 = E_2 = E_3$, then the vertical-radiation characteristics of tower 4 must be

$$f_4(\theta) = \frac{f_2(\theta)f_3(\theta)}{f_1^2(\theta)} \tag{C-11}$$

Since all $f(\theta)$ values are unity along the ground, this condition cannot be detected in the horizontal plane. However, if the parallelogram array is operated at night when high angle radiation is involved, it is necessary to compute the radiation at various elevation angles and the above equation must be considered.

The greatest practical value of Eq. (C-9) is that it gives information concerning the exact location of the four minima, two for each of the two-tower patterns unless spacings greater than 180° are used, and in such cases there may be four minima per two-tower pattern. This information is useful in the design and adjustment of the parallelogram array. It comes from the condition when $\beta = 180°$.

Then the minimum-depth terms give useful information concerning the value of field strength to be expected in these directions. They are helpful in shaping the pattern to meet the design requirements.

The expression inside the brackets completely defines the pattern shape. The factor $2E_1f_1(\theta)\sqrt{F_2F_3}$ outside the bracket defines the pattern size, especially the term E_1, which will be evaluated in a later section of this appendix.

Special Three-tower-in-line Case

If tower 2 is placed on top of tower 3, a three-tower-in-line array will result as shown in Fig. C-2. This arrangement is redrawn in Fig. C-3.

Special Three Towers Not in Line

If in Eq. (C-8) the condition that $F_4 = 0$ is imposed, the equation reduces to

$$E = E_1f_1(\theta)\left[2F_2\left(\frac{1+F_2^2}{2F_2} + \cos\beta_2\right) + 2F_3\left(\frac{1+F_3^2}{2F_3} + \cos\beta_3\right) - 1 + 2F_2F_3\cos(\beta_2 - \beta_3)\right]^{\frac{1}{2}} \tag{C-12}$$

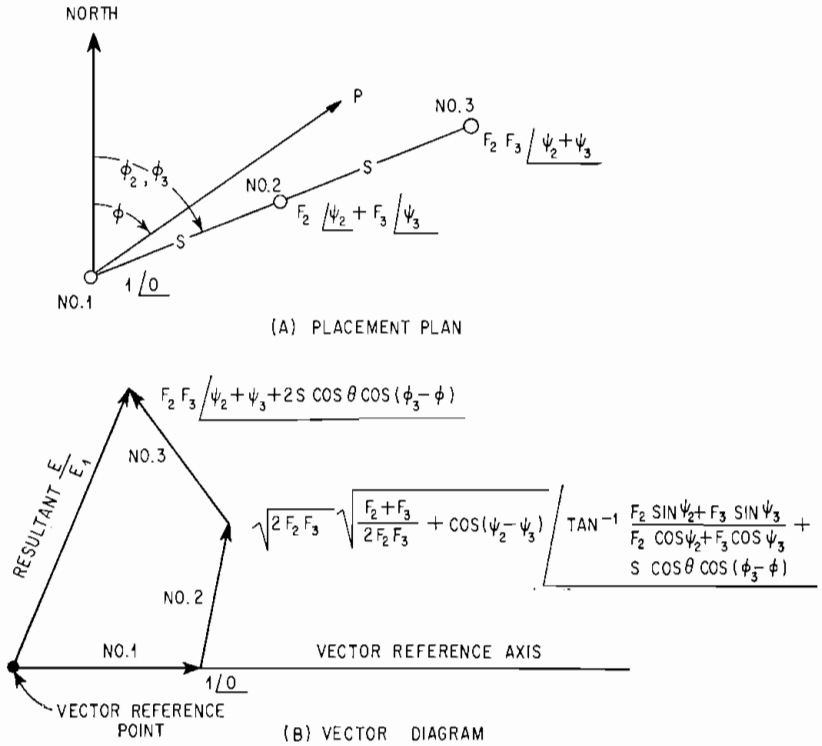


FIG. C-3. Special three-tower-in-line array.

This equation is essentially an addition formula for a three-tower-not-in-line array as shown in Fig. C-4 plus the variable term $2F_2F_3\cos(\beta_2 - \beta_3) - 1$. The -1 merely translates the sum of the other three terms to the left one unit. Hence it remains only to find how the pattern changes with the addition of the two patterns plus the term $2F_2F_3\cos(\beta_2 - \beta_3)$. The effect of change in parameter values can be noted in the computations. The information can be very useful in making adjustments on this type of array.

Pattern-size Determination

Four-tower Array

The equation to determine the field strength from the reference tower 1 is

$$E_1 = E_{1s}\sqrt{\frac{R_{11}}{R_1 + M_{21}^2R_2 + M_{31}^2R_3 + M_{41}^2R_4}} \qquad \text{(C-13)}$$

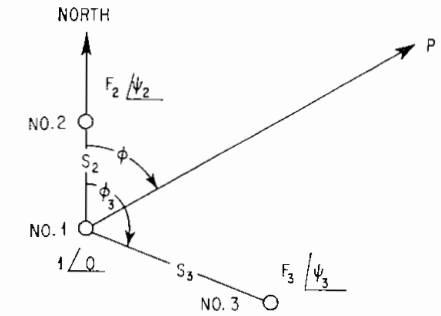
where E_1 = inverse field strength at 1 mile in horizontal plane from tower 1 while operating in the array, mv/m

E_{1s} = inverse field strength at 1 mile in horizontal plane from tower 1 operating alone, mv/m

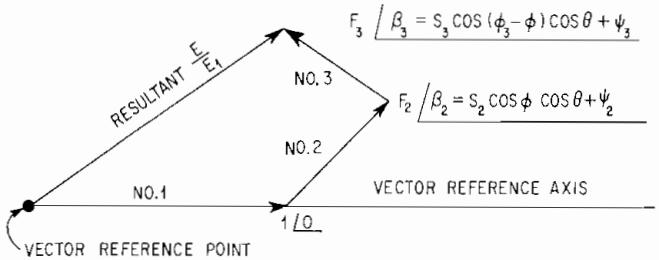
R_1, R_2, R_3, and R_4 = driving-point resistance values at input terminals of towers 1 to 4 respectively, ohms

M_{21}, M_{31}, and M_{41} = loop-current ratios of towers 2, 3 and 4 to tower 1, respectively

Only magnitude values are used in the above equation. The driving-point resistances, as in Eq. (B-5), are made up of self-, mutual-, and loss-resistance terms.



(A) PLACEMENT PLAN



(B) VECTOR DIAGRAM

FIG. C-4. Special three-tower-not-in-line case.

They can be written

$$R_1 = R_{11} + R_{L1} + R_{C1} \quad \text{(C-14)}$$

$$R_2 = R_{22} + R_{L2} + R_{C2} \quad \text{(C-15)}$$

$$R_3 = R_{33} + R_{L3} + R_{C3} \quad \text{(C-16)}$$

$$R_4 = R_{44} + R_{L4} + R_{C4} \quad \text{(C-17)}$$

where R_{11}, R_{22}, R_{33}, and R_{44} = self-loop radiation resistance of towers 1 to 4, respectively, ohms
R_{L1}, R_{L2}, R_{L3}, and R_{L4} = loop-loss resistance of towers 1 to 4, respectively, ohms
R_{C1}, R_{C2}, R_{C3}, and R_{C4} = loop-coupled resistance of towers 1 to 4, respectively, ohms

In Eq. (C-13) the value of E_{1s}, R_{11}, R_{22}, R_{33}, and R_{44} can be obtained from Fig. A-5. R_{L1}, R_{L2}, R_{L3}, and R_{L4} are usually assumed to be 2 ohms for towers 90° high or taller. The values of coupled resistance can be obtained from the mutual-impedance terms in mesh circuit equations, which can be written

$$R_{C1} = M_{21}Z_{12}\cos(\Psi_{12} + \gamma_{12}) + M_{31}Z_{13}\cos(\Psi_{13} + \gamma_{13}) + M_{41}Z_{14}\cos(\Psi_{14} + \gamma_{14}) \quad \text{(C-18)}$$

$$R_{C2} = M_{12}Z_{21}\cos(\Psi_{21} + \gamma_{21}) + M_{33}Z_{23}\cos(\Psi_{23} + \gamma_{23}) + M_{42}Z_{24}\cos(\Psi_{24} + \gamma_{24}) \quad \text{(C-19)}$$

$$R_{C3} = M_{13}Z_{31}\cos(\Psi_{31} + \gamma_{31}) + M_{23}Z_{32}\cos(\Psi_{32} + \gamma_{32}) + M_{43}Z_{34}\cos(\Psi_{34} + \gamma_{34}) \quad \text{(C-20)}$$

$$R_{C4} = M_{14}Z_{41}\cos(\Psi_{41} + \gamma_{41}) + M_{24}Z_{42}\cos(\Psi_{42} + \gamma_{42}) + M_{34}Z_{43}\cos(\Psi_{43} + \gamma_{43}) \quad \text{(C-21)}$$

where $Z_{pq} = Z_{qp}$ = magnitude of loop mutual impedance between tower p and tower q, ohms

$\gamma_{pq} = \gamma_{qp}$ = angle of loop mutual impedance between tower p and tower q, deg

$\Psi_{pq} = -\Psi_{qp}$ = electrical phasing of tower q with respect to tower p, deg

The loop coupled reactance X_{c1}, X_{c2}, X_{c3}, and X_{c4} of towers 1 to 4, respectively can be calculated from Eqs. (C-18) to (C-21) by replacing cos by sin throughout. The coupled reactance values are not needed for the determination of the size of E_1. However, they are useful when it comes to determining the driving-point impedances and setting up the matching networks at the towers.

The mutual-impedance terms required above for ordinary equal-height towers are shown in Fig. B-14. The mutual impedance between top-loaded towers may be assumed equal to the mutual impedance between the same towers not top-loaded in most cases.

The above equations can also be applied to top-loaded sectionalized towers but with major problems. The radiation E_{1s} and self-resistance values are not readily available in general. Also, the mutual impedances must be calculated except for special cases which are available.

When E_1 is determined by Eq. (C-13), the pattern can be plotted to its exact size.

Three-tower Array

The equation to determine the field strength for a three-tower array can be written

$$E_1 = E_{1s}\sqrt{\frac{R_{11}}{R_1 + M_{21}{}^2R_2 + M_{31}{}^2R_3}} \tag{C-22}$$

where the values are defined following Eq. (C-13). The terms involving tower 4 in Eqs. (C-18), (C-19), and (C-20) will vanish.

Horizontal-plane RMS Field Strength of Four-tower Array

The equation for the rms field strength in the horizontal plane of a four-tower array is

$$\begin{aligned} E_0 = E_1[1 &+ F_2{}^2 + F_3{}^2 + F_4{}^2 \\ &+ 2F_2 \cos \Psi_{12}J_0(S_{12}) \\ &+ 2F_3 \cos \Psi_{13}J_0(S_{13}) \\ &+ 2F_4 \cos \Psi_{14}J_0(S_{14}) \\ &+ 2F_2F_3 \cos \Psi_{23}J_0(S_{23}) \\ &+ 2F_2F_4 \cos \Psi_{24}J_0(S_{24}) \\ &+ 2F_3F_4 \cos \Psi_{34}J_0(S_{34})]^{1/2} \end{aligned} \tag{C-23}$$

where E_0 = rms inverse field strength in horizontal plane, mv/m

E_1 = inverse field strength at 1 mile produced by tower 1 while operating in array, mv/m

F_2, F_3, and F_4 = inverse field-strength ratios of towers 2, 3 and 4 to tower 1, respectively.

Ψ_{pq} = electrical phasing of tower q with respect to tower p as designated by the subscript numbers, deg

S_{pq} = spacing of tower q to tower p as designated by the subscript numbers, deg

$J_0(S_{pq})$ = Bessel function of first kind and zero order of the spacing as designated by the subscripts and given in Table B-2

A good check on the arithmetic is to measure the pattern area with a planimeter.

For a four-tower parallelogram array Eq. (C-23) reduces to

$$\begin{aligned} E_0 = E_1[1 &+ F_2^2 + F_3^2 + F_4^2 \\ &+ 2(F_2 + F_3F_4)\cos\Psi_{12}J_0(S_{12}) \\ &+ 2F_4\cos\Psi_{14}J_0(S_{14}) \\ &+ 2F_2F_3\cos\Psi_{23}J_0(S_{23}) \\ &+ 2(F_3 + F_2F_4)\cos\Psi_{13}J_0(S_{13})]^{1/2} \end{aligned} \quad \text{(C-24)}$$

where the terms are defined following Eq. (C-23).

Horizontal-plane RMS Field Strength of Three-tower Array

The equation for the rms field strength in the horizontal plane of a three-tower array is

$$\begin{aligned} E_0 = E_1[1 &+ F_2^2 + F_3^2 \\ &+ 2F_2\cos\Psi_{12}J_0(S_{12}) \\ &+ 2F_3\cos\Psi_{13}J_0(S_{13}) \\ &+ 2F_2F_3\cos\Psi_{23}J_0(S_{23})]^{1/2} \end{aligned} \quad \text{(C-25)}$$

where the terms are defined following Eq. (C-23).

For the special three-tower-in-line array of Fig. C-1 the above equation reduces to

$$\begin{aligned} E_0 = E_1[1 &+ 2F_2^2 \\ &+ 4F_2\cos\Psi_{12}J_0(S_{12}) \\ &+ 2F_2^2\cos(2\Psi_{12})J_0(2S_{12})]^{1/2} \end{aligned} \quad \text{(C-26)}$$

where the terms are defined following Eq. (C-23).

Part 4

MAINTENANCE OF DIRECTIONAL ANTENNAS *

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INTRODUCTION

Except for the development of precise frequency control, it is probable that no other technical development has contributed so much to the efficient utilization of the standard broadcast band as the directional antenna. As of Sept. 1, 1959, there were authorized in the United States some 3,500 standard broadcast stations. Of these, about 1,000, or roughly 30 per cent, use directional antennas in either daytime or nighttime or both. Because some stations use more than one pattern, a total of over 1,200 different directional-antenna patterns are involved.

Before authorization is granted for construction of a directional antenna in the United States, the Federal Communications Commission requires that a complete engineering showing be made. Before a license is granted for the regular operation of a directional antenna, a complete and thorough proof of performance must be made and submitted by the permittee and approved by the FCC.

We can thus assume that each directional antenna is operating properly at the time that it commences regular operation. But what of the problems of maintenance of the antenna in day-to-day operation of the system? Let us examine the factors affecting the maintenance of directional-antenna systems.

Factors Affecting the Maintenance of Directional Antenna Systems

To begin with, the design of the antenna system will affect the maintenance problems. In his design, the engineer must determine whether the array will operate with reasonable stability and efficiency. Generally speaking, the design must be such as to avoid low values of base operating resistance, either negative or positive. Such a condition could lead to excessive losses in the system and possibly to a "flip-flop" operating condition where a small change in tuning results in a drastic change in operating parameters.

In so far as the design engineer can do so, he must avoid deep minima in the pattern, since this results in a condition where a relatively small change in phase or current can cause a relatively large change in field intensity radiated in the directions of the minima.

Further factors affecting the stability of a directional antenna and the problem of its maintenance arise in the design of the phasing and coupling equipment. A design

* Supplemented by material prepared by Dixie B. McKey from the "NAB Engineering Handbook," 4th ed.

which incorporates a minimum of resonant circuits will, in general, exhibit greater stability than one which has a number of such circuits.

In the physical location of phasing and coupling equipment, one method frequently used is to have the power-division and phasing equipment distributed through the system and placed in tuning houses at the antenna bases. While this has the advantage of requiring a minimum length of transmission line and furnishes some protection against unauthorized tinkering by operating personnel, it has the disadvantage of making the initial tune-up and any necessary subsequent readjustment more difficult and lengthy than would be the case with a more convenient arrangement. The alternative and probably better arrangement is to concentrate the phasing and power-dividing equipment in the transmitter building. Here the effect of adjustments can be observed at once with the monitoring system, and the tuning of the array can be completed more easily and quickly. Under this concentrated arrangement, the equipment is usually better housed, thus making for better and easier maintenance.

Transmission Lines

Still more factors affecting maintenance of the directional-antenna system arise in the course of construction of the system. The choice of transmission and sampling lines, for instance, is important. Open-wire lines are unsuited for use with directional-antenna systems. The characteristics of such lines change with the accumulation of water, ice, or snow on the wires and insulators, and this alters the operating parameters of the array.

The solid-dielectric transmission lines having an outer conductor of copper braid, such as RG17U and RG19U, are also unsuitable for a directional-antenna system unless special precautions are taken. The somewhat lower efficiency of these lines must be taken into account in the design of the system. Because the outer conductor of such lines "leaks" RF energy and because of the difficulty of adequately grounding the lines along each run, the most satisfactory way in which to handle this type of line is to install it in well-grounded metal conduit. The expense of doing this, however, increases the cost of the installation so greatly as to nullify the advantage of the lower first cost of the line itself.

No more satisfactory transmission line or sampling line can be found than air-dielectric line having an outer conductor of copper tubing and grounded adequately along each run. When properly installed and maintained, such lines provide many, many years of satisfactory service. The June, 1957, issue of *Broadcast News* contains an excellent article by one of the IRE Professional Group members, Joseph Novik, on Installing Antenna Systems for AM Operations.

In any installation of pressurized lines, particular attention must be given to the arrangement for pressurizing the lines. Maintenance of pressure in the lines is an important part of the over-all maintenance of the system; therefore, the arrangement for pressurizing must be convenient and readily accessible.

It goes without saying that the tuning equipment must be adequately housed, that all ground connections must be well made, and that good workmanship must be used in all details of the installation if maintenance problems are to be kept to a minimum.

Phase Monitor

One of the most important aids in maintaining a directional-antenna system, if not the most important, is an adequate sampling system and a reliable current and phase monitor. A sampling loop mounted on the tower is to be preferred to a resonant pickup circuit coupled to the antenna lead. If the resonant circuit is used, it will be found that the relative phase and current indications of the phase monitor will change as the circuit drifts or is jarred out of resonance. If such a sampling pickup is used, the maintenance procedure at the station should provide for frequent checking of resonance of each such circuit.

The phase monitor at the station should be maintained according to the directions of the manufacturer.

GENERAL MAINTENANCE PROCEDURES

Mention was made earlier of the desirability of avoiding deep minima in the design of the directional-antenna pattern. It follows that in the adjustment of the antenna, the field radiated in the direction of each minimum must not be reduced substantially below the theoretical value, since, if carried too far, such a reduction will result in a low value of field strength difficult to maintain in regular operation.

After an array has been properly adjusted in the initial operation, useful and valuable information can and should be obtained by measuring the reactance of the component branches of all tuning networks. Then if it should be necessary to replace a defective component at a later date, the value of reactance originally established can be quickly achieved. Also, the data obtained from such measurements can be used in later checking the condition of a suspected component.

After a directional antenna has been properly adjusted, a record should be made of all dial settings of variable tuning elements and the position of any clips on tapped inductors should be marked. Such marking can be done quickly and effectively by painting a strip of fingernail polish across the clip and the turn of the coil on which it is located. Where a coil has two or more clips, a different color should be used for each clip. Then, if a clip should accidentally be dislodged, it is a simple matter to replace it in the proper location.

In the maintenance of a directional-antenna system, as in the maintenance of other equipment, one rule is important: Keep it clean! Components should be wiped and blown clean each week. The tuning houses should be kept rodent and reptileproof. It adds nothing to the operation of the system to have a scorched mouse, a dead snake, or a large dirt-dauber's nest scattered among the tuning components.

Vegetation should be kept down in the vicinity of each tower base. Cut vegetation should be raked away from the tower base and burned under supervision to minimize reseeding and to prevent a fire hazard. Chemicals can be used to inhibit growth of vegetation.

Pressure in the transmission and sampling lines should be maintained at 10 to 15 lb, using dry air or dry gas, to prevent the entry of moisture. If a leak develops, it should be located and repaired promptly. Periodic checks should be made of the pressure gauges so as to be certain that no gauge has become stuck and is giving false indications.

It is helpful to apply a very light coating of silicone compound to exposed insulators and end seals to prevent formation of a moisture film during wet weather. It goes without saying that all insulators should be kept free of paint.

Inspection of Components

An important part of the maintenance procedure is to make a weekly visual inspection of all elements of the antenna system. Broken insulators or other damaged elements should be replaced at once. Where necessary, lightning gaps should be respaced, using a piece of flat insulation of the proper thickness as a feeler gauge.

The tightness of all connections in the antenna tuning equipment should be checked at quarterly intervals. At yearly intervals and also after every violent windstorm, a transit should be used to determine whether each tower remains plumb. It is advisable at the same time to check all tower bolts and nuts for tightness and to check for bent members. During these checks, a visual inspection should be made of the guy wires and insulators for any signs of damage or deterioration. If a tower is found to be out of plumb or other difficulties are found, a competent tower erector should be employed to correct the situation.

Meter Readings

Meter readings having to do with the antenna system should be made carefully and logged accurately so that if difficulty arises, a complete and accurate record of

what has transpired is available for reference. If an electrical storm occurs in the vicinity of the antenna, that fact should be entered in the log. Readings of the antenna base meters and the sampling loop meters should be made under conditions of no modulation. Usually, the cooperation of studio operating personnel can be obtained and a pause of 5 sec or so allowed between announcements or musical selections so that each reading can be obtained accurately. When reading antenna base meters, the operator should carry with him a monitor permitting him to discern when no modulation is present. A crystal diode rectifier wired across a telephone jack and equipped with a probe or pickup coil can be used with a pair of headphones to provide such a monitor.

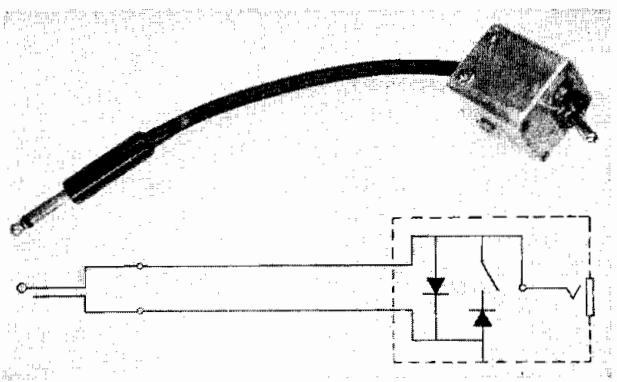

FIG. 4-1. Detector–noise limiter for use in antenna work.

A device which has proved useful in antenna work is shown in Fig. 4-1. With the switch open, this device is a useful monitor. Adequate pickup is obtained by holding the sleeve of the plug in one's hand while touching the tip to a metal panel, messenger cable, or the like. With the switch closed, the device becomes an effective noise limiter for use with a receiver in RF bridge work.

Maintenance Report

Components

A report or maintenance book can be set up as follows. The first section shown in Fig. 4-2 will consist essentially of a complete description of the individual component parts arranged in four subdivisions consisting of inductance coils, capacitors, resistors, and relays. The listing in each of the subdivisions should carry a description of the unit, its location or function in the circuit, its type number, replacement-ordering information, and circuit designation. The listing should also cover the number of turns in use of each inductance coil, the value of each of the capacitors, and the dial settings of the capacitors if variable.

Meters

The second subdivision (Fig. 4-3) should furnish complete information concerning all meters used in the operation of the array and should consist of a listing of these units showing the circuit designations, the location and function of the unit, its range, type and serial number, and the current reading for the required output. The required phase-monitor reading for normal operation should be listed in this subdivision.

CIRCUIT INFORMATION

Circuit Designation	*Circuit Function*	*Adjustment Information*	*Replacement Information*
L1	Shunt input coil	20½ turns	Continnously variable coil—type 4224 MS4—26 μh
L2	Series input coil	9½ turns	Variable tap coil -type 322-4N4—26 μh
L3	No. 1 tank coil	8 turns	Variable tap coil—type 3208NT10—38 μh
L4	No. 2 tank coil	7 turns	Variable tap coil—type 3208NT10—38 μh
L5	No. 1 line feed coil	½ turn	Continuously variable coil—type 4103—HMS5—7 μh
L6	No. 2 line feed coil	7¾ turns	Continuously variable coil—type 4103—HMS5—7 μh
L7	No. 3 line feed coil	7 turns	Continuously variable coil -type 4103- HMS5—7 μh
L8	No. 4 line feed coil	5½ turns	Continuously variable coil—type 4103—HMS5—7 μh
L9	No. 1 line series phase coil	13¼ turns	Continuously variable coil—type 4224 MS4- 26 μh
L12) L13)	No. 2 line series phase coil	8¼ turns	Continuously variable coil—type 4224 MS4—26 μh
L14	No. 2 line shunt phase coil	8½ turns	Variable tap coil—type 4164-N5—16 μh
L15) L16)	No. 3 line series phase coil	11⅓ turns	Continuously variable coil—type 4224 MS4—26 μh
L17	No. 3 line shunt phase coil	5¾ turns	Variable tap coil—type 4164-N5—16 μh
L18) L19)	No. 4 line series phase coil	8¼ turns	Continuously variable coil—type 4224 MS4—26 μh
L20	No. 4 line shunt phase coil	6 turns	Variable tap coil—type 4164-N5—16 μh
L21	No. 1 tower series input coil	11 turns	Variable tap coil—type 3164-N5—16 μh
L22	No. 1 tower series output coil (D)	7 turns	Variable tap coil—type 4165-N5—22 μh
L23	No. 1 tower shunt coil	D10 turns ND 3½ turns	Variable tap coil—type 3106-NT12—10 μh
L25	No. 2 tower series input coil	9 turns	Variable tap coil—type 4165-N5—22 μh
L26	No. 2 tower series output coil	4½ turns	Variable tap coil—type 4105-N5—12 μh
L27	No. 2 tower shunt coil	10 turns	Variable tap coil—type 4164-N5—16 μh
L29	No. 3 tower series input coil	1 turn	Variable tap coil—type 4143-N5—8 μh
L30	No. 3 tower series output coil	4 turns	Variable tap coil—type 4165-N5—22 μh
L31	No. 3 tower shunt coil	11 turns	Variable tap coil—type 4164-N5—16 μh
L33	No. 1 tower series output coil (ND)	10¾ turns	Variable tap coil—type 4165-N5—22 μh
L34	No. 4 tower series input coil	11¼ turns	Variable tap coil—type 3164-N5—16 μh
L35	No. 4 tower series output coil	5½ turns	Variable tap coil—type 3165-N5—22 μh
L36	No. 4 tower shunt coil	12 turns	Variable tap coil—type 3164-N5—16 μh
L24	No. 1 TC choke coil		RF choke
L28	No. 2 TC choke coil		RF choke
L32	No. 3 TC choke coil		RF choke
L37	No. 4 TC choke coil		RF choke
L38	No. 1 tower static drain		
L39	No. 2 tower static drain		
L40	No. 3 tower static drain		
L41	No. 4 tower static drain		
	Condensers	*Setting*	
C1	Shunt input capacity		Type 750FBA90—750 μμf
CA	Series input capacity		Type 1000 FBA90—1,000 μμf
C2	No. 1 tank tuning capacity	45	Type 750FVSP250—750 μμf
C3	No. 2 tank tuning capacity	85	Type 750FVSP250—750 μμf
C4	No. 1 line series phase capacity		Type 1500 FBA90—1,500 μμf
C5	No. 2 line shunt phase capacity		Type 1000 FBA90—1,000 μμf
C6	No. 3 line shunt phase capacity		Type 1000 FBA90—1,000 μμf
C7	No. 4 line shunt phase capacity		Type 1000 FBA90—1,000 μμf
C8	No. 1 tower series output capacity		Type 1000 FBA90—1,000 μμf
C9	No. 1 tower shunt capacity		Type 1250FD150—1,200 μμf
C11	No. 2 tower series output capacity		Type 1000 FBA90—1,000 μμf
C12	No. 2 tower shunt capacity		Type 1000 FBA90—1,000 μμf
C14	No. 3 tower shunt output capacity		Type 1000 FBA90—1,000 μμf
C16	No. 4 tower shunt capacity		Type 1000 FBA90—1,000 μμf
C17	No. 3 tower series output capacity		Type 1000 FBA90—1,000 μμf
C19	No. 4 tower series output capacity		Type 1000 FBA90—1,000 μμf
C20	No. 1 tower series output capacity (D)		Type 1000 FBA90—1,000 μμf
C10	No. 1 TC shunt capacity		Type CD 2-MFD
C13	No. 2 TC shunt capacity		Type CD 2-MFD
C15	No. 3 TC shunt capacity		Type CD 2-MFD
C17	No. 4 TC shunt capacity		Type CD 2-MFD
	Relays		
S1	Antenna array transfer relay		RF contactor
S4	No. 1 tower antenna ammeter switch		MBB switch
S5	No. 1 tower antenna transfer relay		RF contactor
S6	No. 2 tower antenna ammeter switch		MBB switch
S7	No. 2 tower antenna transfer relay		RF contactor
S8	No. 3 tower antenna ammeter switch		MBB switch
S9	No. 3 tower antenna transfer relay		RF contactor
S12	No. 4 tower antenna ammeter switch		MBB switch
S13	No. 4 tower antenna transfer relay		RF contactor

FIG. 4-2

METER INFORMATION

Current

Meter	*Range*	*Model*	*No.*	D	ND	*Unit*
M1	0 8	640	2845	4.58	—	Transmitter input to divider network
M2	0–15	640	2843	1.0	9.9	Transmission-line current—tower 1
M3	0–8	640	2835	3.9	—	Transmission-line current—tower 2
M4	0–8	640	2820	3.8	—	Transmission-line current—tower 3
M5	0–8	640	2830	2.5	- -	Transmission-line current tower 4
M6	0–15	640	2810	1.0	9.45	Transmission-line coupling unit—tower 1
M9	0–8	640	2815	2.6	—	Transmission-line coupling unit—tower 2
M12	0–8	640	2816	3.85	—	Transmission-line coupling unit—tower 3
M15	0–5	640	2819	2.5	—	Transmission-line coupling unit—tower 4
M8	0–15	640	2821	3.0	10.39	Antenna current—tower 1
M11	0–8	640	2822	5.4	—	Antenna current—tower 2
M14	0–8	640	2823	5.35	—	Antenna current—tower 3
M17	0–5	640	2924	3.11	—	Antenna current—tower 4
*M7	0–15	425	3130	3.0	10.39	Remote antenna current—tower 1
*M10	0–8	425	3131	5.4	—	Remote antenna current—tower 2
*M13	0–8	425	3133	5.35	—	Remote antenna current —tower 3
*M16	0–8	425	3134	3.11	—	Remote antenna current —tower 4
MP1	0–150%	743	3638	100%	100%	Phase monitor—tower 1
MP2	0–150%	743	3624	100%		Phase monitor—tower 2
MP3	0–150%	743	3636	100%		Phase monitor—tower 3
MP4	0–150%	743	3621	100%		Phase monitor—tower 4

Note: All meters Weston Electric Company.
* External heater type—see Fig. 4-5 for location in circuits.

Phase Monitor Readings for Directional Operation
Tower 1 Leads tower 2 by 230°
Tower 1 Leads tower 3 by 84°
Tower 1 Leads tower 4 by 302°

FIG. 4-3

Monitoring Points

The third subdivision (Fig. 4-4) should contain a listing of the monitoring points as designated by the Federal Communications Commission's license and should show the number of the monitoring points, a complete description for reaching these points, the bearing and distance, the specified unattenuated field value at 1 mile, the obtained unattenuated field value at 1 mile, together with the actual received field.

Diagrams and Measurements

The fourth and last subdivision (Fig. 4-5) should contain a schematic diagram and, if available, a wiring diagram of the complete antenna array equipment together with the series of curves from the Proof of Performance Report showing the dividing network or driving-point impedance of the array (Fig. 4-6) equipment and operating tower impedance (Fig. 4-7) if a single tower is used for nondirectional daytime operation. Additional pertinent information that would be of assistance to the maintenance engineer, such as transmission-line and capacitor gas pressures, should be included. While it may appear that some of this information will be a duplicate of the Proof of Performance Report, it is believed that by rearranging the data in this form and making them part of the maintenance routine, the constant reference to this information by the station engineering personnel will acquaint them with the equipment and its functions far better than a casual reference to the Proof of Performance Report.

MONITOR POINTS AND FIELD-STRENGTH INFORMATION

Point 4

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
12°	1.89	30	20	3.95

Insert location of measuring point as described in proof of performance

Point 14

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
40°	2.75	90	76	6.5

Insert location of measuring point as described in proof of performance

Point 25

Azimuth angle	Distance, miles	Mv/m mile Specified	Mv/m mile Obtained	Mv/m Measured
63°	1.33	70	25	8.55

Insert location of measuring point as described in proof of performance

Point 62

Azimuth angle	Distance, miles	Mv/m I mile Specified	Mv/m I mile Obtained	Mv/m Measured
181°	1.36	72	40	10.75

Insert location of measuring point as described in proof of performance

Point 82

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
219°	2.18	52	40	5.6

Insert location of measuring point as described in proof of performance

Point 104

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
302°	0.86	40	17	7.6

Insert location of measuring point as described in proof of performance

Point 118

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
337°	1.15	61	40	13.4

Insert location of measuring point as described in proof of performance

FIG. 4-4

Daily Work Schedules

The second section of the maintenance report book should contain a complete list and schedules of the daily work to be done and, where necessary, complete instruction covering the methods and equipment to be used. A suggested list is shown in Table 4-1. In the case of the example used, the antenna maintenance work is divided into two main classifications. The first classification is designed to cover the daily routine inspection and work that is to be handled by the "late trick" station engineer after sign-off. This work has been arranged in such a manner that all parts and circuits

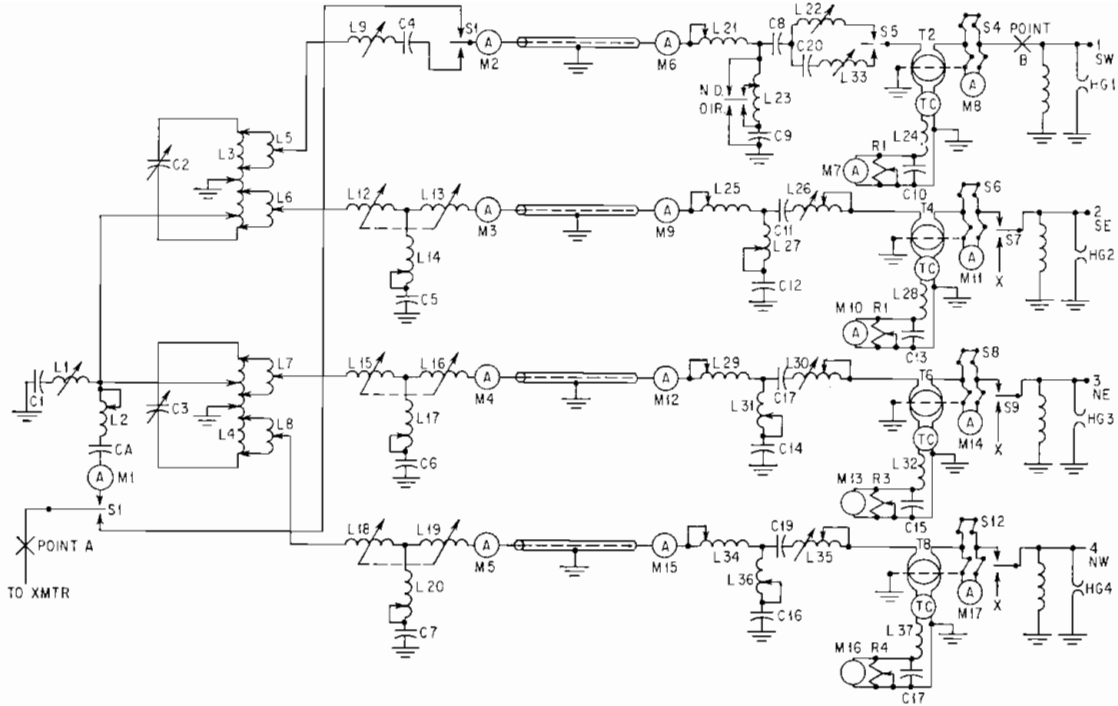

FIG. 4-5. Schematic diagram showing coupling and phasing networks.

will be cleaned and inspected at least once each week. The second classification already mentioned has been designed to cover a series of special maintenance routines for checking the array operation at regular specified intervals.

FREQ (KC)	R (OHMS)	X (OHMS)
1350	47	8.7
1355	58	4
1360	65	0
1365	68.5	-2.5
1370	68	-3
1375	62	-2
1380	51.5	0
1385	48	8.5
1390	54	25.4
1395	64	28
1400	80	23.2
1405	108	14
1410	153	0

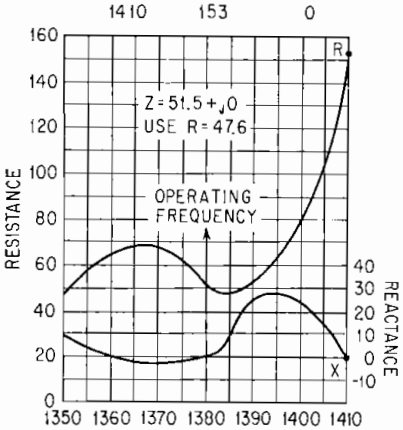

Fig. 4-6. Dividing network impedance.

FREQ (KC)	R (OHMS)	X (OHMS)
1350	41.5	36
1355	42	37.5
1360	43	39.2
1365	44	41.3
1370	45	43.5
1375	45.5	44.5
1380	46.5	46.4
1385	47.5	47.5
1390	48.25	47.8
1395	49	50
1400	50	51.1
1405	51	52.7
1410	52.1	54.1

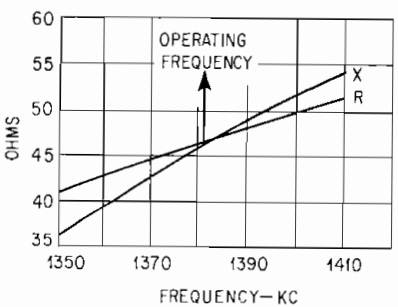

Fig. 4-7. Nondirectional tower 1 impedance.

Weekly Log

The third section of the maintenance report book contains the weekly station maintenance log. This portion of the routine is of extreme importance, as it will provide the station supervisor or chief engineer with a method for checking the work done as well as the data necessary to determine the operating conditions of the array and its equipment at all times. The log shown in Fig. 4-8 as set up for the example station is arranged to cover one week's complete maintenance information divided into daily sections.

Each daily section provides space for recording the temperature, weather, array meter readings, phase-monitor readings, transmission-line pressures, routine maintenance performed, routine tests results, other pertinent data, and the signature of the duty engineer.

The recorded data obtained from the daily and special maintenance tests after a period of six months can be plotted to show the actual operating conditions of the array. Variations from the normal conditions will undoubtedly appear in the graphs. By a careful analysis of the records, it will be possible to identify any variations due to seasonal or weather conditions. This accumulated information properly evaluated should provide the station engineer with a complete and thorough understanding of his directional-antenna-array operating and maintenance problems.

Month			Sun.		Mon.		Tues.		Wed.		Thur.		Fri.		Sat.		Remarks				Eng.			
Date																								
Weather																								
Temperature																								
M1-Dir.																								
M2-N on-Dir.																								
M7-Dir.																								
M7-Non-Dir.																								
M10																								
M13																								
M16																								
#1-#2 Phase																								
#1-#3 Phase																								
#1-#4 Phase																								
TX Line #1 Press.																								
TX Line #2 Press.																								
TX Line #3 Press.																								
TX Line #4 Press.																								
Phase Monitor																								
Prot. Circuits																								
EMC TX Lines																								
Main Phase Unit																								
Non-Dir. Imp.																								
Dir. Imp.																								
FS Mon. Pt. #4																								
FS Mon. Pt. #14																								
FS Mon. Pt. #25																								
FS Mon. Pt. #62																								
FS Mon. Pt. #82																								
FS Mon. Pt. #104																								
FS Mon. Pt. #118																								
Overall Dir. Test																								
#1 Coupling Unit																								
#2 Coupling Unit																								
#3 Coupling Unit																								
#4 Coupling Unit																								

FIG. 4-8. Weekly maintenance report.

It is, of course, realized that the suggestions and recommendations described above are not the total and complete answer to all directional antennas. However, it is believed that the need for establishing schedules similar to the suggested program is well demonstrated and can be fitted to the individual station requirements, and the results of this program will be of mutual benefit to both the engineering staff and management.

Usually, the station license requires that field-strength measurements be made periodically at each of the monitoring points. In the event that the license does not require such measurements, it is a good practice to make them at monthly intervals.* Such measurements should, of course, be made carefully, and an accurate record maintained, indicating the date and time of each measurement and the field strength observed at each monitoring point. If any unusual conditions are encountered, a record should be made of them. If a monitoring point becomes unusable, an informal application should be made to the FCC to change to a new monitoring point along that radial.

In dealing with tuning equipment for directional antennas, we must deal with the component parts which are commercially available, not the idealized components on which theoretical considerations are based. It will be found that as the components of the system age and undergo variations in temperature and vibration, their values will usually drift. Also, tower base impedances will frequently change, and the effective conductivity of the soil will vary with moisture content and temperature. In time, these changes may result in change of the operating parameters of the array to the extent that the field strengths at the monitoring points are no longer within the allowable values and it becomes necessary to readjust the array.

READJUSTMENT OF ARRAY

Any readjustment should be attempted only by personnel familiar with directional antenna theory. Unfortunately, in recent years qualified personnel seem to have left the field of standard broadcasting. This has happened for a number of reasons, primarily financial in nature. Since any adjustments of the tuning elements probably will alter the common-point impedance, it follows that the person making the adjustments must have an RF bridge and associated equipment and must be familiar with their operation.

In correcting for any drift in adjustment of the array, the initial goal should be to reestablish the operating conditions obtained in the original adjustment as indicated by phase-monitor, loop-current, and base-current readings. However, owing to what has been politely termed the perversity of the inanimate objects, it will on occasion be found that reestablishing the original current ratios and phase indications does not result in producing the desired field strengths at the monitoring points. Assuming that the monitoring system is in good working order, it then becomes necessary to readjust the array.

Readjustment Aids

In undertaking readjustment of the array, certain aids may be found useful in guiding the adjustments to be made. For a two-element directional-antenna system, it is helpful to have a copy of the theoretical pattern on which the directions of the minima are indicated, as well as the direction of each monitoring point. Figure 4-9 illustrates such a pattern. It is also helpful to indicate on this pattern the direction in which the minima will move for an increase in phase difference between the towers. It will be recognized, of course, that the depth of the minima will depend upon the current ratio. Theoretically the minima will become complete nulls if the fields radiated by the two towers are equal. This overlooks the effects of reradiation from nearby objects, but this concept does provide a point of departure for adjustment of the array.

* This is particularly important if the station contemplates applying to the FCC for remote control authorization.

A similar device may be found useful in readjusting an array with four towers arranged in the shape of a parallelogram. In this case, it is desirable to portray the basic patterns which go to make up the final pattern, preferably in contrasting colors. Figure 4-10 shows a pattern produced by such a four-tower array. In Fig. 4-11, one

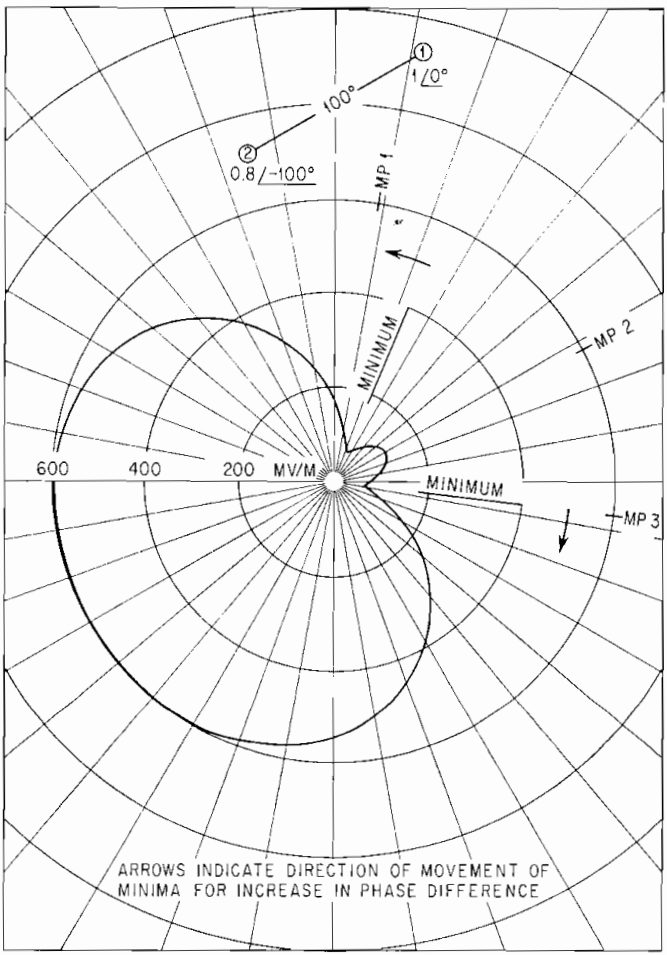

FIG. 4-9. Two-element directional-antenna pattern on which have been indicated directions of minima and directions of movement of minima for increase in phase difference.

of the basic patterns is shown as a solid line and the other as a dashed line. Here, too, arrows have been placed on the basic patterns to indicate the direction of movement of each minimum for an increase in phase difference between the sets of towers making up each basic pattern. The direction to each monitoring point is also given. Since the final pattern is the result of multiplying together the values of the basic patterns in any given direction, the effect of a change of parameters of a basic pattern on the final pattern can be readily visualized.

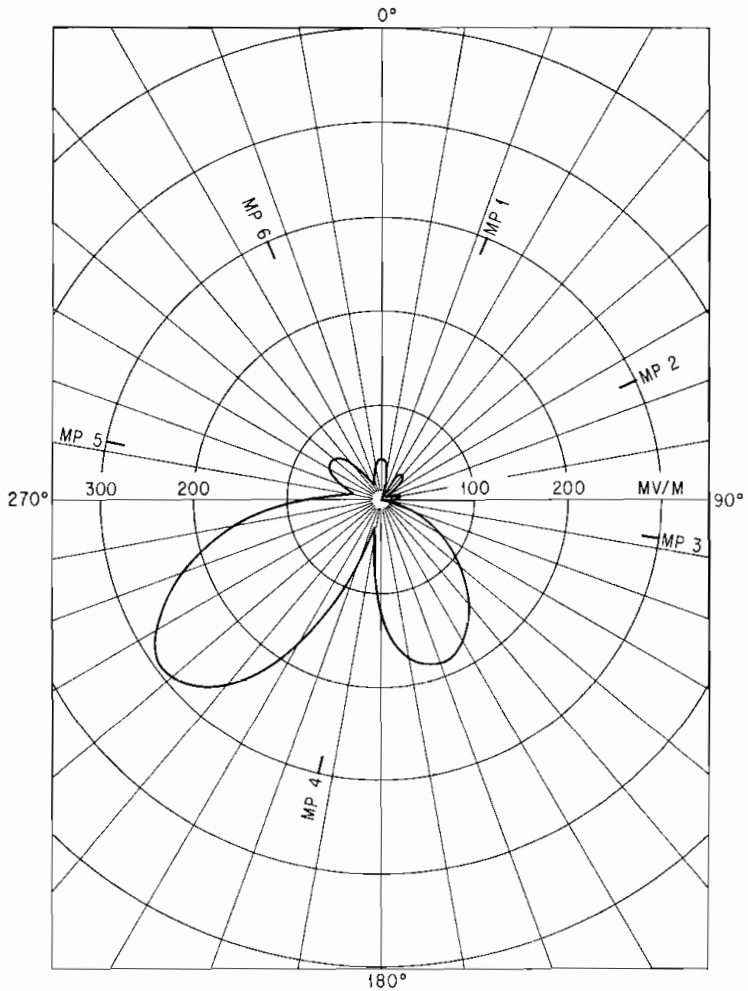

FIG. 4-10. Pattern produced by a directional antenna consisting of four elements arranged in a parallelogram.

Vector Calculator

Of possible use for a two-tower system is a calculator in the form of a circular slide rule, based on an article appearing in the December, 1944, issue of *Proceedings of the IRE*. Figure 4-12 illustrates such a calculator, which was quickly constructed from two sheets of graph paper and a piece of cardboard. In the operation of this calculator, the towers are numbered 1 and 2, and the phase of tower 2, read on the scale on the periphery of the rotary element, is set to the vertical zero degree line. The outer fixed scale on the base represents the bearing from the line of towers, measured from the tower 2 end. A separate outer scale is needed for each tower spacing. The group of figures on the runner represents field ratios. The resultant vector field is

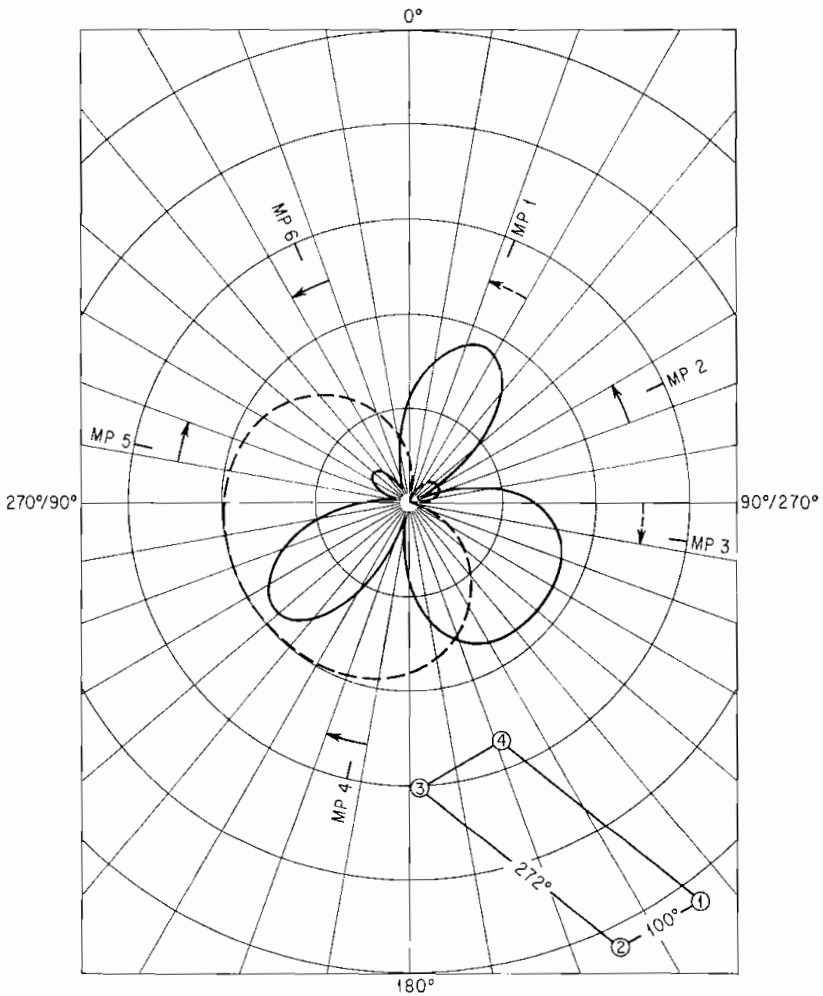

FIG. 4-11. Basic vector patterns which make up the pattern of Fig. 4-10. Arrows indicate the directions of movement of minima for increase in phase difference between pairs of elements.

read from the inner scale opposite the figure for the field ratio. It can be seen that the effect of a change in phase or field ratio on the field radiated in any given direction can be quickly determined.

A modified form of the calculator can be used with a three-element in-line array. The vector representation of the resultant field of such an array in a given direction is as shown in Fig. 4-13, where vector 2 represents the field from the center tower and vectors 1 and 3 represent the fields from the end towers. Considering the position of vector 2 as fixed, vectors 1 and 3 revolve in opposite directions as one's vantage point is moved around the array.

When redrawn, the vector relationship is as shown in the lower half of Fig. 4-13.

Here R is the resultant vector, drawn from the origin of vector 1 to the terminal point of vector 3. If we construct a mechanical device having scales depicting the position of vectors 1 and 3 for various bearings from the line of towers, we can then determine the effect of changes in operating parameters on the resultant field in any desired direction.

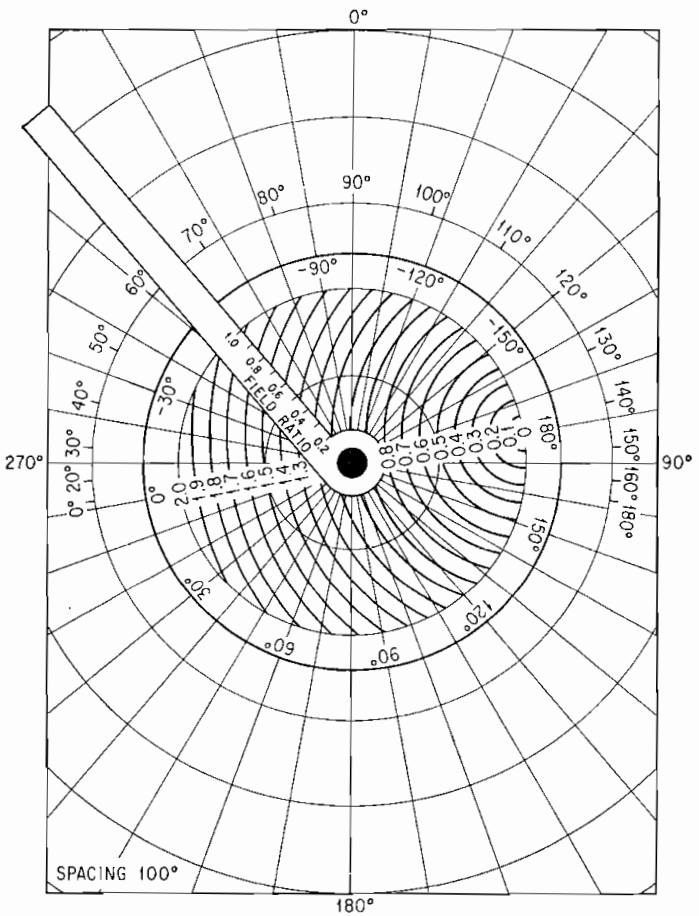

FIG. 4-12. Calculator for two-element directional antenna having spacing of 100° between elements.

Such a device is illustrated in Fig. 4-14. Here the distance between pivot points for the rotary elements has been scaled to represent the magnitude of vector 2. The radius of each of the rotary elements has been chosen to represent the magnitude of vectors 1 and 3. If desired, a scale could be marked on each of the rotary elements along the line from the center to the 0° mark on the periphery.

When this device is used, a pencil mark or a small tab of drafting tape is placed on the periphery of each rotary element at a point corresponding to the phase of the tower there represented.

To determine the relative field radiated in a given direction, the rotary elements

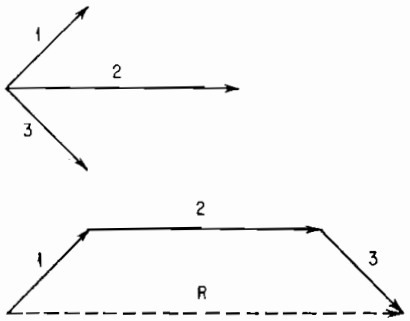

FIG. 4-13. Typical relationship of field vectors for three-element directional-antenna system.

are rotated so that the tab or mark lies at the desired bearing shown on each fixed scale. The distance between the 0° marks on the periphery of the rotary elements then corresponds to the resultant vector field. The effect of a change in phase of any of the towers or a change in field ratios can be readily visualized.

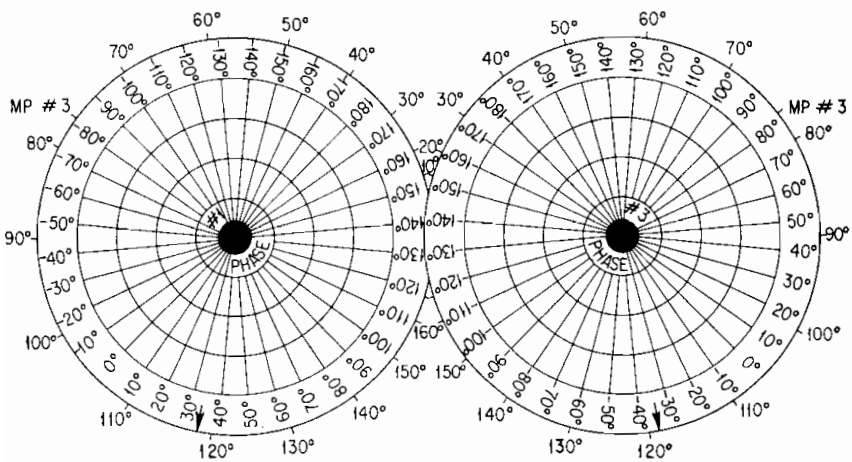

FIG. 4-14. Calculator for three-element in-line directional antenna.

Unfortunately, these relatively simple procedures cannot be so easily applied to arrays with more elements; however, if the basic patterns that go to make up the over-all pattern are known, these procedures can be applied to the basic patterns.

Table 4-1. Maintenance Schedules

Sunday

1. Transfer all towers and antenna phasing units to emergency transmission lines and operate at full power for 5 min.
2. Restore all equipment to regular transmission lines. Check operation under full power.
3. Clean and check all connections, remote meter, phase monitor, and meter panels.
4. Check all phase monitor tubes with tube checker. Check all transmission-line protective circuits.
5. Check and record all transmission-line gas pressures.

Table 4-1. Maintenance Schedules (*Continued*)

Monday

1. Check all condensers and other equipment in antenna phasing unit immediately after sign-off for overheating.
2. Clean and check all transmission-line end seals.
3. Clean interior of all sections of antenna phasing units.
4. Clean contacts and check alignment of antenna transfer relay.
5. Check and tighten all connections in antenna phasing unit.
6. Check gas-filled condensed pressures.

Tuesday

1. With array set for directional operation check drive-point impedance at *X* with radio-frequency bridge at operating frequency (first and third Tuesdays).
2. With array set for nondirectional operation check drive-point impedance at *X* with radio-frequency bridge at operating frequency (first and third Tuesdays).
3. Set up array for normal full-power directional operation. Compare readings of all antenna and remote antenna meters. Make any necessary adjustments.
4. Make complete set of field-strength readings at indicated monitor points (second and fourth Tuesdays).
5. Check and record all transmission-line gas pressures.

Wednesday

Antenna coupling unit 1:
1. Check all condensers and equipment in coupling house for overheating immediately after sign-off.
2. Check spacing and clean antenna and transmission-line horn gaps.
3. Check and clean all antenna lead-in insulators.
4. Check and clean all transmission-line end seals.
5. Clean contacts and check alignment of antenna relay.
6. Clean contacts and check alignment of antenna ammeter switch.
7. Check and tighten all connections of inductance coils and condensers.
8. Clean all meters.

Transmitter building:
Read and record all transmission-line gas pressures.

Thursday

Antenna coupling unit 2:
1. Check all condensers and equipment in coupling house for overheating immediately after sign-off.
2. Check spacing and clean antenna and transmission-line horn gaps.
3. Check and clean all antenna lead-in insulators.
4. Check and clean all transmission-line end seals.
5. Clean contacts and check alignment of antenna relay.
6. Clean contacts and check alignment of antenna ammeter switch.
7. Check and tighten all connections of inductance coils and condensers.
8. Clean all meters.

Transmitter building:
Read and record all transmission-line gas pressures.

Friday

Antenna coupling unit 3:
1. Check all condensers and equipment in coupling house for overheating immediately after sign-off.
2. Check spacing and clean antenna and transmission-line horn gaps.
3. Check and clean all antenna lead-in insulators.
4. Check and clean all transmission-line end seals.
5. Clean contacts and check alignment of antenna relay.
6. Clean contacts and check alignment of antenna ammeter switch.
7. Check and tighten all connections of inductance coils and condensers.
8. Clean all meters.

Transmitter building:
Read and record all transmission-line gas pressures.

Saturday

Antenna coupling unit 4:
1. Check all condensers and equipment in coupling house for overheating immediately after sign-off.
2. Check spacing and clean antenna and transmission-line horn gaps.
3. Check and clean all antenna lead-in insulators.
4. Check and clean all transmission-line end seals.
5. Clean contacts and check alignment of antenna relay.
6. Clean contacts and check alignment of antenna ammeter switch.
7. Check and tighten all connections of inductance coils and condensers.
8. Clean all meters.

Transmitter building:
Read and record all transmission-line gas pressures.

Part 5

TRANSMISSION LINES FOR BROADCAST USE

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Andrew Corporation

INTRODUCTION

Since the early days of broadcasting, transmission lines have been one of the vital elements of the broadcasting plant—the connecting link between transmitter and radiator. The choice of the proper line for adequate planning, construction, and maintenance procedures is an all-important ingredient of a satisfactory system. Transmission-line technology has changed radically along with the radical changes in broadcasting. Starting with open-wire lines in the early days of AM broadcasting, the art has progressed through a wide variety of coaxial-line types, both air and solid dielectric, rigid and flexible, and more recently into waveguides.

It is not the intent here to describe basic transmission-line theory or design methods. A wide variety of transmission lines are available to the broadcaster of today. His chief concern is the selection of the proper one for his application and an understanding of the proper methods of installation and maintenance. Factors to be considered in selecting a line for various broadcast services will be presented. A discussion of recommended installation procedures will allow the broadcaster to lay out and construct a system suited to his specific requirements.

A large number of different transmission lines have been used in the past, including lines of various characteristic impedances, sizes, and physical characteristics.

The coaxial lines and waveguides which will form the basis of this presentation and their flanges and connectors are those that have been standardized or are in the process of being standardized by the EIA (Electronic Industries Association). Most manufacturers of electronic products adhere to these existing and proposed standards so that interchangeability and interconnection between products of different companies can be accomplished. The measures proposed or adopted by the EIA allow for standardization of the transmission-line conductor diameters as well as line flanges and connectors. The standard lines described herein have a 50-ohm characteristic impedance. Other EIA standard lines, such as those having a 75-ohm impedance, are also used, but mostly for special applications. It is, of course, true that some special applications require transmission lines that are not covered by the standards; however, the selection and use of these lines are usually considerations of the equipment designer rather than the broadcaster. Such special lines will therefore not be included in this chapter.

DESCRIPTION AND APPLICATION

In general, a transmission line is selected on the basis of efficiency (degree of attenuation), power handling, and mechanical considerations. In AM, FM, and TV, power handling is one of the most important factors to be considered. After a transmission line has been selected which will satisfy the power-handling requirement, the attenuation rating of the line must then be examined. A long-transmission-line installation requires a lower per-unit attenuation. It is a question of economics, balancing line cost, installation cost, and maintenance, vs. the alternatives of antenna gain, tower height, and transmitter power. These economics usually favor a larger diameter transmission line (having less attenuation) and a better antenna rather than a larger transmitter.

Solid-dielectric Cable

The simplest and cheapest type of RF energy transfer is through the use of solid-dielectric cables such as RG-8/U and RG-17/U, as shown in Fig. 5-1. Solid-dielectric

FIG. 5-1. RG-8/U and RG-17/U solid-dielectric cables.

cables are comprised of a solid or stranded inner conductor, plastic insulating material, and a braided sheath which serves as the outer conductor. These highly flexible cables are used in many applications where the length is short or the frequency is low enough that attenuation is not an important factor. Since attenuation in this type of cable is high, it is not recommended for long runs. Because of its aging characteristics, it is not suited for permanent outdoor use.

In the broadcast field, its use is generally limited to sampling lines, jumper connections, and occasionally as the main feeder line. In FM and TV installations, it is rarely used except for the receiver systems. For microwave, it is used for interconnections between components and in jumper connections at the bottom and top of the air-dielectric run. Radio relay systems use solid-dielectric cables in the 450-Mc band when the transmission lines are quite short. Solid-dielectric cable is frequently used in translator service because of short-length requirements.

Semiflexible Air-dielectric Cable

Semiflexible cable consists of soft-temper copper inner and outer conductors. The inner conductor is concentrically spaced by means of Steatite insulators. Figure 5-2 shows 7/8-in.-diameter semiflexible cable. Bending of the cable assembly is generally limited to one or two bending cycles, and care must be taken, when bending, to avoid kinks.

Semiflexible cable is very popular for general-purpose VHF communications and AM broadcasting because it is economical, dependable, and easy to install. Semiflexible cable, of course, can be used for all the above applications. In addition, because of its lower loss, it can be used for more varied applications. It has a very high efficiency as compared with solid cables of similar size. For example, a 1-kw FM transmitter at 100 Mc will lose 425 watts in a 300-ft run of RG-17/U cable compared with only 250 watts loss in the same length of 7/8-in. semiflexible air-dielectric cable. This cable is widely used for directional AM broadcast arrays. It is a favored cable for moderate-power AM stations and probably the most commonly used for AM sampling lines. Semiflexible cable is occasionally used for FM feeders, TV translator service, and low-power TV.

Continuous Air-dielectric Cable

Continuous air-dielectric (flexible) cable is fast becoming the most popular cable for many installations, since it combines high efficiency with ease of handling and a very low VSWR. It can be used for all the applications listed for semiflexible cable. There are several types on the market today. Electrical and mechanical data can be obtained from the various manufacturers. A typical continuous air-dielectric cable is shown in Fig. 5-3. Cable of this type is comprised of a continuous inner and outer conductor. The inner insulation is also continuous throughout the entire length of the cable. Since the cable is produced by a continuous process, no joints are required even for very long lengths of several thousand feet. The continuous process thus eliminates electrical discontinuities, and a low VSWR is achieved.

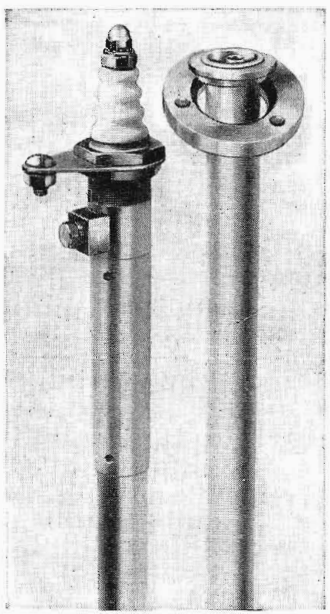

FIG. 5-2. 7/8-in. semiflexible cable.

FIG. 5-3. Continuous air dielectric cable.

Weatherproofing for most continuous cables is accomplished by a tough jacket covering the outer conductor. This enables the cable to be used in any environment such as salt air, direct ground burial, or under water.

Some continuous air-dielectric cables can withstand repeated bending, while others are limited to one or two bending cycles similar to the semiflexible cables mentioned previously. The manufacturer's flexing recommendations should be followed in all cases. Most continuous cables are shipped on reels and are uncoiled without difficulty. They can also be attached directly to a tower, thus eliminating the need for spring or sliding hangers.

Rigid Transmission Line

Rigid air-dielectric transmission line has very low attenuation and VSWR. It is manufactured from hard-temper copper tubing in standard 20-ft flanged lengths.

The rigid inner conductor is supported by Teflon pegs. In the past, ceramic discs were used for the inner-conductor support. The inner connector used with rigid lines has an insulator (also of Teflon) which anchors the inner conductor and supports it in vertical runs. Figure 5-4 shows 1⅝- and 9-in.-diameter rigid lines.

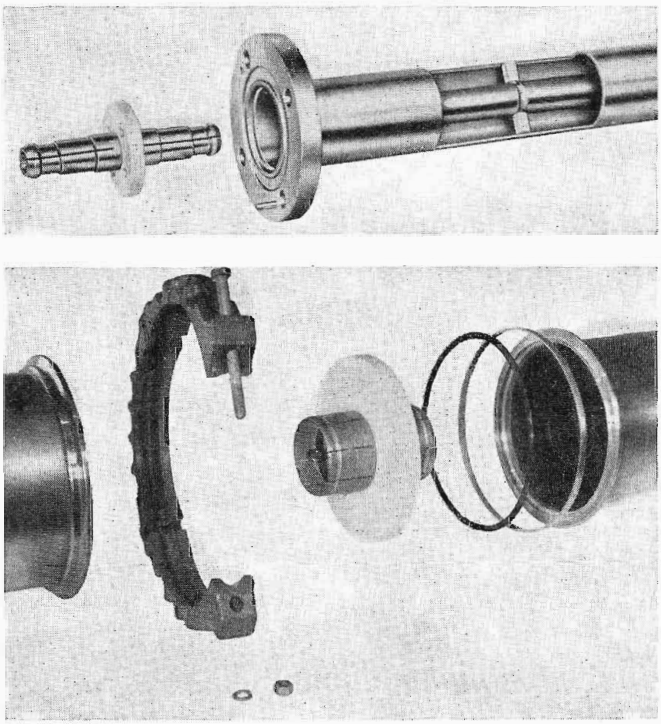

FIG. 5-4. 1⅝- and 9-in. rigid coaxial lines.

Rigid transmission line is used mainly for higher power levels. Its use in AM is generally limited to the main feeder lines on omnidirectional or directional AM arrays using 5 kw or more. In FM and VHF TV, rigid lines constitute 99 per cent of the feeders. In UHF TV, rigid line is used for the transmitter-room interconnections, for the final antenna connection, and usually as the main feeder along the tower. The ⅞- and 1⅝-in.-diameter rigid lines are ideal for inside runs in low- or medium-power communications or TV broadcasting installations. These rigid transmission lines are especially recommended for connections between transmitters, diplexers, receivers, dummy loads, switching systems, and other components.

For short transmission line runs in UHF-TV installations 3⅛-in.-diameter rigid line is particularly economical. It can be used for such applications when the transmitter power does not exceed the line rating (18 kw at Channel 14 and 13 kw at Channel 83). For high-power applications in VHF TV and low-channel UHF TV, 6⅛-in.-diameter transmission line is recommended. For the higher UHF TV frequencies up to 890 Mc (Channel 83) 75-ohm 6⅛-in. line is used. Nine-inch-diameter rigid transmission line has been designed for very high power systems and for low-channel UHF TV.

Waveguide

For the UHF TV broadcaster, the use of waveguide from the transmitter to the antenna provides a lower attenuation than any coaxial line. It is manufactured, using sheet-metal processes, from copper-clad steel or aluminum. Three common types,

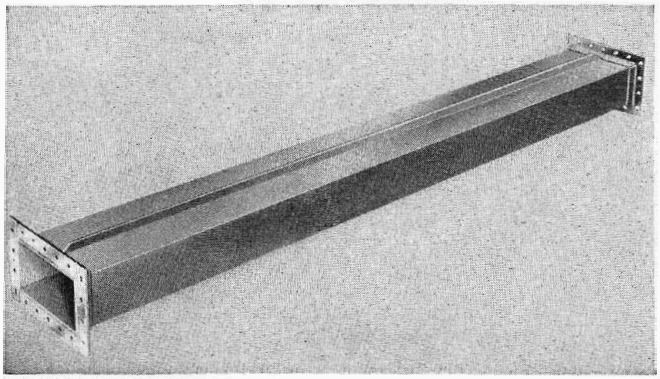

FIG. 5-5. WR-975 waveguide.

supplied in standard 10-ft flanged sections, are WR-1500, WR-1150, and WR-975 with inner dimensions of 15 by 7½, 11½ by 5¾, and 9¾ by 4⅞ in., respectively. A section of WR-975 waveguide is shown in Fig. 5-5.

The copper-clad steel waveguide has two advantages over aluminum waveguide. It has a lower attenuation, and its thermal coefficient is the same as that of the steel tower, eliminating the need for sliding and spring hangers for tower installations. Aluminum waveguide must be provided with a means to accommodate thermal expansion and contraction.

Waveguide is suited for medium and long runs in UHF TV high-power systems because of its power-handling ability, noise-free performance, and its high efficiency.

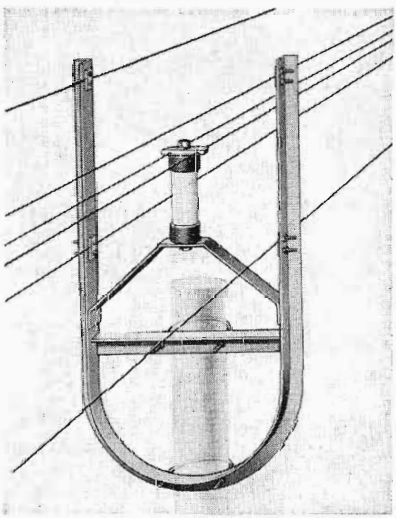

FIG. 5-6. Open-wire line.

Others

Another method of RF energy transfer is the open-wire line. This line is limited in use generally to AM broadcast and high-frequency antenna systems. It generally consists of six solid-copper wire lines acting as a coaxial line. The four outer wires are grounded, and the two center wires are "hot" and connected in parallel. Open-wire line has the advantage of high power ratings and very low loss but has the disadvantage of considerable line maintenance and interference-producing radiation. It is less costly than rigid line of the same power-handling ability; however, open-wire line has been largely supplanted by rigid

air-dielectric coaxial line because of technical considerations. Open-wire line is shown in Fig. 5-6.

ELECTRICAL CHARACTERISTICS OF TRANSMISSION LINES

Attenuation

Attenuation in a transmission line is loss created by imperfect conductivity of the conductors and the imperfect insulating medium or dielectric. In open-wire lines, an additional loss is incurred in the form of radiation. In coaxial lines and waveguides, this loss is not incurred, since the RF field is totally enclosed within the cable. Attenuation for RF cables is generally expressed in decibels per 100 ft. In rectangular or round waveguides with air as the dielectric, the entire loss is conductor loss. In coaxial cable, the losses are conductor losses and the dielectric losses associated with material used as the inner-conductor support. In solid-dielectric cables, the dielectric loss is appreciable and at high frequencies may exceed the conductor losses in spite of high-quality dielectric materials. In so-called "air-dielectric coaxial cables," the insulating supports are limited to a very small portion of the total dielectric space, so that the dielectric is principally air; therefore, the total dielectric losses are generally negligible. At very high frequencies, they may become large enough to become a significant portion of the total loss.

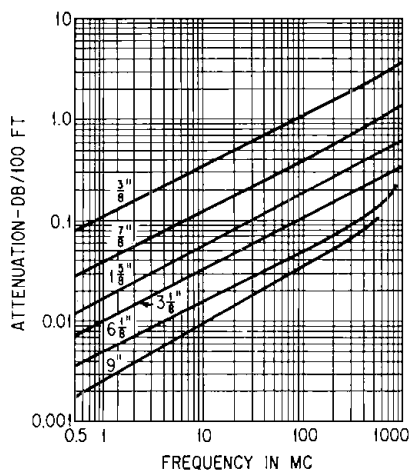

FIG. 5-7. Measured attenuation for several sizes of air-dielectric coaxial lines.

Because of skin effect, the RF current penetrates less of the conductor as frequency increases. Attenuation due to conductor losses thus increases with frequency and is proportional to the square root of frequency. Attenuation due to dielectric loss is directly proportional to frequency. Attenuation can be calculated; however, actual measured values do not always agree with theoretical values. It has therefore become common practice to use measured attenuation values rather than calculated ones. The actual attenuation is generally quite close to calculated values but may vary owing to surface condition, connector alloy, and its actual conductivity. Measured attenuation curves for several line sizes are shown in Fig. 5-7.

Actual attenuation experienced in operation may be further influenced by VSWR occurring on the line owing to an imperfect load. This is generally not a problem from the increased-loss standpoint, since a considerable VSWR is necessary to produce any significant loss increase. Loss is increased by VSWR by the factor $1 + (\text{VSWR})^2/2\text{VSWR}$. Figure 5-8 illustrates this effect.

Efficiency of a transmisison-line system can be easily calculated from the total attenuation.

$$\text{Efficiency} = \frac{1}{\text{antilog } (\alpha/10)} \text{ expressed as a decimal per cent}$$

where α is the total attenuation in decibels. Often line sizes larger than necessary from the power-handling standpoint alone are used in order to obtain better line efficiencies.

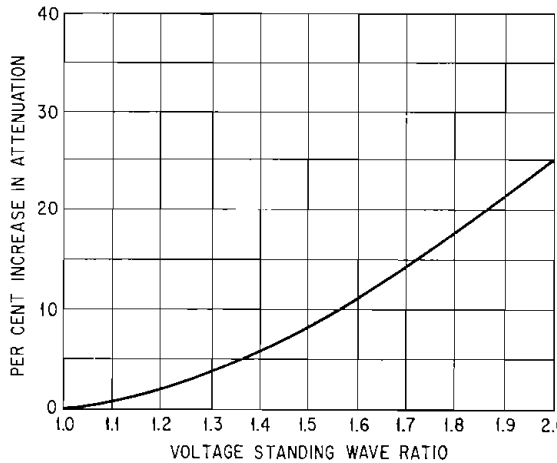

FIG. 5-8. Increase in attenuation in line due to VSWR on line.

Voltage Standing-wave Ratio (VSWR)

When a transmission line is terminated in an impedance different from the characteristic impedance of the line, a portion of the energy traveling down the line is reflected. The amount of reflection depends on the degere of mismatch. The incident and reflected traveling waves combine to produce an uneven voltage distribution along the line, and voltage and current maxima and minima occur. VSWR has been defined as the ratio of the maximum to minimum voltage; that is, VSWR = E_{max}/E_{min}. This effect is measurable with various types of instruments such as slotted lines, bridges, and reflectometers.

As stated previously, the electronics industry has standardized on 50 ohms for characteristic impedance of coaxial cables. There are other impedance cables available for special purposes, as mentioned; however, most antennas, loads, or other coaxial devices are almost exclusively designed for 50-ohm operation. Although the nominal value of terminating devices can be described as 50 ohms (or other impedance level), their actual impedance characteristic may be different when a band of frequencies is considered; thus, an antenna or other load can be described as 50-ohm impedance with a VSWR indicated over a particular band. This means that the impedance of the device is approximately 50 ohms and, over the band considered, would create a VSWR on a 50-ohm transmission line no greater than that indicated.

The effects of VSWR may or may not be a problem, depending on the type of service, power levels involved, etc. As VSWR increases, the maximum voltage points increase, and breakdown problems might occur if the power level and VSWR were high enough and the cable choice was small. Irregular heating along the cable due to current maxima may cause problems also, especially in solid-dielectric cables, where the plastic dielectric material may soften. These possibilities would require large VSWR values to cause problems. Other effects of VSWR, where the cable is not impaired but the service may be, are ghosts in a TV picture, intermodulation in multiplex FM, an undesirable impedance at the transmitter end of the line, etc. As already described in the preceding section on attenuation, VSWR also causes some increase in the actual attenuation of a transmission line.

In many services, a moderate VSWR is of no consequence as long as the line ratings are not exceeded. In AM broadcast applications, VSWR may be as much as 3 or more with perfectly satisfactory operation. In FM broadcasting, system VSWR

is generally less than 1.75. In TV, an industry standard of system VSWR of less than 1.1 has been rather arbitrarily arrived at as desirable, but many stations are operating very satisfactorily with greater values.[1] In general, discontinuities contributing to VSWR that are located close to the transmitter will have little or no effect on picture quality. The transmission line itself, the line fittings, or both may produce some VSWR. This is usually very small and is of little consequence for most services. For TV or certain microwave applications, it is sometimes large enough to influence performance.

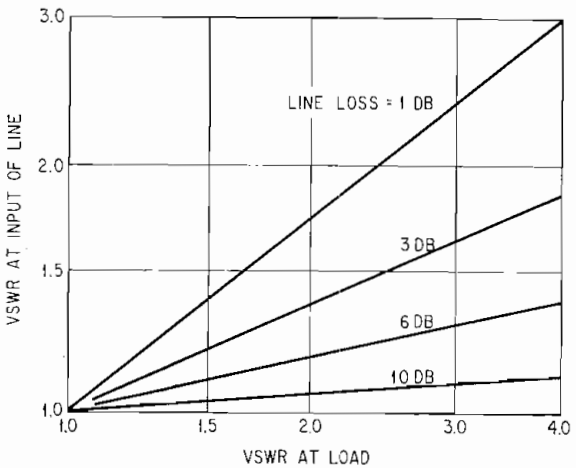

FIG. 5-9. VSWR improvement due to line attenuation.

In cases where the line has considerable attenuation, VSWR at the input end is lower than that of the antenna or load itself. The curves in Fig. 5-9 illustrate the extent of this effect.

Power Ratings

There are two basic types of power ratings for transmission lines. One is based on the maximum heating the cable construction might safely withstand. It is generally referred to as the "average power rating." The other is based on voltage-breakdown considerations and is generally described as the "peak-power rating." Consideration of both ratings is necessary for most services.

Average power is the power in the signal capable of creating heat. Peak power is that maximum rms power which can be reached in any interval (such as during a modulation cycle) and should not be misinterpreted as any relation between peak and rms voltages such as $\sqrt{2}$ in sine waves. In a continuous CW carrier (including FM), peak power equals average power. In 100 per cent AM, the power rises to four times the carrier power, so in this case, the peak power is four times the carrier power. Since average-power rating is limited by heating which is created by line losses, this rating decreases with increasing frequency. Peak-power rating is dependent on voltage considerations which are not significantly frequency sensitive; thus this rating is constant with frequency. Transmission-line ratings can be arrived at by various experimental and calculated procedures. The over-all picture is complicated by the effects of environment, such as ambient temperature, cable pressure, and others. Whatever basis for rating is used, it must be stated with the rating or

[1] Not recommended for other reasons than power losses, etc.

it is meaningless. Once a rating is determined for the conditions stipulated, the rating can be adjusted for other conditions. As was mentioned, ratings can be arrived at by various means. The following procedure is one way which has been used for many years and has been found to be very satisfactory. Curves illustrating these ratings for several popular line sizes are shown in Fig. 5-10.

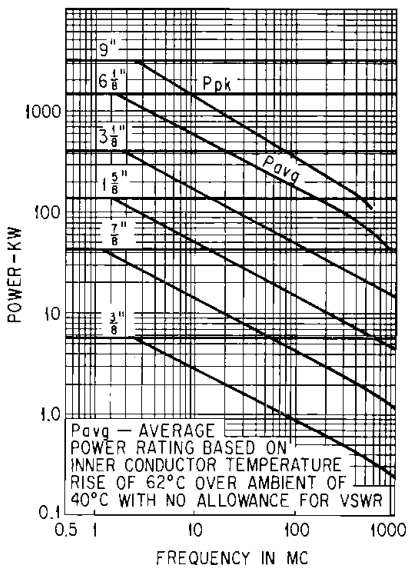

FIG. 5-10. Curves illustrating peak-power and average-power ratings. (P_{pk}—peak-power rating based on dry air at 1 atmosphere absolute pressure at sea level with no allowance for modulation or VSWR.)

Rigid Air-dielectric Coaxial Line

Peak-power Rating. The procedure here is to establish a peak voltage the line will withstand every time if it is manufactured properly. The maximum voltage gradient occurs at the inner-conductor surface in a coaxial line.

A theoretical breakdown gradient cannot be used, since breakdown is a highly variable phenomenon occurring at widely different values depending on small effects such as scratches, dust particles, and insulator condition. Derating theoretical breakdown to 35 per cent of theoretical has been found to be a practical value for a d-c test voltage (or 60-cycle peak test voltage). The equation below is derived from the maximum voltage gradient in a coaxial line and includes factors considering pressure, temperature, and inner conductor curvature. It also includes the derating of 35 per cent described above and results in a very reliable production test voltage. This test voltage is then further derated and used for power rating purposes.

$$E_p = 3.17(10)^4 a\delta \left(\log_{10}\frac{b}{a}\right)\left(1 + \frac{0.273}{\sqrt{a\delta}}\right)$$

where E_p = production test voltage, volts
a = inner-conductor OD, in.
b = outer-conductor ID, in.
δ = air-density factor = $3.92B/T$
where B = absolute pressure, cm of mercury
T = temperature, °K

($\delta = 1$ for $B = 76$ cm and $T = 23°C = 296°K$)

The values are generally rounded off as follows for the common 50-ohm line sizes:

Nominal Cable OD, In.	*Production Test Voltage, DC Volts or 60-cycle Peak Volts*
3/8	2,200
7/8	6,000
1 5/8	11,000
3 1/8	19,000
6 1/8	35,000
9	50,000

The next step is to derate this production test voltage to a realistic RF rms operating voltage. The voltage is derated to 0.7 of its above value to go to RF conditions, by $1/\sqrt{2}$ to go to rms value, and by a suitable safety factor which is usually 2.

$$E_{rf} = \frac{0.7E_p}{\sqrt{2}\,(\mathrm{SF})} = 0.247E_p \qquad \text{volts}$$

where E_{rf} = maximum RF rms operating voltage with no allowance for VSWR or modulation, but including safety factor
SF = safety factor on voltage of 2

This voltage, E_{rf}, determines peak power rating.

$$P_{pk} = \frac{(E_{rf})^2}{z_0} \qquad \text{watts}$$

This rating must be derated further for VSWR and amplitude modulation, although these vary with the application and are not a part of the basic rating. This would be done as follows:

$$P_{\max} = \frac{P_{pk}}{(1 + M)^2\mathrm{VSWR}} \qquad \text{watts}$$

where M is the modulation index and 1 is for 100 per cent. This would derate P_{pk} by 4 for 100 per cent AM due to modulation (as mentioned earlier) to obtain the rating in terms of carrier power or transmitter nameplate rating. Notice that peak-power rating must be reduced directly by VSWR.

A very significant point should be noticed in the equation for E_p, in that the breakdown voltage, in the range of pressures normally used, is approximately proportional to absolute pressure; thus, the peak-power rating is proportional to the absolute pressure squared, and doubling the absolute pressure in any line will multiply the peak-power rating by 4. This is often a valuable tool in achieving high-peak-power operation. Certain high-dielectric-strength gasses other than air, such as sulfur hexafluoride, have also been used to increase peak-power rating. This gas, as compared with air at equivalent pressures, will effect approximately a 2-to-1 voltage- or 4-to-1 peak-power-rating improvement. Combining the effects of using special gaseous dielectrics and pressurizing to several atmospheres pressure are also possible, compounding the improvement.

Average-power Rating (Air-dielectric Coaxial Line). Average-power rating is limited by heating due to line losses. Owing to the character of coaxial-line construction, the loss and temperature rise of the inner conductor are greater than those of the outer conductor. The ultimate temperature that the inner conductor might be safely allowed to reach determines the rating. This temperature is determined by such considerations as inner-conductor expansion and oxidation, dielectric mechanical strength at elevated temperature, etc. The most common standard method in use for many years limits the outer-conductor temperature to 23°C rise over 40°C ambient. The corresponding inner-conductor rise is 62°C rise; therefore, the ultimate inner-conductor temperature for normal conditions is limited to 102°C (216°F). Temperature rise of outer- vs. inner-conductor rise for a 50-ohm air-dielectric coaxial line is illustrated in Fig. 5-11.

The average-power rating can be calculated from the following:

$$P_{\mathrm{avg}} = \frac{16{,}380\sigma D}{db_1} \qquad \text{watts}$$

where P_{avg} = average-power rating for 23°C temperature rise of the outer conductor (62°C rise of inner), watts
D = outside diameter of line, in.
db_1 = 1.085α where α is measured attenuation, db/100 ft (1.085 is increase in α at elevated temperature)
σ = heat-emissivity coefficient of outer conductor, watts/sq in.

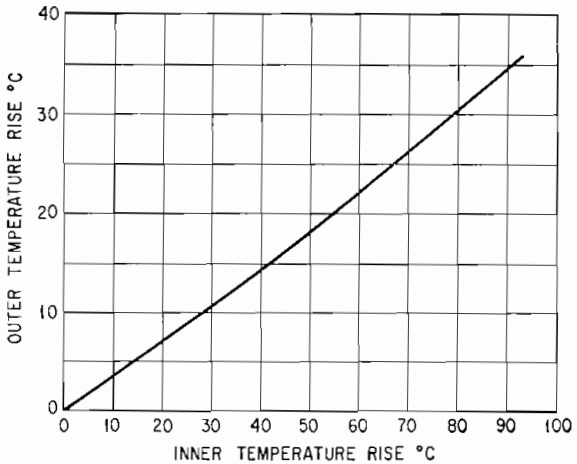

FIG. 5-11. Inner- and outer-conductor temperature rise for a coaxial line with $Z_0 = 50$ ohms.

The values of σ for common line sizes are as follows:

Line OD, In.	σ, *W/Sq In.*
⅜	0.166
⅞	0.134
1⅝	0.120
3⅛	0.111
6⅛	0.10
9	0.095

The resulting average-power rating must be further derated directly with VSWR; however, this is variable, depending on type of service, and is not a part of the basic rating.

The heat emissivity of a conductor varies with surface conditions, and it depends on whether the surface is shiny, oxidized, painted, etc. The values shown above are for copper outer conductors between slightly and normally oxidized. A curve illustrating how σ varies with temperature rise and tube size is illustrated in Fig. 5-12. The values of σ as given are taken from this set of curves.

The curves of Figs. 5-11 and 5-12 are shown to illustrate how an average-power rating can be rerated for other conditions. A study of these two figures will show that it is possible to adjust a rating for different ambient temperatures and predict temperature rises for powers other than the full-power rating. A curve indicating rating change for other ambient temperatures, as generated from these curves, is illustrated in Fig. 5-13. These curves are valuable for quickly predicting performance at conditions other than those specified for the standard ratings.

The heat exchange above is assumed to be in still air with no direct solar radiation. Moving air will improve the situation, while sunshine will increase heating.

Semiflexible Coaxial Lines

These are essentially air-dielectric lines, and power rating is handled the same as in the previous section. The difference in rating procedure occurs only in the average-power rating, which is limited by an ultimate inner-conductor temperature dependent on the temperature characteristics of the dielectric material used. Peak-power rating would be influenced by pressure and VSWR as described in the previous section on rigid air-dielectric coaxial line.

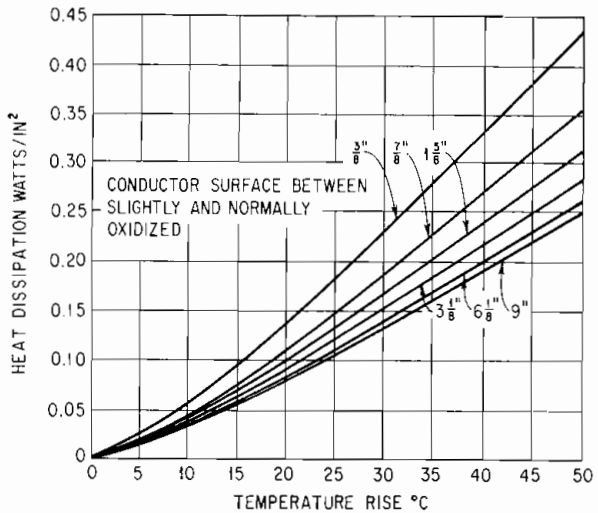

FIG. 5-12. Heat dissipation by radiation and convection vs. temperature rise for various outer-conductor diameters.

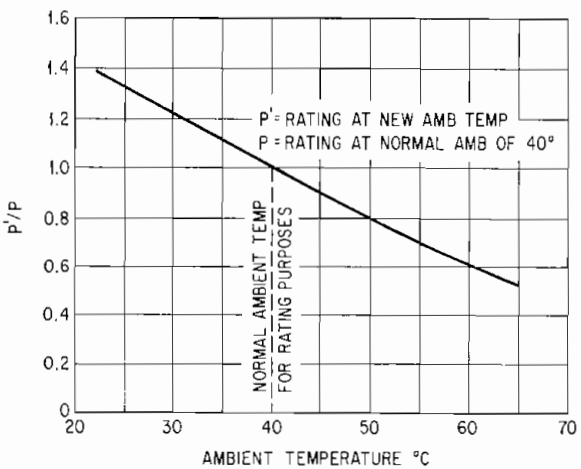

FIG. 5-13. Average-power-rating variation in transmission line for variation in ambient temperatures.

Solid-dielectric Coaxial Lines

Power ratings for solid-dielectric coaxial lines are controlled to some extent by agencies such as ASESA and EIA. Manufacturers' ratings are sometimes different, but the differences are generally small. The rating limitations are based on considerations similar to those described in detail above; however, the average-power rating for polyethylene-insulated cables is limited by an ultimate inner-conductor temperature of 80°C. Most ratings for these cables, such as those given by EIA in Standard RS-199, are for this 80°C maximum inner-conductor temperature at an ambient of 40°C. RS-199 gives conservative power-rating curves and attenuation

curves for many of the popular solid-dielectric cables. RS-199 also gives a table for rerating average-power rating of these cables for other ambient temperatures. It is partially tabulated below.

Ambient Temp, °C	*Rerating Factor*
40	1.00
50	0.72
60	0.46
70	0.20
80	0

Rectangular Waveguides

Waveguides have power ratings considerably in excess of the transmitter powers presently available to broadcasters; thus, power rating is not a factor in the selection of a waveguide.

Power Ratings for Various Services

Power ratings are often published already derated for various types of service depending on expected VSWR, modulation, and peculiarities in transmitter ratings (such as in TV).

In derating for VSWR, it is common to consider system VSWR as follows: broadcast and HF: AM, 3.0; FM, 1.75; TV, 1.1.

In derating for AM services, the peak-power rating is often derated by 4.5 to allow for modulation with some overmodulation, resulting in a rating for AM in terms of carrier power or transmitter nameplate rating.

For TV, black level video power plus aural power is actually 10 per cent greater than the transmitter nameplate rating (for cases where aural power is 50 per cent of peak video synchronizing power); thus, TV ratings are often given already derated by 1.1 for this reason and an additional 1.1 for system VSWR.

Some of these deratings may seem of minor effect but are given to provide consistent ratings for the initial conditions of temperature rise or voltage governing the ratings. The VSWR deratings given above are assumed as typical maxima, and for a particular circumstance where the actual VSWR is known, it would be better to derate accordingly.

INSTALLATION

Mechanical considerations of a radio or TV station involve not only the installation of the transmission line but also line maintenance. Broadcast installations are usually planned for long-term operation. A very carefully planned and executed original installation will assure long and trouble-free operation. Since air time is expensive, it is worthwhile to go to considerable effort to insure continuous uninterrupted operation.

The transmission-line system (in the case of FM and TV) consists of a vertical run which connects to the antenna and a horizontal run which connects to the transmitter or diplexer. A variety of hangers is required for supporting and anchoring the line. Connections between various units of transmitter equipment inside the building are made by unpressurized line, which may incorporate a switching system for switching between units.

Expansion and contraction, due to changes in temperature of the line, are accommodated by use of spring hangers on the tower and swinging hangers for the horizontal run. The line is anchored at the antenna by a rigid hanger and at the transmitter building by a wall anchor, so that movement of the line is away from the equipment. Over a temperature range of -25 to $+125$°F, expansion of the line is about 1½ in. per 100 ft. This amount of movement must be allowed for in the horizontal run. The steel tower expands or contracts with temperature change at a different rate from that of copper, and copper conductors of a transmission line will

change length relative to the tower, approximately ½ in. per 100 ft over the above temperature range. The spring and swinging hangers support the weight of the line but permit free axial movement during changes in temperature. This expansion or contraction of the system accumulates at the base of the tower; therefore, 15 or 20 ft of line on each side of the elbow at the base of the tower must be free to flex and accommodate the change in length. A lateral brace, which is used at the base of the tower, prevents lateral line motion which would be caused by wind forces but does not interfere with movement caused by change in line length.

The importance of the effects of expansion and contraction cannot be overemphasized. The thermal force occurring in rigid transmission lines during a temperature change is sufficient (when causing contraction) to tear hangers from the structure and pull the line from the transmitter building bulkhead fitting. When the line expands, severe buckling can occur and cause tower strain which could eventually end in failure of the transmission line or tower.

Rigid-transmission-line Installation

1. Since rigid-line installations are the most common in use today, the following pages present a step-by-step approach to the installation of a 3⅛-in. rigid-transmission-line system beginning with the Bill of Materials table which gives the approximate items and quantities required for a single-line television installation on a 300-ft tower.

Bill of Materials

Item	*Quantity*	*Use*
1. 90° mitered elbow, flanged	3	For changing line direction
2. Special lengths of line, unflanged	7	For custom applications
3. Soft soldered flange kit	7	For field flanging lines and elbows
4. Rigid hanger	1	For anchoring top of line to tower
5. Mounting adapter	28	For use if tower members do not have holes
6. Combination spring and sliding hanger	27	For hanging transmission line
7. 20-ft section of line	17	For main run
8. 15-ft section of line	2	For main run
9. Lateral brace	1	For prevention of lateral line movement
10. Horizontal hanger	4	For free-swing support of horizontal line
11. Horizontal anchor	1	For anchoring line at building wall
12. Gas barrier	1	For pressure termination of line
13. Automatic dehydrator	1	For automatically pressurizing line
14. Straight coupling	7	For joining unflanged line
15. 90° elbow, flanged one end	3	For changing line direction
16. 90° elbow, unflanged	2	For changing line direction

The antenna input may be a solid-dielectric connection, a flanged connection for a pressurized antenna, or a flanged connection for an unpressurized antenna. To mate the transmission line with the solid-dielectric connection, an adapter for connecting between air- and solid-dielectric cables must be used (see Fig. 5-14). The adapter also functions as a gas barrier. For a flange connection, where the diameter of the antenna input flange is smaller than the diameter of the transmission-line flange, a reducer is used. A reducer is shown in Fig. 5-15.

When the antenna harness is of air dielectric, gas from the transmission line should be permitted to enter the antenna. A gas-inlet fitting (Fig. 5-16) should be inserted at the point of connection for possible use in purging the line. The fitting can be omitted if the antenna harness has a gas port.

If, for any reason, an antenna with an air-dielectric harness is not to be pressurized, a gas barrier, as shown in Fig. 5-17, must be provided at the point of connection. In this case, the unpressurized line above the gas barrier may collect moisture,

so drain holes should be drilled immediately above the gas-barrier insulator. Various antenna connections are shown in Fig. 5-18.

2. Transmission-line assembly normally starts at the antenna and proceeds to the transmitter. Since the connection at the top of the tower depends on the type of tower, type of antenna, and the position of the antenna, a custom connection must be made at the antenna with two mitered elbows and two special lengths of line. Mitered elbows, like the one shown in Fig. 5-19, are used much more than the older sweep-type 90° bends, which are now obsolete, since they are more versatile mechanically and are of higher quality electrically. The special lengths are field-cut to the exact dimension required and are flanged with soft-soldered flange kits (see

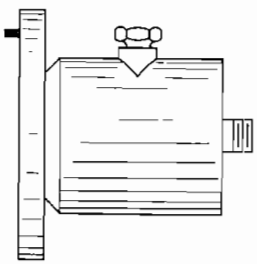

FIG. 5-14. Adapter.

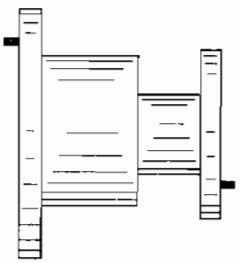

FIG. 5-15. Reducer.

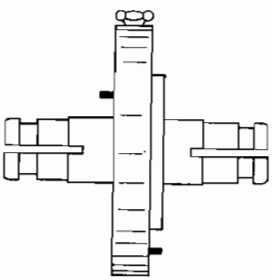

FIG. 5-16. Gas inlet.

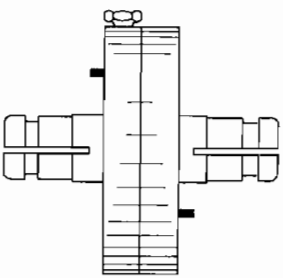

FIG. 5-17. Gas barrier.

Fig. 5-20). A rigid hanger (Fig. 5-21) must be used at the top of the transmission-line run so that thermal expansion and contraction of the line do not affect the antenna. A typical installation at the top of the tower is shown in Fig. 5-22. For new installations using towers having angle-type members, the tower manufacturer, in most cases, will punch the members with holes for mounting the hangers. For towers that are already erected and for new towers with round members, mounting adapters that attach the hangers to the towers without drilling must be used. Tower members should not be drilled without consent of the manufacturer because of possible weakening of the structure.

3. The second phase of the installation is along the tower where the spring hangers and sliding hangers are used. The sliding hangers are merely guides placed at 10-ft intervals along the vertical run to keep the transmission line from any lateral motion. The spring hangers are used to support the weight of the line and to accommodate differential expansion between line and tower. Sliding and spring hangers are made by some manufacturers as a combination hanger, as shown in Fig. 5-23. As the assembly proceeds, make certain to use a combination spring and sliding hanger at 10-ft intervals, placing a hanger 5 ft from each end of the standard 20-ft section (see Fig. 5-24). The most convenient location to hang the transmission line is near the tower ladder, where it is easily accessible for periodic inspection.

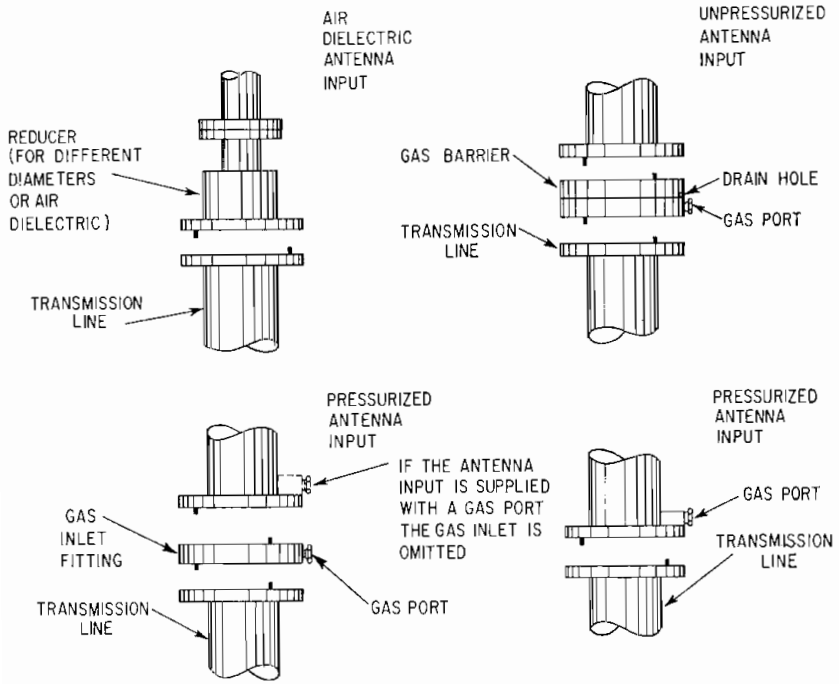

Fig. 5-18. Various antenna connections.

Alternatively, the line can be attached to a tower leg inside the tower. Do not support more than one section of line on a flange joint without using hangers. It is much safer to leave the hoist line tied to the line section until after the hangers are attached. Tapered towers involve changes in the line direction that are different from the 45 and 90° permitted by the standard elbows. In such cases, it is possible to bend a section of transmission line to make a change of up to 5° for 3⅛-in. line or smaller and up to 1° for 6⅛-in. line. For greater changes, special angle elbows must

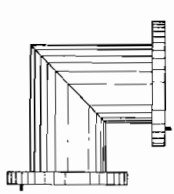

Fig. 5-19. 90° mitered elbow.

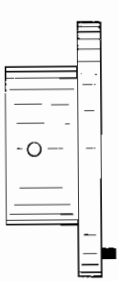

Fig. 5-20. Soft-soldered field flange.

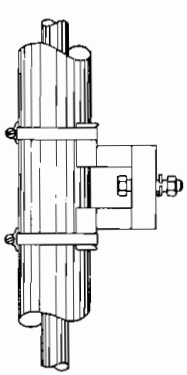

Fig. 5-21. Rigid hanger.

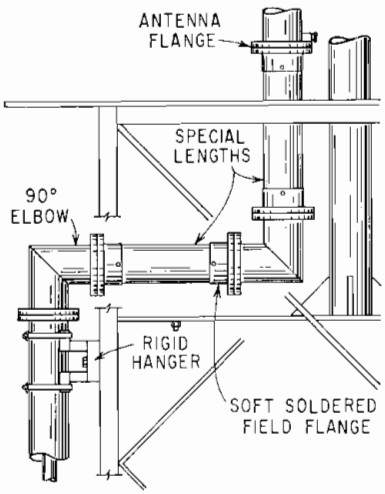

FIG. 5-22. Installation at top of tower.

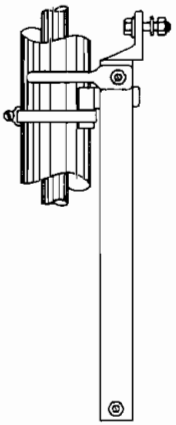

FIG. 5-23. Combination spring and sliding hanger.

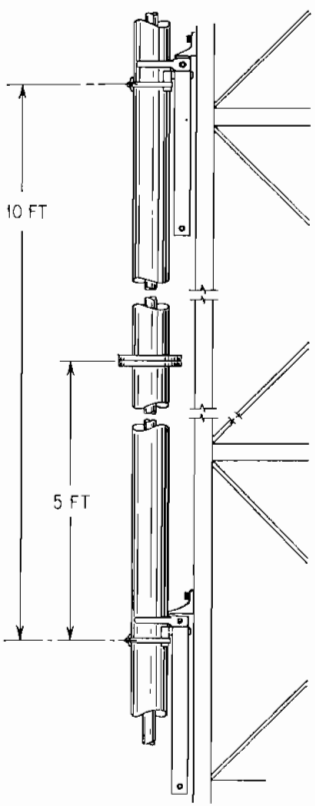

FIG. 5-24. Installation on tower.

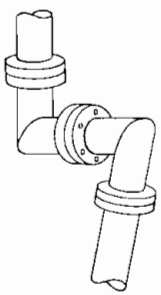

FIG. 5-25. Two 90° elbows in tandem.

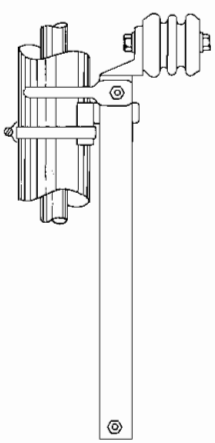

FIG. 5-26. Insulated spring and sliding hanger.

be obtained or two 90° mitered elbows can be connected in tandem, as shown in Fig. 5-25, to produce the desired angle.

If the supporting tower is also used as an AM broadcast radiator, some method must be used to prevent the AM energy from being grounded by the transmission line that feeds the TV or FM antenna. A popular method is to isolate the line up the tower for a distance of a quarter wavelength (at the AM broadcast frequency) from the base, using insulated line hangers. A typical insulated spring hanger is illustrated in Fig. 5-26. Extension spacers must be used with the noninsulated

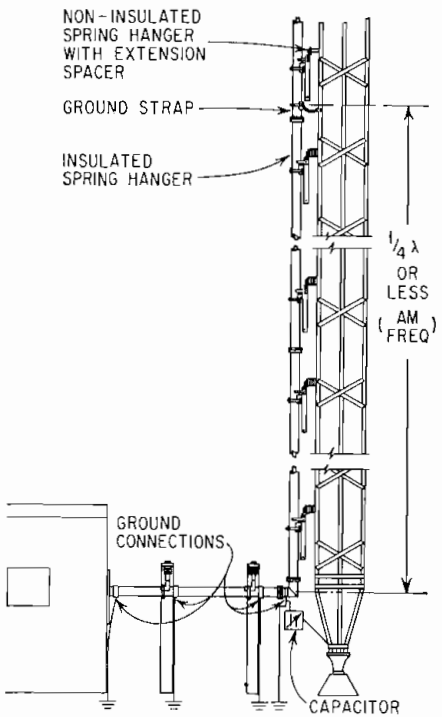

FIG. 5-27. Installation on AM tower.

hangers above the quarter-wave point to space them the same distance from the tower as the insulated spring hangers. This must be done to keep the transmission line in vertical alignment. Because of the quarter-wave isolation at the base of the tower, a very high impedance between the tower and the line is presented to the AM energy. Common practice is to make the isolated section approximately 0.22 wavelength long and to use a variable capacitor at the base of the tower to tune to quarter-wave resonance. Figure 5-27 shows an installation on an AM tower. *Caution:* Since a high RF potential exists between the line and the tower, the line should be mounted where it will not be accidentally touched by anyone on the tower ladder.

4. The third phase of the installation is at the base of the tower. The 15-ft sections of line (Item 12 in the Bill of Materials) are installed here, one length vertically and one starting the horizontal run. These lengths are not supported by hangers but are left free to flex and accommodate the changes in length caused by line expansion and contraction (see Fig. 5-28). If the bend from the vertical run to the horizontal run is 90°, a standard 90° mitered elbow is used; however, if the bend is

of some other angle as in the case of a tapered tower, two 90° elbows can be used in tandem to produce any angle form 0 to 180°. The bottom of the line (near the elbow) is supported with a lateral brace, as shown in Fig. 5-29. The brace prevents lateral motion of the line but permits line expansion and contraction.

The horizontal run, like the vertical run, is also affected by thermal forces, so provisions must be made to provide horizontal support while permitting the line to change length. To accomplish this, the line is supported by horizontal swinging hangers which bolt to support post arms. A horizontal swinging hanger is shown in Fig. 5-30. Some installations use maple rollers for the support, allowing complete freedom for the transmission line. As on vertical runs, the hangers should be placed at 10-ft intervals.

Horizontal runs in icing country should have ice shields iustalled above them. Effective ice shields are made from ¼-in. steel plate installed like a tent over the full length of the horizontal run. The angle generally used is 45° for each of the sides. A 3- by 3-in. steel angle is placed at the top, and a 2- by 2-in. angle is attached to the bottom of each side, making a rigid installation (see Fig. 5-31). In places where icing conditions are severe, this scheme is frequently reinforced by additional angles along the top of the plates. In mountain country, it is not uncommon to have huge chunks of ice break off the tower.

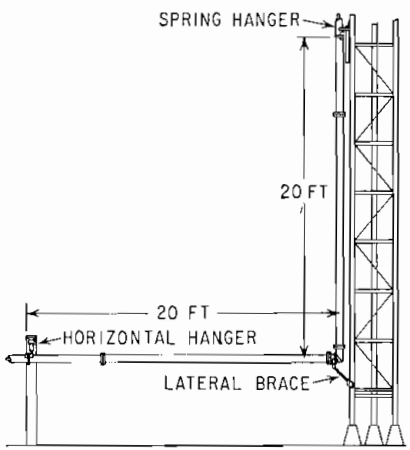

FIG. 5-28. Installation at base of tower.

Heating effects of direct solar radiation on a transmission line may lower its power rating substantially. In cases where this is a limiting factor, the problem can be solved by providing a sun shield that protects the line from direct radiation. The shield must be so designed that it permits circulation of air around the line.

The line is anchored at the building wall with a horizontal anchor which is like the rigid anchor on top of the vertical run. A horizontal anchor is shown in Fig. 5-32. Its purpose is to keep line movement away from the equipment, permitting expansion and contraction to build up at the tower end of the horizontal run.

Long horizontal runs of transmission line are quite common, particularly in directional installations. Frequently towers are spaced at a considerable distance and roads and walkways must be crossed, so occasionally lines are buried in the ground. It must be pointed out, however, that generally speaking, rigid lines are not recommended for burial. The EIA (formerly RETMA) Standard RS-158, par. 6, states, "Lines buried or run underground shall be protected and shall have provision for minimizing the effects of galvanic and corrosive action." To avoid corrosion problems, lines are not buried directly in the soil but are laid in a trench made of wood or concrete which is provided with a cover. Ducts made of tile or other suitable material are also used. When lines must be buried directly in soil, the soil conditions should be carefully checked. If the soil is alkaline, the transmission line will not deteriorate. Vinyl- or polyethylene-covered lines are more suitable for buried installations than bare copper or aluminum lines and should be used if possible. Stray ground currents may attack the line. This condition should be investigated periodically. When lines are buried, markers are placed at convenient intervals, usually at splices in the line.

5. Inside the building, the transmission line connects to the gas barrier immediately upon entering the building. The barrier has a gas port to which the automatic dehydrator is attached. The automatic dehydrator keeps the entire length of line from the building to the antenna pressurized. The transmission line inside the build-

ing (on the other side of the gas barrier) is unpressurized. Connections between line sections inside the building are made with straight ungassed couplings. A coupling is shown in Fig. 5-33. These couplings make it convenient to get at connections for maintenance purposes. Connections from the transmitter to the diplexer and the

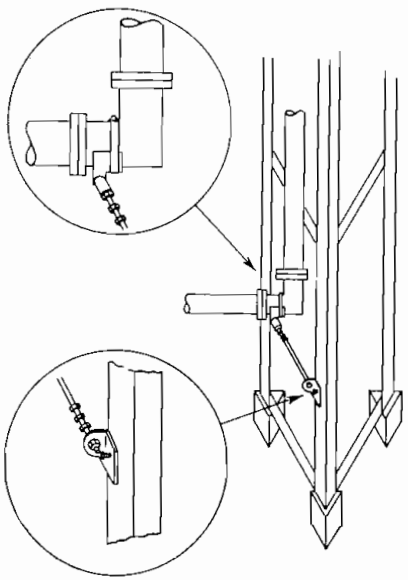

FIG. 5-29. Lateral brace.

line are shown in Fig. 5-34. This is a simple station arrangement. Since all stations are different, the inside connections are never quite alike; therefore, no set installation rules exist.

6. After all outside flange connections are completed and the gas barrier is attached to the transmission line inside the building, the line should be pressurized.

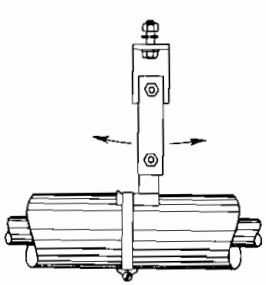

FIG. 5-30. Horizontal hanger.

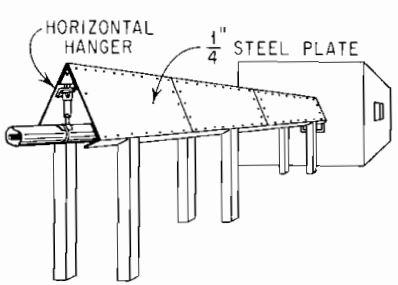

FIG. 5-31. Protected horizontal run.

If moist air has entered the system during installation, it should be purged by pressurizing three or four times, releasing all air between pressure cycles. Proper purging is done by removing the gas port plug located at the antenna end of the transmission line. After purging, replace the plug and pressurize the line. Changes in temperature can cause moisture from any outside air that enters the line to condense and

very seriously impair the efficiency of the line. For this reason, the line should be operated under pressure at all times. A gauge pressure of 5 to 10 psi is adequate for most installations. Dry air is recommended for this purpose. Dry nitrogen can also be used, in which case be certain to use oil-pumped nitrogen.

Uupressurized installations are not recommended. If, because of unusual circumstances, the line is to be operated without pressure, a hole must be provided at the

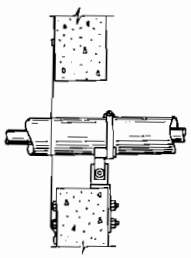

FIG. 5-32. Horizontal anchor.

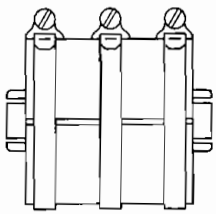

FIG. 5-33. Straight coupling.

lowest point in the system to allow the condensate to drain. This should be done by filing a notch through the outer conductor at the underside of the line, using a triangular file. Do not drill or punch a hole in the line, as this will leave undesirable burrs inside the outer conductor.

7. Coaxial switching systems are recommended for all television installations. Such a system greatly reduces transmitter tune-up and testing time and also reduces off-the-air time caused by equipment failure. Motor-driven coaxial switches are ideal for this application. Manual coaxial switches and coaxial patch panels are also frequently used. Use of switches eliminates time-consuming manual changes of transmission-line connections during emergencies. Standby equipment can be quickly and easily checked under actual operatiug conditions. Many stations usually are equipped with such standby eqnipment as an auxiliary diplexer, standby antenna, and a dummy load for tuning. The chart of Fig. 5-35 shows three frequently used switching systems.

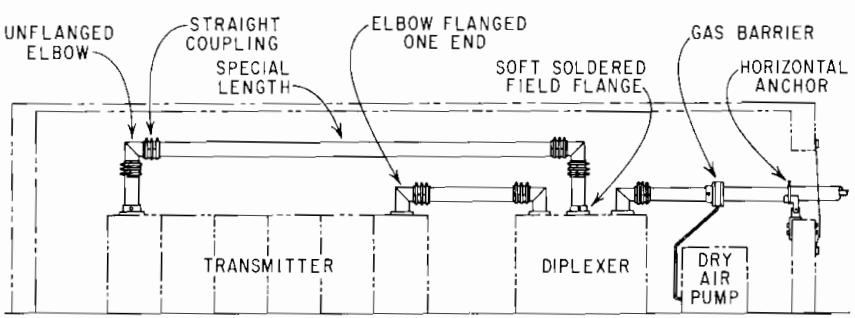

FIG. 5-34. Installation inside transmitter building.

8. There are numerous other accessories used with transmission lines to make broadcast operation more reliable, convenient, and versatile. Some items are breakaway sections, flexible sections, slug tuners, and stub tuners.

a. Prior to the advent of the breakaway section, it was necessary to install four elbows in the shape of a U in order to break into a transmission line installed on a tower in order to measure antenna characteristics or trouble-shoot the line (see Fig.

5-36). Now, with a breakaway section (Fig. 5-37) these four elbows can be eliminated, and it is a simple matter to service the antenna or transmission line. To break a long run before breakaway sections were available, it was necessary to start at the

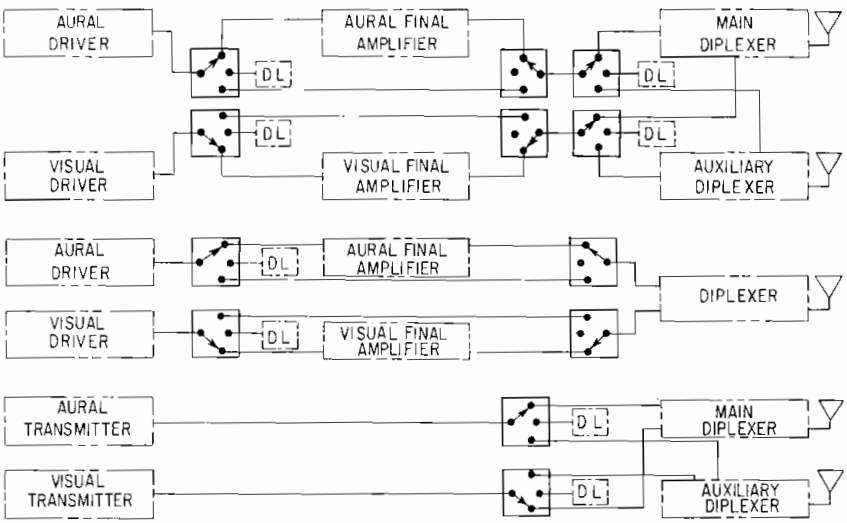

FIG. 5-35. Typical switching arrangements.

bottom and take the line apart all the way up or, alternatively, to push the line down against the pressure of all the spring hangers.

b. Flexible sections (Fig. 5-38) are ideal for correcting slight errors in transmission-line alignment and for providing a slight change iu direction as may be necessary.

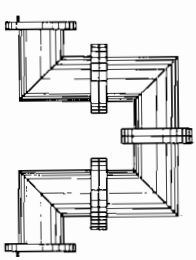

FIG. 5-36. Break in arrangement.

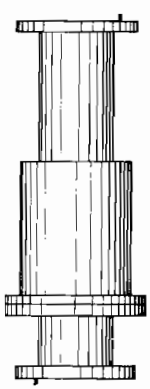

FIG. 5-37. Breakaway section.

The flexible section for 3⅛-in. transmission line is only 18 in. long; yet it can take up to a ½-in. offset in the transmissiou-line path and can also take a 30° bend. The section also accommodates much of the line vibration. Flexible sections are not made to accommodate line expansion and contraction.

c. Slug tuners, single-stub tuners, and double- or multiple-stub tuners are used in the transmission-line system to improve VSWR, to filter harmonics, or to reduce spurious radiations (see Figs. 5-39 to 5-41). A single-stub tuner is primarily used as an even harmonic filter. A single-stub tuner can be used for VSWR tuning if it is

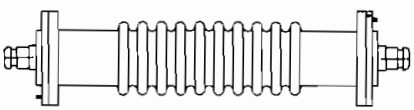

FIG. 5-38. Flexible section.

FIG. 5-39. Slug tuner.

moved along a line section, but this is mechanically hard to do. Slug tuners and multiple-stub tuners are used for VSWR tuning. They operate on the principle of moving or varying reactances in the line. In any VSWR tuning method, the tuner is usually placed near the discontinuity being corrected.

Solid-, Flexible-, and Semiflexible-cable Installation

1. Solid, flexible, and semiflexible cables are much easier to install than rigid cables or waveguide. One of the biggest advantages is that the cable, through its flexing characteristic, nullifies the effects of the thermal forces of expansion and contraction. Without the effects of these forces to consider, the need for rigid hangers, sliding hangers, spring hangers, elbows, breakaway sections, flexible sections, lateral braces, horizontal anchors, expansion loops, etc., is eliminated. This results in a greatly reduced installation cost.

2. The cable is usually shipped on a reel, and to make hoisting easier, the reel should be supported at the base of the tower on an axle so it rotates freely. The cable is uncoiled as it is being hoisted. Before hoisting can be started, of course,

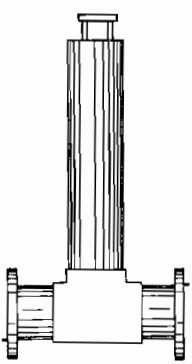

FIG. 5-40. Single-stub tuner.

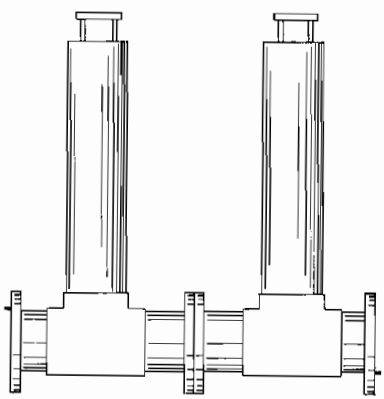

FIG. 5-41. Multiple-stub tuner.

a suitable steel hoisting line or rope that will adequately support the weight of the cable must be obtained. Next, a strong pulley must be placed high enough on the tower to allow the cable to be elevated sufficiently to make the connection to the antenna easily. A means of hoisting, such as a truck or a portable electric winch, is the main requisite for the vertical installation. Short lengths of cable can be pulled satisfactorily by tying the hoist line near the end of the cable. Do not place the weight of the line on the end fitting. A special cable grip or a suitable rope sling

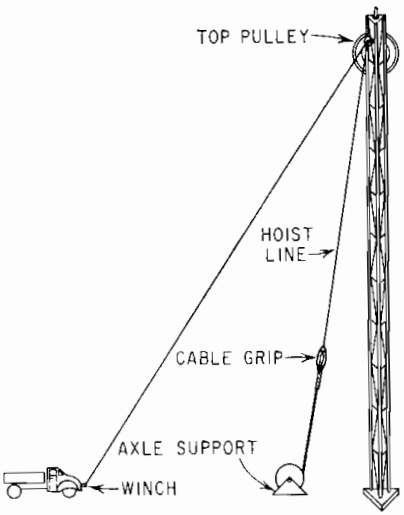

Fig. 5-42. Installation of cable.

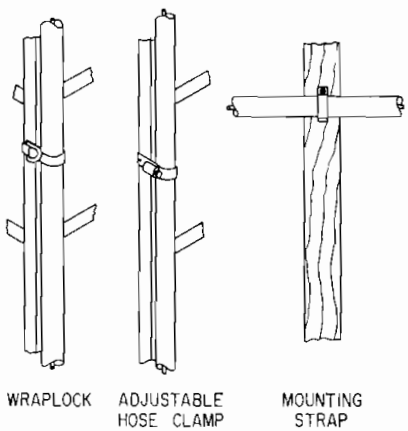

Fig. 5-43. Cable attachment.

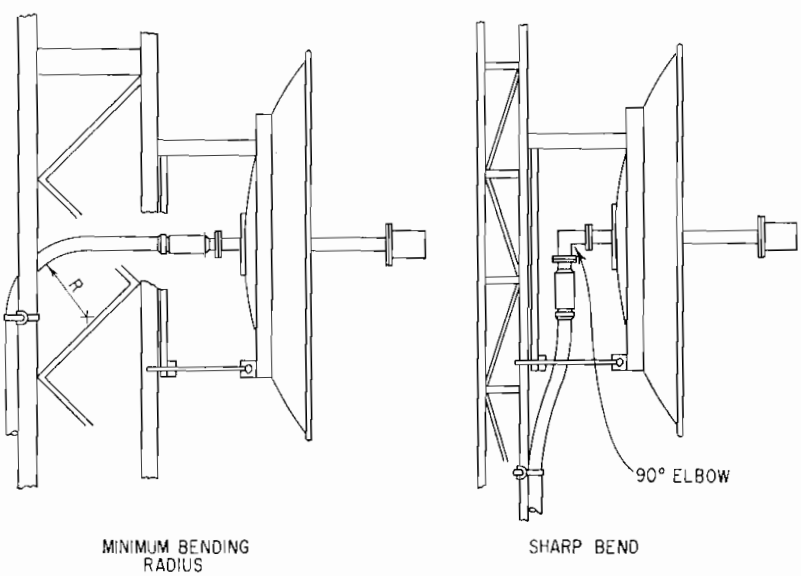

Fig. 5-44. Bending of cable.

should be used to hold the cable without damage. A cable installation is shown in Fig. 5-42.

3. The cable is attached to the tower members with Wraplock, adjustable hose clamps, or even tape for the smaller types and is supported every 5 ft along the tower (see Fig. 5-43). It can be bent around tower members, building corners, and equipment, thereby making the transmission-line path much less restrictive than is possible in rigid-line installations. The bending is limited to a radius that is ten times the cable diameter. In other words, a 1-in.-diameter cable has a minimum bending radius of 10 in. For very sharp bends, a 90° mitered elbow should be used, as shown in Fig. 5-44.

The EIA (formerly RETMA) Standard RS-158, par. 7, Bonding to Tower, states, "The outer conductor of transmission line shall be bonded as a minimum at both the top and bottom of the tower by low impedance conductors to a metallic tower or to a suitable 'down' conductor physically separated from the transmission line if the tower is non-metallic." In addition to the minimum, the cable should be grounded at the point where it enters the transmitter building, especially if there is a long horizontal run. Vinyl-covered cables must have a grounding strap attached to the cleaned outer conductor (after the vinyl has been removed at the bonding point).

4. Support the horizontal run of the cable above the ground by attaching it to a messenger wire or other horizontal supports with Wraplock or adjustable clamps. Use mounting straps when attaching the cable to wood support poles. The cable should be supported every 5 ft as on the vertical run. Semiflexible cable which is not covered should not be buried directly in the soil. It should be either wrapped or placed in a conduit. The flexible cables which are covered with a vinyl jacket can be used in any environment such as salt air, direct ground burial, or under water with no effects of galvanic or corrosive action. This complies with the EIA Standard RS-158, par. 6, Underground Burial.

5. The connections inside the building are made with the same type of cable being used for the transmission line. Where possible, the flexible cable from the antenna is connected directly to the transmitter without any short interconnections.

6. After all connections have been completed, the flexible or semiflexible air-dielectric cable should be pressurized with dry air or dry nitrogen in the same way as is done for the rigid-transmission-line installation.

Waveguide Installation

1. Installation of waveguide for broadcast use requires much more advance planning than a comparable installation of coaxial line. Each installation introduces special problems in mounting the waveguide on the supporting structure and in connecting it to the transmitter equipment. A great advantage of installing copper-clad steel waveguide is that there is no differential problem of expansion and contraction between the tower and the waveguide. This is true for two reasons: first, because the waveguide and tower are both made of steel and are identically affected by changes in temperature, and second, because of the very high efficiency and extremely low loss, no heat is created from the RF energy. Aluminum waveguide, because of its expansion and contraction, must be suspended by spring hangers in the same manner as rigid copper lines. The transitions at either end of the waveguide run are equipped with a gas barrier for pressure termination of the 3⅛-in. coaxial line. Though the waveguide is unpressurized, the antenna and the 3⅛-in. coaxial-line jumper connections outdoors usually are kept under pressure. A small copper tube is used to bring the gas supply up to the antenna.

The coaxial line between the transmitter building and the waveguide is also pressurized. Inside the building, however, the line is not pressnrized.

The following Bill of Materials gives the approximate items and quantities needed for a typical copper-clad steel waveguide installation on a 600-ft tower plus a 30-ft horizontal run:

Bill of Materials

Item	*Quantity*	*Use*
1. 90° mitered elbow, flanged	3	For changing line direction
2. Special lengths of line, unflanged	8	For custom applications
3. Soft-solder flange kit	9	For field flanging lines and elbows
4. Transition, waveguide to 3⅛-in. line	2	For RF energy passage from waveguide to coaxial line
5. Tower hanger	59	For attaching waveguide to tower
6. Horizontal hanger	3	For horizontal support of waveguide
7. Gas barrier	1	For pressure termination of line
8. Automatic dehydrator	1	For automatically pressurizing line
9. Straight couplings	7	For joining unflanged line
10. 90° elbow, flanged one end	3	For changing line direction
11. 90° elbow, unflanged	2	For changing line direction
12. Waveguide, standard 10-ft lengths	62	For main run
13. 90° waveguide elbow	1	For changing waveguide direction

2. At the top of the tower (as in the rigid coaxial transmission-line installation) a custom connection to the antenna is necessary. The coaxial connection from the antenna flange to the waveguide transition is made with two 90° mitered elbows, a special length of line cut as required, and two soft-soldered field flanges, as shown in Fig. 5-45.

3. Along the tower, the waveguide hangers are used at 10-ft intervals. They are placed at the middle of each standard 10-ft waveguide section. Do not support

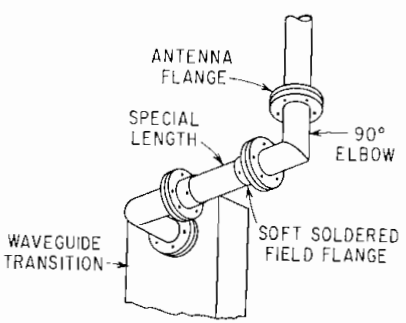

FIG. 5-45. Installation at top of tower.

more than one section of waveguide on a flange joint without using a hanger. It is much safer to leave the hoist line tied to the waveguide section until after the hanger attaches the section to the tower. The hangers used are the type that bolt directly to angle-type towers. Lateral-position adjustment is provided. Attachment to the waveguide is not difficult, as the hardware is captive and the clamping plates slide easily into place after the waveguide is positioned. A waveguide installation is shown in Fig. 5-46.

4. At the bottom of the waveguide run, a 90° waveguide bend is used. The one shown in Fig. 5-46 is an *H*-plane bend. Bends are usually supplied for 45 or 90°, but most suppliers fabricate special bends to customer specifications. A hanger is not required for the bend.

5. The horizontal run is supported with hangers that can be adapted to support the waveguide in either plane, as shown in Fig. 5-46. These are equipped with threaded adjustments so that perfect alignment of the waveguide sections can be made.

6. A transition is added to the end of the horizontal waveguide run for connection to the 3⅛-in. coaxial line. (In some installations, the transmitter building is very

close to the base of the tower. In such cases the transition can be installed at the bottom of the vertical run of waveguide and coaxial line used for the horizontal run.) From the transition, a 90° mitered elbow and two special lengths of line are used to

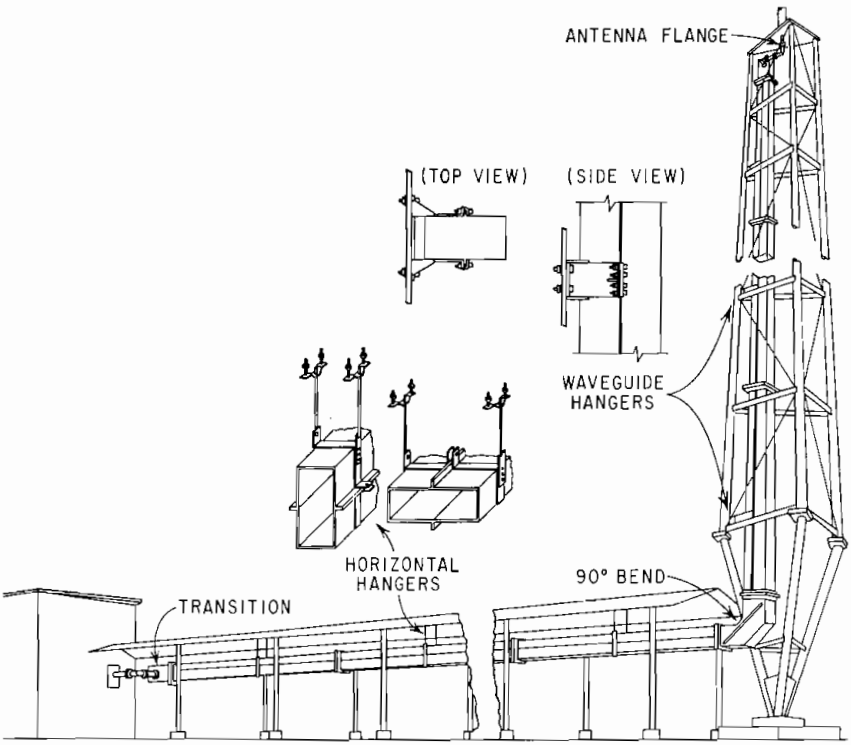

FIG. 5-46. Installation of waveguide.

bring the horizontal run inside the transmitter building. A gas barrier is then attached to the line, and the automatic dehydrator is connected to the gas barrier. For short lengths of line, a dry-air hand pump can he used for pressurization.

7. Once inside the building, all installations, procedures, accessories, etc., are the same for stations using waveguide as they are for those using rigid coaxial transmission line for the main RF feeder.

Part 6

ANTENNAS FOR FM BROADCAST

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GENERAL THEORY

The radiation pattern of an antenna, together with its impedance, can be completely specified from a knowledge of the position, magnitude, and phase of all the current in the system. The equation that specifies the electric field, which will be radiated from an element of current, as developed by Helmholz from Maxwell's equations, is

$$E = \frac{60\pi}{d\lambda} \Delta l I \cos \omega \left(t - \frac{d}{c} \right) \cos \theta \qquad (6\text{-}1)\ *$$

The meaning of the symbols in formula (6-1) is as follows:

E = electric field strength, volts/m
d = distance, m
l = length, m
Δ = an increment of the quantity which follows
I = current, amp
$\omega = 2\pi f$
f = frequency, cps
t = time, sec
c = speed of light, m/sec—3×10^8
λ = wavelength, m

This is probably the most useful equation in antenna theory.

The expression is actually not complete, since E and I are vector quantities and the directions are not specified. In order to visualize the direction of E correctly, let us examine E in terms of the magnetic field H, which is somewhat less difficult to envision.

Recall, then, that the H field is always perpendicular to the direction of the current flow of the current element producing it. Now at a great distance from the antenna, it is simple to think of E and H as mutually per-

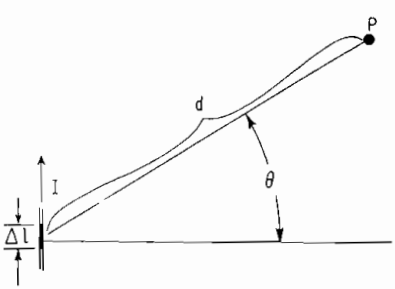


FIG. 6-1. Calculations of E at point P.

* Formula 1 and Fig. 6-1 from F. E. Terman, "Electronic and Radio Engineering," 4th ed., McGraw-Hill Book Company, Inc., New York, 1955.

pendicular and both perpendicular to the direction of transmission of the wave. Therefore, no trouble should be experienced in visualizing the directions of polarization of the field from a complex system of currents.

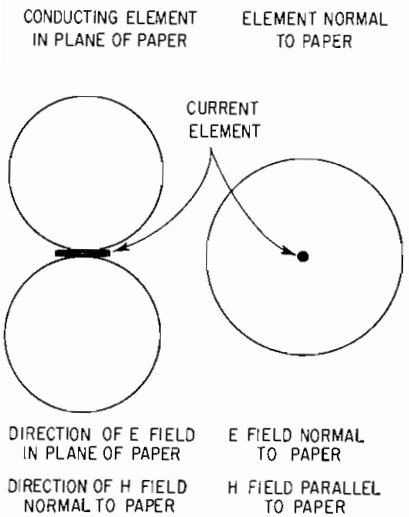


FIG. 6-2. Radiation patterns through and normal to current element.

Attention is invited to the term $\cos \omega(t - d/c)$. This term expresses the sinusoidal variation of the magnitude of the vector E with time at the distance d. It does not indicate the vector direction of the field in space as discussed in the preceding paragraph.

It is of interest to consider the radiation pattern of the single-current element before considering the patterns of complex structures consisting of many such elements. The radiation patterns in a plane through the element and in a plane normal to it are given in Fig. 6-2.

The application of this principle to a horizontal end-loaded loop, such as is used in several commercial FM antennas as the radiating element, will yield the information that the radiation pattern is substantially circular in the horizontal plane and doughnut-shaped in the vertical plane.

Application to a symmetrical V-antenna element will yield a figure-eight radiation pattern. This also can be made to approach a circle in the horizontal plane if the two halves of the V are fed with somewhat unequal currents somewhat out of phase.

FIELD PATTERN OF ANY ANTENNA FROM KNOWLEDGE OF THE CURRENTS AND PHASES OF THE SYSTEM

In order to determine the distant field pattern of any antenna in which the current distribution, directions, and phases are known, simply break the radiating system down into incremental elements of current. Then sum the effects computed by Fig. 6-1, taking due account of the current phases and directions. This is a completely general procedure and can be applied to any antenna, although most useful for loops, Vs, dipoles, and rhombic radiators. It is not so readily applicable to horns and parabolas. One must be sure to include all currents not completely enclosed in metal. Currents within a coaxial transmission line, the diameter of which is small compared with a wavelength, can be neglected.

THE PRACTICAL FM TRANSMITTING ANTENNA

The practical FM antennas presently in production have filtered down into a very simple pattern. They consist of a series of small, lightweight radiating elements spread approximately one wavelength apart and fed unsymmetrically. One side of the balanced radiator only is fed, the other side is excited parasitically. The elements are fed exactly in phase by tapping them off a transmission line exactly one electrical wavelength apart.

It is a well-known transmission-line law that, regardless of whether or not a transmission line is matched, the voltages at a series of points, integral wavelengths apart, will be exactly in phase. It is also well known that loads tapped across a transmission line at points integral numbers of wavelengths apart will appear to be electrically in parallel when viewed from the generator side of the point of connection of the last load. This is shown diagrammatically in Fig. 6-3.

This provides a very simple method of putting together a multielement high-gain transmitting array.

Experience has shown that the mutual impedance between the elements of such an antenna array will be quite small and can be neglected to a first order of approximation.

Hence, the design problem is basically as follows:

Assume that an eight-element FM array is desired. The process would be to space the eight elements along the transmission feed line exactly one wavelength apart with respect to the wave velocity within the transmission line.

Tune each element to present a purely resistive load of eight times the characteristic impedance Z_0 of the transmission line at the point of connection. The transmission line will then be automatically matched at the generator side of the bottom loop, and the voltage applied to all the loops will be automatically in phase.

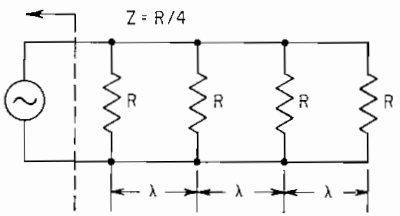


FIG. 6-3. Diagrammatic representation of loads tapped across transmission line.

Each element will receive one-eighth of the total power and (to the extent that mutual impedance can be neglected) will produce $1/\sqrt{8}$ the field of a single element taking all the power. The fields will add in phase. The power gain of a single-loop or V-antenna element is approximately unity.[1] Hence, to a first approximation, the field gain of an eight-element FM antenna, each element of which receives one-eighth of the total power, would approximately equal $8/\sqrt{8}$ and the power gain of the antenna would be 8, or equal to the number of elements in the antenna. Examination of the data supplied by the manufacturers, made a portion of this part, shows the above to be quite a good approximation.

Vertical-radiation Pattern

FM transmitting antennas, consisting of a series of V or loop elements mounted a wavelength apart and fed to produce in-phase fields, will have nulls in the vertical pattern depending on the number of elements used. To a first approximation, the single element can be visualized as having a doughnut-shaped pattern. The vertical patterns will be substantially the same for the three makes of antennas to be discussed.

A family of vertical-radiation patterns supplied for the RCA-BFA series of antennas is shown in Fig. 6-4 and illustrates the position of the pattern nulls. It will apply almost as well to the Andrew and Collins antennas.

An antenna located a substantial height above its service area, such as on a mountain top, may have a pattern null falling in the vicinity of a built-up section of that area. For example, the first null of an eight-bay antenna, 5,000 ft above flat terrain, will be seen from Fig. 6-4 to fall 7.7° below the horizontal or a distance of 7 miles from the site. If a populated area lies in such an area, it would pay to apply what is called electrical beam tilt or null fill or a combination of both.

For example, beam tilt could be obtained in such an eight-element array, if manufacturing details permit, by phasing the upper bank of four loops ahead of the lower bank. Sixty degrees of lead to the upper bank would "tilt" the beam about 2½° below the horizontal.

In addition, it would be feasible to fill the null, as is common practice with television antennas, by adjusting the power ratio between the upper and lower banks. A 60-to-40 division has been extensively used in TV.

For illustration, the pattern of an eight-loop FM transmitting antenna with 60° lead in the upper bank of four antennas and a 60-to-40 power distribution has been computed and is compared with the pattern of the normal eight-bay antenna in Fig.

[1] Referred to a half-wave dipole.

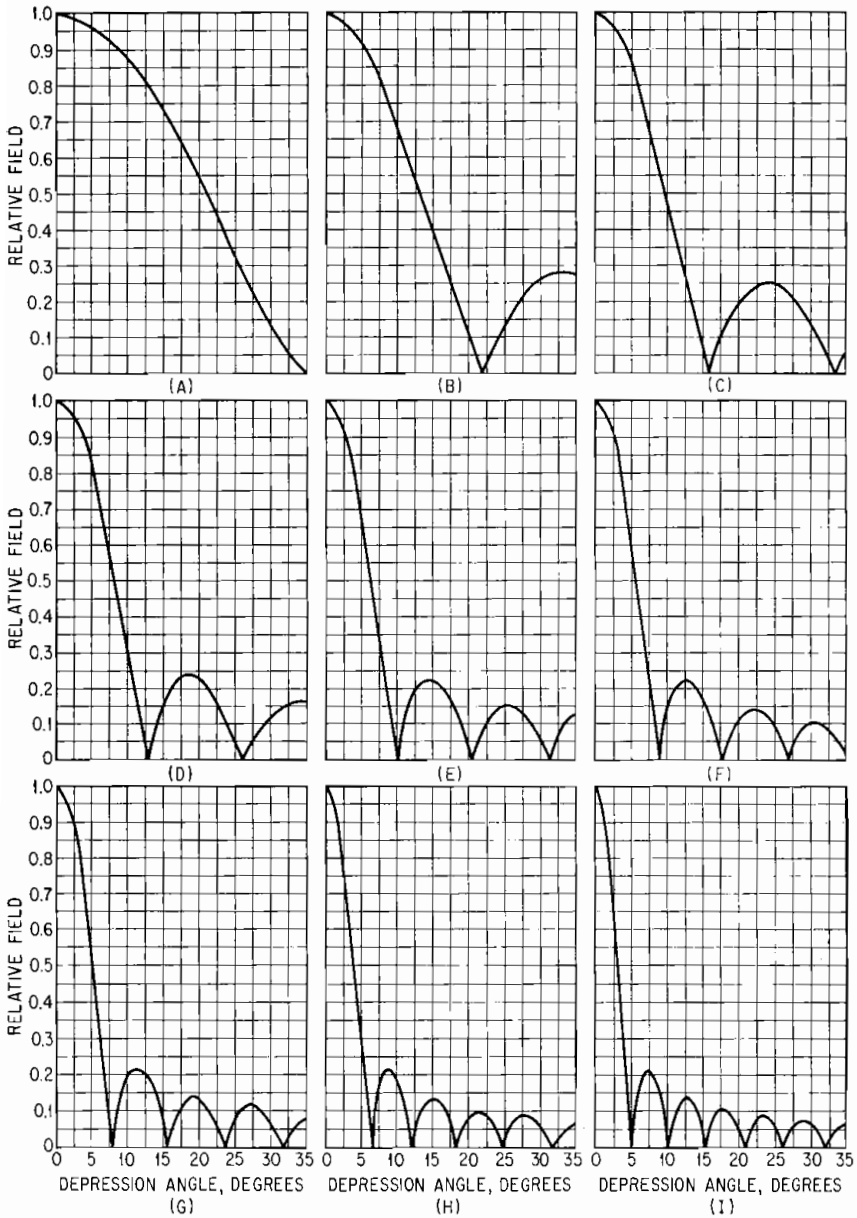


FIG. 6-4. Calculated vertical field pattern: (*a*) RCA BFA 2A. (*b*) RCA BFA 3A. (*c*) RCA BFA 4A. (*d*) RCA BFA 5A. (*e*) RCA BFA 6A. (*f*) RCA BFA 7A. (*g*) RCA BFA 8A. (*h*) RCA BFA 10A. (*i*) RCA BFA 12A.

6-5. Such a modified antenna might be very worthwhile for special mountain-top installations.

POLARIZATION

All the antennas described are for horizontal polarization. The FCC has recently denied a petition requesting permission to use vertical polarization for FM stations but will permit elliptical polarization. Either vertical or horizontal polarization can be quite simply obtained, but elliptical polarization is relatively difficult to obtain,

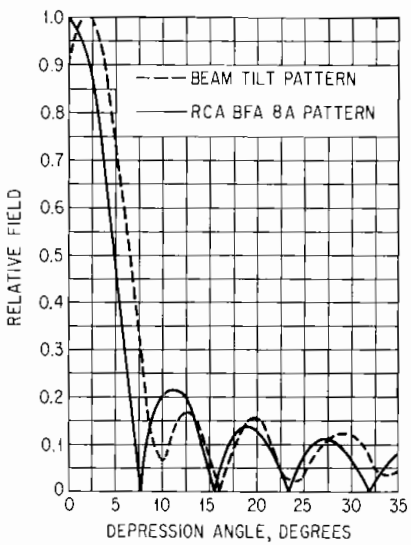


FIG. 6-5. Illustration of beam tilt and null fill for an eight-element antenna.

and there is no presently available FM transmitting antenna suitable for this purpose.

It is possible to obtain tilted linear polarization by tilting the loops, but this practice, although capable of transmitting a component of vertical polarization in some directions, produces a figure-eight pattern for vertical polarization and seems of doubtful value.

Another problem facing the development of a suitable elliptically polarized antenna will probably be the difficulty of side mounting. A greater spacing from the supporting tower is likely to be required to obtain a reasonably circular pattern with a vertically polarized, side-mounted antenna.

SIDE MOUNTING OF FM ANTENNAS

With the early development of FM transmitting antennas, it was assumed that it would be necessary to mount the antenna on top of or symmetrically around the tower. Later tests, however, indicated that in many cases the antennas will operate in a satisfactory manner when side-mounted, and most FM antennas are side-mounted today.

It is believed likely, however, that many FM antennas suffer some deterioration in both pattern and standing-wave ratio, as a result of side mounting on the tower. Experience has shown that the effect on the standing-wave ratio may not be nearly so serious as on the pattern. Hence, it is recommended that if the performance of a side-mounted antenna is seriously suspected, a check be made into the possibility that the pattern has been upset owing to side mounting.

The upset in such cases may be expected to be principally due to two factors. One is believed to be a gain reduction resulting from detuning some of the elements which

might happen to fall adjacent to horizontal members in the supporting tower so that the separate elements no longer radiate equal fields. The other is the excitation of elements of the tower which could radiate appreciable fields, which might tend to cancel the direct radiation from the FM antenna in certain directions.

The following account of one case of side-mounting trouble will be of interest. The performance of a station employing an antenna side-mounted 8 in. off the flat face of an AM tower 36 in. on a side was reported to be extremely bad in the central part of the principal city. The antenna was checked for standing-wave ratio, which was found to be 1.4 to 1, while factory tests prior to shipping showed a standing-wave ratio of 1.1 to 1. Field retuning easily corrected the SWR, but no improvement in the service was reported. Checks of the tower structure showed high circulating currents and resonant voltage points. The side mounting was suspected.

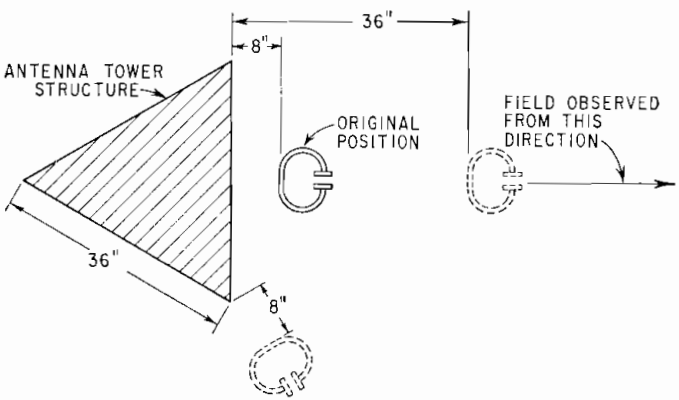


FIG. 6-6. Vertical section through an FM antenna and supporting tower.

A test was made during which the relative field in a direction roughly toward the poor service area was observed while the antenna was temporarily spaced out from the supporting tower. It was also tested on a corner instead of the flat face. A vertical section through the supporting tower and FM antenna tested is shown in Fig. 6-6. The results were as follows:

Antenna Mounting Position	*Relative Field, Db*
Normal position 8 in. off face	0
Moved to a corner	+2.7
22 in. off face	+4.8
36 in. off face	+6.9

Permanent relocation 36 in. off the face appears to have materially improved the coverage in the area previously reporting poor service.

BANDWIDTH, STANDING-WAVE RATIO, AND PROBLEMS INTRODUCED BY MULTIPLEX

FM is a comparatively narrow-band service from the antenna standpoint. For instance, the 6-Mc band of a Channel 2 TV station is 10.5 per cent of the carrier frequency while the 200 kc occupied by an FM station is only 0.2 per cent of the carrier frequency. The narrow-bandwidth requirement permits the use of physically small, lightweight, low-wind-resistance radiating elements such as loops and Vs for FM. Conversely, in the TV service, it has been necessary to resort to massive broadband elements.

At this point, it would appear in order to mention the effect of the recent trend toward multiplex operation on the antenna problem. Tests and calculations of requirements for multiplex operation have indicated that it is desirable to match the antenna feed line of an FM station desiring to use multiplex to approximately 1.1 to 1 over a frequency range of 200 kc even though standing-wave ratios of 1.5 to 1 to 2.0 to 1 have worked quite satisfactorily with ordinary FM service. The reader is referred to the part on Multiplex in Section 8 of this handbook for further information on this subject.

Analysis of manufacturers' data on the Andrew, Collins, and RCA antennas shows that if the antennas were matched closely at center frequency, their bandwidth would be perfectly acceptable for FM, including the multiplex service.

Matching of an FM antenna is usually accomplished at the factory at the desired center frequency. However, mismatch between the transmission line and the antenna can be expected when the antenna is side-mounted on a supporting tower. This mismatch can be expected to result in a VSWR of about 1.5 to 1.

Hence, if a standing-wave ratio not in excess of 1.1 to 1 is desired, a side-mounted FM antenna can be expected to require field tuning after it is mounted on the supporting tower.

HINTS FOR FIELD TUNING OF FM TRANSMITTING ANTENNAS

The RCA antenna is furnished with an adjustable matching section mounted immediately under the radiating portion of the antenna and designed to be used for this purpose. In the case of the Andrew antenna, the procedure will be to purchase a similar device and install it immediately below the antenna in lieu of the first few feet of transmission line. This method can also be applied to the Collins antenna if desired. Since the adjustment of devices of this sort has been adequately covered elsewhere, it will not be explained here.

The Collins antenna can, if desired, be field-tuned without the addition of extra devices, and the procedure for accomplishing this is the following:

The antenna may readily be brought to within 1.1 to 1 by a combination of rotation of all discs the same amount in the same direction, coupled with a slight adjustment of the feed-line straps, again using caution to keep the adjustments together.

It is recommended that before any changes are made, the center spacing of all discs be calipered and the position of all feed straps be measured. This information should be recorded carefully.

In addition to this, the strap positions should be marked on the loops themselves and a prominent mark placed at the top of each disc to estimate rotation in fractions of turns.

Rotation of the discs should be by approximately the same amount for the discs on each side of the capacitor of each loop. By this, it is meant that if a disc on one side of the capacitor is rotated a quarter turn in a direction which reduces the spacing between discs, the disc on the other side of the capacitor should likewise be rotated a quarter turn in a direction to reduce the spacing further.

It is recommended that the impedance be checked at least at carrier, carrier + 100 kc, and carrier − 100 kc for each adjustment of either the loop capacitors or the feed straps. This data should be plotted on a Smith chart. (See Section 9 for use of Smith charts.)

Caution should be exercised that the accuracy of the signal generator used be within about 5 kc. The measurement can be made at the transmitter input to the transmission line using a General Radio admittance meter or instrument of comparable accuracy.

One should remember that field adjustment of this or any other side-mounted FM antenna to correct the upset standing-wave ratio which has resulted from interaction between the radiators and the supporting structure will not, in general, correct any noncircularity of the pattern or gain reduction which may have resulted from the side mounting of the antenna.

SOME ANTENNAS CURRENTLY IN PRODUCTION

Andrew Multi-V FM Antenna

The antenna is available for any frequency within the 88- to 108-Mc FM band at 51.5 ohms input impedance with a standing-wave ratio under 1.5 to 1 and 10-kw power-handling capacity. The eight-bay model is also available with a 50-kw rating.

The antenna radiating element is basically a folded half-wave dipole element bent into a V shape and operated several megacycles above resonance to obtain a basically circular horizontal-radiation pattern. A single element is shown in Fig. 6-7.

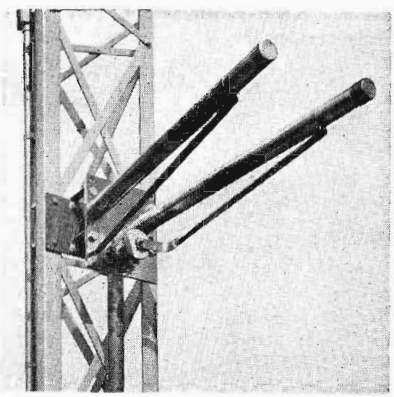


FIG. 6-7. Single radiating element of Andrew multi-V FM antenna.

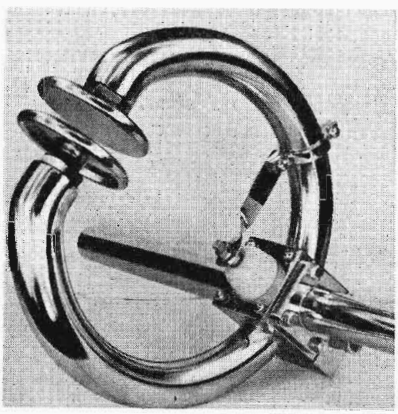


FIG. 6-8. Single radiating element of Collins 37M FM antenna.

The antenna is designed for side mounting.

The antenna is not designed for field tuning. If a 1.1-to-1 standing-wave ratio over the 200-kc band is required for multiplex operation, it is necessary to add an adjustable matching section immediately below the antenna on the tower. (This cannot be placed at the transmitting end of the line.) The manufacturer has developed a slug tuner for this purpose.

Andrew Antenna Characteristics

No. of Bays	*Power Gain*	*Power Rating, Kw*
2	1.6	10
4	3.7	10
8	7.3	10

Collins 37M Ring Antenna

The antenna is available for any frequency within the 88- to 108-Mc FM band at an input impedance of 51.5 ohms. The standing-wave ratio is set at the factory to about 1.1 to 1 but may rise to about 1.5 to 1 when the antenna is side-mounted on a supporting structure. The power rating is 6 kw when the antenna is mounted on 1⅝-in. line and 27 kw when it is mounted on 3⅛-in. line.

The basic radiating element is an end-loaded half-wave dipole bent into a loop so that the end-loading discs form a disc capacitor as shown in Fig. 6-8.

The antenna is designed for side mounting.

The antenna, though not designed specifically for field tuning, can readily be field tuned. Field tuning will be required if a 1.1-to-1 standing-wave ratio over a 200-kc band is required for multiplex operation. Hints on field tuning of this antenna are provided elsewhere in this part.

Deicing equipment is available and is recommended by the manufacturer in areas in which icing conditions occur.

Collins Antenna Characteristics

No. of Rings	*Power Gain*
1	0.9
2	2.0
3	3.0
4	4.1
5	5.1
6	6.2
7	7.2
8	8.3

RCA Type BFA FM Antenna

The antenna is available for any frequency within the 88- to 108-Mc FM band at an input impedance of 50 ohms.

The antenna radiating element is basically an end-loaded half-wave resonant folded dipole bent into a loop. A single element of the antenna is shown in Fig. 6-9.

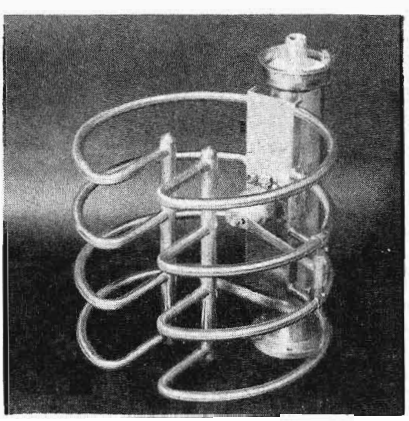


FIG. 6-9. Single radiating element of RCA BFA FM antenna.

The standing-wave ratio is set at the factory so that the mounted antenna will be 1.2 to 1 or better when top-mounted or 1.5 to 1 or better when side-mounted.

This antenna is especially designed for simple field tuning to obtain a standing-wave ratio of 1.1 to 1 or better over a 200-kc band for multiplex operation. Field tuning is accomplished without the necessity of trimming the loop adjustments. An adjustable matching transformer is furnished for this purpose and is located immediately below the antenna.

Deicing equipment is available and is recommended in areas in which icing conditions occur.

RCA Type BFA Antenna Characteristics

No. of Sections	*Power Gain*	*Power Rating, Kw*
1	0.9	3
2	1.9	6
3	3.0	9
4	4.0	12
5	5.1	15
6	6.3	18
7	7.3	21
8	8.4	24
10	10.5	30
12	12.5	36

Part 7

ANTENNAS FOR TELEVISION BROADCAST

H. E. GIHRING

Manager of Antenna Engineering
Radio Corporation of America

GENERAL INFORMATION

Television broadcast antennas presently operate at the following frequencies:

Channels 2 to 6, 54 to 88 Mc
Channels 7 to 13, 174 to 216 Mc
Channels 14 to 83, 470 to 890 Mc

Television antennas are unique with respect to several characteristics.

Since each channel is 6 Mc in width, the antenna must have the proper performance characteristics over this band. Since higher gain antennas are used, especially at the higher frequencies, the vertical pattern must be suitable for the population distribution in the vicinity of the antenna so as to provide adequate field strength for television service.

Definition of Antennas

An antenna is defined as a structure associated with the transition between a guided wave such as may exist in a transmission line and a free-space wave. Such a structure usually consists of radiating elements and means for distributing the energy to these elements.

Antenna Terminals

The antenna terminal is defined as an accessible point where the entire antenna including the distribution system terminates into one [1] feed [2] line at the design surge impedance.

[1] Or two lines for a quadrature system.
[2] In accordance with Electronics Industries Association Standards.

Broadcast-antenna Requirements

Azimuthal Pattern

Definition. An azimuthal pattern is a plot of the free-space radiated field intensity vs. azimuth at a specified vertical angle with respect to a horizontal plane (relative to smooth earth) passing through the center of the antenna.

A horizontal pattern is an azimuthal pattern when the specified vertical angle is zero.

For many higher gain antennas where beam tilt is employed, the azimuthal pattern at the specified beam tilt is significant. In general it has been customary to determine television broadcast-antenna radiation by an azimuthal pattern at the specified beam tilt and a sufficient number of vertical plane patterns all taken at various frequencies in the channel.

An omnidirectional antenna is defined as one that is designed to be omnidirectional. Antennas with variations up to ± 3 db have rendered satisfactory service and are considered to be omnidirectional.

A directional antenna is one which is designed to be directional.

Present FCC Standards have limited the maximum to minimum radiation at 10 db.

Vertical Pattern

Definition. A vertical pattern is a plot of free space radiated field intensity measured in the Fraunhofer region vs. vertical angle in any specified vertical plane which contains the center of the antenna and the center of the earth.

The Fraunhofer region,[3] or "far field," as usually defined extends beyond a point where the distance between the transmitting and receiving point is $2L^2/\lambda$, where L is the length of the radiating portion of the antenna and λ is the wavelength.

Requirement for Broadcast Service. A free-space radiated field should not be influenced by the proximity of the earth in such a way as to set up a nonuniform field over the antenna aperture, and proper precautions must be taken to accomplish this.

Gain

Definition. Gain [4] is the ratio of the maximum [5] power flow per unit solid angle from the subject antenna to the maximum power flow from a thin, lossless, half-wave, horizontally polarized dipole having the same power input when the measurements are made in the Fraunhofer region.

As can be seen from the above, gain depends on several factors.

1. The amount of power concentrated in the maximum direction
2. Losses in the antenna, which include ohmic and other losses such as energy radiated at polarizations other than the desired one

The amount of power concentrated in the maximum direction can be determined by a comparison with a reference antenna [6] or by integrating the total power flow through a sphere,[7] which is done by taking a sufficient number of vertical patterns and an azimuthal pattern.

[3] Kraus, "Antennas," Sec. 1–2.

[4] *Ibid.*, Sec. 2.

[5] "Maximum" refers to the maximum in the vertical plane. For an omnidirectional antenna these maxima must be averaged for a number of vertical patterns taken at various azimuths.

[6] "IRE Standards," Antennas, Methods of Testing. C. C. Cutler, A. P. King, and W. E. Kock, Microwave Antenna Measurements, *Proc. IRE*, vol. 35, pp. 1462–1471, December, 1947.

[7] E. H. Shively and L. D. Wetzel, Pattern Measurements of RCA UHF TV Antennas, *Broadcast News*, vol. 82, pp. 14–21, February, 1955.

Both methods are capable of giving accurate results when the proper precautions are taken.

Ohmic losses are taken into account in the comparison method or can be calculated when using the power integration method. Cross-polarized radiated energy can be measured.

The measurement of gain must be carefully done with a full knowledge of all the problems that are involved.

Gain Requirements. Gain requirements for a television broadcast antenna depend on transmitter, power, economics, and field-strength requirements as determined by the terrain and population distribution.

Transmitter Power. The maximum effective radiated powers currently permitted are:

Channels 2 to 6, 100 kw
Channels 7 to 13, 316 kw
Channels 14 to 83, 5,000 kw

For the most popular transmitter sizes in each range, the following gains are needed allowing 80 per cent transmission-line efficiency:

Channels 2 to 6, 3.6 to 5
Channels 7 to 13, 8 to 18
Channels 14 to 83, 25 to 50 (to achieve 1,000-kw ERP)

Economics. Economics is a factor in antenna choice. As a general rule, combined costs of transmitters and antennas are less to achieve a given effective radiated power when a higher gain antenna is used. This is true until unsupported antenna heights are of the order of 200 ft, where structural considerations cause antenna costs to go up rapidly.

Terrain and Population Distribution. It is usually desirable to have a high uniform field strength over the primary service area. In relatively flat terrain, a higher gain antenna with a vertical pattern shaped to accomplish this is a desirable choice because of the economic factor. In mountainous terrain, under some conditions, a lower gain antenna may be desirable, especially when large amounts of energy must be radiated downward at steep angles for a distance of 5 to 10 miles such as may occur when a city is located at the base of a mountain on which the antenna is placed.

Input Impedance

Input impedance is the complex impedance looking into the antenna terminals throughout the television channel.

Most antennas are designed for the same input impedance as the standard transmission line at the antenna terminal. Impedance-matching requirements for television antennas are generally more severe than for other types to avoid reflected energy which would cause an echo or ghost in the picture when the antenna does not terminate the line properly.

Electrical Performance Changes Due to Mechanically Imposed Conditions

Deflection of Antenna and Tower Due to Wind

Guy tension in guyed towers is usually adjusted so that the tower deflects as a straight member.

Towers for broadcast service when so specified are designed for a maximum deflection of 0.5°, which means that the top plate will deflect this amount for the maximum wind velocity. For instance, a 40-lb tower will thus deflect 0.5° for a 100-mph wind. Since tower deflection varies as the square of the wind velocity, the deflection will be 0.125° for a 50-mph wind.

Structurally a free-standing antenna can be considered as a cantilever beam in which the deflection increases toward the end. Antenna deflection is usually stated as

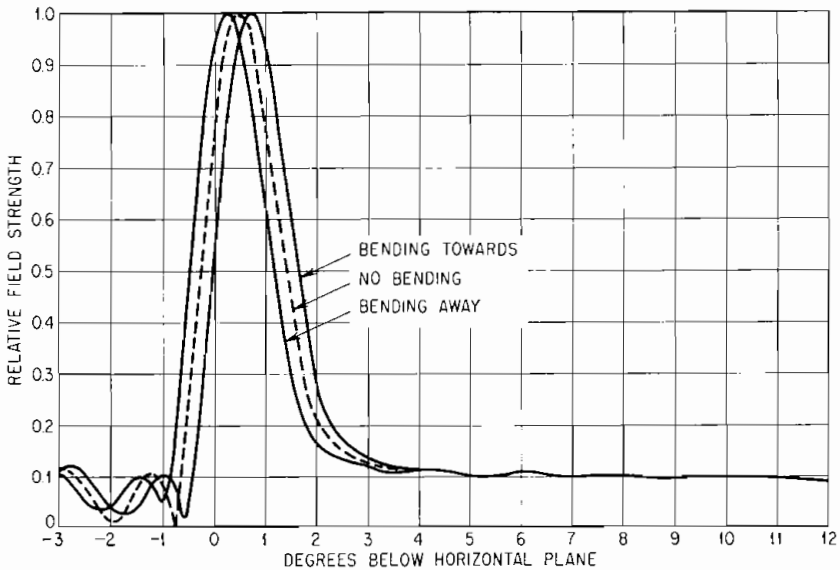


FIG. 7-1. Calculated vertical patterns of the TFU-46C antenna affected by static wind load: flat-surface wind load 10-psf, wind velocity 50 mph.

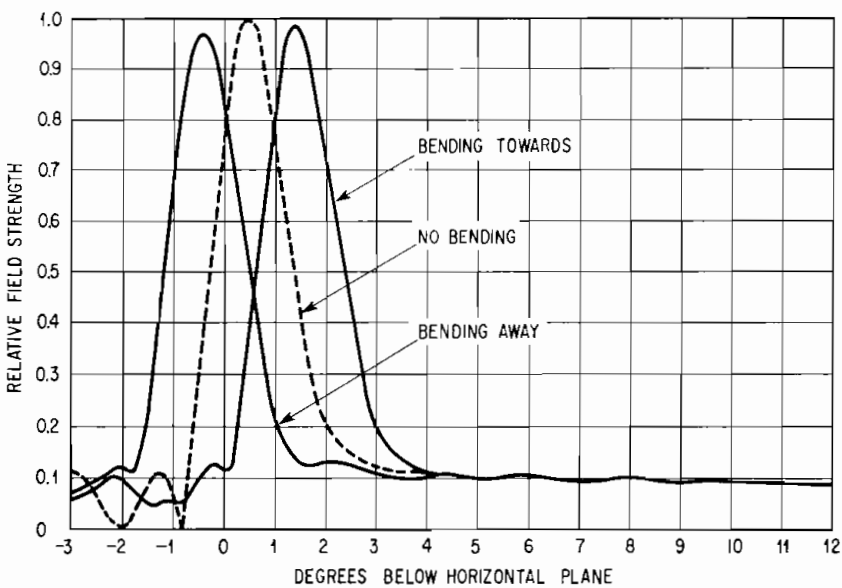


FIG. 7-2. Calculated vertical patterns of the TFU-46C antenna affected by static wind load: flat-surface wind load 40 psf, wind velocity 100 mph.

the angle that a tangent at the center of the antenna makes to the undeflected position.

In order to evaluate the effects of deflection, an example for a high-gain UHF antenna will be given.

Figures 7-1 and 7-2 show the effects of deflection on a UHF antenna of the slotted-cylinder type with a gain of 46 when the antenna is 115 ft in height. The lower half of the antenna is a 16-in. schedule 160 steel tube, and the upper half is a 14-in. schedule 60 steel tube.

The phase and amplitude of each layer of the antenna were synthesized to obtain a vertical pattern for the curved condition where the antenna was bent toward the service area and away from it.

Two conditions are shown for a wind velocity of 50 and 100 mph as summarized in Table 7-1.

Table 7-1

Wind velocity, mph	50	100
Wind load, psf	10	40
Deflection of antenna at top, in.	5.03	20.12
Deflection, wavelengths	0.235	0.94
Deflection of antenna at tangent to center, deg	0.208	0.832
Tower deflection, deg	0.125	0.5
Antenna and tower deflection, deg	0.333	1.332

Signal Variation for Deflection Extremes, db	*Toward Service Area*	*Away from Service Area*	*Toward Service Area*	*Away from Service Area*
At horizon (main beam) antenna only	−0.5	−0.3 [a]	−7.8	−5.8
At horizon for antenna and tower	−0.7	−0.4	−18.8	−13.4
At a location with respect to the vertical pattern where the greatest signal variation occurs for antenna only	+3.6	−2.7	+6	−10.8
At a location with respect to the vertical pattern where the greatest signal variation occurs for antenna and tower	+4.2	−5.3	+12.7	−5.2

[a] Values are not the same, since in this antenna, radiation above the horizon has been suppressed and the pattern is not symmetrical.

The 50-mph wind condition is one that may occur [s] twenty-five times a year at a 1,000-ft elevation above terrain and about four times a year at a 500-ft elevation.

The 100-mph wind is a design-limit figure which rarely occurs and is one during which there would probably be little television viewing. Most outdoor receiving antennas would probably be severely damaged in such a wind, and power service seriously curtailed.

Hence the 50-mph figure is one that is generally considered applicable for an evaluation of this type.

Most television receivers are designed to have a flat AGC response down to 100 mv across the receiver terminals. Hence no effects due to wind acting on the transmitting antenna will be noticeable except in fringe areas where the signal drops below this value.

In the case cited above, the signal variation in the fringe areas would be less than 1 db and could be considered negligible.

The maximum variation in the case cited above occurs at 1.75° below the horizon or at 6.3 miles for a 1,000-ft difference in elevation between the transmitting and receiving antenna. At this distance the field strength is usually at a sufficiently high level so that a 2-to-1 variation will not go below the 100-mv level at the receiver terminals.

Analyzed on this basis even the 100-mph wind condition is not too serious except

[s] Report of TASO Committee 1.3 on Television Antennas. Final Report of TASO Sub-Committee 1.3.2. on Towers, Sec. 3.6.

in the fringe area. It should be noted that the variations are limited by the fact that the antenna is designed not to have nulls near the main beam.

For lower gain antennas with a wider beam the variation would be even less than those shown.

As a confirmation of the above analysis it would be noted that six antennas of the type described with gain from 46 to 52 are in operation in various parts of the United States, some since 1956. In none of these have any complaints or problems occurred with respect to variations in field strengths due to high wind conditions.

Deicing

Desirability. The need for deicing depends on local icing conditions and the sensitivity of the antenna performance to ice.

Local conditions, with respect to frequency and severity of icing, can be ascertained from the local Weather Bureau. It should be remembered that most of their observations are at a low altitude and that conditions are more severe at the antenna height, particularly if it is of the order of 1,000 ft or more above terrain.

The sensitivity of the antenna to ice is specified by the manufacturer.

Both the reflected power and the radiation patterns may be affected. An increase in reflected power with ice as evidenced by an increase in VSWR will often result in secondary images or ghosts. In some cases a higher VSWR may also necessitate running at reduced power. Pattern changes are more subtle but could cause a loss of field strength in some areas. Television antennas are generally more sensitive to ice than other types, and manufacturers usually recommend deicers where icing is likely.

Methods. The most satisfactory method is the use of strip or rod electric heaters fastened in or near the radiating element. In some cases the radiators are heated directly. Other methods such as generating heat at the base of the antenna and distributing it by convection tend to overheat the lower portions and underheat the upper portions, resulting in a loss of both heating efficiency and effectiveness.

Various types of controls are on the market to actuate the deicers. These work on temperature alone or a combination of temperature and precipitation or humidity.

Advantage is taken of the fact that icing occurs only in a narrow range of temperature. Most deicing systems have more than enough capacity to keep the antenna free from ice if they are turned on before the ice starts to form.

Ice removal may require considerable time if a large amount has already formed, especially under high wind conditions when large heat losses occur. Hence the use of an automatic device to turn on deicers is desirable.

DESIGN AND THEORY

Elemental Radiators

Television antennas in common use are developments of one or another of a few basic types of radiator. These are the half-wave dipole, the loop (magnetic doublet), the slot, and the helical. Some of the antennas combine characteristics of more than one of these types.

For purposes of mathematical representation or as a reference for comparison of characteristics of antennas, the concepts of "point source"—a fictitious emitter so small as to have no dimensions—and "isotropic radiator"—which radiates energy uniformly in all directions—are sometimes used.

Antennas of the horn, lens, and long horizontal (Beveridge) or vertical wire types do not currently find application at television frequencies and are not considered herein.

Half-wave Dipole

If the ends of an open-wire transmission line are turned outward, as shown in Fig. 7-3*a*, they form what is known as a dipole. The electric (E) fields, at right angles to and connecting the two sides of the transmission line, extend outward, forming circles in all planes passing through the axis of the dipole, as shown in Fig. 7-3*b*. The magnetic (H) fields, which, in the transmission line encircled the separate wires and tended to cancel each other owing to the opposing directions of the flow of current in the two wires, now appear as circles about the dipole.

If the length of the dipole is made a half wavelength long at the frequency of an imposed signal, it becomes, in a sense, a resonator, with energy reflected from the ends of the radiator setting up standing waves. The energy is alternately stored in the electric and magnetic fields.

At high frequencies, the fields so formed do not have time to collapse completely before other fields, of opposite polarity, are set up. The result is that outer portions of the field never return but are pushed out of the area close to the antenna known as the "induction-field" region and move away, forming the "radiation field." It should be noted that because of the shapes of the fields this effect does not take place off the tips of the dipole whereas it is a maximum in directions at right angles to the dipole.

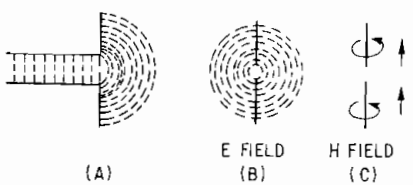


FIG. 7-3. Electric (E) field, and magnetic (H) field of a dipole.

Since the power in the field is dissipated power (I^2R) in the same sense that power appearing as heat due to ohmic resistance in the dipole is dissipated power, it is convenient to relate this power to the current which produces it by a fictitious "radiation resistance." This is in addition to the ohmic resistance in the radiator circuit.

The ratio of stored energy to dissipated energy is called the Q of the antenna circuit. As any circuit contains L, C, and R, this is a function of the relationship between the inductive reactance of the circuit and the resistance. In the case of the dipole the inductance decreases with increasing diameter of the dipole arms. Also the amount of energy reflected from the ends, resulting in greater stored energy, is reduced by increasing the size of the arms. This results in greater bandwidth. Application of this fact leads to the biconical radiators in Fig. 7-4*a* and *b* and to the slot-fed sheet radiator, Fig. 7-4*c*.

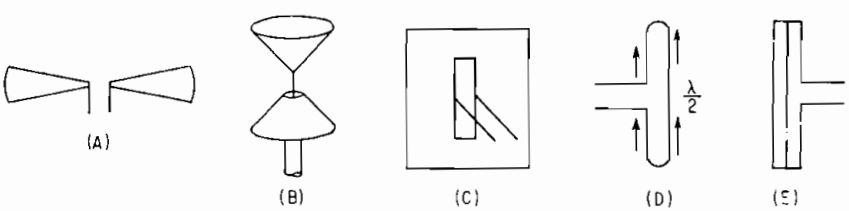


FIG. 7-4. Examples of radiators having dipolelike characteristics: (A) and (B) biconical antennas, (C) slot-fed sheet, (D) folded dipole, (E) folded dipole with additional element.

Another form of the dipole is the half-wave folded type shown in Fig. 7-4*d*. Here, the ends of a simple dipole have been joined by another closely spaced element. Since the voltage distribution is the same in both, the currents are in the same phase and direction. The result is an input impedance of 300 ohms as compared with 73 ohms for a simple half-wave dipole. Addition of rectangles as in Fig. 7-4*e* increases the input impedance by a still greater factor.

Because the folded ends act like stubs, they become capacitive at higher frequencies. This is opposite to the tendency of the series *LCR* circuit by which a dipole can be represented. The result is a cancellation to some degree of the reactances and a tendency for the impedance to remain constant, making the antenna more broadband than the half-wave dipole.

The distant radiated field of the folded dipole is the same as that of the simple dipole.

Loop

The folded dipole discussed above may be considered as a special case of a loop antenna as well as a type of dipole. In fact, any closed loop of conductor which does not carry equal and opposite currents very close together, that is, within the "near," or "induction," zone, will fall into this category and will radiate at least some of the power supplied to it.

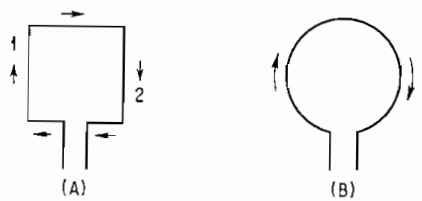


FIG. 7-5. (*A*) Square loop and (*B*) ring radiator.

The loop or ring radiator may be rectangular or circular, as seen in Fig. 7-5*a* and *b*.

Variation in the size of the loop yields radiation patterns of various shapes, in planes at right angles to that of the loop, as could be expected by comparison with the horizontal fields of two AM radiators with various spacing and phase relationship. That is, if sides 1 and 2 of the square loop in Fig. 7-5*a* are considered to he the two AM radiators, the combined radiation pattern in a plane at right angles to them will vary with the spacing between them. For loops with diameters less than 0.585λ the maximum field will be in the plane of the loop, and loops much smaller than a wavelength are therefore most commonly used as elements of television antennas. Radiation in a direction normal to the loop is always zero, regardless of the size of the loop.

Slot Antenna

As has been mentioned under Half-wave Dipole, the slot antenna has a great similarity to a dipole.

Figure 7-6*a* and *b* shows the two types, oriented so that the (*E*) fields of both are horizontal. Currents in the slot type spread out over the entire sheet, and radiation takes place from hoth sides of the sheet.

The resemblance between the two becomes even more pronounced when it is recognized that the field patterns of the two will be equivalent if the physical dimensions of the slot and the cross section of the dipole are the same. For example, the fields of the two radiators in Fig. 7-6*c* and *d* are the same. A very similar situation

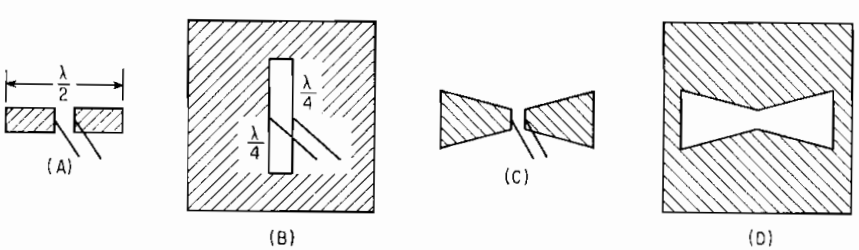


FIG. 7-6. Dipoles (*A*) and (*C*), with complementary slot-fed sheet radiators (*B*) and (*D*).

occurs in optics, where the phenomenon is known as Babinets principle. Using a term from optics, the antennas are said to be complementary where this situation exists.

Furthermore, the impedance of the slot is proportional to the admittance of the dipole of the same dimensions by the relationship

$$Z_{\text{slot}} = \frac{35{,}476}{Z_{\text{dipole}}}$$

and the bandwidth characteristics of one are the same as those of the other.

Actually, the above discussion is rigorously accurate only if the sheet is of infinite extent, but it is substantially correct if the edge of the slot is half a wavelength from the slot.

The input resistance to a slotted sheet is of the order of 500 ohms. This can be modified by shifting the position of feed along the slot. A value of 50 ohms can, for example, be obtained with the feed about 0.1 of the slot length from one end.

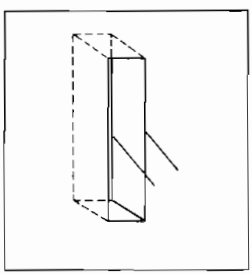


FIG. 7-7. Slot-fed sheet radiator with slot boxed to limit radiation to one side of sheet.

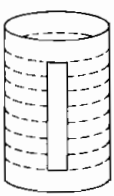


FIG. 7-8. Slot-fed sheet radiator bent to form a cylinder, showing resemblance to stack of ring radiators.

Radiation can be limited to one side of a very large sheet by boxing in the slot on the other side. If the depth of the box is such as to present zero susceptance at the feed point, the input impedance will be appropriately double that of the same antenna without the box (see Fig. 7-7).

Bending the sheet into a cylinder results in another form of slot antenna which also takes on characteristics of a stack of coaxial rings (Fig. 7-8).

Helical Element

A conductor wound in the form of a helix can be made to have maximum radiation either in the axial direction or in a direction normal to the axis, depending on the circumference of the helix and on its pitch. For radiation in the "normal" (or side-fire) mode, the helix dimensions must be small compared with a wavelength (see Fig. 7-9*a* and *b*).

The limitation on the size of a helix for normal operation imposes restrictions on bandwidth. This can be offset to some extent by phase-shifting devices along the helix which compensate for variations in impedance with frequency.

Since the helical element is used in almost a pure form in a commercial antenna to be described under Helical Antennas, further discussion will be left till that section.

Antenna Patterns

Azimuthal Patterns

In television, with the inherent limitations on coverage due to high-frequency propagation effects and the limitation on the number of stations with any area as set up in the existing allocation plan of the Federal Communications Commission, the large majority of requirements have been for omnidirectional antennas.

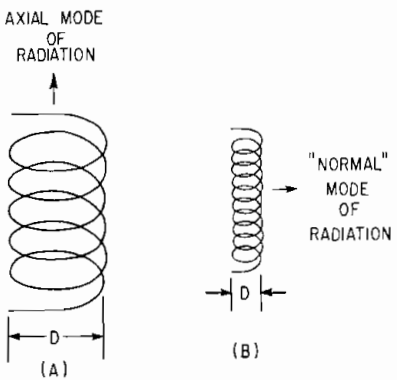


FIG. 7-9. Helical antennas, showing effect of pitch and diameter on direction of maximum radiation.

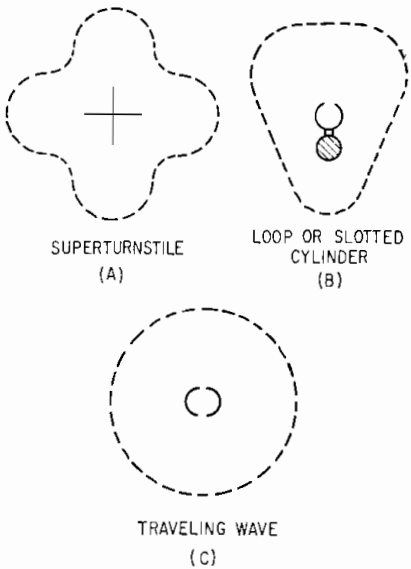


FIG. 7-10. Typical azimuthal patterns of well-known types of TV broadcast antennas.

As is pointed out in the discussion of omnidirectional patterns, the primary criterion of a truly circular or omnidirectional pattern is the intent to make it omnidirectional. In the past, variations of 3 db on each side of a true circle have been accepted as within the meaning of the word omnidirectional.

Since energy flows equally in all directions from a theoretical "point source," its horizontal pattern is a true circle. A thin dipole, vertical to the earth's surface (i.e., with vertical polarization), most nearly approaches this and has a similar azimuthal pattern. Except for these two cases, however, the finite physical size of television transmission antennas and the physical irregularities of their surfaces, due to the requirements of mechanical construction, result in the sum of the energies from various portions of the antenna as received in one direction varying from that received in another. Typical azimuthal patterns of some well-known antennas are shown in Fig. 7-10.

Except for the effects of supporting structures upon which they are mounted, rings or cylindrical antennas inherently have better circularity than other shapes. Ingenious methods have been used, however, to combine noncircular patterns of several radiators to obtain circularity. An illustration of this is the so-called turnstiling principle applied to dipoles. Figure 7-11*a* shows the typical "figure-eight" horizontal pattern of a very small dipole. If a second dipole is placed at right angles to the first, the two patterns will overlap, as shown in Fig. 7-11*b*. If both are fed in phase, addition of the radiated energies will result in a pattern such as is shown in Fig. 7-11*c*.

If the dipoles are fed 90° out of phase, the separate fields will add as shown in Fig. 7-12*a*. Here we have two dipoles 1 and 2 placed in space quadrature, with current conditions in the radiators as shown at various times. At time t_1 the current in dipole 1 and the resultant field of that dipole will be at a maximum, represented by a vector of unity length pointing upward. For dipole 2 they will be zero. The combined field will be unity. At time t_2, 30° in phase later, the field of dipole 1 will have reduced to 0.866 of its value and that of dipole 2 will be 0.5 of its maximum value. Addition of these two vectors at 90° in space phase will produce a resultant which again has a value of unity.

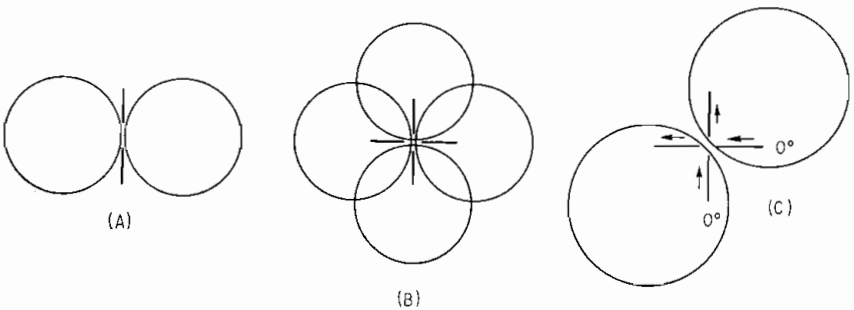


FIG. 7-11. Addition of fields of crossed dipoles. (*A*) Figure-eight pattern of a single dipole, (*B*) superposition of a second dipole at right angles, (*C*) pattern obtained when both dipoles are fed in phase.

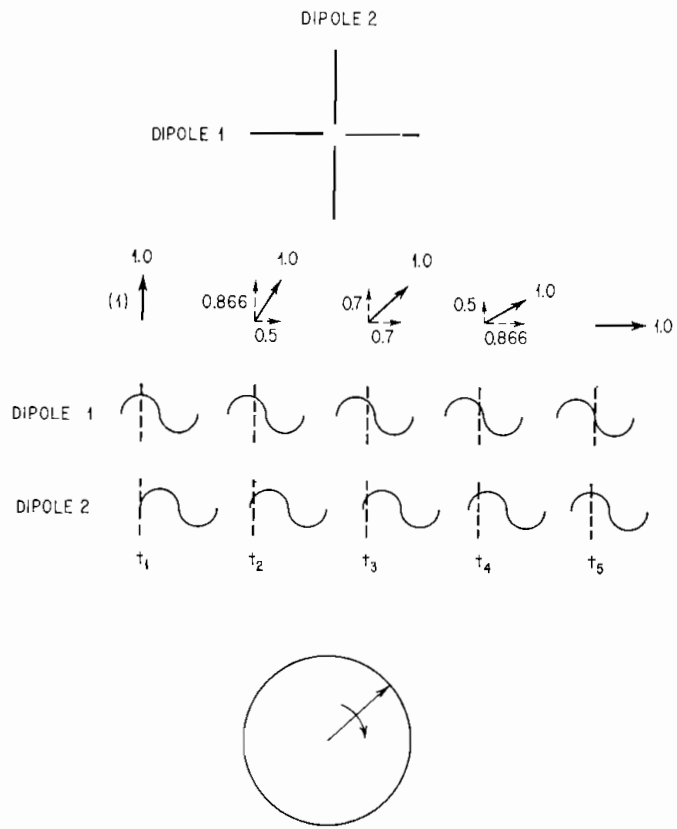


FIG. 7-12. Addition of field of crossed dipoles using "turnstiling" principle to produce circular pattern.

Analysis of the conditions at t_3, t_4, and t_5 indicates that the same total field will be obtained in each case. Ideally, then, we see that turnstiling produces a constant field rotating in the horizontal plane at the rate of the signal frequency.

In actual practice the dipoles are not infinitesimally small, and a supporting pole and feed lines tend to distort the fields of the dipoles from the ideal. The vectors do not then add in such a way as to result in the same total in all directions. The normal pattern is then scalloped, as shown in Fig. 7-10*a*, with the amount of variation from circular increasing with size of the supporting pole at a given frequency and with increase in frequency for a given-size pole.

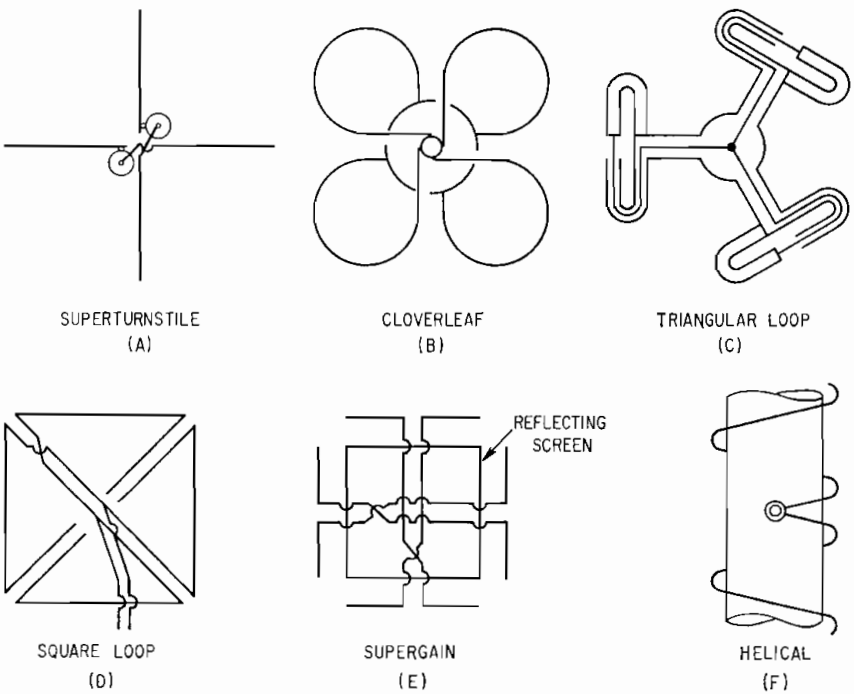


FIG. 7-13. Configuration of elements used to obtain omnidirectional patterns.

Other methods of obtaining omnidirectional patterns which have been used are the "clover leaf" of small loops (Fig. 7-13*b*), the triangle of folded dipoles (Fig. 7-13*c*), the small loop (Fig. 7-13*d*), the "supergain" with the dipoles backed by screens and fed in quadrature (as are the turnstiled dipoles) (Fig. 7-13*e*), and the helix wound around a tower structure with phase compensators to maintain correct phase relationship between successive turns of the helix (Fig. 7-13*f*).

Although omnidirectional antennas predominate in television broadcasting, there are locations where their use is impractical and even insufficient, and it becomes obviously desirable to direct the main portion of the radiated energy in both the horizontal and vertical planes to serve specific areas best. Examples in the United States are the Denver, Colo., area, where the presence of mountains to the rear of logical transmitting sites would set up undesirable reflections if the signal were allowed to radiate toward them, and the southeast coast of Florida, where the populated area borders the coast for great distances with only swamp immediately to the west.

Here the irregularities of the so-called omnidirectional patterns can be exploited to some extent, but truly "directional" patterns are more desirable. In order to obtain directional patterns, in either the vertical or the horizontal planes, correct relation in

amplitude and phase of the signal coming from different portions of the antenna is necessary. This can be accomplished to some extent by physically spacing the radiating elements properly. For a given spacing, the pattern can be further modified by varying the phase and amplitude of the respective radiated signals. An example of this is shown in Fig. 7-14*a* where two point sources are fed in phase with each other but are spaced 180° apart. By the time the signal from *A* reaches *B*, the phase of the signal being radiated from *B* will have changed 180°. If the signals are equal in magnitude, they will cancel in the direction to the right. The same line of reasoning shows that no signal will be radiated to the left. Toward the top and bottom of the page, the signals will always be in phase, giving a total radiation equal to the sum of the two individual ones. Factors showing amplitude and relative phase are given in all four cases.

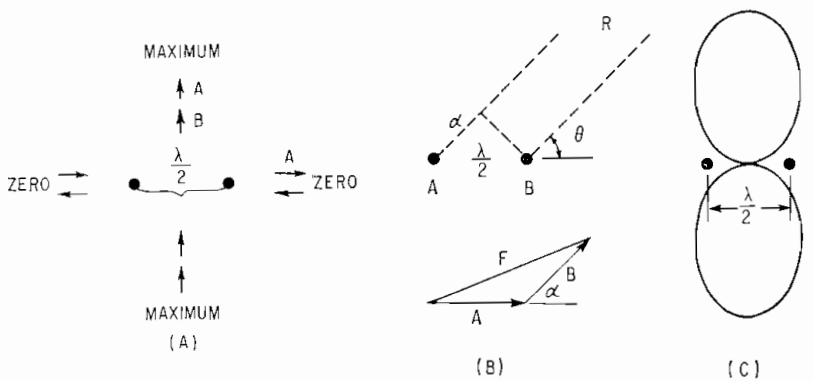


FIG. 7-14. Formation of field pattern from two sources placed a half wavelength apart, as shown in (*A*) and fed in phase. Leg of signal from source *A* in direction *R* is shown in (*B*) and the sum *F* of the signals from *A* and *B* are shown in (*C*).

At some other angle in the plane of the paper, conditions shown in Fig. 7-14*b* will pertain. At some great distance *R*, the signal from *A* will lag that from *B* by an amount α. The sum of the two will have a value *F*, somewhat less than the sum of *A* and *B*, as shown. If this process of analysis is continued for all angles of ϕ and the values plotted as relative magnitudes, a radiation pattern like the one shown in Fig. 7-14*c* (commonly called a figure-eight pattern) will be obtained.

If *A* and *B* are radiating 180° out of phase with the same spacing, signals to the right and left will reinforce each other, and they will by the same reasoning cancel at right angles to this, as shown in Fig. 7-15*c*.

For a spacing of one wavelength and a phase difference of 90° the signal from *A* will lag that of *B* by 90° toward the right, giving a resultant of 0.707 of the value of one signal. At an angle of $\phi = 60°$ toward *R*, the two will become equal but opposite in phase and the signals will cancel (Fig. 7-15*a*). Continuing this analysis yields a pattern shown in Fig. 7-15*b*.

It can be seen that varying the third parameter, amplitude of sigual, from either or both sources will increase the number of patterns which can be obtained, since the vectors now being added vary in length as well as in angle to each other.

The same method of analysis can be applied to more than two sources, with a corresponding increase in the number of vectors. In fact, the effect so analyzed actually takes place with any type of antenna which is not a point source, since each small portion of the antenna acts as a point source with particular phase, amplitude, and position relationship to every other such position.

Where individual radiators of finite size, having by themselves patterns which are directional in character (as, for example, a dipole), are grouped to form an "array,"

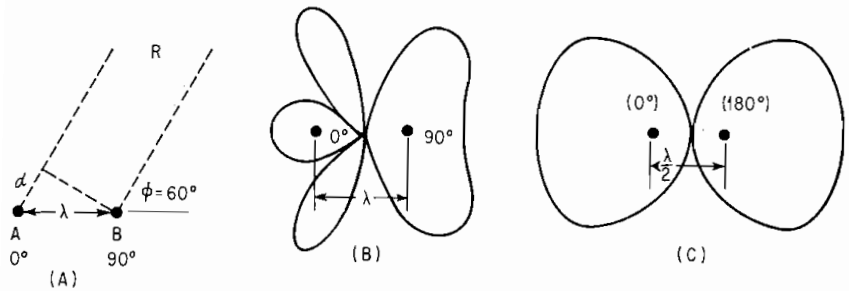


FIG. 7-15. Field patterns resulting from sources (*C*) a half wavelength apart fed 180° out of phase and (*B*) a wavelength apart fed 90° out of phase. (*A*) Formation of a null at $\phi = 60°$ for condition (*B*).

it is customary to consider each as a point or isotropic radiator in determining the phase at which their signals must be added to those of the other individual radiators, or "elements." For arrays of reasonable complexity, this relationship can usually be expressed as an equation, and the pattern which it represents is known as the "array pattern."

If the pattern of the individual element is itself expressed as an equation, the total field pattern (i.e., pattern of relative magnitudes of field intensity) of the array can be obtained as the *product* of the "element pattern" and the array pattern.

To find the phase of the resultant signal in any direction it is necessary to *add* the phase of the element pattern to that of the array pattern in that direction.

As pointed out above, an "element" may be considered in turn as a group of smaller elements. We have thus a tool for handling the calculation for quite complex arrays as illustrated in Fig. 7-16*a*. Assume that elements 1 and 2 are fed in phase and 3 and 4 are fed in phase but 1 and 3 are fed 90° out of phase. 1 and 2 give a pattern shown in Fig. 7-16*b*.

Now if 1 and 2 are considered as one single element with effective center of radiation halfway between the two and 3 and 4 are considered another element, the array pattern of the two new elements is a cardioid (Fig. 7-16*c*). Multiplying the patterns of Fig. 7-16*b* and *c* together in all directions yields the pattern shown in Fig. 7-16*d*.

If all elements of an array do not have the same element pattern, or if the array is quite complex in phase, amplitude, and geometry of elements, it is necessary to combine the element patterns on an angle-by-angle basis taking into account the

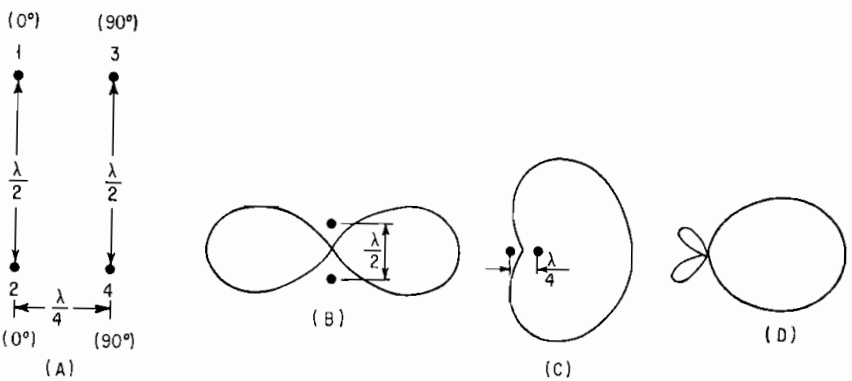


FIG. 7-16. Evolution of a pattern (*D*) by multiplication of an element pattern (*B*) by an array pattern (*C*). [Sources located and phased as shown in (*A*).]

array factor. An illustration of the method is shown in Fig. 7-17, where two point sources are fed with unequal currents in the ratio of 2 to 1 and with the upper one lagging the lower by 30°. In the direction $\phi = 60$, A lags B by $\lambda/2$ owing to its relative position. It lags an additional 30° due to the imposed phase. The unequal vectors are therefore combined at an angle of 90° + 30° = 120°, giving a total amplitude of 1.732. Increasing the number of elements simply requires the addition of more vectors with correct relative signal strength and phase.

Examples of directional patterns of antennas in current use are shown in Fig. 7-18.

A reversal of the above procedure makes it possible to start with a desired pattern and to determine what relative phases and amplitudes are required to obtain it. A particular type of element and form of array must be presumed, of course, to make such a computation possible. This procedure is known as pattern synthesis. The speed of electronic computing devices renders this approach highly practical and effective.

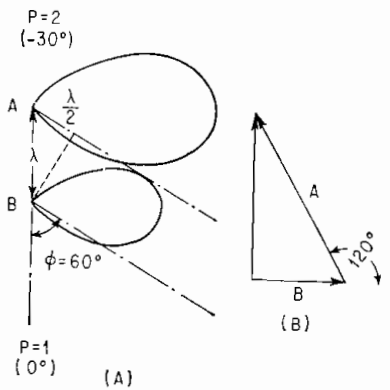


FIG. 7-17. Combination of signals from two sources having unequal currents and phase and positioned a wavelength apart.

The above discussion of the calculation of patterns has ignored the effects on element patterns of the presence of other radiators in close proximity. Mutual effects among elements alter current and phase conditions within the element and must be taken into account if the effect is appreciable.

A word should be said about the limitation on the use of directional antennas for commercial television in the United States. Where there is clear indication that directionalizing will not be against the best interests of the market area being served, the Federal Communications Commission will approve its use. The broadcaster may desire this to conserve power by limiting radiation over nonpopulated areas or to

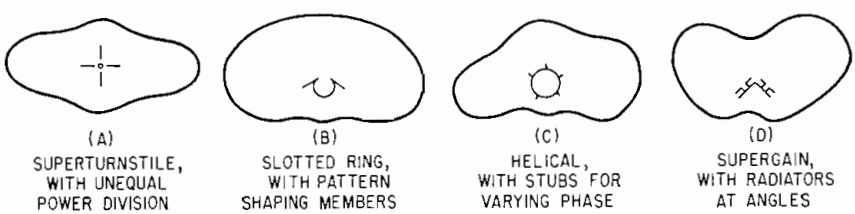


FIG. 7-18. Examples of directionalized horizontal patterns in current use.

avoid multipath echoes from nearby mountain ranges. There is currently in effect a rule which provides that the difference in field strength between the maximum signal and the minimum signal in the horizontal plane shall not exceed 10 db.

Vertical Patterns

The need for higher gain (see under Gain) than can be obtained with a single radiating element requires "stacking" the elements one above another. This, on the undesirable side, increases the condition of "lobing," or wide variations in the amplitude of the resultant radiation pattern in the vertical planes. On the desirable side, however, it provides more separate elements by control of which the patterns can be made nearly ideal for television broadcasting.

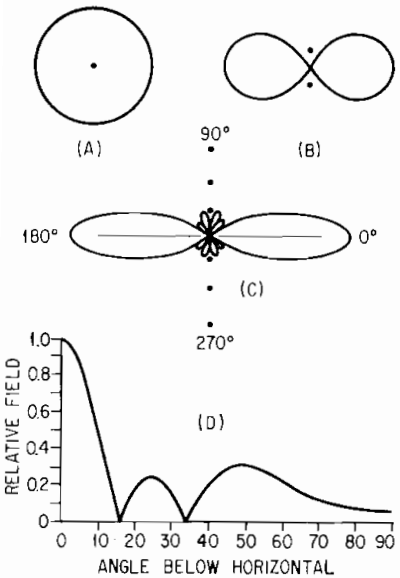


FIG. 7-19. Effect of stacking several point sources having equal currents and phase. (*A*) Vertical pattern of single source, (*B*) two sources, (*C*) six sources. Information given in (*C*) is shown in rectangular coordinate form in (*D*) for angles between horizoutal (0°) and directly below the array (270°).

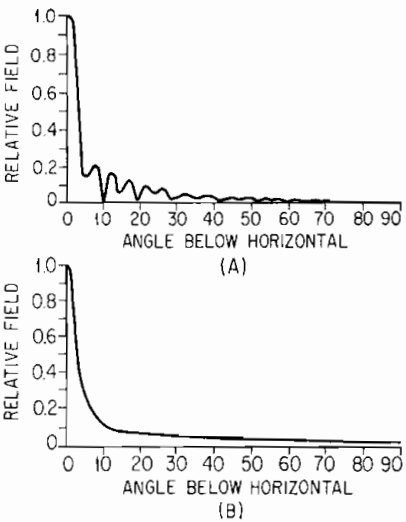


FIG. 7-20. (*A*) Vertical field pattern of antenna with a gain of 12 having twice as much power in the upper half as in the lower half. (*B*) Vertical field pattern of an antenna with many separate radiating elements with ideal phase and power distribution to obtain smooth pattern.

Reference is made to the discussion of Azimuthal Patterns for an outline of the theory of pattern formation. The same principles apply in the vertical plane. Figure 7-19*a* shows the vertical pattern of a point source or of a horizontal dipole. Figure 7-19*b* and *c* shows the effect of stacking two- and six-point sources one above another, a half wave apart, with currents of equal amplitude and phase. Figure 7-19*d* shows the same information as Fig. 7-19*c* for the portion of the pattern between $\phi = 0°$ (horizontal) and $\phi = 270°$, on rectangular coordinates, with field intensities plotted against angle below the horizontal. This is the customary method of pattern representation, enabling one to see in convenient manner the relative field strength at any angle into the area served by a broadcast station down to the base of the antenna tower.

The presence of nulls in the pattern of a television broadcast antenna is undesirable, because receiving areas at the angles where nulls are indicated received either less than the required signal or one which is the sum of reflections from objects which lie outside the null area. This latter condition often results in multiple "echoes" in the received picture.

The angles at which nulls appear for the case of a vertical array of equally spaced radiators fed by signals of equal amplitude and phase can be approximately found by the relation

$$\phi = \arctan \frac{\pm K}{nd}$$

where K is the null in question (the one nearest the main beam having a K value of 1, the next one 2, and so on). The number of elemeuts is given by n, and the spacing of elements in wavelengths by d.

A quick rule-of-thumb method to obtain the distance of a null is to multiply the antenna height by the antenna gain and divide by K, thus

$$d = \frac{hg}{K}$$

Various methods are used in the design of antennas to "fill in" the null axis. Simple power division, whereby the upper or lower half of the elements are fed with a greater amount of power than the other half, results in the elimination of all odd-numbered nulls (see Fig. 7-20*a*).

A more complex power distribution was proposed by J. S. Stone, wherein successive elements are fed with amplitudes proportional to the coefficients of a binomial series. Thus for three elements the distribution would be in the relation 1, 2, 1, and for five 1, 4, 6, 4, 1. The result is an elimination of all minor lobes and all nulls except the ones directly at the base of the tower and directly above the antenna.

A similar result is obtained if the amplitude is exponentially tapered from one end of the antenna to the other, as in the traveling-wave antenna.

Still more elaborate is a combination of power division and phasing to obtain specific desired pattern shaping (see under UHF Antennas).

With the number of elements available in antennas having gains of 30 and upward, patterns have been obtained by these methods which are almost without a visible ripple (see Fig. 7-20*b*).

The filling of nulls, while highly desirable in cases where the area served would be otherwise affected, must be done at the expense of gain to some extent, since power is usually drawn from the main beam to furnish the filling signals. Proper pattern synthesis can, however, reduce this effect to a minimum, taking power instead from the portion of the pattern above the horizon, where it would otherwise serve no useful purpose.

Directionalizing the vertical pattern so as to direct the main lobe of energy at other than the horizontal direction is permitted by the Federal Communications Commission where it can be shown that the public can be more adequately served. Certain restrictions limit the type and amount of such directionalizing, however, namely:

1. The power radiated in the main lobe may not exceed that authorized for non-directional operation for the particular area.
2. Power radiated in any direction above the horizontal may not exceed the power radiated in the horizontal after directionalizing.
3. Requirements for Class A and Class B coverage must still be met.

Directionalizing in the vertical planes is normally accomplished by variation in phasing among elements in the array. This may be a lumped effect, as when the lower half of an antenna is fed in such a way as to lag the upper half in phase, or it may be a smooth transition of progressive phasing throughout the length of the antenna. In either case, the net result is to tilt the main beam downward, so that it points to the horizon or below. Antennas on Mt. Wilson in California, serving the Los Angeles area, offer examples of this type of directionalizing to obtain maximum coverage of the area with the least loss of power over the ocean beyond.

Combinations of electrical and mechanical "tilt" are used when the antenna is on top of a plateau overlooking a city in which a strong signal is desired. When the electrical and mechanical tilt are made equal, the total tilt toward the city is double the electrical tilt alone, with no tilt in the opposite direction along the plateau.

In considering the formation of total patterns a word should perhaps be said on the effect of distance on this formation. With antennas having a length (or "aperture") of several wavelengths, there is a distance within which the shape of the pattern is found to vary. This occurs because the distance is so small that radiation from the separate elements comes to the receiving point at different angles from the source rather than along parallel paths. Movement changes the angles and the distances from the separate elements at an unequal rate, resulting in variations in the sums of the individual signals. The field within this region has not "stabilized," and

calculations which assume parallel paths of the rays do not yield an accurate result. The region from the outer border of the near or "induction-field" zone to the point at which the rays become essentially parallel and the pattern stable is known as the Fresnel zone. Beyond this region the formed pattern takes the form investigated by Fraunhofer, and the region is known as the Fraunhofer zone. For practical purposes the distance to the boundary between the zones is

$$d = \frac{2a^2}{\lambda}$$

where a is the total aperture in wavelengths.

Gain

Directionalizing horizontal and vertical patterns has been discussed in previous sections. The object is to force the energy to radiate in directions in which it can be usefnlly employed. In television broadcasting, these directions involve all the region below a plane tangent to the earth's surface and passing through the antenna. The area with which we are concerned is from the base of the antenna out to points somewhat beyond the horizon. Power radiated above this region serves little useful purpose, and it is desirable to reduce it as much as possible.

To indicate the effectiveness of this directionalizing process, the increase of signal intensity obtained thereby is related to the signal intensity which would be received from some standard reference antenna such as a half-wave dipole or an isotropic source having the same input power. The value of the ratio so obtained is called the "gain" of the antenna. A more specific definition of gain is given on page 2-222.

It should be noted that because of the fixed relationship between the shapes of the patterns of the two antennas commonly used for reference, a gain value as compared with a half-wave dipole can be converted to a corresponding value nsing an isotropic source as a base of comparison by use of a mnltiplying factor of 1.64.

As has been seen, the effect of adding more and more basic elements in a linear array with equal spacing between them and energized by equal currents in the same phase is to force the formation of a major lobe of energy. The result is greater gain in the direction of that (main) lobe. Gain can just as well be stated for any other direction, and at times this is done, but usually statements of gain are limited to the main-lobe direction.

Ideally, the determination of the value of gain of an antenna would be made by measurement of the received signal in the direction being considered followed by the same measurement with the reference antenna inserted in place of the antenna being evaluated. This is one of the methods in use. Various precautions must be taken to ensure accuracy, such as the construction of a theoretically exact reference antenna and recognition of the change in propagation conditions during the substitution process and of the difference caused by the electrical effect of the environmental condition (the supporting structure, for instance).

For all practical purposes, it has been found to be just as accurate to measure the radiated pattern of the antenna being considered in as much detail as is necessary to be able effectively to reproduce a solid, the distance to each point of which from the antenna position within it is representative of the relative value of field strength in that direction.

To determine the gain, it should be remembered that with the same input power to the two antennas being compared and omitting ohmic losses, the total radiated power will be the same in both cases. If, then, we imagine the solid referred to above as being remolded into a sphere (in the case of comparison with an isotropic source) of the same volume, this volume will be the same as that of the pattern of the reference antenna with the same power input. With this condition and holding the volume constant, if the pattern of the measured antenna is allowed to re-form to its proper shape, the main lobe will project beyond the surface of the sphere. The radius of the sphere and the distance to the tip of the main lobe will be in terms of volts. Corresponding powers will be proportional to the squares of these values. Compari-

son of these powers will give the power gain desired as compared with an isotropic source in this instance.

An illustration of this in one plane only is given in Fig. 7-21. The circle contains the same area as the pattern being considered and represents the field pattern of an isotropic source with the same power input. The gain in the main lobe, ignoring losses, will be

$$G = \frac{E_A}{E_i}$$

For an antenna having the same vertical pattern in all directions of azimuth, comparison using the pattern in only one plane is sufficient. Since such an ideal case never exists. However, integration of the entire pattern is required to take account of directivity of the horizontal pattern and variations in the shape of the vertical patterns.

As an example, gain determination of a superturnstile antenna is found to be quite accurate if one horizontal pattern is taken along with vertical patterns every 30° about the antenna. These patterns can, of course, be computed for a given antenna if enough information of the characteristics is available to justify confidence in the accuracy of computations. Determination of the gain in this case follows the same method as with measured patterns.

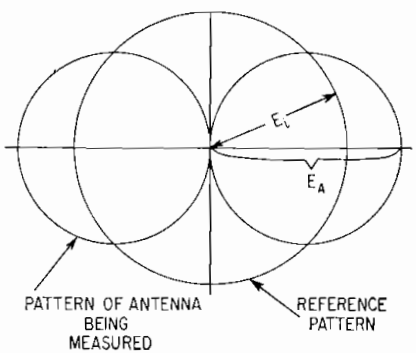


FIG. 7-21. Comparison of pattern of a measured antenna with circle of equal area to determine gain.

The method of obtaining measured field patterns of broadcast television antennas is to support the antenna in a horizontal position at a sufficient distance from ground and nearby objects to minimize the effects of reflection. By the principle of reciprocity a signal radiated from a distant source and picked up by the antenna under test will appear at the input to the antenna with the same value as if the input and output conditions of the antenna and the distant source were reversed. This simplifies the measurement, since in this way work on the antenna and measurement of the pattern can take place at the same location with the distant source fixed and the signal simply radiated.

With these conditions, rotating the antenna about a vertical axis will provide a vertical field pattern in one plane (and for both sides of the antenna). Revolving the antenna 30° about its own (normally vertical) axis will place it in a position where a new vertical pattern can be taken.

With the antenna at right angles to a line to the "source," revolution about its own axis will yield a horizontal pattern.

For any other position than that normal to the line to the source, an azimuthal pattern can be obtained for the angle being considered (for instance, the pattern of the variation of the maximum value of a main lobe tilted below the horizontal).

Since it is customary to measure the gain of an antenna in terms of the amount of signal radiated with the desired polarization considered effective, all energy with other polarizations being considered lost for effective use, measurement of this lost energy is also necessary, the amount being accounted for as a decrease in gain. This is usually done by rotating the polarity of the transmitting source and determining the amount of energy received for this condition by the antenna under test.

In the statement of gain for commercial purposes, losses in the feed system and radiating elements must also be accounted for.

Gain is proportioned to aperture, which, for the types of antennas used in telecasting, is the active height of the antenna. Length represents both antenna cost and

an overturn load for which the tower must be adequately designed. The efficiency with which the aperture is used becomes an important criterion of antenna design. Gain per wavelength is a yardstick by which this efficiency is indicated. This yardstick must, of course, be used judiciously, since desired characteristics such as null fill and directionalizing must, in turn, be paid for in terms of gain. In general, omnidirectional broadcast antennas currently being built and used have gains per wavelength which vary between 1.05 and 0.80, depending on the amount of null fill.

It is interesting to note that for a uniform current sheet, with all elements of the sheet having equal phase and amplitude, the theoretically maximum gain per wavelength which can be achieved for antennas over two wavelengths is 1.22. With such a value, full nulls would exist throughout the pattern. No commercial antennas now in use attain this ideal value.

Impedance

Transmission-line theory tells us that maximum transfer of power takes place when a load terminating a line has the same impedance as the characteristic impedance of the line. Since the final load in a radiating system is space, it is desirable that the antenna match the impedance of space, or approximately 377 ohms, at the point of radiation.

The ease with which a signal is radiated determines the effective impedance of the antenna at the boundary with space. Thus, a logarithmic horn of the type shown in Fig. 7-22 flaring outward to a considerable diameter at the mouth expands the wavefront and launches it practically without interference. If the characteristic impedance of the horn (determined by the ratio of D to d) is maintained down to the entrance to the taper, that entrance (input to the antenna) will have an impedance of 377 ohms. Because the impedance throughout the elements is constant and resistive in nature, the antenna is not sensitive to frequency, signals of all frequencies being transferred equally well. This insensitivity to frequency is called "bandwidth," and the horn has nearly the ultimate in bandwidth.

A biconical dipole antenna (Fig. 7-4*a* and *b*) with flaring arms, has a similar action and an input impedance of around 300 ohms. This, too, has a large bandwidth. On the other hand a dipole with thin areas is very critical to frequency and so transfers the energy to the radiated field at a maximum rate only at the frequency where the over-all length is $\lambda/2$. At other frequencies considerable reflection occurs and the input impedance changes rapidly. At the resonant frequency the input impedance is about 73 ohms.

The input impedance of a superturnstile antenna (see under Superturnstiles) is about 150 ohms (both batwings together), of a helical antenna 100 ohms and of a resonant fullwave slotted cylinder about 40 ohms.

In each of these cases it will be seen that the antenna has, because of its construction and electrical response, effectively transformed the impedance as seen at the space boundary to some other value. If, in the process, compensation has been made so that the impedance seen by the signal is relatively constant at all frequencies involved, the antenna will have adequate bandwidth. If compensation is not made, the bandwidth will be narrow. The superturnstile, with its broad radiators and compensation afforded by the slot between radiator and pole, is very broadband. A ring or a thin-dipole antenna, on the other hand, is extremely narrow.

If the load terminating a line does not have an impedance equal to the characteristic impedance of the line, some of the power is not transferred but is reflected back down the line. Combination of this energy with that coming up the line sets up "standing waves" similar to those found at sound frequencies in musical instruments or on a vibrating string. The ratio of the maximum to the minimum voltage of such a wave is called the voltage standing-wave ratio (VSWR) and is denoted by the symbol ρ. It is used as a figure of merit to indicate the efficiency of transferal of power.

Another such figure of merit is the ratio of reflected to incident component of voltage at the load or at an impedance discontinuity. This is denoted by the symbol Γ and is called the reflection coefficient.

The values of ρ and Γ are related by the formula

$$\rho = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

There are several undesirable results of a mismatch of impedances of line and antenna. Because of the standing waves set up, high current regions occur every half wavelength along the line. If the mismatch is of considerable magnitude, the ohmic losses resulting may overheat the line, causing damage, particularly at junction points. The high voltages of the standing wave, which also occur every half wavelength, may exceed the rated voltage of the line, causing corona or flashover.

A third effect of an impedance discontinuity and the resulting reflection of power is the possibility of creating an "echo," or repeated picture as viewed by a receiver. If the portion of the signal reflected from a mismatch in the line or antenna is not totally absorbed in the output circuit of the transmitter, it is rereflected toward the antenna. The part of this which reaches the antenna and is radiated appears as a second picture, to the right of the primary one, which may be of such intensity as to be very objectionable.

Where an echo causing mismatch occurs, it is possible to locate approximately the section of line in which the reflection occurs by measuring the distance between the initial picture and the echo on a receiver screen. Since the width of a picture represents 53 μsec of time, and since a signal can travel 26,150 ft through a transmission line and return to the starting point in this length of time, the proportion of the picture width (in inches) which the delay (in inches) of the echo represents is the same proportion of 26,150 ft which the signal traveled before striking the reflecting mismatch. That is,

$$D = 26{,}150 \times \frac{\text{delay of echo beyond initial picture, in.}}{\text{width of receiver screen, in.}}$$

where D is the distance from transmitter to discontinuity.

It has been pointed out that antennas may transform the impedance seen at the space boundary to some other impedance at the input. If, for instance, the D/d ratio of the horn shown in Fig. 7-22 was changed gradually along its length, there would be a smooth transition to some new impedance looking into the input of the value

$$Z_c = 138 \log \frac{D \text{ (input)}}{d \text{ (input)}}$$

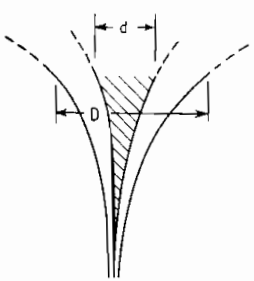


FIG. 7-22. Logarithmic horn used as ideal broadband radiator.

Because the horn is difficult and costly to manufacture, it is customary to use simpler and more abrupt transformations in order to match two unequal impedances. A simple and effective transformer for a narrow band of frequencies is obtained by inserting between the impedances to be matched a quarter-wave section of line having a characteristic impedance equal to the geometric mean of the two impedances. That is,

$$Z_c \text{ (of transformer)} = \sqrt{Z_1 Z_2}$$

Since the length of the transformer is $\lambda/4$ for only one frequency, the bandwidth of the transformation is small. Matches over wider bandwidths can be obtained, however, by using several such transformers end to end (thus approximating the

tapered horn). Choice of proper characteristic impedances for the various sections can be made by following standard techniques or by cut and try.

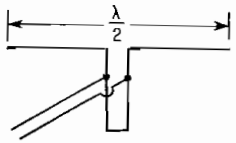


FIG. 7-23. Impedance matching by selection of point of feed of dipole with shunt stub.

Another method of impedance matching is to choose a point in the line where the input admittance appears as pure susceptance. Insertion of a lumped susceptance of opposite sign (for instance, a disc of Teflon as capacitive susceptance) will balance that in the line and yield a matched condition. This method is good only for a single frequency.

Impedance matching of an antenna to a line can be accomplished by choosing a point to feed the antenna where the impedance of the antenna appears as the desired value. Off-center feed of a slot, for example, offers a considerable choice of input impedance.

The placement of input to a $\lambda/2$ dipole along a quarter-wave shorted stub offers again a large range of input impedance (see Fig. 7-23).

Bandwidth

As discussed under Impedance, the range of frequencies over which a circuit maintains a more or less constant impedance is called its impedance bandwidth. Limits of the bandwidth occur when the impedance exceeds some value agreed upon for defining the bandwidth.

Methods of obtaining this bandwidth have been touched upon. Basically they consist of so designing the antenna or intermediate transforming elements that they are not sensitive to frequency change. The horn, through its shape, presents only resistance at the input. The superturnstile (see under Superturnstiles), by paralleling a parallel-resonant circuit (which becomes capacitive with increase in frequency) with the series-resonant circuit of its radiator (which becomes inductive with increase in frequency), obtains a virtual cancellation of reactance over a considerable frequency range, rendering this antenna one of the most broadband television antennas in general use.

The same principle is applied in the traveling-wave antenna, which, instead of using quarter-wave stubs in parallel with the feed point as in the superturnstile, utilizes a slot whose shape provides the response of a parallel-resonant circuit.

On other antennas, broadbanding stubs and, at times, a series of half-wavelength transformers, spaced at proper intervals apart, are used to obtain impedance bandwidth.

Another interesting method, quite different from the above, is the use of a "power equalizer" to broadband otherwise narrow-band radiators. In supergain antennas (see under Supergain Antenna), which are quite narrow band at low channels (2 to 6), the bridge diplexer (see Aural and Visual Transmissions) can be effectively used to absorb most of the power reflected from the antenna. Figure 7-24 shows east and west radiators being fed 90° out of phase with north and south radiators.

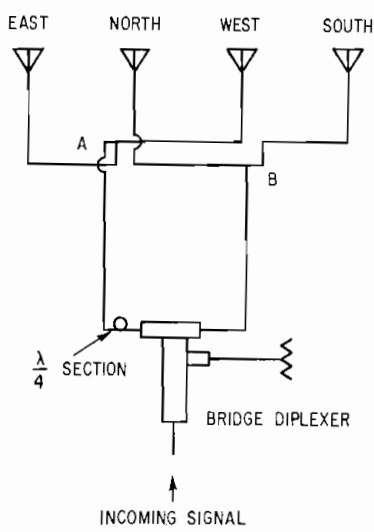


FIG. 7-24. Use of bridge diplexer as "power equalizer" in broadbanding of supergain antenna.

The incoming signal fed from a notch diplexer or filterplexer through a single-line feed enters the visual input of the bridge diplex and leaves it as two signals 180°

out of phase (or + −). After passing through the additional 90° length on the left line, the signal in this line reaches *A* 270° out of phase with that reaching *B*. With equal reflection from *A* and *B*, the reflected signals return to the diplexer.

The 90° section again shifts the phase in line *A*, and the two signals reach the diplexer *in phase*. The diplexer action is such that both reflected signals are now passed out through the aural input to a load which absorbs all the power. Since none return to the transmitter by way of the visual input, there is no standing wave, and the transmitter therefore appears to see an impedance match over the whole channel.

An antenna may have impedance bandwidth, but its radiation pattern may vary with frequency. That is, it may not have pattern bandwidth. This normally occurs because radiating portions of the antenna, being fixed in position mechanically relative to other elements, in effect change this relative spacing as the frequency changes (i.e., in terms of wavelength). The higher the frequencies of operation, the less sensitive antennas are to this as a general rule, because, for a given spread of frequencies (6 Mc for television), the present bandwidth (ratio of operating range, Mc/center frequency of range, Mc) becomes less at high frequencies. Thus, a change of 6 Mc at 600 Mc is only 1 per cent, while at 60 Mc it is 10 per cent.

The traveling-wave antenna, operating normally in the vicinity of 200 Mc, takes care of the problem by incorporating circuit elements which effectively retard the phase of the signal with increase in frequency and advance it with decrease in frequency (see Traveling-wave Antenna). The result is to maintain the wavelength constant at all frequencies of a channel and so in turn to maintain the radiating elements at constant virtual spacing from each other.

Pattern bandwidth is important to the maintenance of video response. Correct relationship of amplitude and phase of signal is important at all frequencies within the channel, within the limits of good engineering practice, particularly in color transmission.

Gain bandwidth is the range of frequencies over which the gain remains constant. This is, of course, closely related to pattern bandwidth. It is particularly important in television, where it is desirable to use a given physical size of antenna over a broad number of channels to obtain approximately the same characteristics at each channel.

Feed Systems

The feed system of a television broadcast antenna is commonly considered that portion of the transmission system having its input at the antenna terminal which is at the top of the vertical run of coaxial transmission line in the tower and its output at the radiating elements.

Most antenna gains in the manufacturers' literature take the losses of the feed system into account, which are considered as reduced antenna gain. Therefore, when system losses are calculated, the feed-system loss should be excluded, having already been accounted for.

Types

In the television broadcasting field, three types of feed systems are in wide use. They are the branching, standing-wave, and traveling-wave feed systems. Each meets a need peculiar to its own application. Where frequencies vary from 54 to 890 Mc, where power-handling-capacity requirements vary from 500 to 100,000 watts, where gains vary from 0.5 to 60, and where pattern shapes vary between extreme limits, it is logical that good economics dictates various types of feed systems.

Branching. The branching-type feed system is used in the superturnstile antenna. It is characterized by the progressive subdivision of input signal in a more or less uniform manner, from the input of the antenna to the end seals. A large majority of the antennas using this feed system accomplish the subdivision of power by means of a junction-box assembly into which is plugged the individual radiator feed lines.

Figure 7-25 is a picture of a junction box. If filling of the first null is desired on antennas of 12 sections, the power can be divided 70 per cent in the upper six sections and 30 per cent in the lower six sections to obtain a fill.

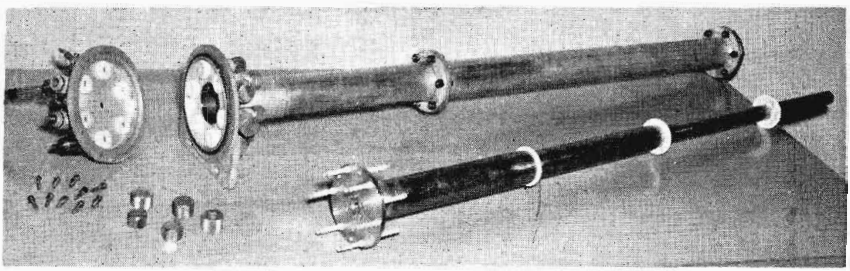


FIG. 7-25. A junction box as used in 12-section superturnstile antenna. Twelve feed lines at a 77½-ohm impedance from 12 radiators are combined. The net impedance is transferred to the line impedance of 51½ ohms by means of a three-section transformer.

Standing Wave. The standing-wave-type feed system is used in slotted-cylinder UHF antennas. For details refer to *Slot Types* on page 2–263.

Traveling Wave. The traveling-wave feed system operates on the principle of a gradual attenuation of the input signal through radiation resistance as it progresses from the input along the aperture of the antenna. An application of this principle is the helical antenna. Page 2–254 gives more details. A more recent development is the application of this feed system to a cylindrical-slot antenna known as the traveling-wave antenna described on page 2–257.

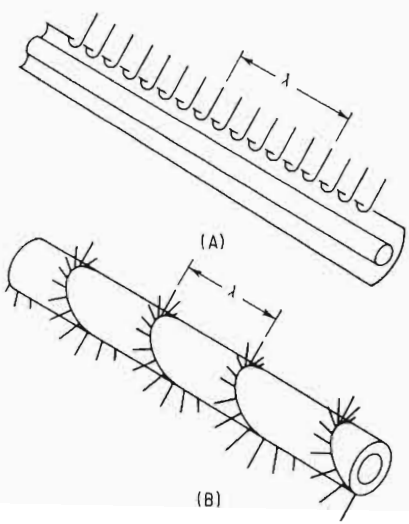


FIG. 7-26. Basic principles employed in the traveling-wave antenna feed system.

Figure 7-26*a* shows the principle of this feed system using short rod radiators to illustrate the theory. A number of radiators per wavelength uniformly spaced are loosely coupled to a coaxial line. Because of the number of radiators and the relatively slight reflection due to each, the effect is essentially that of a uniform loading. The result is a uniformly attenuated traveling wave in the line. Since a traveling wave has a linear-phase characteristic, the excitation of each successive radiator will be lagging from the previous one by an amount which depends on the spacing between the radiators and the velocity of propagation in the line. If the radiators are alike, their currents will have the same phase relationship as the excitation. Thus the radiating currents will be successively lagging, and repetition of phase occurs after every guide wavelength.

To obtain an omnidirectional pattern the radiators, instead of being in line, can be moved around the periphery to form a "spiral" as shown in Fig. 7-26*b*. For a horizontal main beam the pitch of the spiral has to be equal to the guide wavelength in the transmission line. In this arrangement all the radiators in any one vertical plane on one side are in phase and the phase difference between radiators in different planes equals the azimuth angle difference between the planes; that is,

the phase rotates around the periphery. The rotating phase produces a rotating field which, because of the relatively small amount by which the magnitude of current changes from layer to layer, produces an omnidirectional pattern.

Aural and Visual Transmissions

For the broadcasting of standard television signals, the video-signal amplitude modulates a separate visual transmitter and the audio-signal frequency modulates a separate aural transmitter, the output of which is generally one-half the peak visual power output of the visual transmitter. To radiate these two separate signals, various techniques can be employed.

Separate Antennas. Separate antennas can be used, one to radiate the visual signal, the other to radiate the aural signal. When this procedure is used, a separate transmission line connects the output of the particular transmitter to the input of the respective antenna. Two precautions should be observed: (1) The isolation of the individual antennas must be sufficient to prevent interaction and cross modulation within the systems. (2) The patterns of the individual antennas must be sufficiently alike so that the ratio of the visual signal to the aural signal is neither too large nor too small. An example of this kind of installation is the use of the upper half of a superturnstile antenna for visual and the lower half for aural transmission.

Bridge Systems. The bridge diplexed system of antenna feed is used in the superturnstile antenna. The complete antenna is used in both visual and aural transmission. The superturnstile antenna is fed through a bridge network where the two inputs are in quadrature. The radiating systems are also arranged in a quadrature relationship so that the azimuthal pattern is substantially circular as described under Azimuthal Patterns. The north-south system, which radiates a figure-eight horizontal pattern is constructed in a vertical plane at right angles to the plane of the east-west system, which also radiates a figure-eight pattern with 30 db or more isolation between the two systems. Each of these radiating systems forms a termination for the two legs of the "Wheatstone-bridge-type diplexer" as shown in Fig.

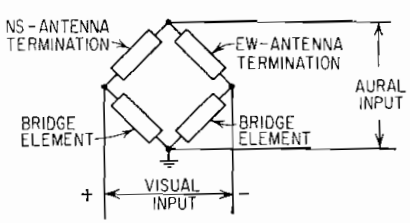


FIG. 7-27. Bridge diplexer represented as a Wheatstone bridge.

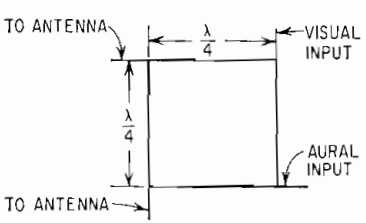


FIG. 7-28. Ring T diplexer schematic showing inner conductors only.

7-27. The visual signal is fed into the bridge balanced to ground, and the aural signal is fed in unbalanced to ground.

The superturnstile antenna can be fed with a "ring-T" type of diplexer, which also requires a two-line feed as illustrated in Fig. 7-28.

Notch Diplexer. Where an antenna has a single input, a network for combining the visual and aural signals is required. One type of circuit which accomplishes this function is shown in Fig. 7-29. The aural signal, divided by means of a balun (*bal*anced to *un*balanced network [9]), is reflected from the cavities tuned to aural frequency. These cavities are arranged so that they present a very low impedance across the line. Because of the quarter-wave separation the aural signal on the lower line in the figure travels an additional half wave to and from the cavity reversing the phase so that the signal enters the balanced antenna terminals instead of returning to the

[9] Balanced is sometimes referred to as push-pull, and unbalanced as push-push.

unbalanced aural input. Any anral energy which leaks past the cavities is absorbed in the terminating load.

The balanced visual signal enters the balanced antenna terminals. Any energy in the visual signal which is at the aural frequency is rejected and because of the quarter-wave separation of the cavities is reversed in phase and is absorbed by the terminating load. In order to obtain the proper visual response, a shaping cavity is sometimes associated with each aural cavity.

Filterplexer.[10] A vestigial-sideband filter is a device used with some types of transmitters to absorb the rather small lower sideband energy lying outside the 6-Mc channel. When a notching diplexer is used, it is desirable to combine the visual-sideband filter and the notching diplexer into a single unit.

This is accomplished in a manner similar to the notching diplexer described above. As shown in Fig. 7-30, two additional pairs of cavities are used on opposite sides

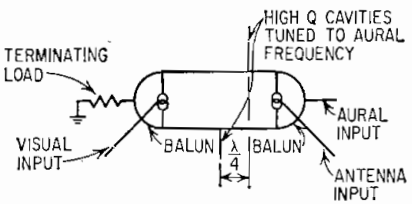


Fig. 7-29. Notching diplexer schematic.

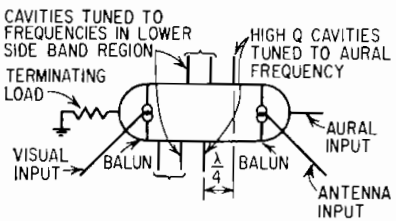


Fig. 7-30. Schematic of filterplexer.

to provide reject points in the portion of the lower sideband lying outside the 6-Mc channel. The rejected lower-sideband energy is dissipated in the terminating load.

Isolation Using Traveling-wave Feeds. On an antenna which employs a traveling-wave-type feed, the input power is radiated as the signal proceeds away from the input along the aperture. By the time the signal arrives at the end of the aperture, it should be so low that the reflected energy from the end is quite small. In practical designs this energy is about 20 db below the input. Therefore, if the visual signal is fed at the center of the aperture, the aural signal can be fed at the ends. The helical antenna described on page 2–254 uses this method of feed.

System Performance

The EIA specifications, while recognizing the need for a system specification, has never established one. By system specification is meant the performance of the entire antenna system including the antenna with its feed system, the main transmission line from the station to the antenna, switches and various fittings in the station, and the diplexer. Most antennas are built to a VSWR specification of 1.1 to 1. In some cases the same value was used for the transmission line. At times the same specification has been used for the entire system. Since there is bound to be vector addition in some parts of the band, which can be found if the measurements are sufficiently discerning, it is difficult, if not impossible, to meet a system VSWR of 1.1 if each component is designed to the same specification. Hence, in many cases it is necessary to make changes in the system, which do not improve the picture, merely for the purpose of meeting a specification which does not truly describe system performance. System performance, to be meaningful, must be related to the quality of the picture transmitted. This is best described by the ability of the system to faithfully reproduce a square-wave pulse since in essence a picture is composed of a series of such pulses. Hence a specification is currently being studied based on the relative reflection voltage returning from a radio-frequency pulse propagated along the line

[10] Also designated as a Filtrexer.

to the antenna. If narrow pulses and broad pulses are used, the complete system can be analyzed in a manner which determines true performance.

Since this study is currently in progress, full details cannot be given at this time.

Multiple Antennas

In an area where two or more television stations are providing coverage, various advantages accrue to the broadcasters if they enter into what is referred to as a multiple-antenna installation.[11] These advantages include reduced costs of individual tower and better reception, since all receiving antennas can be oriented toward the common source of radiation. Furthermore, the fact that tall towers can be located only in limited areas, owing to air-space restrictions, offers a further incentive for a common installation.

Multiplex TV Installations

The most notable multiple television installation is the Empire State tower system. At present there are seven television stations radiating signals from this structure. Three installations (in Minneapolis, Minn.; Havana, Cuba; and Hamilton, Ontario) provide three-station operation with vertically stacked antennas. Many installations provide for two stations with vertically stacked antennas.

Instead of mounting the antennas vertically, some have found it more desirable to mount their antennas on a common platform at substantially the same elevation. Illustrations of this approach can be found in Baltimore, Md., and Dallas, Tex. Such an arrangement does not limit antenna design and permits antenna modification or replacement more readily.

AM and TV Installations

There are occasions when an existing AM tower can be adapted for a television antenna. Usually two problems must be faced. First, a portion of the tower must be removed to accommodate the television antenna so as to minimize the detuning effect of the AM system, and second, the wind load of the television antenna over the portion of tower removed and the transmission lines running the full length of the tower is increased. The ability of the tower to withstand this load must be determined. The costs of alterations must be considered in relation to the cost of a new tower.

A further consideration is the need for isolating the television transmission lines from ground in order to mount on the AM tower. This is usually accomplished by the use of insulated hangers for one-quarter wavelength along the tower. This same problem must be faced where it is intended to mount a television tower in the proximity of an AM array. The television tower is insulator-mounted, and the transmission lines are isolated with a quarter-wave run of insulated hangers.

Systems Planning

Many times, the individual aspects of a television installation are meticulously scrutinized, and yet how they work together is given secondary consideration. An exhaustive check list would be almost endless. But a few important items are listed:

1. Detailed study of coverage taking terrain and competitive signals into account
2. Antenna location relative to population centers
3. Antenna vertical pattern design for best coverage
4. Antenna mounting methods
5. Layout of transmission lines

[11] Predicting the Operating Characteristics of Closely Spaced Antennas on the Same Supporting Structure, by Irl T. Newton, Jr., and M. S. Siukola, presented at the 11th Annual NAB Engineering Conference, April, 1957.

a. In the vicinity of the tower top
b. Main tower run
c. Horizontal run to station
6. Transmitter and associated equipment locations
7. RF filter networks and load locations
8. Station layout
9. Emergency provisions
a. Emergency antenna
b. Emergency transmission lines
c. Standby provisions
d. RF switching features

A few of these will be discussed in more detail.

Propagation Study

In hilly terrain, especially at higher frequencies, shadow areas will occur which cannot be predicted from FCC curves. A method of predicting the Coverage of a Television Station by J. Epstein and D. W. Peterson, *RCA Rev.*, vol. 12, no. 4, December, 1956.

Antenna Mounting Methods

The method is determined by the antenna manufacturer, and the tower must be built to accept the antenna. Common methods in use are:

Buried pole section in which a pole socket at the bottom of the buried pole supports the dead weight of the antenna.

A guide flange supports the antenna laterally near the tower top.

A guide flange and pole socket are normally supplied by the antenna manufacturer, but the tower should be drilled to receive them.

Pedestal Mounting. The pedestal is mounted on the tower and receives the butt end of the antenna.

Flange Mounting. The base flange of the antenna rests directly on the tower top which is drilled to receive it.

For these methods a much heavier tower top must be designed. In each case the tower design must be coordinated with the antenna.

Layout of Transmission Lines

In the Vicinity of the Tower Top. Usually, it is desirable to avoid as many elbows in a system as possible. However, near the tower top, it has been found advisable to have a pair of 90° miter elbows at the end of the vertical run in order to provide access to the system. It also provides a measure of mechanical flexibility, depending on the horizontal length of line between elbows. This flexibility is very desirable. The amount required is dependent on the movement, due to antenna sway, expected from the lines coming down from overhead.

Where complicated circuitry involving power-dividing Ts, transformers, phasing sections, and cut-over elbows (for an emergency feature) are used, considerable thought should be exercised in planning the hanger supports and line layout in cooperation with the tower designer.

Since mismatches at or near the antenna are the most potent source of echoes, any equipment in this area should be very well matched.

Main Tower Run. Normally, in tower-transmission-line runs composed of 20-ft sections, the top section is supported with two fixed hangers spaced 10 ft apart and the sections below on spring hangers located on 10-ft centers. Care must be applied at installation to locate the transmission-line sections so that the hanger springs do not cross over or rub against the transmission-line flanges. When the spring hangers are installed, they should be stretched according to the chart supplied by the manufacturer. If this is not done properly, it may require an excessive pull to separate

the line in hot weather and the line may not be supported adequately by the springs in cold weather. At the base of the tower, clearance must be provided to accommodate the differential expansion of the steel tower and copper transmission line.

Horizontal Run to Station. If the run from the tower to the station is short, 20 ft or less, and the tower run is 500 ft or more, the mounting of the horizontal line must be arranged to allow for the vertical movement of the line due to differential expansion between the tower and tower-transmission-line run.

If the run from the tower to the station is long, 100 ft or more, the horizontal run can be anchored at the station wall. At the base of the tower, the differential expansion of both the horizontal and vertical runs must be considered. Proper hangers and mounts should be used to secure the line, providing for the expansions involved and yet restrict its movements for high wind conditions. In areas where icing conditions are troublesome, protection from falling ice should be provided over the horizontal run.

RF Filter Networks and Load Location

The sideband filter, filterplexer, and similar networks should be located with sufficient clearance so that easy access to all portions for servicing and cleaning is possible. While ceiling mounting conserves floor space, accessibility of all elements should still be a consideration. Since many of these devices use cavities which cannot be pressurized, a clean atmosphere is important, since dust accumulation inside the cavity will eventually cause trouble. Cavities should be arranged so that they are in the same ambient temperature. A difference in height when a high-temperature gradient exists or sun heating of one cavity may result in unbalance. Since hot air is less dense than cooler air, a hot location will reduce the safety factor for voltage breakdowns.

Emergency Provisions

It has always been the desire of the broadcaster to keep the ratio of nonscheduled "off-the-air" time to schedule "on-the-air" time as small as possible—preferably zero. An efficient maintenance procedure is excellent insurance. Emergency facilities can also help to keep this ratio small. A great variety of items are available. A word of caution—do not make the emergency provisions too complex and check their operation periodically.

Emergency Antenna. The simplest emergency-antenna provision is that found in the superturnstile, where, if one portion of the antenna fails, the power going to that half can be absorbed in a load while the other half continues to provide some measure of service with a figure-eight pattern. In various antenna designs the power is distributed to the upper and lower halves through combining networks mounted at the tower top. Simple change-over equipment permits the selection of either the upper or lower half for emergency service. Relatively low-gain antennas have been used mounted on the sides of towers and some inside towers for emergency use. It must be remembered that the tower will distort the antenna pattern somewhat. At UHF this distortion may be small. However, at low VHF the pattern is practically unusable, depending on what degree of pattern distortion, and system reflections will be tolerated for this type of service. Some very elaborate emergency systems have been installed to the point where every item of transmission has been duplicated for emergency purposes.

Emergency Transmission Line. One extra provision of insurance can be provided by the installation of a spare transmission line so located that it can be inserted in place of the main run with a minimum of change-over connections at the input and output. It is wise to use gas stops at both ends and keep it pressurized.

Standby Provisions. How much insurance one wishes to buy in the form of standby equipment can be based on the losses incurred by interrupted service. Where broadcasters have expanded their operations to higher power, the replaced transmitters have been retained for standby use. In some new installations broadcasters have

obtained duplicate transmitters and worked them both on alternate schedules. In addition to this excellent emergency feature, a large portion of maintenance work can be scheduled during regular working hours. A standby Diesel generator set, duplicate microwave equipment, duplicate RF networks, and duplicate tower and antenna all contribute to potentially more reliable service.

RF Switching Features. Perhaps the most common emergency feature is the cutback circuit from transmitter amplifier to driver. This usually is performed quite rapidly using motor-driven RF switches. Where a standby system, including transmitter and RF networks, is available but a common antenna is used, motor-driven RF switches can be inserted to transfer the input of the antenna from the main transmitter to the standby system. Many elaborate cutover and cutback systems have been proposed.

In many switching applications the speed of the motor-driven switch is not required and a manual transfer panel is adequate. To terminate various points in the RF system with a dummy load, it has been found convenient to install a single-pole double-throw switch to break open a line so that the load termination can be made by way of a separate multiposition manual-transfer panel.

TYPES OF ANTENNAS

The development of television was such that Channels 2 through 13 (54- to 216-Mc band) were assigned first and, later, with the demand for more stations, Channels 14 through 83 (470- to 890-Mc band) were assigned. The lower of these two bands, referred to as VHF, resulted in antenna types suited to those frequencies. The higher of these two bands, referred to as UHF, required a type different from those previously developed.

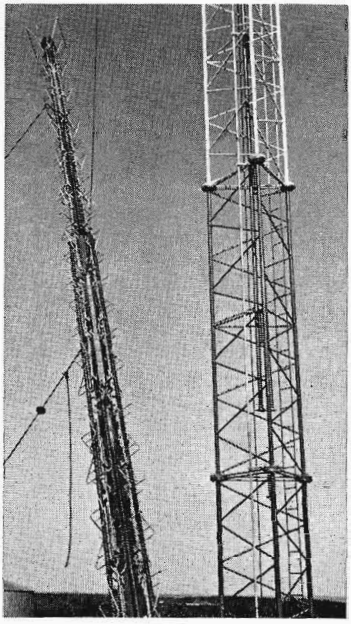


FIG. 7-31. Erection of a TF12AH superturnstile antenna at KTBC-TV, Austin, Tex.

VHF Antenna Types

Even within the VHF band various applications dictated antennas of differing designs for both electrical and mechanical reasons.

Superturnstiles

The first antenna developed for commercial service was the superturnstile.[12] It consists of a central sectionalized steel pole upon which are mounted the individual radiators, or "batwings." These radiators are mounted in groups of four around the pole in north-south and east-west planes to form a "section," and the sections are stacked one above the other to obtain the desired gain. Figure 7-31 illustrates this construction showing a 12-section high-band Channel 7 to 13 antenna.

In this type, each of the radiators is fed separately by its own feed line to whose impedance that of the radiator is carefully matched. The feed lines, in turn, are combined in sets of 12 at junction boxes, which perform the dual function of feeding power simultaneously to all feed lines and of transforming the combined impedance of these lines to that of the 51½-ohm transmission line which carries the power from the base of the antenna.

[12] R. W. Masters, The Superturnstile Antenna, *Broadcast News*, January, 1946.

This latter function is achieved by the use of three-stage transformers immediately below the junction box.

At the base of the antenna at the tower top, a combining network is used when there are more than two junction boxes. These networks accomplish power division between portions of the antenna if so desired. These antennas are manufactured in various gains from 3 to 12 for Channels 2 to 6 and 6 to 18 for Channels 7 to 13.[13] They can also be obtained for various types of null fill [14] (see under Vertical Patterns) and wind loading. They have also been used in stack and candelabra installations.[15] Antennas can be split by the use of additional junction boxes for emergency use and for other purposes. Elliptical azimuthal pattern can be obtained by changing the power division between the north-south and east-west planes.

Supergain Antenna

The supergain antenna [16] consists of half-wave dipoles mounted in front of reflecting screens. The construction of the diploes is modified to achieve a high degree of mechanical strength. The addition of a power-equalizing [17] circuit (see under Bandwidth) for Channels 2 to 6 is required to assure the necessary bandwidth.

The reflecting screen forms a square, each side of which is one-half wave in length. This antenna lends itself to stacked arrangements for a number of channels as carried out in the Empire State installation.[18]

A single layer of supergain consists of the tower screens and four dipoles directed in the four principal horizontal directions. In order to increase gain, these layers are stacked vertically. Feed lines from the north-south dipoles terminate in one set of junction boxes, and those of the east-west in a second set. The power equalizer divides the power equally between these two systems and through the use of a terminating load absorbs the reflected power from the dipoles.

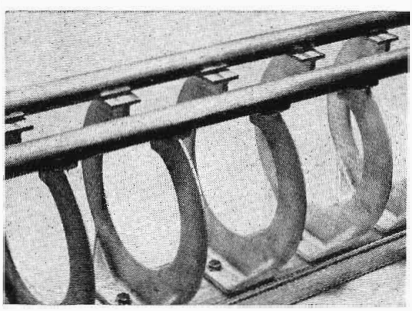


FIG. 7-32. Portion of a slotted-ring antenna.

AMCI Slotted-ring Antenna

Description. The AMCI slotted-ring antenna is designed for VHF television broadcast transmitting service. It consists of a series of slotted rings mounted on a channel as shown in Fig. 7-32. The rings are lenticular in cross section with the long axis in the plane of the rings so that the wind resistance of the structure may be as low as possible. Two rods are mounted to the rings, parallel to each other, one along each side of the open portion of the rings to form a continuous slot and to act as a

[13] H. H. Westcott, New 50 KW VHF Superturnstiles, *Broadcast News*, May–June, 1953.

[14] Irl T. Newton, Jr., and H. H. Westcott, The New 12BH High Gain Antenna, *Broadcast News*, March–April, 1954.

[15] Matti Siukola, Predicting Performance of Candelabra Antenna by Mathematical Analysis, *Broadcast News*, October, 1957. R. H. Wright and J. V. Hyde, The Hill-Tower Antenna System, *RCA Engr.*, August–September, 1955.

[16] L. J. Wolf, High Gain and Directional Antennas for Television Broadcasting, *Broadcast News*, vol. 58.

[17] R. W. Masters, A Power-equalizing Network for Antennas, *Proc. IRE*, July, 1949, p. 735.

[18] J. B. Dearing, H. E. Gihring, and R. F. Guy, Multiple Television and Frequency Modulation Transmitting Antenna Installation on the Empire State Building, *Proc. IRE*, March, 1953.

balanced transmission line. Figure 7-33 shows a larger portion of the slotted-ring antenna mounted on a supporting mast. In certain instances, the antenna can be mounted directly on the side of a tower.

Each bay consists of two radiating elements ("half bays") arranged one above the other and fed with a single 3⅛-in.-diameter rigid coaxial transmission line.

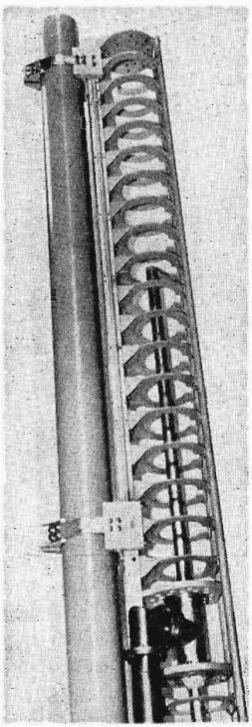


FIG. 7-33. Portion of a slotted-ring-antenna bay.

The antenna is provided with a feeding arrangement of a type which enables each bay to handle high power and allows the entire exposed feeder along with every other active part to be deiced. When necessary, tubular sealed heaters are supplied as a part of the antenna for deicing purposes.

Each bay is approximately 3.4 wavelengths long and has an average power gain of approximately 4. As many as five bays can be stacked one above the other to give additional gain, the gain being proportional to the number of bays used.

When several bays are stacked to give a higher gain, they are joined through the use of a rigid coaxial transmission-line harness into a single feed line for the entire array. This type of feed requires only a single transmission line from the transmitter up the tower to the array.

Null fill-in and/or beam tilt, where required, are achieved through the proper selection of line transformers and transmission-line lengths in the coaxial feed lines between the bays.

The horizontal-radiation pattern of the slotted-ring antenna itself is essentially circular, with slight maxima along a diameter which passes through the slot of the antenna and with slight minima at approximately right angles to this diameter as shown in Fig. 7-34*a*. Since the potential at the point of attachment to a supporting mast is small, masts of adequate size can be used without substantially affecting the operation of the antenna or its horizontal circularity.

Directional horizontal-radiation patterns are achieved by the addition of pattern-shaping members to the basic antenna. Usually, there are two beam-shaping members connected to each alternate active ring in a directional antenna. The rings provided with these members act differently from simple rings in that a substantial portion of the current which normally flows in a ring is directed into the beam-shaping member. The radiation pattern of a directional-antenna bay, then, depends on the configuration of these additional members and on the proportion of modified loops. Figure 7-34*b* shows a typical directional horizontal pattern of a modified slotted-ring antenna.

Theory of Operation.[19] The operation of the slotted-ring antenna can best be understood by considering a balanced transmission line shunted by a number of small loops or rings. It is possible by arranging the separation and cross-sectional area of the rings substantially to increase the phase velocity at which a high-frequency wave is propagated along the transmission line. Figure 7-35*a* shows such a loaded transmission line which has been short-circuited at one of its ends and is fed with an RF source at the other. The standing waves which are set up along the line have an apparent wavelength, λ. When the number of rings along the balanced transmission line is of the order of 12 per free-space wavelength and the diameter of each ring is of the order of 0.14 free-space wavelength, the apparent wavelength will be approximately twice the free-space wavelength.

[19] A. Alford and H. H. Leach, High-gain Antenna Arrays for Television Broadcast Transmission Using a Slotted Ring Antenna, *IRE Conv. Record*, part 7, pp. 87–94, 1956.

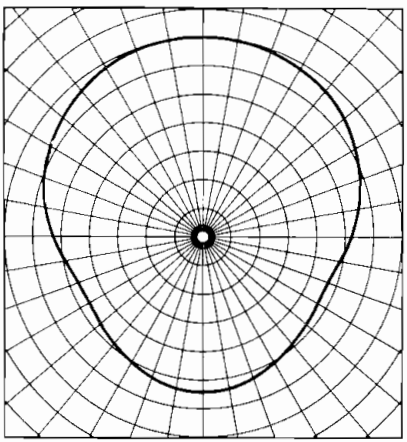


FIG. 7-34*a*. Typical omnidirectional horizontal radiation pattern, relative field.

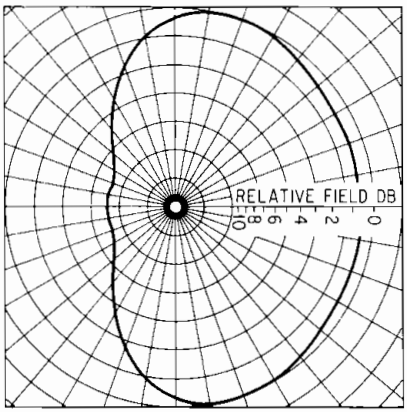


FIG. 7-34*b*. Typical directional horizontal radiation pattern, relative field.

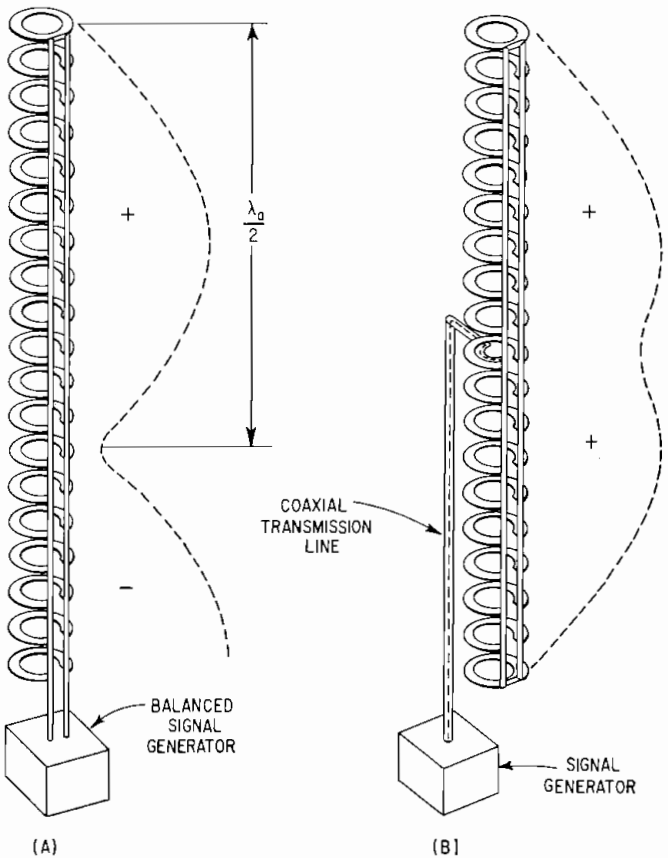


FIG. 7-35*a*. Balanced transmission line loaded with shunt rings.

FIG. 7-35*b*. Unbalanced transmission line loaded with shunt rings.

If this same arrangement is fed at the center through a length of transmission line as shown in Fig. 7-35*b* and short-circuited at both ends, then a wave propagates from the center feed point toward each of the two short circuits. The reflections from these short-circuited ends set up a standing wave, and the difference of potential between the conductors of the balanced transmission line is distributed approximately as shown by the dotted line. The phase of this difference of potential is substantially constant over the entire length of the line.

The potential which exists between the balanced conductors causes circumferential currents to flow in the shunting rings. Since the potential and hence the currents are very nearly cophasal, the over-all behavior of the loaded line is similar to that of an array of closely stacked loops. This fact results in a substantial concentration of the power radiated by the rings in the direction of a plane passing through the halfway point along and perpendicular to the balanced conductors.

Construction. Corrosion-resistant aluminum alloys, both wrought and cast, are the primary materials of construction in the AMCI slotted-ring antenna. Stainless-steel screws and bolts are used throughout the antenna. The total weight of a bay is approximately 300 lb when designed to operate at Channels 7 or 8, with the higher channel bays weighing slightly less.

There are two Teflon seals per bay. The diameter of the inner conductors which pass through these seals is approximately 1¾ in. The outer-conductor diameters are approximately 3 in.

The antenna itself is designed to withstand wind velocities exceeding 200 mph and to present a small surface area to the wind. The antenna can be mounted on a standard mast (designed for a wind loading of 50 psf on projected flat surfaces), on special masts (designed for larger wind loadings), or, in certain instances, on the corner of a tower.

VHF Helical Antenna General Description

The VHF helical antenna is essentially a coil of uniform pitch wound around a usually round mast section. A left-hand and a right-hand helix are used, joined at the center. In some cases a triangular or square tower section is used instead of a round mast. The tower section is partially covered by screens to back up the helix.

In operation, a radio-frequency wave is established which travels between the helix wire and ground "plane" formed by the mast. The wave thus travels circumferentially around the mast, turn after turn. It progresses axially up or down the mast because of the pitch of the helix.

The antenna is designed to radiate in "side-fire" fashion. That is, the beam maximizes at right angles to the helix axis. In order to have successive turns of the helix work together to give additive side-firing fields, each helix turn has a circumferential length equal to an integral number of wavelengths, such as one, two, three, or four. The two-wavelength turn is most commonly used because it yields good structural dimensions.

While the wave travels circumferentially around the helix, it radiates power and becomes attenuated. The attenuation rate depends on the spacing of the helix coil from the mast. A value of attenuation of 3 to 6 db per turn is used, depending on the channel, gain, and bandwidth requirements.

In traveling axially up or down the helix, the radiating wave distributes the radiation over the length of the helix. This results in excitation of a fairly large aperture from a single feed point and so gives a considerable gain per feed. Nominal values of gain per feed are between 3 and 5 rms over a dipole. This makes it possible to simplify the feed harness because of the fewer number of feed points required for high-gain antennas.

The turn-to-turn phase of the radiating traveling wave determines how well the side-fire beam is formed. This phase varies as the frequency changes from its optimum center value. Over a certain frequency range, there is a sort of "locked-in" mode over which the beam formed is quite uniform in its main characteristics. Outside this range the beam broadens and gradually breaks up. The frequency range

over which a certain sized helix can be used depends on its attenuation rate and number of turns. For example, a helix pair giving a gain of 5 per feed forms a good beam over about 6 to 7 per cent frequency range. For a gain of 3 per feed, this increases naturally to about 10 per cent. The beam-forming bandwidth can be increased further by suitable electrical "loading" of the helix, which alters its phase-velocity vs. frequency relationship.

The radiating traveling wave does give very good VSWR characteristics, because there is very little resonant energy in the helix. The wave energy reflected from the ends of the helices is down about 40 db when it returns to the feed, and so it affects the feed impedance very slightly.

The wave dies down by about 20 db before reaching the end of the helix. This makes it feasible to put a second feed here. Two different signals can then be diplexed directly into the same antenna. The visual normally is fed in the center and the aural at the ends in this "self-diplexing" scheme. Though 20 db of isolation is sufficient operationally, more is needed to prevent a visual ghost. This ghost would result from visual signals going down the aural feed line and reflecting back to be reradiated as a delayed signal. To increase the visual to aural isolation, a visual reflecting cavity is placed on the aural input near the antenna. This increases the visual to aural isolation to about 40 db.

For certain requirements, the helical antenna lends itself to "wrap-around" construction. This is done by assembling the helix around a tower already in existence, using techniques similar to those used for the low-channel helical as described on page 2–257.

In those cases where horizontal directional patterns are desirable, the azimuthal radiation of the helix can be modified. This is usually done by attaching radial or tangential stubs directly to the helix. These stubs are short compared with a wavelength and are nonresonant.

To maintain optimum performance under icing conditions, the helical antennas can be provided with deicing means. The helix itself, being made of copperweld material, is used as the heater. Several hundred amperes of 60-cycle current are caused to flow through the helix from a transformer located at the tower top. A nominal deicing power intensity of about 2 watts per square inch of helix is used for normal conditions. Figure 7-36 shows an aural feed point with deicing connection.

High-channel Helical Antenna, Channels 7 to 13, Specific Description. These antennas are built in a standard series by General Electric. Gains vary from 4 to 25, from one to five bays being used. The physical length is constant (for fixed number of bays) through the channel range, and so the gain varies over the channel.

The mast is made from 24-in.-diameter steel tubing or piping, varying in thickness from ¼ to ¾ in. for different sections.

The helix is made from 0.365-in.-diameter copperweld material. It is supported on insulators made from Steatite, Teflon, Cymac, or Stycast. A low-loss, low-dielectric-constant material is preferred. Height of the insulators is adjustable by plates under the mounting to accommodate helix-diameter changes needed for on-channel moding. Figure 7-37 shows an antenna during assembly.

Feed systems provide either single- or two-line feed up to three bays and single line only for four and five bays. Space limitation reduces the size of feed lines that can be used if dual feeds are wanted for four- or five-bay antennas. The standard feed harnesses use 3⅛-in. EIA-type line as a minimum. The one-bay antenna may use 6⅛-in. lines to permit full ERP operation from one bay, say with a 100-kw transmitter. The feed lines include a quarter-wave series-isolating capacitor which isolates the 60-cycle deicing current from the remainder of the transmission-line system.

Nominal feed impedance at the helix is about 100 ohms. A quarter wave of 70-ohm line is used to transform this to the 50-ohm EIA standard. An elbow with end-seal mounts through a hole in the mast provides means for attaching and feeding the helix. A close-up of a feed point showing the helix attachment is given in Fig. 7-38. This elbow is 70 ohms and is part of the quarter-wave transformer.

Mechanically, the feed harness is so arranged that pieces of harness can be lowered inside the mast after loosening bolts from outside the mast only. A rope is dropped

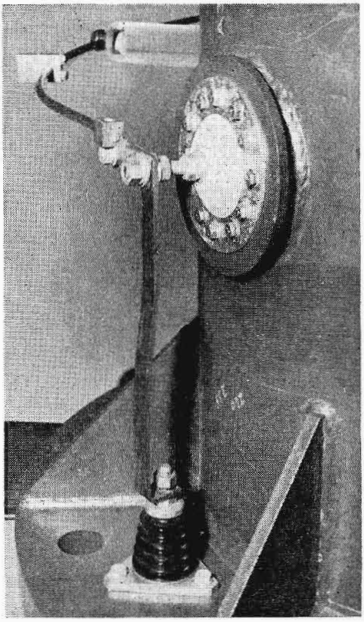


FIG. 7-36. Aural feed point on self-diplexed two-line-feed high-channel helical antenna. The deicing current connection is also shown. It is a quarter-wave long to the bypassing feed-through capacitor, thus not upsetting electrical performance. The small slug on the helix is for fine matching. (*GE photograph.*)

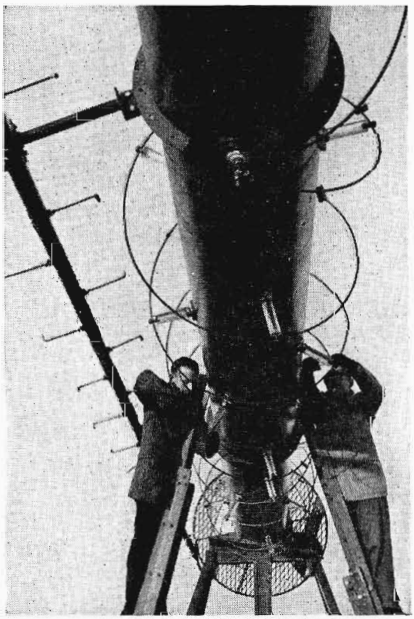


FIG. 7-37. A view of a high-channel helical antenna during assembly. The climbing pole is outrigger-mounted from the antenna mast. The metal "slugs" on the helix near the feed are for fine matching. (*GE photograph.*)

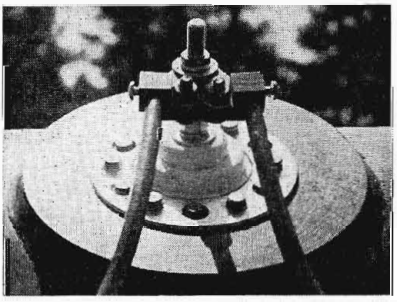


FIG. 7-38. This view shows the end-seal feed mounting in the mast and the helix attachments. Before shipment, the helices are brazed into the attachment blocks and the temporary set screws are removed. (*GE photograph.*)

through the mast from the top and fastened to the elbow, using a handhole in the mast for access.

Low-channel Helical Antenna, Channels 2 to 6, Specific Description.[20] The basic operating principles of the low-channel antenna are identical with those already described. As mentioned earlier, the bandwidth of the helical antenna is controlled mainly by its beam-forming characteristic. To form a fairly constant beam over a

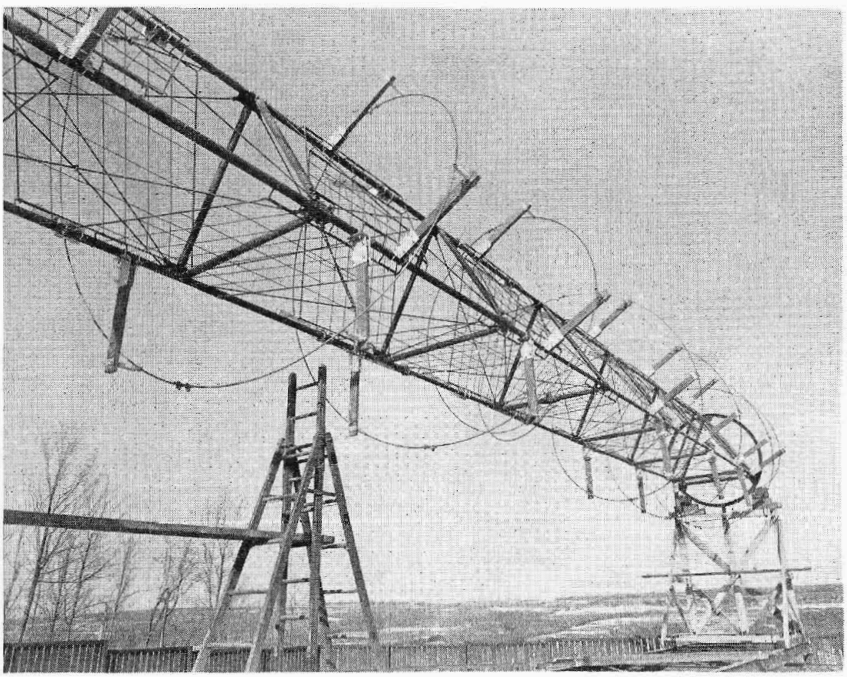


FIG. 7-39. A low-channel helical-antenna prototype in pattern test. Note the open grids mounted on the triangular tower section. The insulating helical supports shown are temporary for the prototype work only. (*GE photograph.*)

wider frequency range, the active aperture must be reduced. Fewer turns with higher attenuation per turn are the basic answer. In addition, further increase in beaming bandwidth can be achieved by electrically "loading" the helix.

Use of a triangular tower section for the mast accomplished some "loading" due to corner discontinuities. Also, a standard tower section for a "mast" is preferable because of the size. Backup screens of open-grid construction are placed under the helix by fastening to the tower section. See Fig. 7-39 for a picture showing a low-channel prototype.

Traveling-wave Antenna

The traveling-wave antenna embodies principles found in the operation of the superturnstile, the slot antenna, and the helix but employs these principles in a manner which results in its being different from any of them.

[20] See also "The TV Helical Antenna Adapted to Structural Tower Shapes" by Ronald E. Fisk, General Electric Company, presented at the 12th NAB Engineering Conference, Los Angeles, Calif., 1958.

In form, the antenna is a coaxial line, with pairs of slots in the outer conductor spaced at intervals of a quarter wavelength throughout its length. Probes at the center of each slot distort the field within the line to place voltages across the slots. These, in turn, drive currents on the periphery, setting up a radiated field. Attenuation of the signal by withdrawal of a portion of the power at each slot reduces it to a very low value at the upper end of the antenna. There, a special pair of slots, designed to match the line, extracts the remaining portion and radiates it.

Figure 7-40 shows the physical shape of the antenna. The signal, entering through

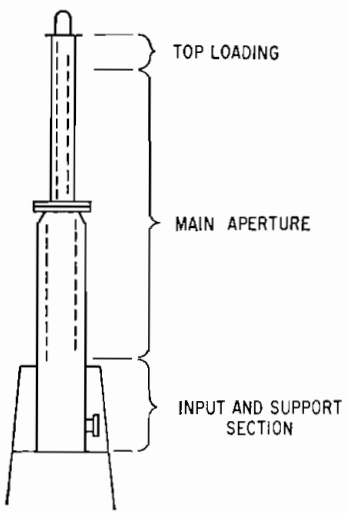


FIG. 7-40. The traveling-wave antenna—external appearance.

FIG. 7-41. Cross section of traveling-wave antenna at input, aperture, and top.

the input section (normally in the buried portion below the tower top), is progressively attenuated as it passes through the main aperture. The portion reaching the top is radiated from the "top-loading" section.

Figure 7-41 shows cross sections of the antenna in the three main portions. It will be noted that the entire inner connector is supported by the base plate of the antenna and can be removed through this base.

Operation of the antenna can be better understood if the section of the aperture having pairs of slots are recognized as being, in effect, dipoles. Figure 7-42 shows this similarity.

Successive pairs of slots are alternately in one plane and in another at 90° to it, so that the antenna can be simulated by stacked dipoles with a 90° angle between successive layers.

In a given plane, reversal of the direction of feed every half wavelength (by placing the probes on opposite side of the slots), together with the half-wave change in phase of the signal as it passes along the aperture through this distance, results in all the "dipoles" in that plane being fed in phase. The same action takes place in the other plane except that they are fed 90° out of phase with the first plane owing to their 90° displacement along the antenna.

The result is shown in Fig. 7-43.

Each plane of dipoles radiates essentially a figure-eight pattern. Since the planes are fed in quadrature, addition of the patterns results in a circular pattern, as outlined

under Azimuthal Patterns. Because of the circular cross section and the lack of obstructing radiators, the resulting horizontal pattern is almost a true circle, varying from circular by only about 0.5 db in a typical case.

As slot spacing is actually 90° only for a specific frequency in the channel, variation in frequency across the channel would be expected to result in a progressive lag or lead in the signal as radiated from successive slots inasmuch as the spacing becomes

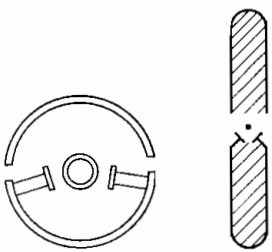


FIG. 7-42. Cross section of traveling-wave antenna at a slot pair level, showing resemblance to a dipole.

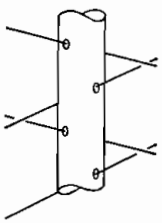


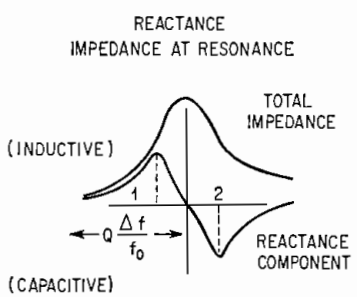
FIG. 7-43. Stack of half-wave dipoles which traveling-wave antenna resembles in operation.

greater than 90° for higher frequencies and less than 90° for lower frequencies. Correction for this effect would obviously be accomplished if, at each slot pair position, another circuit element were added which, with change of frequency, had the opposite effect on the phase.

Such an element is available in the form of a parallel-resonant circuit with resistive loading with its familiar reactance characteristics (Fig. 7-44). The resistive portion is the radiation resistance.

In the region between 1 and 2 (Fig. 7-44), increasing frequency results in a lower inductance (higher capacity) while decreasing frequency yields a more inductive circuit. If this circuit is placed across the transmission line at a slot position, the effect will be to cause the voltage at this position to lead the voltage at the preceding

FIG. 7-44. Universal curve (high-Q parallel-resonant circuit).



slot at higher frequencies and to lag it at lower frequencies within the frequency range 1 to 2 (Fig. 7-44).

By adjustment of the values of inductance and capacity the slope of the response curve can be changed until a compensation is obtained over a considerable frequency range for the apparent change in line length between slot pairs due to frequency change.

The above circuit is obtained by shaping the slots to obtain the required value of

inductance and capacity, the length of the slot and the shape of the end portions controlling the former and the width of the slot at the center of the latter.

A further control of the phase at each slot is obtained by the insertion between slots of compensating probes. By means of these, the phase can be made progres-

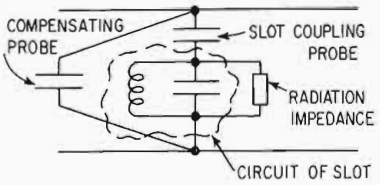


FIG. 7-45. Equivalent circuit of one slot pair section of traveling-wave antenna.

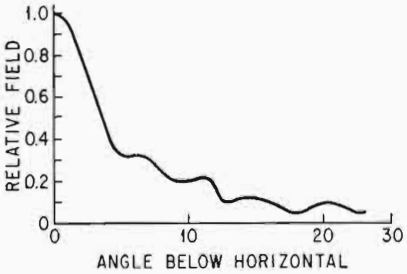


FIG. 7-46. Vertical field pattern of traveling-wave antenna with gain of 12.

sively more lagging from top to bottom, bringing about a downward tilt of the main beam if desired.

Omission of particular slot pairs is a method which has been used to obtain special effects such as reduction of signal at a particular angle in the vertical plane to "protect" areas where radiation is undesirable. Such a situation has arisen where important radio-frequency measurements on equipment being manufactured in a particular location would have been disturbed by the reception of television signals.

This equivalent circuit of each layer is shown in Fig. 7-45.

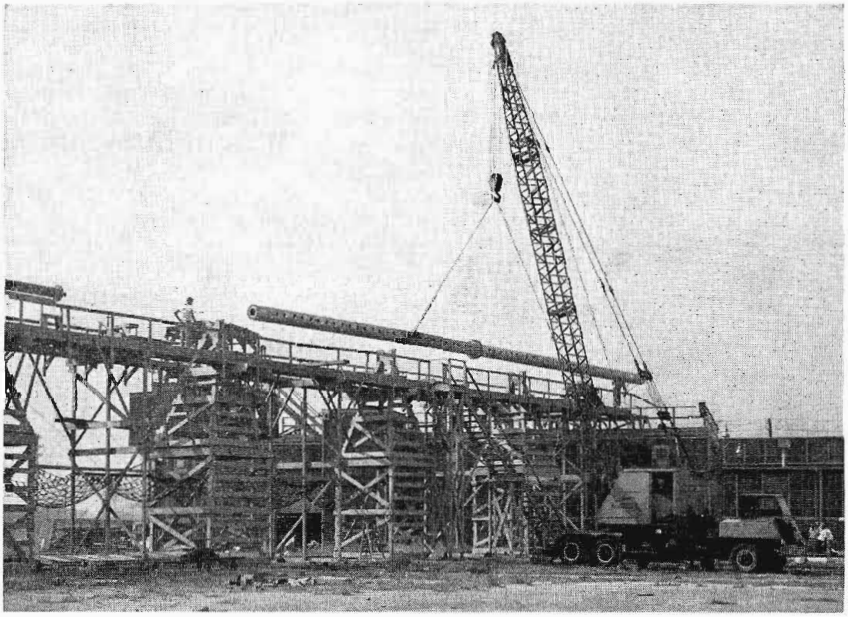


FIG. 7-47. Section of traveling-wave antenna being lifted to high horses for check of attenuation and phase velocity.

The coupling probes are all set at the same depth. As a result, the same percentage of power arriving at the slot location is picked up and radiated at each slot. The amount of power so radiated is therefore decreased exponentially from the bottom to the top of the antenna, giving the effect of a constantly changing power division except for the elimination of slots necessary for the insertion of flanges, and for the change at the top-loading slots the result is a smooth vertical pattern without any nulls. The flanges and top loading cause a small ripple in the pattern, but the effect is slight. Figure 7-46 shows a typical vertical pattern of a traveling-wave antenna with a gain of 12.

Because the slots are a quarter wave apart, giving an impedance-compensating effect similar to that of insulators similarly spaced in a coaxial transmission line, and because the slots are only lightly coupled into the line, there is almost no reflected energy returning to the input of the antenna. The action of the top loading further reduces the chance of energy reflection. As a result the standing-wave ratio at the input is inherently low, and no input-matching transformers are required to broadband the impedance.

As the antenna is primarily a large-size transmission line, the power-handling capacity is very high.

The antenna tubing is of steel, hot-dip galvanized. The inner conductor is copper tubing. Hardware is of stainless steel with the exception of the probes, which are of aluminum treated to resist atmospheric corrosion. The slots are covered with polyethylene covers to keep out rain, snow, and ice.

Figure 7-47 shows a portion of a traveling-wave antenna being lifted to the test platform for a check of the attenuation and phase velocity. This type of high support is used to ensure that no errors are introduced by reflection from the ground. The shape of the slots employed to obtain the electrical compensation referred to above is shown.

UHF Antennas

Need for High Gain. The power gains used for UHF transmitting antennas are higher than those enstomarily used for VHF, since it is more economical to obtain effective radiated power in this manner. This is true, since the costs of generating power generally trend upward with frequency. Conversely, the cost of obtaining antenna gain is less, since for a given height, gain is related to frequency. For instance, with an antenna 100 ft in height a gain of 6 is obtained at Channel 2. At Channel 30, however, a gain of 46 is obtained for this same height. Gains of this order, however, result in problems in coverage which must be solved. Figure 7-48 shows a vertical pattern of an antenna in which all the radiating elements have the same current and phase. Snch an antenna provides a maximum gain for a given height. However, in covering the service area, nulls, or areas of low signal strength, occur periodically from the base of the antenna out to 7.4 miles, which seriously affects the coverage.

Null Filling. To overcome this problem a number of methods have been used. Earlier types of slotted-cylinder antennas used power division in which more power per layer was radiated from the lower elements than the upper. This resulted in a certain degree of null fill as shown in Fig. 7-58 (TFU-24DL). The power division helps fill the first null closest to the main beam, but to fill the second null effectively requires tilting the main beam below the horizon. Since this gives rise to a secondary lobe above the horizon, the gain is reduced depending on the degree of tilt.

Eliminating Nulls. Another solution resulting in a smoother pattern can be obtained by varying the current distribntion of each radiating element of the whole antenna. For instance, if snccessive radiators, spaced less than one-half wavelength, have current ratios of 1 to 4 to 6 to 4 to 1 as shown in Fig. 7-49, the vertical pattern resulting from such a distribution will be as shown in Fig. 7-50.[21]

Beam Tilt. Since UHF antennas have a relatively narrow main beam as compared with VHF, being of the order of 1.5 to 2.5° wide across the half-power (or 0.707-

[21] Kraus, "Antennas," Sec. 4–7, p. 94.

voltage) points, it is desirable to tilt the beam downward to aim at the horizon or even lower when there is insufficient effective radiated power to reach the horizon. For an antenna 1,000 ft above terrain the beam should be depressed 0.5° to aim at the horizon.

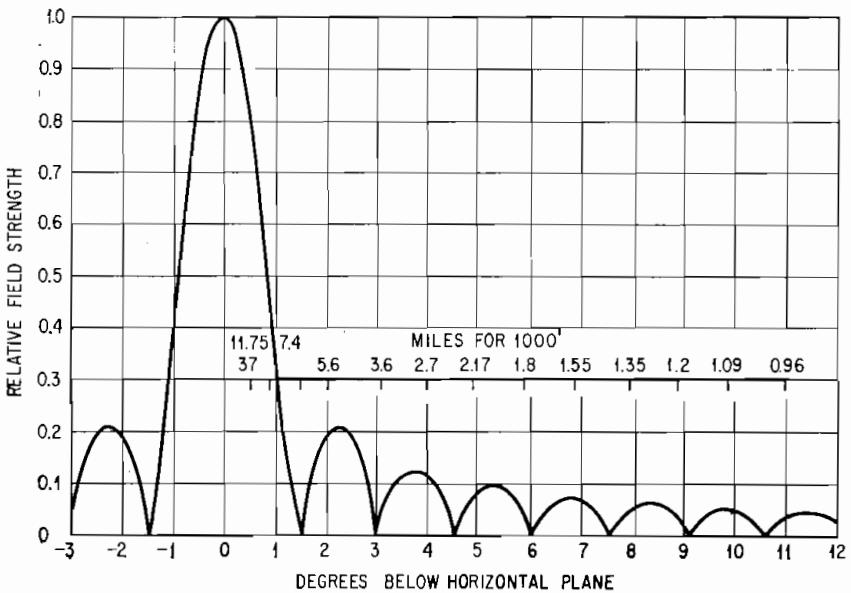


FIG. 7-48. Vertical pattern of an antenna having uniform distribution for an aperture of 38 wavelengths with sources in phase.

It is possible to tilt the beam and retain the smooth vertical pattern of Fig. 7-50 by progressively changing the phase of each radiating element—advancing the phase in the upper half of the antenna and retarding it in the lower half.

Reducing Radiation above the Horizon. In Fig. 7-50 as much energy is radiated above the horizon as below, assuming that the main beam is aimed at the horizon.

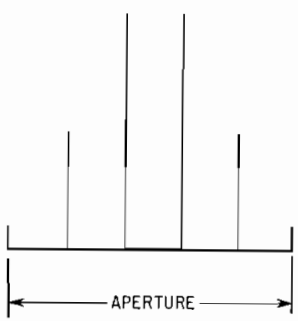


FIG. 7-49. Binominal distribution.

This means that only one-half of the energy is effectively used. It is possible by properly choosing the phase of each radiating element greatly to reduce radiation above the horizon and thus make the energy available for use below the horizon, thus increasing the gain for a given height of antenna.

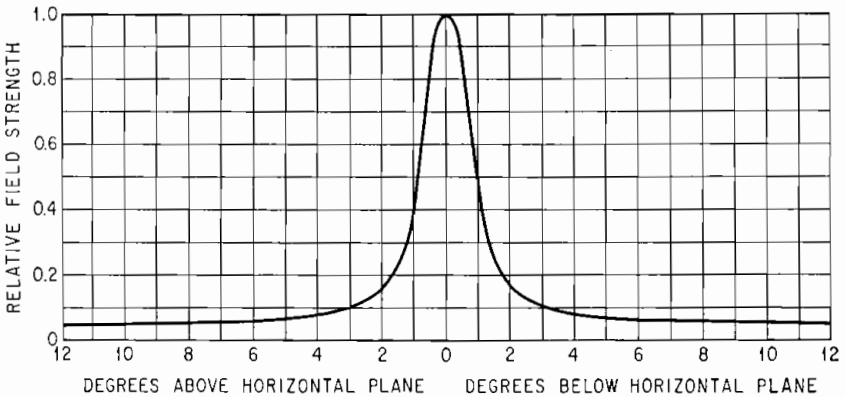


FIG. 7-50. Vertical pattern resulting from binominal distribution.

Pattern Synthesis. In order to accomplish the objectives discussed above, namely:

1. The elimination of nulls
2. Beam tilt by progressive phasing
3. Reducing energy radiated above the horizon

a method of synthesizing the desired pattern is possible.[22]

The vertical pattern depends entirely on the current amplitude and phase of each radiating element. With the use of an amplitude and phase distribution such as shown in Fig. 7-51, a pattern as shown in Fig. 7-52 can be achieved. The method is quite flexible, and a great variety of patterns for various needs can be synthesized.

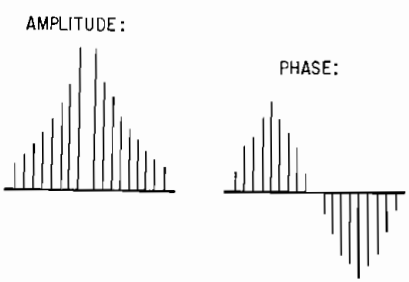


FIG. 7-51. Amplitude and phase distribution required to achieve a smooth pattern with minimum radiation above the horizon.

Slotted-cylinder Type

These antennas consist of a self-supporting galvanized-steel pole using slots as radiating elements.[23]

Energy is coupled to the slot either inductively or capacitatively from the feed system inside the cylinder so that a voltage appears across the slot. This causes currents to travel around the cylinder at right angles to the long slot dimension, which generates an RF field which is horizontally polarized. The amount of cross polarization is quite small with this type of antenna.

If the path around the cylinder is of such length that the current attenuates ap-

[22] P. M. Woodward, A Method of Calculating the Field over a Plane Aperture Required to Produce a Given Polar Diagram, *Proc. Inst. Elec. Engrs.*, London, 1946.

[23] O. O. Fiet, A New UHF Television Antenna TFU-24B, *Broadcast News*, March–April, 1952. Kraus, "Antennas," chap. 13. Jordan, "Electromagnetic Waves and Radiating Systems," Sec. 15.11. See under Slot Antenna in this Part.

preciably owing to radiation, the circularity is affected. Advantage is taken of this fact in designing directional antennas. To maintain the circularity required, a number of slots similarly fed are used at the same level.

The feed system is of the standing-wave type as shown in Fig. 7-53. Each coupling loop extracts sufficient energy so that the VSWR reaches a low value at the feed point. It should be noted that the phase steps in the region of high VSWR, which exists over most of the antennas, are well defined. This is important in achieving pattern and impedance bandwidth.

Mechanical Description. The cylinders vary in diameter from 3 in. for an antenna which has a single slot and a gain of 6 to 16 in. in diameter for an antenna which has

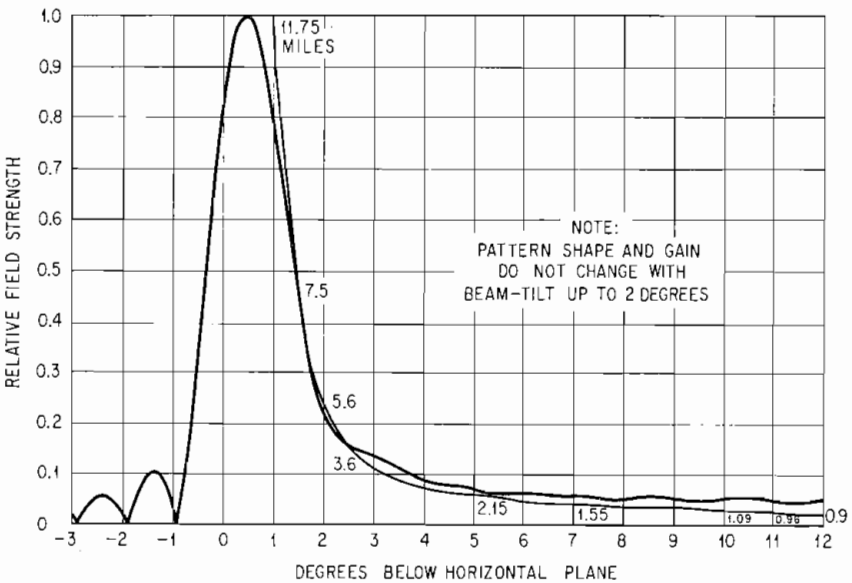


FIG. 7-52. Pattern of an antenna with a nominal gain of 50 using pattern synthesis.

four slots and a gain of 46 and is 134 ft in length at Channel 14. The larger cylinders are constructed of hot-dipped galvanized steel tubing. Radiation results entirely from currents traveling on the surface of the cylinder. The diameter of the cylinder, except in special cases, is determined by structural requirements only.

The lower half of the feed system is a single coaxial copper transmission line with an end seal near the center of the antenna. The upper half consists of the outer conductor only. The feed system appears as a continuous copper tube of constant diameter with an end seal at the center. Energy is picked up from this feed system by coupling loops or cylindrical couplers described below, there being no actual contact with the feed system. The feed system can be removed by sliding it out of either end of the antenna. Nothing inside the antenna needs to be disconnected.

Deicing is accomplished by long electric strip heaters placed adjacent to the slots.

Ultragain UHF Slotted-cylinder Antenna. A specific design is an antenna having a gain of 46 for Channels 14 to 30 shown in Fig. 7-54. The antenna is ready for a pattern test which is made on the turntable shown in the background. Figure 7-55 shows the correlation between the calculated and measured pattern. This antenna has a minimum 10 per cent fill for areas where good coverage in the first few miles is required for city locations.

A unique method of coupling is used in this antenna consisting of cylinders of varying diameters placed adjacent to the slot.

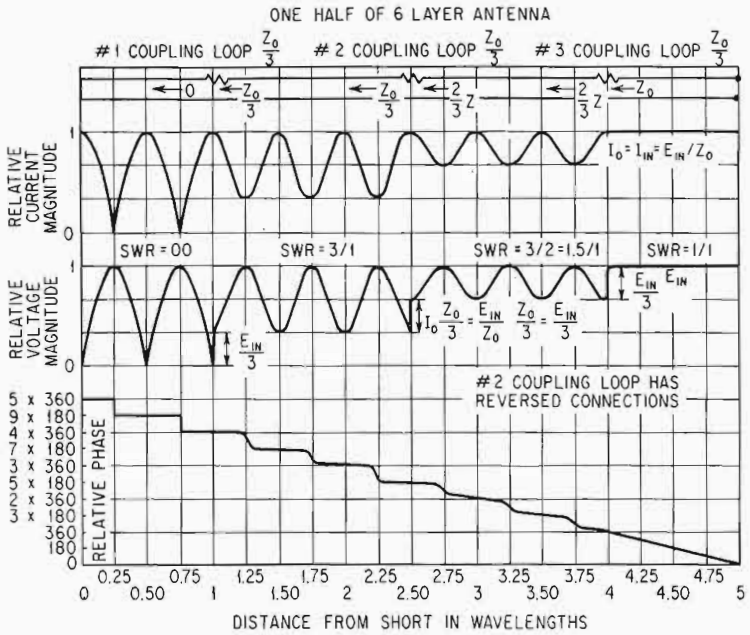


FIG. 7-53. Simplified illustration of current- and voltage-distribution principle used in the standing-wave feed system in the slotted-cylinder type.

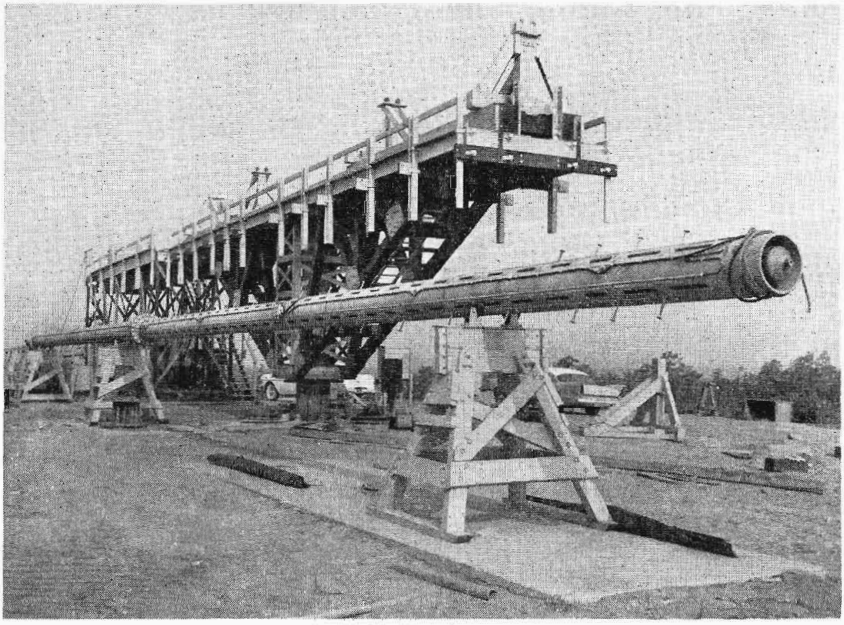


FIG. 7-54. UHF antenna of the slotted-cylinder type with a gain of 46 ready for pattern tests.

The cylinders are shown in Fig. 7-56, and their relation to the slot in Fig. 7-57. They are capable of handling high power and also make achieving the necessary bandwidth possible because a desirable loading can be chosen independent of the illumination.

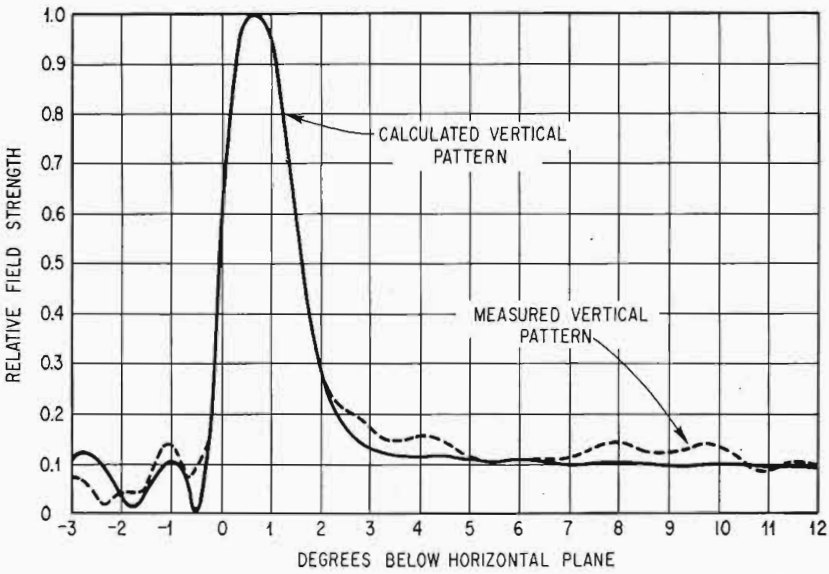


FIG. 7-55. Calculated and measured performance of an antenna with a gain of 46 having a 10 per cent fill.

Medium-gain UHF Slotted-cylinder Antenna. The same coupling means and the method of synthesizing the pattern described above can be applied to lower gain antennas. Figure 7-58 shows the vertical pattern of an antenna with a nominal gain

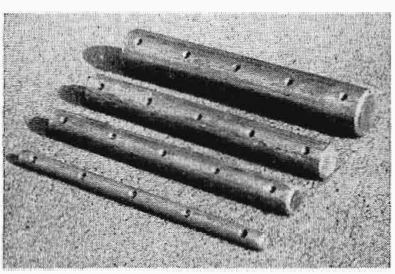


FIG. 7-56. Coupling elements used in slotted-cylinder antennas which have replaced coupling loops used in earlier types.

of 25 and a power rating of 60 kw. The pattern of an earlier type of antenna using loop coupling is shown in comparison.

Increasing ERP by Means of High Gain While Maintaining Local Coverage. In some cases it is desirable to have the local coverage of a lower gain antenna and the

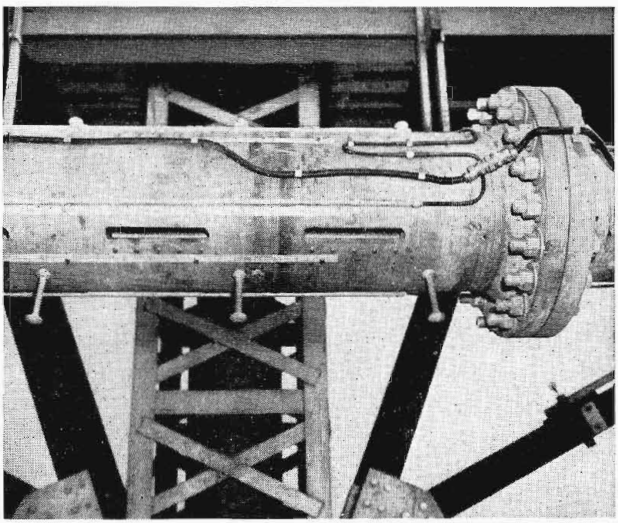


FIG. 7-57. Coupling elements shown in relation to the slot. Sleet melters are shown adjacent to the slot. The beacon cable is also shown.

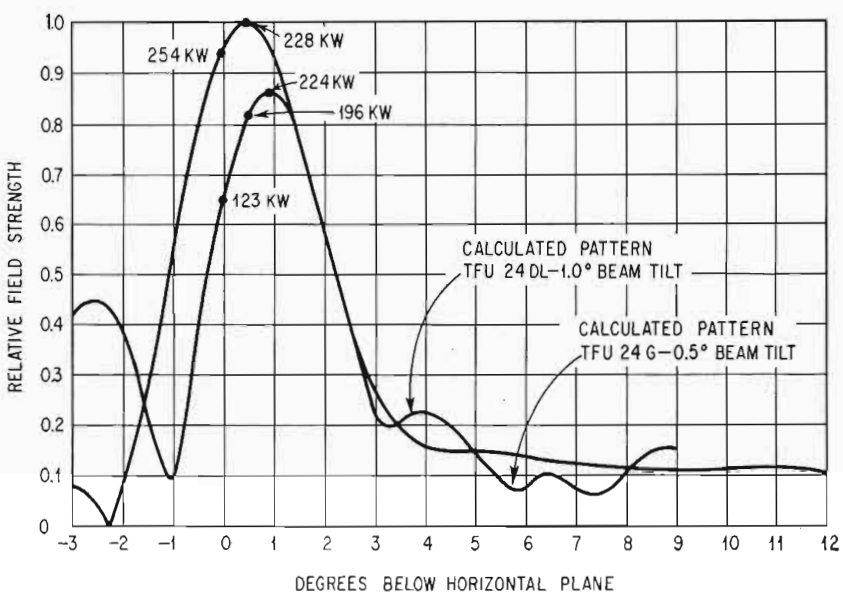


FIG. 7-58. Comparison of vertical patterns of a later and earlier type of low-gain antenna. Pattern synthesis and cylindrical coupling elements are used on the TFU-G type.

effective radiated power of a higher gain antenna. A closer approach to a good compromise is possible by the use of pattern synthesis as shown in Fig. 7-59.

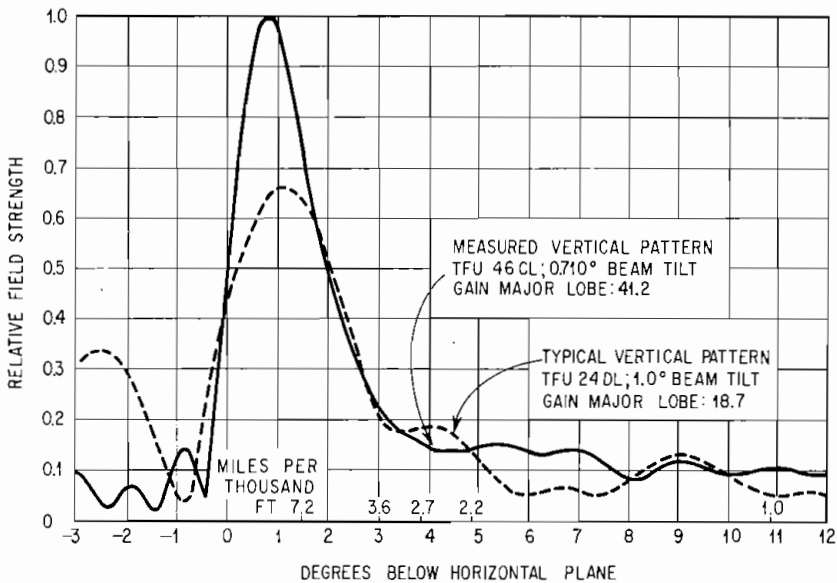


FIG. 7-59. Vertical patterns which can be synthesized for special conditions such as providing the same local coverage with a higher gain antenna as previously obtained with a lower gain antenna.

UHF Helical, General Description [24]

The basic operating principle of the UHF helical antenna is as already described under Helical Antennas. The UHF antenna differs from the VHF antenna primarily in its method of feed. The helix is made from 0.247-in.-diameter copperweld.

At UHF, the per cent bandwidth becomes small, and it is feasible to end-feed the vertical array at least up to gains of 25. If matched condition is maintained along the feed as power drops off at the different bays, the beam will tilt with frequency an amount 57.3 $\Delta F/f_0$ degrees, where f_0 is the mid-frequency and ΔF is the change in frequency relative to f_0. With a gain of 25, a half-power beamwidth of about 2¼° is obtained and a ±¼° tilt causes no difficulty.

UHF Helical Antenna, One to Five Bays. The basic UHF antenna bay has a gain of 5. Its leugth is varied with channel, so that its gain is constant. These bays are stacked together end to end, up to five bays.

Each bay is like a coaxial of about 90 ohms Z_0, with a capacitive feed probe coupling out power to the helix.[25] The top bay couples out all the power remaining. Impedance match is maintained throughout the feed for optimum impedance bandwidth.

Phasing of the bays relative to one another is done by relative rotation of the bays. (Because the wave travels circumferentially around, the phase varies with azimuth.)

[24] *Electronics*, August, 1951, pp. 107–109.

[25] Additional information on the feed may be found on p. 130 of Convention Record of the IRE, 1954, part 1, Antennas and Propagation, as part of paper "A Comparison of Antenna Problems at UHF and VHF-TV" by Lloyd O. Krause, General Electric Company.

Swivel flanges are used to fasten the sections together to make this rotation easy to perform. Rotation of the upper one or two bays can even be done after erection for slight modification of pattern contouring if desired.[26] Figure 7-60 shows a five-bay UHF helical antenna.

UHF Helical Antenna, 10-bay.[27] This antenna is made by stacking two five-bay antennas one above the other. A structural adapter is used to mount the top antenna above the bottom one. These antennas have half-power beams about 1° wide, and

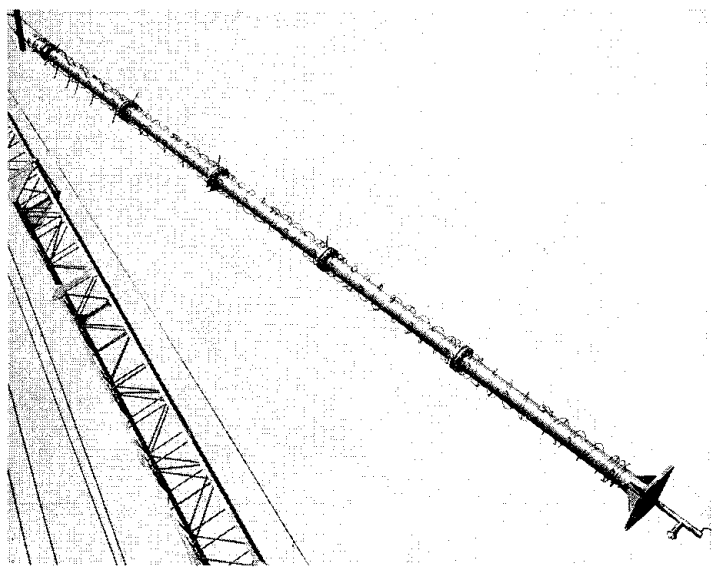


FIG. 7-60. This is a complete five-bay UHF helical antenna. Note the five feed points, one at center of each bay. The input adapter is mounted at the bottom for connection to standard 50-ohm EIA line. The projecting "spikes" are climbing steps. (*GE photograph.*)

structural rigidity becomes important. For this reason, the center of the antenna is guyed to outriggers at the tower top.

To ensure proper coverage, the beams from these antennas are usually carefully contoured and extensive pattern measurements are made during manufacturing test. A view of such an antenna in position for pattern test is shown in Fig. 7-61.

The feed for the upper five-bay antenna runs along the lower five bays and connects to a feed adapter mounted in the structural adapter. See Fig. 7-62 for a closer view of this arrangement.

Because of the special nature of these antennas, a table of standard characteristics is not warranted.

[26] Simple contouring of patterns is discussed in a paper "Contouring TV Antenna Patterns" by L. O. Krause, Tele-Tech & Electronic Industries, April, 1954.

[27] Description of a particular 10-bay antenna may be found in the paper A Simplified 5 Megawatt Antenna for the UHF Broadcaster by R. E. Fisk, *IRE Trans. on BTS*, PGBTS-9, December, 1957, pp. 46–51.

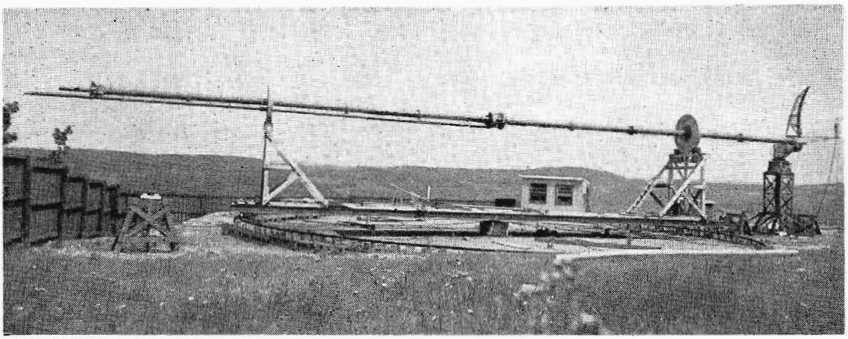


FIG. 7-61. A view of a complete 10-bay UHF helical antenna in position for pattern test. The feed line to the upper five-bay antenna is readily visible. The large rollers are made from wood and nylon for easy antenna rotation for taking horizontal patterns. (*GE photograph.*)

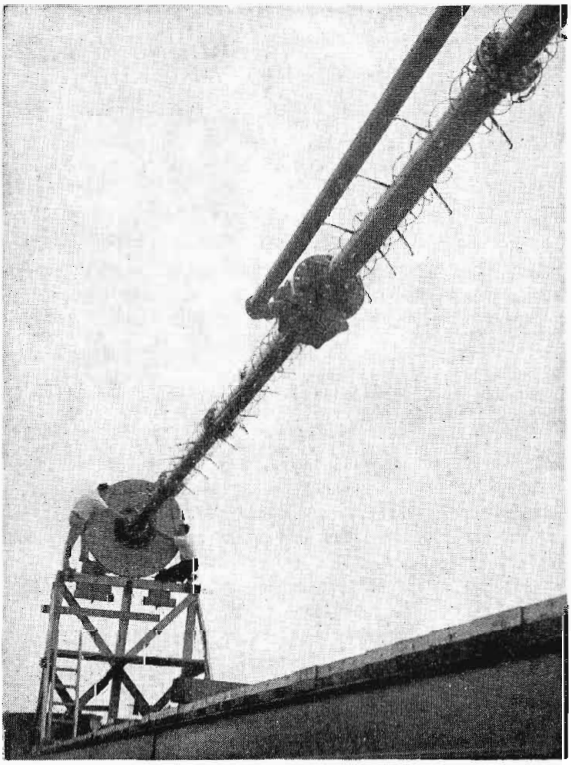


FIG. 7-62. A closer view of a one-bay UHF helical antenna, showing the feed and mounting arrangement for the upper five-bay antenna. (*GE photograph.*)

ANTENNA TESTS

Before Shipment

Antennas are tested to meet the necessary requirements for impedance and patterns. This is usually done for all prototype antennas but not necessarily on the repeat antennas of the same type before shipment.

Custom antennas are usually impedance-tested before shipment, and in most cases patterns are taken unless sufficient background exists to make this unnecessary.

Impedance is tested by taking VSWR measurements over the channel at the input of the antenna. In order to facilitate work on the antenna, the antenna is placed in a horizontal position parallel to the ground. Since objects in the field of the antenna, including the earth, affect the impedance, it is necessary to measure the antenna only when such objects are two to three wavelengths removed in order to reduce this effect to a negligible value. In order to reduce the error when the two- to three-wavelength height is impractical and to reach design center as closely as possible, space cloth can be used below the antenna, which is a material having the impedance of space, or 377 ohms. When the cloth is backed by a metal surface or screen removed one-quarter of a wavelength, energy at that wavelength is absorbed, so that the reflected energy from the earth does not affect the impedance.

Measurements are usually made with a slotted line which indicates the voltage standing-wave ratio (VSWR). If the impedance of the slotted line is the same as that intended for the antenna, then a unity standing-wave ratio indicates a match. The resistance and reactance component of the impedance can be obtained with a slotted line when a reference point, called the antenna point, is taken at each frequency at which the standing-wave ratio is to be measured by placing a short circuit across the transmission line that is to be connected to the antenna. This antenna point is a voltage node that falls on the slotted line some multiple of a half wavelength from the short-circuited transmission line.

After the short is removed and the input system is connected to the antenna, the standing-wave-ratio measurements are made. Voltage nodes, called *E*-min points, are obtained by moving a probe box along the slotted line in the same manner the antenna points were obtained. The slotted line is 12 ft long and therefore provides enough length to obtain *E*-min points for the lower-band as well as the medium- and high-band channels. The difference between the antenna point *A* and *E*-min divided by the wavelength at each frequency gives the rotation on the Smith chart at a radius of the standing-wave ratio obtained at that frequency. These points *A-P-E*-min/wavelength, are then plotted on the Smith chart, (1) toward the load and (+) toward the generator, giving an impedance plot of the antenna system at each frequency under consideration.

For superturnstile antennas these measurements are made on both the north-south and east-west systems and all effort possible is made to make the one system identical with the other at the best standing-wave ratio obtainable. Individual radiator adjustments can be made to help improve the input impedance by varying the length or width, or both, of the slot between the radiator and pole.

Pattern Tests

The object of a pattern test is twofold. One of the objectives is to determine the gain as compared with a dipole for which perhaps a substitution method could be used. The other objective, however, is to determine the amount of radiation at all vertical and horizontal angles which have an influence on the coverage. Both objectives can be accomplished by taking patterns as described under Gain, since the gains can be determined by integrating all the power flow through an imaginary sphere.

To pattern-test the antenna it can be placed upon 25-ft-high wooden turntable which has a speed-controlled motor drive.[28] Figure 7-61 shows such a turntable.

[28] The RCA Test Facilities for TV Antennas, *Broadcast News*, October, 1958.

From the reciprocity theorem it is possible to use the antenna as a receiving antenna as well as a transmitting antenna and obtain the same resulting pattern. This is done for the sake of convenience, since it permits the pattern recorder and the antenna under test to be located at the same point, thus allowing quick analysis of the results. The transmitting dipole, remotely controlled to turn either vertical or horizontal, is placed some distance away. To obtain the required patterns, the transmitting dipole is placed in a vertical position, since the antenna under test is in the horizontal position of the turntable. In this manner, the exact radiating and receiving positions of both antennas are simulated as if the antenna being tested was actually standing vertical and was radiating an electric field which the receiving dipole would have received in its normal horizontal position. The signal in the antenna under test is amplified in a receiver, and the pattern is drawn out on a recorder. A voltage regulator is inserted between the recording instruments and the supply line to avoid line-voltage fluctuations. From the recorded patterns, the actual coverage can be determined as well as the gain. The gain [29] is determined by integrating $E^2 \sin \theta$ over the entire sphere, which is simulated by eight or more equally spaced longitudinal lines, which are the vertical patterns, and one latitudinal line, which is the azimuthal pattern.

After Shipment, before Erection

After the antenna is erected, the difficulties of working on it are greatly compounded. Since few engineers climb, the work must be done entirely by riggers, who do not have the background to do electrical testing. Furthermore, the time during which work can be performed on the antenna is very limited, owing to both scheduled operation and the weather, which frequently prevents work or even climbing. Hence, it is extremely important that thorough tests be made on the ground before erection. Both electrical and mechanical tests should be made.

A thorough mechanical inspection should be made to see that the required components are in their proper places and securely fastened using the specified fastening materials. The pressurized portions should be pressure-tested for a long enough period to be certain that there are no slow leaks. A loss of over 2 lb in 24 hr should be investigated. The fit of major mechanical assemblies should be checked on the ground, since any discrepancies during the rigging operation can become major problems. Such fits include field joints between portions of the antenna and the fit of the pole into the pole socket or pedestal.

Electrically, resistance measurements should be made, when applicable, to assure proper electrical contact at all points. End seals and insulators should be checked with high voltage or with a megger if the antenna requires this test. The most important electrical test is the impedance test or VSWR vs. frequency across the channel. Continuous readings or frequent readings taken across the channel are advisable. This information is extremely difficult to obtain after the antenna has been erected. Since VHF antennas are usually less than two to three wavelengths above the ground, the impedance may not conform to the required values. If any doubts exist, the antenna can be picked up and suspended above the ground at a greater height in order to obtain a more accurate measurement. For some types of antennas it is desirable to recheck a few points after the antenna has been hoisted to a vertical position just prior to erection. This will assure that nothing has radically changed when the normal strains are imposed on the components. All auxiliaries should also be tested. Full power should be supplied to the sleet melters to see that they operate, and the beacon lighting should be checked also.

[29] Pattern Measurements of RCA UHF TV Antennas, *Broadcast News*, vol. 82, February, 1955.

After Erection

Over-all Test

After the complete antenna system is installed, it should be checked. New RF and d-c pulse techniques are currently being evaluated which will be more discerning than previous VSWR measurements. The antenna system should then be connected to the line, and over-all measurements taken.

Reflectometer Test

In order to protect antenna and line components properly it is mandatory that a reflectometer be used on both visual and aural transmitters to interrupt power when the VSWR exceeds a predetermined value. If an arc occurs in the antenna system, it usually loads the transmitter so that meter readings may fail to give a warning resulting in major damage to the antenna system.

Hence, before application of power to the antenna system the reflectometers shonld be checked for proper operation.

INSTALLATION

Advance Planning

The instruction book for a particular antenna usually contains considerable useful information which should be carefully read and followed. There are a number of items, however, common to most antennas which will be discussed.

Preinstallation Procedure

Usually it is advisable to have the manufacturer's serviceman take care of assembly supervision and testing. Some detailed procedure is outlined below.

Antenna Mounting Trestles

Most antennas are impedance-tested on the ground before erection. This is a wise precaution, since any corrective work, if required, is extremely difficult to accomplish once the antenna is at the tower top. The impedance of the antenna is affected by the ground, and trestles are required to obtain adequate clearance. Usually the furnishing of the trestles is the responsibility of the station, although the design is furnished by the manufacturer. They should be on hand when the antenna arrives located on reasonably level ground close enough to the base of the tower so that the antenna can be hoisted directly but far enough away so that assembly work can be done on the antenna without danger of falling objects from the tower while the riggers are working on it. The antenna should be placed so that the tower is not in the radiated field of the antenna, which would affect the impedance during the ground test. This will vary with the type of antenna and the frequency, and the manufacturer's recommendation should be obtained.

Precautions during Unpacking and Assembly

Antennas are usually heavy and appear to be quite rugged. Riggers used to handling heavy, rugged components often overestimate the ruggedness of the antenna, since many of the components can be damaged by rough handling.

If lifting lugs are not provided, the usual practice is to use cable wrapped around the mast with a 2 by 4 "corset" to protect feed lines, slot covers, or other components mounted on the pole. Special oak 2 by 4 lumber should be used for this purpose, since regular lumber crushes, causing damage to components.

Long poles can be given a "set" or internal components damaged if the pole is not properly supported over its entire length when it is lifted from a horizontal position. Strains can be set up under this condition which exceed the maximum wind-load conditions.

To ensure proper handling, a qualified rigger who has a reputation for making successful antenna installations is desirable. Some manufacturers will, if the customer desires, provide a "package" for the tower, line, antenna, and all installation work. This avoids split responsibilities and has many other advantages.

Checking Shipment

It is a wise precaution to check the shipment in detail against packing lists and see that no damage has occurred during shipment. The per-diem rate for a crew of riggers is costly, and any delays due to missing or damaged parts will prove expensive. If there is any damage or shortage, the shipper should be notified immediately.

Pressurized Equipment

Equipment that is normally pressurized should be either stored in a dry place or kept under pressure during storage. The latter will also establish whether any leaks have resulted from shipment.

Assembly

Usually the manufacturer furnishes detailed instruction for the assembly which should be carefully followed.

Special tools are sometime furnished or called for in certain operations which should be used.

Since the antenna is primarily a piece of electrical equipment, cleanliness at points of electrical contact is mandatory.

Electrolysis can occur if proper hardware specified is not used.

Forcing parts into place will usually result in future difficulties. The reason should be investigated.

All hardware should be tight and secure.

If anything does not appear to be correct, consult the manufacturer rather than take a chance.

If any field welding is required, certified welders should be used, since failure could result in loss of human life.

Tests before Erection

It is extremely important that certain tests both mechanical and electrical be performed before the antenna is erected, since the difficulties of working on it after erection are greatly compounded. These tests are described under After Shipment, before Erection.

Erection

The erection procedure should be left in the hands of a qualified rigger. It is highly desirable to erect the antenna in one piece when this is feasible. If not, the rigger must be thoroughly instructed in the assembly procedure. The orientation of the antenna should be carefully established and well marked so that there is no misunderstanding.

In some antennas when transmission lines pass through the top plate of the tower, orientation is doubly important.

Vertical Alignment

For a buried-pole or pedestal-type mounting, vertical alignment is relatively simple. For flange mounting, shims should be used. Vertical alignment is best checked with

transits from several directions. Allowance must be made for wind deflection. Accurate vertical alignment is especially important at UHF, where beamwidths are much narrower owing to the use of higher gain antennas.

Tests before Application of Power

These tests are important to ensure that the over-all requirements are met and also to be certain that the system is ready to receive power. Much damage can be done if there are loose or open connections or if the reflectometer circuits in the transmitter are not properly adjusted.

MAINTENANCE

Daily Operation

A drop in gas pressure (in excess of 2 lb in 24 hr), an increase in VSWR as indicated by the reflectometer, or the appearance of an echo on the monitor indicates an unusual condition in the antenna system.

Gas leaks can usually be located by sectionalizing parts of the system. An increase in VSWR may denote icing or a change or failure of some part of the system. Power should be reduced when the VSWR rises, since the power-handling capability is inversely proportional to the standing-wave ratio.

The appearance of an echo is a symptom of some change in the system which should be investigated. New pulse techniques will make the location of faults much simpler.

Weekly

In superturnstile antennas it is advisable to take resistance readings between the inner and outer conductor for each side of the line. Any significant change from the initial readings should be investigated.

Semiannually

A qualified rigger who is thoroughly familiar with all the aspects of the line and antenna should inspect the system. He should inspect for signs of corrosion, loose clamps or hardware, condition of slot covers, need for paint, physical damage, etc., as the particular antenna requires.

SAFETY IN WORKING NEAR RF FIELDS

It is always necessary to have the power off when working on or near the antenna. At times, however, it is necessary to go through or work near to the field of an emergency antenna located on the same tower.

Frequencies under 1,000 Mc can cause deep heating of which the individual may not be aware. If the field is too intense, the body may not be able to dissipate the excess heat. Body temperatures under certain conditions may go up to 106° with heat exhaustion, heat stroke, possible collapse, or destruction of body cells. The blood circulation permits adequate cooling at 0.01 watt/sq cm. The U.S. Navy in areas such as radar rooms where people are exposed for fairly long periods tries to keep fields below 0.01 watt/sq cm. Complete knowledge does not as yet exist on this subject, but the following data have been reported in papers.

0.01 watt/sq cm = 60 volts/m is considered safe for continuous day-to-day exposure as in a radar room aboard an aircraft carrier for instance.

0.1 watt/sq cm = 190 volts/m is considered safe for limited exposures. This figure has been used when engineers were exposed during a test of an antenna lasting a number of hours.

1.0 watt/sq cm = 600 volts/m according to one paper will cause brain damage at UHF frequencies in 45 min.

For a given effective radiated power in kilowatts for free-space propagation these fields will occur at the following distance in feet:

0.01	watt/sq cm at	$12.1\sqrt{P_{kw}}$	ft
0.1	watt/sq cm at	$3.82\sqrt{P_{kw}}$	ft
1.0	watt/sq cm at	$1.21\sqrt{P_{kw}}$	ft

In areas where the exact power or field configuration is not known, a simple dipole can be built with a ¼-watt unmounted neon bulb (no base) connected across the open center of the dipole. For 0.1 watt/sq cm, 47 volts will exist across the center of the dipole. The neon bulb generally requires 85 volts to ignite and will stay lit as it is gradually removed from the field down to 50 or 60 volts. Hence, the area in which it just extinguishes will correspond approximately to 0.1 watt/sq cm.

Part 8

THE MEASUREMENT OF FM AND TV FIELD STRENGTHS (54–890 MC)

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INTRODUCTION

The coverage of a broadcasting station and the technical quality of the service provided are determined by the received signal and field strengths. Presently available methods of estimating field strengths within the service ranges of FM and television stations are only approximate, and even the best methods of calculating field strengths often fail to take into account variations due to important local conditions. For operating stations the best determination of station coverage is provided by properly made field-strength measurements.

This part describes equipment and techniques for measuring field strengths over the frequency ranges employed for FM and television broadcasting. These services are assigned to several bands between 54 and 890 Mc, as shown in Table 8-1.

Table 8-1. Frequencies Employed for FM and Television Broadcasting

Service	*Frequencies, Mc*	*Channel Nos.*	*Channel Bandwidth*
TV	54–72	2–4	6 Mc
TV	76–88	5–6	6 Mc
FM	88–108	201–300	200 kc
TV	174–216	7–13	6 Mc
TV	470–890	14–83	6 Mc

The quality of service is related to the field strength by considerations of receiver sensitivity and noise figure, receiving antenna gain and transmission-line loss, and tolerable signal-to-noise ratios. The required fields vary with the class of service and frequency assignment. Interfering signals from other transmitters on the same or adjacent channels may limit service to higher values of field strength. Table 8-2 lists values of median field strength required for various grades of FM and television service in the absence of interfering signals, as established by the Federal Communications Commission's Technical Standards.[1, 2] There are also included revised estimates of the

* Superscript numbers refer to References at end of Part 8.

Table 8-2. Median Field Strengths Required for Various Grades of Service in the Absence of Interfering Signals

FM Broadcasting (All Channels)

Grade of service	μv/m	dbu *
Principal city	5,000	74
Urban	1,000	60
Rural	50	37

Television Broadcasting

(FCC Technical Standards)

Grade of service	Ch. 2–6		Ch. 7–13		Ch. 14–83	
	μv/m	dbu	μv/m	dbu	μv/m	dbu
Principal city	5,000	74	7,000	77	10,000	80
Grade A	2,500	68	3,500	71	5,000	74
Grade B	225	47	630	56	1,600	64

(Based on TASO Data)

Primary	250	48	1,400	63	7,500	75
Secondary	50	34	200	46	630	56
Fringe	20	26	55	35	180	45

*This abbreviation was coined by the FCC for television service and signifies the field strength in decibels above 1 μv/m. 0 dbu = 1 μv/m.

fields required in the television bands to provide acceptable grades of service based on the practical experience of operating stations and the findings of the Television Allocations Study Organization (TASO).[2] These latter have not as of the present date (May 15, 1959) been officially adopted by the Commission.

Service is defined in Table 8-2 in terms of the median field at a receiving antenna at a height of 30 ft above ground. In these frequency bands, the field usually varies appreciably with antenna height, generally tending to increase with increasing antenna height. However, the variation in field with height may not follow simple laws, as discussed more fully in subsequent paragraphs.

The presence of trees, buildings, and terrain irregularities[3–7] often results in considerable variation in the signal from one location to another, even within relatively small areas. The variation in field strength with location must be taken into account in measuring the field strengths as well as in specifying service. Service is usually defined in terms of the *median value* of field strength, which is the value exceeded for at least 50 per cent of the time at the best 50 per cent of the receiving locations.

The results of field-strength-coverage surveys are customarily presented as contour maps, showing lines of constant median field strength which represent the outer limits of various grades of service. A typical map of measured television-station coverage is shown in Fig. 8-1. Methods of preparing contour maps are described in detail under the heading "FCC Standard Method."

Much of the present knowledge of wave propagation in these frequency bands

has been derived from field-strength-coverage surveys on operating FM and television stations. The information gained from these commercial coverage surveys has added to the body of scientific knowledge, but field-strength-measurement surveys employing

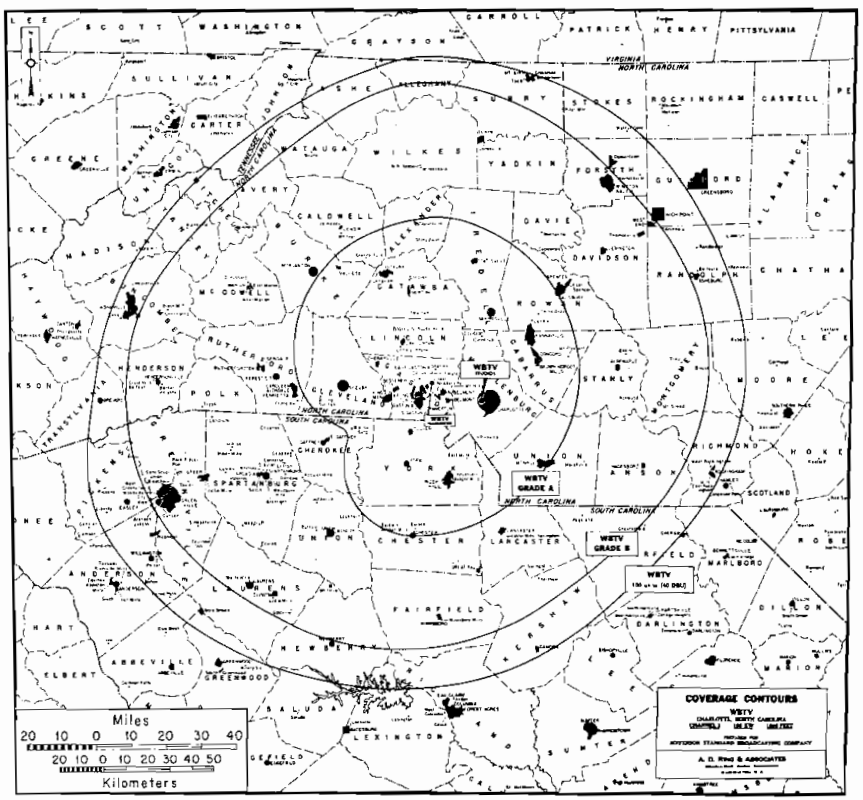

FIG. 8-1. Map showing measured service contours for an operating television station. (*Courtesy of Jefferson Standard Broadcasting Company.*)

special techniques are often needed to supply data for special propagation problems. Examples of such special techniques are discussed under "Recommended TASO Method for Special Studies."

BASIC EQUIPMENT PRINCIPLES

Field strengths in the VHF and UHF bands (30 to 3,000 Mc) are ordinarily measured by determining the voltage which the field induces in a half-wave dipole. The basic relationships can be expressed in several forms. The power transferred between two half-wave dipoles in free space separated by a distance d is given by

$$\frac{P_r}{P_t} = \frac{(1.64\lambda)^2}{4\pi d} \tag{8-1}$$

where P_r = received power
P_t = transmitted power
λ = wavelength in same units as d

In terms of the field at the receiving dipole, the power delivered to a matched load by a half-wave dipole in a field of E volts/m is

$$P_r = (0.0186E\lambda)^2 \quad \text{watts} \tag{8-2}$$

where λ is expressed in meters. For a resistive load of R ohms, the voltage V developed across a matched load by a dipole in a field E is

$$V = \frac{E\lambda}{53.2\sqrt{R}} \tag{8-3}$$

The fundamental problem presented, therefore, is that of measuring the developed RF voltage by a practical instrument of acceptable accuracy.

Figure 8-2 is a graph showing the available power and voltage developed across a matched 56-ohm load as a function of frequency for a half-wave dipole in a uniform field of 1 volt/m at the frequency indicated. This graph summarizes the relationships shown in Eqs. (8-2) and (8-3).

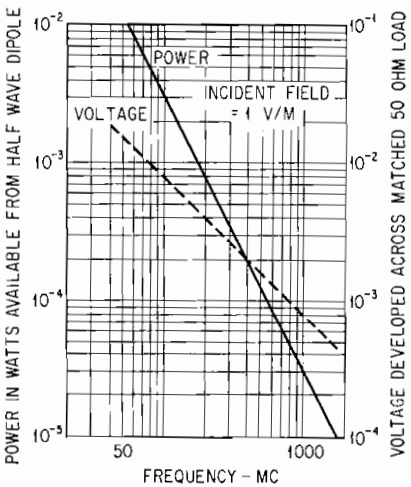

FIG. 8-2. Power and voltage extracted by a half-wave dipole in a field of 1 volt/m as a function of frequency in megacycles.

The voltage-measuring device is ordinarily separated from the antenna by a length of cable. The cable may introduce losses, and any impedance mismatch must be sufficiently small that calibration errors are not introduced by differences between the antenna and cable impedance and the internal impedance of the calibrating oscillator.

PRACTICAL FIELD-STRENGTH METERS

Figure 8-3 is a block diagram of a practical field-strength meter. The antenna delivers its received power to a transmission line leading to the receiver input. If the receiver input is unbalanced to ground, a balance-to-unbalance transformer ("balun") is required. The transmission line between the antenna and the receiver is shielded to avoid stray pickup.

The RF attenuator shown serves two purposes: to avoid overloading of the receiver input on strong signals and to improve the impedance match when the receiver input impedance is substantially different from the characteristic impedance of the transmission line. It is frequently omitted when not required for either of these purposes.

The signal at the receiver input is amplified and converted to the intermediate frequency. Amplification and attenuation at the intermediate frequency permit operation over a wide range of field strengths; further range is provided by the receiver gain control. The rectified receiver output operates the indicating meter.

In operation, the attenuators and gain control are adjusted to provide an on-scale reading of the indicating meter. The receiver input is then switched between the output of the transmission line and the output of the calibrating oscillator, which is tuned to the frequency being measured. The output of the calibrating oscillator is adjusted to a predetermined fixed value using the RF power monitor, and the calibrated attenuator is adjusted until the indicating meter deflection is the same as that obtained from the antenna and transmission line.

For this condition, the voltage at the output of the calibrated attenuator is the same as that from the antenna and transmission line. By taking line and balun losses into account and applying Eq. (8-3) above, the field at the antenna required

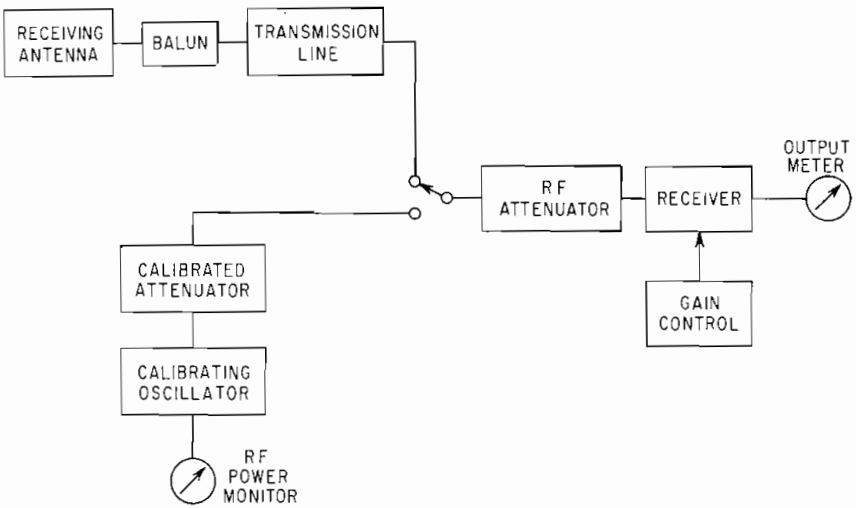

FIG. 8-3. Block diagram of practical field-strength meter.

to produce this voltage can be determined. The relationship between field strength and receiver input voltage is usually expressed as $E = KV$, where K is a function of frequency. Figure 8-4 is a typical graph showing values of K for a UHF field-strength meter.

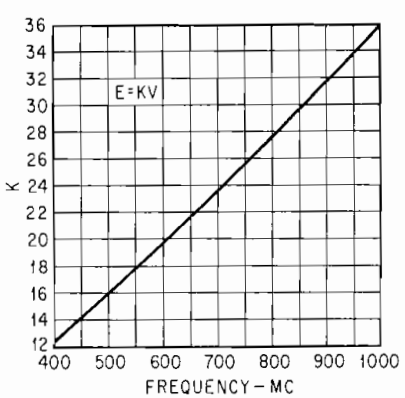

FIG. 8-4. Graph of K for typical UHF field-strength meter. $E = KV$.

A typical commercial field-strength meter of professional quality is shown in Fig. 8-5. The instrument shown is a Nems-Clarke type 107-A, covering the VHF FM and television band from 54 to 216 Mc. A companion instrument, similar in appearance, covers the UHF television band from 470 to 890 Mc.

Accurate instrument calibration is essential in measuring RF fields. During use, the calibration of the instrument described is provided by the calibrating RF voltage source, which is usually an integral part of the field-strength meter (see Fig. 8-5). The calibration of the oscillator and the over-all calibration of the instrument

as a whole must in turn be established and maintained by reference to laboratory standards.

The most direct laboratory calibration of the complete field-strength meter is established by generating a known standard field in which the receiving antenna is placed. Standard-field ranges have been developed and constructed at VHF [8] and are sometimes used in primary calibration of VHF field-strength meters. Most commercial laboratory calibrations at VHF, however, are made by removing the dipole elements from the standard antenna and applying a known RF voltage at the proper frequency to the dipole terminals in series with an impedance equal to the receiving-antenna impedance. The calibration of the balun, line, and receiver is established in terms of this applied voltage, which is then related to field strength through Eq. (8-3) above.

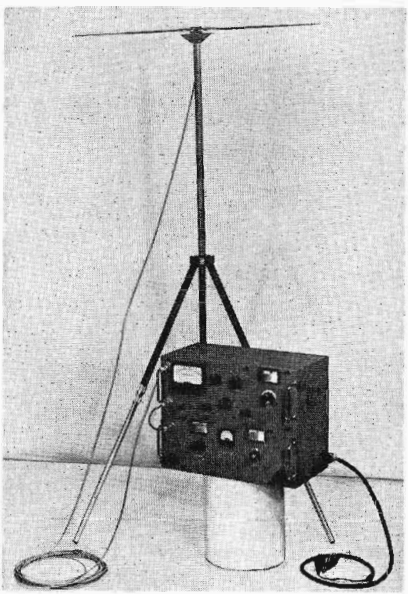

FIG. 8-5. A VHF field-strength meter of professional quality. (*Courtesy of Nems-Clarke Company.*)

Standard-field ranges have not yet been developed at UHF, and both primary and secondary calibrations are made in terms of the voltage appearing at the receiver input. The line and balun losses are measured or calculated from line-attenuation data.

The calibration of the internal reference oscillator section includes the calibration of both the oscillator proper and the variable-output attenuator. The attenuator is usually of the inductively coupled piston type,[9] which depends only on its dimensions for proper functioning; this can be checked against the correct dimensions or against a laboratory standard attenuator. The oscillator can be compared with a standard oscillator, or its output can be measured with a laboratory standard such as a bolometer bridge.[10] This calibration is normally performed only by the manufacturer.

If measurements are made on the visual carrier of a television station, the difference between the peak and average powers of the transmission must be taken into account. This can be done by establishing a calibration in terms of average power for a still scene (such as test pattern or black picture), or a peak-reading voltmeter can be employed to indicate the level of the synchronizing peaks. Such peak-reading voltmeters are an integral part of many of the commercial field-strength meters such as the one illustrated in Fig. 8-5. A schematic diagram of a typical peak-reading voltmeter is shown in Fig. 8-6.

In addition to the field-strength meter, several accessory items are needed in making a field-strength survey. The principal items and their use are described in the following paragraphs and include (*a*) a special receiving antenna, (*b*) an antenna-supporting mast, (*c*) a chart recorder, and (*d*) power supplies. The size and weight of the equipment usually dictate that it be mounted in an automobile or light truck. Figure 8-7 shows a large station wagon containing permanently mounted equipment for field-strength surveys.

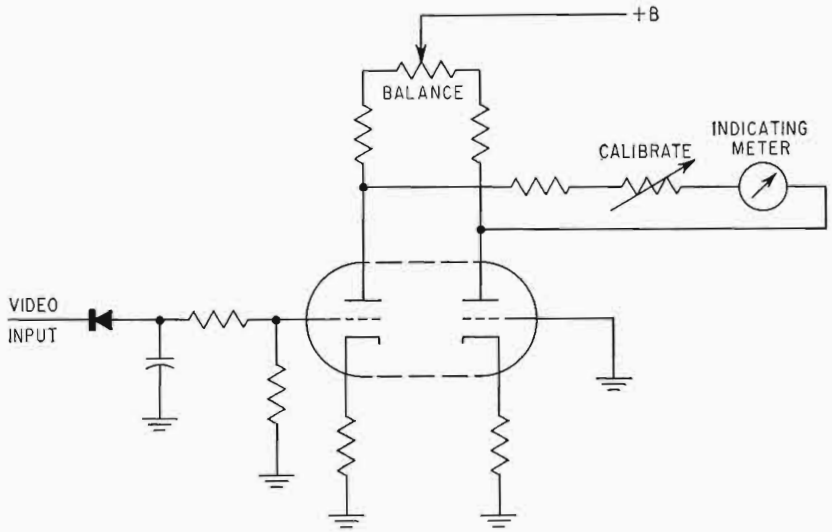

FIG. 8-6. Schematic diagram of bridge circuit for reading voltage corresponding to synchronizing peaks. The component values in the grid circuit are chosen to provide a long time constant.

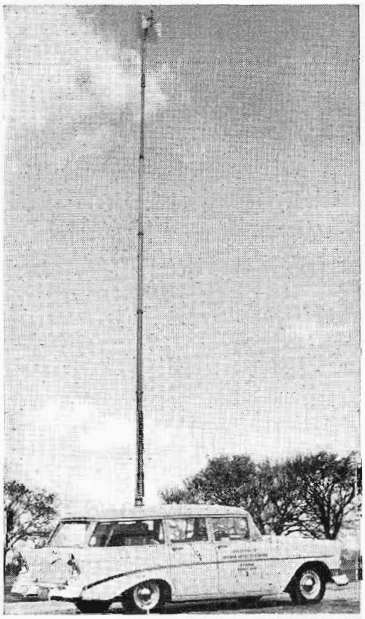

FIG. 8-7. Station wagon equipped for making field-strength-coverage measurements showing 30-ft hydraulic mast. A UHF receiving antenna is mounted on the mast. (*Courtesy of Association of Maximum Service Telecasters, Inc.*)

RECEIVING ANTENNAS

The measurement survey can be made employing the standard dipole antenna furnished with the field-strength meter, or other antennas can be utilized. An antenna which is essentially omnidirectional in the horizontal plane does not require orientation as the vehicle is moved. Figure 8-8 shows a typical nondirectional receiving antenna designed for this purpose. Directional receiving antennas can be employed when their gain is needed (principally for UHF measurements) or when their rejection is desired to eliminate unwanted signals from sources other than the transmitter being measured.

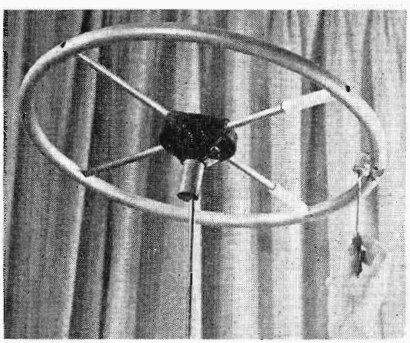

FIG. 8-8. Nondirectional VHF receiving antenna for making coverage surveys.

The antenna employed for the measurements must be calibrated on the measurement vehicle.[11] The received field is first measured using the standard dipole antenna removed from the vehicle. The antenna to be used in making the survey is then mounted on the vehicle at the height to be employed in making the survey, and the receiver input voltage determined with the receiving antenna at the same spot in the field. If an omnidirectional receiving antenna is employed, the circularity of the pattern of the antenna as mounted on the vehicle must be determined. Unless the vehicle can be rotated, this can be done by driving the vehicle in a small circle in an area of uniform field and recording the received signal.

The gain of the service antenna can be established relative to the dipole antenna by means of measurements with the antennas stationary, but more consistent results are often obtained by making short mobile runs over identical paths and recording the signals from the two antennas. For either procedure, the voltage gain of the service antenna G_s relative to the standard dipole antenna G_d is $G_s/G_d = V_s/V_d$, where V_s and V_d are the voltages delivered to the receiver input using the service and standard dipole antennas, respectively.

If the transmission line or balun between the antenna and receiver is different from the standard cable and balun supplied with the instrument, the antenna calibration must include the cables and baluns.

ANTENNA-SUPPORTING MAST

The receiving antenna is ordinarily supported at a height of 10 to 30 ft above ground, depending on the measuring technique employed. For the 10-ft height, a simple mast of metal tubing can be used. For the 30-ft height, a special mast is required to raise and lower the antenna, and the mast arrangement should permit the vehicle to move over limited distances with the mast elevated.

The measuring unit shown in Fig. 8-7 employs a telescoping mast of five sections of aluminum tubing ° elevated by low-viscosity oil forced in under pressure; the mast descends under gravity when the pressure is relieved. A handle inside the vehicle permits the mast to be rotated to orient the receiving antenna.

CHART RECORDER

For measurements made with the vehicle in motion, a chart recorder is employed. The chart can be driven from the vehicle speedometer or a drive motor.

° The mast shown was manufactured and installed by the Thomas Mold & Die Company, Wooster, Ohio.

The pen element of the chart recorder is driven by a galvanometer coil; excitation of the galvanometer is provided by a d-c amplifier, which may be built into the field-strength meter or may be a separate accessory.

When the chart recorder is employed, the recorder pen element must be calibrated against the receiver output indicator of the field-strength meter. The d-c amplifier is adjusted for balance at the ends of the meter scale, and a calibration curve is prepared for intermediate values.

POWER SUPPLIES

The power drain of the measuring equipment can be fairly substantial, especially if much accessory equipment is employed. It is usually preferable to provide a power source for the measuring equipment separate from the vehicle battery. This may consist of a separate battery bank to operate the meter and accessories, or a separate 115-volt a-c generator may be mounted in the vehicle.

MEASURING PROCEDURES AND TECHNIQUES

The FCC FM and TV Technical Standards prescribe measuring methods to be employed in making measurements to be submitted to the Commission. These methods are also usually employed in making station-coverage surveys, although variations from the official procedure are frequently taken. The Television Allocations Study Organization report recommends a number of changes in the FCC procedure and also recommends the testing of a radically new measurement technique. The following paragraphs summarize the present requirements of the Commission's Standards and indicate the changes recommended by TASO. The proposed revised method is also described.

FCC STANDARD METHOD [12]

The Commission's Technical Standards require field-strength-measurement surveys to be made with mobile equipment along roads following as closely as possible to radial lines from the transmitter, laid out along bearings separated by 45° beginning with true North. Measurements are required out to a point in each direction somewhat beyond the field-strength contour which it is desired to establish. Continuous recordings of the field strength are made along the roads employing the chart recorder. A minimum chart speed of 3 in. per mile is required. Figure 8-9 shows a sample of a typical chart recording obtained by this method.

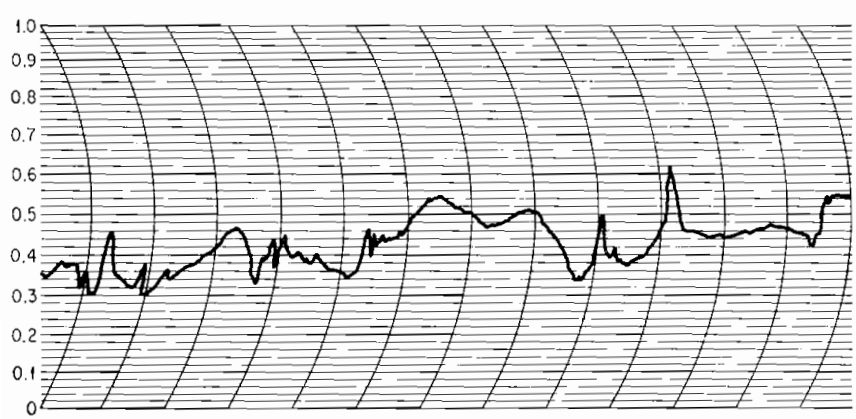

FIG. 8-9. Sample of typical recording chart showing the chart record obtained in making mobile field-strength recordings.

The completed recorder charts are divided into not less than 15 sections in each direction. Each section of the chart is analyzed to determine the median (50 per cent) field for each section. The chart median values are then converted to received field strength by combining the individual calibrations of the antenna, transmission line, field-strength meter, d-c amplifier, and chart recorder as discussed above.

The received fields must be corrected for the field expected at a receiving antenna height of 30 ft above ground. The Commission's Standards do not specify the conversion factor to be employed, bnt it has been common practice to assnme the field strengths to increase linearly with antenna height, as indicated by classical propagation theory. For this assumption the relationship between the field E_{30} which would be expected at 30 ft and the field measured at a receiving antenna height H_r is $E_{30}/E_H = 30/H_r$. For example, the ratio of the field at 30 ft to the field at 10 ft is 30/10 = 3.0, or 9.5 db.

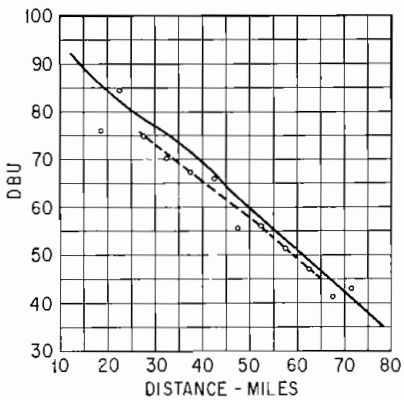

FIG. 8-10. Graph of measured field strength vs. distance for a typical radial route series of measurements. Each circle represents the median value of field strength for a 5-mile recording interval. The dashed line is a best-fit curve through the points. The solid line is the expected field strength computed using the FCC F(50,50) curves.

The median fields as established in accordance with the procedure described above are plotted as a function of distance from the transmitter, and a smooth curve is drawn through the plotted points. Figure 8-10 is a typical graph showing the plotted field strengths as a function of distance from the transmitter, together with the smooth curve through the plotted points. The dashed curve in Fig. 8-10 is the predicted field strength calculated using the propagation cnrves and prediction methods specified in the FCC Television Broadcast Technical Standards.[13]

Individual graphs of median field strength vs. distance as shown in Fig. 8-10 are prepared for each of the direc-tions along which the measurements were made; the distances to the desired field strength contonrs, selected from Table 8-2, are determined in each direction. These distances are then plotted on a suitable map, and contours are drawn to prodnce a finished map such as shown in Fig. 8-1.

TASO RECOMMENDED CHANGES IN FCC PROCEDURE

TASO has recommended that the radial route-measuring pattern be modified to permit wider discretion in the selection of the measuring routes. A minimum of eight routes is recommended, selected to encounter representative terrain and to permit reasonable interpolation between adjoining radials. Additional routes, includ-ing branch routes, are recommended where needed.

In the analysis of the recorder tapes, TASO has recommended that the sec-tions of the route chosen for analysis be as nniform as possible, with a minimnm length of 2 miles.

One of the most important changes recommended by TASO in the present pro-cedure is in the antenna height-gain correction factor. The application of the linear height-gain function discussed above is recommended only in relatively flat terrain, and in rolling or rough terrain the following height-gain factors (in decibels) are recommended to convert from 10- to 30-ft fields:

Channel	*Smooth Unobstructed Terrain*	*Rolling Hilly Terrain*	*Rough Terrain*
2–6	9.5 db	8 db	7 db
7–13	9.5	7	5
14–83	9.5	5	2

NEW METHOD RECOMMENDED BY TASO FOR FIELD TRIALS

TASO has also recommended field trials of a radically new method of measurement. The measuring pattern for this method is laid out as a series of five concentric circles centered on the transmitter rather than along eight radial lines as now employed. Four hundred measuring points are established on these five circles distributed in approximate proportion to the square root of the radii of the circles.

Field-strength measurements are to be made at each of the 400 points so located. If the designated point is inaccessible, the measurement should be made at a location as close to the designated spot as possible and as nearly as possible at the same ground elevation. Each of the 400 measurements is to consist of a single spot measurement made with the receiving antenna at a height of 30 ft above ground.

The data collected are to be analyzed by dividing the area surveyed into eight or more sectors not exceeding 45° in width. These sectors are to be chosen so as to include reasonably homogeneous terrain in so far as possible. For each constant-radius arc within each sector, the mean value of the spot measurements is determined.* This analysis provides five values of field strength as a function of distance in the direction of each section, from which curves of mean field strength vs. distance for the sector can be drawn. Linear interpolation can be employed for intermediate distances between adjoining circles.

RECOMMENDED TASO METHOD FOR SPECIAL STUDIES

For purposes of scientific investigation of field-strength behavior, measurements are often required employing special techniques. One such method, recommended by TASO in making measurements to be analyzed in terms of the terrain profiles between the transmitting and receiving antennas, is briefly outlined in the following paragraphs.

A precise radial line is laid out from the transmitter on topographic maps to the distance to which measurements are to be made.† Along this radial line, measuring locations are marked at exact 2-mile intervals, beginning at exactly 10 miles from the transmitting antenna. The actual measurements are made precisely on the radial, at locations as close as possible to the exact 2-mile marks established as described.

The individual measurements consist of short mobile runs (100 ft along the road) at each location so chosen, with the receiving antenna at the 30-ft height. The chart recorder is used, and the median, minimum, and maximum values of the field for each recording are determined from the chart recording.

PRACTICAL PROBLEMS ENCOUNTERED IN MAKING FIELD-STRENGTH SURVEYS

Before any field-strength-measurement survey is undertaken, the radiated power of the transmitting installation must be established as closely as possible. The transmitter output power should be determined by means of the dummy load and maintained as closely as possible to the proper value throughout the survey. The

* When the signal is below the noise level at one or more locations in each group, the median value rather than the mean value should be established.

† Precise methods of calculating accurate radial lines for this purpose are described in detail in the TASO report.

radiated power is established from the measured transmitter output power, taking into account the antenna power gain and the transmission line and diplexer losses.

The use of a 30-ft receiving antenna mounted on a vehicle requires special permission from police or highway authorities in most states. These requirements vary among the individual states, but full details can be obtained from the state police or highway headquarters in the various state capitals.

The operation of a 30-ft mast presents safety hazards which require the exercise of utmost caution in the use of an elevated mast. The TASO field-strength measuring specification includes a special appendix dealing with safety requirements. When measurements are made with an elevated antenna, the need for caution must be borne in mind at all times.

FADING OF SIGNALS NEAR THE RADIO HORIZON

Fairly substantial variations in field strength with time are frequently noted near and beyond the radio horizon. These variations may be relatively rapid, occurring over a period of a few minutes, or slow variations may appear over periods of several hours. Average field strengths in this region are usually lowest during winter afternoons, and higher average fields may be observed during the evening hours and during summer. The variations in field strengths with the passage of time must be taken into account in planning and making field-strength-coverage surveys.

The observed fluctuation of the field near the horizon is believed to be due principally to variations in the refractivity gradient of the lower atmosphere, which in turn is determined by the temperature, humidity, and barometric-pressure gradients. Measurements for coverage surveys should not be made beyond the radio horizon during periods when unusual conditions of temperature, humidity, and barometric pressure are believed to prevail. In particular, such measurements should not be made during changing weather conditions or if weather fronts are known to be in the area.

The variations in field with time often result from causes which are not readily apparent, and it is frequently difficult to determine whether typical propagation conditions prevail. One method which has been proposed and tried with some success is that of establishing fixed recording stations in one or more directions, at locations near the expected outer limit service, and recording the received signal over a period of several days. These recordings will give an indication of the signal to be expected under average conditions; the coverage survey measurements beyond the horizon can be made during a period when the recordings indicate propagation conditions to be typical. Measurements should not be made on days when these recordings indicate excessively high or excessively low field strengths.

REFERENCES

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13. Federal Communications Commission's Rules, Sec. 3.684.

Part 9

FIELD-STRENGTH MEASUREMENTS (540–1600 KC)

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INTRODUCTION

Shortly after broadcasting began in the early 1920s, when "wavelength" was checked by a Kolster Decremeter, power was estimated from the product of plate voltage and plate current, and antennas were flat tops or cages hung on a roof, broadcasters sought some uniform and reliable means of describing their service areas. Expressions such as "You're coming in loud and clear" or the more flattering "You're coming in like a ton of bricks" needed to be reduced to some accurate descriptive system.

These desires for better information about coverage or service gave birth to the field-strength meter. In the beginning, this device consisted of a standard signal generator and a stable loop antenna receiver. This apparatus was so bulky that it was usually permanently mounted in a car, and where the car couldn't go—well, there were no measurements. Later on in the twenties, Western Electric wrapped the whole works up in one unit about the size of a piano, but one still required a medium-sized truck to transport the device.

In the early thirties RCA made the first step, albeit a short one, in the right direction. They put handles on a couple of boxes and advertised them as "portable." One contained the field-strength meter and the other an assortment of dry batteries, loops, and plug-in coils. Most of the hunchbacked engineers alive today got that way because their bosses believed that word "portable" in the ads.

In the late thirties Jim McNary in cooperation with Federal reduced the size and weight to somethiug less than backbreaking, but this meter was still far from what engineers needed to do a really good and complete survey job.

At last, shortly after World War II, Allen Clarke of Silver Spring, Md., brought forth that sweetheart of an instrument called the 120-D or WX-2, depending on whose nameplate it bears. Self-contained, direct reading throughout the broadcast band, and not much larger than a press camera, it almost makes the job of measuring field strength a pleasure (see Fig. 9-7). Its only drawback is that we no longer have an excuse that some desirable measuring sites are inaccessible. Wherever we can walk, there we can take this meter and measure the field strength.

FACTORS TO BE CONSIDERED

Now that the equipment situation is in hand (no pun intended), let's take a look at the FCC Standard Broadcast Technical Standards and Rule 3.186 in particular. This section only partially details the requirements for good, supportable, and intelligent field-strength measurements. Along with the instructions given in the Standards there are many more factors to be considered and applied that make the difference between acceptable and questionable data. Some of these factors are applicable to all field-strength measurements, and some assume greater importance in specific applications of field-strength measurements.

Reasons for Measurements

Of the many reasons why we may desire field-strength measurements, the following may be considered the most usual:

1. Location of contours of specified intensity or the determination of quality of service (This started it all!)
2. Interference range of the transmitter
3. Proof of performance of a directional antenna
4. Proof of efficiency of a nondirectional antenna
5. Site survey—to determine the adequacy of a proposed transmitter site
6. Determination of the amplitude of the radio-frequency harmonic radiation of the transmitter
7. Evaluation of the sky-wave-signal intensity from a distant station

RADIAL MEASUREMENTS

General Considerations

In all the above situations with the exception of 6 and 7, strict adherence to the radial bearing from the transmitter is most important. Lay the radial out on the best available map (topographic preferred), and then stick to it! Examine the radial in fine detail and measure as often as practical in unobstructed locations (see Fig. 9-1). This is particularly important when establishing the unattenuated field strength at 1 mile. What do we mean by "unobstructed"? Well, we mean, stay away from overhead wires or similar conducting obstructions. Stay away at least five times the obstruction height and if at all possible ten times the obstruction height. Don't worry about whether this puts us off the "tenth-mile" or "quarter-mile" distance referred to in Sec. 3.186 of the Rules. The bearing is of primary importance; the distance is unimportant as long as it is known and as long as we have a sufficient number of measurements in each distance range. Something slightly in excess of a passing glance at a sheet of log-log paper or semilog paper will impress the idea upon you.

Also, stay away from underground cables, pipelines, etc., in the same manner. These nuisances are usually shown on topographical maps and are usually marked by painted stakes where they cross rights of way. These "gadgets" are particularly obnoxious when they happen to run radially from the transmitter site.

How do we know when we are at a sufficient distance from such obstacles? Usually, that little field-strength meter is a reliable source of such information. Just note the direction of the approaching wavefront. Is it coming from the direction of the transmitter? If not, the measurement is suspect. Note the depth of the null as the loop is rotated. Is it sharp and deep? If not, the measurement is suspect. What do we do? We record the signal measured and note the observed effect in our measurement log. Maybe when we get to plotting it along with the other measured data, it fits the curve nicely and fills in a blank space we need. On the other hand, if it is out in left field, we just forget we made that one and go looking

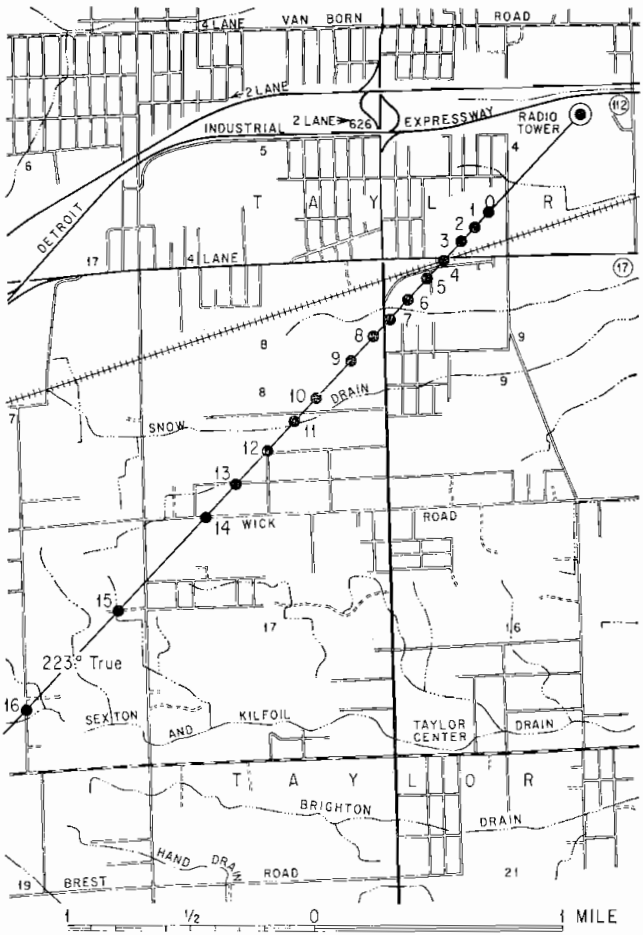

FIG. 9-1. Typical radial with numbered measuring points.

for another place or places in that area where we can get some better information to fill in the blank spots.

Detailed Plotting

Let's try a typical radial. Also, let's assume that we are going to try to prove a protected radial from a directional antenna. This just about covers all the more important factors which will concern us in making ground-wave measurements, with the exception of determining the location of distant service or interference contours.

Preferred Maps

First, obtain the most accurate map available for the path to be measured. U.S. Geological Survey maps are to be preferred if they are of recent issue and/or are the result of an adequate survey. The map should say: "This map complies with National Map Accuracy Standards" on the lower edge. It should be accepted subject to careful checking if it says: "Surveyed by Reconnaissance Methods." If these are

not available, county road maps can be employed. However, some road maps are not very accurate, and they should be checked by an auto odometer before placing full reliance in them. On the map, carefully locate the transmitting antenna site. Any significant error in the antenna location will result in a distorted pattern and consequently inaccurate radial data. Then carefuly project a meridian (true North line) through the transmitter site. With the site as the origin and with a good protractor, lay out the radial bearing and continue its projection for at least 15 or 20 miles from the site. (The precise determination of radial bearing recommended by TASO is not required in the standard broadcast band.)

Nondirectional Measurements

Now we are ready to begin a radial with the antenna operating nondirectionally. Nondirectional data are required by the Commission because they usually give smoother attenuation information than will be obtained in a deep null (see Fig. 9-5).

STATION WZZZ
APRIL 31, 1958
RADIAL 123° TRUE

POINT NO.	e-MV/M	DIST	DESCRIPTION
1	398	.432	HARDEL - DEAD END
2	329	.534	BIRCH & BEVERLEY
3	225	.604	N. OF ECORSE & RWY AT NEW CASTLE
4	243	.689	100' S. OF ECORSE ON PINE OPP.# 23481
5	265	.799	GUIDOT AND BUTZEL
6	189	.9	SW OF FACTORY AT HAYES AND CORNELL
7	170	1.015	E. OF TELEGRAPH 100' ON CROWLEY
8	152	1.125	W. OF TELEGRAPH - FACTORY LINES UP WITH ARRAY
9	134	1.23	BEVERS RD. 0.15 W. TELEGRAPH BEHIND BARN
10	124	1.36	CHERNICK RD. 0.3 W. TELEGRAPH N. OF REDHOUSE
11	113	1.56	CHERNICK RD. 0.4 MI W. OF TELEGRAPH
12	101	1.68	INTERSECTION HAIG AND GULLEY
13	90	1.85	HASKELL
14	80	2.06	WICK
15	65	72	

FIG. 9-2. Example of radial measurement log.

Now, beginning at a distance of about five times the height of the antenna we start looking for unobstructed measuring locations *on the radial*. Upon reaching the first acceptable point on the radial, we observe the field strength, paying particular attention to the direction of the arrival of the wavefront and to the depth of the null on the meter when the loop is rotated 90° to the direction of the transmitter. Having recorded the value of the signal in our notebook, we mark the location on our map, number the location, and most important, describe the location in sufficient detail so that we can return to the exact same spot in the future (see Fig. 9-2).

We proceed along the radial, obtaining as much data as we can and preferably obtaining more data than are required by 3.186 of the FCC Rules. If because of topography or if we encounter large reservations in which we cannot measure, then we try to obtain additional data in other distance ranges to compensate partially for the missing distance range. As a minimum, we should have measured at least 25

points along the radial within a 15-mile distance. If the directional antenna, which we are going to try to prove on the basis of these data, is a complicated one, then we should get more than 25 and probably as many as 40 points on the radial. The reason for the additional points becomes apparent when we rerun the radial directionally (see Fig. 9-5).

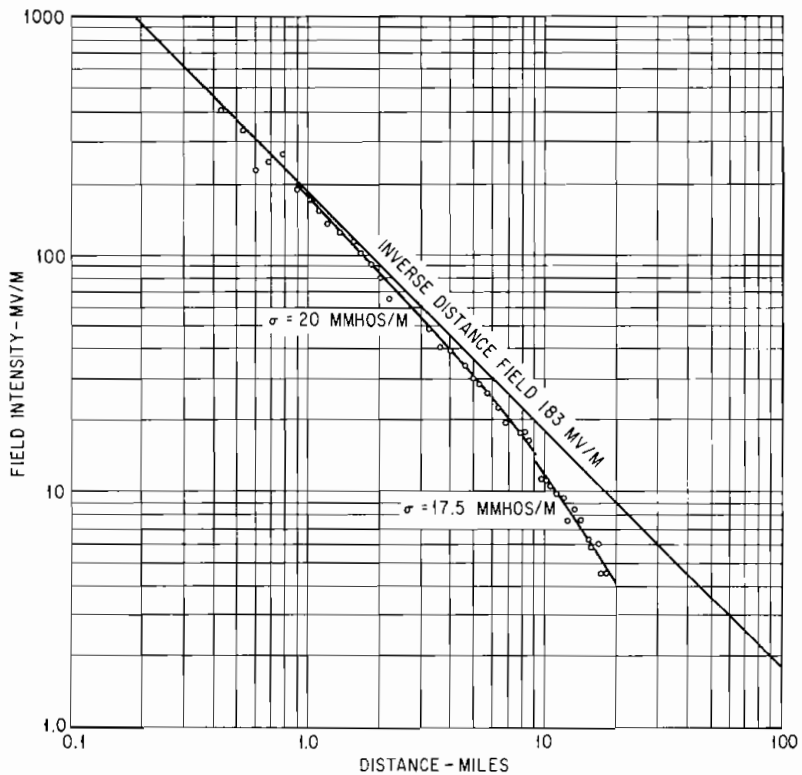

FIG. 9-3. Inverse distance and measured fields: nondirectional operation in direction of protected null, 223° true.

Plotting

Now, we return to the map, carefully measure the distance from the transmitting antenna to each of the measuring points, and tabulate these distances opposite the signal values. The values of field strength which we have measured can now be plotted as a function of distance, and for this plot we can use one of the following commercially available graph papers or its equivalent:

1. If we wish to employ the charts of ground-wave field strength found in Part 3, Radio Broadcast Services (January, 1956, edition), or "FCC Broadcast Engineering Charts" available from the Superintendent of Documents, the data can be plotted on K&E "Ground Wave Field Intensity," paper No. 61729. This paper has the same logarithmic scale as that employed in the above FCC documents, and the data which we have measured can be matched directly against the appropriate graph for the frequency involved. By matching the abscissa of our data with that of the FCC graph, we can then slide the ordinate information data up and down as described in Sec. 3.186, and when the "best fit" is obtained, we have determined both the un-

attenuated field at 1 mile and the conductivity along the radial path. On a light table or against a window, mark the inverse distance field and trace off the apparent conductivity.

2. For those who prefer a slightly higher order of accuracy, we should refer to Graph 20 of the above publications "Ground Wave Field Intensity Versus Numerical Distance over a Plane Earth." By use of this graph, we can construct a new family of attenuation curves for our exact frequency for any desired values of conductivity

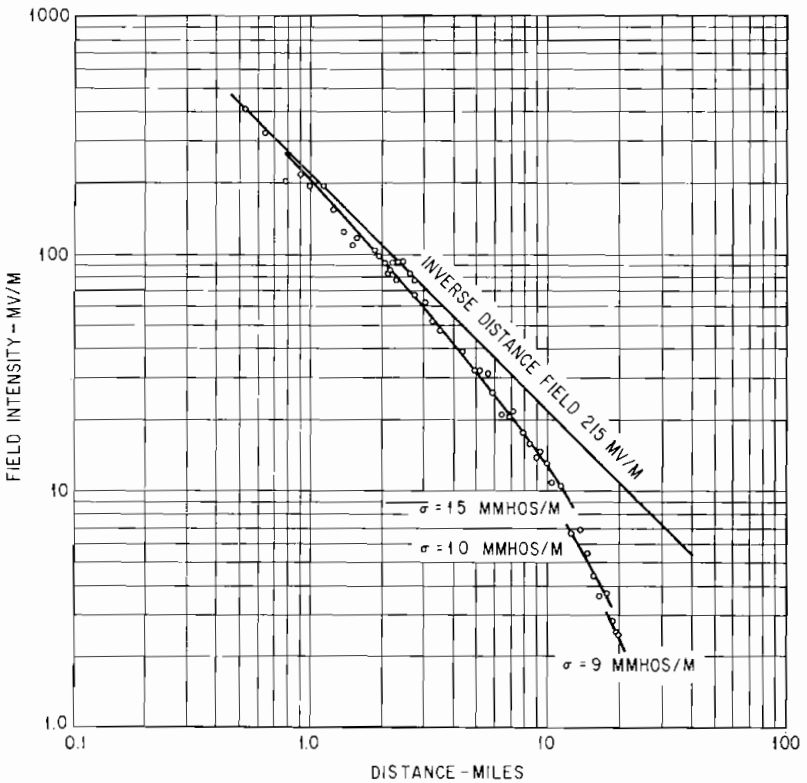

FIG. 9-4. Inverse distance and measured fields: nondirectional operation in the direction of the maximum, 6° true.

and also for several values of dielectric constant. For each value of conductivity and its associated value of dielectric constant we must compute the numerical distance in terms of $R(1 \text{ mile})$ from the equations shown on Graph 20 for vertical polarization. After drawing the inverse distance line on our graph paper, we then simultaneously match this line with the equivalent line on Graph 20 while holding our 1-mile distauce line on the computed numerical distance value. We then draw the attenuation curve most closely approaching our calculated value of b, interpolating where necessary. This is repeated for each value of conductivity and dielectric constant chosen.

For convenience, it is most practical to assume one value of dielectric constant, compute the numerical distance for several values of conductivity, and plot this family on one graph sheet. If other values of dielectric constant are assumed, the same conductivities assumed before should be computed and a separate graph employed for this family. The plotted radial data can then be matched to these families.

3. If a still higher order of accuracy is desired, the curves shown on Graph 20 can be transferred to either Dietzgen 3- by 3-cycle logarithmic graph paper No. 340-L33 or K&E No. 359-120, which is equivalent. Using this paper and having our own Graph 20, we can construct our families of attenuation curves as outlined in the second method above. The principal advantage gained by the use of this latter method is that the data are well spread out and more precisely analyzed. Again we match measured data to theoretical graph.

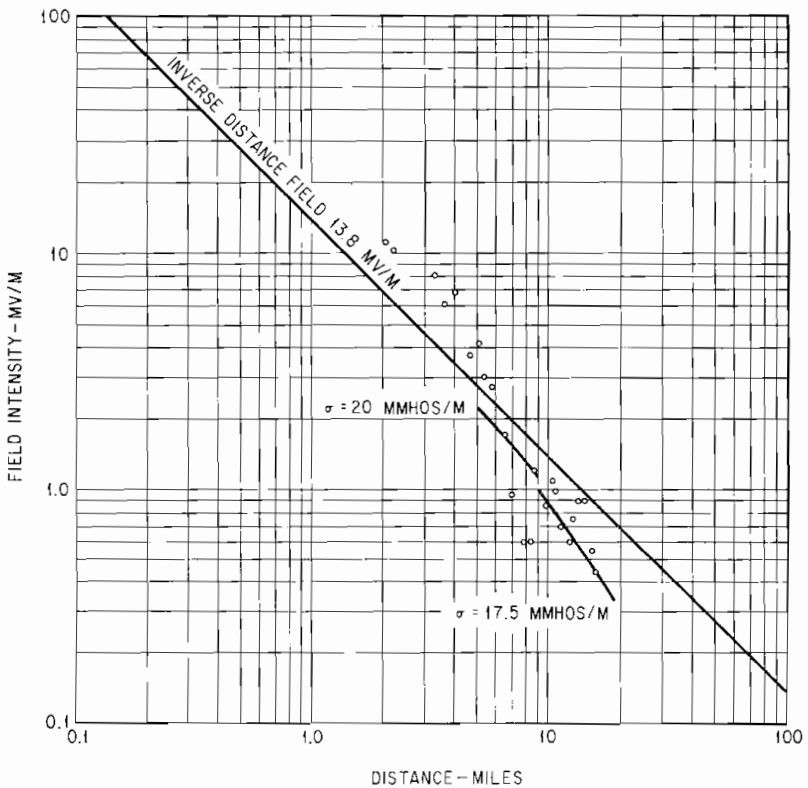

FIG. 9-5. Inverse distance and measured fields: directional operation on radial of protected null, showing increased scattering, 223° true.

If we have prepared the data by the third method above, we should have a radial plot similar to Figs. 9-3 and 9-4. Here we have more data than are needed for a nondirectional radial alone, but we are preparing for more difficult tasks ahead. When we have completed a sufficient number of such radials to determine the nondirectional pattern and have analyzed them, we are prepared to measure our directional pattern or patterns.

Directional Measurements

If we have taken our nondirectional data carefully and noted the exact location of each measuring point, the measurement of the directional data will be easy. If we have been careless in describing the measuring points, we are in for trouble, and the deeper the null in the directional pattern, the more trouble we are likely to encounter. Take heed! Do it right the first time.

The basic difference in the measurement of directional vs. nondirectional antennas is that the directional looks much less like a point source of radiation. Where we began our nondirectional measurements at five times the tower height, we now begin our directional measurements at about ten times the maximum separation between the extremities of the array. In some instances even this is too close, which will appear as wide scattering of the measured values at locations close to the transmitter. We must then depend on data at greater distances where the scatter has diminished to establish the unattenuated field of the array (see Fig. 9-6).

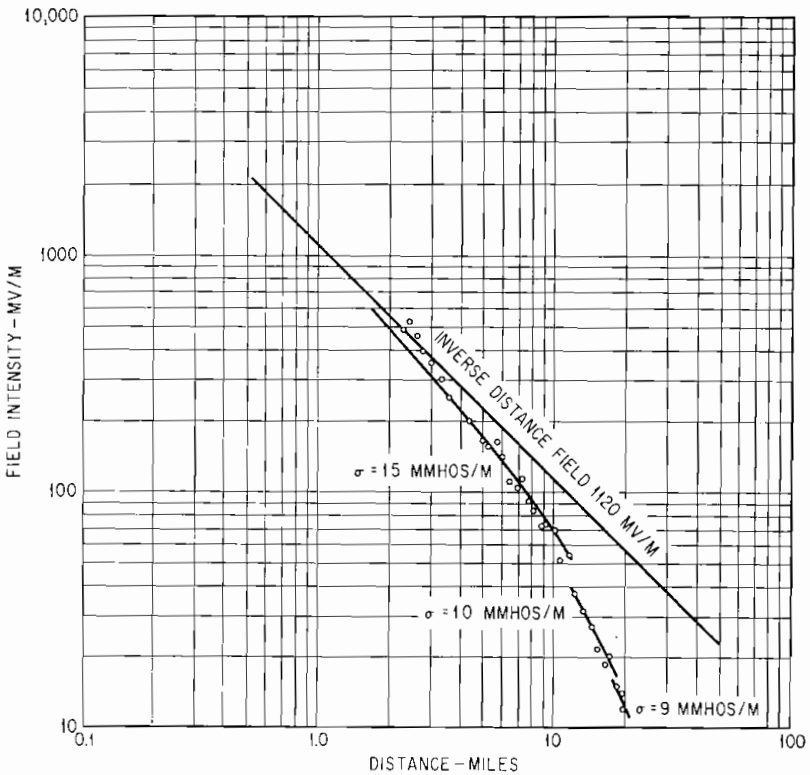

FIG. 9-6. Inverse distance and measured fields: directional operation in the direction of the maximum, 6° true.

It is of the utmost importance, in the directional case, to verify the direction of the approaching wavefront. If in doubt, refer to a good magnetic compass and be sure to correct for the earth's magnetic variation.

After the radial has been run in the directional case, we again plot our data as before but this time we try to match it with the previously analyzed nondirectional data. Now you can appreciate the importance of adequate data carefully taken in the nondirectional case! In most cases, there will be more scatter to the directional data, and the scatter is usually emphasized where we have one or more of the following conditions prevailing:

1. Widely spaced arrays in terms of frequency
2. Deep nulls
3. Poor soil conductivity or rugged terrain
4. Metallic obstacles near the path

5. Reradiation from obstacles near the antenna
6. Buried pipelines running near the path

Under such circumstances it is necessary that we obtain as many data as possible and depend upon the most probable grouping of measurements to determine the directional field. Most often we find that the points at the greater distances give the best comparison with the nondirectional field values. Refer to Fig. 9-5. This is the same radial that is shown nondirectionally in Fig. 9-3. Note that we started our data at a greater distance from the antenna and we still encounter severe scattering. In this particular case, the scattering is attributable to conditions 1 and 2 above. Note also that some of the points measured and plotted in Fig. 9-3 are omitted from the plot in Fig. 9-5. Either these points produced poor nulls on the field-strength meter or the wavefront arrived from some direction other than that of the transmitter or both.

In contrast, see Figs. 9-4 and 9-6 taken on the same array but in the direction of maximum directional radiation. Here, we observe that there is little or no scatter in the directional data in spite of the fact that condition 1 above still applies. These data are typical.

Monitoring Points

The next order of business is to locate the "monitoring points" required on the protected radials. At least one such point and preferably one or two alternate points must be established on each such radial. They must be easily accessible. The loca-

FIG. 9-7. Typical monitoring point location. Note freedom from overhead wires, etc., at point of measurement.

tions should be clear of obstacles and likely to remain so. The measured values at the point should lie reasonably close to the attenuation curve shown on the graph of the measured data, and there should be some readily identifiable object near by that will show in the photograph of the point. The description of the point itself should be clear, and the route from the transmitter to the point should be specified along main highways or well-traveled and marked roads. Figure 9-7 illustrates a good monitoring point.

Requirements for Satisfactory Results

Now for a few tips—

1. Read the rules of the FCC and understand them before you begin.
2. Obtain accurate and up-to-date maps and check them.

3. Use a recently calibrated meter or check it against another meter which has been recently calibrated.
4. Start out with fresh batteries and have a spare set available.
5. Stay on the radial.
6. Dont' skimp on the amount of data even at the larger distances.
7. Accurately describe each point so you can find it again.
8. You don't need headphones if you have a car radio receiver. Listen to the station and then to the heterodyne when you turn the calibration oscillator on.
9. Treat your meter with care—it's expensive and is a precise instrument.

Establishing Coverage

Everything that has been written so far has dealt with the signal intensities relatively close to the transmitter. If we wish to extend our data further for the purpose of establishing our coverage, we merely continue along our radials until the desired signal level has been reached and passed by a reasonable margin. Fairly abrupt changes in conductivity can extend the average contour distance beyond that anticipated on the basis of just passing the desired signal value. Besides, if this does occur and the boss wants the data for sales purposes, he may be happy enough to "cough up" a raise.

For extended measurements, to establish the degree of electrical interference which may be expected, and where these data are to be submitted to the Commission either by petition or in hearing, strict adherence to the rules in principle as well as in fact is demanded. Furthermore, it is of the utmost importance that measurements taken at the larger distances be made several hours after sunrise and be completed several hours before sunset. During these hours, propagation via the ionosphere is at a minimum and more realistic values of the ground wave obtain.

So far we have limited the discussion to those techniques required to cover the originally stated usual reasons for making field-strength measurements in the broadcast band with the exception of items 5, 6, and 7. Actually, we have covered 5 because a site survey is in most cases just a nondirectional survey with low effective power. In the few instances where this statement doesn't hold, we may be required to make a directional survey at low power. In either case, the procedures previously outlined apply.

Harmonic Radiation

In measuring the performance of a broadcast transmitter to satisfy the annual and prelicense renewal requirements of Rule 3.47(a)(5), we are told by FCC that field-strength measurements are preferred to observations made with a communications receiver although the latter will be accepted. *Actually, either method yields nothing more than the field strength in either absolute or relative values at the point or points at which a measurement was taken.* Neither method defines the harmonic content of the transmitted signal. Only in the case of the relatively short (compared with a wavelength at the fundamental frequency) nondirectional antenna do field-strength measurements of the harmonic have any meaning. Here they do give a fair approximation of the harmonic content of the *system*. In the case of a directional antenna, we know energy distribution of neither the horizontal plane nor the vertical plane; hence, emphasis on the italicized sentence above.

This doesn't mean that harmonic radiation from a broadcast antenna system can't cause serious interference to other services. The author has experienced too many instances of such interference to deny it. It does mean, however, that when operating directionally, a few field-strength measurements of the harmonic signal near by won't prove a thing.

The best solution to the problem is to locate some point where the harmonic signal is audible and using a Communications receiver with an S meter, insert between the transmitter and the common point a trap or low-pass filter, then adjust it for minimum S-meter reading. Thereafter, once the harmonic signal is sufficiently reduced, com-

parative checks of the harmonic intensity can be made using the same receiver and antenna.

If absolute values of the harmonic signal are required, alas the Clarke 120-D is of no use. Start looking for an old RCA TMV-75B, 308-B, a Federal 101 with high-frequency loops, or resort to one of the newer products of Stoddart, Empire Devices, Polarad, or equal.

Sky-wave Signals

The measurement of sky-wave signals from distant stations by individuals has passed into limbo in recent years. The Commission has consistently held that snch data will not be admitted in contested hearings and that these data are admissible ouly in "rule-making" procedures. Since there have been no such procedures recently—no sky-wave data! Besides that, FCC and the Central Radio Propagation Laboratory of the Bureau of Standards have miles of recordings for every inch an individual could assemble, and they've been collecting it for years. Hence, there is little incentive to go to the trouble to set up the equipemnt and then analyze the recorded data.

Section 3

TRANSMITTERS

Part 1

STANDARD BROADCAST TRANSMITTERS*

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INTRODUCTION

Most standard broadcast transmitters in current production use the familiar design in which a final Class C RF amplifier is plate-modulated by a push-pull Class B or Class AB modulator. Of twenty-two modern transmitters described in the following pages, all but four use this design. Transmitters using other designs are all in the high-power category. One 5-kw and one 10-kw transmitter use grid modulation of the final RF amplifier. One 50-kw transmitter uses a high-efficiency linear-output amplifier, while one 50-kw transmitter uses the phase-to-amplitude modulation system.

Modern standard broadcast transmitters have been simplified to such an extent that a typical 250-watt unit employs only three tube types with a total tube complement of 10. One of the 50-kw transmitters uses only five tube types with a total tube complement of 14.

The use of semiconductors in place of tube rectifiers in the power supplies has helped to make this possible. Two of the 50-kw transmitters use semiconductor rectifiers exclusively.

Through circuit simplification and use of smaller components, transmitter dimensions have been reduced to such a degree that a modern 50-kw unit occupies little more space than that required for a 5-kw unit some years ago. This program of size reduction has been carried to the point where some manufacturers now make their high-power transmitters self-contained. Several 5- and 10-kw transmitters and one in the 50-kw class are in this category. Some manufacturers do not endorse this development, however, but maintain that operating advantages result from locating large transformers, reactors, blowers, and contactors outside the main transmitter enclosure.

The use of air-cooled tubes is found to be universal in standard broadcast transmitters in current production. Another feature found in all transmitters is the use of single-ended circuitry in RF amplifiers.

* The following manufacturers provided information and photographs for this part: Bauer Electronic Manufacturing Co., Collins Radio Company, Continental Electronics Manufacturing Company, Gates Radio Company, General Electric Company, and Radio Corporation of America.

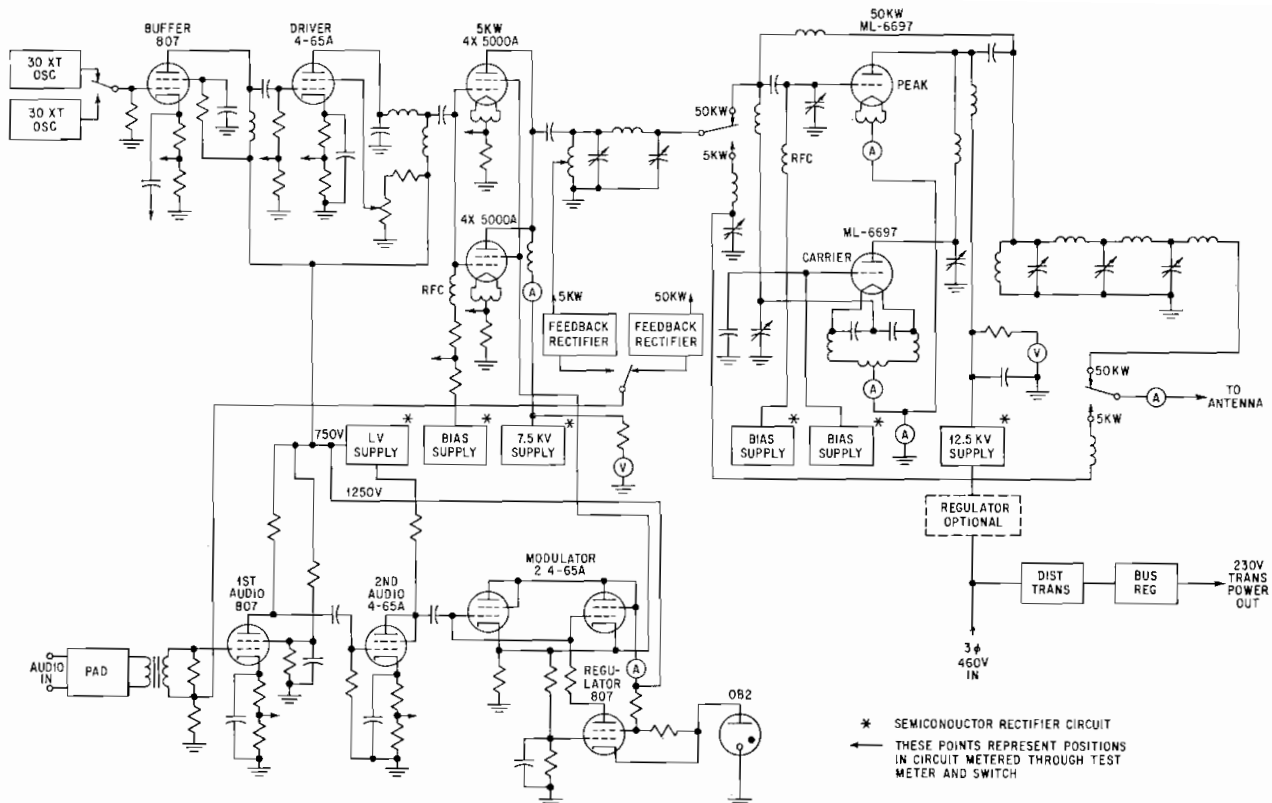


FIG. 1-1. Simplified schematic diagram—Continental type 317B 50,000-watt AM transmitter. (*Courtesy of Continental Electronics Manufacturing Company.*)

According to the manufacturers, all transmitters surpass FCC requirements as regards frequency stability,[1] audio-frequency response, distortion, carrier shift, and noise level.

Details of various transmitters arranged by power classes will be found in the following pages.

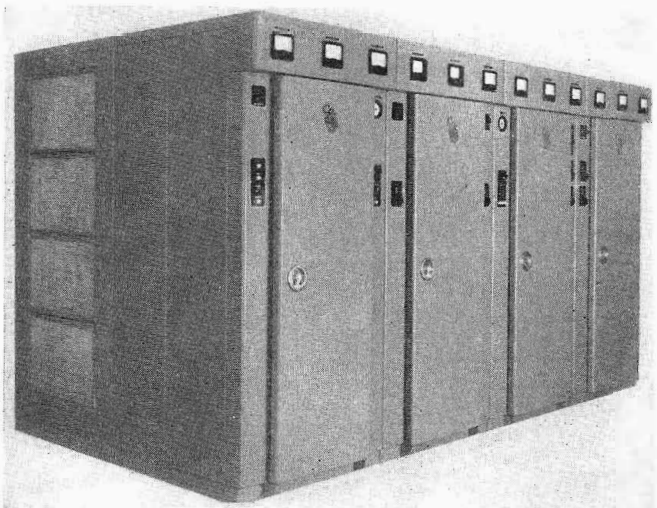


FIG. 1-2. Continental electronics type 317B 50-kw transmitter. (*Courtesy of Continental Electronics Manufacturing Company.*)

CONTINENTAL ELECTRONICS MANUFACTURING COMPANY TYPE 317B TRANSMITTER

This 50-kw transmitter uses a high-efficiency linear amplifier driven by a Continental Electronics type 315B 5-kw transmitter. Figure 1-1 shows the simplified schematic diagram of this transmitter, while its physical appearance is seen in Fig. 1-2.

In this circuit, modulated output of the exciter is applied to two separate amplifiers whose outputs are combined in a common load. Bias and excitation are adjusted, so that at carrier level, one amplifier (called the carrier amplifier) is operated in a nearly saturated Class B condition but the other amplifier (called the peak amplifier) is drawing essentially no plate current.

For negative excursions of modulation, the carrier amplifier, operating in a conventional Class B linear fashion, still supplies all the output power. When the positive-modulation swing starts, however, the peak amplifier begins to draw plate current and contributes power to the load. This causes the load on the carrier amplifier to decrease, thus permitting it to deliver more power. At positive-modulation crest, each amplifier develops twice the carrier power, thus supplying the fourfold carrier power required for 100 per cent modulation.

In the 317B transmitter, the grid of the carrier tube is operated at ground potential as far as the signal is concerned. The cathode of this tube is operated "above ground" and is connected to the excitation source through a phase-lag-correction network. This causes the output of the tube to have proper phase relation to the load circuit.

Some of the advantages claimed for this circuit are:

1. Neutralization not required for the carrier tube

[1] A recent NAB survey indicates that the average frequency deviation for standard broadcast stations in the United States is ±3 cps.

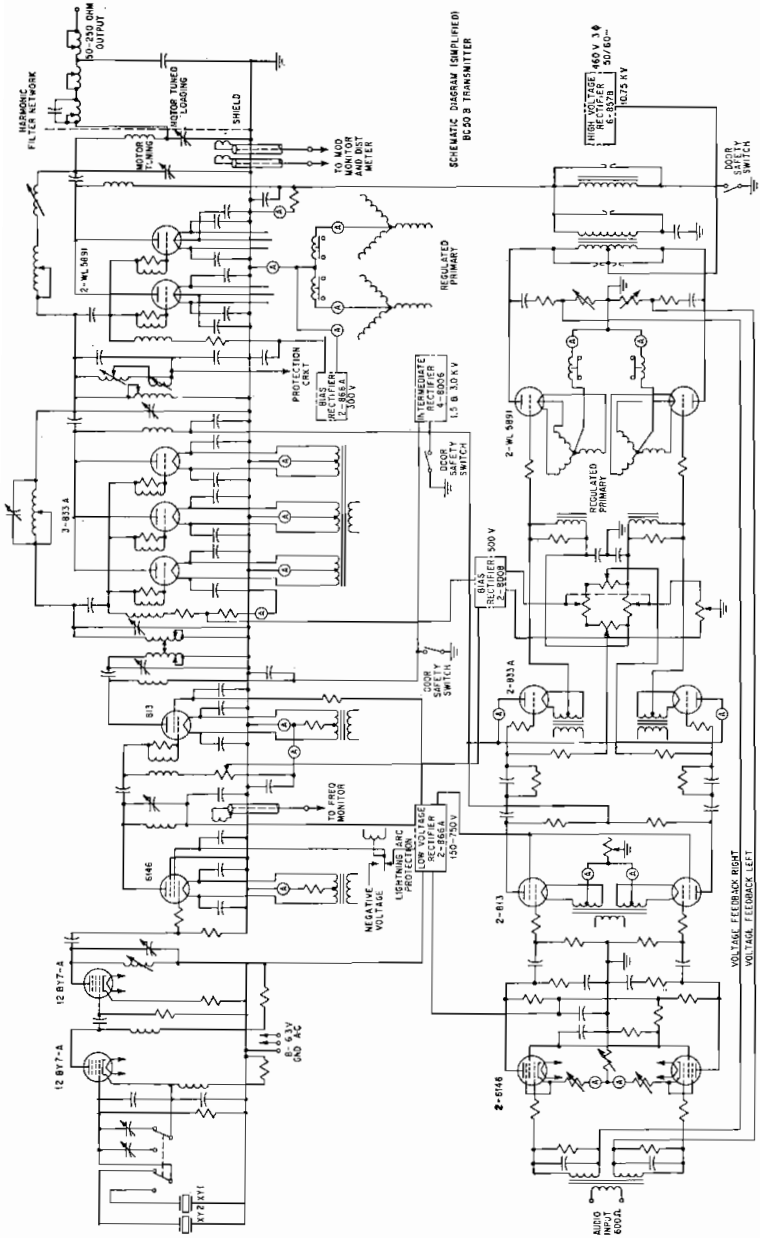


FIG. 1-3. Simplified schematic Gates model BC-50B transmitter. (*Courtesy of Gates Radio Company.*)

2. Reduction of power requirement for the amplifier, since exciter power appears in the output

3. Reflection of antenna load back to the exciter, thus eliminating the necessity of "swamping" resistors normally used with exciters driving Class B linear amplifiers

4. Reduction of harmonic content through use of lag networks (low-pass filters) in both input and output of the carrier amplifier

The 317B transmitter is self-contained within a 12-ft by 72- by 78-in. enclosure. It uses semiconductor rectifiers in all power supplies. Additional details can be found in Table 1-1 on page 3–13.

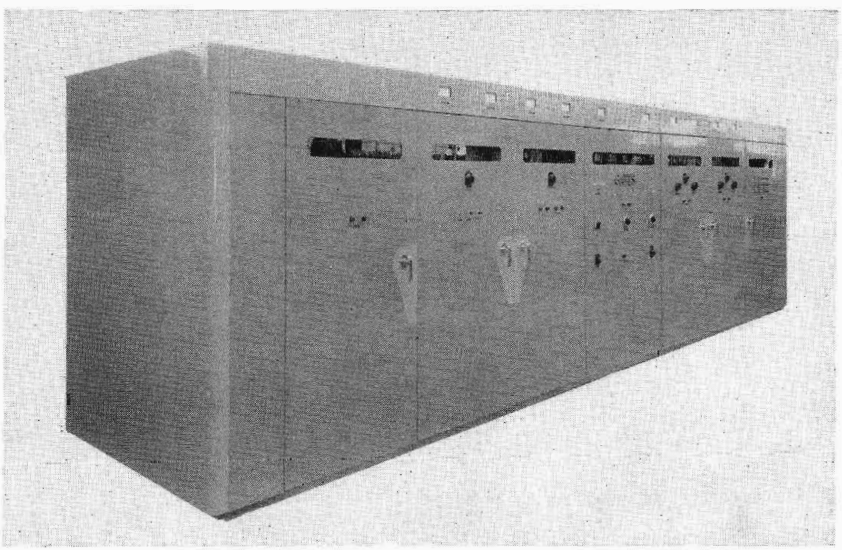


FIG. 1-4. Gates model BC-50B transmitter (50-kw). (*Courtesy of Gates Radio Company.*)

GATES MODEL BC-50B TRANSMITTER

The Gates Model BC-50B 50-kw transmitter is shown in simplified schematic form in Fig. 1-3.

Five stages of RF amplification are used following the crystal oscillator. The final RF amplifier is operated Class C and plate-modulated with a Class B push-pull modulator. Three stages of push-pull audio amplification precede the modulator. Audio feedback in this transmitter is obtained through a resistor-capacitor network across the primary of the modulation transformer and fed back to the grid of the first audio amplifier. Approximately 15 db of feedback is employed.

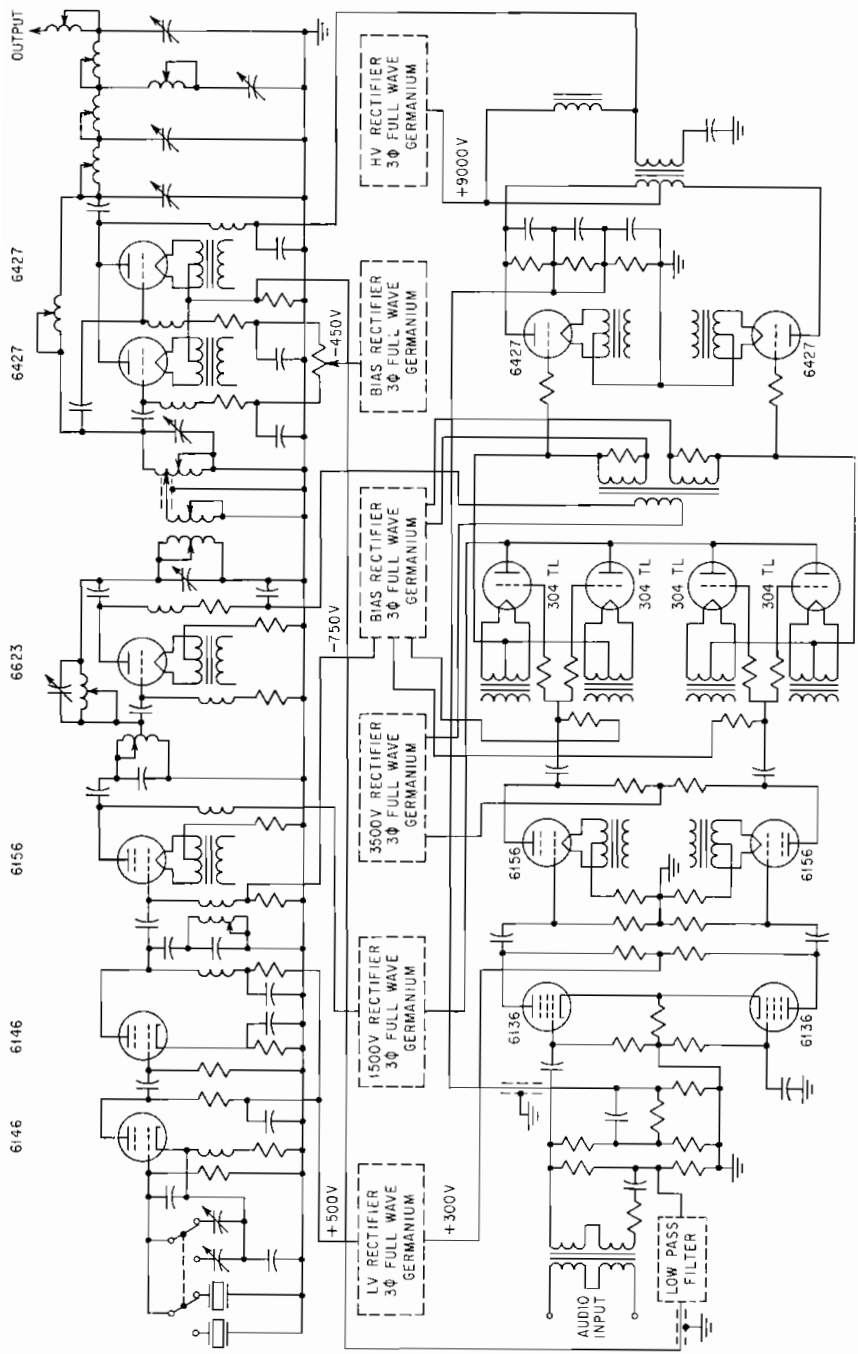
According to the manufacturer, this is physically the largest of the 50-kw transmitters. The manufacturer emphasizes its "massive" design, which provides walk-in accessibility and conservatively rated components.

A spare final RF amplifier tube and a spare modulator tube are mounted in the transmitter. Provisions are made to switch either of them into active service in case of tube failure.

Although this transmitter uses tube rectifiers throughout, the number of tube types employed has been kept to a minimum by using the same tube types in the RF and audio amplifiers.

One of the features of this transmitter is a filament voltage regulator which automatically holds the voltage on the primary of each filament transformer within ½ of 1 per cent.

An extensive harmonic filter network has been incorporated in the BC-50B trans-


OUTPUT
6146
6146
6156
6623
6427
6427
6427

mitter which limits its harmonic output to at least 70 db below the fundamental output.

Detailed information concerning this transmitter can be found in Table 1-1.

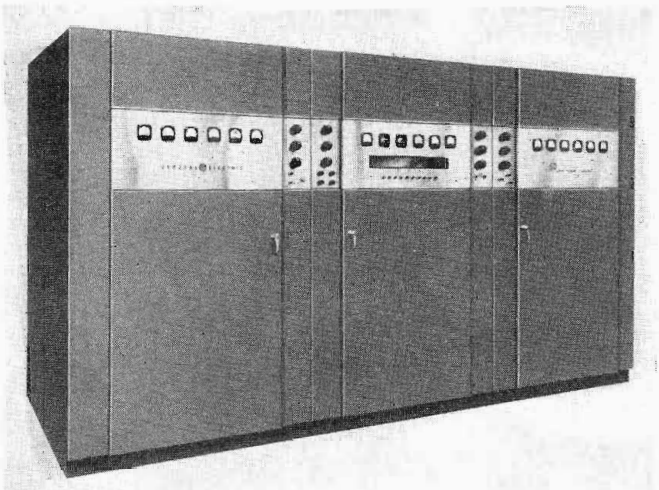


FIG. 1-6. General Electric type BT-50-A transmitter (50-kw). (*Courtesy of General Electric Company.*)

GENERAL ELECTRIC TYPE BT-50-A TRANSMITTER

The General Electric type BT-50-A transmitter is shown in simplified schematic form in Fig. 1-5.

Four stages of RF amplification are used following the crystal oscillator. The final RF amplifier is operated Class C and plate-modulated with a Class B push-pull modulator. A small amount of modulation is also applied to the intermediate RF amplifier in this transmitter. Two stages of push-pull audio amplification are used, together with a cathode-follower stage which drives the modulator.

Two feedback circuits are used in this transmitter. Primary feedback, which operates at higher audio frequencies, is obtained from the modulation transformer primary and fed back to the grid of the first audio amplifier. Because of very tight coupling between the two halves of the modulation-transformer primary, feedback is taken from only one-half of the primary. Approximately 10 db of feedback is supplied by this circuit above 1,000 cps.

Secondary feedback is derived from the secondary of the modulation transformer by means of a resistor in the cathode circuit of the final RF amplifier and returned to the grid of the first audio amplifier. A resistor-capacitor network in this circuit allows only frequencies below 1,000 cycles to be passed. Approximately 10 db of feedback is used at 250 cps.

All power supplies in the BT-50-A transmitter use three-phase, full-wave, germanium rectifier circuits. Included are bias supplies for the modulator and final RF amplifier and four plate supplies delivering voltages of 500, 1,500, 3,500, and 9,000 volts.

The main enclosure of this transmitter is the smallest in this power class. Plate, modulation, and distribution transformers; filter and modulation reactors; the blower; and the plate-contactor assembly are located outside this enclosure.

A completely shielded harmonic filter network is included in the output circuit of the BT-50-A transmitter. No harmonic is less than 80 db below the fundamental output.

Design of the exhaust-air system in this transmitter is such that hot air from the tubes is drawn directly out of the transmitter while incoming air is first drawn through the cubicle. This serves to keep the temperature of the transmitter components at a lower level.

Solenoid-operated vacuum switches are used for applying primary power to the high-voltage rectifier in this transmitter. This provides improved overload protection due to very fast operation of the vacuum switches.

Additional overload protection is provided by a current-limiting reactor in the primary circuit of the high-voltage rectifier.

Detailed information about this transmitter can be found in Table 1-1.

RCA TYPE BTA-50G TRANSMITTER

This 50-kw transmitter uses the phase-to-amplitude system of modulation, which RCA has termed "Ampliphase."

In this system, phase-modulated RF is applied at low levels to two amplifier chains in such a manner that when the phase is advancing in one chain, it is retarding in

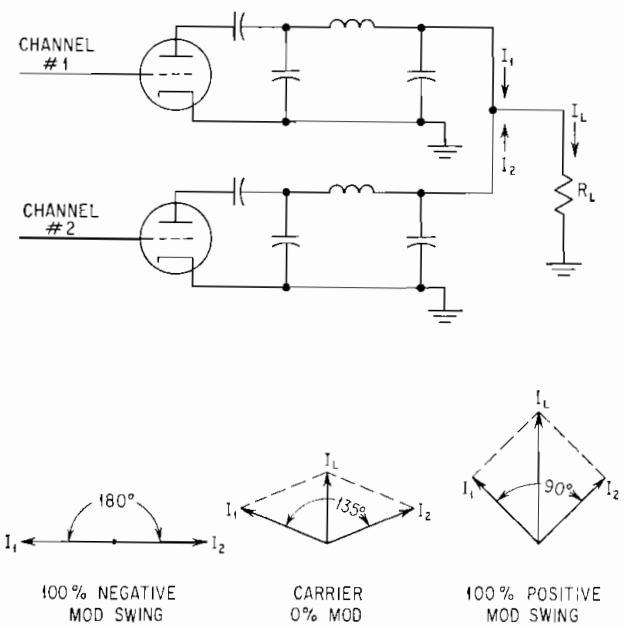


FIG. 1-7. Simplified schematic of output stage and vector diagrams illustrating "ampliphase" system.

the other. Resultant outputs of the two chains are combined in the load to produce amplitude modulation.

Referring to vector diagrams of Fig. 1-7, at carrier level (zero modulation), there is a 135° phase difference between the output currents I_1 and I_2 of the two amplifier channels, which combine to produce load current I_L. At 100 per cent negative modulation swing I_1 has advanced 22½° and I_2 has retarded 22½°, making the phase difference between them 180°, thus causing the amplitude of I_L to drop to zero.

At 100 per cent positive modulation swing, I_1 has retarded 22½° in phase from the carrier condition and I_2 has advanced 22½°. This makes their phase difference only 90°, with a resulting increase in the amplitude of I_L to twice the carrier level. Thus,

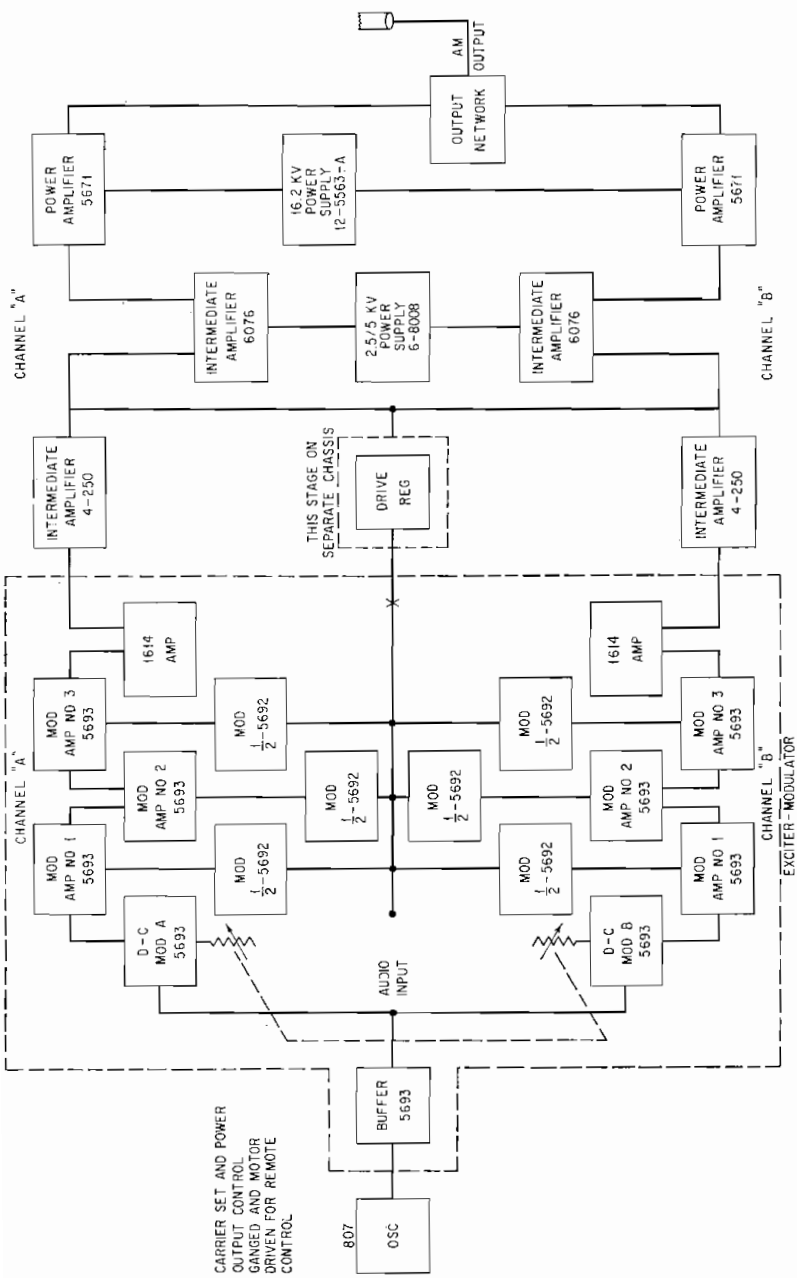


FIG. 1-8. Block diagram of RCA type BTA-50G transmitter (50-kw). (*Courtesy of Radio Corporation of America.*)

conditions necessary for 100 per cent amplitude modulation are achieved by shifting the phase angles of I_1 and I_2 plus and minus 22½°.

As shown in the block diagram of Fig. 1-8, the oscillator is followed by a buffer amplifier, with two outputs to feed the two amplifier chains. This buffer amplifier has a push-pull output tank circuit, which provides excitation voltages, with a phase difference of 180° for the two separate RF channels. The first stage in each channel is an adjustable phase-shift amplifier capable of shifting the phase of its output voltage plus or minus 25°. These amplifiers are normally adjusted to produce the 135° phase difference between the two channels required for carrier-level condition.

However, the phase-shift controls on the two amplifiers are mechanically connected in such a way that they can be varied simultaneously to provide a convenient control of carrier level.

Following the adjustable phase-shift amplifier in each channel are three modulated amplifier stages in which the phase is shifted by the audio signal. Each of these stages is capable of a maximum phase excursion of plus and minus 7½°. When three stages are used in cascade, the 22½° phase excursion required for 100 per cent modulation is achieved.

Following the modulated amplifiers in each channel is a conventional amplifier which provides approximately 5 watts of RF power to excite the 4-250 stage which in turn drives the intermediate amplifier using a type 6076 tetrode. The output amplifier in each channel uses a type 5671 triode.

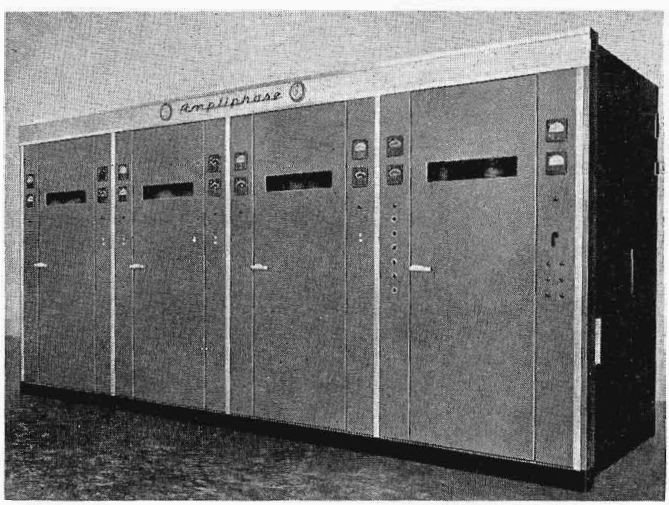


FIG. 1-9. RCA type BTA-50G transmitter (50-kw). (*Courtesy of Radio Corporation of America.*)

Because of the shifting phase relationship between the two output tubes, the load impedance into which they work varies widely during the modulation cycle. In order to maintain reasonably constant efficiency over the modulation cycle, it has been found desirable to vary the excitation to the output tubes with modulation. In the BTA-50G transmitter, this is accomplished by applying a degree of grid modulation to the type 6076 intermediate amplifiers.

The modulator consists of three type 807 tubes in a cathode-follower circuit. A three-stage audio amplifier precedes the modulator. The modulator and its associated audio amplifier are called the drive regulator in the BTA-50G transmitter. Approximately 90 per cent amplitude modulation of the excitation is used for 100 per cent modulation of the output.

A small amount of over-all feedback is used in this transmitter by rectifying a sample of the amplitude-modulated output and applying it in phase opposition to the incoming audio.

A completely shielded, multielement harmonic filter network has been incorporated in this transmitter to limit its harmonic output to a value at least 83 db below the fundamental output.

Additional details concerning this transmitter can be found in Table 1-1.

Table 1-1. Specifications for 50-kw Transmitters *

	Continental Electronics 317B	Gates BC-50B	General Electric BT-50-A	RCA BTA-50G
Physical data:				
Width	12 ft	22 ft 6 in.	13 ft 6 in.	15 ft 1 ½ in.
Depth, in.	72	64	54	63
Height, in.	78	78	84	84
Approx. wt., lb	12,000	25,070	13,000	12,000
Input supply:				
Voltage	460	460	480, 2,400, 4,160	460
Phase	3	3	3	3
Frequency, cps	50 or 60	50 or 60	50 or 60	50 or 60
AF input level, dbm	+10	+10	+10	+10
AF input, ohms	150/600	150/600	150/600	150/600
Load impact, ohms	50 or as specified	40–250	50–230	50 (nominal)
Frequency range, kc	535–1,620	540-1,600	535-1,620	535–1,620
Max. output, kw	53.0	53.0	53.0	53.0
External equipment	Self-contained	Contactor cabinet Blower 4 transformers 2 reactors	Plate contactor 5 transformers Blower 3 reactors ΔY switch	2 circuit breakers ΔY switch 6 transformers 2 regulators

* The above information was supplied by the manufacturers.

5- AND 10-KW TRANSMITTERS

Most manufacturers produce only one transmitter in this power range with provisions to modify it for either 5- or 10-kw operation.

All but two of the transmitters in these power classes use a Class C final RF amplifier, which is plate-modulated by a Class B or Class AB push-pull modulator. Tetrodes are used in both the final RF and modulator stages in most units, although one manufacturer uses triodes. One manufacturer uses plate modulation of the intermediate RF amplifier as well as the final RF amplifier.

The Continental Electronics 5- to 10-kw transmitter differs from the others in that it uses screen-grid modulation of the final RF amplifier. The modulator in this case is connected as a cathode follower.

Five of the 11 transmitters in the 5- to 10-kw class are entirely self-contained.

All the 5-kw transmitters are provided with 1-kw power cutback facilities for stations using this lower nighttime power.

Tables 1-2, 1-3, 1-4 give detailed specifications of the 5- and 10-kw transmitters. Simplified schematic diagrams and photographs of typical units are shown in Figs. 1-10 through 1-16.

Table 1-2. Specifications for 10,000-watt Transmitters *

	Collins 21M	Gates BC-10P	General Electric BT-73-A	RCA BTA-10H
Tubes used:				
Oscillator	6AU6	12BY7A	6146	807(2)
1st RF amplifier	6SJ7	12BY7A	6146	807(2)
2d RF amplifier	807	6146	4-250A(2)	833A
3d RF amplifier	4-125A(2)	4-250A		
Final RF amplifier	3X2500A3(2)	3X2500F3(2)	3X2500F3(2)	5762(3)
1st AF amplifier	6SJ7(2)	6SN7	5814A	807(2)
2d AF Amplifier	4-125A(2)	6BG6(2)	4-125A(2)	828(2)
3d AF amplifier	.....	6528(4)	.....	813(4)
Modulator	3X3000A1(2)	3X2500F3(2)	3X3000F1(2)	5762(2)
Bias rectifier 1	5U4G	6W4(2)	5R4GY	Selenium
Bias rectifier 2	866A(2)	5R4GYA(2)	866(2)	
Low-voltage rectifier	866A(2)	5R4GYA	5R4GY(2)	8008(4)
Intermediate Rectifier	872A(2)	5R4GYA(2)		
High-voltage Rectifier	575A(6)	673(6)	673(6)	5563A(4)
Physical data:				
Width, in.	105 ¼	73 ½	66	130
Depth, in.	28	39 ½	21 ½	32 ½
Height, in.	76	78	83	84
Approx. weight, lb.	3,000	2,650	4,500	5,500
Input supply:				
Voltage	208/230	230	208/230	208/230
Phase	3	3	3	3
Frequency, cps	50 or 60	50 or 60	60	50 or 60
AF input level, dbm	+10	0	+10	+10
AF input, ohms	150/600	150/600	150/600	150/600
Load imp., ohms	40–600	40–270	50–230	40–250
Frequency range, kc	540–1600	535–2000	540–1600	535–1620
Max. output, watts	10,600	10,600	10,600	10,600
Miscellaneous data	Plate transformer external	Self-contained	1 transformer 2 Reactors external	1 transformer external Bi-level modulation

* The above information was supplied by the manufacturers.

Table 1-3. Specifications for Continental Electronics 5- and 10-kw Transmitters *

	Type 315B	Type 316B
Tubes used:		
Oscillator	6AG7(2)	6AG7(2)
1st RF amplifier	807	807
2d RF amplifier	4-65A	4-65A
Final RF amplifier	4X5000A(2)	4X5000A(3)
1st AF amplifier	807	807
2d AF amplifier	4-65A	4-65A
Modulator	4-65A(2)	4-65A(3)
Bias rectifier	Selenium	Selenium
Low-voltage rectifier	Selenium	Selenium
High-voltage rectifier	Selenium	Selenium
Two-oscillator regulator	0B2(2)	0B2(2)
Modulator regulator	807	807
Voltage reference	0B2	0B2
Feedback rectifier	6X5	6X5
Physical data:		
Width, in.	72	72
Depth, in.	36	36
Height, in.	78	78
Approx. weight, lb	5,000	5,300
Input supply:		
Voltage	208/230	208/230
Phase	3 (open Δ)	3
Frequency, cps	60 (50 avail.)	60 (50 avail.)
AF input level, dbm	+10	+10
AF input impedance, ohms	150/600	150/600
Output impedance, ohms	50 (or as specified)	50 (or as specified)
Frequency range, kc	535–1,620	535–1,620
Max. output, watts	5,500	10,600
Miscellaneous data	Self-contained	Self-contained

* The above information was supplied by the manufacturer.

Note: These transmitters are not listed with the other 5- and 10-kw transmitters because of their different tube classifications resulting from the use of screen-grid modulation of the final RF amplifier.

Table 1-4. Specifications for 5,000-watt Transmitters *

	Collins 21E	Fritz Bauer FB-5000C	Gates BC-5P	General Electric BT-72-A	RCA BTA-5H
Tubes used:					
Oscillator	6AU6	6AG7	6AG7	6146	807(2)
1st RF amplifier	6SJ7	6AG7(2)	6146	6146	807(2)
2d RF amplifier	807	813	4-250A	4-250A	833A
3d RF amplifier	4-125A(2)				
Final RF amplifier	3X2500A3	3X2500F3	3X2500F3	3X2500F3	5762(2)
1st AF amplifier	6SJ7(2)	807(2)	6SN7	5814A	807(2)
2d AF amplifier	4-125A(2)	845(2)	6SN7	4-125A(2)	828(2)
3d AF amplifier	.....	.....	6550(4)	.....	813(2)
Modulator	3X3000A1 (2)	3X2500F3 (2)	3X2500F3 (2)	3X3000F1 (2)	5762(2)
Bias rectifier 1	5U4G	5R4GY(2)	5R4GY	5R4GY	Selenium
Bias rectifier 2	866A(2)	.....	6W4(2)	866(2)	
Low-voltage rectifier	866A(2)	5R4GY	5R4GY	5R4GY(2)	8008(4)
Intermed. rectifier	872A(2)	.....	5R4GY(2)		
High-voltage rectifier	575A(6)	8008(6)	8008(6)	8008(6)	5563A(4)
Physical data:					
Width, in.	105 ¼	90	73 ½	66	130
Depth, in.	28	36	39 ½	21 ½	32 ½
Height, in.	76	72	78	83	84
Approx. weight, lb	2,700	3,000	2,186	4,500	5,300
Input supply:					
Voltage	208/230	230	230	208/230	208/230
Phase	3	3	3	3	3
Frequency, cps	50 or 60	60	50 or 60	60	50 or 60
AF input level, dbm	+10	+10	−5	+10	+10
AF input, ohms	150/600	500/600	150/600	600	150/600
Load impact, ohms	40–600	50–250	40–270	50–230	40–250
Frequency range, kc	540–1,600	540–1,620	535–2,000	540–1,600	535–1,620
Max. output, watts	5,500	6,000	5,600	5,500	5,500
1,000-watt power cutback	Yes	Yes	Yes	Yes	With kit
Miscellaneous data	Plate transformer external	Self-contained	Self-contained	1 transformer 2 reactors external	Plate transformer external Bi-level modulation used

* The above information was supplied by the manufacturers.

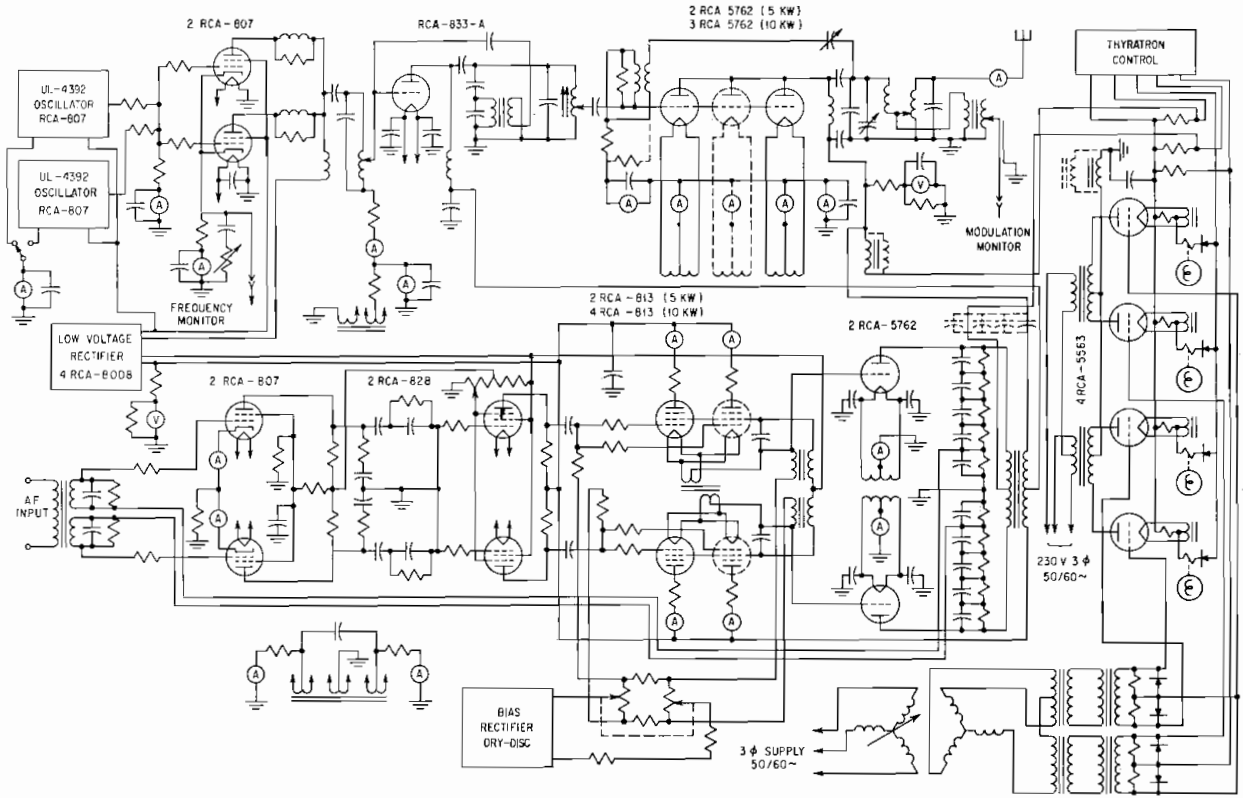


FIG. 1-10. Simplified schematic RCA type BTA-5H (5-kw) and type BTA-10H (10-kw) transmitters. The dotted lines indicate changes required for 10-kw operation. (*Courtesy of Radio Corporation of America.*)

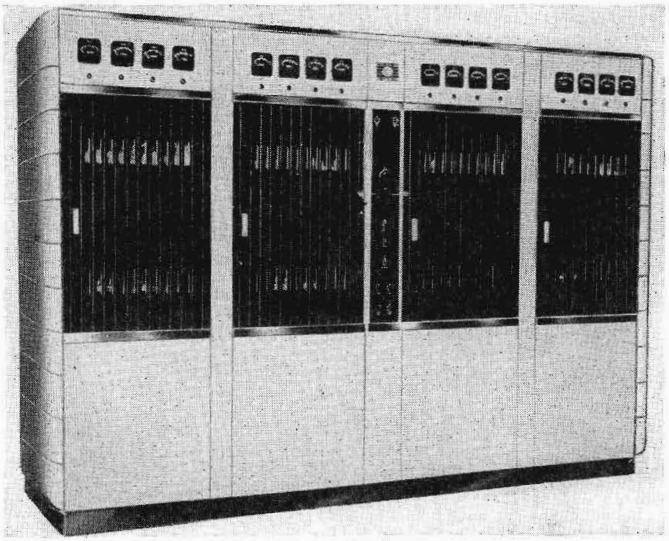


FIG. 1-11. RCA type BTA-5H/BTA-10H transmitter (5- or 10-kw). (*Courtesy of Radio Corporation of America.*)

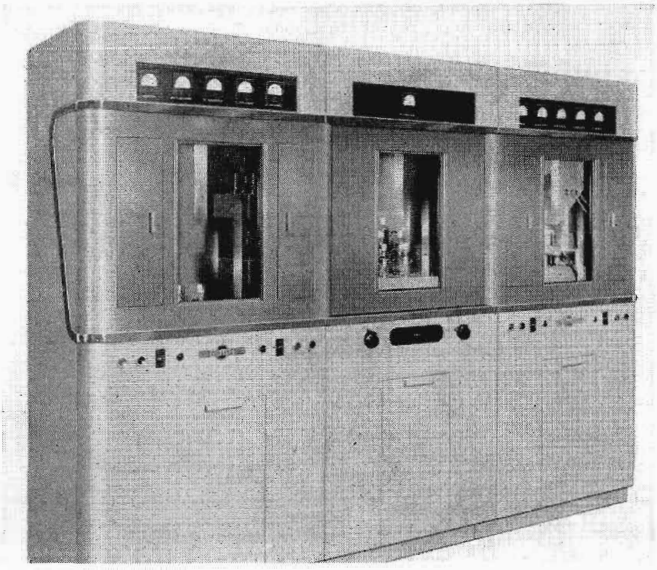


FIG. 1-12. Collins 21E/21M transmitter (5- to 10-kw). (*Courtesy of Collins Radio Company.*)

FIG. 1-13. Continental Electronics type 315B/316B 5- to 10-kw transmitter. (*Courtesy of Continental Electronics Manufacturing Company.*)

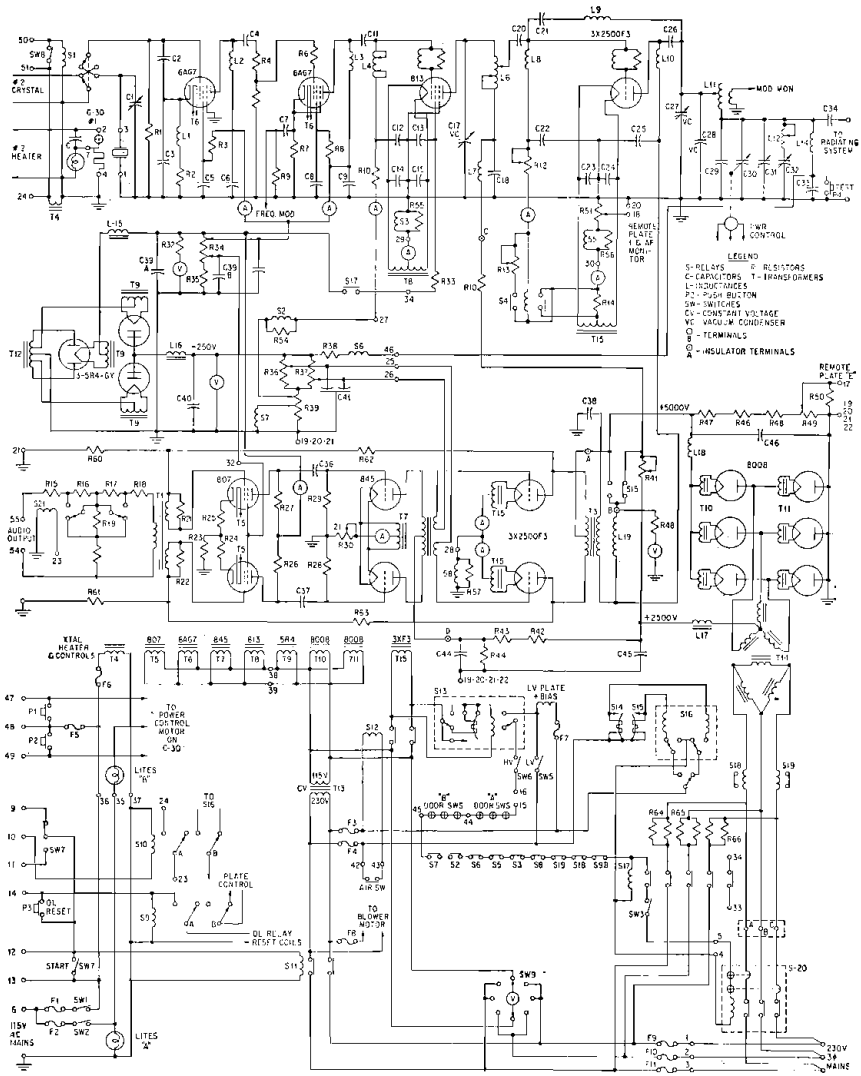


FIG. 1-14. Schematic diagram Fritz Bauer type FB-5000-C transmitter (1- to 5-kw). (*Courtesy of Bauer Electronic Manufacturing Company.*)

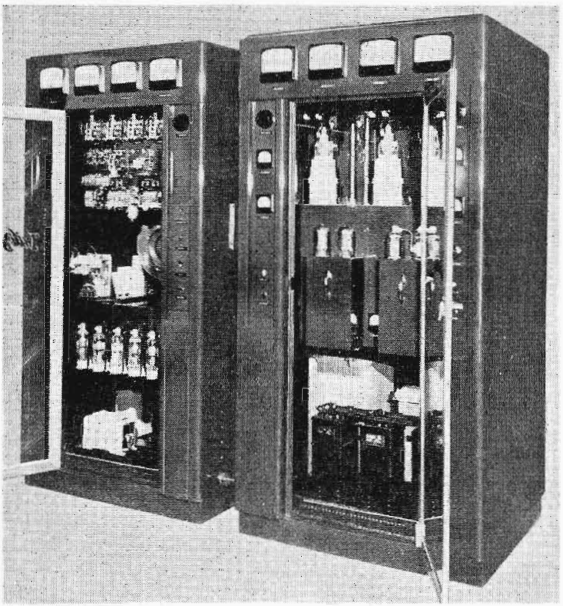


FIG. 1-15. Fritz Bauer FB-5000-C transmitter (5-kw). (*Courtesy of Bauer Electronic Manufacturing Company.*)

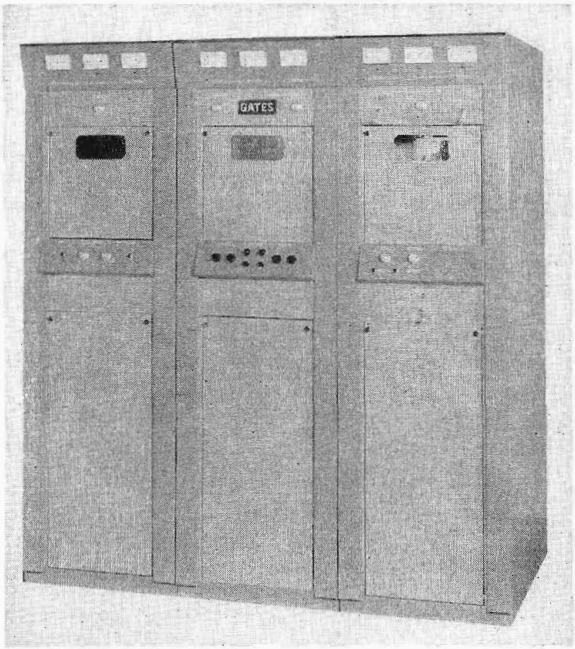


FIG. 1-16. Gates model BC-5P transmitter (5-kw). (*Courtesy of Gates Radio Company.*)

250- AND 1,000-WATT TRANSMITTERS

Since there are so many points of similarity in the 250- and 1,000-watt transmitters, they can be described together. Some manufacturers, in fact, use identical cabinets, control circuits, and low-level stages for their 250- and 1,000-watt units. Required changes are made in the final RF and modulator stages and in the capacity of the high-voltage power supply.

In both power classes, the transmitters have been designed for simplicity and economy. Each uses a crystal oscillator, followed by one or two intermediate RF amplifiers, and a Class C final RF amplifier which is plate-modulated by a push-pull Class B or Class AB modulator. One or two stages of push-pull audio amplification precede the modulator. One manufacturer uses modulation in the intermediate RF amplifier as well as in the final RF amplifier.

Three power supplies are used for bias, low-voltage plate, and high-voltage plate, respectively. Only one manufacturer has adopted the use of semiconductor rectifiers in power supplies.

In all cases, these transmitters are self-contained, but there is considerable variation in size.

Several manufacturers produce 500-watt transmitters which are slightly modified versions of their 1,000-watt units. Changes are so minor that the 500-watt models will not be described in detail in this report.

Following are detailed specifications of the 250- and 1,000-watt transmitters, together with simplified schematic diagrams and photographs of typical units.

Table 1-5. Specifications for 1,000-watt Transmitters *

	Collins 20V-2	Fritz Bauer FB-1000J	Gates BC-1T	RCA BTA-1R
Tubes used:				
Oscillator	6AU6	6AG7	12BY7A	6AK5
1st RF amplifier	6SJ7	807	12BY7A	5763
2d RF amplifier	807	.....	6BG6G(2)	6146
Final RF amplifier	4-400A(2)	4-400A(2)	833A(2)	4-400A(2)
1st AF amplifier	6SJ7(2)	807(2)	6BG6G(2)	2E26(2)
2d AF amplifier	.....	.....	6BG6G(2)	
Modulator	4-400A(2)	4-400A(2)	833A(2)	4-400A(2)
Bias rectifier	5U4G	5R4GY	5R4GY	Selenium
Low-voltage rectifier	866A(2)	5R4GY	866A(2)	Selenium
High-voltage rectifier	872A(2)	8008(2)	8008(2)	8008(2)
Physical data:				
Width, in.	38	34	36	34
Depth, in.	27	23	32	32 ½
Height, in.	76	78	78	84
Weight, lb	1,150	700	800	1,700
Input supply:				
Voltage	208/230	230	230	208/240
Phase	1	1	1	1
Frequency, cps	50 or 60	60	50 or 60	50 or 60
AF input level, dbm	+10	+10	+12	+10
AF input, ohms	150/600	500/600	150/600	150/600
Load impact, ohms	40–600	50–250	50–70	40–250
Frequency range, kc	540–1,600	540–1,620	540–2,000	535–1,620
Max. output, watts	1,100	1,100	1,100	1,100
Miscellaneous data	.....	Dummy antenna supplied	Dummy antenna supplied	Bi-level modulation used

* The above information was supplied by the manufacturers.

Table 1-6. Specifications for 250-watt Transmitters *

	Collins 300J-2	Gates BC-250-GY	RCA BTA-250M
Tubes used:			
Oscillator	6AU6	807	807
1st RF amplifier	6SJ7	813	807
2d RF amplifier	807		
Final RF amplifier	4-125A(2)	810(2)	813(2)
1st AF amplifier	6SJ7(2)	6L6(2)	807(2)
Modulator	4-125A(2)	810(2)	813(2)
Bias rectifier	5U4G	5V4	Selenium
Low-voltage rectifier	866A(2)	5V4	Selenium
High-voltage rectifier	872A(2)	8008(2)	866A(2)
Physical data:			
Width, in	38	40	28
Depth, in	27	33	20 ½
Height, in	76	78	84 ⅞
Weight, lb	900	900	600
Input supply:			
Voltage	208/230	230	110/125
Phase	1	1	1
Frequency, cps	50 or 60	60	50 or 60
AF input level, dbm	+10	+14	+10
AF input, ohms	600/150	600	150/600
Output load, ohms	40–600	30–300	20–250
Frequency range, kc	540–1,600	540–1,600	535–1,620
Max. output, watts	275	280	275
Miscellaneous data	100-watt power cutback	.....	Bi-level modulation used

* The above information was supplied by the manufacturers.

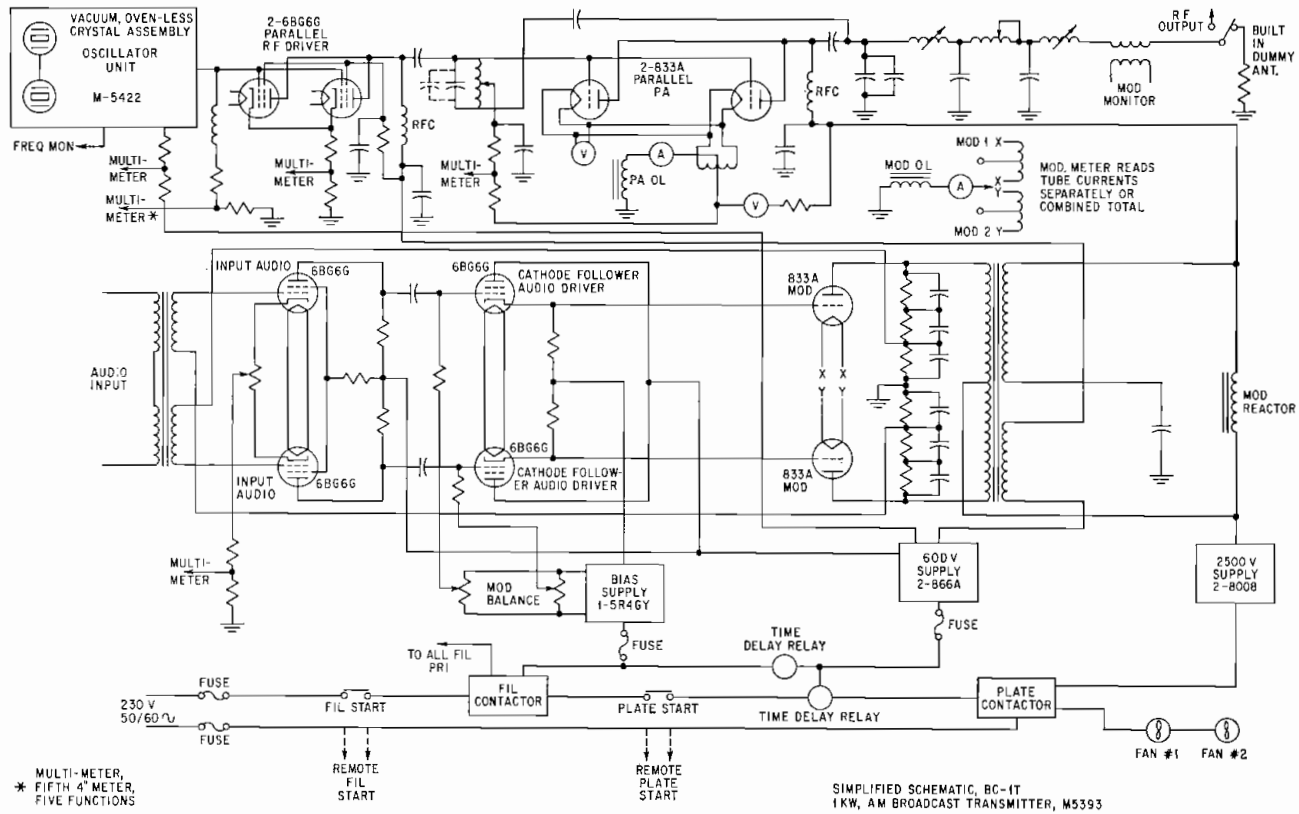


FIG. 1-17. Simplified schematic diagram—Gates model BC-1T 1,000-watt AM broadcast transmitter. (*Courtesy of Gates Radio Company.*)

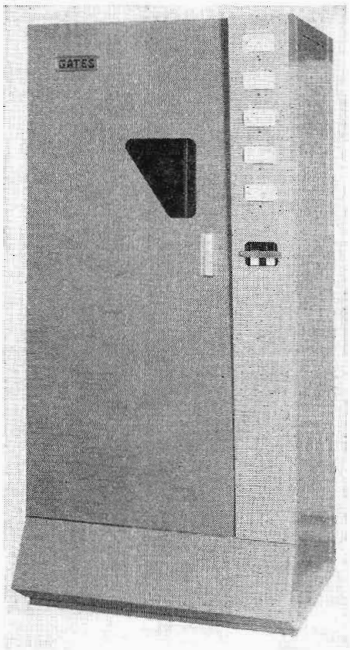


FIG. 1-18. Gates BC-1T (1,000-watt) AM broadcast transmitter. (*Courtesy of Gates Radio Company.*)

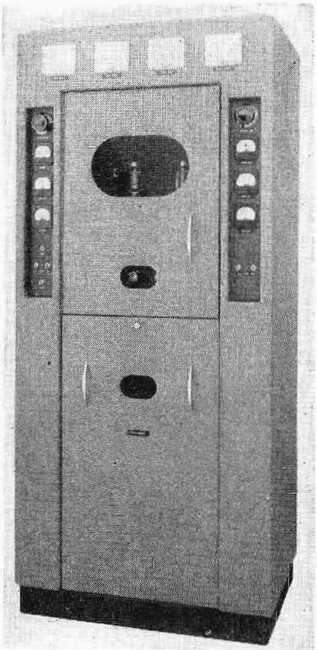


FIG. 1-19. Fritz Bauer FB-1000J (1,000-watt) AM broadcast transmitter. (*Courtesy of Bauer Electronic Manufacturing Company.*)

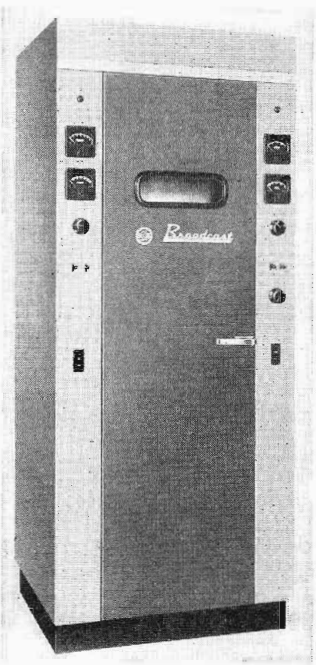


FIG. 1-20. RCA type BTA-1R (1,000-watt) AM broadcast transmitter. (*Courtesy of Radio Corporation of America.*)

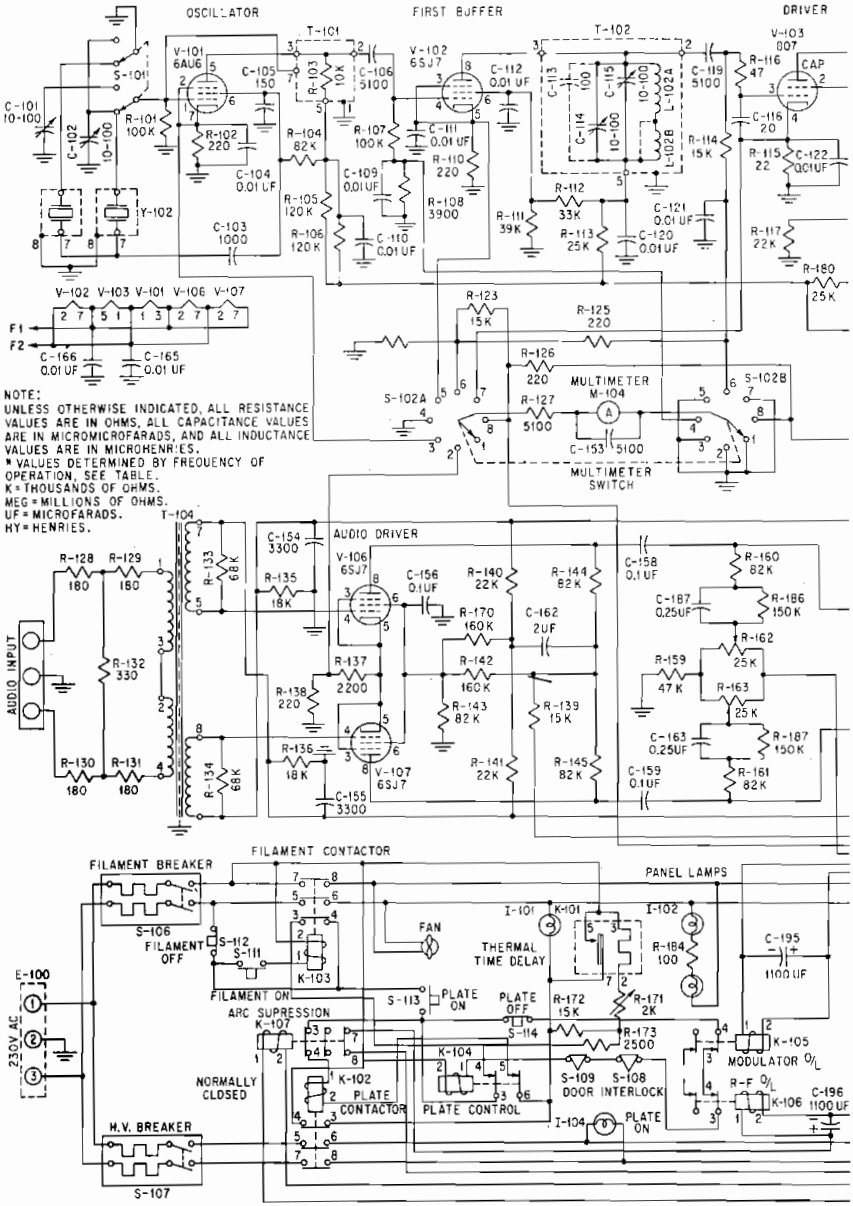
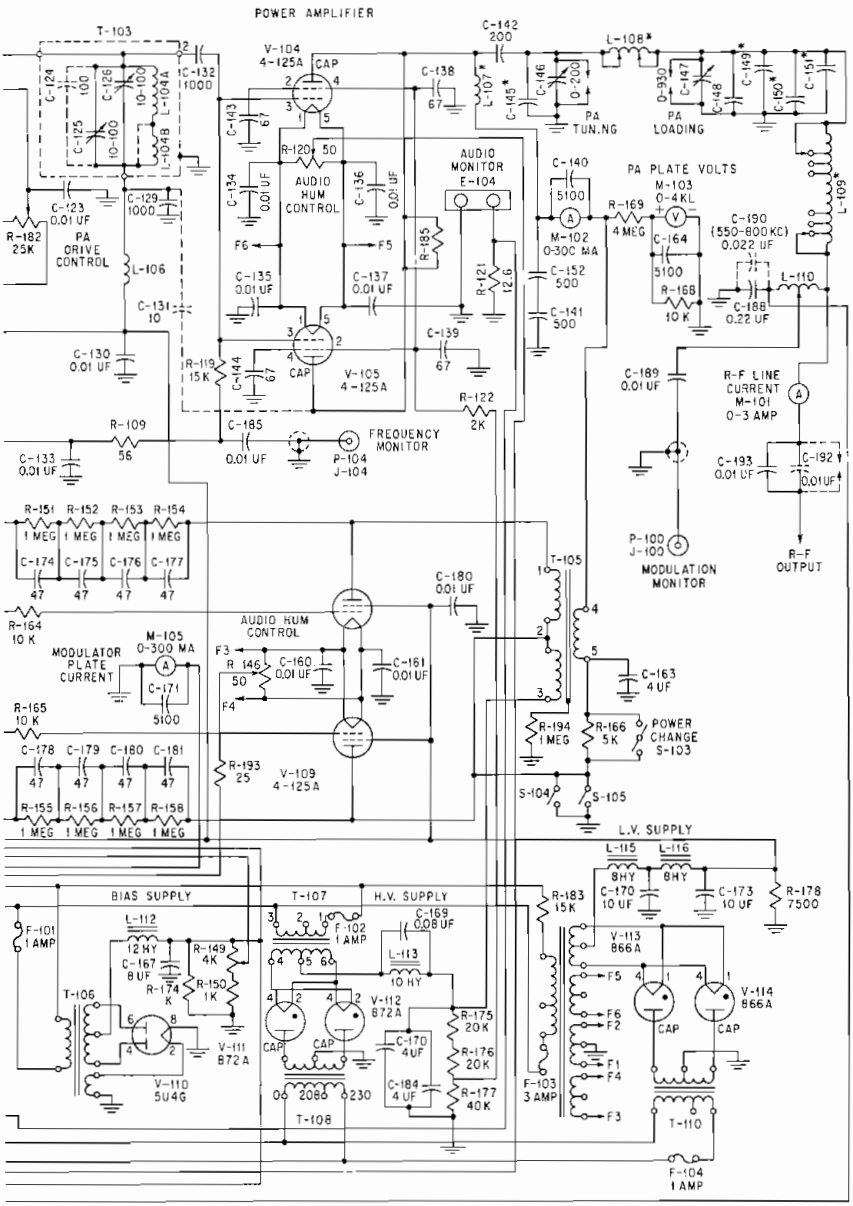


FIG. 1-21. Schematic diagram Collins 300J-2 transmitter (250-watt). (*Courtesy of Col-*



lins Radio Company.)

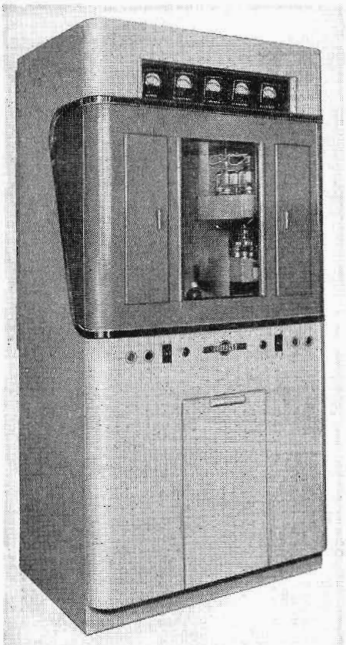


FIG. 1-22. Collins 300J-2 (250-watt) and 20V-2 (1,000-watt) AM broadcast transmitters. These transmitters have the same external appearance. (*Courtesy of Collins Radio Company.*)

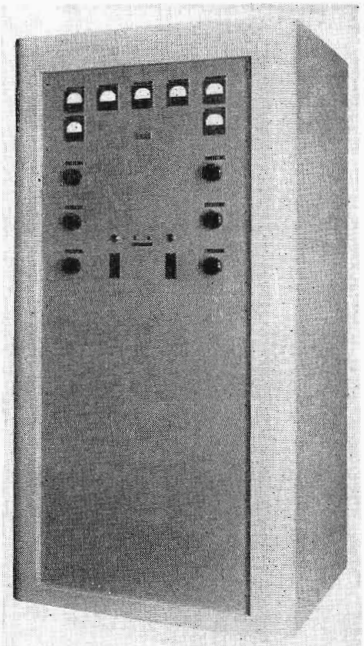


FIG. 1-23. Gates BC-250-GY (250-watt) AM broadcast transmitter. (*Courtesy of Gates Radio Company.*)

TRANSMITTER MAINTENANCE

A transmitter can give reasonably trouble-free performance year after year only if it receives regular maintenance. Manufacturers' instruction books usually contain maintenance information applicable to each specific transmitter, but the following general principles may be useful.

At most stations, a routine maintenance system is set up by the station engineer for guidance of maintenance personnel. Various maintenance operations are usually listed on cards or sheets, with spaces provided for the maintenance engineer to initial and date each operation as it is completed. Maintenance operations are classified on these cards or sheets according to the frequency with which they are repeated, such as weekly, monthly, or semiannually. Following are some of the most important maintenance operations.

Cleaning

All equipment, particularly tubes, insulators, and other high-voltage components, must be kept free of dust and oily deposits. A source of medium-pressure air is useful for removing dust from hard-to-reach places, such as around terminal boards or between capacitor plates.

Some stations install small air-compressor units for this purpose, but in most cases, vacuum cleaners with suitable attachments are used.

It has been argued that blowing the dust from these inaccessible places is ineffective, since much of it will settle back again. If a vacuum system with adequate suction

were available, it would doubtless be better for removing the dust. Unfortunately, an ordinary vacuum cleaner does not develop enough suction for this purpose. One technique that has been used successfully is first to blow dust from hard-to-reach places. After the dust settles, use a dust cloth on all accessible surfaces. Finally, use a suction device to remove the loose dust from inaccessible places.

A cloth moistened with carbon tetrachloride is effective for removing oily deposits. The use of lintless cloths is recommended for transmitter cleaning and for removing the film residue left by carbon tetrachloride.[2]

The frequency with which the cleaning operation needs to be repeated depends upon transmitter construction and local conditions. Many stations put this maintenance activity on a monthly schedule.

Air Filters

Nearly all modern standard broadcast transmitters are air cooled; thus proper care of the air filters is most important. They should be inspected at least once each month.

When dirty, the filters must be replaced or cleaned and recharged, depending upon the type used. Specific information on the care of air filters can usually be found in the individual transmitter instruction book.

Tightening

All connections involving screw-type terminals should be periodically checked for tightness. This can be done on a semiannual or annual basis in most cases.

Breakers, Switches, Contactors, and Relays

At least once yearly or in case of repeated tripping, the contacts of main circuit breakers should be inspected. If badly pitted, they should be repaired as recommended by the manufacturer. In breakers using dashpot timers, the liquid level should be checked semiannually and filled to the indicated level.

The operation and timing of all time-delay relays should be checked periodically. Small relay contacts can be cleaned, if needed, with Kraft paper. Badly pitted contacts should be smoothed with a fine file or burnishing tool.

Contactors should be checked for burned or pitted contacts. A flat file and/or sandpaper should be used for correcting such conditions. Discretion should be used here, as it is possible to overmaintain these contacts.

It is essential that metal filings be kept out of all relays. Air should be used to blow out any filings which may have accumulated on the pole faces.

Contacts of overload relays should be inspected monthly and cleaned if necessary. Action of the relays should also be checked. After work of this kind, always allow time to test the transmitter before program time.

Door interlocks should be checked frequently for proper alignment and condition of contacts. Safety grounding switches, if used, should be checked in the same manner.

Rotating Equipment

Bearings of motors and blowers should be checked regularly for proper lubrication. It is well to follow the manufacturer's recommendations very closely in this case, since it is possible to overlubricate as well as underlubricate many bearings.

Drive belts should be inspected frequently for signs of wear and for proper tension.

Impeller blades on blowers should be kept free of dirt and oil. If rust spots develop, they should be scraped clean and repainted.

[2] Observe safety precautions when using carbon tetrachloride.

High-power Tubes

New tubes should be inspected, when received, for possible damage resulting from shipment. Each new tube should be used in the transmitter for at least one day as soon as possible after it is received. Spare tubes should be given one day of regular operation every six months. This will clean up any gas that may have been liberated and assures that spares are in usable condition.

Records should be kept on the life of high-power tubes. This is usually done by assigning a card to each tube. The tube hour-meter reading is then recorded on the card each time the tube is installed and removed from the transmitter.

When a new tube is first placed in service, it should be operated at rated filament voltage without plate voltage for 15 min. Approximately half of the normal plate voltage should then be applied for 15 min, followed by full plate voltage for 15 min. Modulation should then be applied gradually up to 100 per cent. If a gas kick occurs at any point in the process, plate voltage should be reduced to the previous level and additional aging time allowed.

Rectifier Tubes

When first placed in service, high-power mercury-vapor rectifier tubes should be operated for at least 30 min with normal filament voltage but without plate voltage.

Spare rectifier tubes should be given a one-day period of operation in the transmitter every six months.

In addition to keeping life records for these tubes, it is desirable to make a monthly check of the peak breakdown voltage of each tube in service. One method of making this check is as follows:

1. Remove the regular plate connection from the tube and apply filament power.
2. Connect the 120-volt secondary winding of a 300-va isolation transformer in series with the tube and a 50-ohm 200-watt current-limiting resistor.
3. Connect the vertical deflection plates of an oscilloscope across the tube.

The pattern of tube voltage will show a sharp peak at start of conduction, and the amplitude of the voltage at this point indicates the initial breakdown voltage of the tube. Peak breakdown voltage of a good tube will be between 10 and 20 volts. When this value reaches 30 volts, arc backs may be expected. When it reaches 50 volts, the tube probably should be replaced.

Small Tubes

Small tubes should be tested when received, either in the transmitter or with a portable tube tester. This process should be repeated at six-month intervals.

PERFORMANCE TESTS

A regular schedule of performance tests should be included in the maintenance routine. This is done each month at many stations but less frequently at others. The following measurements should be included:

1. Carrier noise level
2. Distortion at 95 per cent modulation from 50 to 7,500 cycles
3. Audio response from 30 to 10,000 cycles
4. Carrier shift at 400 cps with 100 per cent modulation

Another item, which might be called a performance test, is to obtain a measurement of the carrier frequency of the station from an outside source.[3] This probably need not be done more often than semiannually with modern transmitters. However, many broadcasters make such checks on a monthly basis.[3]

[3] Not required by the FCC.

PERSONNEL TRAINING

Despite the most careful maintenance, every transmitter will occasionally fail during regular program transmission. Since time off the air means lost revenue to stations, it is imperative for transmitter personnel to locate and remedy the source of trouble quickly. Each individual should study the equipment, the circuit diagrams, and the instruction books until he is familiar with every part of the transmitter.

A further step in personnel training is a program of simulated failures. This must be carried on during off-the-air time. It consists of one member of the staff (usually the station engineer) deliberately placing a fault in the equipment, after which other staff members observe the fault symptoms and endeavor to locate and correct the trouble as quickly as possible.

Such a program is difficult to carry out in a standard broadcast station where off-the-air time usually occurs after midnight. However, it has proved to be very effective in improving personnel efficiency.

Part 2

FM TRANSMITTERS *

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INTRODUCTION

Since the introduction of frequency modulation by Major E. H. Armstrong in 1936, a large variety of circuits have been developed to produce FM. Only those circuits used for FM broadcast will be discussed.

The original Armstrong modulator used a balanced modulator generating sidebands with a suppressed carrier in one path and a 90° phase-shift circuit in the other path. The two signals were then added to each other to produce phase modulation (PM), with modulation capabilities of ±30° and good linearity. A large number of multipliers were required to achieve a total deviation of 75 kc at the lower audio frequencies. In general, the PM signal was multiplied a number of times, then heterodyned down to a lower frequency, and again multiplied to obtain the desired final operating frequency. The use of a correction network in the audio input line converts the PM characteristic to that of FM.

MODULATION THEORY

There are basically two modulation methods that have been used in postwar FM transmitters. The first is direct FM, using a stable oscillator with a reactance-control tube or device across the frequency-determining circuit and a servo circuit to stabilize the mean center frequency by comparing it with a reference crystal oscillator. The second is indirect FM, using phase modulation of a crystal-controlled crystal carrier with a large number of multipliers to achieve the desired frequency deviation.

A variety of circuits were developed by a number of manufacturers to control the mean center frequency accurately. The direct FM method requires the use of a frequency-comparison circuit. In some cases, the output from these circuits is a two-phase voltage used to control the mean center frequency through a motor-driven

* The author wishes to thank Mr. D. A. McCormick of Standard Electronics Corporation, Messers A. H. Bott and J. A. Aurand of the Radio Corporation of America, Mr. Bernard Wise of the Industrial Transmitters and Antenna Company, and the Gates Radio Company for supplying the material pertaining to their equipment.

capacitor connected across the oscillator frequency-controlling circuit. In other cases, the output is in the form of a d-c voltage applied directly to the frequency-controlling element of the modulation reactance tube. The amplitude and polarity of the d-c voltage depend on the direction and magnitude of frequency shift of the modulated oscillator.

An unmodulated carrier wave is a single-frequency, constant-amplitude, sinusoidal wave. To transmit intelligence, this wave must be varied in some way. This process of superimposing intelligence on a carrier wave by some variation is known as modulation.

There are two fundamental forms of modulation:

1. Variation of amplitude (AM)
2. Variation of repetition rate (FM of phase modulation)

More complicated systems of modulation are actually variations or combinations of these fundamental methods.

Considering a very simple case of a carrier that is amplitude modulated with a single-frequency sine wave, we can express the result mathematically in the following manner:

$$e = E(1 + m \cos \Omega t) \cos \omega t \tag{2-1}$$

where m is the modulation factor.

$$\begin{aligned} e &= E(\cos \omega t + m \cos \Omega t \cos \omega t) \\ &= E[\cos \omega t + \frac{m}{2} \cos (\omega + \Omega)t + \frac{m}{2} \cos (\omega - \Omega)t] \end{aligned} \tag{2-2}$$

Equation (2-1) is in the form of a sine wave of carrier frequency with an amplitude that varies at the modulation rate. This might be shown in pictorial form similar to that in Fig. 2-1.

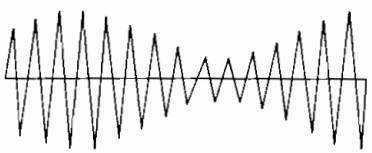


FIG. 2-1. Amplitude-modulation RF envelope.

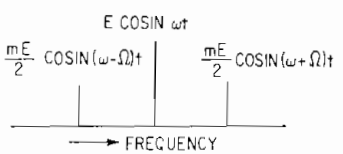


FIG. 2-2. AM sideband representation.

On the other hand, Eq. (2-2), which was derived directly from Eq. (2-1), shows that there are three frequencies present: the carrier frequency, having the same angular velocity ω as the original unmodulated carrier and the same amplitude E, and also two angular velocities $\omega + \Omega$ and $\omega - \Omega$ which correspond to frequencies above and below the carrier frequency, separated by the modulating frequency, as shown in Fig. 2-2. This can also be represented in vector form as shown in Fig. 2-3.

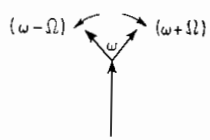


FIG. 2-3. Simplified AM vector representation.

These three ways of representing or picturing an amplitude-modulated wave are not different things but are merely somewhat imperfect ways of trying to visualize a single phenomenon, as is evident when we realize that they come from the same mathematical formula merely changed in form by straightforward trigonometry from Eq. (2-1) to Eq. (2-2).

Phase modulation can be expressed mathematically by the expression

$$e = E \sin (\omega t + \phi) \tag{2-3}$$

where ϕ varies with modulation, so that

$$e = E \sin (\omega t - m \sin \Omega t) \tag{2-4}$$

This is in a form similar to that of Eq. (2-1) for amplitude modulation.

In phase modulation, m is a modulation factor similar to the modulation factor used in AM and represents the maximum angular deviation during modulation.

In frequency modulation, where a fixed value of modulation represents a certain frequency deviation, we make the modulation factor

$$m = \frac{\Delta\omega}{\Omega} \tag{2-5}$$

where $\Delta\omega$ is the maximum departure of the angular velocity from the unmodulated value during modulation and Ω is the modulating frequency.

Now, expanding this expression,

$$e = E[\sin \omega t \cos (m \sin \Omega t) + \cos \omega t \sin (m \sin \Omega t)]$$

However,

$$\cos (m \sin \Omega t) = J_0(m) + 2[J_2(m) \cos 2\Omega t + J_4(m) \cos 4\omega t + \cdots]$$

and

$$\sin (m \sin \Omega t) = 2[J_1(m) \sin \Omega t + J_3(m) \sin 3\Omega t + \cdots]$$

Therefore,

$$e = E \sin \omega t\{J_0(m) + 2[J_1(m) \sin \Omega t + J_2(m) \cos 2\Omega t + \cdots]\}$$

$$e = E\{J_0(m) \sin \omega t + J_1(m)[-\cos (\omega + \Omega)t + \cos (\omega - \Omega)t] + J_2(m)$$

$$[\sin (\omega + 2\Omega)t' \sin (\omega - 2\Omega)t] + \cdots\} \tag{2-6}$$

This is similar in form to Eq. (2-2) for AM in that it consists of a carrier-frequency term and side frequencies. In this case, however, the carrier amplitude varies with modulation, and there is a series of side frequencies spaced from the carrier by multiples of the modulating frequency.

We can represent a frequency-modulated wave pictorially as shown in Fig. 2-4.

A vector representation is valid only for very small angular deviations, but for this special case it is that shown in Fig. 2-5.

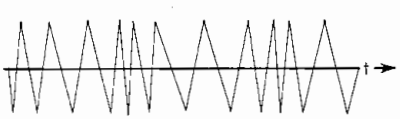


FIG. 2-4. Frequency-modulation RF envelope.

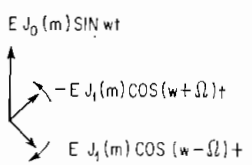


FIG. 2-5. Simplified FM vector representation for small deviation ratios.

The absolute magnitude of sideband-spectrum representation corresponding to Fig. 2-2 for AM is shown in Fig. 2-6 for three different deviation ratios.

The Bessel functions $J_0(m)$, $J_1(m)$, etc., which expressed the magnitudes of the various frequency components, can be obtained from mathematical tables in exactly the same way as we find values of the ordinary circular functions sin, cos, etc.

We can make practical use of many of the properties of these Bessel functions. For instance, we notice that $J_0(x)$ goes to zero for certain values of x: $x = 2.4048$, 5.5201, 8.6537, ... The J_0 function describes the amplitude of the carrier for any modulating frequency and deviation.

The following is an example of the application of this method. Using a selective AM receiver tuned to the IF of the station modulation monitor or a good FM receiver, modulate the FM transmitter with an audio tone of 8,666 cycles. It will be observed

that as the level of the audio signal is increased, the carrier will disappear for c levels of audio signal. If the audio level is gradually increased until the carrier gone to zero three times, then the transmitter will have a deviation of ±75 kc.

$$8.666 \times 8.6537 = 75 \text{ kc}$$

Using this method, any value of deviation can be accurately determined by choosing the proper Bessel function and audio-modulating frequency.

BANDWIDTH

A study of the Bessel functions also shows us the requirements for bandwidth with frequency modulation. Theoretically, the bandwidth is infinite, but practically we

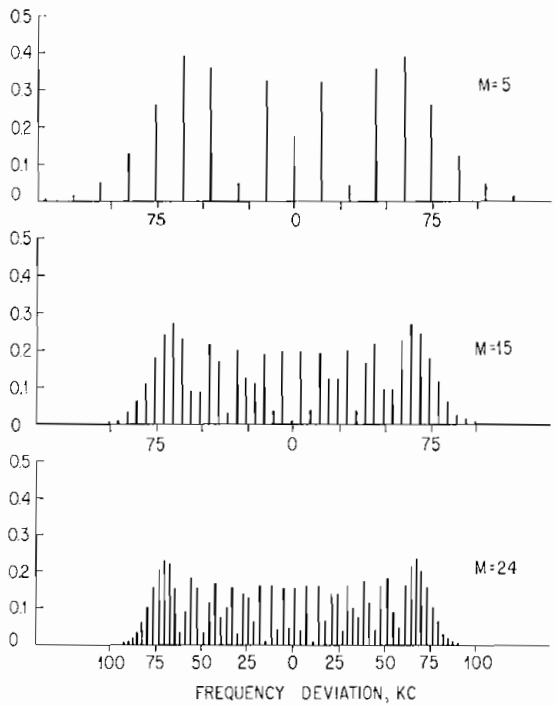


FIG. 2-6. Sideband amplitudes of a frequency-modulated wave.

see from Fig. 2-6 that the amplitudes of the side frequencies beyond the maximum swing become very small and can be neglected. We should remember, however, that even for very small swings, we need a bandwidth sufficient to include the first-order sidebands or no intelligence will be included.

A good "rule of thumb" for bandwidth (BW) requirements is

$$\text{BW} = 2(f_m + \Delta f)$$

where f_m is the modulating frequency and Δf is the maximum frequency deviation. Though this rule is not accurate, it is a good practical method for ordinary use.

Insufficient bandwidth results in distortion of the modulation. This is different from the case of AM, in which restricted bandwidth affects the frequency response

of the system but does not affect wave shape. It should also be noted that to have frequency modulation free of distortion, the system should have all frequency components transmitted not only without relative changes in amplitude but also without relative phase changes. This means that there must be a flat frequency response within the passband and a linear phase characteristic.

A frequency-modulation system, however, does not require a linear amplitude response, and in fact, its chief advantage, that of noise reduction, is obtained by purposely introducing an extremely nonlinear element, the limiter, in the receiver.

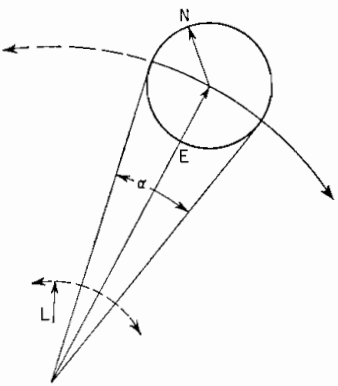


FIG. 2-7. Simplified vector diagram of noise added to the RF carrier.

NOISE REDUCTION

The effect of a limiter in reducing noise is most easily visualized by the method used by Roder in his article, Noise in Frequency Modulation, *Electronics,* May, 1937. This explanation uses a vector representation of the frequency-modulated wave similar to that of Fig. 2-5, except that when we are considering large frequency swings, we cannot show the various frequency components and the wave is represented merely as a single vector which must be pictured as rotating back and forth through the angular deviation caused by the modulation. The noise is represented as a vector having a magnitude equal to the peak value of the noise and any arbitrary phase.

It can be seen from the diagram in Fig. 2-7 that, if the peak noise amplitnde is less than the signal, it can produce a phase modulation not greater than ±90°. If the amplitude variations are removed by limiting, the noise contribution will be reduced by a factor which varies with the ratio of this angle to the maximum deviation angle of the frequency-modulated signal.

Mathematically, the reduction of noise can be expressed as a wideband gain

$$G = \sqrt{3} \cdot \frac{\Delta f}{f_m}$$

where f_m, in this case, is the highest modulating frequency to be transmitted by the system and Δf is the maximum frequency deviation.

It should be noted that this gain holds only for signal levels where the signal is greater than the noise and that below this value, which is called the threshold, the signal is rapidly wiped out by the noise.

PREEMPHASIS

Further improvements in the signal-to-noise ratio of a system transmitting voice or music can be obtained by the use of preemphasis and deemphasis. This system takes advantage of the fact that very little energy is normally contained in the higher frequency components of speech or music by distorting the frequency response of the transmitter input so that above a frequency of, let us say, 1,500 cycles the amplitude increases in proportion to the frequency. A compensating network in the receiver restores the over-all frequency response of the system.

The gain resulting from the use of preemphasis with FM takes advantage of the fact that the noise of a flat system is proportional to the modulating frequency. This effect is shown graphically in Fig. 2-8.

The improvement is not quite so great as the ratio of areas, since the audio input level must be reduced slightly to prevent overmodulation by high-frequency components, but for an audio spectrum up to 15,000 cycles, a preemphasis of 75 μsec gives a gain of about 10 db.

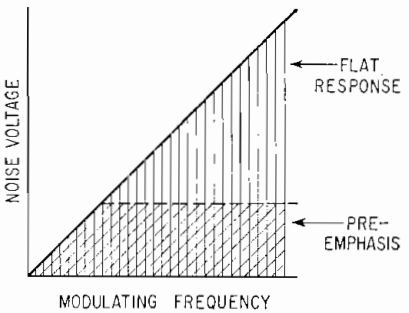


FIG. 2-8. Gain resulting from the use of preemphasis with FM.

This same gain for preemphasis cannot be obtained with AM because it does not have a triangular noise spectrum.

COMMERCIAL FM BROADCAST EQUIPMENT

Direct FM System

The first postwar FM transmitter manufactured by RCA (the type BTF-250A) used push-pull reactance tubes connected across the frequency-determining circuit of the modulated oscillator. The automatic frequency-control circuit is completely independent of the modulator circuit. Center-frequency stability is maintained by comparing a subharmonic of the modulated signal against a standard temperature-controlled oscillator. The error signal resulting from any difference between the mean frequency of the modulated oscillator and the standard oscillator is used to drive a two-phase motor that positions a condenser connected across the frequency-determining circuit of the modulated oscillator. The advantages of this type of modulator are that small frequency multiplication is required and very low harmonic distortion is introduced by the reactance modulator tubes.

Phasitron System

The Phasitron [1] modulator was originally proposed by Dr. Robert Adler of the Zenith Radio Corporation. It requires the use of a special tube developed for this type of service by the General Electric Company. This development permitted a reduction in the number of multipliers required.

A crystal-controlled carrier is first generated by the crystal oscillator. A phase-splitting network supplies the three-phase voltage for the deflector elements. An audio air-cored inductor is placed around the tube so that the axes of the coil and tube are the same. The coil is designed to appear as nearly as possible like a pure inductauce over the entire audio-frequeucy range. When a constant voltage is held across the coil at all audio frequencies, the current through the coil and, consequently, the magnetic field in the Phasitron tube will be inversely proportional to the modulation frequency. This is exactly the condition required to convert from phase modulation to frequency modulation. The Phasitron is capable of ± 3.5 radians as compared

[1] Registered U.S. Patent Office.

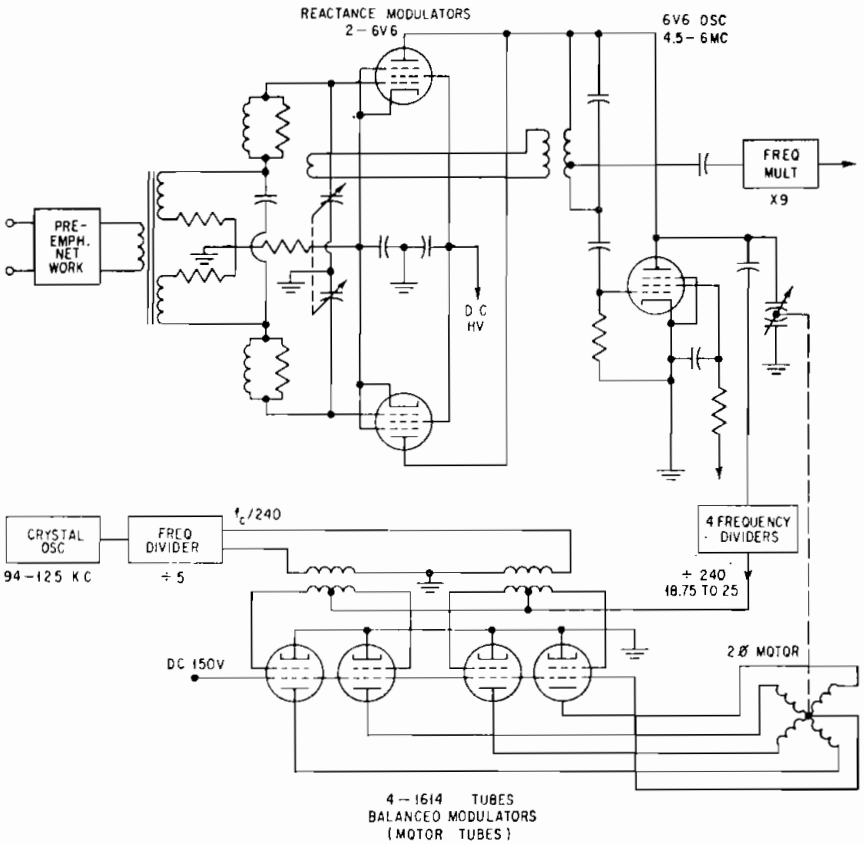


FIG. 2-9. Frequency-controlled FM modulator.

with approximately ±0.5 radians, using a conventional phase modulator with corrections circuits. Using ±3.5 radians as the maximum phase shift obtainable, the required multiplication rate can then be calculated as follows:

$$M = \frac{f}{f_a \cdot \phi} = \frac{75{,}000}{50 \times 3.5} = 428$$

Operating frequency = 88 to 108 Mc
M = multiplication rate
f = desired frequency deviation, ±75 kc
f_a = lowest audio frequency to be used, 50 cycles
ϕ = phase shift, radians

The lowest multiplication number that can be obtained using only doublers and triplers is 432 times. This is the multiplication rate used by most manufacturers employing the Phasitron for standard FM broadcast use. When RF feedback is used, the distortion at the lower audio frequencies can be made to be less than 1 per cent.

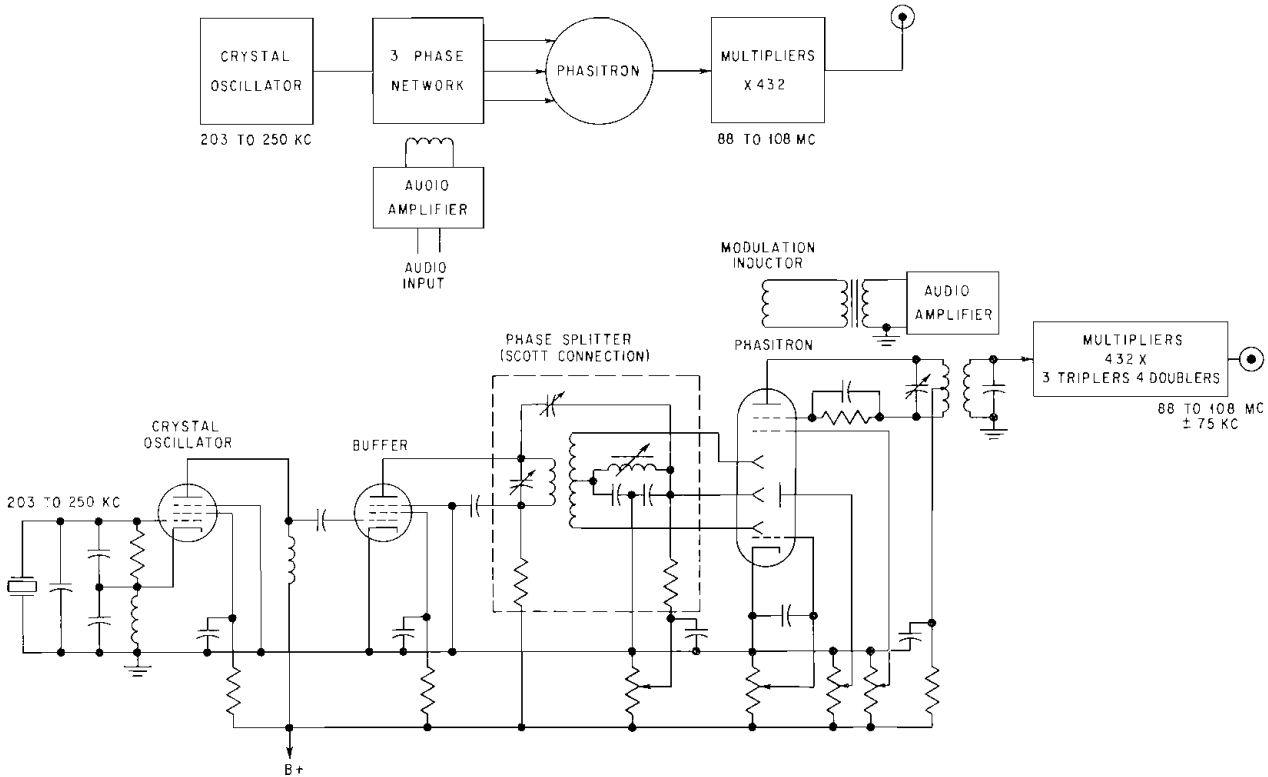


FIG. 2-10. General Electric Phasitron FM modulator.

INDUSTRIAL TRANSMITTERS AND ANTENNA COMPANY

A brief description of the ITA Company FM transmitters follow. The discussion is divided into the following categories: (1) General Packaging, (2) Meter and Control Circuitry, (3) Exciter, (4) RF Power Amplifiers.

General Packaging

The modern FM transmitter should be compact and capable of being placed in a facility having restricted floor space. It should be capable of being operated by remote control and should require only periodic maintenance. In addition, it must

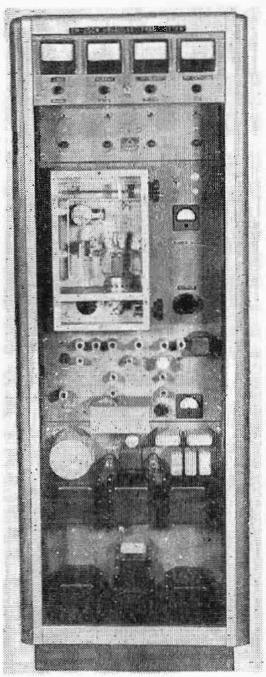


FIG. 2-11. ITA 250-watt FM transmitter.

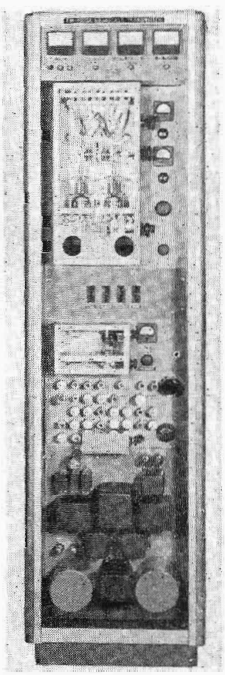


FIG. 2-12. ITA 100-watt FM transmitter.

conform to the latest FCC specifications, which endeavor to limit spurious emissions and cabinet radiations.

Bearing these requirements in mind, the ITA transmitter designs utilize only high-gain stages wherever possible. This reduces the total number of components, thereby reducing the over-all size of the package. For example, the 5-kw transmitter requires only 9 sq ft of floor space. In addition, all the components are mounted in vertical panels. This permits ease of viewing circuits and trouble-shooting when necessary. Every wire that enters an RF enclosure in the transmitter passes through a feed-through capacitor, thus reducing the possibility of cabinet radiation. Every effort has been made to utilize commercially available components. The selection of standard components assures the broadcaster of proved reliability and ready availability of replacement parts. Figure 2-11 and 2-12 exemplify the packaging of the transmitter.

Meter and Control Circuitry

The function of the meters and the controls in the transmitter is quite apparent. However, as mentioned above, in the majority of cases the FM transmitter will be operated unattended and will be controlled from some remote location. Thus, all the meter circuits, except for AC line voltmeter, are connected to ground. In order to read their indications remotely, a sampling resistor is inserted between the meter and ground and the voltage developed across it is applied to a remote meter line. For the same reason, each transmitter has control circuits which require only the application of line voltage before the transmitter will automatically advance through the various stages of filament, exciter, and amplifier plate and screen voltages. Provisions have been made available to control the various supplies in the equipment independently. Time-delay units are used throughout to prevent the application of voltage prior to adequate preheating of rectifier and power tubes.

Exciter

The method used for achieving frequency modulation in the ITA exciter is by the "indirect," or phase-modulation, method. In this system, the oscillator circuit is not affected by the modulation, and thus, carrier-frequency stability is dependent only on the oscillator circuitry components.

The major limitation of a phase-modulating system is that the maximum frequency deviation that can be obtained is a very small percentage of the modulating frequency. Thus, in order to obtain the required 75-kc deviation at low audio frequencies, modulation must occur at a very low subharmonic of the carrier. This frequency is then multiplied manyfold. Multiplication also increases the deviation.

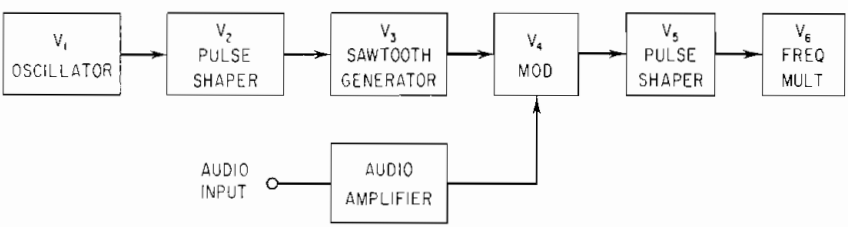


FIG. 2-13. Block diagram of basic Serrasoid FM modulator.

A type of phase modulation, developed by J. R. Day and commonly referred to as a Serrasoid modulator,[2] has greatly extended the modulation capability of phase modulators using conventional tubes. Figure 2-13 is a block diagram of the basic exciter which uses this system. V_1 is a conventional crystal-controlled oscillator. V_2 modifies the oscillator waveform into pulses. These pulses trigger V_3, a sawtooth oscillator. The output of the sawtooth oscillator is fed to the grid of the modulator tube V_4. Owing to the grid conduction of this stage, the sawtooth is truncated. Figure 2-14*a* represents the waveform at the grid of V_4. Thus, if the grid voltage is varied at an audio rate, the point of truncation can be changed. Figure 2-14*b* shows the waveform at the input to V_4 under the condition of audio modulation; V_5 differentiates the output of V_4 so that it produces a pulse at the point at which truncation occurs. Because of the modulation process, the point of truncation and, thus, the output pulse from V_5 will change in time position. Figure 2-14*c* describes this action.

V_6 is a frequency multiplier. The pulses from the proceeding stage drive V_6 into saturation, and its output tank circuit is tuned to a harmonic of the oscillator frequency. As these pulses change in time position owing to modulation, the ontput sine wave of V_6 changes in phase. The carrier has become frequency-modulated at the audio rate.

[2] Registered U.S. Patent Office.

Following V_6 are a number of Class C frequency multipliers which produce the output carrier frequency. Interconnecting each of these stages are double-tuned circuits.

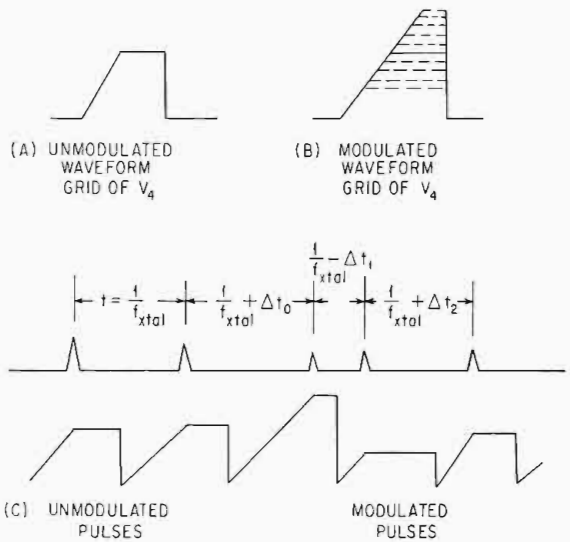


FIG. 2-14. Typical RF waveforms of the Serrasoid modulator.

Figure 2-15 is a picture of the ITA exciter. It utilizes 14 tubes and has a multiplication factor of 864. All the stages can be tuned from the front panel by maximizing the grid drive to the RF multipliers. These transformers are pretuned at the factory and rarely require any field adjustment. The output power of the exciter is 10 watts at the final frequency.

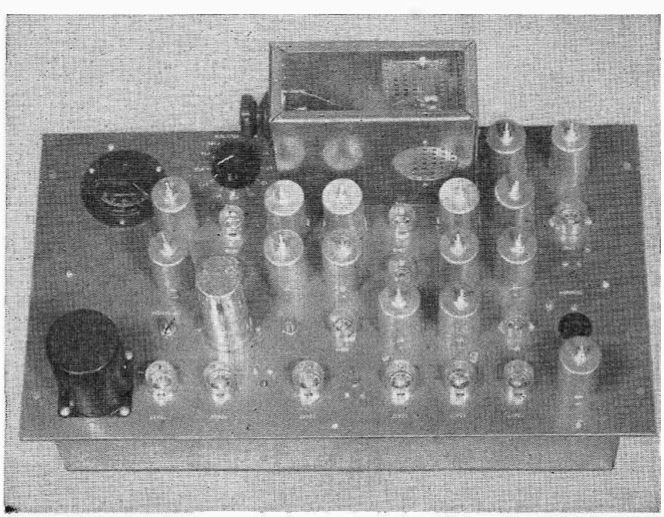


FIG. 2-15. ITA FM exciter.

RF Power Amplifiers

There are available today a number of power tubes with extremely large transconductances which, when driven by a modest power, can produce substantial power outputs. Their proper selection will result in transmitter simplicity, economic packaging, minimum operating expense, and trouble-free operation.

The following tubes are used at the various power levels for commercial FM broadcast transmitters manufactured by ITA:

Drive Requirement, Watts	*Power Output, Watts*	*Tube Types*
5	250	4-250A
10	500	4-400A
20	1,000	(2) 4-400A
200	5,000	4CX5000A

For ease of explanation, the discussion that follows will be divided into three sections: input circuit, neutralization, and output circuits.

Input Circuit of Class C RF Power Amplifier

The grid circuit of an RF amplifier at 100 Mc is determined by the magnitude of the grid-to-cathode interelectrode capacitance and the inductance within the tube

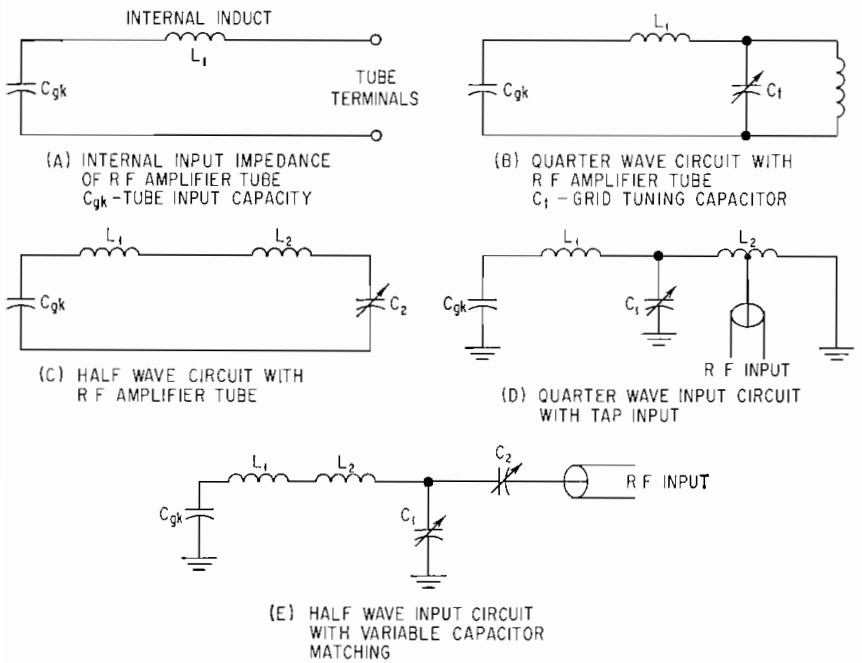


FIG. 2-16. Equivalent circuits.

envelope between the electrodes and its terminals. Fig. 2-16*a* represents an equivalent circuit for this capacitance and inductance. If this combination is resonant at a frequency higher than the desired frequency, resonance can be obtained by adding a fixed inductance external to the tube. Tuning can be accomplished by using

variable air capacitors or changing the amount of external inductance. Figure 2-16*b* describes this "quarter-wave mode" of operation.

If the combination of the input electrode capacity and lead inductance is resonant at a frequency lower than the desired operating frequency, the combination pictured in Figure 2-16*c*, commonly referred to as a half-wave mode, can be used. Since the latter arrangement is a longer circuit electrically, it represents a greater storage of energy and, thus, will have less bandwidth than the quarter-wave circuit described earlier. Nevertheless, both circuits will normally provide adequate bandwidth for FM transmission.

The question now arises as to how to couple into this type of circuit. One of the acceptable methods is to use a fixed tap a short distance away from the short-circuited end of a quarter-wave input circuit. This point should correspond to approximately 50 ohms in impedance when the input circuit is tuned to resonance. This coupling arrangement is shown in Fig. 2-16*d*.

When coupling into a half-wave circuit, the circuit shown in Fig. 2-16*e* can be used. Here the series coupling capacitor is approximately 5 $\mu\mu$f when coupling a 50-ohm line into a stage utilizing one of the previously mentioned tetrodes. This is due to the fact that the series circuit of coupling capacitor and 50-ohm line represents a resistance of approximately X_c^2/R, which can be adjusted to match the high impedance present at the end of a half-wave circuit.

In the 1-kw transmitter, a push-pull arrangement is used. In order to drive this stage from an unbalanced line, a coupling loop is used. The use of a push-pull circuit reduces the input capacity to one-half the interelectrode capacity of a single tube. This reduction in capacity permits the use of a quarter-wave mode.

Neutralizing

To avoid introducing distortion and intermodulation, the amplifier must have a linear phase-vs.-frequency characteristic. This requires that the amplifier be well neutralized.

Most power tetrodes that are used in FM transmitter applications are so constructed

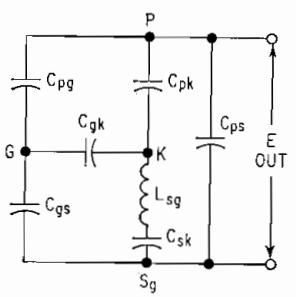


FIG. 2-17. Equivalent circuit of interelectrode capacities of a tetrode.

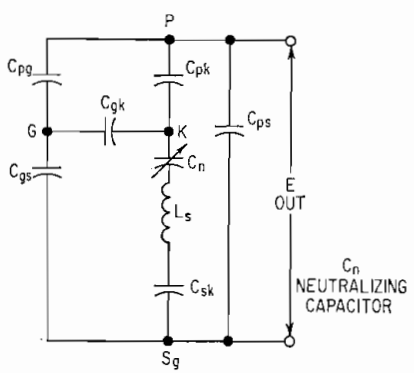


FIG. 2-18. Equivalent circuit of a tetrode with neutralizing capacitor in series with screen.

that their screen grids have considerable inductance between their active area and terminal connections. Figure 2-17 describes the equivalent circuit of a typical power tetrode, including the high interelectrode capacities and lead inductance. By referring to this figure, it can be seen that the output voltage of the stage is developed across a bridge circuit whose arms consist of the electrode capacitors and the screen inductance. If this bridge is balanced, the difference of potential across the grid-to-

cathode electrode capacity approaches zero. Accordingly, in this condition, the amplifier will be stable. Referring to Fig. 2-17, it is evident, however, that the screen inductance unbalances the bridge, so that the tetrode amplifier circuit will have feedback and oscillations can exist. In order to compensate for this unbalance, a series screen capacitor can be used to balance the bridge. Figure 2-18 describes the equivalent circuit of the arrangement.

In practice, the procedure used for neutralizing the stage with screen neutralizing is relatively simple. The input circuit is tuned for a maximum indication of grid current. An absorption meter is placed in the output circuit with the plate and screen voltages removed, and the plate circuit tuned for a maximum indication on the absorption meter. The screen neutralizing capacitor is then adjusted for a minimum indication on the absorption meter.

Output Circuits

The output circuits for the ITA, 250-watt and 1-kw transmitters are shown in Figs. 2-19 and 2-20.

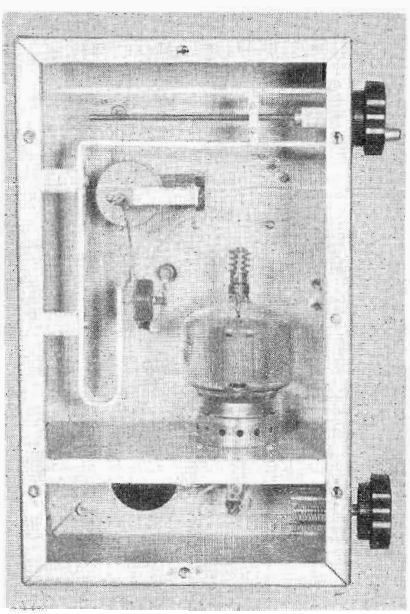


FIG. 2-19. ITA 250-watt RF amplifier.

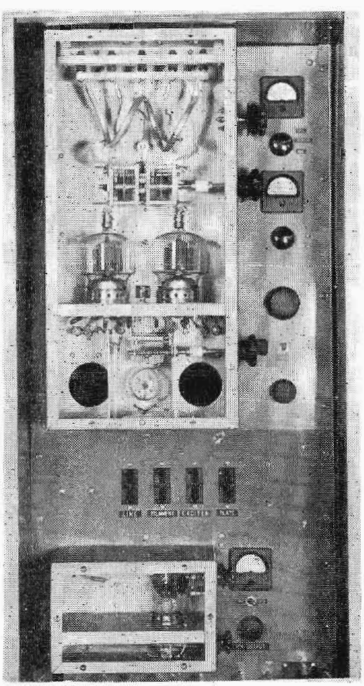


FIG. 2-20. ITA 1,000-watt RF amplifier.

The 250-watt amplifier has a capacity-tuned, quarter-wave plate tank circuit. The antenna is directly coupled to a low-impedance point through a d-c blocking condenser. Proper loading of the stage is achieved by varying the point at which the output line is tapped.

The 1-kw transmitter, using two 4-400A tubes operating in push-pull, also uses a quarter-wave, capacitively tuned plate tank. The antenna is inductively coupled to the final tank and is series-tuned for proper loading.

GATES RADIO COMPANY FM TRANSMITTER

The Gates FM-5B, 5,000-watt FM broadcast transmitter (Figs. 2-21 and 2-22) consists of a M5534 Serrasoid modulator exciter, a 4X250B intermediate-power amplifier, and a pair of 6076 tetrodes operating push-pull in a grounded-cathode circuit.

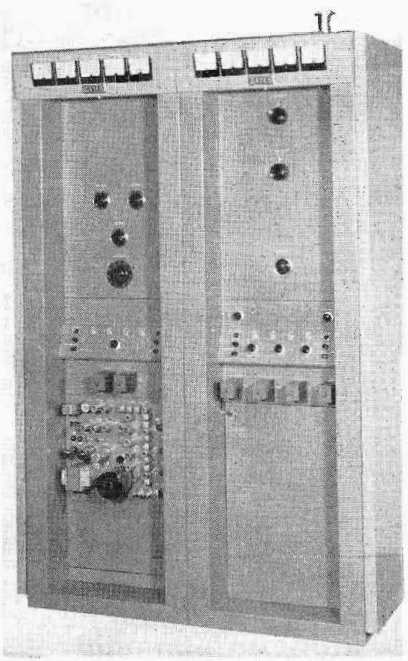


FIG. 2-21. Gates 5,000-watt FM-5B complete transmitter.

The exciter is constructed on a standard 19-in. panel for rack mounting. This unit is complete with its own power supply and has provisions between the fifth and sixth multiplier stages to insert additional multiplex channels from a separate chassis. The last stage in the exciter uses a type 6360 tube as an amplifier and can supply up to 10 watts for use as either a complete transmitter or as a driver for a higher powered amplifier. The operation of a Serrasoid modulator has been previously described.

The output from the exciter drives the intermediate-power amplifier. This amplifier consists of a single 4X250B tube operating in a grounded-cathode circuit.

The input is a half-wave circuit, with the output from the exciter inductively coupled to it. The driving power can be adjusted by varying the position of the loop. The plate circuit is a modified π, being capacity-tuned and capacity-loaded (see Fig. 2-23).

The final amplifier consists of two 6076 tetrodes operated in a push-pull grounded-cathode circuit. The input is again a half-wave capacitively tuned circuit. Input coupling is accomplished by connecting the inner conductor of the transmission line from the driver to one grid line. The plate tank is electrically a quarter wave long and tuned by use of a vane. The output circuit is inductively coupled by means of an adjustable loop. For complete stability of the amplifier, cross neutralization is provided (see Fig. 2-24).

Each stage of the transmitter is metered by a multimeter system, and the power amplifier with a separate plate ammeter. Power output is monitored with a Micromatch directional coupler that is calibrated for power output and also standing-wave ratio. The amplifier tubes are air cooled by pressurizing a plenum chamber in which the grid circuit is also built. The transmitter is thoroughly protected from overloads and malfunctioning of other components, such as blowers and so forth.

STANDARD ELECTRONICS COMPANY FM TRANSMITTER

In the Standard Electronics FM broadcast 3-kw transmitter will be found the high degree of carrier stability inherent in a rigid control device. The generation of the RF signal from a quartz crystal oscillator with temperature control in an oven ensures a high degree of frequency stability. When this source of RF is used directly in a Serrasoid modulator, a combination of high-frequency stability, frequency response, and very low distortion can be achieved.

The frequency response and low distortion are produced by the circuitry of the Serrasoid modulator. The modulator is designed around four receiver-type tubes,

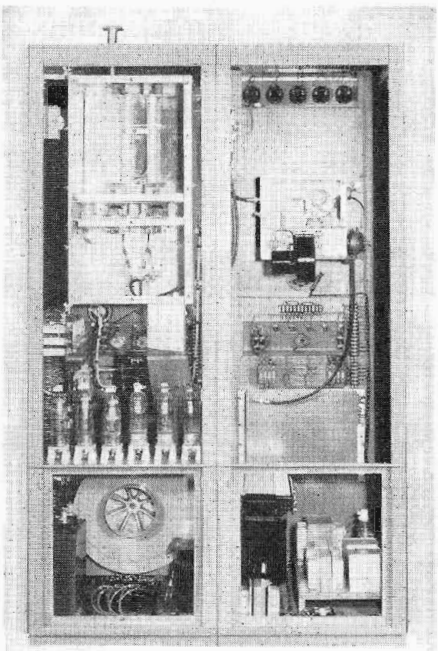


FIG. 2-22. Rear view of Gates 5,000-watt transmitter.

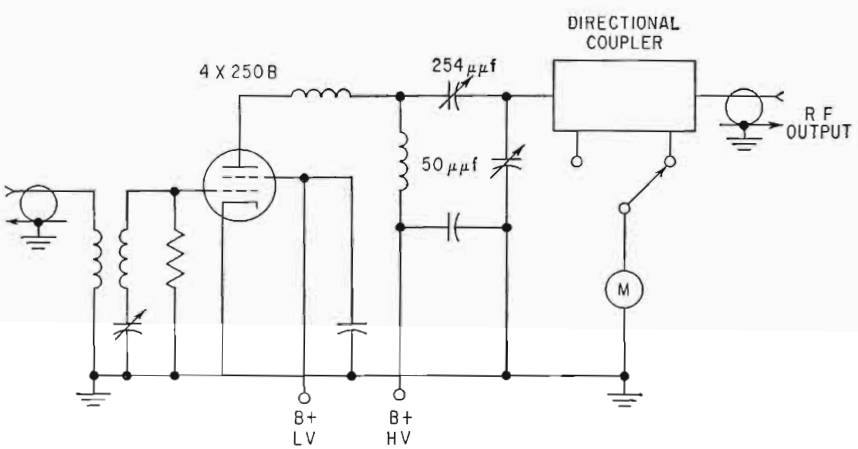


FIG. 2-23. Simplified schematic of Gates Radio Company FM-250B, 250-watt amplifier.

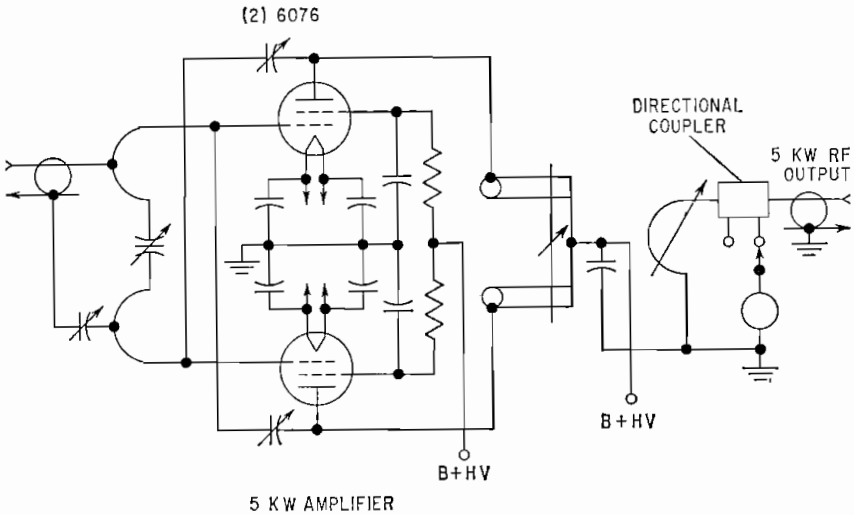


FIG. 2-24. Simplified schematic of Gates Radio Company FM-5B, 5,000-watt amplifier.

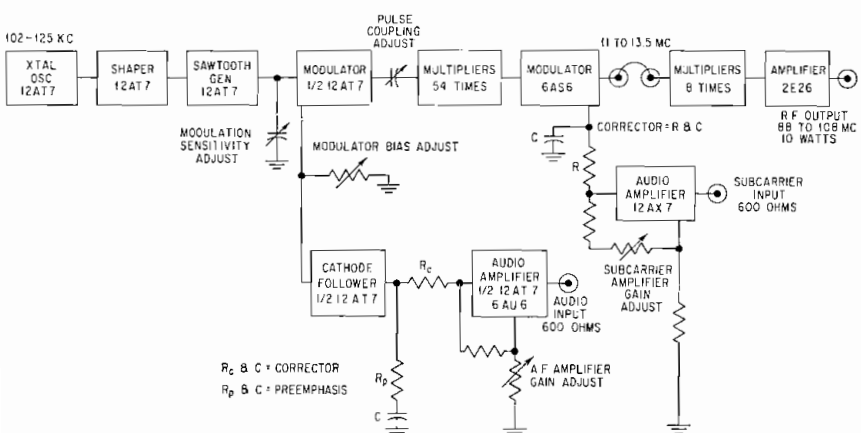


FIG. 2-25. Block diagram of Standard Electronics Serrasoid FM modulator.

V_1 and V_4 (12AT7's) (see Fig. 2-25). The quartz crystal in conjunction with the first 12AT7 generates an RF signal at the crystal frequency. This frequency may range anywhere from 102 to 125 kc, depending upon the authorized frequency of the station.

The second tube, V_2, shapes the oscillator buffer output to produce a steeply rising waveform at the crystal frequency, while the third tube, V_3, is a driven sawtooth generator with a bootstrap circuit to ensure linear rise of the generated waveform. The fourth tube, V_4, the modulator, clips off the sawtooth wave by an amount varying with the amplitude of the modulating signal impressed on the cathode of this tube.

Prior to its application on the cathode of the modulator, the audio signal is passed through a corrector network and a preemphasis network. The corrector network compensates for the tendency of the high audio frequencies to produce more equivalent frequency modulation than the low audio frequencies.

The preemphasis network is nsed in the transmitter with a corresponding deemphasis network in the FM receiver. The purpose here is to raise the level of the high audio frequencies to such a degree that they will override noise. That is, it would produce a better signal-to-noise ratio at the receiver.

Referring again to the modulator tube V_4, the output of this tube is a series of sharp positive pulses at the crystal frequency. The audio information appears in the form of phase modulation of the above-mentioned positive pulses. The effect of the phase-modulated pulses on the grid of the first frequency multiplier tube V_5 is to produce an equivalent frequency modulation.

The audio-frequency amplifier, V_{15} and V_{16}, used on the modulator panel of this transmitter incorporates inverse feedback. The frequency response up to the corrector network is flat between 50 and 15,000 cps. The distortion in terms of total harmonic is less than 1 per cent from 50 to 15,000 cps.

The audio input level is a standard +10 dbm. A potentiometer is provided to change the over-all gain of the amplifier. The +10-dbm input level will produce 100 per cent modulation, which, in this case, is a deviation of ±75 kc at carrier frequency.

Total frequency multiplication on the modulator panel is 108. The freqnency range at the output of this panel is 11 to 13.5 Mc. The available power from the final amplifier stage, V_{14} (type 5686), is approximately 1 watt into 50 ohms.

A second input is provided on the modulator panel by means of which a multiplexed signal can be introduced. A subcarrier generator outside the transmitter under discussion generates a carrier in the frequency range of 25 to 75 kc. The modulation of the subcarrier is FM. The subcarrier is amplified by V_{17} and applied to the main carrier channel in the form of phase modulation. The phase modulation of the main carrier at V_{12} is accomplished by the combination of two quadrature voltages at the output of V_{11} and V_{12}. The grids of these tubes are driven by RF signals that are approximately 90° apart. They combine to form a resulting vector at their common plate load. When subcarrier modulation is applied to the grid of V_{17}, the gain of this tube varies and its output amplitude changes. This new vector which varies in amplitude above and below a static level combines with the fixed amplitude and thus produces phase modulation. The rate and amount of phase modulation is proportional to the multiplex subcarrier frequency and amplitude. When the multiplexing feature of this modulator panel is used, the modulation level of the main channel must be reduced so that the combined modulation of the main program input and the subcarrier input will not produce a total FM deviation greater than ±75 kc.

Pin jacks are provided on this panel as well as on the frequency-multiplier panel for checking tube voltages. A combination of selector switches and a meter provide metering access to every RF stage in the 250-watt driver. In case of signal failure, the trouble point can be rapidly isolated by means of the selector switch.

As mentioned before, the total frequency multiplication on the modulator panel is 108. A further multiplication of 8 takes place on a frequency-multiplier panel. Three doubler stages and an output amplifier stage complete the panel. The input impedance of the frequency-multiplier panel is 50 ohms. This feature permits inserting a power-monitoring device between panels and checking the RF power. In

addition, the use of a directional coupler for this purpose will give an indication of VSWR and in turn a relative indication of match between units. The normal use of the directional coupler and its power-indicating meter is to monitor constantly the power output of V6011, the 4X250B stage. This equipment as described up to this point occupies one relay rack and can be used as an individual 250-watt FM transmitter. It is completely self-contained. It will operate from a 208/230-volt single-phase line. A variable voltage control Transtat [3] corrects the line voltage for the entire relay rack to 230 volts for line variations from 187 to 250 volts. The corrected voltage is read on an a-c voltmeter mounted on the control panel. Sufficient capacity has been built into the Transtat in the 250-watt rack to take care of the filament primary requirements of the 3-kw amplifier mounted in a companion relay rack. The 3-kw amplifier, V701 (type 5924A), is a self-contained amplifier mounted in a relay rack 84 by 24 by 22 in.; although it was designed to be a companion unit to the 250-watt transmitter, it can be operated with any low-power transmitter with sufficient drive (see Figs. 2-27 and 2-29*b*).

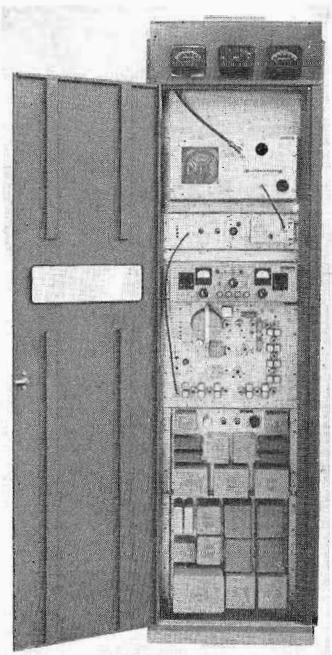


FIG. 2-26. Standard Electronics 250-watt FM transmitter.

The input tuning system, consisting of two tuning stubs separated by an eighth wave, permits the amplifier to work with any driver. The input can be tuned to ideal flatness by means of the directional coupler in the driver or by making use of the coupler supplied with the amplifier.

The output tuning system of the amplifier is a quarter-wave line cavity foreshortened by capacitance. The capacitance plates are ganged and are controlled by a multiturn knob on the front of the cavity. Variable-loop coupling is provided to adjust the loading of the amplifier stage to the antenna system.

A "patch-over" is supplied in this amplifier to facilitate operations in case of amplifier failure. By means of the patch-over the amplifier can be removed from the RF signal path and the driver connected directly to the antenna. In the patched-out condition, the amplifier can be worked on and, when repaired, can be put back on the air with a minimum of lost air time.

The amplifier is designed for 208/230-volt three-phase a-c operation. The primary side of the high-voltage transformer is supplied with taps to accommodate the differences in line voltage.

Although the input connection is ordinarily made by flexible coaxial line with type H fittings, the same connection can be made with 1⅝-in. rigid coaxial line. The output connection is made with 1⅝-in. rigid coaxial line. The patch-over feature previously mentioned is made by means of a U-shaped 1⅝-in. line located at the rear of the cavity. The physical arrangement of the patch-over includes a Micro Switch [4] which operates in the patch-out condition. Operation of the Micro Switch permits the amplifier to be worked on while the driver remains in an operating condition.

Another feature of this transmitter is the use of diffused junction silicon diodes as rectifiers in both the high- and low-voltage power supplies. The diodes are arranged on strips of bakelite with banana plugs and jacks to permit rapid replacement of a leg in any rectifier bridge or full-wave application.

[3] Registered U.S. Patent Office.
[4] Registered U.S. Patent Office.

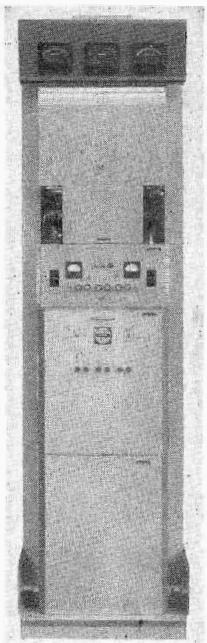


FIG. 2-27. Standard Electronics 3-kw amplifier with skins removed.

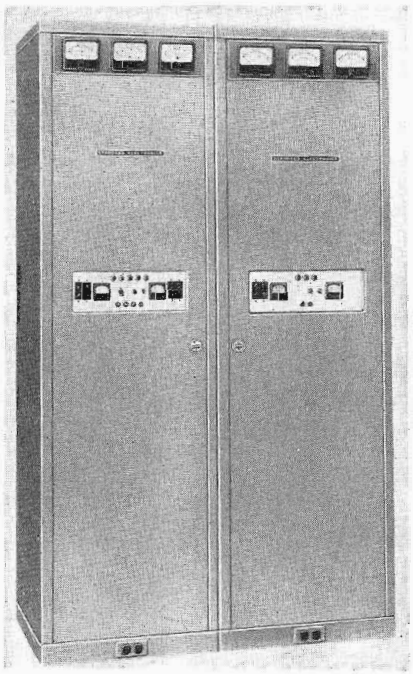
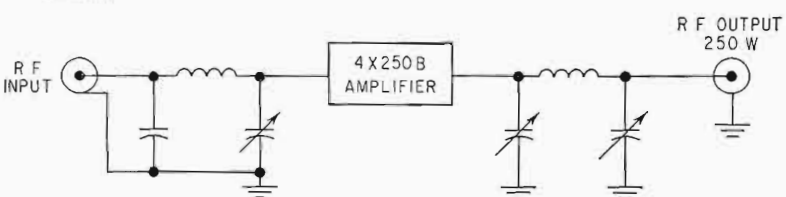
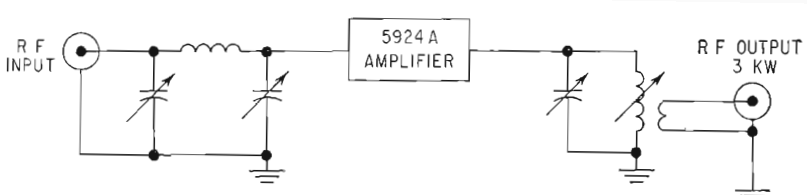


FIG. 2-28. Complete Standard Electronics 3-kw FM transmitter.



(A) 250 W AMPLIFIER



(B) 3 KW AMPLIFIER

FIG. 2-29. Simplified schematic of Standard Electronics 250-watt and 3-kw amplifier.

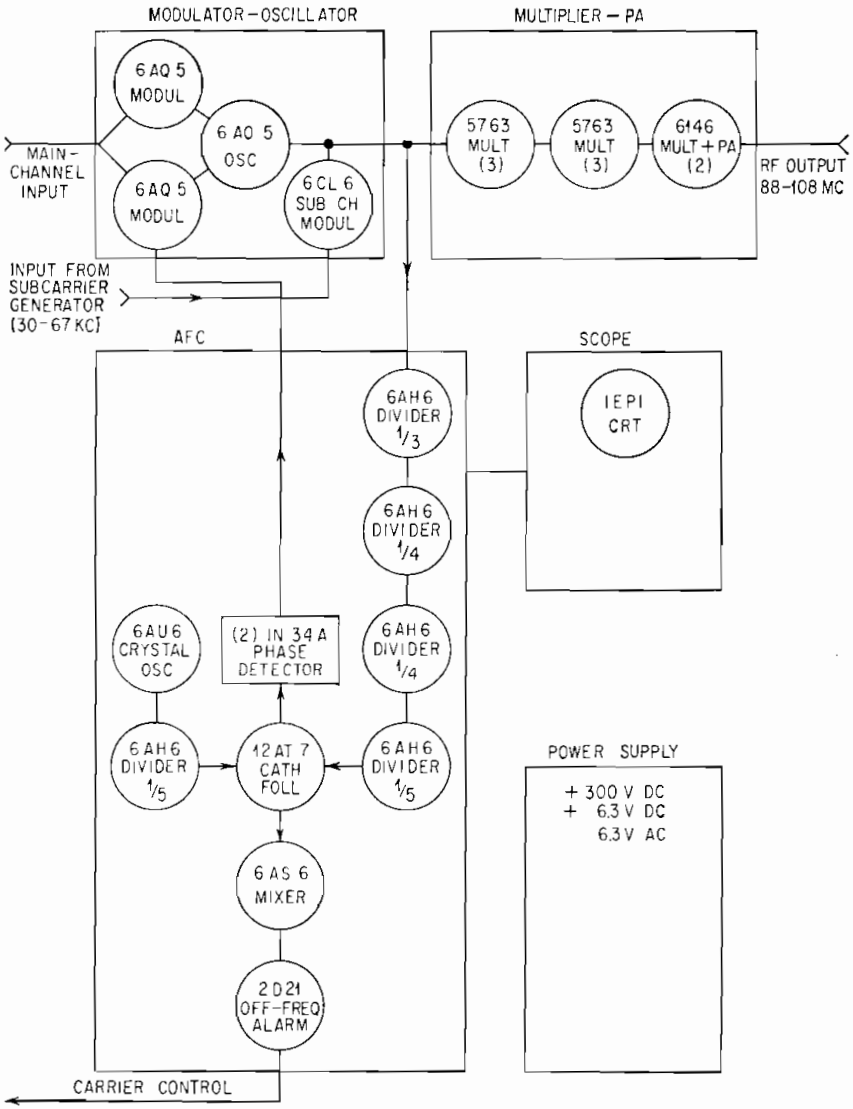


FIG. 2-30. Block diagram of RCA BTE-10B FM exciter.

RADIO CORPORATION OF AMERICA FM TRANSMITTER

The RCA type BTE-10B exciter is used in conjunction with the 250-watt IPA to drive a single 4CX5000A tube in the BTF-5B FM transmitter for ordinary FM service or multiplex operation.

Figure 2-30 is a block diagram of the exciter. A simplified schematic of the modulator-master oscillator portion is shown in Fig. 2-31. A Hartley-type oscillator is used in conjunction with two reactance tubes for the main channel, and a third reactance tube for the modulation of the subcarrier on the main (RF) carrier. This method has several advantages.

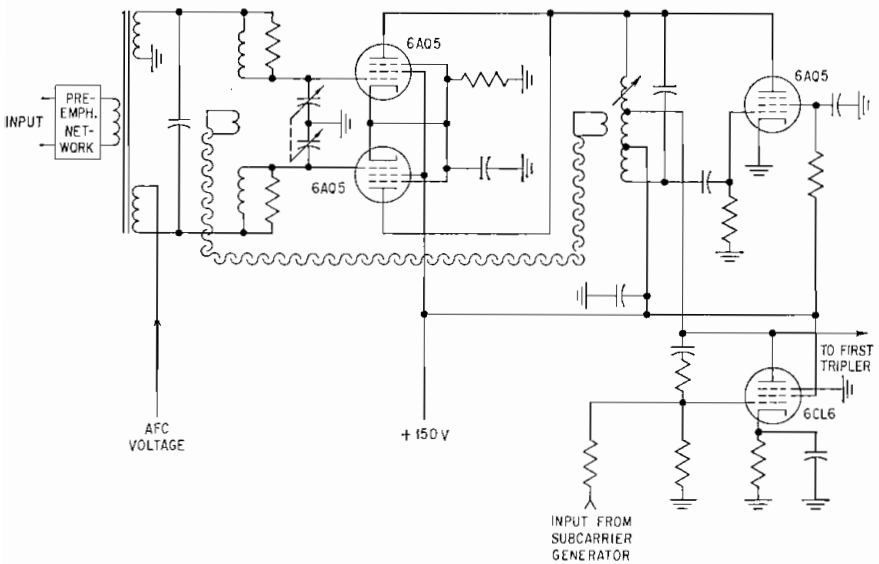


FIG. 2-31. Simplified schematic, oscillator, and modulator.

The highly linear push-pull modulator results in very low harmonic distortion. The coupling circuit is such that each tube is almost a pure reactance, one inductive, the other capacitive. In this way, loading of the oscillator is greatly reduced. The low AFC control voltages required assure proper operation even if the uncontrolled oscillator is off frequency. The subcarrier reactance tube is coupled only to a small part of the oscillator coil, since the deviation of the RF carrier by the subcarrier is small.

Both modulating circuits are very effectively decoupled to minimize the possibility of cross talk between the two channels.

Automatic Frequency Control

Automatic frequency control is accomplished by the use of a phase detector to develop a control voltage that establishes and maintains a phase lock between a reference crystal oscillator and the derived signal. Thus, the system is actually an automatic phase-control system which achieves a stability precisely matching that of the crystal reference source. To confine the phase deviations of the master oscillator signal to within range of the phase detector and in order not to exceed the possible speed of the low-pass network in the AFC circuit, the frequency and swing of the master oscillator must be reduced. This is accomplished in locked-oscillator-type dividers with an over-all division of 240. The maximum phase deviation at the lowest

audio frequency is thus ±28° (at ±100-kc deviation of the final frequency) and is well within the limits of linearity of the phase detector.

The limited pull-in range normally associated with precise frequency control is overcome by the use of an off-frequency circuit which extends the pull-in range to ±400 kc (at the final frequency) and simultaneously provides a safeguard against uncontrolled and possible off-frequency operation.

Circuits of the AFC system are diagrammed in Fig. 2-30. A small RF voltage is fed from the master oscillator circuit to the divider chain, where it is divided by 240 to a range of 20 to 25 kc. At the same time, deviation due to modulation is reduced from a maximum of ±5 kc to ±20 cps. From the dividers, this voltage is fed through a cathode follower to a phase detector employing two 1N34A diodes. A reference voltage of the same frequency, fed into the phase detector, is obtained by dividing by 5 the frequency of the reference crystal oscillator.

Phase Detector

Operation of the phase detector is illustrated in the simplified diagram shown in Fig. 2-32 and by the vector diagram in Fig. 2-33. Assuming that the master oscillator is exactly on frequency with no correction bias applied to its grid, the two input

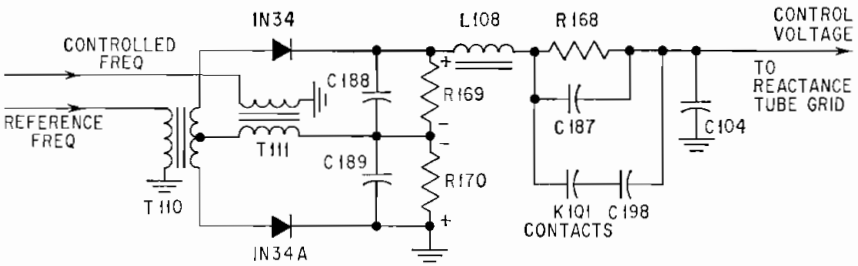


FIG. 2-32. Simplified schematic of phase detector.

signals applied to T_{110} and T_{111} are therefore of the same frequency but 90° out of phase. The reference frequency signal is applied to T_{110}, and the voltage developed across the top half of the secondary is represented by vector BA in Fig. 2-33*a*, while the voltage across the lower half is represented by vector BC. These two voltages are equal in magnitude and 180° out of phase. The controlled frequency signal is applied to T_{111}, and the voltage developed across its secondary is represented by vector BD, which is 90° out of phase with each of the other two. The voltage impressed across each 1N34A crystal rectifier and its associated load (R_{169} and R_{170}) is then the vector sum of the series voltages E_1 and E_2, respectively. Since the magnitudes of E_1 and E_2 are equal, the d-c voltages across R_{169} and R_{170} will be equal and of the polarity shown. Hence, the voltage as measured from the top of R_{169} to ground will be zero.

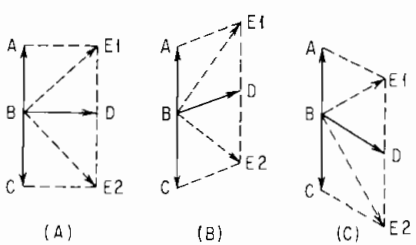


FIG. 2-33. Vector diagram—phase detector.

If, however, the frequency of the master oscillator should decrease, the relative phase of the two input signals and their vector relationships will change as shown in Fig. 2-33*b*. Since the magnitude of E_1 is now greater than that of E_2, the d-c voltage across R_{169} will be greater than that across R_{170}, and a net positive correction voltage appearing at the top of R_{169} will be applied to the reactance tube grid, correcting the frequency. Accordingly, if

the oscillator frequency should increase, the vector relationships change as shown in Fig. 2-33c and a net negative correcting voltage is applied to the reactance tube grid. Thus, any departure from the 90° phase relationship between the two signals is instantaneously corrected by a proper error voltage. High-frequency components of the input signals are filtered out of the control voltage by capacitors C_{188} and C_{189} and choke L_{108}.

The network consisting of capacitors C_{104}, C_{187}, and C_{198} and resistor R_{168} extends the control range of the phase detector beyond the ±90° phase-difference limit that would otherwise be imposed by feeding a small amount of the beat frequency back to the reactance tube grid. This beat frequency then causes the frequency of the master oscillator to swing in both directions at the difference-frequency rate. The amount of frequency deviation is proportional to the amplitude of the signal at the

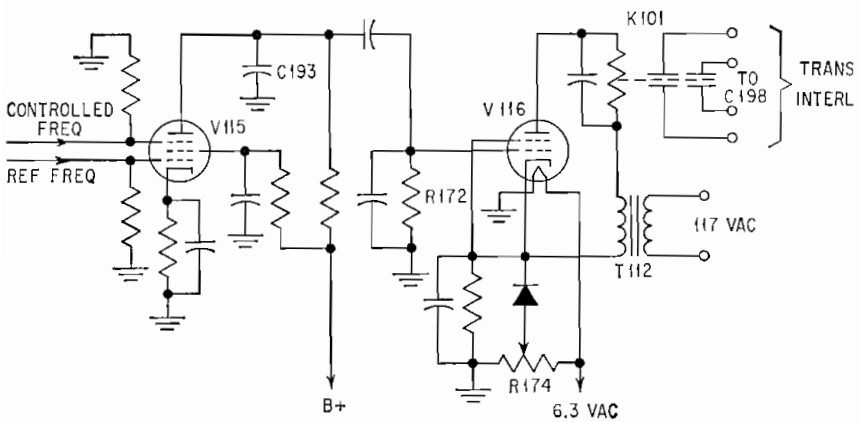


FIG. 2-34. Simplified schematic off-frequency detector.

reactance tube grid, and in order to produce sufficient swing without objectional audio-frequency feedback, capacitor C_{187} is made small and is paralleled by a large capacitor C_{198}, which is switched in only when the master oscillator is "hunting." The switching is done automatically by the off-frequency detector described in a later paragraph.

If the signal at the reactance tube grid is sinusoidal, there will be no d-c component and the mean frequency of the master oscillator will remain unchanged. However, the beat frequency at the phase detector output, when it is not locked in, is nonsymmetrical and has a d-c component of the proper polarity to change the mean frequency of the master oscillator toward its correct frequency.

Protection against loss of control by the automatic-frequency-control system and possible off-frequency operation is provided by the off-frequency detector circuit shown in Fig. 2-34. Tube V_{115} is a 6AS6 mixer stage which is fed from the last divider in each chain as shown in Fig. 2-31. The plate load of the stage is bypassed by capacitor C_{193}, which is a low impedance to the beating frequencies and to the sum of the beating frequencies, eliminating these signals in the output.

When the master oscillator is on frequency, there is no difference frequency produced in V_{115}, and therefore, the output of the stage is zero. If for any reason a difference occurs in the two beating frequencies, however, the difference-frequency component appears across the plate load and hence across the thyratron grid resistor R_{172}. If the positive half of this alternating voltage exceeds the fixed cathode bias applied to the thyratron, V_{116}, the tube conducts, energizing relay K_{101}. One (normally closed) set of contacts on relay K_{101} operates the transmitter interlock circuit, preventing plate power from being applied to the PA; another set of contacts (nor-

mally open) switches in the feedback capacitor C_{198}, shown in Fig. 2-32, for purposes previously described.

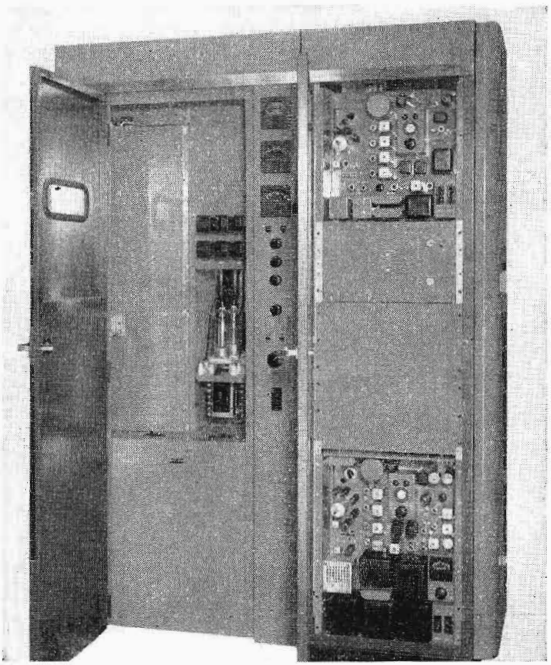


FIG. 2-35. RCA BTF-5B, 5,000-watt transmitter.

The sensitivity of the circuit is adjusted by the thyratron bias resistor R_{174}. This adjustment is set so that the low modulating frequencies will not trigger the thyratron but so that the beat frequencies will cause it to fire.

RF Section

The RF section of the BTF-5B FM transmitter is composed of two high-gain tetrode, Class C amplifiers with the necessary cooling system, power supplies, and control

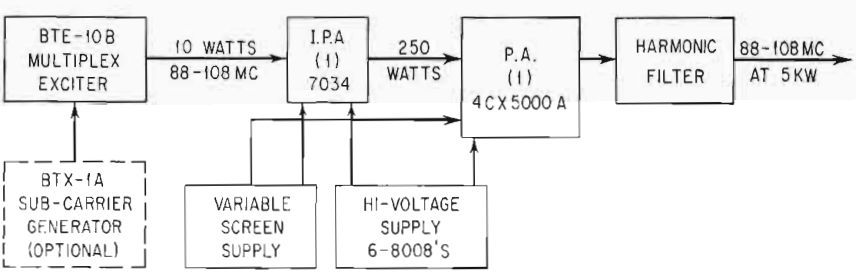


FIG. 2-36. Block diagram BTF-5B transmitter.

circuits to produce the required 5 kw of output power. The complete transmitter, including the BTE-10B exciter, is contained in two metal cubicles with operating

controls and meters on the front vertical panels of the larger cubicle. Space is provided in the smaller cubicle for mounting a multiplex subcarrier generator, type

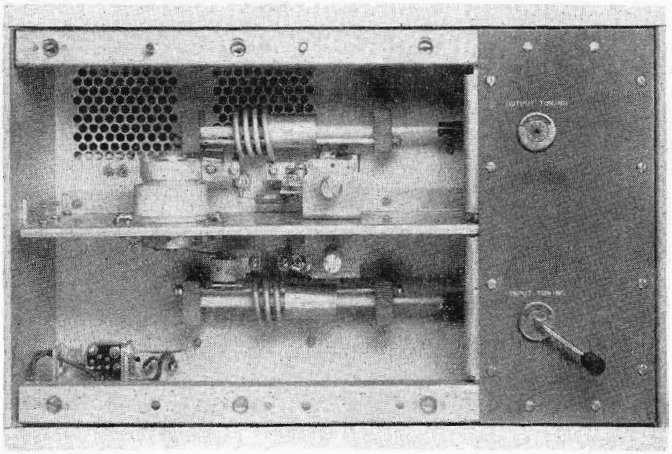


FIG. 2-37. RCA 250-watt intermediate-power amplifier.

BTX-1A. Radio-frequency connections between the exciter and the two RF stages is achieved by using 52-ohm coaxial cable. A variable, common screen supply is used to control power output of both stages, providing an output-power variation of 1 to 5 kw (see Figs. 2-35 and 2-36).

The tetrode IPA circuit consists of two tetrode stages, the first of which uses a 7034 tube located in its own compartment mounted above the exciter (see Fig. 2-37). Both the input and output networks of this stage consist of conventional π networks with variable capacitors as the matching components to match the characteristic impedance of the interconnecting cable (see Fig. 2-38). The frequency variation from 88 to 108 Mc is achieved by varying the inductance. The effective inductance of the coil is reduced by the insertion of a silver-plated brass slug into the center of the coil. No neutralization is required for this stage to achieve an output of approximately 250 watts to drive the PA stage. Both cathode and grid resistance are used to provide grid bias for this IPA stage in such a manner as to prevent excess dissipation when RF drive is removed.

The final stage, the 5-kw PA circuit, uses a 4CX5000A tube located in the larger rack along with the power supplies and the control circuit (see Figs. 2-39 and 2-40). The input circuit to this stage is a modified π network in which the input capacity of the tube is shunted by an inductive line to reduce the effective input capacity of the stage. This inductance also supplies the means for varying the input circuit loading. The inductive component of the circuit is varied by means of capacity in parallel with the coil.

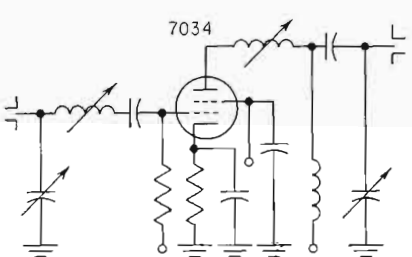


FIG. 2-38. Simplified schematic intermediate-power amplifier.

The output circuit of this stage is also a π network with the tube capacity shunted by a variable inductance. Loading and tuning are achieved by the variation of the two inductive-line components. For mechanical simplicity, the π network is inverted, placing one end of the inductance at ground potential. This removes the

mechanical and electrical problems of insulating the variable component from ground; however, the output line must be parallel to the inductance to bring it to ground potential. This is done by extending the output line down one side of the inductive line. This stage is neutralized by the variation of the inductance in series with the screen capacity. The efficiency of the final stage is approximately 70 per cent.

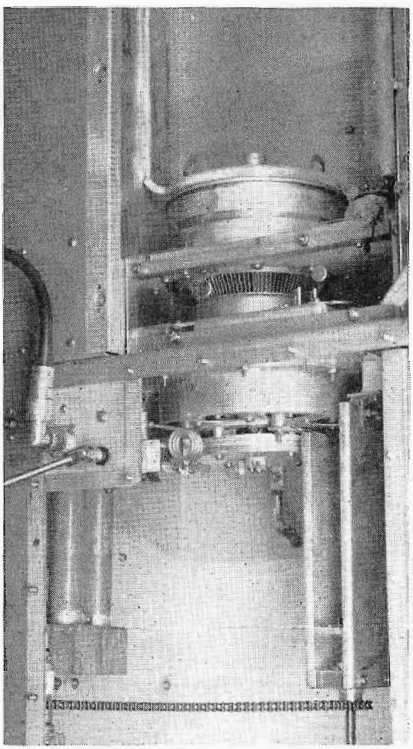


FIG. 2-39. RCA 5,000-watt power amplifier using a 4CX5000.

Tuning to cover the FM range (88 to 108 Mc) requires the changing of only one frequency-determining part in the 4CX5000A input circuit.

Harmonic Reduction

To reduce the harmonics radiating directly from the cabinets, the two power amplifiers are built in shielded compartments. Access doors and panels are equipped with contact fingers to prevent radiation, and all meter and power leads to these compartments enter through feed-through capacitors. The 4CX5000A plate voltage lead was at first bypassed only at the point of exit from its compartment. In order to reduce radiation coming from this lead from a maximum value of 60 db down from carrier to one of at least 72 db, it was necessary to add both a feed-through and ceramic bypass capacitor. Harmonic radiation from the transmitter output is of the order of 38 to 70 db down from carrier and requires the use of a harmonic filter in the output line.

For initial tuning, approximate settings for all variable components are set from tuning curves. Final adjustment is then begun under reduced screen voltage for circuit protection.

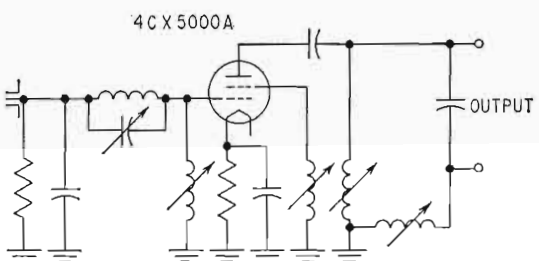


FIG. 2-40. Simplified schematic 5-kw power amplifier.

Control Circuits

The control circuit provides a starting sequence which prevents the application of plate voltage before the filaments are warmed up and the cooling system is operating.

It also provides overload protection and off-frequency shutdown. A time-delay relay of 45 sec provides adequate warm-up time for filaments and exciter. The overload circuit returns the transmitter to the air on the first two overloads after a clearing time of 2 sec. If the overload persists for the third time, manual resetting is required. Overload relays are located in the high-voltage and screen supplies, as well as in the cathode circuits of the IPA and PA stages. The control circuit is designed for unattended operation. By using latching relays in the control circuit all major operations can be remotely operated with a remote-control system, giving momentary closing contacts to the terminals brought out to the transmitter terminal board. In this way the transmitter can be turned off and on, an overload reset, and power output adjusted. Metering resistors provide currents proportional to the final plate voltage and current and power output for remote reading with a 200-μa meter.

Power Supply

The exciter power supply employs semiconductor rectifiers. One bridge-type germanium rectifier is used for the high-voltage supply, and a full-wave silicon rectifier for the modulator oscillator filament. The exciter can be operated from any single-phase source having a voltage of 197 to 251 volts or 106 to 128 volts a-c at 50 to 60 cps.

One circuit breaker is provided in the high-voltage supply, and one in the a-c input. Both breakers serve at the same time as master and standby switches. There is a separate connection for the 117-volt crystal oven-heater supply. The oven heater should be energized continuously. Each circuit (one operational and one spare crystal) is protected by ½-amp fuses.

The high-voltage supply is a three-phase, full-wave circuit using six 8008 mercury-vapor rectifier tubes. A single-section inductive input filter produces 5,000 volts at approximately 1.7 amp to supply the plate of the 4CX5000A tube. The center-tap voltage of the transformer supplies the 7034 plate through a double-section *RC* filter, which filters and reduces the voltage to approximately 1,800 volts. The screen voltage supply uses germanium rectifiers in a bridge circuit to feed both stages. The primary of this transformer is supplied from a variable transformer to control its output voltage.

Three-phase power is applied to the transmitter at the line breaker located on the right-hand front panel of the 5-kw cabinet. Power is then fed to three other breakers. The first supplies power to the filaments, exciter, and control circuit; the second, the high-voltage supply; and the third, the screen supply.

The FILAMENT ON switch applies power to the blower, to the filaments, and to the exciter provided the blower is operating. The filament line passes through a buck-boost circuit so that it can be adjusted to the exact voltage for which the primary filament transformer taps are set. The 45-sec time-delay relay is also energized, preventing the operation of the high-voltage circuit until the time-delay contacts close and all door interlocks are closed. This condition is indicated by the lighting of the READY LIGHT.

The TRANSMITTER ON switch applies the plate and screen voltage to the two tetrode stages. This is indicated by the lighting of the TRANSMITTER ON light. A motor-controlled variable transformer in the screen-supply line adjusts the screen voltage by means of the PROPER ADJUST switch.

Cooling System

The cooling-system blower is located in the bottom of the 5-kw cabinet, feeding air directly into the 4CX5000A stage. A constant-speed blower is used which will deliver enough air to cool the final tube up to an altitude of 7,500 ft. The air for the 7034 stage is tapped off the side of the 4CX5000A box by means of a flexible tubing that feeds through the side of the cabinet. Air interlocks are provided in both stages to remove plate and screen voltage if the air should stop.

Performance Data

In conventional FM service (meaning the transmission of only one program on the RF carrier and no subchannels) there are mainly three transmitter-design considerations which affect performance: (1) frequency response, (2) harmonic distortion, and (3) the ratio of the wanted signal to the unwanted noise (signal-to-noise ratio,

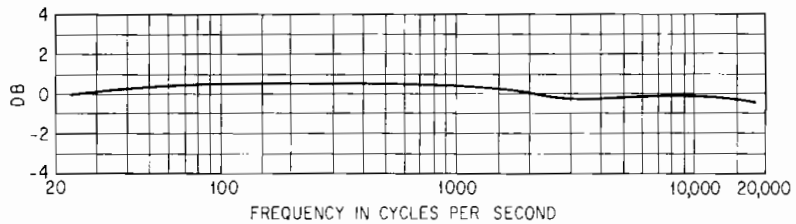


FIG. 2-41. Typical frequency response.

or S/N). Cross talk between channels would have to be added when a multiplex system is considered.

Typical performance data for frequency response are given in Fig. 2-41. Performance is measured from 50 to 18,000 cps. The frequency response of the transmitter is mainly determined by the quality of the audio-frequency components used in the modulator section of the exciter. The RF circuits following the reactance tube modulator and the master oscillator have no appreciable effect on frequency response. The exciter needs only three tuned stages to get up to the final output frequency in the FM broadcast band.

Nonlinearities of the phase-vs.-frequency curve of the tuned circuits create harmonic distortion. The degree of distortion depends upon the degree of nonlinearity. The

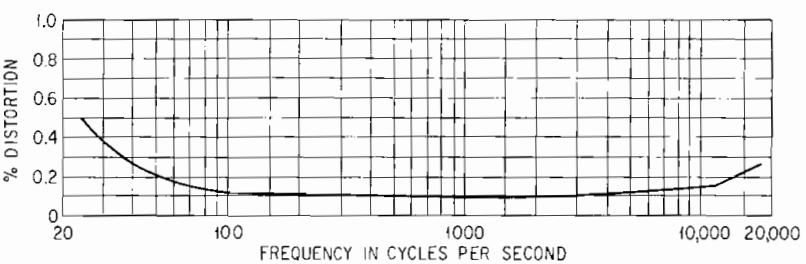


FIG. 2-42. Typical distortion characteristic.

distortion can differ greatly at different audio frequencies, and it is, of course, dependent on the percentage of modulation. To a lesser degree, distortion is also created by improper amplitude response of the tuned circuits, but under practical conditions this can be disregarded. It should be remembered that in order *to get the ultimate* of low-distortion output from any FM transmitter (or receiver), all tuned stages should be tuned for minimum distortion, employing a distortion analyzer as an indicating device.

Figure 2-42 gives typical performance data of a BTF-5B transmitter for harmonic distortion. The distortion is so low that the limit of accuracy of the measuring device is of the same order of maguitude.

The AM noise level is −57 db with reference to the carrier voltage, and the FM noise level is −69 db.

Coupled with RCA's new broadband FM antennas, the BTF-5B transmitter can provide effective radiated powers from 4 to 60 kw. The entire chain meets all current FCC and industry standards.

Part 3

TV BROADCAST TRANSMITTERS

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INTRODUCTION

Once a television scene has been reduced to an electrical signal with the necessary synchronizing information included for proper reproduction, it becomes necessary to deliver the composite signal to the receiver in the home. It is customary to take the composite signal and send it out as high-frequency electromagnetic information to be received and decoded by a television receiver.

In order to eliminate the confusion of signals which would occur if there were no control or regulation of what frequencies to use for television transmission, the government, through the Federal Communication Commission, has set up certain rules and regulations for governing the service.

From a study of the Federal Communications Commission's Rules and Regulations, it is seen that the visual portion of the signal is an amplitude-modulated RF signal while the aural signal is a frequency-modulated RF signal. Because of the great demand for portions of the frequency spectrum, the FCC has set aside many television channels of 6-Mc bandwidth. The visual and aural signals must fit into the 6-Mc bandwidth with their carrier frequencies separated by 4.5 Mc. Because of the different types of modulation and the slightly different frequencies required, it has become the practice to use separate transmitters for the aural and visual signals, with the over-all transmitter power rating being the synchronizing peak power of the visual transmitter. The aural-transmitter power rating must be from 50 to 70 per cent of the visual synchronizing peak power.

For convenience of discussion the composite transmitter will be divided into the visual transmitter, the aural transmitter, the rectifiers and regulated power supplies, and the control circuitry.

VISUAL TRANSMITTER—BASIC CIRCUITRY

The visual transmitter can be broken down into the various functional parts shown in Fig. 3-1.

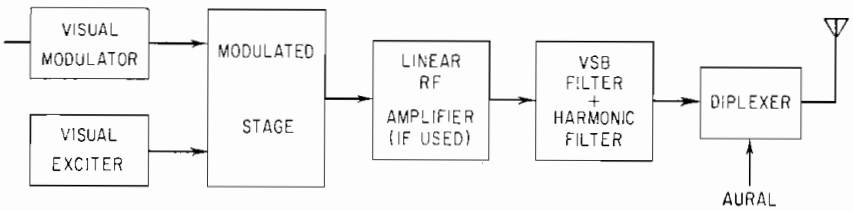


FIG. 3-1. Block diagram—visual transmitter.

Visual Modulators

The prime purpose of the visual modulator is to take the composite video signal of approximately 1 volt peak to peak and amplify it to a level sufficient to modulate the visual RF carrier and to establish a d-c reference to control the modulation of the RF in direct relation to the brightness level of the video signal.

The following factors must be considered in any visual modulator:

1. Input signal level. At least 0.8 volt for full modulation, with the modulator continuing to operate on signals as small as 0.5 volt peak to peak.

2. Signal output to modulated stage. Dependent upon tube and method used for modulation, with grid modulation being the most common and thus requiring synchronizing positive output.

3. Load impedance. Usually highly capacitive.

4. Bandwidth. Usually in excess of 6 Mc to assure minimum time delay of the high-frequency picture detail referred to the low-frequency information.

5. Direct current insertion. This is the d-c level of the signal blanking and is a function of the modulation method and the tube in which modulation takes place.

6. Additional features. Synchronizing pulse stretch, white clip, and linearity-correction circuits.

Since the video amplifiers are the most important parts of the visual modulator, special attention should be given them in the original design to assure optimum performance. With several video amplifiers in series, it is best to assure a uniform over-all amplitude-vs.-frequency response by designing with excessive bandwidth, using the equations for maximum flatness. The extra bandwidth eliminates bandpass limitation from cascading stages and assures a uniform time delay through the amplifiers of the critical frequencies. A bandwidth per stage of 7 Mc is a reasonable design figure for a visual modulator.

Most video amplifiers in present-day modulators employ pentodes and can be designed using equations based on a simple uncompensated stage (see Fig. 3-2). From an inspection of Fig. 3-2*b* it is seen that the amplitude of the output signal will fall off at both the high frequencies and the low frequencies owing to the shunt

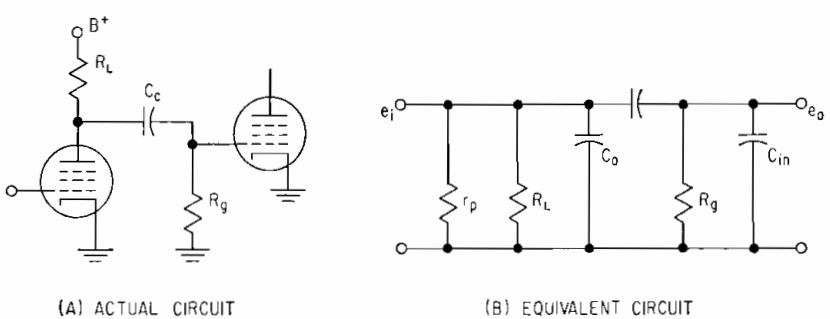


FIG. 3-2. Typical video amplifier—uncompensated.

capacities and the coupling capacitor, respectively. Figure 3-3 shows Fig. 3-2*b* further simplified.

Since there are two distinct regions of the simple video amplifier passband which suffer attenuation, two methods of compensation are necessary.

For convenience, consider the equivalent circuit of a pentode amplifier shown simplified in Fig. 3-3. Figure 3-3*a* shows that the load impedance is simply R_L and

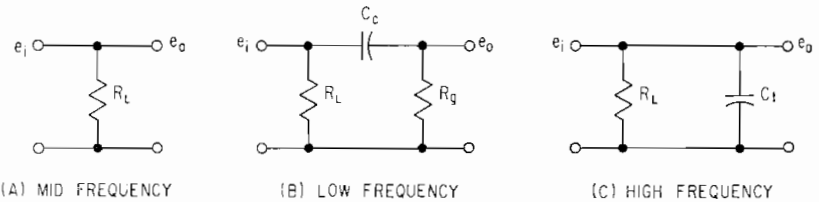


FIG. 3-3. Equivalent circuits of Fig. 3-2*b*.

as such is called the mid-frequency case, that case in which both low- and high-frequency attenuation effects can be neglected. Therefore, the gain of this amplifier is simply

$$\text{Voltage gain} = g_m R_L$$

As the information frequency passing through the amplifier is decreased, the coupling capacitor impedance increases, allowing less and less signal voltage to reach the grid of the next tube. In practice, R_g is made as large as the tube will allow, generally 0.5 megohm, while the coupling capacitor is usually made about 0.5 μf. Then, referring to Fig. 3-3*b*, it is seen that the low-frequency gain is

$$\text{Voltage gain} = \frac{g_m R_L R_g}{R_L + R_g - X_{cc}}$$

If it is decided to extend the low-frequency response, a form of low-frequency compensation can be incorporated which tends to counterbalance the term

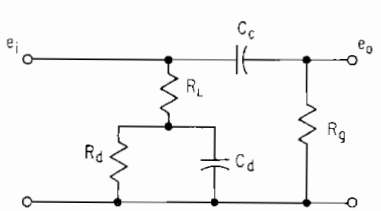


FIG. 3-4. LF compensated equivalent circuit.

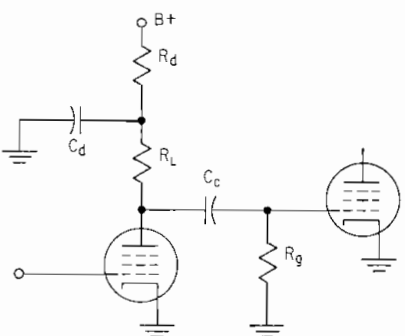


FIG. 3-5. Practical circuit of Fig. 3-4.

$R_g/R_L + R_g - X_{cc}$. The equivalent circuit of Fig. 3-4 appears as a slightly modified circuit as shown in Fig. 3-3*b*. Optimum results are obtained if

$$\frac{R_d R_L}{R_d + R_L} C_d = R_g C_c$$

As the information frequency passing through the amplifier is increased, the shunt capacity C_t of Fig. 3-3*c* steadily decreases the total load impedance, resulting in the gain of the amplifier decreasing with increasing frequency. The obvious approach to improve the bandwidth is to use low-capacity tubes and to minimize wiring capacities, but when this approach has been exhausted, the following forms of high-frequency compensation can be used.

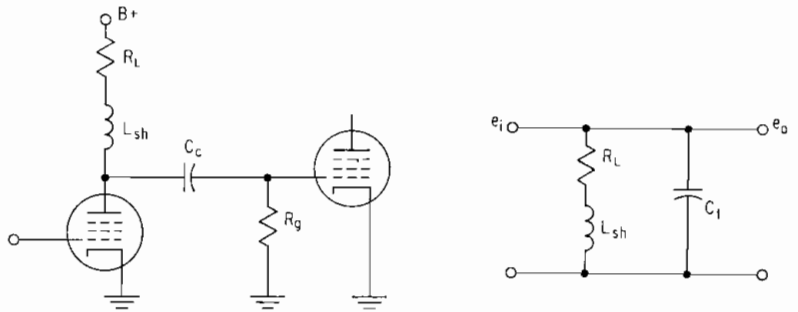


FIG. 3-6. Shunt compensation.

For a moderate amount of bandwidth extension, shunt compensation is commonly used as shown in Fig. 3-6.

As a compromise between maximnm flatness and uniform time delay,

$$L_{sh} = \frac{0.44R_L}{W_h}$$

where L_{sh} = shunt peaking inductance
R_L = load resistance
W_h = 3-db point on high-frequency side of uncompensated amplifier

A second form of high-frequency compensation, called series peaking, is shown in Fig. 3-7. While a great deal of trial and error is used in the selection of the correct value of L_{se}, the following design equations can be used as an approximation:

$$L_{se} = 0.67C_tR_L^2$$

$$R_L = \frac{1.5}{W_hC_t}$$

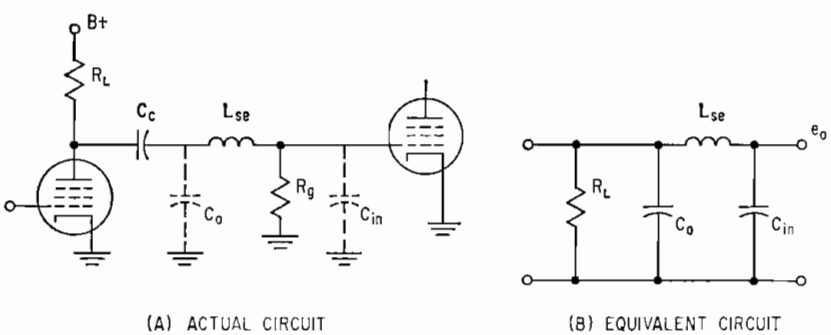


FIG. 3-7. Series peaking compensation.

where $C_{in} = 2C_o$

where C_o = plate output capacity of amplifier
C_{in} = grid input and wiring capacity of next stage
$C_t = C_o + C_{in} + C_{\text{wiring}}$

A third method of compensation is a combination of both shunt and series peaking and takes the form shown in Fig. 3-8. This form also takes some trial-and-error selec-

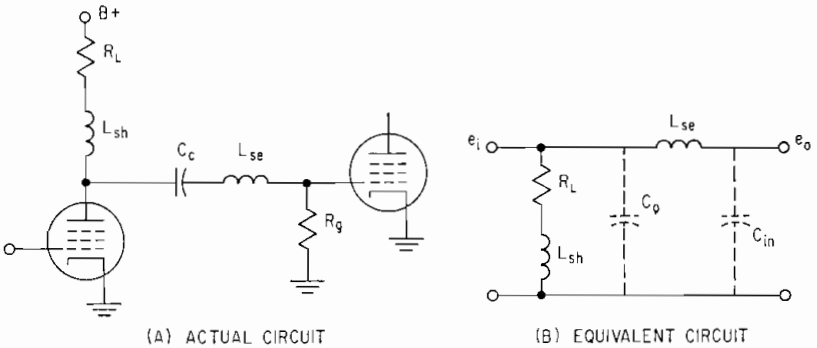


FIG. 3-8. Series shunt compensation.

tion for the proper component values, but the following design equations can be used for a good approximation:

$$R_L = \frac{1.8}{W_h C_t}$$

$$L_{sh} = 0.12 C_s R_L^2$$

$$L_{se} = 0.52 C_t R_L^2$$

where $C_t = C_o + C_{in} + C_{\text{wiring}}$
L_{sh} = shunt peaking inductance
L_{se} = series peaking inductance
R_L = equivalent load resistance
W_h = 3-db point on high-frequency side of uncompensated amplifier

While there are other forms of video compensation used either to increase the amplifier bandwidth or to increase the gain for a given bandwidth, the above forms of compensation are the most commonly used. At all times, component layout and lead length of interconnections are important and to a degree determine the final component values used in the compensated amplifiers. In practical amplifier circuits the peaking coils are generally made variable to compensate for variations occurring in circuit capacities between various units being manufactured.

Once the video amplifiers have been used to obtain the desired voltage gain and signal polarity, the signal must be sent to the modulated stage. Since most modulated stages have high input capacitance, the modulator output stage must be capable of operating into large values of capacitance while supplying a video signal unhampered by whatever grid conduction takes place in the modulated stage.

Although an anode follower is sometimes used when no grid conduction of the modulated stage occurs, some form of cathode follower is generally used. For relatively small signal outputs a simple cathode follower is used, but with large ontput signal requirements a more elaborate circuit is required. The circuit shown in Fig. 3-9*a* is commonly used. For the lower frequency components of the signal, the circuit of Fig. 3-9*a* acts like a simple cathode follower as in Fig. 3-9*b*. For the high-fre-

quency components of the signal, when C_{in} has difficulty discharging on the negative portion of the cycle, the circuit appears as that shown in Fig. 3-9c.

One way of analyzing the action of the stage is to consider that the circuit is acting as a cathode follower for low frequencies and as a switching circuit for high frequencies. For positive-going signals, V_1 of Fig. 3-9 charges C_{in} at a rapid rate, and for

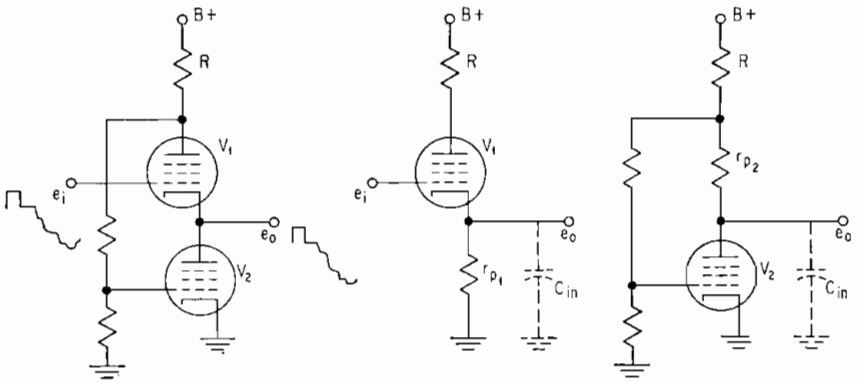


FIG. 3-9. A modulator output stage.

negative-going signals, V_1 acts as a high impedance. A signal sampled from R to the grid of V_2, however, is positive and switches V_2 into heavy conduction to discharge C_{in} at a rate rapid enough to keep pace with the output signal. For purposes of gain determination, the circuit gain of a simple cathode follower can be used, meaning that the maximum voltage gain approaches unity.

In addition to the modulator requirement of amplifying the video signal and sending it to the modulated stage, there is also the requirement of inserting a d-c component into the signal. This d-c insertion is required, since the pedestal level and

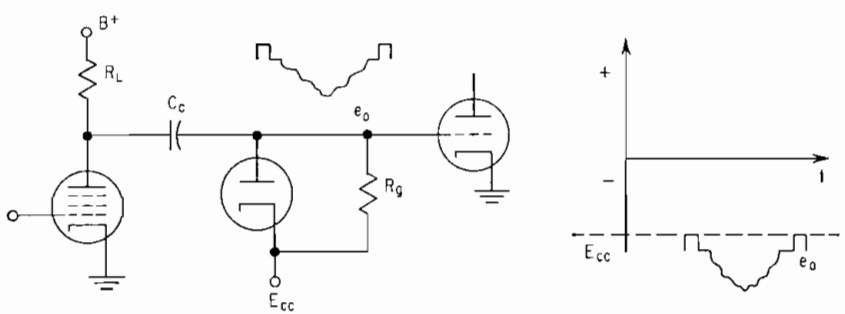


FIG. 3-10. Diode clamp.

the synchronizing peak level must remain at constant power output levels regardless of signal content (whether mostly black or mostly white picture). Since a d-c component is necessary, there are two commonly used methods of inserting direct current. The most simple method is that of using an ordinary diode clamp as shown in Fig. 3-10. Referring to Fig. 3-10, the grid of V_2 is always biased to $-E_{cc}$ through re-

sistor R_g. Each time the signal attempts to go more positive than $-E_{cc}$, the plate of the diode tends to become more positive than its cathode and conduction occurs; this causes the diode to appear as a short circuit and causes the synchronizing peak to always be at $-E_{cc}$. The ability of this clamp to hold synchronizing peak at $-E_{cc}$ under all conditions of signal content is limited by the diode impedance under con-

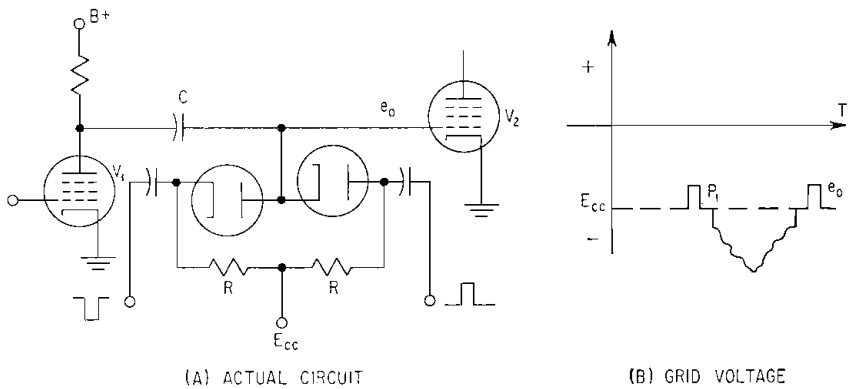


FIG. 3-11. Keyed clamp.

duction. Generally, some degradation occurs in the vertical interval pulses because the energy content is different from the energy of the horizontal synchronizing pulses.

A second type of clamping circuit commonly used for establishing a d-c reference on the composite video signal is called a driven or keyed clamp and is shown in Fig. 3-11.

The circuit shown in Fig. 3-11 consists of a dual diode arranged in a balanced-bridge circuit. At the instant the two keying pulses occur, the two diodes are forced into conduction, placing the grid circuit of V_2 at $-E_{cc}$ during the clamping interval. Once the clamping or keying pulses have ceased, the video signal is free to travel in both a positive and a negative manner about E_{cc}. This clamping is usually set to

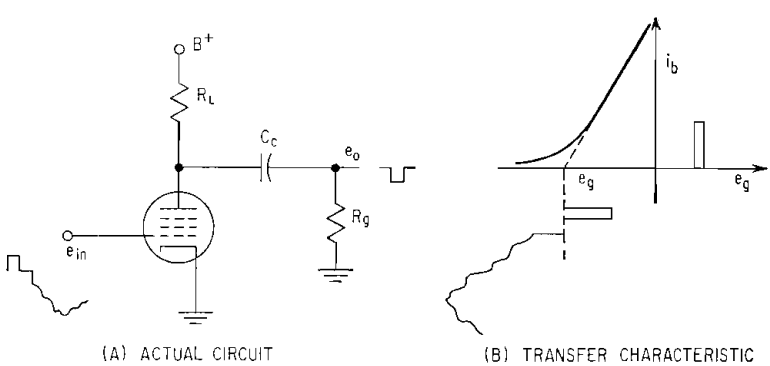


FIG. 3-12. Sync separator.

occur at P_1, which is the back porch of each horizontal synchronizing pulse, and this ensures a solid clamping action regardless of signal content (whether all white or all black).

In order to use the keyed clamp circuit of Fig. 3-11, keying pulses must be generated. This generation is usually accomplished by using standard synchronizing

pulses derived from the video signal, using a synchronizing pulse-separator circuit such as that shown in Fig. 3-12.

Once the synchronizing pulses have been derived from the composite signal, as shown in Fig. 3-12, the keying pulses are generally derived by either of two methods: a differentiating circuit or a shorted delay line. Figure 3-13 shows a differentiating circuit for deriving keying pulses.

Referring to Fig. 3-13, it is seen that both a negative and a positive spike are obtained from the differentiating circuit, and either can be used for keying pulses. The

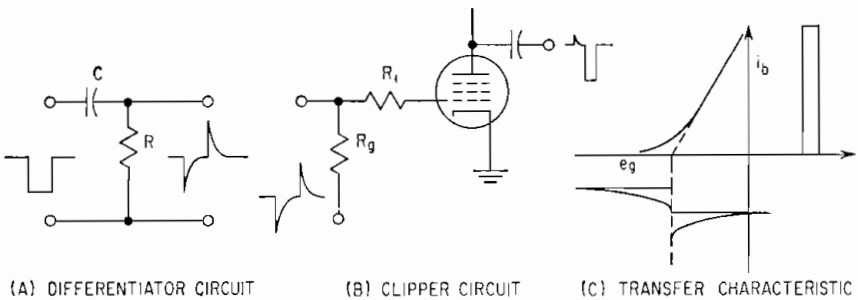


FIG. 3-13. Differentiator key derivation.

first spike can be used for clamping on synchronizing peak, while the second can be used to back porch clamp and is used more commonly in present-day operation. The simple limiter of Fig. 3-13 is biased so that the first spike is below cutoff and is thus discarded, while the second pulse is limited by R_1 when grid current tends to flow, resulting in a keying pulse.

Figure 3-14 illustrates another method of obtaining keying pulses from synchronizing pulses. A shorted delay line acting as a reflecting circuit gives both a positive and a negative pulse equal in width to twice the electrical length of the delay line. In practice, the delay line has an electrical length between 0.5 and 1 μsec, resulting in a keying pulse width from 1 to 2 μsec. A limiter similar in nature to that of Fig. 3-13*b* is used to select the desired pulse. The advantage of this method is that it takes less signal voltage to derive the keying pulses than the differentiator circuit of Fig. 3-13*a* and is less sensitive to tube-capacity and signal-level changes.

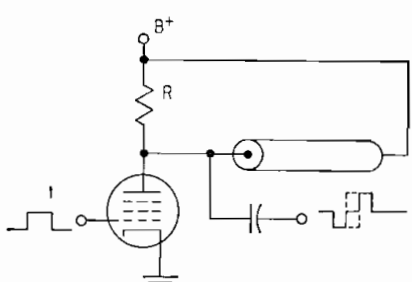


FIG. 3-14. Shorted delay line key derivator.

As an added feature, some transmitters have incorporated in the visual modulators white clippers that limit the depth of modulation in order to prevent intercarrier noise resulting from overmodulation. The circuit of Fig. 3-15 is typical of white-clipper circuits. Whenever the plate voltage of Fig. 3-15*b* goes below E_1, the diode ceases to conduct, preventing e_0 from going more white and effectively limiting the depth of visual modulation.

For purposes of increasing the over-all linearity of the transmitter, black-and-white stretchers are sometimes incorporated in one of the video amplifiers of the visual modulator. The circuit shown in Fig. 3-16*a* is commonly used.

In general, R_k furnishes degeneration for the stage. When e_k goes to a voltage below E_1, CR_1 conducts, causing the effective cathode resistance to be reduced, resulting in less circuit degeneration and higher voltage gain. Likewise, when e_k goes

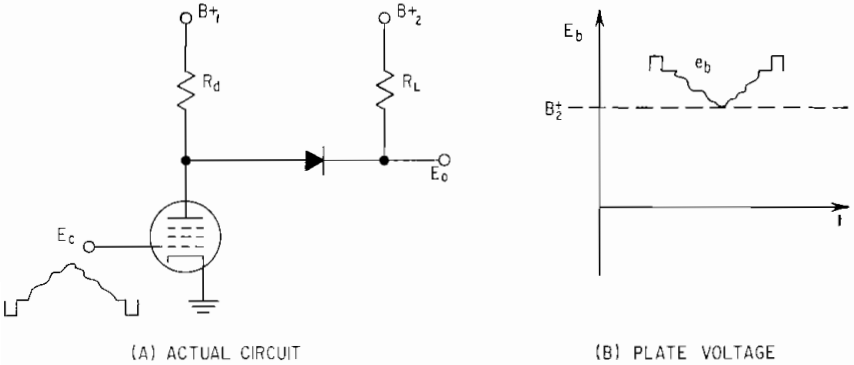


FIG. 3-15. White clipper.

above E_2, CR_2 conducts again, reducing the degeneration. The plate output signal appears as the e_0 waveform of Fig. 3-16*a* with the stretching having occurred on the shaded areas.

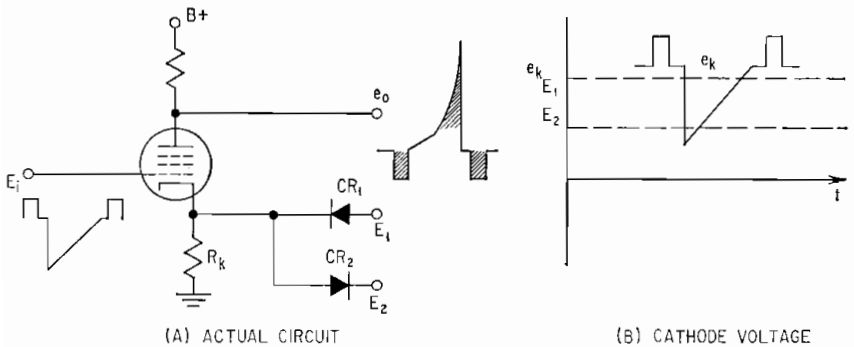


FIG. 3-16. Stretcher circuits.

Visual Exciter

The visual exciter supplies the carrier-frequency signal to the modulated stage at the proper frequency and at the necessary power level.

Because of the accurate frequency control necessary to meet the FCC requirements on the frequency stability, the oscillator generating the frequency will be crystal-controlled and it can be similar to the Colpitts oscillator shown in Fig. 3-17.

It is common practice to make the crystal-controlled oscillator function at some submultiple of the final frequency and then to frequency-multiply to arrive at the final carrier frequency. For Channel 2 operation, where the visual carrier frequency is 55.25 Mc, a frequency-multiplication factor of 12 has been used, necessitating a crystal-oscillator operation at precisely 4.60417 Mc. The indicated precision is necessary, since the crystal tolerance must be

$$\text{Crystal tolerance} = \frac{\text{FCC tolerance}}{\text{multiplication factor}}$$

$$= \frac{\pm 1{,}000\ (\text{FCC tolerance})}{12} = 83.3 \text{ cps}$$

This 83.3-cps tolerance must include all sorts of drift such as that which arises from temperature changes and short-term variations of the crystal.

Once the fundamental frequency has been generated, there remains the problem of multiplication. If the required multiplication is 12, then two doublers and a tripler will be necessary.

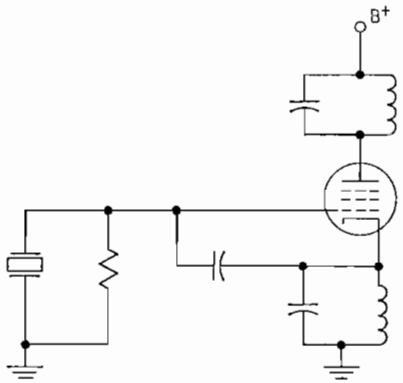


FIG. 3-17. Visual exciter crystal oscillator.

As seen in Fig. 3-18, multiplication results in the generation of many frequencies. To prevent the appearance of undesired frequencies, the multiplier stages should have highly selective tuned-circuit elements. These tuned-circuit elements often take the form of double-tuned inductively coupled circuits for maximum selectivity, and they are generally tuned and coupled for a condition slightly less than critical coupling.

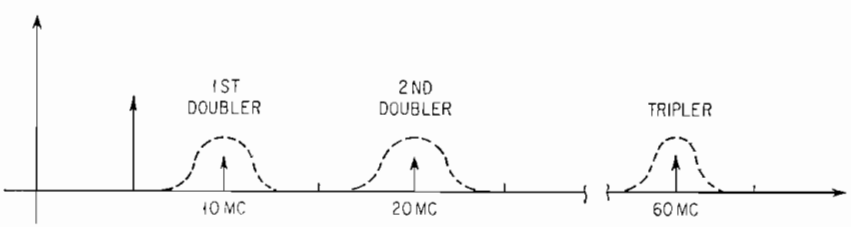


FIG. 3-18. Frequency-multiplication spectrum.

Once the proper carrier frequency has been obtained, there remains the task of amplifying the carrier signal to the level required by the modulated stage. Class C amplifiers are used for the amplification, with the necessary c-w power being a function of the type of modulation used and the level of modulation.

Modulated Stage

The modulated stage is one of the most important parts of the visual transmitter, since it must perform the function of converting the video signal to an amplitude-modulated RF signal with a minimum of amplitude or phase distortion. Although various methods have been used for modulating the visual transmitter, practice has settled on grid modulation for best performance, with either low-level or high-level modulation being used.

Low-level modulation deals with low-level signals and takes the form of square-law-type modulation or power modulation operating at a low power output. When low-level modulation is used, it is necessary to have several stages of wideband amplification in order to arrive at an output power which is useful in commercial

operation. This requirement of several stages of power amplification must be balanced against the savings made in lower power visual modulators and exciters.

The square-law-type modulator can best be understood by reference to Fig. 3-19, which shows both the general circuit configuration and the transfer characteristic. From the general circuit configuration it is seen that the grid signal is composed of both video direct current coupled from the visual modulator and the carrier signal alternating current coupled from the visual exciter. The grid signal is essentially a low-level RF signal together with a slowly varying bias consisting of the video signal. The stage then acts as a Class A RF amplifier. Since the transfer characteristic is nonlinear, the gain will not be a constant but will be a function of the bias or of the

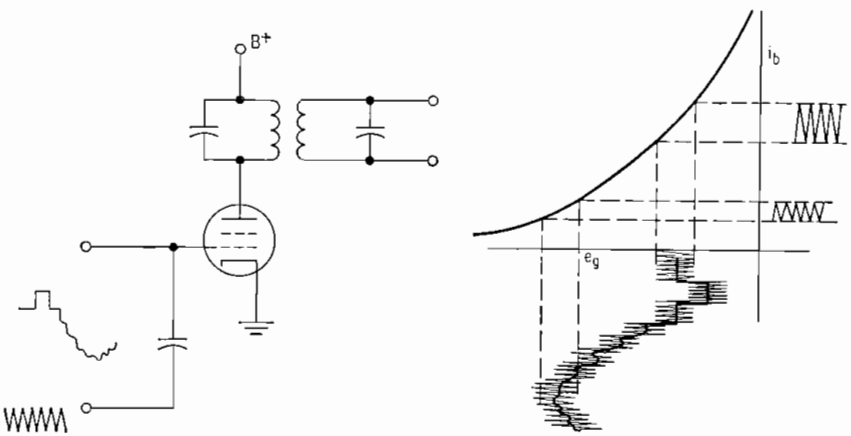


FIG. 3-19. Square-law-type modulation.

video signal. For the proper degree of modulation the circuit shown must have a linear gm variation of 10 to 1 between synchronizing peak and reference white, since the RF voltage gain of the stage is

$$\text{Voltage gain} = gmZ_L$$

where gm = transconductance
Z_L = load impedance

A power-modulated stage is similar to the modulated stage shown in Fig. 3-19, except that it operates on the assumption of a linear transfer characteristic. The general circuit is that shown in Fig. 3-20*a*, with the transfer characteristic shown in Fig. 3-20*b*.

Again, the grid signal consists of an RF signal a-c coupled from the visual exciter and a slowly varying bias voltage which is the video signal d-c coupled from the visual modulator. In this case, the video voltage generally has a peak-to-peak amplitude equal in magnitude to the projected cutoff bias voltage, with a d-c reference

$$E_{cc} = \text{d-c insertion} - E_k$$

$$\cong 1.3E_{\text{cutoff}} - E_k$$

where E_k = cathode voltage of pedestal level
d-c = pedestal insertion voltage from visual modulator

The RF level is such that the peak-to-peak RF is at least twice the peak-to-peak video level, or

$$\text{RF voltage} \geq 2E_{\text{video}}$$

$$\geq 2E_{cc}$$

As seen in Fig. 3-20*b*, the stage operates as a simple Class B RF amplifier at the synchronizing peak level and as a Class C RF amplifier at the reference white level, resulting in an RF signal output linearly amplitude-modulated according to the grid video signal. Since the transfer characteristic is not linear near the cutoff region, an improvement in linearity can be had by using some cathode video degeneration.

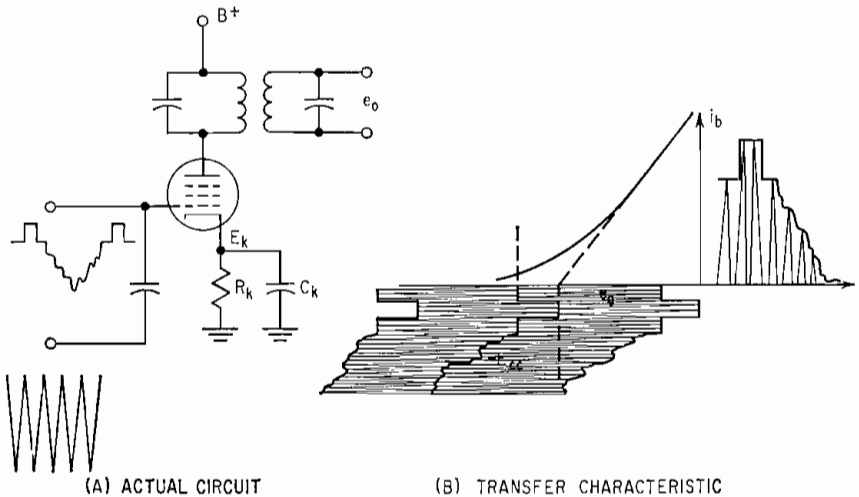


Fig. 3-20. Power modulator.

In general, most tubes used in modulated stages require a grid circuit which has a frequency response at least twice that of the modulating frequencies. This requirement becomes a necessity as grid conduction takes place.

Neutralization is extremely important, since the possible depth of modulation is affected by the feed-through RF, thus influencing the modulation linearity and the differential phase shift.

Wideband and RF Amplifiers

In order to transmit the required frequency components of a television signal, the RF circuits through which the modulated RF signal passes must be wideband to pass the modulating frequencies uniformly out to at least 4.2 Mc.

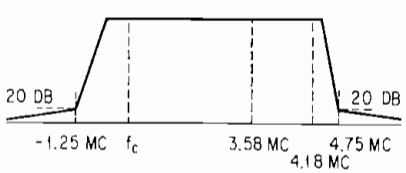


Fig. 3-21. FCC bandpass.

The bandpass of Fig. 3-21 shows the requirement of the FCC and serves as a guide for wideband-amplifier design.

From an observation of Fig. 3-21 it is seen that the required RF bandpass is approximately 5 Mc wide. This required bandwidth and the tube capacities usually determine what power output can be obtained from a given tube. Since the majority of wideband amplifiers used in television transmitters employ double-tuned circuits, the equation of Fig. 3-22 relates the bandwidth and the tube capacities to the effective load impedance for slightly overcoupled circuits.

Once the effective load impedance that is realizable from the proper consideration of the tube capacities and the bandwidth needed is known, it is possible to estimate the tube power capabilities on the basis of a Class B RF tuned amplifier. The con-

stant-current curves are generally most useful for determining the tube operation (Fig. 3-23).

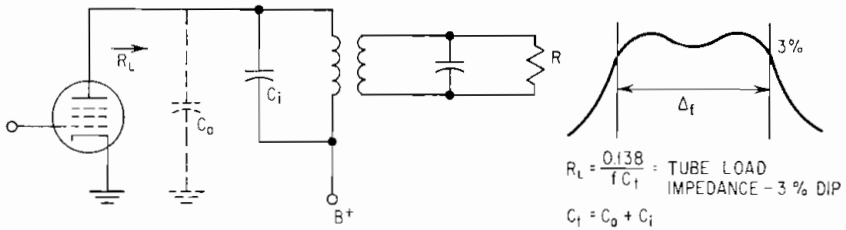


FIG. 3-22. Double-tuned circuit.

Based on the assnmption of a Class B linear circuit with the plate current flowing in half-wave-rectified sine waves, the following equations hold as a first approximation:

$$P_{out} \cong \frac{(E_{bb} - E_{min})I_{max}}{4} \qquad \text{assumes negligible idle current}$$

$$P_{outS.P.} \cong \frac{(E_{bb} - E_{minS.P.})I_{maxS.P.}}{4} \qquad \text{point } A \text{ sync peak power output}$$

$$P_{outP.L.} \cong \frac{(E_{bb} - E_{minP.L.})I_{maxP.L.}}{4} \qquad \text{pedestal level power output}$$

$$I_{avg} \cong I_{max}$$

$$R_{eff} \cong \frac{2(E_{bb} - E_{min})}{I_{max}}$$

As a general approximation, the rated plate dissipation of a given power tnbe can be used as an indication of the power-output capability. In wideband operation of 5 Mc, the synchronizing peak output-power capability is approximately equal to the rated plate dissipation for most tubes used in VHF transmitters.

The above method of approximating the tube operation can be used for both the modulated stage and any subsequent RF linear Class B amplifiers. If a more accurate and detailed analysis of the tube operation is desired, resort must be made to an exact method of graphical calculation, which takes into account tube nonlinearities.

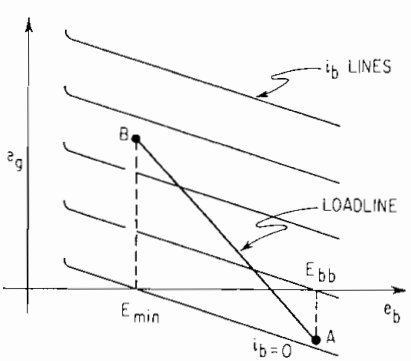


FIG. 3-23. Typical constant-current curves.

Output Circuits

Once the tube circuitry associated with the visual transmitter has been determined, there remains the job of shaping the bandpass to conform to the FCC requirements of adjacent channel interference. The important items are a vestigial-sideband filter, an upper sideband filter, and a harmonic filter, together with a diplexer if separate antennas are not used.

The purpose of the vestigial-sideband filter is that of limiting the lower sideband of the transmitter in order to ensure 20 db of attenuation at frequencies of $f_c - 1.25$

Mc and below. In general, there are two basic types of VSB filters used: constant impedance and nonconstant impedance.

The most simple VSB filter mechanically, and therefore the more economical, is the nonconstant-impedance type, which is usually a transmission-line trap. The equiv-

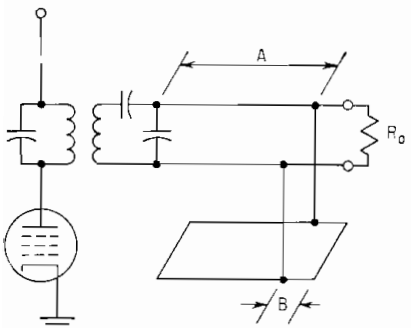


FIG. 3-24. Nonconstant-impedance VSB filter.

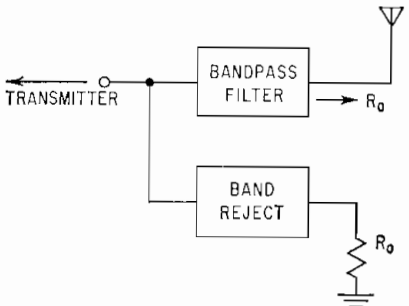


FIG. 3-25. Constant-impedance VSB filter.

alent circuit is shown in Fig. 3-24, and the filter must be tuned in conjunction with the preceding double-tuned circuit of the output tube. Briefly, the trap in the transmission line acts as a sharply tuned trap to form the sharp rate of attenuation shown in Fig. 3-21. The spacing A of Fig. 3-21 is such as to rotate the reflected impedance of the trap to match and cancel the double-tuned impedance below $f_c - 1.25$ Mc, while the spacing B controls the cutoff sharpness. The over-all result is that of presenting to the tube a wide bandpass determined by a triple-tuned circuit. The circuit can be easily tuned or adjusted without special test equipment other than a RF sweep generator.

A constant-impedance sideband filter is simply what its name implies. It has a constant input impedance across the frequency range concerned and, as such, is not primarily a part of the tube output circuit. Figure 3-25 shows functionally one type of constant-impedance filter. Operationally, this type of filter is composed of a bandpass filter which has, shunting its input side, a band reject filter so tuned that the two filters complement each other, thus presenting to the transmitter a constant-impedance resistive load. This filter is usually more costly, and it normally requires more skilled personnel for its alignment. Constant-impedance filters can take other

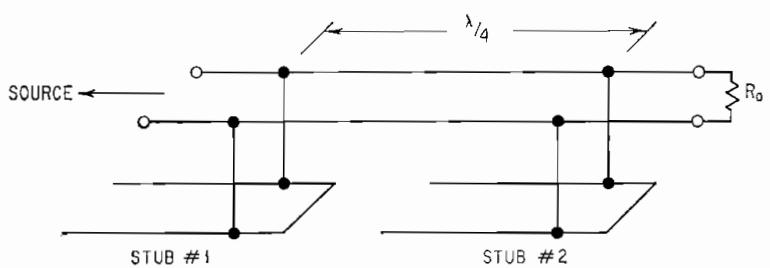


FIG. 3-26. Subcarrier trap.

forms, such as, for example, the use of two bandpass sections so phased that the filter presents a constant resistance to transmitter.

The subcarrier trap, $f_c - 3.58$-Mc trap, used to remove the lower color-subcarrier sideband is sometimes made a part of the VSB filter and at other times is a separate

filter in the antenna transmission line. When the trap is in the transmission line, it can be similar to that shown in Fig. 3-26. Stubs 1 and 2 are such as to be series resonant at f_v – 3.58 Mc and are spaced electrically $\lambda/4$ apart at f_c to have their reflected reactive components cancel at the actual carrier frequency.

The upper-sideband filter is generally a video-frequency low-pass filter with 20-db attenuation starting at 4.75 Mc.

The harmonic filter is of the transmission-line variety which can take the form of either a bandpass filter or a low-pass filter. Whenever it is desired to feed a single antenna with both aural and visual transmitters, some form of diplexer is necessary. A bridge diplexer is used to feed batwing antennas, while a "slot" diplexer can be used to feed an antenna such as a helical, which requires a single-line feed only.

AURAL TRANSMITTER—BASIC CIRCUITRY

Since the aural transmitter is basically a FM transmitter and is covered in another chapter, this portion will be touched upon very lightly.

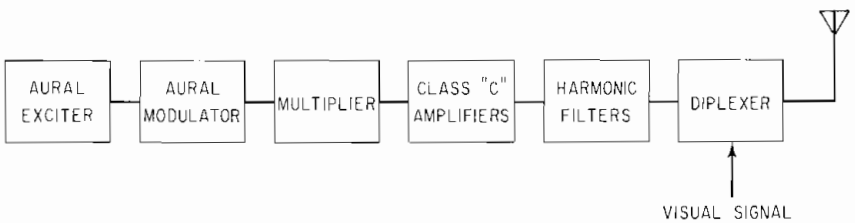


FIG. 3-27. Block diagram—aural transmitter.

Figure 3-27 is a block diagram of the aural transmitter, basically separate from the visual, and shows its functional parts.

Aural Exciter

The aural exciter generates and determines the frequency, which, after suitable frequency multiplication, serves as the aural carrier or center frequency.

Those equipments employing phase modulation to achieve the FM signal use a separate crystal oscillator to derive the basic frequency signal. With a crystal-controlled oscillator it is possible to achieve the degree of accuracy needed to place the final aural carrier or center frequency 4.5 Mc above the visual carrier frequency.

In general, when using a phase-shift type of modulator, the frequency at which the oscillator operates is selected on the basis of many considerations. The selection of the frequency is a compromise based on the optimum frequency for phase-shift modulation, considering the low-frequency distortion allowable and the amount of frequency multiplication necessary to achieve the required frequency deviation. The optimum crystal-oscillator frequency is between 100 and 200 kc for Channels 2 through 83, with the low VHF channels using a nominal 100-kc frequency and the other channels using a norminal 200 kc.

For those aural transmitters that use a reactance-tube modulator, the basic oscillator is not crystal controlled, since the oscillator frequency must be made to vary in accordance with the audio modulation to produce the desired FM signal. Since the center frequency is not directly crystal controlled, some means must be provided to maintain the center frequency at the desired or assigned frequency. This center-frequency control is generally accomplished by sampling the output signal, frequency-dividing it down, and then comparing the resulting signal with a known crystal. The error in frequency or phase is then fed back as a correction signal to the oscillator.

Aural Modulator

Two types of frequency modulation are commonly used in aural television transmitters: one is direct frequency modulation using a reactance tube modulator, and the other is phase-shift modulation which is converted to frequency modulation by means of filters and limiters.

In the reactance-tube modulator, direct frequency modulation takes place by having the reactance of the oscillator vary at an audio rate to cause the oscillator frequency to deviate the required amount to achieve a maximum frequency deviation when the audio signal is a maximum. Figure 3-28 shows a simplified reactance-tube modulator.

In the reactance-tube modulator the basic oscillator is a free-running oscillator whose center frequency of oscillation is determined by the total tuned-plate impedance of the oscillator. If the frequency of oscillation is to vary, it will be necessary somehow to change the reactance of the oscillator output circuit. In order to pro-

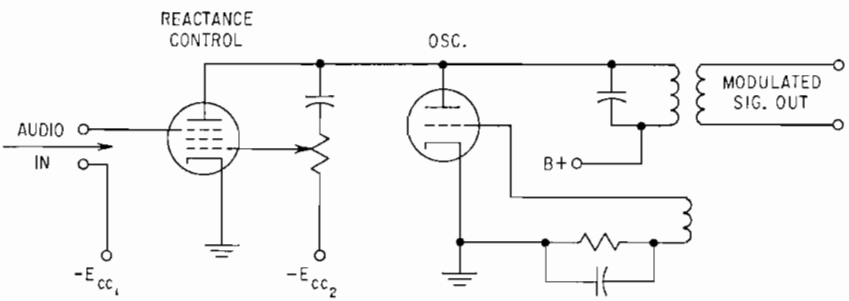


Fig. 3-28. Simplified reactance-tube modulator.

duce an apparent change in the reactance of the oscillator circuit, a sample of the output can be taken through a RC network to derive a current 90° out of phase with the tank voltage. This 90° current can then supply a grid voltage to the reactance tube in such a manner as to cause the reactance tube to supply a 90° current component to the oscillator tank. If the 90° reactance-tube current is then varied at an audio rate, the result is an oscillator output which varies in frequency at an audio rate.

While this is a relatively simple method of obtaining FM modulation, the problem of maintaining the center frequency within the required limits is complicated by the fact that the oscillator is not directly crystal controlled. To achieve the required center-frequency stability it is, therefore, necessary to sample the modulated output frequency and to divide down to some low frequency for comparison purposes with a crystal-controlled reference oscillator. Both the divided frequency and the crystal reference frequency are beat together, with their difference frequency or phase error used as a control signal to be fed back to the main oscillator as a correction factor.

The other commonly used method of obtaining FM is to employ a phase modulator which, by the use of a proper filter in the audio and limiting of the RF, will result in the desired FM output signal. Of the two familiar types of phase modulators, the type that makes use of the varying-amplitude trapezoid is most often used in television transmitters.

A crystal-controlled oscillator supplies the center frequency for the clipped sawtooth-phase modulator. The crystal frequency is used to drive a sawtooth generator which is clipped into a trapezoid at different levels, depending upon the level of the audio signal. Once the clipped trapezoids have been derived, the signal is sent through a differentiating circuit, which results in a position-modulated signal varying at an audio rate. Once the position-modulated signal is derived, a simple series of

frequency multipliers and limiters are used until the desired final frequency is achieved with the proper frequency deviation.

Figure 3-29 shows an ideal sawtooth which is to be clipped. Referring to Figs. 3-29 and 3-30, it is seen that the maximum phase shift possible is 2π radians or 360°. Practically, something less than 2π radians can be achieved because the sawtooth does

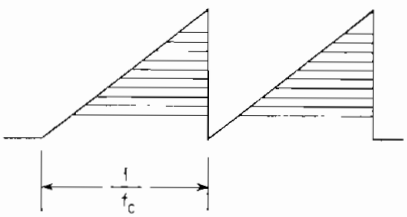


FIG. 3-29. Clipped trapezoid.

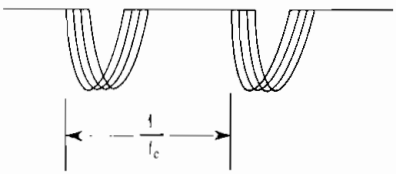


FIG. 3-30. Position modulator.

require a definite rise time. From the knowledge of the maximum phase shift obtainable or to be used, the following relations determine the frequency multiplication and the crystal frequency at which the phase modulation occurs.

$$\Delta f_1 = m f_m$$

where m = radians swing at the crystal frequency
f_m = audio-modulating frequency
Δf_1 = maximum frequency swing from center or crystal frequency

$$M = \frac{\Delta f_2}{\Delta f_1}$$

where M = multiplication factor to achieve required swing at final carrier or center frequency
Δf_2 = maximum frequency swing around carrier or center frequency

$$f_{cr} = \frac{f_{ca}}{M}$$

where f_{ca} = aural center frequency
f_{cr} = crystal frequency

In order to process the signal from phase modulation to frequency modulation, it is necessary for the audio amplitude-vs.-frequency response to have a drooping response, so that f_1 is a constant with change in audio frequency. This attenuation rate must be $m = k/f_m$, so that $\Delta f = m f_m = k f_m / f_m = k$.

The FCC specifies that pre- and deemphasis be used in aural transmitters and receivers, respectively, in order to obtain a more favorable noise situation. The preemphasis of 75 μsec uses a simple reactance-resistor circuit which is placed in the audio circuit.

Frequency Multipliers

Once the desired modulation has been achieved, it is necessary to use frequency multipliers to arrive at the final aural center frequency. This frequency multiplication can consist of straight multiplication or a combination of multiplication and heterodyning. If other than straight frequency multiplication is used, due consideration must be given to the proper Δf_1 at the crystal or modulation frequency.

RF Amplifiers

Since an ideal FM signal is a constant-amplitude signal with the intelligence located in the instantaneous frequency, it is possible to use the most efficient type of power amplifier to achieve the desired RF power output to the antenna—Class C amplifiers.

The design of Class C amplifiers is reasonably well known; therefore, this subject will be touched upon very briefly.

Since the object of using Class C amplifiers is to achieve maximum power output together with maximum plate efficiency, the preliminary work should be done on a set of the manufacturer's tube curves, preferably the constant-current curves. Using the constant-current curves, it is possible to determine the tube and circuit performance by the use of graphical integration. Once the d-c and fundamental voltages are found, the following relations hold:

$$\text{Power input } (P_{in}) = E_{bb}I_b$$

where E_{bb} = supply voltage
I_b = direct plate current

$$\text{Power output } (P_o) = \frac{E_0 I_{pl}}{2}$$

where I_{pl} = RF fundamental current (peak)

$$R_L = \frac{E_0}{I_{pl}}$$

where R_L = impedance presented to tube
E_0 = fundamental frequency-voltage component (peak)

$$\text{eff} = \frac{P_o}{P_{in}}$$

The tuning of the Class C amplifiers is simple and is done with the normal circuit meters.

1. Tune the plate circuit for a minimum d-c plate meter reading. This minimum meter reading indicates a maximum R_L for the most practical case where the tank circuit Q is reasonably high.

2. The grid circuit d-c ammeter will indicate a maximum if the grid circuit is properly tuned and coupled, provided, of course, that the tube normally draws grid current. (This presupposes that the stage is sufficiently neutralized.)

The FCC specifies that the output power shall be determined by the indirect method, using the efficiency factor determined by the equipment manufacturer.

$$P_o = E_{bb}I_bF$$

where E_{bb} = plate supply voltage
I_b = direct plate current
F = efficiency factor

The direct method of measuring power can be used for checking the power output and the efficiency factor. The direct method uses some type of dummy load for the antenna with a calibrated meter indicating watts output to the load. Since an antenna and a dummy load may present slightly different load impedances, it is necessary to have equal I_b meter readings for both cases. Equal I_b readings generally require a slight final plate circuit adjustment when moving from the dummy load to the antenna.

RECTIFIER AND REGULATED POWER SUPPLIES

Along with the consideration given to the proper audio, video, and RF circuits, equal care must be taken with the all-important power supplies.

In the visual and aural circuits the choice must be made as to whether or not to use regulated power supplies and whether to use multiphase or single-phase sources. All such decisions, of course, must be made on the basis of an individual design, considering the power rating of the equipment, the hum requirements, the regulation necessary, and so forth.

For television transmitters the economical crossover point for the choice between single-phase and three-phase a-c supplies seems to be the 1-kw output rating.

In general, regulated power supplies are used for visual modulators and screen supplies of the visual RF stages. Unregulated but highly filtered supplies furnish the additional voltages required by visual exciters, aural exciters, aural modulators, and the high voltages for the plate circuits of the RF stages.

In selecting a rectifier circuit, the choice of whether to use rectifier tubes or semiconductors is one which must be made on the basis of economy and performance. For low-voltage circuits it is economical to use germanium or silicon semiconductors, while in high-voltage rectifiers the low peak inverse rating of semiconductors may make it more economical to use mercury or high-vacuum tubes. Likewise, on the basis of performance there is room for making a choice: gas kicks and flash arcs occur in tube rectifiers, while problems can also occur in series semiconductors if they are improperly applied.

If tube rectifiers are used, some form of current protection should be employed to limit any instantaneous overload in current due to arc backs and short circuits. In addition, quarter-phasing of the filaments sometimes improves the current rating of the rectifier tubes in polyphase rectifiers. Reference to Fig. 3-31*a* and *b* will aid in the explanation for the quarter-phasing of voltages in rectifier tubes. When a rectifier tube conducts, the voltage drop across it is relatively small, so that the filament voltage is a significant value in comparison. If both the plate voltage and the filament voltage are in phase, one side of the filament cathode tends to draw most of the current, causing excessive localized heating of one side of the cathode heater. If the filament cathode presented a uniform or constant voltage for the instant of maximum i_b, then the current to the cathode would be received in a uniform manner across the cathode surface. Quarter phasing, or causing the filament voltage to be 90° out of phase from the supply voltage e_b, will allow the filament voltage to be at zero potential when the i_b current is a maximum.

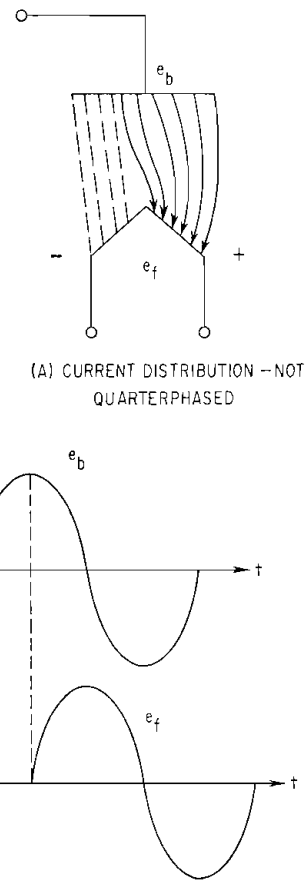


FIG. 3-31. Quarter-phasing rectifiers.

The procedure for designing filters to remove the various ripple voltages is presented adequately in numerous textbooks. It is enough to say that generally for unregulated power supplies a filter is required which will result in a hum level attenuation of 65 to 70 db for the ripple frequency out of the power supply. It is obvious

that a single-phase a-c source will require more filtering than a three-phase source because the fundamental ripple frequency is lower and the percentage of ripple is higher. In addition, it is important that the input inductance of the first filter section (when LC filters are used) should be such that current flow is always maintained. In other words, the minimum inductance should be

$$L = \frac{E_1}{E_0}\frac{R_{\text{eff}}}{\omega}$$

where E_1/E_0 = ratio lowest frequency ripple component to d-c voltage output
$\omega = 2\pi \times$ lowest ripple frequency
$R_{\text{eff}} = E_{dc}/I_{dc}$ (lowest)

It is important to consider the effective source impedance of the rectifier-filter combination. The regulation of the supply should be good enough to allow meeting the signal-regulation requirement from a black to a white picture.

Again, regulated power-supply design is adequately covered in numerous texts and will not be covered here except to say that the filtering required is generally in the order of 45 to 50 db, since the process of regulating the voltage from the filter does add a significant degree of effective filtering. Also, it is important that where twin triodes are used as the passing tube in series regulators, a small cathode resistor should be used in each section to balance the current. A small resistor in each plate also tends to reduce the possibility of oscillations.

Concerning fixed bias supplies, the choice of whether to use regulated supplies or not is generally a choice based on economy. The most practical choice, generally, is to use an unregulated filter supply with a high ratio of shunt bleeder current to grid current. A bias supply of this nature will commonly have a 5-to-1 ratio of bleeder current to grid current.

It is important to bear in mind that in all power-supply circuits associated with video and RF circuits the video impedances must be minimized. If, for instance, the visual wideband RF stages see a video impedance back through any of the power leads, the RF circuit will not perform as expected and the picture will in some manner deteriorate.

CONTROL AND PROTECTIVE CIRCUITRY

In television transmitters as well as in other transmitters the control and protective circuitry is of extreme importance. This circuitry has many configurations, depending upon the design and the designer, and consequently, only a general discussion can be presented here.

For control work, it is important to bear in mind what is to be controlled, what the sequence of control is to be, and the degree of control desired. In general, the items to be controlled are the cooling medium, the filaments, the low-voltage power supplies, the bias voltages, and the high-voltage supplies. In addition, it is common practice to allow for separate application of the voltage supplying the aural and visual transmitters if common power supplies are used. To the extent possible, the control circuitry should be such that minimum operator effort is required.

The following sequence of control is usually employed:

1. The transmitter START button or switch is operated in such a way that the air blower or the water pump operates first.
2. The filament supply is then automatically activated.
3. When the filament supply is activated, a time-delay circuit associated with the filaments automatically places at least a 30-sec time delay in the way of subsequent circuit activation. The delay is for the filament warm-up time necessary for some of the higher power tubes. Were the delay not incorporated, the tubes could be damaged should plate voltage be applied before sufficient filament warm-up.
4. Once the filaments have sufficiently heated during the delay time of 30 sec, the low-voltage and bias supplies are activated. Once the low-voltage supplies are activated, the transmitter is in a position to operate with one additional operation.

5. For complete operation of the transmitter, the final operation of the high voltage is, or should be, an operator function.

Thus, it is seen that the operation of the transmitter can be accomplished with two manual operations, the first operation automatically handling the sequence of blower, filament voltage, and low-voltage activation, the high-voltage activation for output power being the second operation.

Incorporated throughout the control circuit should be pertinent protective circuitry to protect both the equipment and the operating personnel. Interlocks on access doors should interrupt all power, except to coolants and filaments, when access

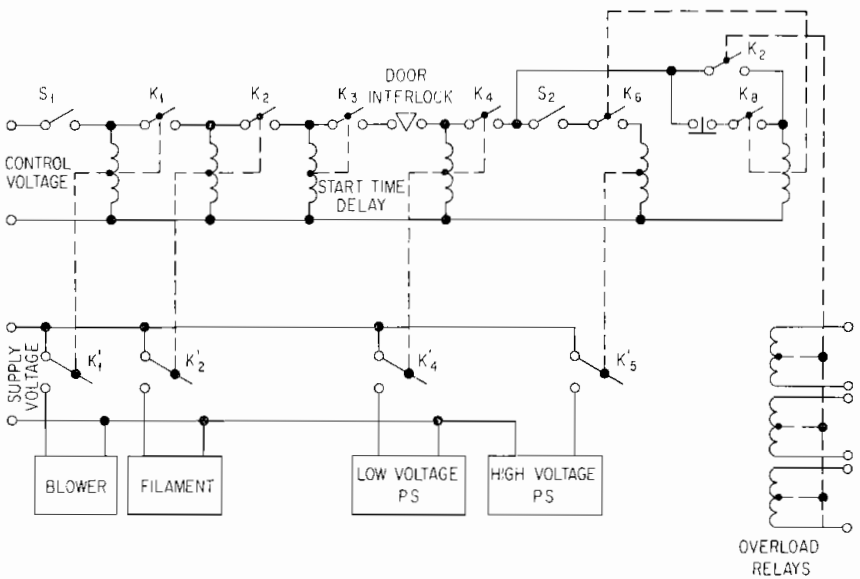


FIG. 3-32. A simplified control circuit.

doors are opened. Overload relays should protect all power tubes by removing pertinent supply voltages to screens and plates.

Because relays are commonly used for automatic sequencing and circuit protection, much reliability must be placed directly on the relays themselves. Any failure of the relays, of course, means service interruption.

Figure 3-32 shows a much simplified control circuit which could be used in either or both of the aural and visual transmitters. Since this control circuit is in its simplest form, the sequence of operation is easily followed.

Starting Sequence

1. When S_1 is activated, the blower starts operating. (The blower should have an air interlock to prevent filament activation should the air fail or the blower run in reverse.)

2. After the blower operates, the filament relay is activated, closing the filament voltage contacts.

3. As the filament contactors are activated, a time-delay relay of 30 sec commences operation.

4. Once the 30-sec delay period ends and the door interlocks are closed, the low-voltage relays are activated, thus closing the contactors supplying the low-voltage power supplies.

5. With all the foregoing operations automatically completed, the operation of applying high voltage is under the control of the operator through operation of S_2.

The control circuit in Fig. 3-32 shows overload protective relays which could be placed in the cathodes of any given tube. As shown, whenever an overload relay is activated, C_7 closes, in turn activating a relay to open C_6 and to close C_8, thus maintaining the plate voltage in the OFF position and preventing the plate voltage from chattering off and on. Pushing the reset button will place the high voltage on again.

Stopping Sequence

Still referring to Fig. 3-32, the stopping sequence is a two step operation:

1. Open S_2, thus removing the high voltage.
2. Open S_1, thus deenergizing all the control relays. The relay that controls the blower should have an opening time delay in the order of 3 min to allow tubes time to cool off.

The control circuit shown is, of course, extremely simplified, but should more sophistication be desired, it could easily be incorporated with a rapid increase in the number of relays required.

A TYPICAL TRANSMITTER—TYPE TT-36-A HIGH-CHANNEL 50-KW TELEVISION SYSTEM

The General Electric Type TT-36-A high-channel 50-kw system shown in Fig. 3-33 consists of the following auxiliary equipment: a type TT-32-B 10-kw driver, a type TF-5-A 50-kw amplifier, a constant-impedance vestigial-sideband filter, two harmonic filters, and a diplexer if the system requires a separate diplexer. Some installations can call for a slot diplexer, which can then be a part of the VSB filter.

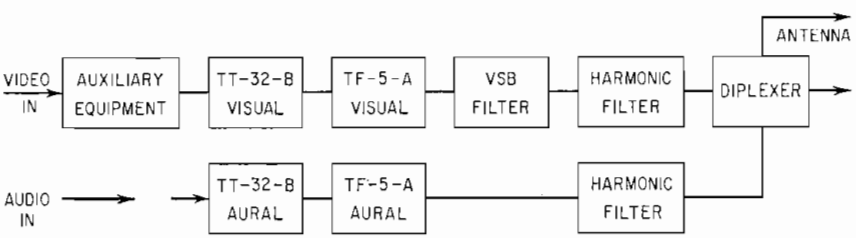


FIG. 3-33. Simplified diagram, type TT-36-A transmitter system.

Referring to Fig. 3-33, it can be seen that the video signal passes through some auxiliary equipment before reaching the transmitter. This auxiliary equipment consists of a video low-pass filter for attenuating 4.75 Mc and above, a variable low-frequency envelope-delay corrective filter, a receiver corrective filter, and a variable high-frequency envelope-delay filter. The variable filters compensate for the VSB filter and the upper-sideband phase error due to the bandpass restrictions of transmitters. All filters are isolated from one another by isolation amplifiers of 75 ohms forward and backward to minimize reflections.

The video then passes to the visual modulator. The video passes through two video amplifiers, a cathode follower, a linearity corrective stage, and an output stage to the modulated stage. The video stages are similar to those described in the theory. The modulator output stage is similar to the "stacked" amplifier described in the theory, using two 6146 tubes, thus making the modulator capable of driving into 180 $\mu\mu$f with a video voltage in excess of 100 volts and with a frequency response flat beyond 7.5 Mc. Two keyed clamps are used to establish the d-c levels, one at the linearity corrective stage and one at the last amplifier to establish the d-c insertion or blanking level at the modulated-stage grid. The keying or clamping pulses are formed as outlined in the theory, using a shorted delay line and clipper tubes.

The carrier signal is generated in the visual exciter, which uses a crystal frequency in the range of 5 Mc, and after a multiplication of 24 the exciter delivers the carrier-frequency signal to the first of two C-W amplifier stages. The two amplifiers operate as Class C amplifiers to deliver the required power to the grid of the modulated stage.

The modulated stage can be described as a medium-level power-modulated stage. The modulation is the grid modulation discussed in the theory, with the modulated stage operating between Class B and Class C. The output of the modulated stage is wideband to accommodate the sidebands of the now modulated carrier.

Following the modulated stage are two Class B linear wideband amplifiers operating in a grounded-grid fashion. The circuitry is of the cavity type owing to the frequency range involved but is basically slightly overcoupled double-tuned circuits of the nature described in the theory. The final amplifier delivers 10 kw when the driver operates alone, but when driving the 50-kw amplifier, its output is reduced to the 5 kw needed to drive this amplifier to its rated output.

Following the type TT-32-B driver is a wideband Class B linear amplifier, type TF-5-A, using two GL6251 tetrodes in parallel, which delivers a 50-kw output. This stage operates as a grounded-grid stage with an input-matching circuit to transform the circuit input impedance to the impedance into which the driver is designed to work. While the amplifier circuit is cavity-type circuitry, the output again assumes the slightly overcoupled double-tuned circuit described in the theory.

Immediately after the amplifier is a harmonic filter and a vestigial-sideband filter in that order. The VSB filter is of the constant-impedance type which lends itself readily to switching various driver and amplifier combinations. After the harmonic filter and the VSB filter, the RF signal passes to the diplexer.

The aural transmitter begins at the aural exciter of the driver, which has a separate oscillator of the Colpitts variety operating at a nominal 200 kc. Since frequency modulation is arrived at through the type of phase modulation described in the theory, it is possible to crystal-control the center frequency accurately without referencing to the visual exciter. Following the oscillator is a sawtooth generator, which the audio signal modulates by clipping. Following the sawtooth clipping operation by the audio there is a differentiating circuit which derives the 200-kc pulses that now appear as a pulse-position-modulated signal. The resulting signal is limited, filtered, and multiplied 972 times to arrive at the desired final aural carrier center frequency. The audio signal is processed both for the preemphasis required by the FCC and for the linear deemphasis dictated by the phase-modulation process prior to modulation of the sawtooth.

The FM signal out of the modulator-exciter is amplified by three Class C stages which deliver a nominal 5 kw of aural power, although when the type TF-5-A aural amplifier is driven, a nominal 2.5 kw is required. The circuitry and the construction essentially duplicate the like stages in the visual driver.

The type TF-5-A aural amplifier delivers a 26.6-kw signal, again using the basic circuit of the visual amplifier with the circuit tuned to a narrower bandwidth. The circuit also operates as a Class C stage instead of Class B as in the visual.

The FM signal leaves the aural amplifier through a harmonic filter to the diplexer and finally out to the antenna along with the visual signal.

INSTALLATION CONSIDERATIONS

When installing a transmitter it is wise to make sure that sufficient space is available to situate the transmitter so that complete access to its various parts is possible. Space should be available for necessary supporting auxiliary equipment with room left for expanding the equipment complement, such as, for example, a standby transmitter.

It is important to have a good grounding system for the installation in order to reduce feedback of spurious signals into low-signal equipments, thus degrading the output signal.

In addition to a good ground, it is usually wise to keep the signal cables separated from the a-c power lines, since the transients from rectifiers can mix with the incoming

signals, again degrading the signal. It is wise to use separate wiring ducts for signal cables and a-c power lines. Where it is not possible to keep the lines separated, a good means of shielding must be used.

A disconnect device capable of interrupting the power source on a short circuit should be connected between the transmitter and the power source. Various power sources can have different current capabilities which may need to be interrupted. If the disconnect device is not capable of interrupting the source short-circuit current capability, equipment damage can result. This disconnect device should be coordinated with the protective circuits of the transmitter so that it operates only in the event of operating failure of the protective circuit of the transmitter.

Before operation of the transmitter it is important to check the protective circuitry to prevent damage to equipment and/or personnel should there be short circuits, open circuits, and so forth. The various manufacturers' instructions on starting a given transmitter should be followed, since the procedure has been set up with equipment protection taken into account.

TEST AND ALIGNMENT

Once a visual transmitter is installed for operation, there remains the procedure of tests and alignment to ensure optimum operation.

If a transmitter has more than one wideband RF stage, it is necessary to align each stage with an RF sweep generator or some equivalent method. The general procedure is to start with the highest level stage and to tune successively lower power stages until all stages are tuned.

Once the RF stages are tuned, the video-frequency stages can be tuned or adjusted. The video-frequency stages consist of both the visual modulator stages and any auxiliary equipments, such as low-pass filters, phase-correction filters, and isolation amplifiers. The object is to have all the video stages as a system present a uniform amplitude-vs.-frequency response to the modulated stage of the transmitter. Since the auxiliary filters associated with the transmitter can accumulate an amplitude-response error, it is common practice to compensate for the response errors with the

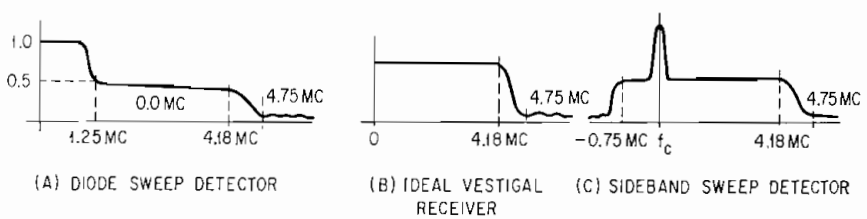


FIG. 3-34. Amplitude vs. frequency sweep detection.

peaking coils of the isolation amplifiers. The general approach is to have all auxiliary units flat, as a group, and the visual modulator flat, so that the two can be separated operationally should the need arise.

Once the video circuits and the RF circuits have been properly adjusted, an over-all amplitude-vs.-frequency response check should be made to determine the transmitter system response. Figure 3-34 shows what the over-all response should look like, using the three possible methods of detection. For proof-of-performance tests a point-by-point amplitude-vs.-frequency response check is generally performed, using a field-strength meter. It is important that the proper operating conditions prevail when making the above test. If a composite test signal is used (with synchronizing pulses), there is no problem on setup, but if a noncomposite signal is used, the average power should be approximately one-fourth rated synchronizing peak power, since this ensures the measurement being made in the black-to-white picture region.

Once the desired amplitude-vs.-frequency response is achieved, the power-output

capability of the transmitter should be checked, because a bandwidth which is too wide could limit the power-output capability. The power can be checked with either black-picture modulation or with no modulation. The following equations hold for determining the synchronizing peak power when reading the average power on a calibrated wattmeter on a dummy load. The P_o reading should be that read on the dummy load for the peak power rating of the transmitter:

$$P_{\substack{o \\ \text{Pedestal} \\ \text{level}}} = \frac{\text{peak-power rating}}{1.68} \qquad \text{(for modulation with rated synchronizing pulses}$$

$$P_{\substack{o \\ \text{Pedestal} \\ \text{level}}} = \frac{\text{peak-power rating}}{1.78} \qquad \text{(for no modulation)}$$

With the amplitude response and the power output properly adjusted, the linearity should be measured and adjusted if needed. The most commonly used procedure is to have a composite video signal with rated synchronizing pulses and a stair-step or sine-wave signal covering the black-to-white region, having 3.58-Mc sine waves superimposed. Care must be taken to have the transmitter operating at the desired operating power with the proper percentage of synchronizing height before attempting to measure the linearity. The linearity measurement must be made with a linear detector so that the depth of modulation can be controlled in order not to exceed $87.5 \pm 2\frac{1}{2}$ per cent. Figure 3-35 shows the system line-up for linearity testing.

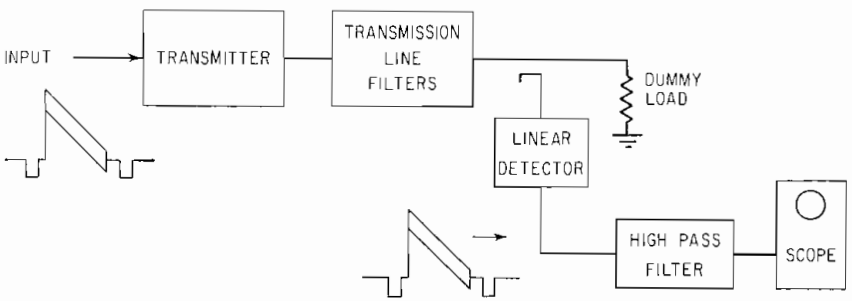


FIG. 3-35. Setup for linearity testing.

As seen in Fig. 3-35, the output from the linear detector will show the depth of modulation, and if the signal is then passed through a high-pass filter, the 3.58-Mc component can be displayed on an oscilloscope. While this display is viewed from a high-pass filter, the black-and-white stretch controls are adjusted so that the scope presentation shows a uniform amplitude (see Fig. 3-36).

Using suitable phase-measuring equipment, the above linearity-test setup can be used for measuring the differential phase shift between different brightness levels.

Measuring the envelope delay of the system is a difficult procedure because of the unavailability of commercial equipment to measure the entire frequency range under consideration. Therefore, it is common practice to use square-wave-type testing of the system to arrive at the desired transient response. The transmitter system, including delay-correction filters, is monitored with a vestigial-sideband demodulator similar to that shown in Fig. 3-37. The ideal demodulator should be envelope-delay-corrected in order not to introduce errors itself. With the envelope-delay predistortion required by the FCC out of the system, the transmitter delay-correction filters

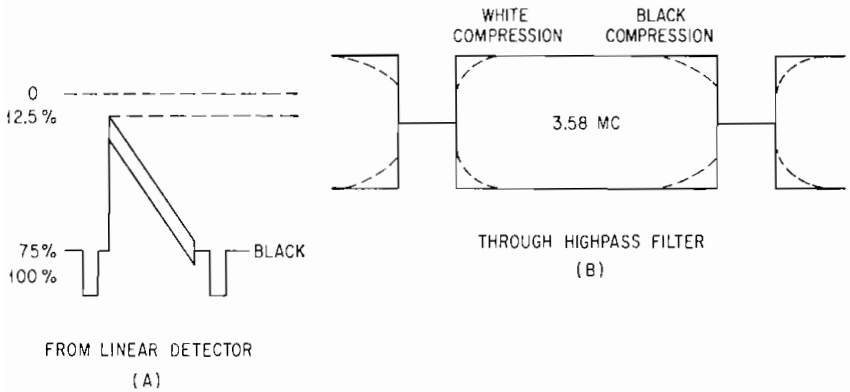


FIG. 3-36. Presentation for linearity test.

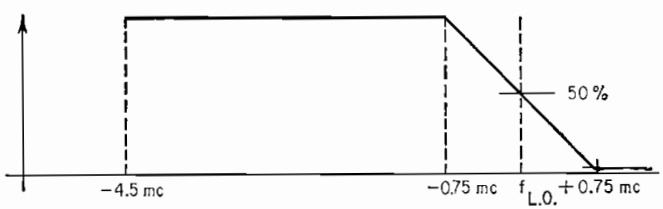


FIG. 3-37. Vestigial sideband detector IF response.

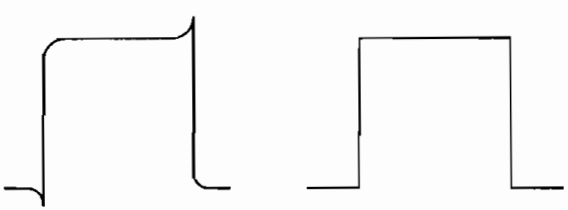
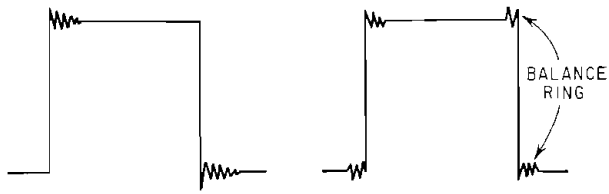


FIG. 3-38. Square-wave response—low frequency.

should be varied until the best transient response of 100-kc square wave is obtained (Figs. 3-38 and 3-39).

In addition to square-wave testing, some use is being made of $\sin^2 x$ testing, but this requires additional test equipment to furnish the test signal.

Once the transient response is optimized, the receiver predistortion is inserted into the system and the system is ready for visual operation. (The receiver predistortion



(A) HIGH FREQUENCY ENVELOPE DELAY ERROR

(B) COMPENSATED WITH HIGH FREQUENCY DELAY FILTER

FIG. 3-39. High-frequency square-wave response.

will cause high-frequency ring to appear on the leading edges of the square wave. This ring will minimize in the home receiver.)

The aural tuning can be accomplished by peaking grid current and minimizing plate currents of the RF stages. Neutralizing can be checked and adjusted by having the plate-current minimum occurring as a grid maximum occurs while varying the plate tuning.

For a complete proof-of-performance test more complete testing is required both for setup and for obtaining numerical data.

MAINTENANCE CONSIDERATIONS

The maintenance procedure should be designed to offer the most satisfactory equipment performance, and it can be broken down into two classifications: equipment maintenance and signal-quality maintenance.

Equipment Maintenance

A periodic procedure should be set up to maintain the equipment operation at top form. The frequency at which the periodic maintenance is carried on depends to a great extent upon the local conditions, together with the desired reliability of operation.

In a dusty locale it is quite important to have frequent cleaning of dust from inside the cubicle, particularly from around high-voltage and high-frequency components. A vacuum cleaner is useful for gathering loose dust. When cleaning dust from around bypass "sandwiches," it is extremely important not to use a cleaning agent which would cause sheet mica to split or separate, since arcing can then result. Split mica sheets should be replaced as soon as possible.

Screws should be periodically tightened to prevent intermittent operation. Blower vibrations, particularly, can in time cause screws to loosen. Water-cooling systems should be inspected and cleaned periodically to reduce scaling, since scaling tends to restrict water flow in addition to reducing the heat transfer in heat exchangers.

Periodic inspection of contactors, switches, relays, and grounding devices should be made to assure continued equipment and personnel protection. Relays and contactors do become "pitted" and corroded with time and repeated operation, thus requiring maintenance at least on an annual or semiannual basis.

A set procedure for monitoring the operation of various tubes can aid tremendously in reducing off-air time. Once the approximate life and operating habits of a given

tube in a particular circuit are established, keeping a record of the operating hours of the tubes will indicate when a tube should be changed. On the subject of tubes, it is best to follow the manufacturer's suggestion upon first placing a tube in service, since proper installation procedure can help assure longer operation.

Signal-quality Maintenance

Maintaining signal quality assures that the picture and sound will consistently be satisfactory to the viewer while serving to keep the operating personnel informed on the system operation.

In addition to the proof-of-performance tests conducted each year, it is good practice to conduct special tests at rather frequent intervals to assure proper system operation.

In the visual transmitter, it has been found that the following tests help to maintain signal quality:

1. System amplitude-vs.-frequency response check
2. Linearity or differential gain adjustment
3. Transient-response test

The amplitude-vs.-frequency response check will assure the maintenance of the necessary bandpass to pass the signal frequency components properly. This test is easily made with a video sweep generator or a frequency burst generator. To a degree, this test is about the most important because the transient response is affected by the amplitude-vs.-frequency response, which is related to the phase- or envelope-delay response. It is desirable to have each portion of the video system flat within itself, with the over-all system flat within the limits set by the equipment manufacturer.

The linearity check and adjustment should be made when the amplitude-vs.-frequency test is made. This test can be made with any adequate stair-step or sawtooth test signal. In this test the first step is to establish a standard video signal level for the system. A 1-volt synchronizing peak to reference white at the transmitter is commonly used. With 1 volt of video going to the transmitter, the input gain of the transmitter should be set to give the rated depth of modulation, and the linearity should then be adjusted to the desired degree. A linearity of 90 per cent is generally considered adequate.

A transient-response test is made simply by observing the system performance using a square-wave signal, such as a window generator. This test will indicate tilt, smear, spiking, and ringing, and if photographs are used for comparing the system from time to time, it is possible to maintain the operation consistently.

PERSONNEL TRAINING

Too much personnel training cannot be done. All the operation and maintenance of a station is dependent upon the operators, and the quality of operation is directly related to their skill. Both equipment maintenance and picture quality are best assured by training each man.

Each operator should be very familiar with the equipment with which he is concerned. The individual instruction books should be read and studied. A planned system of rotating the operators on the maintenance of the various parts of the system will make sure that each person has the opportunity to learn by doing. In addition, planned trouble shooting on simulated problems can be conducted during off-air time to give practice in rapid repair.

In addition to equipment training, the operators can be trained to know what constitutes a quality signal. Often a trained person can observe the signal waveform and determine when maintenance is required. Signal quality can be improved if personnel are familiar with the FCC specifications and the EIA standard Electrical Performance Standards on Television Broadcast Transmitter, TR104. The EIA Standard includes methods of measurement which are standard for the industry.

Section 4

PROGRAM-TRANSMISSION FACILITIES

Part 1

NETWORK FACILITIES FOR RADIO AND TELEVISION TRANSMISSION*

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GENERAL CONSIDERATIONS

Network Requirements

Multiple-channel Requirements

Whenever it is desired to broadcast the same program material, either audio or video, simultaneously from two or more broadcasting stations, or when it is desired to record a program at a point remote from its origin for retransmission at a later time, it is necessary to provide a transmission channel of suitable grade from the point of origin to the remote point or points. The combinations of transmission facilities which make up such channels are known as networks. They are further distinguished as radio or television networks, the latter consisting of a "package" which includes video channels and associated TV-audio channels.

If such channels were required only to connect a few fixed points to a single program source, the operation would be relatively simple. In the United States, however, there are several principals who operate networks to provide program material to associated stations. Programs on each of these networks may be originating at different poiuts, and at various times the points of origin on each network may change. In addition, in many population centers, there are several broadcastiug stations, each associated with a different network and operating competitively for the available audience. Thus, while the networks are independent of one another, they largely serve the same geographical locations and duplicate facilities are required on essentially the same routes.

* The material in this section has largely been abstracted from technical papers and operating information published by the American Telephone and Telegraph Company. The contributions of the anonymous authors of this material are hereby acknowledged.

Reliability and Protection

Reliability of service and satisfactory transmission are essential requirements. Any transmission channel, however, is subject to complete interruption by the failure, in service, of any one of the thousands of individual components of which it is composed. Since there is no known way of completely avoiding such failures, the reasonable approach is to provide similar facilities which can be rapidly interchanged for the defective parts with a minimum of lost service time. This adds a further requirement for duplicating facilities.

Flexibility

The variation in time across the United States is another factor which enters into network operations. A program which originates in the East at a time when the greatest audience attention would be expected would not, if broadcast simultaneously in the West, encounter the same favorable time period. Regional shifts to daylight saving time further complicate the time factor. It has, therefore, become standard practice to record a program at some strategic point from a regional network on which it is being carried "live" and then to retransmit it later on another regional or subnetwork. At any given time, therefore, a station associated with a network may be:

1. Broadcasting a local program
2. Broadcasting a network program simultaneously with all other stations on the network
3. Broadcasting and recording one program from a network while retransmitting to another network a program previously recorded
4. Broadcasting and feeding to the entire network a local program of national interest
5. Other possible combinations of these conditions

From the foregoing, it is fairly obvious that if each network principal were to establish his own network facilities with the requisite distribution, reliability, and flexibility, the economic burden would be considerable. If, however, the channels could be provided on a cooperative basis, avoiding duplicate construction and maintenance costs, and if backup facilities and equipment could be provided for groups of channels rather than for each individual channel, a considerable saving could be effected. If these costs could be further shared through the combination of network facilities with other communication channels which also serve the same geographical areas, further economy is apparent.

Common-carrier Operation

It is primarily for these economic reasons that the provision and maintenance of audio and video network facilities, for the most part, have become the responsibility of communications common carriers. It is the function of such carriers to provide channels for the transmission of electrical communications of every type between any points where it is economically justified to provide them.

The Bell Telephone System

Functions of Major Corporate Units

The Bell System includes the American Telephone and Telegraph Company, the parent organization; the Bell Telephone Laboratories, the research and development organization; the Western Electric Company, the manufacturing and supply organization; and 21 associated operating companies, such as the Northwestern Bell Telephone Company, the New York Telephone Company, the Bell Telephone Company of Pennsylvania and the others, and the Long Lines Department of the American Company. The areas served by the associated companies are shown in Fig. I-1.

The American Telephone and Telegraph Company, with headquarters in New York,

as the parent company, coordinates the various Bell Companies into a system having a common policy. With respect to network service particularly, this includes basic research and development work, planning and coordination of manufacturing and construction activities, assistance in financial matters, and expert assistance in all phases of operation and maintenance.

The development and research function is carried on by the Bell Telephone Laboratories, which is owned jointly by the American Company and the Western Electric Company. For the American Company, the Laboratories carries out the necessary fundamental research in all branches of communication; for the Western Electric

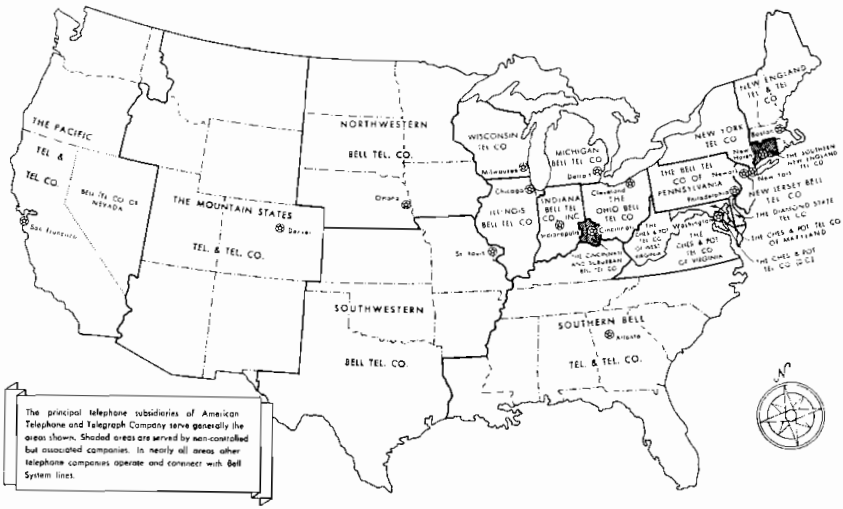


FIG. 1-1. Map of the areas served by Bell System operating companies.

Company it prepares manufacturing designs and specifications based on these researches. In the field of broadcasting, both the American Company and the Laboratories maintain active contacts with broadcasting principals and the engineering societies to keep abreast of progress and requirements in the art.

The Western Electric Company, which is owned almost wholly by the American Company, manufactures most of the equipment, cable, and wiring used in the construction of communications facilities; arranges for the acquisition of the remaining supplies; and installs all central office equipment. It also maintains stockpiles of material at strategic points for use in emergencies. Through this source, a supply of standard, uniformly high-quality equipment is available at reasonable cost to all the associated companies. This standardization also makes possible emergency assignments of maintenance personnel in any area, since the equipment and arrangements are uniform and standard regardless of location.

The associated companies engineer, install, maintain, and operate all the local communications facilities in their respective territories and also the short-haul (primarily intrastate) intercity services. In carrying out this function they have arrangements with the independent companies in their areas for extending services and providing intercommunications. In certain cases they may offer engineering assistance or other similar services.

The Long Lines Department

The Long Lines Department is the operating department of the American Company. Broadly, its function is to provide, maintain, and operate the long-haul facilities which interconnect the facilities of the associated companies.

Within the Long Lines Department, the Commercial Department is responsible for conducting the business relations of the Company with the network principals, for establishing the regulations and rates under which service is furnished, and for filing this material with the proper governmental regulatory bodies. In the conduct of the business relations one of the functions of the Long Lines Commercial Department is to be continually aware of new customer requirements in both the immediate and more distant future. If the new requirements are for plant expansion of facilities similar to those already in use, routine channels are followed to provide them when required. If advances in the art are in prospect which require capabilities beyond those of existing facilities, the full cooperation and facilities of the Bell Laboratories, the American Company, and the Long Lines Engineering Department are enlisted. The Laboratories normally would provide the design of the new systems to meet the requirements, the American Company would coordinate the activities of all companies, the Long Lines engineer would plan and coordinate the installation and construction of the interexchange facilities, and the associated companies would do likewise for local connecting facilities. Using information provided by all the engineering and manufacturing groups, the Commercial Department would handle all matters pertaining to a coutract for a new type of service.

The Long Lines Engineering Department is, in general, responsible for the planning and construction of the over-all network facilities, basing layouts on standard components developed by the Bell Laboratories. It is responsible for determining the most propitious time for introducing new types of equipment or systems into the plant. The new facilities need not be for the purpose of handling a new service. It is a natural outcome of Bell Laboratories continuing fundamental research to develop systems and equipment which will perform the same functions as existing equipment more reliably, more efficiently, and more economically. These new systems are introduced into the plant under existing rate structures at the time and in the location decided by the engineer after consideration of all related factors.

Network Operation

Operation of network facilities is the function of the Plant Departments of the associated companies and the Long Lines Department in their respective areas. Maintenance personnel carefully check all components of every system and test and line up over-all channels before they are put into service. Subsequently, they perform regularly scheduled routine tests on components and systems, set up and execute network changes, and handle reports of trouble. Reported troubles are verified, network reroutes are established, the source of trouble determined, and men dispatched to clear the trouble.

In connection with the development and maintenance of network services, mention of two special committees is of interest, the Video Transmission Engineering Advisory Committee (VITEAC) and the Network Transmission Committee (NTC). The VITEAC is composed of the engineering and operating heads of the major networks and the American Telephone and Telegraph Company, both Headquarters and Loug Lines Department, and the New York Telephone Company. It is the function of this committee to promote the common understanding of the various factors of an engineering and policy nature related to network service. Special emphasis is placed on avoiding consideration of day-to-day operating conditions.

The Network Transmission Committee is the working subcommittee of the VITEAC. This group is composed of broadcasting and telephone engineering personnel who are normally concerned with network operation. It is the function of this group to collect data for the VITEAC, to check the over-all performance of the networks by periodic surveys, to investigate those network operating difficulties which require engineering attention, and to devise standard testing procedures and transmission objectives.

Routes of the Bell System

Message Service Routes

It is the function of the Bell System and the independent telephone companies to provide channels for the transmission of electrical communications among any points in the United States and, by interconnection with the facilities of other agencies, from points in the United States to points anywhere in the world. Within this country, as pointed out previously, local communication channels are provided by associated companies and independent companies in their areas and long-haul interconnecting channels are provided by the Long Lines Department of the American Telephone and Telegraph Company. Since the major requirement for long-haul channels exists among major population centers or cities, it is natural that a series of "routes" has been developed, linking groups of these cities in tandem. The wire or radio facilities on these routes are equipped at all intermediate points with through or terminal types of equipment to provide groups of channels between any two cities on the route and, from them, to any connecting channels in their areas. At the terminals of the routes, interconnecting facilities are provided between routes to extend connections to any part of the country. Through the normal growth of the system, new routes have been developed and added, so it is now possible to interconnect many points by any of several routes. This provides protection against a major failure on any route.

It is fortunate that the broadcasting stations which desire network service also are close to or in the cities through which the major long-distance routes extend, although some television stations are notable exceptions. This makes it possible to provide for network-transmission channels along with channels for other communication services and thereby to derive the economies previously pointed out.

Network Facilities

Since the inception of network service it has therefore been Bell System policy to include in all new construction facilities which are suitable for various grades of network transmission. The number and types of such facilities provided in any section are determined by long-range forecasts, based on the best available customer and company estimates, to be adequate for a considerable time. It, therefore, is possible that wire facilities would be constructed in advance of actual requirements to secure the construction economy but that central office equipment would not be added until some later time when service was actually ordered.

In the development of network service over the years, it has frequently been necessary to make temporary modifications of existing communications channels in order to adapt them to meet an early service date for network service. These short-term arrangements have then been superseded as soon as possible by standard arrangements developed and installed particularly to meet specified service requirements. This article will not refer to any of the temporary arrangements but will discuss only the standard facilities now provided for network service.

Figure 1-2 shows the major routes along which facilities have been provided for full-time television network service. Radio-network facilities are available on these routes and to many other points not included on the map. The facilities provide for all present full-time radio- and television-network requirements, including adequate facilities for protection and for occasional services.

Facilities are also available for occasional and recurring services on short notice, and facilities can be provided, as for remote pickups, to points not on existing routes by special inquiry. In most cases these pickups require special temporary construction.

Channels are also available for audio-program service from all the principal cities in the world. Normally these are not considered as part of a network. Rather they are provided for short periods in the form of "mike leads" as for news commentators. The mike lead may be fed live to a network, or a recording may be made for later broadcast. Most of the overseas channels are derived from radio message circuits suitable for voice transmission only. The undersea cables to London and Hawaii

recently added to Long Lines plant, however, are equipped to provide wideband (schedule A or B) audio-program channels. Arrangements for these channels are handled through normal Commercial Department contacts.

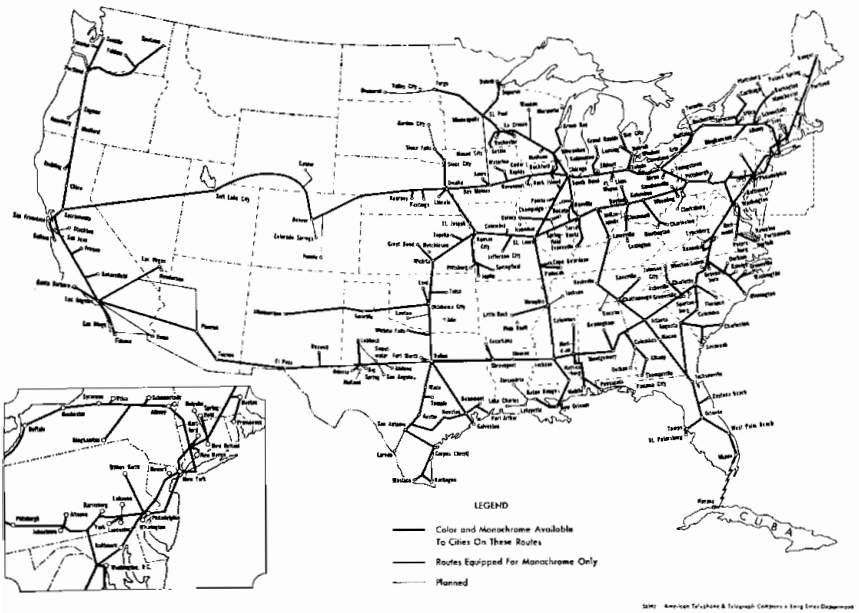


FIG. 1-2. Routes of the Bell System television network as of July, 1958.

Network-facility Arrangements

Network Sections

The facilities which are provided for network services are normally established in sections. For audio networks they are designated as PGCU's, or program circuit units, and for video networks they are designated as VUR's or VUC's, or video units, radio or cable. The various units are further identified by number and letter codes which indicate the type of facility, the direction of transmission, the terminal cities, aud, in some cases, additional information.

The units are combined to form network sections. Audio network sections which are operated as units by the broadcasters are designated by letter codes assigned mutually by the broadcaster and the telephone company. Combinations of units, which are not specifically assigned to a network, are designated SPC's, or special program circuits. Television units are combined to form TVS's, or television sections, which are identified by number and letter codes. Combinations of TVS's are used to provide complete networks which are designated by the same procedure as the audio networks.

Units and sections of the same type are identical with one another at their terminals and in their component parts so that such sections are interchangeable in whole or in any part. Units and sections on different types of facilities are identical with respect to levels and equalization at their terminals, through the use of appropriate terminating arrangements, so that different types of facilities can be either interconnected or substituted at these terminals. This provides a layout which is completely flexible in relatively large units. These units may be permanently connected into a

fixed network, or switching arrangements may be included to permit rapid switching to convert the over-all network into several regional networks. Some combinations of facilities have remained in relatively fixed arrangement with respect to routing and connections for long periods and thereby have tended to become identified with a particular network principal. Despite such identification, networks are provided, not as physical entities, but as transmission or channel services at charges based on distance and period of use.

Since network facilities are provided in sections along major communications routes, the most economical method of reaching all points which desire network service is to establish a channel by the interconnection of sections which pass successively through each service point. This leads to some long and circuitous routings for some service points, but with the present transmission performance of network facilities, the transmission penalty is small in comparison with the operating economies derived.

Reversible Operation

It has been pointed out that programs may be originated at different points on any network or that it may be desired to operate several regional networks over the same facilities that normally comprise a larger network. Two features are available which facilitate network operations in these situations, namely, reversible channels and round robins. Reversible operation is limited to audio channels, but round-robin operation is applicable to both audio and video channels.

Program channels assigned to cable or open-wire program units are normally reversed by the operation of remotely controlled relays which reverse the input and output connections of the amplifiers at each repeater point through suitable associated equipment. Program units assigned to carrier systems on cable or radio are not susceptible to this type of reversing. However, since carrier channels are normally assigned in pairs for opposite directions of transmission, as required for telephone service, switching is normally accomplished at the ends of a channel where remotely controlled switches are operated to select the desired direction of transmission. Reversible operation is normally furnished on a nominal 15-sec basis in order to allow time for the sequential operation of all the circuit features. The remote-control features may be operated by the telephone company on orders from the broadcasters which will specify either a time cue or an audible cue, or the control may be extended to a studio location on the network. Reversible channels normally will result in shorter mileages between pickup points and service points than will be obtained by round-robin operation. This results in an automatic improvement in those transmission parameters which are directly related to length.

Round-robin Operation

Round-robin operation consists of connecting facilities in tandem through the points desiring service in a manner to form a closed loop back to the originating point. Transmission over such a network is always in the same direction, either clockwise or counterclockwise as required by the broadcaster. Stations may be bridged onto the main line by local channels, or the network may be routed "in and out" of the local studio. With the latter arrangement programs or inserts can be originated and fed to all stations on the round robin. It is important that the previous originating studio close through the in-and-out connections for continuity, but the closing must be delayed sufficiently after the cue to permit opening the loop at the succeeding originating studio. This will avoid setting up a closed loop which, in the case of audio networks, would produce an audible oscillation and, in the case of video networks, would produce bright flashes on video monitors or receiving sets. At any point on the round robin, side legs of varying lengths can be connected which, for audio, are usually reversible.

While round-robin operation has many operating advantages, it does result in long, circuitous routings for many points. An audio round robin, for example, might start at New York, go to Boston and then back via Albany to Buffalo, Cleveland, Chicago,

St. Louis, Pittsburgh, Washington, and other intervening points to New York, for a total distance of about 3,000 miles. Thus, Philadelphia, about 90 airline miles from New York, is fed at the end of the 3,000-mile channel.

Network Layouts

The basic, or backbone, layout of a particular network as regards routing and stations connected is normally a relatively long-term condition which is provided in accordance with orders for service by the network principal. Thus, as previously mentioned, some combinations of facilities have come to be identified as permanent networks. The regional shifts to and from daylight saving time are the principal factors which influence recurring major revisions. These layouts are established by the Plant Departments involved on the basis of permanent circuit orders which are prepared by the Engineering Departments. The broadcaster knows that this basic layout, equipped with the necessary switching equipment, is at his disposal during all service periods contracted for.

Operation Orders

Directions and cues for the daily switching and temporary rearrangements of the network are transmitted to the Plant Department either in service orders or operation orders. These orders are received at the plant general control office two days in advance and are transmitted to every point on the network where a change is to be made one day in advance of the requirement. At all such points, on all networks, program and television operating centers (TOC) have been established. In some cities, as for example, New York, where large local networks are also maintained, the associated company provides locations where testing and facility rearrangements are concentrated. At all these locations specially trained personnel execute network operations, conduct and direct routine local and over-all channel tests, and take action to sectionalize and clear any troubles noted or reported.

Separation of Audio and Video Networks

In the discussions thus far reference is made to network service in general and three classes of networks have been mentioned, audio, TV-andio, and video, indicating that the andio and video portions of television programs are carried on separate networks. In this country this is usually so.

As far as technical considerations are concerned, the two networks could be derived from the same basic facilities and travel together throughout. Since sound broadcasting preceded television by many years, however, substantial quantities of audio facilities had been built up about the country and could be added to in kind, readily, when the television sound requirements began to materialize. As a result, video and associated sound networks are completely independent, often not even traveling over the same route among the cities in which they serve broadcasting stations. This has no important disadvantage, since the sound channels used are from pools of such channels existing on all routes to the extent required to care for established needs for all types of broadcasting. On the contrary, this independence usually has the advantage of making the sound channels largely immune to failures affecting video channels.

The method of charging for broadcasting channels is based, in general, on airline distance between service points, so charges are not affected by the fact that the video and accompanying sound channels may travel different routes between television service points unless intermediate service points are provided for the broadcaster on the sound channel.

Although video and associated audio networks thus remain independent in operation, a "package" audio-video service was made available in 1954 at some saving in cost, based on a limited service period per day.

Differential Audio Delay

Although the television sound and picture channels are physically independent, they function essentially as though they were derived from the same basic facility. The only special consideration involved is that the picture and sound signals travel nearly enough at the same speed so that sounds heard will appear to be properly in step with the action on the screen from which they seem to emanate. This does not require absolute synchronism. Human perception normally experiences considerable delay in sound accompanying action seen. For example, a sound coming from action observed only about 100 ft away will arrive at the ears of an observer nearly $\frac{1}{10}$ sec delayed without his being conscious of anything unusual. This is contributed to somewhat by the fact that the exact instant that the sound is produced is not so readily discerned at even a 100-ft distance as at a shorter distance, a conclusion supported by the fact that a comparable delay from action observed as a close-up on a television screen a few feet away will be less tolerable. The nature of the action plays an important part in this.

A sharply defined impulse type of sound where the action is such that the eye can easily detect the exact instant the sound is produced, such as that of a hammer striking a nail, is most susceptible to differential delay effects. Lip sounds coming from a clearly enunciating speaker observed in a close-up also are particularly revealing of differential delay, if present. In both of these instances observation is aided by unconscious ability of average human perception to recognize rhythm or rate of development of a motion and to anticipate the exact instant of its completion whether it actually occurs or not.

A series of tests conducted by the Long Lines Department with different types of program material and different amounts of sound delay over loops of regular network facilities showed that a differential delay of the sound up to about 0.06 sec (60 msec) was not detectable on any of a number of representative commercial programs observed by a group of average observers under conditions comparable to those in the average home. The tests also showed that in much of the action a differential delay of 100 msec or more would pass unnoticed. Beyond about 100 msec the effect became observable more frequently when looked for specifically.

Tests have also been made with "leading" sound (in advance of visible action), which showed considerably less tolerance for this condition. This is consistent with the fact that it is a condition not encountered in nature. It is also a condition not encountered in the networks with current routing practices, since most long sound channels include some relatively slow-speed program-loaded cable circuits and usually have a number of sets of carrier terminal equipment in tandem, all of which introduce more delay than encountered in the video channels. A typical transcontinental audio channel of this type about 3,500 miles long (New York to Los Angeles) before television affected the situation might have had about 150-msec total delay. A video channel on microwave over the same distance, on the other hand, would probably have only about 20-msec delay. The differential of 130 msec would be considerably more than desirable. Special measures are applied in the circuit layout engineering of channels to be used for television sound to minimize the transmission time of the sound. In particular, loaded cable is avoided on "backbone" routes over which service reaches large areas. Also, carrier program channels are so arranged or routed that they will make the longest practicable jumps between terminals where the carrier channels have to be brought down to voice frequency. By such measures differential delay on transcontinental hauls can be kept within acceptable limits.

While it would be possible technically to delay the video signal by the use of delay networks to accomplish the same purpose, it has not been necessary to attack the problem in this way.

Grades of Service—Audio

Facilities for both program and TV-audio network services are offered in a number of grades and for different time intervals, including the following high-quality services:

Table 1-1. Grades of Audio Services

Designation	*Approximate frequency range, cps*	*Notes*
Schedule AAA	50–15,000	Full time 8-hr day
Schedule AA	50– 8,000	Full time 8-hr day
Schedule A	100– 5,000	Full time 8-hr day
Schedule B	100– 5,000	Part time by hour or fraction

NOTE: As of July 1, 1958, there were roughly 183,700 miles of Schedule A service in operation about the United States under Long Lines contract alone, not counting a substantial mileage under associated company contract. Of those 183,700 miles, about 82,000 miles were used for TV-audio.

In addition to the high-grade channel services listed, several lower grade services, Schedules C, D, and E are also available. Aside from bandwidth, there is an important difference between the lower and the higher grade channels. The high-quality channels are amplitude- and delay-equalized to provide satisfactory transmission over the longest distances between originating and delivery points that should be encountered normally within the continental limits of the United States, and with something to spare. The lower quality services, on the other hand, make use of channels designed and constructed primarily for telephone purposes, which are equipped with telephone-type repeaters (amplifiers), repeating coils (transformers) and other equipment. Some modifications in the adjustment of this equipment are made to secure small increases in effective bandwidth or improvement in signal-to-noise conditions. These changes are possible because the channel need transmit in one direction only, thereby eliminating balance requirements involved in normal two-way telephone service. While the improvements thus obtained are beneficial for program-transmission purposes, transmission impairments accumulate to objectionable magnitudes for program purposes at relatively short distances with the lower grade circuits. The controlling factor in this is usually delay distortion which increases with distances and with bandwidth. Delay distortion is much more objectionable in broadcast reception than in speech over a regular telephone instrument. For these reasons the Telephone Company usually places some limitation on the distance over which the lower quality services should be used, particularly where transmission of music is a requirement. Despite these limitations, however, there is an extensive demand for the lower quality services, particularly for baseball and similar sports reporting, because of the saving in cost afforded.

Service Preferences

At the present time the preponderance of full-time sound network service is of the 5,000-cps type. The nearest approach to this is a 3,500-cps medium-quality service of which about 30,000 miles were in use in 1958. The 5,000-cps service appears to represent a balance point between cost and quality, including consideration of such things as limitations in response of the average radio receiver, indifference of a large segment of the listening public to wider band quality, and the fact that a 100- to 5,000-cycle band can provide pleasing results. The weighting of these various factors is, of course, established by the broadcasters who pay for the service.

The same preference for 5,000-cps audio service appears to be extending to television, as will be noted from Table 1-1. The possibility exists that the picture will tend to divert critical attention from the sound quality. Relative cost to the broadcaster can be expected to be the controlling consideration.

Grades of Service—Video

For video-network service two grades of facilities are offered, one suitable for the transmission of monochrome signals and one suitable for the transmission of color signals. These services are available on a time and distance basis.

As is the case with audio facilities, the higher grade facility for color transmission requires closer attention to the control of frequency response and differential phase and gain in the region of the color carrier, which necessitates the provision of additional equipment and greater maintenance effort.

Special Services

Special services, as for example, 15-kc audio service or 8- or 10-Mc video service can also be provided. The demand for such services at this time is not sufficient to justify the maintenance of permanent facilities of these grades. They are provided therefore only on special inquiry and with a time interval to permit engineering and, when necessary, special construction and installation or modification of central office equipment at the points involved.

Service of standard quality to points not located on existing routes normally is also provided only on special inquiry as previously mentioned.

VIDEO-NETWORK FACILITIES

Local Channels—The A2 System

General

Local video service is that service which includes such channels as remote studio to master control, studio to transmitter and master control to and from the telephone company intercity network connecting office. This service normally does not involve a multiplicity of channels between any two points and the distances are usually quite short. For these reasons carrier-type facilities are not economically justified and, while some channels are established on single-channel radio links, the majority of them are established on wire facilities which transmit the video base band. The channels are usually required in urban areas in which other communications services are provided in exchange-type cables. The usual wire facilities in these cables, however, have very high losses at the higher video frequencies, and are unsatisfactory for a number of other reasons. Because of these factors the Bell Telephone Laboratories designed a wire facility particularly for short-haul video service and developed a complete transmission system based on the use of this cable. This system is known as the A2 System. A newer version of the basic A2 System designated the A2A System is also in use for local video service.

An over-all system includes, in addition to the wire facilities, transmitting and receiving terminals with associated amplifiers and equalizers and intermediate amplifiers and equalizers as required by the length of the channel. All of these units are provided in equipment blocks which may be combined as required to meet the over-all requirement. The maximum length channel in current use is about 13 miles long and the median length is about 1.5 miles.

Video-cable Facilities

Three types of video cable pairs are now in use in the plant. These are illustrated in Fig. 1-3.

The 16 PSV-S pairs are polyethylene-string-insulated 16-gauge wires covered with two copper wrappings, spirally wound in opposite directions.

The 16 PSV-L pairs are similar to the 16 PSV-S pairs except that the inner copper tape is applied longitudinally instead of spirally. This construction results in improved crosstalk performance and a small reduction in attenuation.

The 16 PEV-L pairs are also 16 gauge but the conductors are individually insulated with expanded (foamed) polyethylene and the fillers are the same material. Longitudinal and spiral copper tapes are applied as for 16 PSV-L. This construction results in a cable whose impedance can be held to closer tolerances and one with reduced internal echoes due to manufacturing irregularities.

A number of video pairs may be enclosed in a sheath to provide a cable exclusively for video service or a number of these pairs may be enclosed in the same sheath with the paper-insulated pairs used for local service. Both arrangeemnts are in use and, by virtue of the inclusion of video pairs in many exchange area cables in the larger metropolitan areas, where the need is anticipated, a local network of channels is readily made available by adding the necessary amplifier equipment.

Because of the effective shielding in this type of video cable, there is no limitation on the direction of transmission or the number of pairs which may be operated in a single sheath, either with respect to interchannel interference or interference to or from the paper-insulated pairs in the cable. Freedom from such interference is im-

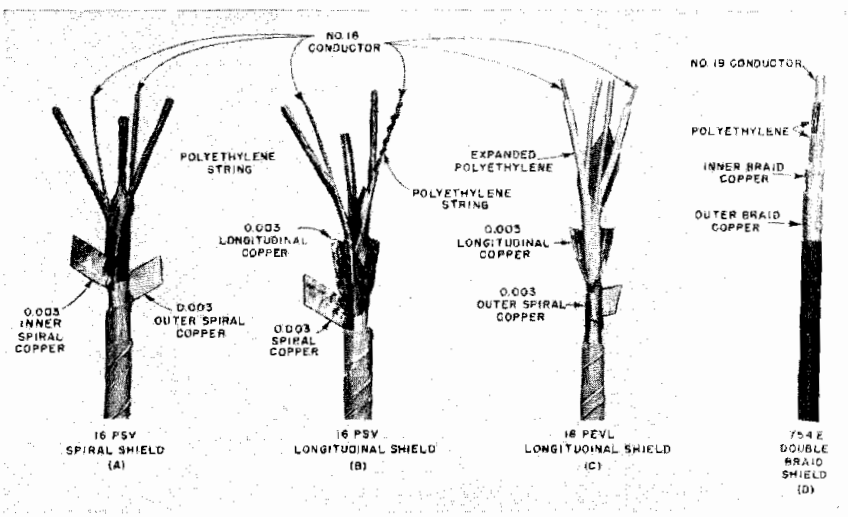


FIG. 1-3. Video-cable pairs and balanced office cable.

portant since impulse noise from relay contacts, switch-hook operation and other sources is high in local cables.

The transmission loss of the heavy-gauge copper pairs is not excessive at high video frequencies so that reasonable repeater spacings may be achieved. Normal repeater spacing may be as much as 3.5 miles but, with the use of network amplifiers, this may be extended to 4.5 miles. The actual transmission losses of video cable pairs are given in Table 1-2.

Variations in attenuation due to temperature changes in 16-gauge video cable are about $\frac{1}{10}$ of 1 per cent per degree Fahrenheit, expressed in decibels. For all practical purposes it may be assumed that this change is a change of slope equal to one-tenth of 1 per cent per degree Fahrenheit of the normal 4.5-Mc loss of the cable at 75°. Thus the primary effect of seasonal temperature variations is to change the effective length of the cable. This may be compensated by a change in the variable equalizers that are provided.

The characteristic impedance (Z_0) of 16 PSV and 16 PEV cable is almost a pure resistance of 124 ohms at the higher video frequencies. Below about 500 kc the resistance component increases to a value of about 1,000 ohms at 60 cycles and the reactive component, which is essentially zero at the higher frequencies, increases to about the same value as the resistance at 60 cycles. The characteristic impedance approaches infinity as the frequency approaches zero. Certain of the characteristics of 16 PSV and 16 PEV pairs are given in Table 1-2.

In the design of equipment components which are associated with the video cable plant in the A2A system, particular attention was paid to matching the characteristic

impedance in the range below 500 kc. This results in a smooth over-all frequency-response characteristic and decreases the need for field-designed supplementary mop-up equalization for systems of nominal length.

Inside Cabling

Several types of balanced and unbalanced office cable also have been designed for video circuits. The conductors are insulated with a solid polyethylene dielectric and shielded with a double copper braid. The outer covering can withstand pulling into cable ducts so that it may also be used in outside plant but here its use is limited

Table 1-2. Attenuation of Video Line Facilities

Type	Shielding	Loss per 1,000 ft, db at 75°F		Loss per mile, db at 75°F	
		0 *	4.5 Mc	0 *	4.5 Mc
Shielded video pairs:					
16 PSV-S	Spiral inner tape	0	3.65	0	19.3
16 PSV-L	Longitudinal inner tape	0	3.52	0	18.6
16 PEV-L	Longitudinal inner tape, expanded polyethylene	0	3.52	0	18.6
Office cabling:					
Paired:			at 70°F		
720	Single braid	0	10.0		
754A	Single braid	0	5.3		
754B	Single braid	0	5.3		
754D	Double braid	0	5.2		
754E	Double braid	0	5.2		
KT51	Double braid	0	6.6		
KT52	Double braid	0	5.3		
Coaxial:					
KS-8086	Double braid	0	11.0		
724	Double braid	0	5.2		

* It can be assumed that for the lengths of cable employed in A2A repeater sections the loss at essentially zero frequency is 0 db.

to temporary service, as for pickups or for emergencies. The transmission characteristics of these cables, also given in Table 1-2, are sufficiently similar to video cable pairs that the same equalizers may be used in conjunction with them.

Cable Terminations

Interconnection between inside and ontside wire facilities is made through special cable terminals which most frequently are located in the video equipment bays and are spliced directly to the lead-sheathed PSV or PEV facilities. If the video facilities which enter a building are in a completely video cable, the cable is extended directly to the terminals. If the video facilities are included in an exchange cable with paper pairs, they are separated at the building entrance and extended to the terminals in a separate lead-sheathed video cable. This avoids any exposnre to low-frequency noise or impulse noise due to relays, pulse circuits, or switch-hook operation which might occur if the cables were routed through the office distributing frames.

A2A Equalizaztion System

The basic equalization plan provides a highly flexible video-transmission system through the use of blocks of equalization which can be combined in the number and type required to equalize a given repeater section. Amplifier units are then provided

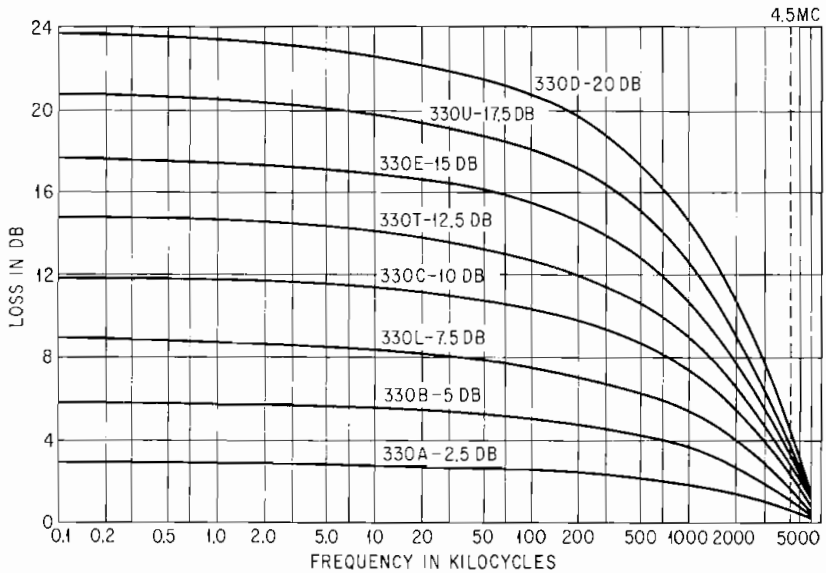


FIG. 1-4. Characteristics of 330 type fixed equalizers.

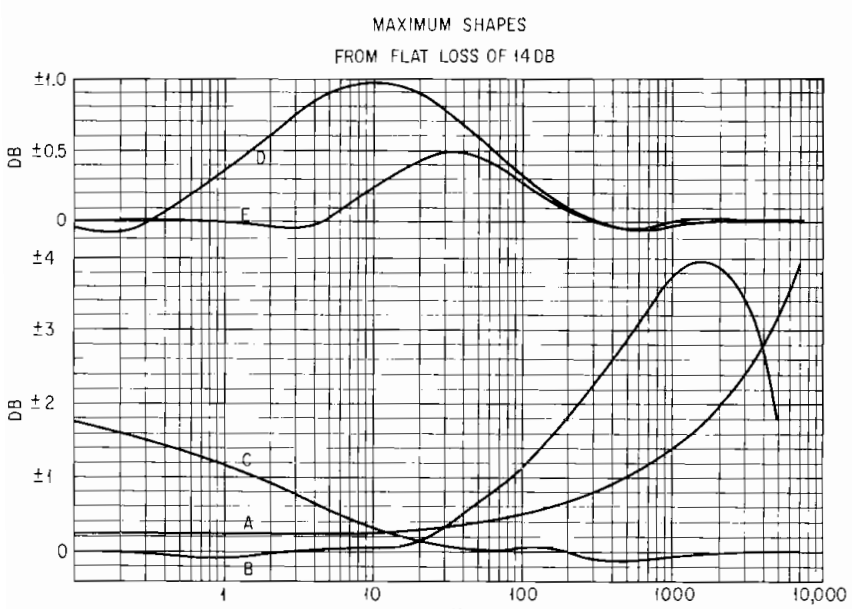


FIG. 1-5. Characteristics of 331 type variable equalizers.

to supply the necessary gain. The fixed equalizer units which are used in the A2A system, whose characteristics are shown in Fig. 1-4, provide for equalization in 2.5-db steps at 4.5 Mc so that at any repeater point the equalization will not necessarily be flat. In general, the transmitting point will be preequalized, and at the receiving terminal the equalization will be adjusted by fixed equalizers to within ±1.25 db.

Each block of the attenuation equalizers also provides the amount of phase equalization required for the length of cable involved. Therefore, as the channel is being attenuation-equalized, phase equalization is automatically provided.

In the A2A system the fixed equalizers are supplemented at the receiving terminals by three variable equalizers, each of which in turn consists of several independently controlled shapes. The characteristics of these equalizers are shown in Figs. 1-5 to 1-7. It is the function of these equalizers to provide the fine adjustments necessary

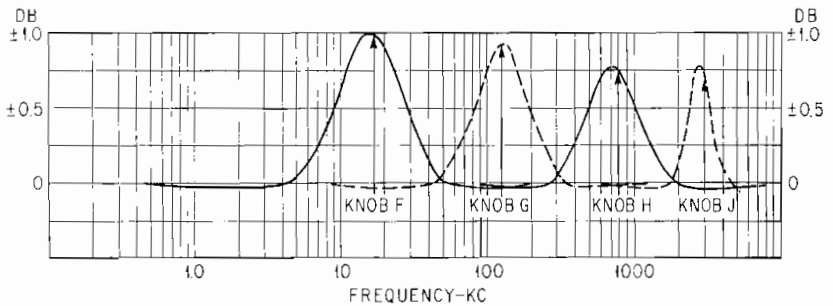


Fig. 1-6. Characteristics of 330M type variable equalizer.

to compensate for response variations which result from such factors as manufacturing variations in the cable, differences in characteristics between PEV and PSV cable, interaction effects due to impedance mismatch at cable terminations, and seasonal variations due to temperature changes.

Except in the case of very long channels, the provision of these adjustable equalizers largely eliminates the necessity for constructing mop-up equalizers in the field. They also simplify the adjustment of equalization which is necessary to compensate for the seasonal variation of the video cable characteristic.

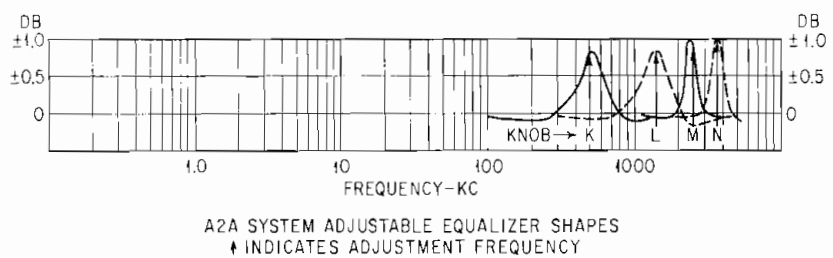


Fig. 1-7. Characteristics of 330S type variable equalizer.

A2A Amplifiers

Four basic types of amplifiers are provided for the A2A system. These are combined with the fixed equalizers in the arrangement that is required to provide the necessary gain in the channel. A further extension of the equalization range of a repeater point is provided by network input and network output amplifiers.

The output amplifier, used at transmitting terminals and at repeaters, is a two-stage balanced amplifier whose gain characteristic is flat over the frequency band extending from a few cycles to 4.5 Mc/sec. The input may be either 75 ohms unbalanced or 150 ohms balanced. The balanced 150-ohm input may be considered as 75 ohms to ground on either side and is provided so that the same unbalanced equalizer that is used in other parts of the system can be used. The output contains a (Z_0 – 124-ohm) network to match the output of the amplifier to 16-gauge video cable at low frequencies. An inductor is connected to provide a high impedance to interfering longitudinal voltages encountered on the cable pair. The amplifier is operated at a nominal gain of 11 db, which can be adjusted by means of the gain control which is provided.

The input amplifier is used at repeater points and receiving terminals. It contains a Z_0 network in shunt with its input to provide the termination for the 16-gauge cable pairs. It is a two-stage balanced amplifier which is flat to 4.5 Mc. The output is 75 ohms, and it is normally connected to the fixed cable equalizers through jacks and plugs. Suppression of longitudinal noise is accomplished in an electron-tube circuit which acts as a high resistance to longitudinal voltages. The amplifier is operated at a nominal gain of 10 db and has a manual gain control.

The interuediate amplifier is used at repeater points or at receiving terminals to provide amplification among blocks of equalizers where the gain of the input and output amplifiers is inadequate. It is a balanced three-stage amplifier with 75-ohm input and output impedances that match the equalizers to which it is directly connected through jacks and plugs. The nominal gain of the amplifier is 24 db, and a small range of manual gain control is provided.

Network input and network output amplifiers are provided when very long repeater sections are encountered. They are two-stage balanced amplifiers whose input and output impedances are designed to match the video cable pairs. They are further equipped with an input and output high-frequency voltage step-up network and an equalizing network. The step-up network results in about 15-db extra gain at high video frequencies with respect to the low frequencies, and the equalizer adjusts this to have an inverse cable characteristic. The additional available high-frequency gain thus supplements the equalization provided by the fixed equalizers.

The receiving terminal amplifier (RTA) provides the final block of gain in the system at the receiving terminal. The input is 75 ohms unbalanced, and the output is either 75 ohms, with a nominal flat gain of 20 db, or 124 ohms balanced with a nominal gain of 23 db. A 7-db switchable attenuator and a continuously variable gain-control potentiometer permit gain adjustment over a range of 10 db. This range permits precise gain adjustment of the over-all facility.

A2A Clamper

The purpose of the clamper used at the receiving terminal is to attenuate low-frequency distortion and interference, that is, to reduce the low-frequency components which have been added or redneed in transmission. It is bridged on to the circuit at a point where the level ranges from −26 to −14 dbv at an impedance of 37.5 ohms. It operates by sampling the black-negative crests of the synchronizing pulses and detecting the envelope of the pulses to determine the low-frequency distortion. The detected envelope is amplified and returned to the line in phase opposition to the original signal, thereby reducing the signal distortion.

A2A Power Supply

The A2A power supply consists of two units: a regulator and alarm unit and a metallic rectifier. The regulator unit provides 115-volt regulated alternating current to the filament transformer primaries, which are located in the amplifier panels, and to the metallic rectifier, which can supply a load of 610 ma at 200 volts. One regulator supplies four filament supply panels and two rectifiers and provides connections to an alarm circuit to signal power failures. One pair of units will handle a single channel with the largest amplifier load or more than one smaller channel terminal.

Typical A2A System Design

The general design objectives in laying out an A2A system are as follows:

1. Transmitting terminal equipment is required to provide a proper impedance match to the video cable pair. Normally an active terminal with an output amplifier is provided, but a passive terminal can be used.
2. The signal should be preequalized the maximum amount that will result in a correct level at the input amplifier at the first repeater in order to obtain the best signal-to-noise performance.
3. The number of repeaters should be kept to a minimum for best differential gain and phase performance. Network amplifiers can be used, but if their use does not reduce the number of repeaters required, they should be avoided.
4. The receiving terminal should be made as small as possible.
5. Repeater locations should be in telephone company premises.
6. The low-frequency output level of any output amplifier should not exceed -10 dbv. This will keep the high-frequency, preequalized signals within the output power limit of the amplifiers.
7. The minimum high-frequency input level at any repeater with a nonnetwork input amplifier should be above -57.5 dbv, based on satisfactory random-noise magnitudes in the system.

Based on these general considerations, a typical circuit, as shown in Figs. 1-8 and 1-9, would be designed as follows:

It is required to provide a circuit between two points over a cable route consisting of 25,555 ft of 16 PEV-L cable. The 4.5-Mc over-all loss of this cable is 90 db.

The use of network amplifiers at both terminals will not eliminate the need for an intermediate repeater, so a repeater will be used. It is found that a repeater can be located in an office located 75 db from the transmitting terminal.

The length of this first section determines the transmitting-terminal and, to a large extent, the repeated design. For a section of this length, the preferred arrangement is to provide a network output amplifier at the transmitting terminal and a nonnetwork input amplifier at the repeater.

The network output amplifier provides 31.5 dbv of equalization. With a low-frequency level of -10 dbv at the output of the amplifier, the 4.5-Mc output level is then $+21.5$ dbv. The input level at the repeater input amplifier is then $+21.5 - 75 = -53.5$ dbv as shown in Fig. 1-8.

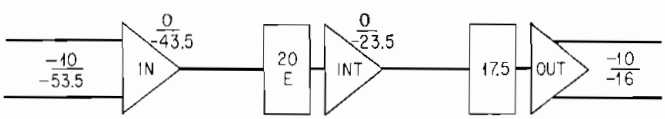


FIG. 1-8. Typical A2A intermediate repeater.

The length of the second repeater section is 15 db. For a section of this length the preferred arrangement is to provide nonnetwork amplifiers at both terminals of the section. This establishes the 4.5-Mc maximum level at the output of the intermediate repeater at $+5$ dbv and determines the equalization required at the repeater. This is, of course, the sum of the slope at the input of the repeater and the slope at the output, or $53.5 + 5 = 58.5$ db.

Referring to the chart of equalizer losses, it is found that the combination of two 330D (20 db) and one 330U (17.5 db) come within 1 db of the requirement. Two intermediate amplifiers would provide the necessary gain.

Looking ahead to the receiving terminal, however, it is found that this repeater arrangement would result in an unsatisfactory condition at the terminal. A more satisfactory design results if one of the 330D equalizers is assigned to the receiving terminal to provide additional range for compensating seasonal variations. When this is done, the 4.5-Mc output at the repeater output amplifier is not at its maximum,

but this is satisfactory because the input level at the receiving terminal remains well above the minimum. The intermediate repeater thus contains an input amplifier, one 330D equalizer, an intermediate amplifier, one 330U equalizer, and an output amplifier.

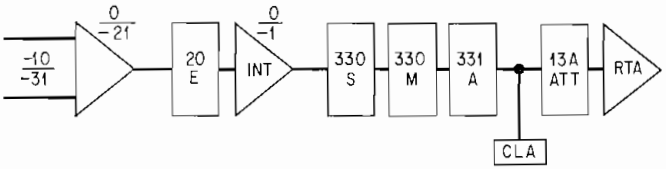


FIG. 1-9. Typical A2A receiving terminal.

The receiving terminal, as shown in Fig. 1-9, will therefore consist of an input amplifier, one 330D equalizer, an intermediate amplifier, the three variable equalizers, a receiving-terminal amplifier, a variable attenuator, and a clamper.

A2A Terminating Conditions

The transmitting-terminal input and the receiving-terminal output can both be arranged for either 75- or 124-ohm impedances. A terminal in a telephone company office is usually 124 ohms balanced. Connections to broadcaster's equipment are normally 75 ohms unbalanced. For either condition the A2A system is designed and aligned to receive a 1-volt peak-to-peak flat signal and to deliver a 1-volt flat, clamped signal.

In the design and alignment of the A2A system, equalization is provided and adjusted to compensate for all cabling to the actual point of interconnection with adjacent facilities. It frequently happens that the last (or first) A2A amplifier is some distance removed from the jack where the interconnection is actually made. The inside cable for this run is equalized within the A2A system. It is important that this cable length, at either terminal, be kept as short as practicable because a long run of unbalanced cable might be subject to excessive noise interference.

A2A Transmission Objectives

The A2A system has been designed to transmit either monochrome or NTSC color video signals without noticeable picture impairment. The transmission objectives are such that several channels can be included in an intercity network channel and provide transmission to meet present standards.

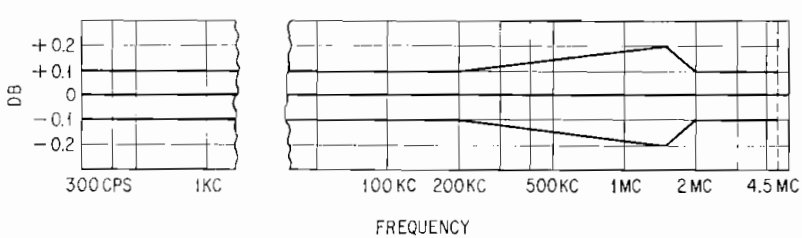


FIG. 1-10. Typical frequency-response objective, A2A system.

A typical frequency-response objective for an over-all A2A system is shown in Fig. 1-10. The region below 200 kc is maintained to very close limits in order to avoid smearing and streaking. The region above 2 Mc is maintained to the same close limits to avoid impairment of color information in that region.

The differential gain objective in a properly adjusted A2A system is ±0.4 db, and the maximum differential phase less than ±0.5°.

The low-frequency noise components, consisting principally of 60 cycles and harmonics, on an rms basis, should be at least 60 db below the peak-to-peak signal voltages.

Low-frequency longitudinal noise voltages encountered on the cable pair will be suppressed at least 60 db by features included in the system.

Impulse noise should be at least 17 db below the peak-to-peak signal voltage.

Random weighted noise on an rms basis should be at least 65 db below the peak-to-peak signal level.

Intercity Facilities—The TD-2 System

General

The transmission of video program material requires a channel capable of transmitting a frequency band extending from a few cycles to 4.5 Mc. In their search for facilities capable of such wideband transmission, the Bell Telephone Laboratories early recognized the attractiveness of the wide-frequency spectrum in the SHF radio range. Work in this field resulted in the development of an intercity radio relay system which was first placed in service between New York and Boston in 1947. Experience with this system and further development work led to the TD-2 radio relay system which was first placed in service between New York and Chicago in 1950. This system now provides a network of channels which virtually covers the United States. Some 80 per cent of the video network channel miles in service are derived from the TD-2 system.

The TD-2 system operates in the frequency range of 3,700 to 4,200 Mc, which is one of the bands allocated by the Federal Communications Commission for common-carrier use. The over-all band is divided into 12 channels each 20 Mc wide with a guard band 20 Mc wide between adjacent channels. The center frequencies of each channel are therefore separated from each other by 40 Mc. To provide for two-way service, six of the channels are arranged to transmit in one direction and six in the opposite direction. As shown in the diagram in Fig. 1-11, adjacent frequencies,

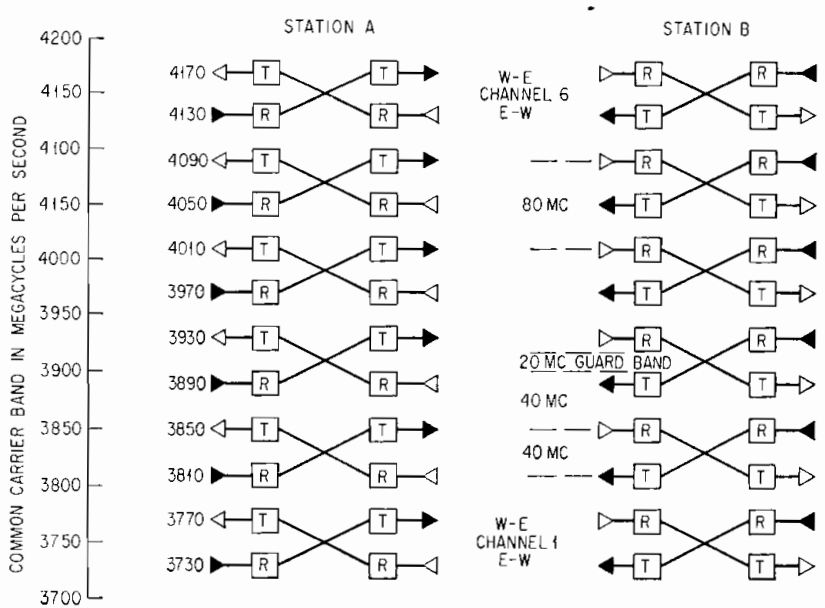


Fig. 1-11. TD-2 frequency-assignment plan.

40 Mc apart, are assigned to the two directions of a given channel. At each repeater point the received signal is shifted 40 Mc toward its oppositely directed mate before it is transmitted to the next repeater point. This is done to reduce interference between transmitters and receivers at the same repeater point and to help overcome overreach at adjacent stations.

Each channel on the TD-2 system is capable of transmitting either a video signal or, by the application of carrier techniques, 600 one-way telephone messages. Most of the routes now in existence, as is common with other telephone plants, are used jointly for video network service and telephone-message service.

FM Transmitter

The major components of the TD-2 system are:
1. Terminal transmitting and receiving equipment
2. Intermediate repeaters
3. Bridging arrangements
4. Protection

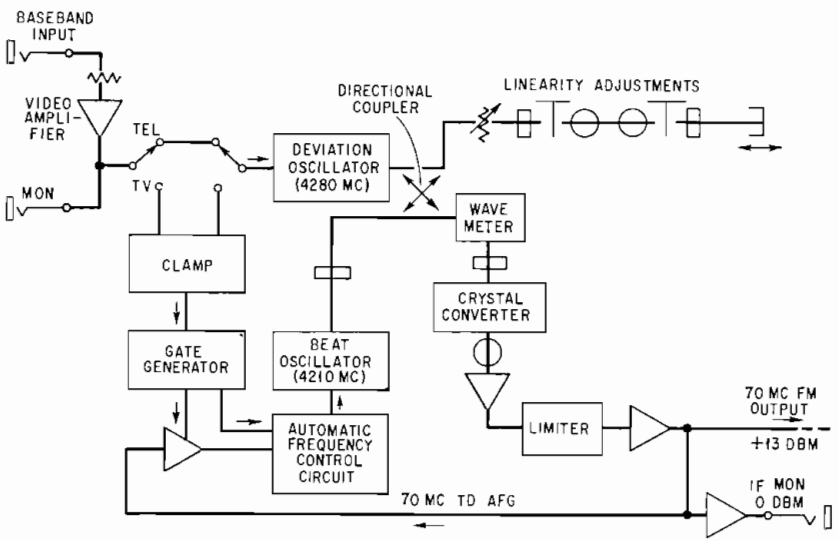


FIG. 1-12. Block schematic of FM transmitter.

Modulation in the TD-2 system is accomplished in two steps, the first of which occurs in the FM transmitter.

The FM transmitter, shown in block schematic form in Fig. 1-12, consists of five major units: a video input amplifier, an FM generator, a control panel, an automatic-frequency-control panel, an automatic-frequency-control unit, and a limiter amplifier. The input video amplifier accepts the input signal from the balanced 124-ohm or unbalanced 75-ohm line at 0.2 volt peak to peak. The input signal is preemphasized by a network which rolls off the low-frequency signal components by 13 db with respect to the components above 2 Mc. Gain adjustment is provided by an attenuator at the amplifier input.

The output of the video amplifier is applied to the repeller of a 4,280-Mc reflex klystron deviation oscillator in the FM generator unit. The signal applied to the repeller is about 10 volts peak to peak, and it causes the oscillator to change frequency in accordance with its magnitude. This type of reflex oscillator has the

characteristic of shifting its frequency in a fairly linear manner over ±5 Mc with negligible variation in output power as the voltage applied to the repeller is varied. The maximum swing used in the operation of the TD-2 system is ±4 Mc.

A second reflex klystron is used as the beating oscillator at a nominal frequency of 4,210 Mc. The output of this beating oscillator is combined with that of the deviation oscillator in the directional coupler to produce a frequency-modulated signal with a 70-Mc rest frequency. Automatic frequency control is provided by circuitry which feeds back a rectified voltage to the repeller of the beating oscillator so that the "at-rest" output frequency is maintained at 70 Mc. The AFC circuit therefore acts to correct for drifts of both oscillators.

The limiter amplifier amplifies the FM signal and, through its limiting action, operates to remove any AM introduced in the signal.

FM Receiver

The FM receiver accepts the IF-modulated signal from the TD-2 receiver with a center frequency of 70 Mc and a power level of +3 dbm. The major components are the limiter detector, the video amplifier, and the meter and control panel. Figure 1-13 shows the FM receiver in block schematic form.

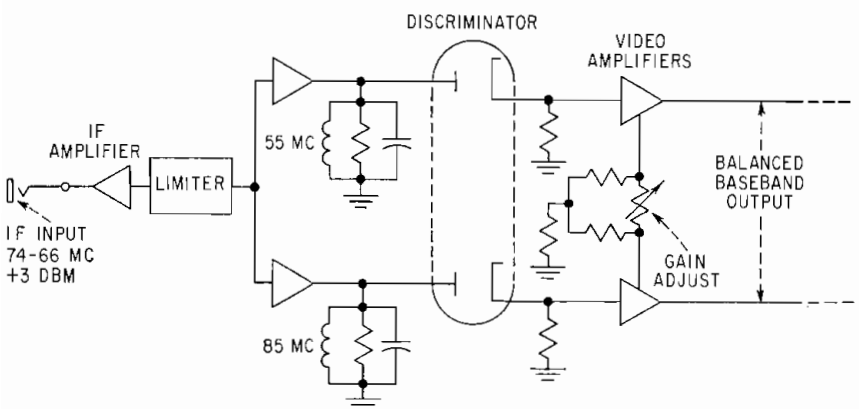


FIG. 1-13. Block schematic of FM receiver.

The first two stages of the limiter detector comprise an IF amplifier from which the signal passes to two limiting stages. Limiting is accomplished by silicon varistors, the bias on which is adjusted to secure proper limiting. The output of the limiter stage is impressed simultaneously on the grids of two independent amplifier stages. Each stage has a tuned antiresonant network in its plate circuit, one tuned to about 55 Mc and the other to about 85 Mc. Consequently, the transmission characteristic through these tubes in the vicinity of 70 Mc will vary with frequency. The slopes of these characteristics are equal but opposite in sign. If the input signal is frequency modulated, the frequency deviations on the input will appear as amplitude deviations on the output of these tubes. These deviations are then applied to two diodes from which, in turn, the video signal is derived.

The video amplifier next receives the signal and amplifies it to +6 dbv for transmission to a 124-ohm output. A restorer network, complementary to the preemphasis network at the transmitter, restores the signal to a flat characteristic. The necessary gain and clamping are provided by an amplifier and clamper in the connecting circuit to the TOC.

Antennas

In the 3,700- to 4,200-Mc range in which the TD-2 system is operated, line-of-sight transmission is required between adjacent stations. This means that repeaters are required periodically on a long route, the locations being governed by such factors as terrain, interference from or with other microwave systems, obstructions, and, of course, the transmission loss of the path. The distances between repeaters on the TD-2 systems vary considerably, but 30 miles is a nominal figure. At main route repeater stations a receiving and transmitting antenna are required for each direction of transmission. Light routes are sometimes built utilizing a single antenna for both transmitting and receiving. These antennas are mounted on buildings or on steel towers at the required heights. Two types of antennas are in use in the TD-2 systems, the delay-lens type and the horn-reflector type.

The delay-lens antenna connects to the waveguide at one end and flares to an opening 10 ft square in a length of 10 ft. The delay lens is constructed across the opening. It consists of a large number of horizontal aluminum strips sealed into blocks of solidified polystyrene foam. The active part of the lens structure is thickest in the middle and becomes thinner toward the outer edges. The effect of the metal strips is to slow down the waves, and since the lens is thickest in the middle, the waves are slowed down more in that position, with the result that all parts of the wave emerge at the same time. This forms a flat wavefront which travels as a beam along the axis of the antenna and is very accurately directed to the receiving antenna at the next repeater point.

The horn-reflector antenna opens from a circular waveguide into a vertical metal horn of square cross section. After passing this area, the wave is directed horizontally by a reflector which is an integral part of the antenna structure and whose surface is a portion of a paraboloid. The over-all structure is about 20 ft high and 10 ft wide at the top. In the TD-2 range it provides the same mid-band gain of 39.5 db as the delay-lens-type antenna, but since it has no frequency-sensitive elements, it will be applicable in the higher microwave region where new systems will be operated.

Repeaters

At a receiver, the incoming microwave signal from the adjacent station may contain any combination of one to six channel signals. This complex signal is received by the antenna and carried by waveguide to the transmitter-receiver bay. Located in the waveguide at the top of each frame is a receiving-channel-separation filter shown schematically in Fig. 1-14.

The channel-separation filter combines a hybrid junction and a band-reflection filter in such a manner that at each bay the proper channel frequency is dropped, for amplification through that bay, while the remaining frequencies are passed through the waveguide to other dropping filters and amplifier bays.

From the channel-separation filter the signal is passed to the receiver converter, where it is modulated with a frequency generated locally by a microwave generator (main stations) or a microwave generator plus a 40-Mc shifter (auxiliary stations). The 70-Mc IF output is then fed to the IF preamplifier and the IF main amplifier, where the major signal amplification occurs. The IF main amplifier includes an automatic-gain-control circuit which is capable of compensating about 30 db of fading.

Phase equalization is accomplished by the use of combinations of fixed units inserted in the IF circuit. Automatic protection switching, remotely controlled program switching, and bridging and patching arrangements are all provided at the output of the IF main amplifier. At a terminal the IF signal would next be applied to the FM receiver, and at a repeater it is applied to the transmitter equipment.

In the transmitter, the 70-Mc IF signal is introduced by means of coaxial cable to

the transmitter modulator. In the modulator, the signal is combined with the local beating frequency to produce a signal of the frequency to be transmitted. After passing through a waveguide filter, the signal is applied to a three-stage microwave transmitter amplifier where it is brought to the desired transmitting level.

The transmitter amplifier consists of three 416B triodes mounted in cavity assemblies. The interstage tuners, input tuner, and output resonant filter are all mounted, with the triode cavities, in one rigid waveguide type of assembly which is bolted into the waveguide.

The amplified signal passes through the channel-combining filter where it is combined with a maximum of five other channels and carried by means of waveguide to the transmitting antenna. A directional coupler is introduced in the waveguide system to provide a means of power measurement and to energize alarms in the event of output failure.

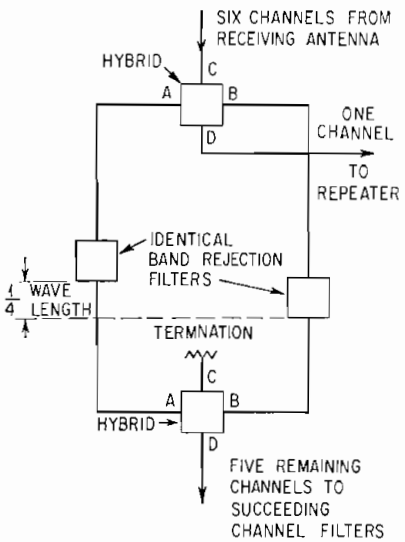


FIG. 1-14. TD-2 channel-separation filter.

Bridging Arrangements

The TD-2 system was designed as a backbone facility with 4,000-mile transmission capability. Video network service, however, requires network interconnections at all points where broadcast stations are located, and these may occur at less than 100-mile intervals. There are also numerous station locations which are not directly on a TD-2 main route, and these must be fed from branches or side legs. In order to maintain the integrity of the main backbone facility and still provide the maintenance and program-switching flexibility required for network operations, an extensive IF switching system has been developed and installed. It was pointed out previously that at each repeater station and terminal office, the microwave frequencies are converted to the 70-Mc IF. It is in this portion of the system that bridging is accomplished rather than at video frequencies, where additional stages of modulation would be encountered.

Where the broadcast station is at or near a city on the main line of a TD-2 route, normal procedure is to provide an IF bridging amplifier on each video channel on the route. The IF bridging amplifier provides two outputs from a single input. One output is for the through channel which passes only through passive elements of the amplifier. The input of a unity-gain amplifier is bridged across this circuit which provides compensation for the shunting effect of the bridging capacitance, and the second path is taken from the output of this amplifier. Each channel obtained by bridging is connected to a receiving FM terminal where the video base band is derived. The base-band channels are then routed by office cable to the TOC, where switching operations are performed.

Broadcast stations not located on the main route may be served by TD-2 side legs. The number of channels on a side leg and the amount of flexibility built into the switching arrangements vary greatly from point to point depending upon the service requirements. In general, however, a bridging amplifier is placed in each channel to which access is required. The branches may then be passed through other bridging amplifiers and a series of remotely controlled IF switches. These are coaxial-type switches specifically designed for the IF switching application. The control point for these switches is at a nearby TOC where the proper combinations of switches can be operated to connect the desired channel to the desired leg.

Access to a channel at any point for transmitting to the network, either on a temporary basis, as for a remote pickup, or on a recurring basis, is obtained in the same general manner except that an FM transmitting terminal is provided.

Automatic Protection

Radio systems are subject to two types of interruption, equipment failure and radio fades. Eqnipment failures can be minimized by the use of conservatively designed systems composed of high-grade components and by continuous out-of-service routine maintenance. Radio fades are due to atmospheric and reflection conditions which affect microwave transmission. The repeaters in the TD-2 system are provided with automatic gain control, which can compensate for about 30 db of fading. During certain periods of the year and particularly in certain sections, deeper fades occur. These are usually of short duration, but they occur frequently enough to prove troublesome on long systems. Manual patching is not effective, not only because of the short fade duration, but because most of these fades are selective, passing through the TD-2 band and affecting different channels successively. To provide protection against these failures an automatic protection switching system has been devised.

A full TD-2 system provides six channels in each direction of transmission. To provide the automatic-protection feature, one channel in each direction, normally Channel 1, is not used for service but is designated the protection channel. An overall system is further divided into switching sections. The number of repeater sections included in a switching section varies widely, being dependent upon the system layout as well as on a statistical analysis of the probabilities of failures. In each switching section the equipment arrangements are identical.

The circuits of the system can be divided into three main categories:

1. Switching circuits
2. Evaluating circuits
3. Control circuits

The purpose of the switching circuitry is to transfer the signal from an impaired regular channel to the protection channel. IF switches are employed both at the transmitting and at the receiving end of each switching section. These are the same type of switches (223 type) that are used for program switching.

The evaluating circuits determine when and where a transfer is to be made and when the transfer back to normal should be made. The evaluating function is located at the receiving end of each section and is performed by the iuitiator.

The control circuits are the connecting links between the evaluating and switching circuits. They accept information from the evaluating circuits and cause the switching circuits to operate. The control circuits are preferably operated over carrier telephone facilities not routed over the TD-2 system to be protected as shown in Fig. 1-15.

The initiator associated with each channel, including the protection channel, is continuously monitoring the incoming frequency-modulated carrier and the channel noise. The protection channel normally carries an 8.5-Mc protection pilot when it is idle. The initiator will respond to a loss of carrier or an increase of noise, either condition signifying a trouble condition. When this occurs on any channel, the initiator associated with that channel sends a signal to the receiving switching-control circuit. This circuit enables the receiving IF switch but does not operate it. It also sends a discrete identification tone to the switching-control circuit of the transmitting terminal. This circuit then bridges the protection channel across the impaired channel. The signal then is being transmitted over both the regular and the protection channels.

If the signal arrives at the protection initiator in satisfactory condition, the initiator completes the IF switch and the feed is established from the protection channel. If transmission on the protection channel is impaired, or if the signal fed to the protection channel is impaired because of a failure in a preceding switching section, the protection initiator will not operate the switch. This eusures that a switch will take place only in a failed section.

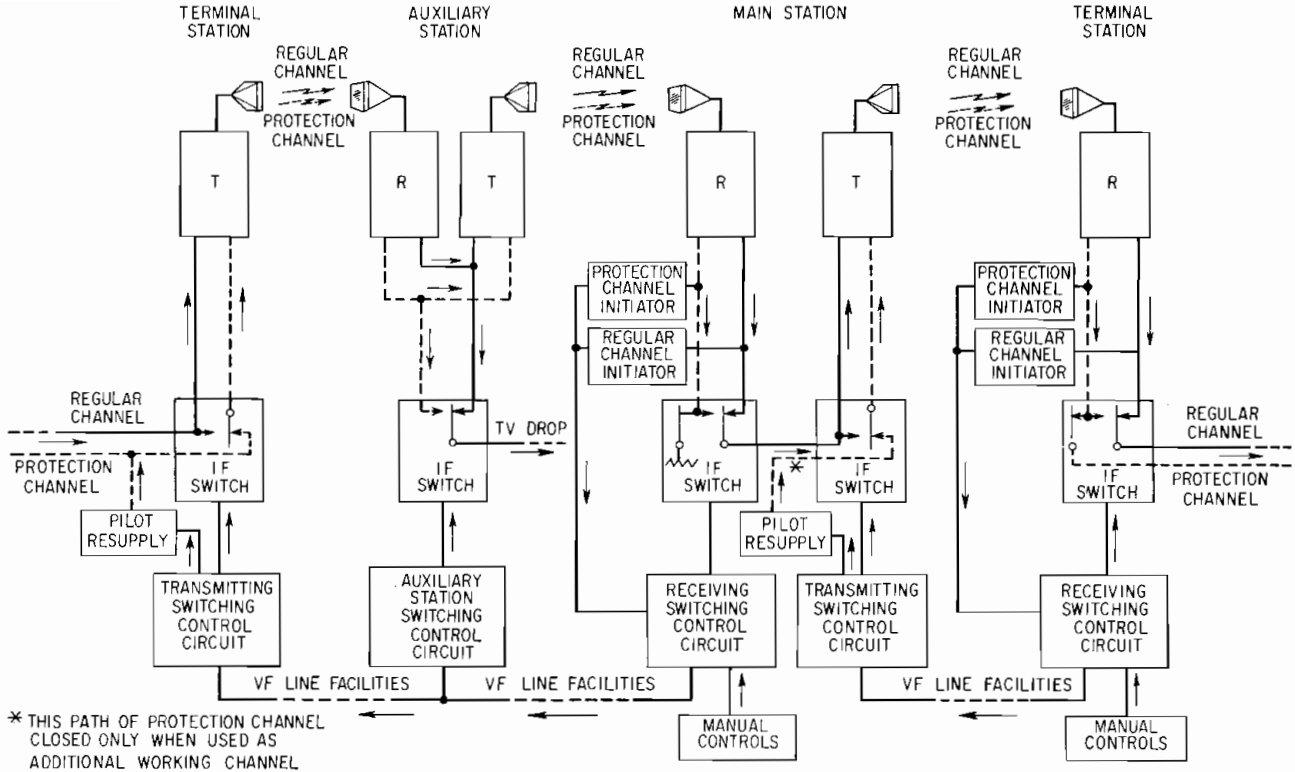


FIG. 1-15. Automatic protection switching for TD-2 systems.

When transmission on the impaired channel has returned or been returned to normal, the initiator so signals the control circuit and the switches are restored.

When transmission is impaired on two or more channels at the same time in the same section, the initiators for each channel will cause the receiving control circuit to apply tone toward the transmit end for each channel. No action will be taken at the transmit end at this time, as the transmitting control circuit is designed to ignore the request for a switch when more than one channel-identification tone is received. At the receive end, however, the control channel locks out all but the lowest numbered channel calling for a switch. When the lockout is completed, the tone of the lowest numbered channel only will be received and the transmitting control circuit will then operate the IF switch for that channel. If, owing to a trouble condition, the switch of the lowest numbered channel cannot be completed within 50 msec, that channel will be locked out for 10 sec and the control circuit will attempt to complete a switch for the next lowest number channel. When a switch is completed, all other channels will be locked out until the protection channel is available again, but if a switch cannot be completed for any channel, the receiving switching-control circuit will try again in 10 sec, starting with the lowest numbered channel.

In order to provide for switching at those stations intermediate in a switching section from which side legs are fed, auxiliary switching circuits are installed. These switches are enabled by a transmitting control circuit but are not actually operated until the IF switch in the backbone receive switching circuit operates. The side-leg feed is then switched to protection channel at the same instant that the backbone route switch is completed.

Intercity Facilities—Coaxial-cable Carrier Systems

General

In accordance with its basic policy of developing more efficient transmission systems for long-haul message service, the Bell Telephone Laboratories has made extensive progress over the years in developing carrier systems for use over intercity cable facilities. Concurrent with this development, new line structures were investigated which would be capable of handling wider frequency bands with lower transmission losses. One of the structures, the coaxial cable, was ultimately developed as a basic cable carrier facility.

A complete transmission system to operate over the coaxial cable was developed and was designated the L-1 coaxial-cable carrier system. This system operates at line frequencies extending from 64 to 3,096 kc and, by means of terminal channelizing equipment, provides 600 two-way message channels on a pair of oppositely directed coaxials. While the transmission losses at the relatively high frequencies used are considerably less than those of long-haul cable pairs, they are still appreciable and require the use of repeaters (amplifiers) at 5- to 8-mile intervals depending on the structure of the coaxial cable used. The cable routes were laid out so that existing telephone repeater stations could be used for some carrier repeater points, and additional small buildings were erected to house the intermediate repeaters on an unattended basis. The repeater amplifiers provide gain and, through the use of networks controlled by pilot frequencies transmitted over the line, automatic regulation of levels and equalization. Additional dynamic equalizers and, also, manually operated equalizers are provided at the section terminals.

The L-1 system was already in use on several major routes in the eastern and north-central portions of the country when the first video network requirements began to materialize in 1945. The system, which was designed primarily for telephone-message use, can be equipped to provide a useful video bandwidth of about 2.7 Mc. It was found by subjective tests that, in spite of the limited bandwidth, very acceptable pictures could be transmitted over the L-1 system. Accordingly, special video terminals and equalization were provided by means of which the entire available bandwidth could be used for a single video channel.

The inherent limitations apparent in the use of the L-1 system for television and the continuing need to keep pace with advances in the art led to additional developmental work which resulted, in about 1953, in the introduction of a new system known as the L-3 coaxial-cable carrier system. This new system, which can be substituted for the L-1 system where this seems desirable, provides a high-quality television channel. Present plans contemplate that the small amount of L-1 in service in the television network at this time will eventually be superseded either by conversion to the L-3 system or by TD-2 radio relay systems which will serve the same points though not necessarily by the same routes.

The L-3 Coaxial-cable Carrier System

A primary consideration in the design of the L-3 system was that it be applicable to the coaxial-cable plant already in existence. Two basic coaxial structures are in use, and the L-3 system can be applied to either. The one most generally used consists of a thin-walled metallic tube of 0.375 in. inside diameter with an internal solid copper wire of about 10 AWG supported coaxially and insulated from the outer tube by polyethylene discs placed at 1-in. intervals. The other is similar except that the outer tube has a diameter of 0.27 in. and the inner wire is about 13 AWG. The coaxials are placed in lead-sheathed cables in the number required on a particular route. As many as eight coaxials have been placed in one cable. In addition, paper-insulated pairs are normally included in the same sheath to provide alarm and control facilities for the system and also to provide additional wire facilities independent of the coaxials.

The L-3 system uses line frequencies up to 8.5 Mc. At this frequency the loss of 0.375-in. coaxial cable is approximately 12 db/mile, and repeaters are required at 4-mile intervals. This necessitates the construction of additional buildings along the L-1 routes which are to be converted. Small variations in repeater section lengths are compensated for in the amplifiers, but very short sections are corrected by the use of cable building-out networks.

The term repeater connotes the combination, in one station, not only of the amplifiers but also the regulating and equalizing networks, power-supply arrangements, and other devices required at the station. The repeater which occurs most frequently is designated an auxiliary repeater. At an auxiliary repeater station no power is generated. The power required for the operation of the repeater is supplied over the coaxial-cable system.

When the layout of a section is such that equalization must be provided at some intermediate point but no line-switching or power-feed functions are required at that particular station, the repeater is designated an equalizing auxiliary repeater.

A main repeater is one from which power is transmitted over the coaxial cable in both directions. A main repeater may be equivalent to an equalizing auxiliary repeater with respect to equalization, or it may be a switching main repeater, in which case additional equalization is provided.

The manner in which the various functions are allocated and the method of gain control are discussed under Equalization Plan and Power Supply.

The 8.5-Mc band of the L-3 system provides, on a pair of oppositely directed coaxials, 1,860 message circuits or a combination of 660 message circuits plus two one-way video channels each with a bandwidth slightly in excess of 4 Mc.

The over-all design objective is to provide high-quality transmission over a channel 4,000 miles or more in length. For video transmission, this involves maintaining in-band transmission flat within $\pm .25$ db and extending the equalization beyond the cutoff sufficiently to ensure that delay differences do not exceed 0.1 μsec. For network-service requirements, it is also necessary to meet these requirements at intermediate dropping points, which occur at an average interval of 125 miles.

Service protection is provided by means of a spare high-frequency line and by the use of interchangeable components. The transfer to the spare high-frequency line is accomplished automatically at switching terminals, which are located at intervals along the system. A further requirement, then, is that any automatic transfer to the standby

channel or any replacement of components shall not result in any noticeable change in over-all transmission.

In a 4,000-mile system the difference in total loss between the extremities of the band is about 40,000 db, which represents amplitude distortion that must be equalized. In a system which contains some 1,200 line and office amplifiers, a systematic change of each amplifier characteristic of only 0.05 db can result in an over-all change of 60 db. In a week, the normal aging of some 7,000 tubes in the circuit can be expected to produce a 6-db change over all, despite negative feedback in the amplifiers. Changes in repeater temperature can produce an 8-db gain change in a week, and cable-temperature changes can result in a 100-db gain change per week over all. These in-band changes of the attenuation characteristic are also accompanied by changes outside the band which result in changes of the in-band delay characteristic. These are the major sources of deviation from the desired transmission characteristic which must be corrected by equalization.

Equalization Plan

Equalization is defined as the process by means of which the loss-frequency and the delay-frequency characteristics of a system are corrected to be within over-all objectives. Regulation refers to that portion of equalization which, by automatic means, corrects for relatively rapid changes in transmission.

From the preceding section, it may be observed that the deviations from the desired flat characteristic can be assigned to one of three categories: (1) fixed deviations, (2) slowly varying deviations, and (3) rapidly varying deviations. The distinction between slowly and rapidly varying deviations relates to the frequency of adjustment necessary to maintain the system within tolerances.

In the design of the L-3 system, each cause of transmission deviation was investigated and evaluated with respect to amount and shape. Certain of these deviations would naturally result from differences in the performance of equipment units, particularly amplifiers, manufactured at different times and from components which differ in themselves. To evaluate the probable deviations, a group of amplifiers was manufactured to extremely close tolerances under laboratory control procedures. These, then, formed the basis of a standard from which performance objectives for all amplifiers were projected.

Quality Control

It is characteristic of equipment manufactured under the usual quality-control methods to have systematic deviations; that is, all units, since they are derived from components which meet certain standard tolerances, will tend to deviate from the design standard. The tolerances are therefore specified so that an accumulation of systematic deviations in an over-all system will never become objectionable. To meet such an objective for the L-3 system, however, would require that all amplifiers, for example, would have to meet a manufacturing tolerance of better than ± 0.001 db, which is a practical impossibility. To meet the over-all objectives, therefore, a completely new quality-control system was developed.

The extent to which over-all system objectives can be attained is largely dependent upon the performance of the amplifiers in the system, and their performance, in turn, is dependent upon the component elements of which they are made as well as upon assembly techniques. The basic concept of the L-3 quality-control system is that, rather than having all amplifiers meet specified tolerances, all amplifiers will have characteristics which follow a normal statistical distribution, within a close average, about the design objective. To meet the over-all amplifier objective, the method is extended to include all those components which were determined, by study, to be particularly sensitive with respect to their effect on the over-all amplifier characteristics. In addition to this control over the components, extremely close control is exercised over their placement in the final assembly, to the position and routing of wiring, and similar considerations. To assure complete uniformity among amplifiers,

supporting structures of cold-casting resin are used into which the components are molded and thus held rigidly in place. Further to ensure uniformity, no gain control or other adjustments, other than those which are a function of the regulating network, are provided in any amplifiers. The amplifiers are, however, designed for plug-in operation so that they can be replaced as units in the field and maintained at a central test center.

With the over-all system thus standardized with respect to the amount and shape of transmission variations expected from various sources, it is possible to develop the over-all equalization plan. The equalization system includes three major types of equalizers that correspond to the rates of variation previously mentioned. These are (1) fixed, (2) manual, and (3) automatic.

Fixed Equalization

The line amplifiers may be considered as the first unit of fixed equalization, each amplifier being designed to match closely the loss of a 4-mile cable section under reference conditions. Next are the artificial cable networks which are used to build out short cable sections to 4.0 ± 0.2 miles and the basic amplifier equalizer which adjusts for the difference between the coaxial-cable types. The final step of fixed equalization is the so-called design-deviation equalizer which is associated with all A equalizers, as described under Equalizer Assignment. The function of this equalizer is, first, to correct for the design error of the average repeater and, second, to recenter the manual (cosine) equalizers in their adjustment ranges.

Manual Equalization

A new system of manual equalizers has been developed for the L-3 system and, along with them, a new line-up procedure which gives a positive indication of the best adjustment. The new equalizers, known as cosine equalizers, are based on the principle that any continuous function can be matched over a 180° interval by a Fourier series of cosine shapes. When this principle is applied to the L-3 system, the 0 to 8.5-Mc range is taken as 180° with allowances for out-of-band equalization to preserve the delay characteristics. As illustrated in Fig. 1-16, successive sections of the equalizer are harmonically related to the fundamental which encompasses the 8.5-Mc frequency range. The degree to which any transmission characteristic can be matched is, of course, dependent upon the number of harmonic terms which are provided. In the L-3 system two combinations of terms are provided for the basic equalization pattern and a third combination provides the additional attenuation equalization required for television service.

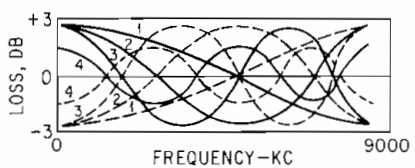


FIG. 1-16. Characteristics of four terms of the cosine equalizer.

Dynamic Equalizers

Automatically controlled equalizers are located periodically in L-3 sections to compensate for those variations which occur too rapidly to permit manual line-up and adjustment in the usual maintenance intervals. To provide the information required by the dynamic equalizers to perform their functions, six pilot frequencies are transmitted over the system. Each pilot controls an individual regulator which, in turn, controls a network with a specific transmission characteristic.

The earliest L-3 systems were installed with only three pilot frequencies and three active networks to control the major, or first-order, variations. Studies were made on these systems, and data were obtained to supplement the calculated design data on the

required range and shapes of the three additional networks. The complete pilot systems, which were scheduled to start going into service late in 1958, are based on the principle of providing certain separate noninteracting networks to equalize independently the telephone and the TV line-frequency ranges and certain other networks which will be effective over the entire line-frequency range. The pilot frequencies and the networks they control are as follows:

1. 308 kc. This pilot controls a low-frequency (0 to 4-Mc) shape network active in the telephone band.
2. 556 kc. This pilot controls a second low-frequency (0 to 3-Mc) shape network which operates in conjunction with the first network to provide the necessary composite corrective shape.
3. 2,064 kc. This pilot controls the network which equalizes the coarse deviations in gain due to the changes in transconductance of tubes which result from aging. The network is effective over the entire line-frequency range.
4. 3,096 kc. This pilot controls a network which is effective over the entire line-frequency range and which has a shape similar to that in the feedback circuit in the line amplifier.
5. 7,266 kc. This pilot controls a regulator by means of which the gains of the line amplifiers are varied to hold the pilot at a fixed level. The function of the regulating network is to compensate for deviations due to changes in cable temperature; therefore it has a square root of frequency characteristic which extends over the entire line-frequency range. Dynamic regulation is not required at every auxiliary repeater. At intervening auxiliary repeaters, thermometer regulators are used. At these points a temperature-sensing element is buried with the cable near the repeater building and connected to a thermistor regulator. This regulator, in turn, varies the gain of the amplifier as the temperature changes.
6. 8,320 kc. This pilot controls a network which has a high end whip characteristic. Its function is to provide the correction in the television frequency range which is not provided by the other networks which operate in the same range.

The Computer

Each of the regulating networks provided in the L-3 system acts over a wide frequency range, and the effects of some overlap the effects of others. The range of equalization is also extended beyond the frequency range actually used in order to maintain the in-band delay-frequency characteristic. In order to allocate properly the amount of correction provided by each equalizer, a multiterminal voltage-dividing network is used. The computer consists of a network of resistances into which voltages representing equivalent pilot levels are fed. The resultant voltages are so distributed at the output of the computer network that, if one pilot changes, all regulating networks correct, but in such proportion and polarity as to produce a gain change only at the pilot frequency which requires correction. Thus, the use of the computer in the regulator circuit prevents interaction between broad equalization shapes.

Equalizer Assignment

Repeaters for the L-3 system are spaced at 4-mile intervals, so that the first step of fixed equalization is located every 4 miles in that the over-all gain characteristic of each repeater is designed to complement the loss characteristic of the preceding cable section.

The design-deviation equalizer, provided in two sizes, one to compensate for sections containing up to 19 amplifiers and the second for sections containing up to 28 amplifiers, is another unit of fixed equalization. This unit is one of the components of an A equalizer, described later. If a section contains less than 10 sections, no deviation equalizer is required.

The spacing of the dynamic equalizers is largely dependent upon the lengths of sections between switching terminals or service points. A service point, that is, an

office where message circuits or the TV channel are dropped, is naturally a switching point. However, if the service points are widely separated, an intermediate switching point can be assigned. Furthermore, if a switching section is more than 125 miles long, dynamic equalizers are required at some intermediate repeater which then becomes an equalizing auxiliary or an equalizing main repeater, depending upon whether or not it is a power-supply point.

The dynamic equalizers are designated A1, A2, B1, and B2. The A1 equalizer consists of the dynamic equalizer controlled by the 3,096-kc pilot, a manually adjusted flat pad, and four terms of the manually adjusted cosine equalizer. The A2 equalizer consists of the dynamic equalizer controlled by the 2,064-kc pilot, the design-deviation equalizer, and five additional cosine terms. The B1 equalizer consists of cosine terms 11 to 14 and the dynamic regulator controlled by the 556-kc pilot. The B2 equalizer consists of the dynamic regulators controlled by the 308- and 8,320-kc pilots and three manually adjustable "bump" equalizers.

At an equalizing auxiliary or main repeater the A1 and A2 equalizers are assigned, acting through the computer with the line amplifier regulator under the control of the 7,266-kc pilot.

At a switching main or terminal repeater the B1 and B2 equalizers are assigned in addition to the A1 and A2 equalizers, again in conjunction with the line amplifier regulator. At switching points, therefore, all five dynamic equalizers with 14 cosine terms are available for line-up. After the cosine equalizers are adjusted, small residual deviations usually remain at the pilot frequencies. This results in the introduction of additional deviations determined by the magnitude of the residue at the pilot frequencies and by the shapes of the dynamic equalizers. Three additional bump equalizers are provided at 308, 3,096, and 8,320 kc which are manually adjusted to remove any residue.

When a line carries TV service, an additional mop-up equalizer is provided at about 400-mile intervals or at TV service points. This equalizer provides 23 additional gain terms and 15 terms of cosine delay equalization, all effective only within the television band.

At each equalizing point the major blocks of equalization are followed by flat-gain amplifiers which compensate for the flat loss of the equalizers. The over-all equalization plan, then, is on a block-of-equalization, block-of-gain basis. A typical equalizing auxiliary repeater is shown in Fig. 1-17, which shows how the dynamic equalizing networks are associated with flat-gain amplifiers.

Power Supply

Reference has previously been made to auxiliary and main repeaters. This distinction relates primarily to the power-supply arrangements, a main repeater location being the power source for a group of auxiliary repeaters in the adjacent line section or sections.

At a main repeater station power is supplied by a motor-alternator set which produces 60-cycle power at 230 volts. The a-c motor of this set is driven from a commercial source. On the same shaft as the a-c motor and alternator is a d-c motor which is connected to the central-office batteries. If the commercial a-c power fails, drive for the alternator is immediately transferred to the d-c motor. In addition, a standby unit is operated continuously at no load to permit instantaneous switching under automatic control in the event of an equipment failure.

This plant provides operating voltages for the main station repeaters and also provides power, over a high-voltage power loop, to auxiliary repeaters in the adjacent power sections. The lengths of the power loops are determined by many factors, but the maximum length is generally restricted by the voltage limitations of the cable. Voltages in excess of the maximum permissible value produce corona noise and, possibly, dielectric breakdown.

A power loop consists of a series loop of the center conductors of two oppositely directed coaxials routed through the primary winding of power transformers at the successive auxiliary repeaters on one side of the main station to the farthest office on

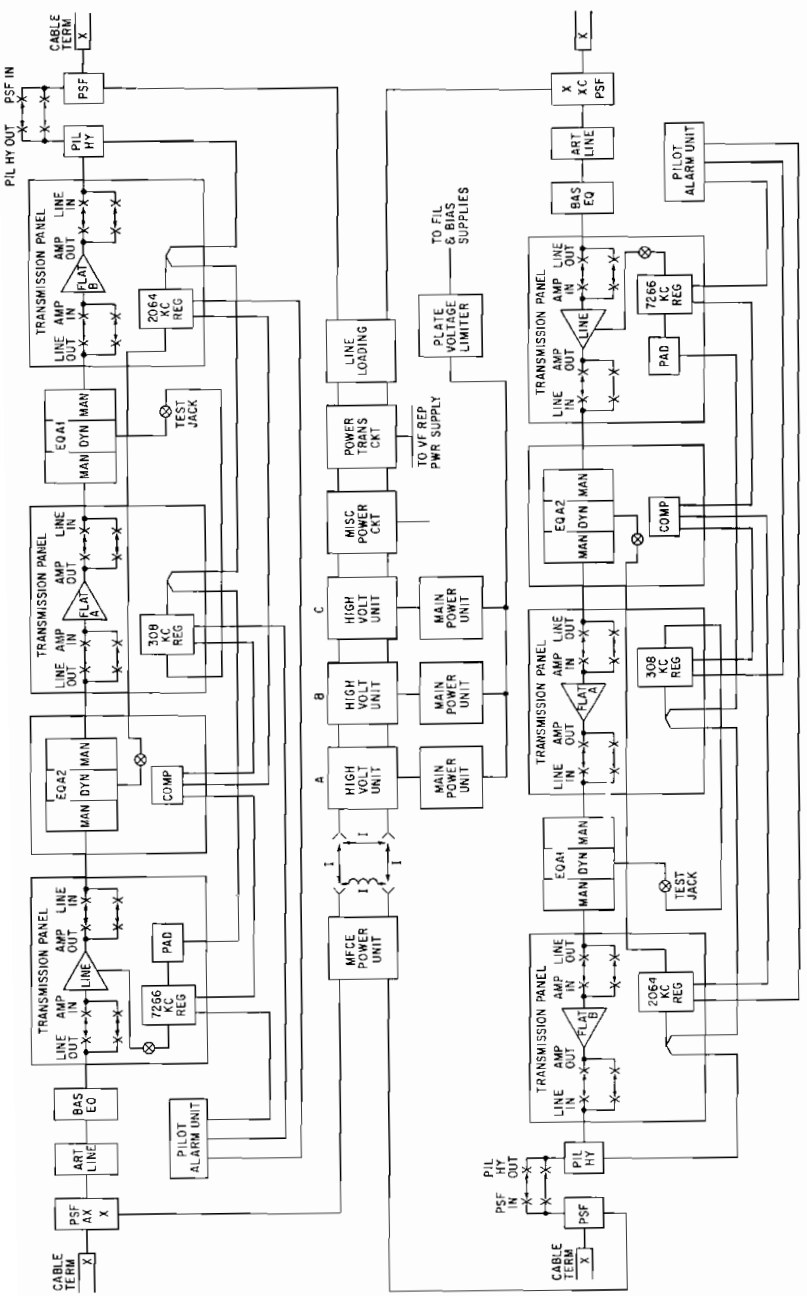


FIG. 1-17. Transmission schematic of an equalizing auxiliary repeater.

the loop where it is closed on itself through a power looping coil. At each auxiliary repeater the carrier and power frequencies are separated by power-separation filters. The power voltage is developed through a transformer at the main station, and a constant current is maintained in the loop by automatic regulators. The voltage is stepped down to the required value at each auxiliary repeater and rectified by bridge-type metallic disc rectifiers in a circuit designed to provide a constant resistance termination to the rectifier bridge. This provides almost unity power factor over the circuit and avoids the generation of harmful harmonics.

L-3 Amplifiers

It has already been noted that the regulating repeaters in the L-3 system include a line amplifier and flat-gain amplifiers while auxiliary repeaters have only a line amplifier. Reference has also been made to the production and quality-control methods

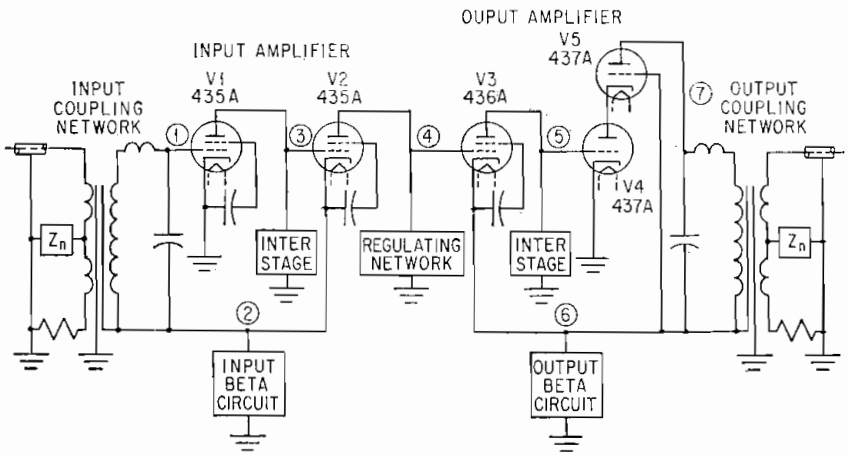


FIG. 1-18. Schematic of an L-3 line amplifier.

used in the manufacture of these amplifiers. The flat-gain amplifiers are essentially the same in design as the line amplifiers with only those changes necessitated by elimination of the interstage regulating network and some increase in feedback.

The basic amplifier configuration is shown in Fig. 1-18. It consists of two independent feedback amplifiers with a regulating network between them acting like a two-terminal interstage network. Each of the amplifiers is essentially a two-stage circuit, the input amplifier literally so and the output amplifier essentially so, since the double-triode output circuit acts like a single stage.

Each amplifier is connected to the coaxial through a coupling network which consists of a transformer plus gain-shaping and impedance-adjusting elements. Since there is no feedback around the coupling networks, they directly affect the insertion gain of the amplifier as do the two feedback networks and the regulating network. The required shaping of the insertion gain across the transmitted band is obtained and controlled by these networks, which constitute the first step of fixed equalization for the system.

L-3 Coaxial Video Terminal

A set of video terminals that has been developed to operate with the L-3 coaxial-cable system includes several important departures in design from those of the L-1

system. These terminals operate in the frequency range between 3,639 and 8,500 kc above a telephone band carrying up to 660 telephone channels.

The method of producing the line-frequency signal from the video input to the L-3 terminals differs from that employed in the L-1 system. In the L-1, the video-frequency signal is first translated upward in modulation to a frequency range well above the final line signal. One sideband is then eliminated except for a vestigial portion, and the remaining signal is then translated back down to the line-frequency range. This is the time-honored method for avoiding interference effects, where the sidebands to be transmitted partially overlap the original signal band.

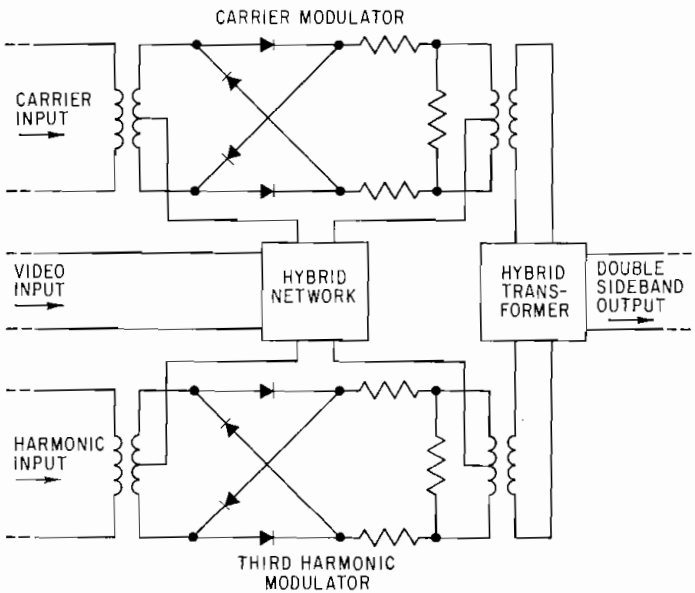


FIG. 1-19. Schematic of L-3 video modulator.

In the L-3 system, the sideband to be transmitted is produced by one step of modulation, and the products of the inevitable overlapping of fringe components of the original band and the sideband are suppressed by canceling them out in the modulator. Figure 1-19 shows a modulating arrangement employed which comprises two identical varistor-type modulators. The signal is fed to both modulators through the input hybrid network and modulates the carrier in the upper one. Some of the products of this modulation, lying in the lower sideband of the third harmonic of the carrier, overlap the upper sideband frequencies of the carrier and produce undesirable effects in the picture unless eliminated. A third harmonic of the same carrier is, therefore, supplied to the lower modulator and also modulated by the signal. This operation produces modulation products which can be made equal in amplitude and opposite in phase to the unwanted products from the upper modulator and thus made to cancel them in output. Great precision is, however, required in maintaining the necessary balance conditions in the modulator. Furthermore, a frequency stability of 2 ppm is required at this point to permit satisfactory use of carrier regeneration at the receiving terminal where product demodulation is employed. To accomplish this, a carrier oscillator with crystal-controlled frequency and thermistor-controlled amplitude is employed.

Excess-carrier-ratio Modulation

Still another new feature of the L-3 system is the use of "excess-carrier-ratio modulation," which means modulation greater than what is commonly known as 100 per cent. In the L-3 system, the carrier amplitude is made one-half of the peak-to-peak modulation amplitude and a saving of several decibels in maximum carrier power is obtained. This affords an advantage in signal-to-noise ratio, as the signal carries greater information in proportion to its peak amplitude than one produced by the more usual modulation relationships. This modulation feature, however, requires special demodulating arrangements.

At the receiving point, demodulation is accomplished by the use of the "homodyne," or "product demodulation," method, since use of envelope detection would produce a distorted signal. Product demodulation accomplishes the additional end of effectively eliminating the quadrature component which is inherent in vestigial sideband transmission and which would otherwise be excessive in the L-3 system because of the use of overmodulation. This requires very close phase relationship between the demodulating carrier and the carrier that produced the signal.

The demodulator oscillator in the L-3 receiving terminal is synchronized and held in the necessary close phase relationship with the transmitting carrier by reference to the phase of the carrier components in the vestigial sideband signal received, averaged over periods corresponding to about a single frame.

Another feature of excess-carrier-ratio modulation, however, does introduce a complication at this point. The polarity of the carrier reverses as it goes through half-peak value, so it cannot be used directly in obtaining a regenerated carrier but must be put through a "square-law" circuit. This produces a result which is free of polarity reversals, but the ability to indicate proper polarity has now also been eliminated. This is regained at a later point in the demodulator operations, however, by a polarizer circuit which recognizes the polarity of the video output signal coming from the demodulator from the characteristics of the vertical blanking and sync portions which occur 60 times per second. From this it is able to maintain the proper polarity at its output.

Automatic Switching

A standby high-frequency line is provided for either one or a group of working lines, depending upon the number of coaxials on the route. If only one working line is to be protected, both the standby and working lines are fed at the head end through a hybrid. Switching is thus required at the receiving end only. Where several working lines are to be protected, switching is provided at both terminals. The switches are controlled by an initiator which operates in response to a deviation in any pilot level.

When a 2-db deviation is registered in the initiator, it acts to cause a "slow" switch by:

1. Blocking the transmitting-switch control in the succeeding section for several seconds in order to prevent all switching sections from transferring.
2. Sending out an identification tone which initiates the switch transfer at the transmitting end of the section in trouble

When the transmitting switch transfers, a verifier tone is sent back which causes completion of the receiving-end switch.

When normal levels are restored, the control circuits operate to restore service to the working line and release the spare line for other switches.

The control system can be operated manually to release any line for maintenance work, or it can be disabled.

A "fast" switch is accomplished if the 7,266-kc pilot deviates from its normal range by ± 3.0 db. This is accomplished by feeding the rectified 7,266-kc signal to an electronic control circuit which eliminates the delay feature.

TV Branching

In its fundamentals, TV branching is relatively simple. At a TV service point the high-frequency line is passed throngh a receiving branching filter which separates the video and message frequencies. The video channel is then passed through the supplementary equalizers previously described and applied to the video terminal equipment. At a branching point where transmitting service is desired, the ontput of the video terminal is applied to a transmitting combining filter where it is combined with the message channel and fed to the line.

Television Operating Centers

General Functions

Network service is considered by the Telephone Company as a specialized service with respect to both operations and maintenance. For this reason all work incident to network service is concentrated in a single location in any city. These locations, designated program or television operating centers are normally in a telephone bnilding where long-haul communications facilities which serve that city are terminated. All the intercity network facilities and all the local facilities which provide the interconnections between the broadcasters' locations and the networks are terminated in these centers.

Since audio and video networks are derived from different facilities and are operated independently from each other, the program and the television operating centers are normally separate units, although they frequently are located adjacent to each other and are under the supervision of a single office chief. The functions of program and television operating centers are broadly similar.

The functions of a television operating center are briefly as follows:

1. To supervise the establishment and line-up of the network layout ordered by each customer on the facilities prescribed by the Engineering Department
2. To analyze customer service and operation orders and interpret them in terms of facility requirements and switching operations
3. To execute the switching operations incident to customer requirements from period to period
4. To keep informed of service conditions by frequent though not necessarily continuous inspection of monitors
5. To receive trouble reports from broadcasters in their local area and initiate appropriate action to clear trouble conditions
6. To make or supervise those routine tests which are necessary to ensure continuously satisfactory performance
7. To exercise general supervision over service in the area for which they are responsible

Control-office Plan

The amount of work performed at the particular TOC in any of the general categories listed is dependent upon the responsibilities delegated to that office under a control-office plan. Under this plan, New York operates as the general control office with responsibility for the over-all network operations. Other offices located at strategic network points, such as Chicago, Atlanta, Los Angeles, and others, are designated as control or subcontrol offices with specific responsibilities for certain network sections. The office in or nearest to the city where a broadcaster takes network service is responsible for the service to that station and maintains contacts with the station. Some offices having no network operating responsibilities, as such, are responsible for the transmission performance of the systems routed through them. It is seen then that any control or subcontrol office, for example, Chicago, will have all responsibilities.

Layout and Service Orders

As was outlined in the general section, customers' orders for network service are converted in the Engineering Department to terms of specific facility and equipment requirements, and orders are issued to all offices involved. The scheduling of the necessary facility changes and the testing and line-up of the new channels are coordinated by the control offices concerned.

Similarly, service orders and operation orders are transmitted to all offices involved. It is the responsibility of the control office, in consultation with other control offices when necessary, to make the specific facility assignments to meet the requirements and then to transmit this information to each office in his section. Each office, in turn, correlates the service orders he has received with the assignments and prepares his own detailed switching schedule.

Troubles and Maintenance

Trouble reports can be originated at any broadcaster's location and referred to his local serving TOC. All reports are relayed immediately to the control office where the trouble-locating procedures are coordinated. The normal procedure is to establish a patch or reroute as quickly as possible and then to clear the trouble on the regular facilities. Maintenance responsibility, like the regular service responsibility, is delegated through a control-office plan to an office which is made directly responsible for the maintenance of the failed facility.

Routine tests are regularly scheduled during nonservice periods on all components and on over-all channels to ensure reliable service. The intervals during which facilities may be released for testing are scheduled by the control offices. Each office then makes local and sectional tests to coordinate with the over-all line-ups which normally follow the local tests.

Office-equipment Arrangements

From the foregoing it is apparent that, aside from the clerical work of the operating center, the layout must be designed to permit two basic functions: switching and testing. Also, since the load varies among all offices, operating centers are not standardized but vary in size and equipment. Basically, however, a TOC provides a point where all the channels in the intercity networks and all the local channels which may be interconnected with the networks are brought to a common voltage and state of equalization. The inside cables by which the channels are extended from the carrier terminal room, the radio terminal room, or the local facility terminals are all equalized and, in the case of radio facilities, also include one or more knob-controlled variable equalizers. At the TOC, therefore, all channels look alike at the switching point and hence can be interconnected by video switches.

In an office where only one station is fed and there is no requirement for switching, the incoming channel is connected directly to distribution amplifiers. The distribution amplifiers have high-impedance inputs which are arranged so that several can be bridged across a terminated incoming line and provide unity gain which is nominally flat over the video band. In the one station office, two distribution amplifiers are bridged on the line with negligible effect on transmission. One output is used to feed the customer, and the second to feed the office video monitors.

High-impedance Switching

In an office that feeds two or three stations and where switching is necessary, the incoming lines are connected to the horizontal, terminated busses of a manual push-button switch. The inputs of the distribution amplifiers from which the outgoing lines are fed are connected to successive verticals of the switch. The operation of a push button connects the input horizontal to the output vertical at the particular cross point.

Through mechanical interlock, any other switch in that vertical is disconnected so that an outgoing line can be fed from only one source.

The basic push-button video switching panel consists of ten inputs and six outputs and is provided with push buttons at the 60 cross points. For larger requirements panels can be multiplied horizontally and vertically. When it becomes necessary to feed more than three outgoing lines on a high-impedance basis, special measures are necessary to maintain high-frequency equalization and the switch flexibility is seriously impaired. For this reason the use of the push-button panel is limited to the smaller offices where the number of outgoing lines connected to any incoming bus is less than four.

In both of the foregoing arrangements testing equipment is normally provided on a portable basis and is moved to the patching bays on tea wagons when in use.

Low-impedance Switching System

In the larger television operating centers the manual push-button switch has been superseded by a low-impedance switching system. Any new installations will be on this basis. The more important features of this system are:

1. Switching is done on a 124-ohm balanced basis rather than on a high-impedance bridging basis.
2. The control panel actuates only d-c control leads. The actual switching is done by wire spring relays in the equipment bay.
3. The basic building block is a 10 by 12 unit which can be used in various combinations up to 30 by 36.
4. All unused inputs and outputs on the switch are terminated so that the load on any input circuit is constant.
5. Switch operations can be preselected, checked, and then operated when required.
6. Individual switches can be operated, or groups of switches can be transferred to one of four "salvo" controls. Operation of a salvo causes rapid sequential operation of each switch transferred to that group.
7. The condition of any switch is indicated at all times by signal lamps on the control panel.
8. The control panel can be adapted to remote-control systems to control video, audio, or IF switches.
9. The cabling and circuitry of the switch are capable of flat transmission through 10 Mc, but the amplifiers presently installed are limited to 4.5 Mc.

Switching Plan

The principle of the switching system is illustrated in Fig. 1-20, which shows the plan of a 10 by 12 unit.

Each incoming line is connected to a 1 by 12 resistance splitting pad. The through loss of this pad is about 27 db, and the loss between any two outputs is 54 db, which is sufficient to prevent interaction between output circuits. Figure 1-21 shows the physical structure of the splitting pad. One incoming line is reserved for a test trunk whose function is described later.

Each output branch of each splitting pad is cabled to the 10 by 12 switching unit as shown in Fig. 1-20. This unit consists of 12 blocks of 10 wire-spring relays which perform the actual video switching. Each of the 10 relays in a block connects to the same output channel, and the 12 blocks care for the 12 outputs. One relay in each block connects with one branch of each input splitting pad, so that every output circuit has access to any input circuit.

When it is desired to expand the switch capacity, a 1 by 3 splitting amplifier is connected to the input of each splitting pad so that each incoming line now can be connected to a maximum of 36 outputs. On the output side of the switch a 3 by 1 relay is added to permit the selection of one of a group of three 10 by 12 units and thereby to increase the input capacity to 30 lines. This is the present design maximum. The cabling arrangement is shown in Fig. 1-22.

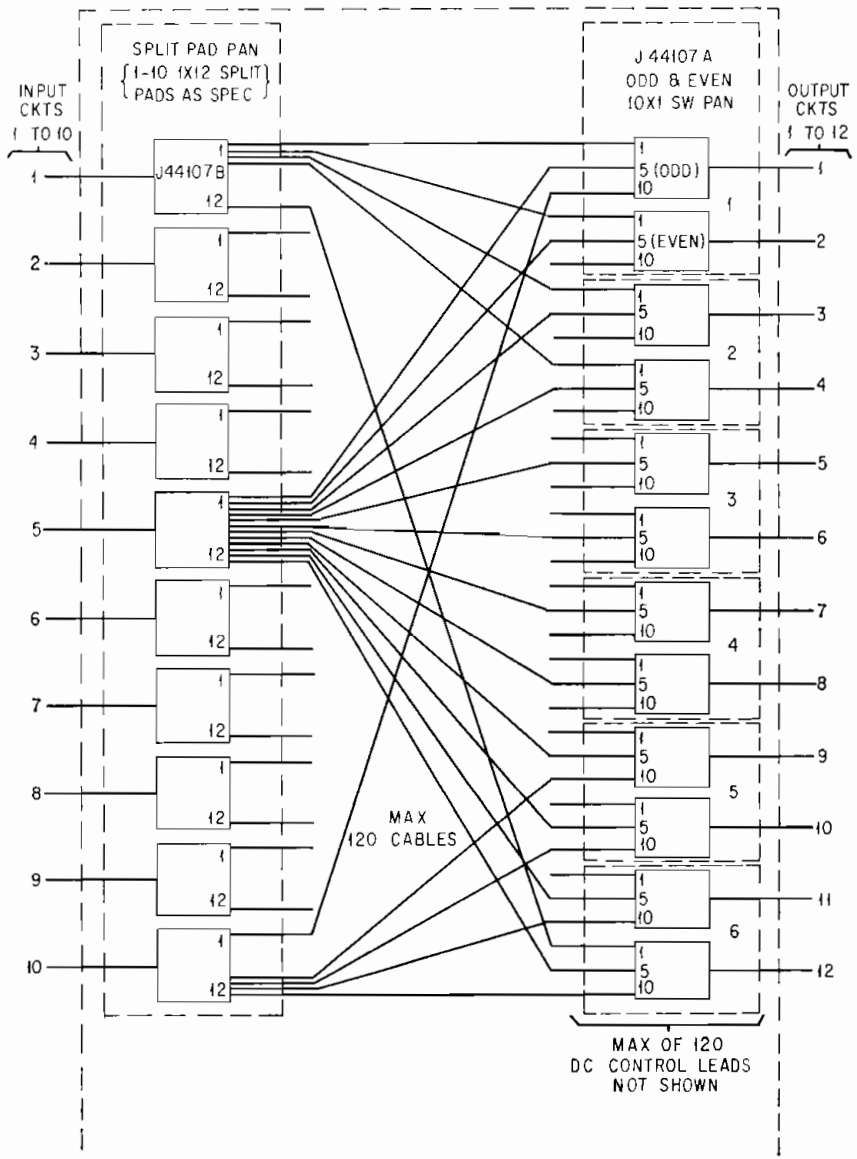


Fig. 1-20. Basic 10 by 12 switch unit.

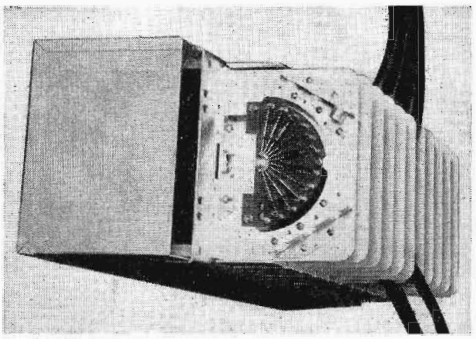


FIG. 1-21. Mounting arrangement for 1 by 12 splitting pads.

Switching Equipment

The wiring and cabling for each switching system are laid out and installed to meet the anticipated ultimate requirement for an office but are not necessarily fully equipped initially. Careful control is exercised to ensure that all cables between common points in all switching paths are cut to uniform lengths and within definite limitations. By this means uniform transmission is assured between any switch input and any switch output. It is also the reason for installing cabling initially to meet the ultimate requirement.

The transmisison losses in the switch are compensated by an amplifier in each output circuit. This amplifier is identical with the receiving terminal amplifier used in the A2A system and is therefore designated an RTA. The 1 by 3 splitting amplifier does not provide gain with respect to the over-all switch but provides zero loss between the amplifier input and each of the three outputs. All switch components are designed for 124-ohm balanced interconnection.

Transmission loss through the switch from the input-video patch-bay jack to the output-video patch-bay jack is not flat but is designed to have a cable shape roll-off characteristic which can be compensated by variable cable equalizers associated with the channels connected to the switch. Channels connected to the switch are equalized flat only to a point *X* internal to the switch at the 10 by 12 switching units where the channels are actually switched. Access to point *X* is obtained only through input and output test trunks. Interconnections of facilities at points other than point *X* will not be properly equalized unless special steps are taken.

Test and Monitor Trunks

Depending upon the size of the switch, one or two inputs and outputs are designated as test trunks. Each of the test trunks can be equalized to be perfectly flat from point *X* to its termination in a "test" bay. Input and output switch-control leads are also extended to the test bay so that the input test trunks can be remotely switched to any outgoing channel or any incoming channel can be switched to an output test trunk. Since the switched connection is made at point *X* and the test trunks are maintained at zero flat loss, all testing equipment is effectively connected to point *X*.

From each 10 by 12 switching unit two output trunks are connected directly to monitor and control positions. These trunks are also carefully adjusted to zero flat loss from point *X* to their termination. Switch-control leads are extended to the monitor positions so that the video monitors can be connected to monitor any incoming channel. Voice communication circuits which parallel the routes of the channels controlled by a particular office and direct talking circuits to local broadcasters' locations and to other terminal rooms in the building are also terminated in the monitor positions. An attendant, therefore, has immediate access, through automatic signaling,

to all points in his control section for directing trouble-locating activity, arranging temporary reroutes, and all other functions incident to video-network operation.

Testing functions are concentrated at the test position(s) where access to all chan-

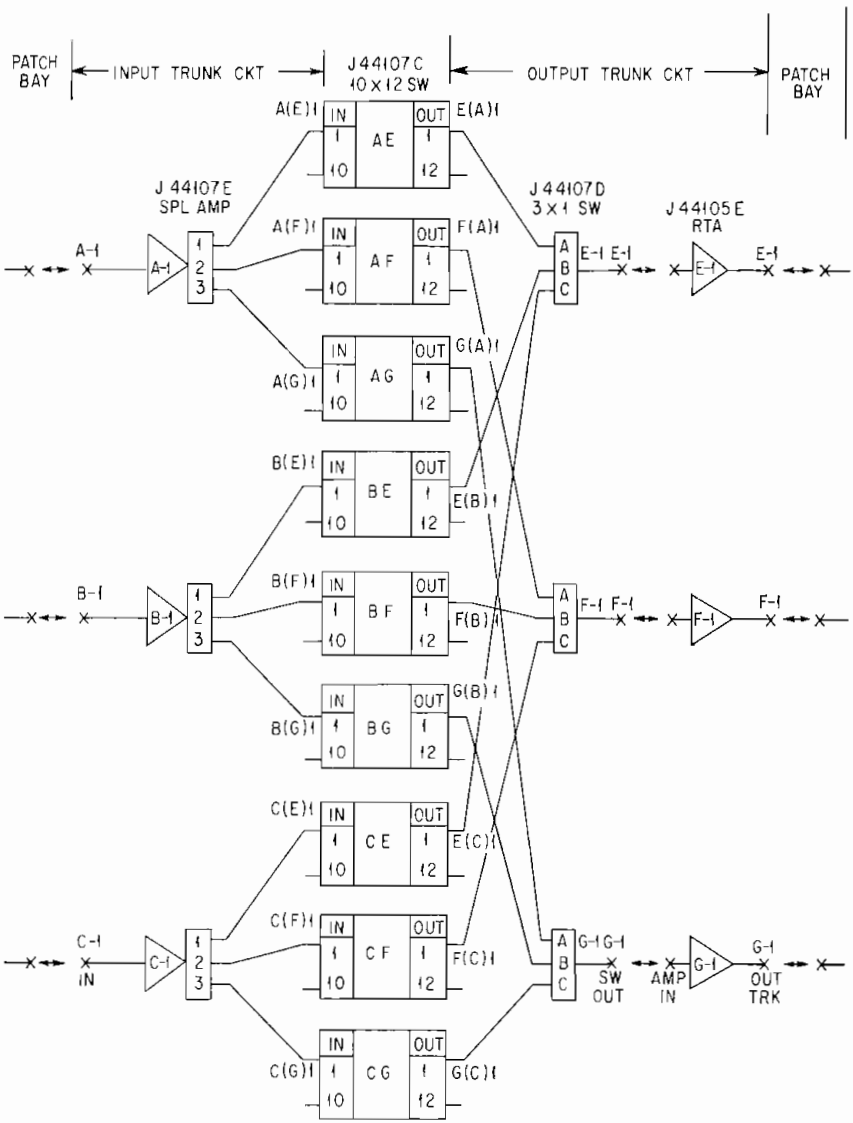


FIG. 1-22. Cabling plan of a 30 by 36 video switch.

nels is provided by the test trunks previously mentioned, and communication is provided by multiples on the monitor position circuits. All the test equipment is mounted in these positions, and any unit can be connected to the test trunks in a small patching jack field where the units are terminated through cables carefully cut to uniform length.

Switch Control

Switching is controlled from the control panel where d-c control leads are terminated in a coordinate pattern. All incoming lines are arranged on the horizontal and all outgoing lines on the vertical rows. Signal lights are provided at each intersection.

Preselection is accomplished by simultaneously operating the buttons opposite the horizontal and vertical which represent the channels to be connected. This brings up a white signal light at the intersection. This preselected switch can, if desired, be transferred to a given salvo row, on a horizontal along with other preselected switches which must be made simultaneously. Four salvo rows can be provided, and any number of preselected switches up to the capacity of the switch can be transferred to any one of the salvo rows. Upon completion of preselection the entire board can be checked against the switching schedule by a second attendant by observing the condition of the signal lamps. Errors can be corrected by operation of an ANNUL button. Actual operation of the switches is completed on cue by simultaneous operation of a MASTER EXECUTE button and the appropriate individual vertical or salvo button. As mentioned previously, the control panel can be arranged to control remote video or IF switches as well as local video switches, and they can be assigned to the same salvo for simultaneous operation. Completion of the switch is indicated by a red signal lamp at the intersection which represents the connected channels.

The master control panel supersedes the switch controls at the test bay in that the test-bay switch controls will not function unless the switches at the master control have been operated to the NO SERVICE position. This makes it impossible for anyone at the test position inadvertently to open a channel which is in service.

Objectives of Video-network Transmission

General

It was pointed out in the general section that the video network provided for any broadcaster is not necessarily a permanent combination of facilities but rather is a variable combination of television sections (TVS's), probably combining several types of video facilities and provided from day to day as required. Because of these variations it is not feasible to specify transmission objectives for a network. Instead, the individual TVS's are lined up and adjusted within tolerances such that all normal combinations, including local interconnecting channels, will provide a satisfactory grade of transmission over all. When certain combinations of facilities, through daily use, become identified with one broadcaster and the pattern of operation is relatively fixed, over-all tests are made periodically to check over-all network transmission and particularly to verify that the deviations in individual TVS's are not adding cumulatively in the same direction to result in an unfavorable over-all characteristic.

Video-network facilities are provided for the transmission either of a monochrome signal or an NTSC color signal. The transmission requirements for both types of facility are essentially the same, with the exception that for color transmission the frequency response in the region of the 3.58-Mc color carrier must be more closely controlled and differential phase and gain must be kept within definite tolerances. A channel which has been lined up for color transmission will, of course, satisfactorily transmit a monochrome signal, since the measures taken to provide color transmission also enhance monochrome transmission.

Levels

All telephone company video-transmission systems are designed to operate with a 1-volt peak-to-peak signal at those input and output terminals which are located either at customer locations or at TOC's. Different levels may apply at junctions of different types of facilities at points other than TOC's, but they are established with respect to the TOC reference level.

Transmission level measurements of single-frequency sine-wave signals are made with thermocouple-type instruments which are calibrated in decibels. Here, the

1-volt peak-to-peak signal is considered as the reference of 0 dbv and the decibel reading of the meters are based on the fundamental relationship

$$db = 20 \log \frac{V_2}{V_1}$$

where V_2 is the measured voltage and V_1 is the 1-volt reference voltage.

Single-frequency level measurements and adjustments are made only on an out-of-service basis. Adjustments are provided on all channels, either in the facilities or in the TOC terminating circuits, so that they can be adjusted within ± 0.5 db of the required level.

In-service checks of levels are made with oscilloscopes equipped with IRE scales and with vertical amplifiers having a standard IRE roll-off characteristic. In this instance the 1-volt peak-to-peak reference corresponds to 140 divisions on the IRE scale. When level variations occur during service, temporary adjustments can be made based on the scope reading. On all scopes used in the TOC's, the amplifier characteristic is switch-selected. It is important that all scopes used to determine where the level has varied and, hence, where the temporary adjustment should be made are adjusted to the IRE characteristic because use of a wideband scope characteristic could lead to errors. Whenever a temporary in-service adjustment is made to compensate for a variation in network facilities, it is followed up by single-frequency transmission measurements during the next out-of-service period in order the sectionalize and correct the cause.

Frequency Response

The low-frequency-response characteristics, up to about 250 kc, of all video channels are maintained to very close tolerances in order to avoid streaking and smearing. The characteristics are measured by the use of single-frequency sine waves and power meters. Waveform transmission in the low-frequency range is checked by observing the transmission of a "window signal," which is a critical indicator of low-frequency-transmission impairment.

In the high-frequency range different tolerances apply to color and monochrome channels. Color facilities in general are equipped with special equalizers which operate in the range of the color carrier and its sidebands. These equalizers are used to adjust the high-frequency characteristics to close tolerances. Typical objectives for color and monochrome channels on TD-2 facilities for single-frequency sine waves measured with power meters are shown in Fig. 1-23. It will be noted that the ob-

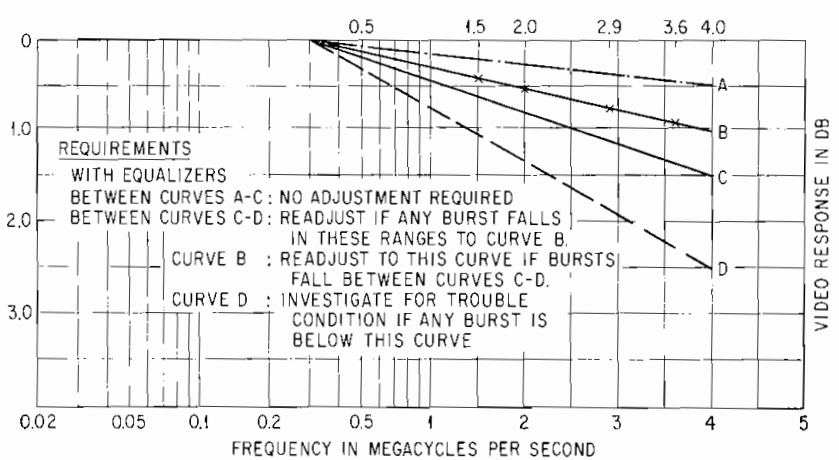


Fig. 1-23. Typical frequency-response objectives for TD-2 channels.

jective is to maintain a slight roll-off in order to minimize any tendency of the channel to ring.

Rapid checks of over-all channel characteristics are made using the multiburst signal. In addition to giving an indication of the frequency response of the channel at the burst frequencies, this signal also indicates sync compression or other distortions of the synchronizing pulses, video compression, harmonic distortion, and axis shift. Any of these impairments in the transmission of a composite waveform can be related to normal transmission parameters of the facility and can be sectionalized and cleared.

The tendency of a channel to ring, that is, to set up damped oscillations following rapid signal transitions of relatively large magnitude, can be checked by transmitting a sine-squared pulse and observing the magnitude of any oscillations.

Differential Phase and Gain

Differential phase and differential gain, as defined in the IRE Standards, are not significant in monochrome transmission but require close control on channels for NTSC color transmission because of their effect on the hue and saturation of the color signal. All the facilities designed for video transmission, with the exception of the TD-2, exhibit satisfactory differential phase and gain performance without supplementary adjustment when all components are operating normally. Any deviation from the normal differential phase and gain performance on these systems can therefore be traced to some system irregularity, and no supplementary adjustments are necessary.

In the TD-2 system the video signal is converted to a frequency-modulated intermediate-frequency signal centered on 70 Mc. The negative and positive voltage peaks of the video signal thereby are shifted to positions at about 74 and 66 Mc in the IF band. The portions of the signal intermediate between maximum and minimum occupy positions between 74 and 66 Mc in proportion to the amount the rest frequency is shifted in response to the input voltage change. In the IF portion of the TD-2 system therefore, the relative phase shift of the carrier for different levels of the video signal is directly dependent upon the delay-frequency characteristic of the IF path. If the delay in this path can be made uniform, then video differential phase will be zero.

A series of IF delay equalizers has been developed, and all TD-2 channels are delay-equalized periodically on a switching section basis. The equalizers are placed in the main-line IF paths.

For color transmission the differential phase of a 3.58-Mc signal is of particular interest. The over-all delay equalization of the radio facilities is therefore supplemented by routine TOC-to-TOC measurements of the differential phase and gain at 3.58 Mc. When required, additional equalizers are placed in the IF side leg or dropping leg at each service point to reduce the differential phase to a minimum.

As in the case of other facilities, differential gain is not a problem when all system components are operating normally.

AUDIO-NETWORK FACILITIES

Local Audio Channels

Facilities

Local audio channels include those provided between remote studios and master control, between studio and transmitter, and between master control and the point of interconnection with the intercity networks. These channels normally are concentrated in metropolitan areas and, generally, are relatively short. The wire facilities for these channels, therefore, are usually pairs in exchange area cables.

Whenever the length of the local channel is such that an intermediate amplifier is not required, nonloaded cable facilities are used in preference to loaded cable facilities because they can be equalized by relatively simple means.

If the length of the local channel is such that nonloaded facilities cannot be used

without intermediate amplification because of noise or cross-talk considerations, loaded facilities of suitable bandwidth can be used in preference to providing an intermediate amplifier. However, when an intermediate amplifier is necessary, either loaded or nonloaded cable can be used as the wire facility.

Equalization

Equalization is the process by which the loss of a transmission channel is adjusted to be approximately equal at all frequencies in the required transmission band. In the audio range this normally involves introducing low-frequency-loss components which complement the high-frequency loss of the cable facilities. Two methods are widely used to accomplish this on nonloaded local channels. One is to bridge across the receiving terminal of the channel an attenuation equalizer which is adjustable to meet the requirements of different lengths of facilities. The second is to apply 4-to-1 impedance-ratio transformers at the two terminals of the channel with the low-impedance side facing the cable. The transformers introduce mismatch losses at the low frequencies and can, thereby, equalize short lengths of cable depending upon the bandwidth desired and the gauge of the conductors. Transformers can be used alone for equalization, but when an adjustable equalizer is applied it is almost always used in conjunction with a transformer. Transformers alone can be used to provide transmission uniform to within about 1.0 db from 35 to 8,000 cycles for the cable lengths and gauges shown in Table 1-3:

Table 1-3. Lengths of Nonloaded Cable Which Can Be Equalized by the Use of 4-to-1 Coils

Gauge	*Length, miles*
16	5.0
19	2.3
22	1.5

Beyond these lengths an equalizer is required, either by itself or in conjunction with the 4-to-1 transformers. For those circuits involving the transmission of frequencies from 30 to 15,000 cycles, the equalizer and transformers are generally used together to provide a circuit whose transmission frequency response is uniform within about 1 db of the response at 1,000 cycles.

When facilities are specially constructed for long-term service, loading can be applied in the same pattern as is used on long-distance cables. For these facilities, type 17 equalizers, which are described later, can be used to secure the required transmission characteristic.

When equalized local channels are furnished and no special requirements are imposed as to the arrangements to be provided, equalizers and 4-to-1 impedance-ratio transformers are likely to be installed in combination. The same transmission characteristics on an over-all channel can be obtained when a 1-to-1 impedance-ratio transformer is used, by proper adjustment and choice of the equalizer, except in the cases of channels of irregular make-up or of lengths approaching the limits which can be equalized as one section. Other considerations, such as are involved in the use of volume indicators, may determine the more satisfactory arrangement.

Equalization is always applied at the receiving terminal of a channel in order to minimize the possibility of excessive noise and cross talk being experienced as a result of low signal levels. In those cases where a channel may be used for either transmitting or receiving, duplicate equipment is provided at each terminal which can be connected or disconnected readily to provide equalization at the receiving terminal in either case.

Transmission Objectives

Channels for local service are provided to transmit the band of frequencies specified by the customer in his order. Within this band all frequencies are to be transmitted with uniform loss within abont 1 db.

The over-all noise on 5-kc local channels will not exceed 36 db above reference noise (program weighting) measured at the receiving end of the circuit with a 2B noise-measuring set and with the input terminated in 600 ohms, and no intelligible cross talk (words or syllables) will be audible. This will be equivalent to a signal-to-noise ratio of 62 db at the +8 VU transmission level points and will be adequate on all channels on which the equalized net loss does not exceed 12 db.

Signal levels in excess of +8 VU should not be transmitted over local channels in order to avoid the possibility of cross talk into other communications channels. Signal levels should be carefully checked and maintained by the proper use of standard volume indicators.

Volume Measurements

It has been pointed out that audio program networks are frequently rearranged by switching operations and that the point of program origin is not always the same. Networks are not necessarily lined up as over-all entities but are lined up as sections in a manner such that normal switching operations and reroutes due to trouble conditions can be rapidly effected without transmission adjustments. In the over-all network, different levels may exist at different points at any one time, depending upon the types of equipment and facilities assigned and their operating requirements, but the over-all system is so adjusted that these levels will be correct when the input level is correct. It is obvious that an incorrect level at the input to a system which has been properly lined up will result in incorrect levels throughout the system. It is also apparent that an adjustment made in one part of a system to compensate for a variation in another part of the system can seriously interfere with the entire coordinated operation.

Excessively low volume levels at any point will result in objectionable noise being heard on the over-all system, and excessively high levels will result in undesirable distortion, particularly that which results from amplifier overloading. To ensure that neither of these conditions occurs it is essential, therefore, not only that all channels be correctly aligned in transmission tests but also that the volume level of the program material at the source be correctly maintained. The transmission line-up of network facilities is a telephone company responsibility, and the responsibility for maintaining correct levels at the program source rests with the broadcasters.

The local channel is the meeting point between the telephone company and the broadcasters, and it is at this point that the principal need for uniformity of thought and practice exists. For this reason the following discussion of volume measurements, although it applies to over-all network operation as well, is included in this section on local channels.

Transmission line-ups of program units are based on the use of a single-frequency signal at 0-dbm level at the +8-VU input point to the unit, and the levels at all points are adjusted with respect to this fixed level. It is the nature of program material, however, to vary considerably in volume, the range of variation and the maximum volumes being dependent upon the type of program. The operating conditions on a network, therefore, are vastly different from the line-up, so it becomes necessary to correlate the volume of program material with the level of transmission measurements. The standard volume indicator, having the characteristics prescribed in "American Recommended Practice for Volume Measurement of Electrical Speech and Program Waves," ASASPC 16.5, 1942, is accepted as the industry standard for this purpose, and it is used for the measurement and comparison of program volumes at all significant network points. The correct use and interpretation of the readings of these instruments are therefore of primary importance in proper network operation.

To maintain volumes which are satisfactory within the tolerances of network facili-

ties, the technique of controlling volume at originating points consists of keeping the average maximum volume as close as possible to +8 VU without having to reduce too many volume peaks with a consequent loss of volume range. If this average maximum volume is maintained at the zero-transmission-level point at the input to the local channeel, then correct levels will obtain throughout the network. It also follows that the same volume should be read at all other network points which have been lined up to zero level on single-frequency line-ups. The readings at any other points can be corrected to an equivalent zero reading. Then by simultaneous readings at various points it is possible to verify that all network sections are operating properly or to determine in which section or sections deviations exist.

Information concerning the circuitry and calibration of the volume indicator is available in other literature. The following information relates specifically to certain conditions which may be encountered in network operation where the proper interpretation of volume indicator readings is dependent upon the manner of connecting the instrument to the circuit.

Methods of Connecting Volume Indicators

In the methods of use of volume indicators illustrated in this section the use of amplifiers with 600-ohm input and output impedances is assumed and the gain of the amplifier is the gain measured with a 600-ohm measuring set.

Figure 1-24 shows two variations of a method of use of the volume indicator in which it is connected permanently across the circuit or loop on which the volume is to be measured.

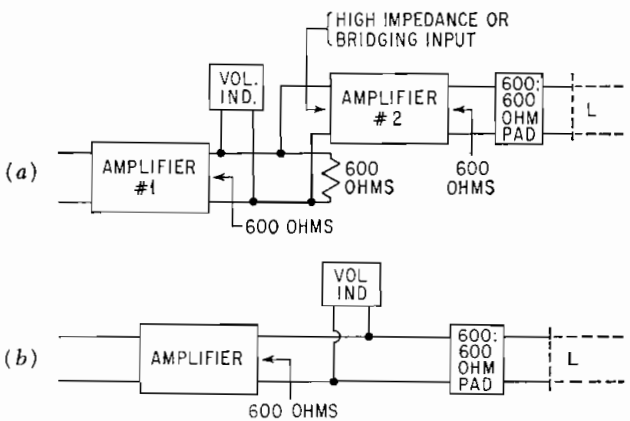


FIG. 1-24. Volume indicator permanently connected across loops.

In the arrangement shown in Fig. 1-24*a*, the indication of the volume indicator plus the gain of amplifier 2 minus the loss of the pad is considered the volume at point *L*.

In the arrangement shown in Fig. 1-24*b*, the volume indicator reading minus the loss of the pad is considered the volume at point *L*.

NOTE: In some cases the impedance of the loop or circuit may differ from 600 ohms by such an amount as to require a correction to the actual volume-indicator reading. This correction can be determined as given under the Correction of Volume-indicator Readings.

The arrangement shown in Fig. 1-25 is used by the Telephone Company at many network branching points where it is necessary to feed a number of circuits simultaneously. The resistance bridge has constant loss and impedance for all branches. Amplifier gains either are identical or differ by calculated amounts, depending upon

the types of circuit being fed. The volume indicator is connected to one of the branches through its own amplifier. It does not, therefore, affect the power transmitted to the various branches.

With equal pad values and with amplifiers 1 and 2 set for identical gains, the indication of the volume indicator is considered the volume at point *L*.

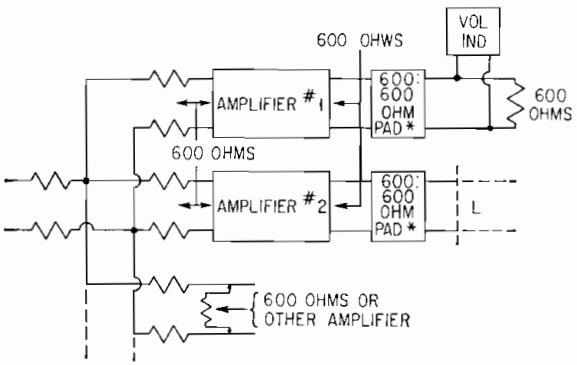


FIG. 1-25. Volume indicator connected across a bridge output.

The volume indicator in the arrangement shown in Fig. 1-26 does not take any power from the main circuit.

The volume-indicator reading minus the gain of amplifier 2 less the loss of the pad gives the volume at point *L* (see note regarding circuit impedances).

Figure 1-27 shows two ways of connecting volume indicators by means of bridge circuits.

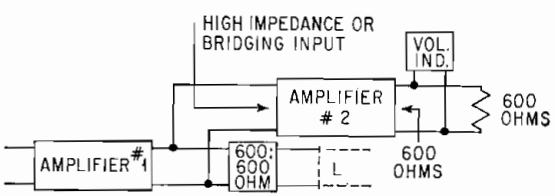


FIG. 1-26. Volume indicator bridged across a 600-ohm termination.

The volume-indicator reading, without any correction, is considered as being the volume at point *L*. The loss introduced between the amplifier and point *L* in either case is about 6 db. The balance obtainable with an amplifier of 600-ohm nominal output impedance should be sufficient (practically) to eliminate any effect of the loop impedance upon the volume-indicator readings. The entire wiring of the unbalanced circuit *A* should be shielded.

Transmitting Pads

The readings of a volume indicator on average program material are influenced mainly by the energy in the frequencies below 1,000 cycles. The impedance below 1,000 cycles, presented by a local channel, therefore is of most importance in its influence on the readings and, consequently, on the amount of isolation needed between the volume indicator and the local channel for correct readings. For the usual channel of nonloaded cable this impedance varies with frequency, the range of variation depending upon the length, the gauge of the conductors, the equalizing arrange-

ment applied, and, if a transmitting transformer be used, its impedance ratio. If this is a 1-to-1 impedance-ratio transformer or if the transformer is omitted altogether, a 6-db pad will normally be sufficient to make the readings of the volume indicator on average program material agree within 0.2 or 0.3 db with what they would be if the volume indicator faced a pure 600-ohm resistance in the direction of the local channel. If, however, a 4-to-1 impedance-ratio transformer is used at the transmitting point, as is done in most nonloaded cable equalizing arrangements, the impedance faced by the volume indicator will be much higher than with a 1-to-1 impedance-ratio transformer and the errors in the volume-indicator readings, even with a 6-db pad, may be

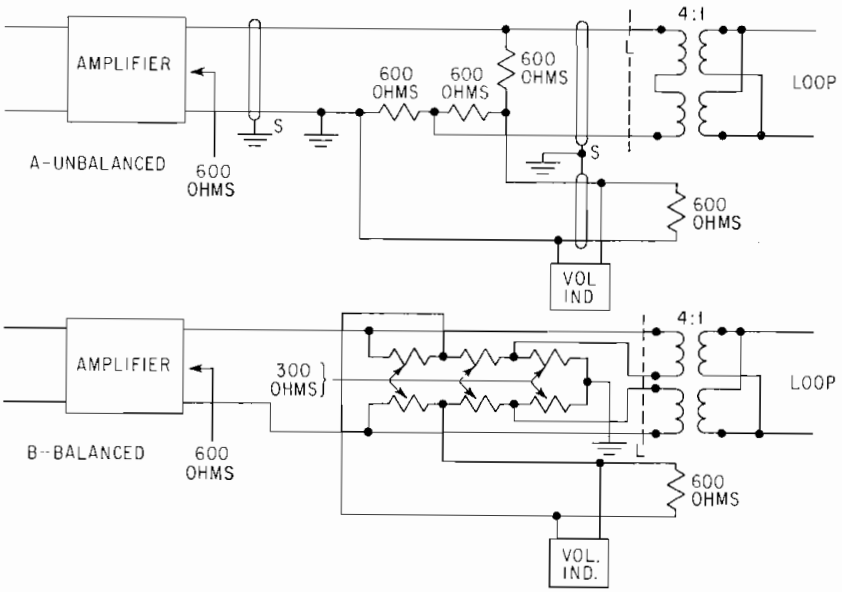


FIG. 1-27. Volume indicator connected by bridge circuits.

1 db or more. Use of larger pads will reduce these deviations, but this will increase the outpnt requirements on the amplifier, and alternative arrangements, as discussed subsequently, should be considered.

Most amplifiers now in use in broadcasting plants for transmitting into local channels have adequate output capacity to permit use of 6-db isolation pads and still apply a +8-VU level to the local channels without objectionable distortion.

Taking all the foregoing factors into consideration, 6 db should be the minimum value for an isolating transmitting pad where a transmitting transformer of 1-to-1 impedance ratio is used or where the transformer is omitted entirely.

Special Isolating Measures

Where a transmitting transformer of 4-to-1 impedance ratio is used, other measures will be required for obtaining a correct indication of the volume being transmitted to the loop. Among these may be mentioned:

1. The use of pads larger than 6 db where practicable.
2. The application of specially designed impedance-adjusting pads.
3. The use of pads which provide isolation between two branches of a circuit by application of the Wheatstone-bridge principle.
4. The connection of the volume indicator to a paralleling branch of the circuit

having a separate amplifier, as is shown in Fig. 1-25. This arrangement is one used quite generally by the Telephone Company in its offices.

An example of a balanced-type output circuit is shown by Fig. 1-27*b*. The circuit in this case case incorporates a 4-to-1 impedance-ratio transformer connected to the local channel. The loss of this circuit is about 6 db, and the isolation of the volnme indicator will, as in the previous example, depend upon the match between the amplifier impedance and 600 ohms but will normally be several times the amount of loss introduced into the circuit by this arrangement.

Correction of Volume-indicator Readings

Under Transmitting Pads, various measures arc considered for reducing the influence of a nonuniform channel impedance on the accuracy of volume-indicator readings. Application of some of the arrangements discussed, particularly in the cases of Figs. 1-24*b* and 1-26, may still leave an objectionable residual error. The amount of this error at any given frequency (say 400 or 500 cycles) can be determined by comparing the volume-indicator reading (at that frequency) when the channel is connected in the normal operating condition with the corresponding volume-indicator reading obtained when a 600-ohm resistance is substituted for the channel.

In this test the transmitting transformer, if used, forms part of the channel and should be disconnected along with the channel when the 600-ohm resistor is substituted. Tones of the frequencies mentioned can safely be transmitted at 0 dbm without danger of interference with neighboring circuits, and their effect on volume indicators compares closely with that of average program material for a test of this kind.

Where the difference between the two readings obtained in this test is not more than 0.3 db, it will usually be satisfactory to care for this by adjustment of the slide-wire resistor in the volume-indicator circuit. The procedure in this case is as follows: Make sure the volume indicator has been properly calibrated for use as in Fig. 1-24. Connect the 600-ohm resistance in place of the channel, and adjust the testing tone until the volume indicator shows the volume level to be transmitted (e.g., +14 VU with a 6-db pad). Disconnect the 600-ohm resistance, and reconnect the channel. Adjust the slide-wire until the volume indicator again reads +14 VU.

If the correction is found to be larger than 0.3 db, compensation by this method might disturb the dynamic characteristic of the volume indicator to an undesirable degree and other measures for reduction of the deviation, as discussed under Transmitting Pads, should be considered.

If a deviation of any appreciable magnitude is not to be corrected physically, the corrections should be applied algebraically in checking measurements with other points.

In the case of the method of use shown in Fig. 1-26, the correction can be determined by the same procedure as just described for Fig. 1-24. In this case, however, the gain of amplifier 2 is adjusted to obtain the desired compensation.

In the arrangements shown in Figs. 1-24*a*, 1-25, and 1-27, no deviations due to the effect of loop impedance will be involved.

Volume-indicator Scale for Peak Checking

Peak checking between the Telephone Company and the broadcasters will normally be done by reference to the 0 to 100 scale on the volume indicator.

The broadcasters prefer the use of the 0 to 100 scale because it is applicable to direct indication of the per cent modulation of the radio transmitter or the per cent utilization of the facilities involved.

Differences in volume should preferably be discussed in terms of decibels. The justification for this lies in the relationship to the need for changing amplifier gains or pad values, which are designated in terms of decibels. The use of the term VU in this connection is permissible, although incorrect.

Intercity Facilities—The B-22 Cable System

Cable Facilities

The B-22 cable program system was developed to provide a high-quality network transmission system capable of transmitting a frequency band from 35 to 8,000 cycles. The wire facilities are 16-gauge pairs which are included in intercity cables along with other long-haul wire facilities which are normally quadded.

The designation B-22 relates to the pattern of loading of the facilities. Loading consists of connecting into each pair of wires in the cable lumps of inductance in the form of loading coils whose function is to counteract the distributed capacity of the pair. While this inductance does reduce attenuation, the combination of inductance and cable capacity creates a filter configuration which has a definite cutoff frequency. This is related to the amount of inductance added and the spacing between loading points. The B-22 system employed for cable program transmission facilities is based on the use of 22-mh inductance coils every 3,000 ft, or B spacing.

Intercity cables usually are composed of quads of wires. That is, two wires are twisted to form a pair and then two pairs are twisted to form a quad. The four wires of each quad are carefully balanced in order to permit the derivation of a third channel, or phantom, from each quad. For the B-22 program facilities single or non-quadded 16-gauge pairs are used which are laid up in the cable with the 19-gauge quadded complement. This cable make-up results in improved performance with respect to cross talk, babble, and other interferences. Connection from the cable facilities to office equipment is made through a lead-covered cable which connects the two units directly, bypassing office distributing frames. This cable is made up in quads, but only one pair in each quad is used, the idle pair providing separation to reduce cross talk.

Program Amplifiers

Two types of program amplifiers are in general use on B-22 cable systems: the 12-C and 14-C. The 12-C program amplifier is a two-stage amplifier using W. E. Co. 101F and 102F tubes. It is designed for essentially flat gain from 35 to 8,000 cycles with an output level of +4 VU and a maximum gain of 36.5 db. On 5,000-cycle circuits it can be operated at +8-VU output level. The input and output impedances are 600 ohms.

The input circuit is provided with a shielded input transformer to prevent longitudinal potentials which originate on the line from acting on the amplifier circuits. Following this are two pads for coarse-gain adjustment and terminals between which any required gain- and delay-equalizing networks can be connected. The interstage is a resistance-capacitance network which provides satisfactory low-frequency delay distortion. Terminals are provided in the output circuit for connection of automatic-gain-regulating networks between the tube and the output transformer. The output transformer is essentially a hybrid coil which provides a monitoring or bridging winding. The level at the terminal of this winding is approximately 20 db down from that at the output terminal, and the gain-frequency characteristic is identical.

The 14-C amplifier is also a two-stage amplifier, but each stage is push-pull, and negative feedback is provided, derived from a winding on the output transformer. The amplifier provides a flat gain of 40 db over the range of 35 to 8,000 cycles to a 600-ohm load or of 34 db over the same frequency range through a bridging multiple to a +8-VU outlet. At 600 ohms, the output level may be as much as +20 VU. Unlike the 12-C amplifier, gain and delay equalizers are connected externally at the input of the amplifier and no provision is made for connecting automatic-gain-regulating networks. It cannot, therefore, be used as a regulating repeater.

Regulation

In long-cable systems a considerable variation of transmission loss is encountered as a result of continuous changes in cable temperatures. This variation, which is not uniform over the frequency band, is of such magnitude that it must be continuously and automatically compensated. In intercity cable systems this process is designated regulation and is under the control of a pilot-wire regulating system. In this system, a loop of the two wires of one pair in a cable on either side of the regulator station is extended to the ends of the regulator section. A regulator section is usually three to four repeater sections long, and the regulating office usually is located near the middle. The pilot-wire pair is connected into a Wheatstone-bridge circuit at the regulating office so that any change in its resistance will unbalance the bridge. This unbalance is automatically compensated by the regulator circuitry, and the correction is transformed into mechanical movement of an arm which wipes successively over a series of contacts. As these contacts are made, other relays are actuated which in turn change the networks which are associated with regulating amplifiers. While the change in pilot-wire resistance is continuous, regulation is in steps, as contact is made at successive points. The regulating networks apply a gain correction which varies with frequency in a manner to balance the gain-frequency change which occurs on the cable as its temperature varies.

Equalization

In the B-22 cable system, variations in the gain-frequency characteristic due to temperature changes of the cable are compensated automatically as just described. It is necessary, however, to provide equalization which is adjusted manually at certain intervals in order to remain within the operating range of the automatic system. This basic equalization is provided by a series of fixed and adjustable equalizing networks which are combined as required to complement the characteristics of various lengths of repeater sections. In general, a basic network is used which approximately matches the line section and supplementary networks are added as found necessary by measurements. The characteristics of each network are adjustable through the use of plug-in resistance pads. Delay equalization is provided by fixed delay equalizers which are assigned as required with the attenuation equalizers.

When used with 12-C amplifiers, the equalizing networks become a part of the amplifier circuit. With 14-C amplifiers the networks are electrically separated from the amplifier. In this application, transformers are used at the input and output of the equalizer network grouping to isolate the unbalanced equalizers from the balanced connecting circuitry.

Bridging

A variety of bridging arrangements have been standardized for use in meeting various circuit requirements, as, for example, varying numbers of outlets, terminal or through transmission, in and out or bridged local channels, and the type of program amplifier used. A typical arrangement is described in the following section on Reversible Facilities.

Reversible Facilities

In the general section it is pointed out that network operation frequently involves a change in the point of program origination. This can be provided for either by round-robin operation or by the use of reversible facilities. Reversible operation is obtained by the remotely controlled operation of relays which interchange the amplifier input and output connections at all repeater points. The operation can become quite complex and involve the switching of equalization when the cable lengths on either side of a repeater are markedly different and the switching of local channels

from receive to transmit when a receiving point becomes the originating point. A single representative arrangement will be described.

Relay control at any intermediate point is extended to the control office over a control circuit which is obtained from the transmission pairs themselves by means of a resistance simplex bridged across the pairs in the station apparatus. The line relays are controlled by direct current transmitted over the simplex circuit from the control point. The arrangement is such that the circuit is set up by the control point to transmit away from that point; that is, the direction of the circuit is under the control of the transmitting point and cannot be set up to transmit toward the control point while that point retains control. Any control point, once having obtained control of the network, retains control until it is released. In other words, a station having control locks out the control at all other points. Upon release of control, the transmission path remains unchanged until reversed by control from some other point.

The control current is relayed at each nonbridging repeater point through the line relays directly, so +130 volts is supplied at each point to the next repeater section.

A control and reversing panel is provided at each point where transmission into the program network is to take place. This panel is equipped with the keys necessary to perform control and reversing functions on one system. Visual indications of the circuit condition are also provided.

Figure 1-28 represents a typical station arrangement at a bridging station employing a 14-C amplifier and associated G-type bridge. The G-type bridge shown is one of several of the general type of resistance-splitting devices designed to provide different numbers of outputs and levels (+8 VU for cable, +14 VU for open wire) from a single input fed by a 14-C program amplifier. Reference is also made to secondary and tertiary controls.

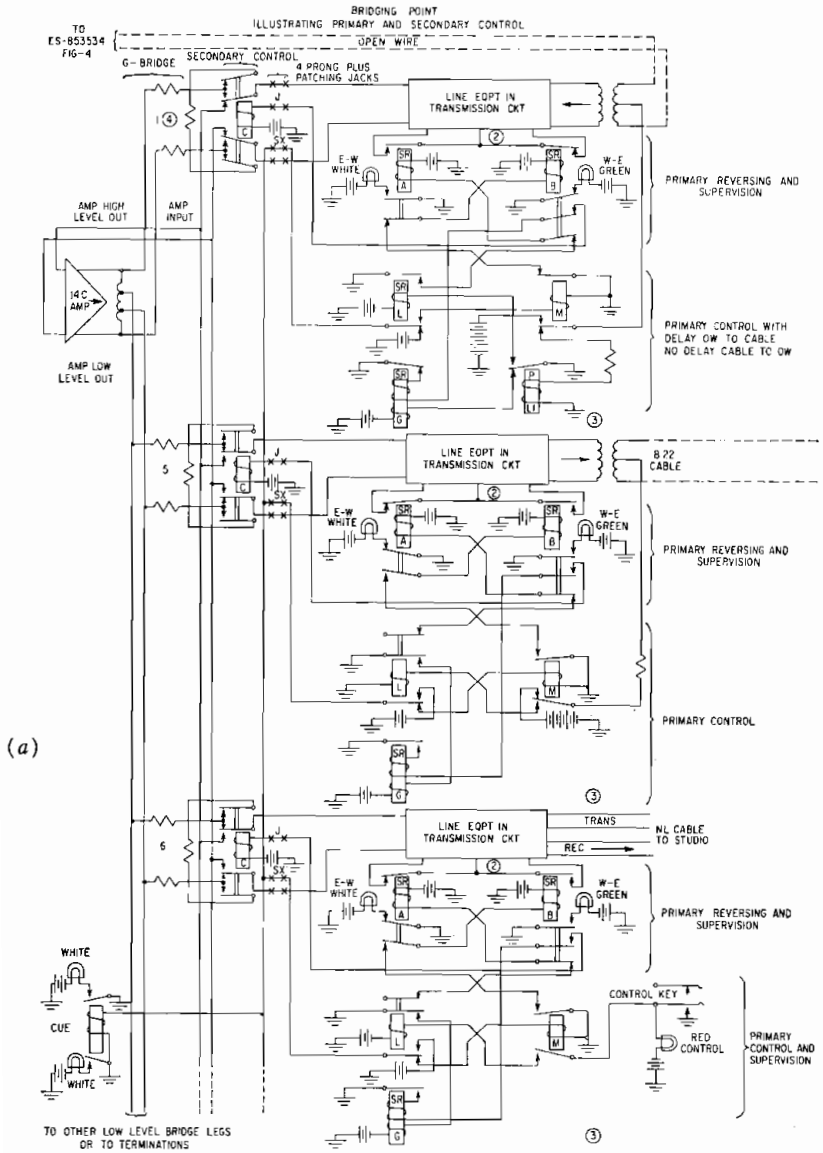
Secondary controls are associated with G-type bridges to transfer the line associated with a particular leg either to the input of the 14-C amplifier when the primary control is in one direction or to the output of the bridge when the primary control is in the opposite direction.

The function of the tertiary control is to provide switching at the input of the 14-C amplifier to connect or disconnect certain common equipment as required by the transmission path established.

The control current is taken from the program pairs through the simplex leg of the line repeating coil on the incoming program circuit and is relayed through the primary control to an Sx lead which parallels the bridging multiple and is connected to all the primary controls associated with this bridge. It is this Sx lead which ties all the lines together for this bridge as far as the control circuit is concerned so that a control signal coming in on any line can take the proper control and be relayed to all outgoing lines as desired. Delay is introduced in the release of the L relay associated with open-wire circuits connected to G-type bridges having both open-wire and cable facilities in order to prevent intermittent interference being imposed on the cable facilities.

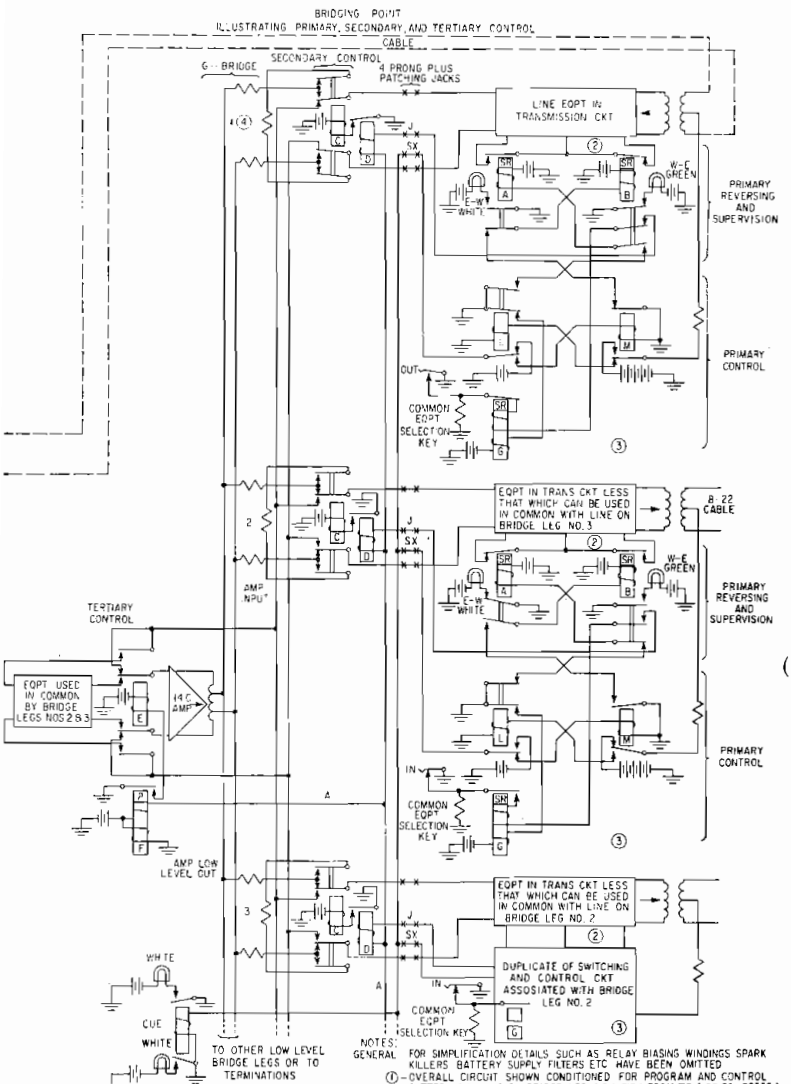
In some cases at a bridging point where several similar lines are associated with the bridging multiple, it may be possible that certain line equipment associated with each line is common for several lines, and so economy in equipment can be obtained if such equipment is installed at the input of the 14-C amplifier and used in this position, in common for all those lines. A case where some, but not all, of the lines use common equipment is shown by Fig. 1-28*b*.

In the drawing, the bridge is shown connected both to cable channels employing common equipment and to those having individual equalizers, so that the arrangements are the same as those described above except for this point regarding the common equipment. Here the secondary control is equipped with an additional relay *D* which is controlled by the *J* lead from the primary control. This *D* relay controls the *C* relay for switching at the output of the bridge. In addition, the "tertiary control" is controlled by the *A* lead, which is a continuation of the *J* lead beyond the *D* relay. This tertiary control controls switching at the input of the 14-C amplifier and determines whether or not the common equipment is in the circuit. The operation of the tertiary control is also controlled by means of the common equipment-



(*a*)

FIG. 1-28 (*a*) and (*b*). Typical B-22 reversing equipment.


BRIDGING POINT
ILLUSTRATING PRIMARY, SECONDARY, AND TERTIARY CONTROL
CABLE
SECONDARY CONTROL
6 BRIDGE
4 PRONG PLUG PATCHING JACKS
LINE EQPT IN TRANSMISSION CKT
PRIMARY REVERSING AND SUPERVISION
PRIMARY CONTROL
COMMON EQPT SELECTION KEY
EQPT IN TRANS CKT LESS THAT WHICH CAN BE USED IN COMMON WITH LINE ON BRIDGE LEG NO. 3
B 22 CABLE
TERTIARY CONTROL
EQPT USED IN COMMON BY BRIDGE LEGS NOS 2 & 3
AMP LOW LEVEL OUT
EQPT IN TRANS CKT LESS THAT WHICH CAN BE USED IN COMMON WITH LINE ON BRIDGE LEG NO. 2
DUPLICATE OF SWITCHING AND CONTROL CKT ASSOCIATED WITH BRIDGE LEG NO. 2
WHITE
CUE
TO OTHER LOW LEVEL BRIDGE LEGS OR TO TERMINATIONS
NOTES:
GENERAL FOR SIMPLIFICATION DETAILS SUCH AS RELAY BIASING WINDINGS SPARK KILLERS BATTERY SUPPLY FILTERS ETC HAVE BEEN OMITTED
① – OVERALL CIRCUIT SHOWN CONDITIONED FOR PROGRAM AND CONTROL BATTERY INCOMING ON BRIDGE LEG NO.1 FIG 1 FROM FIG 4 OF ES–853534
② – ONLY ONE OF SEVERAL SETS OF CONTACTS CARRYING TRANSMISSION SHOWN
③ – DIRECTIONAL KEY NORMALLY FURNISHED WITH EACH GROUP OF REVERSING AND CONTROL RELAYS KEY SHOWN IN FIG 4 OF ES–853534 ONLY
④ – ONLY ONE TERMINATION PER BRIDGE ACTUALLY FURNISHED FOR COMMON USE WHEN ANY LINE FEEDS INTO BRIDGE MONITORING CIRCUIT CAN BE USED FOR THIS TERMINATION SEE DRAWING ES–853539

(*b*)

selection key on the primary control. This is accomplished by controlling the amount of current sent from the primary control over the *J* and *A* leads. The *F* relay in the tertiary control is equipped with a biasing winding and is marginal in its operation. It will not operate when the 250-ohm resistance normally between the *J* lead and ground is in but will operate when this resistance is shorted out by the operation of the selection key when the common equipment is to be used. The *D* relay in the secondary control operates on either value of current. In Fig. 1-28*b* the arrangement shown is for the use of common equipment for the cable channels associated with legs 2 and 3 of the bridge while the cable channel associated with leg 1 does not use the common equipment and has all the necessary line equipment associated directly with the line itself.

Intercity Facilities—Cable-carrier Systems

General

It has previously been mentioned that the Bell Telephone Laboratories, in their development work directed toward producing ever more efficient communication-transmission systems, had concentrated much effort on carrier techniques. As more advanced systems were developed and placed in operation, each was assigned an alphabetical-type designation. Improved versions of the same general type of system were further identified by numerical additions to the alphabetical designation. Among the systems which are used to provide the long-haul backbone facilities, two types of cable carrier systems are in wide use:

Types K-1 and K-2 cable carrier systems which provide 12 two-way message channels on two cable pairs in separate cables, one for each direction, using the same line frequencies on each pair.

Types L-1 and L-3 cable carrier systems which use coaxial cables. These are described in the Television System section.

All these systems use basically the same terminal equipment (channel banks) to modulate 12 message channels into successive frequency positions 4 kc apart to form the basic groups. These groups are then further modulated as required by the particular system. The message channels thus derived have a bandwidth which extends from about 300 to 3,000 cycles and meet all transmission requirements for high-grade message service.

It is readily apparent that, by appropriate means, a band equivalent to three message channels would provide frequency space for an 8-kc program channel with adequate margin for filters on either side of the band to eliminate interference completely from or to adjacent message channels. In a similar manner a 5-kc program channel can be derived from the space of two message channels. The necessary terminal equipment has been developed and is in wide use in audio-network service, particularly for television audio service, where differential delay between the picture and the television sound is an important consideration.

A variety of equipment arrangements are available to meet the network requirements for flexibility; for bridging, dropping, or reversing; for occasional services and similar considerations. As a typical example the 5-kc system for application to K carrier will be described along with a representative bridging arrangement.

Terminal Equipment

Five-kilocycle program-transmission channels (schedules A and B) are derived from K carrier systems by the application of C-1 terminal equipment. This equipment may be permanently associated with a particular channel bank, or it may be installed separately and so arranged that it can be associated with any channel bank in the station.

In either case, when it is in use, it occupies the frequency position of message Channels 6 and 7. When not in use, it can be remotely switched out and the message

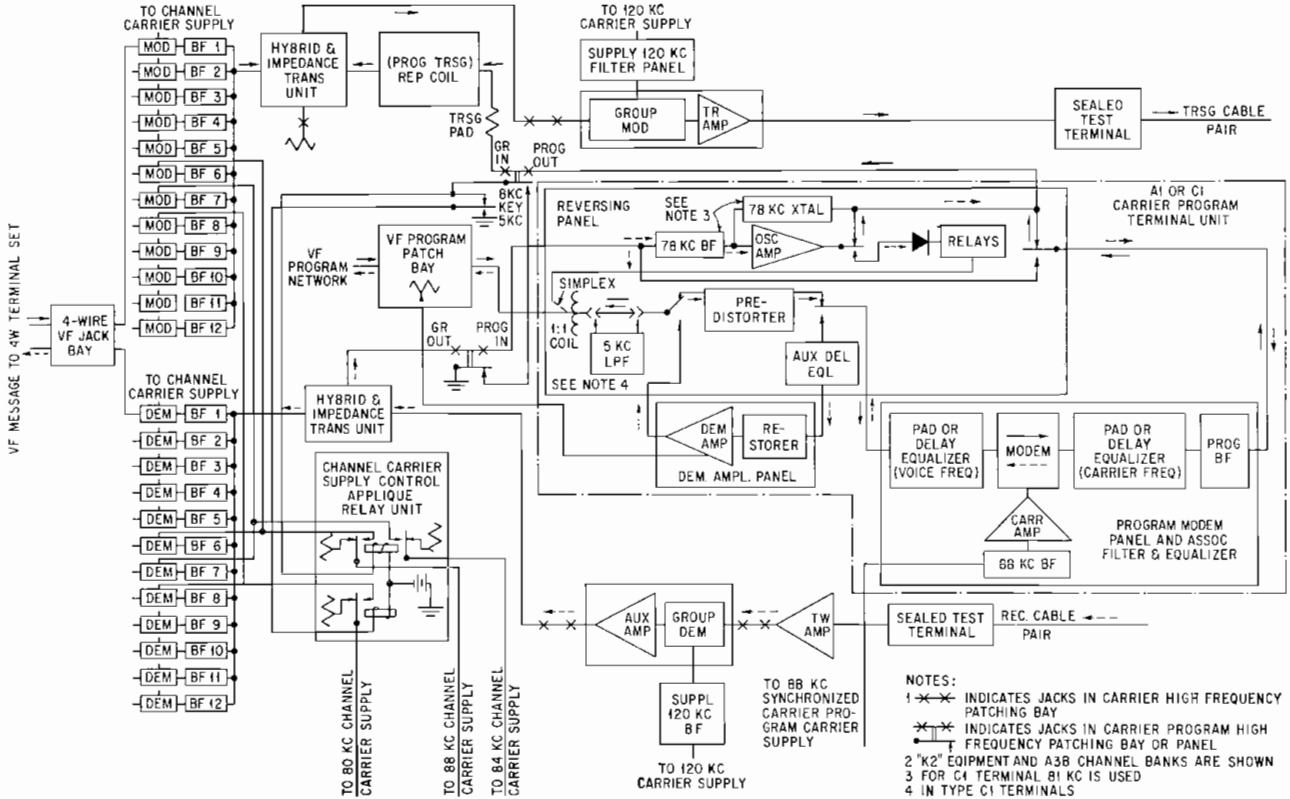


FIG. 1-29. Schematic of type C-1 program terminal.

equipment, which is always provided, put in use. A block schematic of the major features of the terminal is shown in Fig. 1-29.

The terminal is conditioned to transmit or receive by the presence of a control tone from either direction, as described later. In the transmitting direction, message Channels 6 and 7 are disabled and the program terminal is prepared for transmitting by d-c signals applied to the simplex channel at the high-frequency patch bay and the program control room, respectively. The voice frequency program material is received from the program control room and passed through a 5-kc low-pass filter and a preemphasis network to a modulator where it modulates an 88-kc carrier. The upper sideband and carrier are suppressed, and the lower sideband is combined with an 81-kc control tone and applied to a branch of a hybrid coil where the signal is combined with the working message channels in the range between 60 and 108 kc. The entire group is then again modulated with a 120-kc carrier, which produces frequencies in the range between 12 and 60 kc that are transmitted to the line.

At the receiving terminal the reverse action takes place. After the first stage of demodulation, the program and message signals are divided into two paths by the receiving hybrid. The 81-kc control tone conditions the program terminal for receiving, and the program material is passed through a filter to the demodulator and the delay equalizing networks. The voice frequency program signals are then passed through the restorer network and an amplifier and transmitted to the control room.

Bridging Arrangements

Bridging and splitting arrangements can be provided at any amplifier point where the line characteristics have been suitably equalized. Several types of bridging and splitting arrangements are available for use in meeting different requirements. As an example, assume a bridging point which may receive program from the through line most of the time but is occasionally an originating point from which program must be fed in both directions.

To provide for receiving from a 5-kc program channel, blocking filters are inserted in the main line which pass the line-frequency signals of message Channels 1 to 5 and 8 to 12 and permit the line-frequency program signals to be picked off. The program signals are then passed to a receiving program channel which is conditioned by the control tone and delivers the audio-frequency material in the same manner as at a channel terminal. Normally program is received from only one direction at a time at an intermediate point. One reversible program terminal arranged for switching to the desired direction of receiving would meet the requirement. However, program branching points can be equipped with two reversible terminals for greater flexibility. With two terminals arranged for transmitting, program can be fed in both directions simultaneously by connecting one to each of the oppositely directed main line circuits. It is also possible to receive from one direction and transmit in the opposite direction on the same main-line channel. This is sometimes done to provide "in-and-out" service to the local station.

The filters which are used in the arrangement, however, introduce delay distortion because of their sharp cutoff characteristic. Tandem use of terminals is therefore avoided whenever possible, and at branching points arrangements are provided whereby the blocking filters are removed from the through line and the receiving terminals are bridged on. When transmission from the branching point is desired, the circuit is set up by manually controlled relays for transmission in either or both directions.

Part 2

TV MICROWAVE SYSTEMS ENGINEERING

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INTRODUCTION

Microwave systems used by TV broadcast stations must be engineered to provide as high a degree of relability as other units in the television station. A microwave system is truly a link between the broadcaster's program source and his transmitter. Sometimes this reliability must be achieved with one or more microwave repeaters. The frequencies currently allocated by the FCC for television video use by broadcasters are those channels in the 2,000-, 7,000- and 13,000-Mc bands. These frequencies are so high that radio transmission in this spectrum behaves very much like light waves. Such waves are heavily attentuated when they travel over the ground. These frequencies, on the other hand, when traveling upward, are not reflected back to earth by the ionosphere, as are the VHF frequencies. As a result of discontinuities in the lower atmosphere (from ground to 2 miles up), they may, at times, be deflected upward or downward. These changes can occur very rapidly, sometimes in a matter of seconds.

In view of these and other factors, it is advisable to locate TV relays where a line of sight exists between the transmitting and receiving antennas. The actual amount of clearance for various conditions and techniques for overcoming various propagation difficulties will be discussed.

The TV broadcaster does not usually have a choice of sites for his microwave units. The positioning is usually dictated by the location of his studio and his transmitter, for studio to transmitter links, and the place of origination for remote pickups. It is up to the engineering staff of the television station to make the best possible use of these predetermined sites.

A microwave link, in order to operate satisfactorily, must have an overall system gain which exceeds the system attenuation by an amount necessary to provide high-quality video and a high order of reliability. In addition, if audio is multiplexed, its subcarrier must not degrade the video nor must the video degrade the audio program.

Through the use of sound engineering practices, excellent performance may be had in television microwave systems. Suggested specifications for performance requirements are set forth in Table 2-1. They apply to both short-haul remote pickups and studio-to-transmitter links (STL) as well. Studio-to-transmitter links up to 40 miles as well as multihop links should be capable of meeting these specifications. Engineering data and information are submitted to make possible such performance.

* No longer employed in this capacity.

Installed systems not meeting these specifications of performance can be improved by following the suggestions for improvement outlined in the last portion of this part.

Table 2-1. Microwave Relay System Performance Specifications for STL and Remotes

Video performance (with simultaneous single-channel audio):
1. Carrier frequency stability of transmitter to be ±0.05%.
2. Amplitude frequency response to be within 0.5 db from 60 cycles to 5 Mc.
3. Differential gain from blanking level to peak white to be equal to or better than 0.5 db with 100% modulation.
4. Differential phase with respect to reference burst, to be equal to or less than ±1° at 100% modulation.
5. Signal-to-noise ratio shall be better than 53 db, peak-to-peak video signal to rms noise, from 60 cycles to 5 Mc.
6. Sync compression shall be less than 10%.
7. Composite video input level to be 1.0 volt peak to peak.
8. Video output level to be 1.4 volts, peak to peak.
9. AFC system shall provide for unattended operation of system.

Audio performance (with simultaneous color video transmission):
1. Amplitude frequency response to be uniform within ±1 db from 50 to 15,000 cycles.
2. Distortion with sine-wave audio and EIA test pattern video shall be less than 1.5% from 50 to 15,000 cycles.
3. Audio signal-to-noise ratio to be greater than 58 db, with EIA test pattern video.
4. Audio input level to be −5 dbm minimum.
5. Audio output level shall be +8 dbm maximum.

WAVE PROPAGATION

Attenuation may be defined as a decrease in the intensity of electromagnetic waves. There are a great many factors which cause microwave attenuation. The fundamental loss results from the spreading of energy through space. When microwave relay stations are installed, the distance between the transmitter and the receiver is of great importance. The attenuation of the transmitted signal will largely determine the maximum range obtainable for reliable reception of the signal.

Distributions of temperature, barometric pressure, and water vapor materially influence the propagation of radio waves in the troposphere. This is the area of the atmosphere from the earth's surface up to about 6 miles. The variations of the temperature, pressure, and water vapor are expressed by the index of refraction. This index decreases linearly with an increase in height in the standard atmosphere. The normal value of the refractive index is in the order of 1.0003. Most reference texts use a modified index of refraction which includes a term to compensate for the curvature of the earth, so that beam-ray diagrams can be plotted on the basis of a plane earth. Since the units are inconveniently small, a refractive modulus is used and defined as

$$M = \left(n + 1\frac{h}{a}\right) \times 10^6$$

where M is the refractive modulus, n is the refractive index, and h is the height in the same units as a, the earth's radius. Thus, the normal value of M at the earth's surface is approximately 300. A positive gradient of $3.6M$ units per 1,000 ft of height corresponds to a standard refraction.

Greater than standard refraction is caused by smaller positive M gradients. Negative gradients cause superrefraction, or ducting. Upward bending of the transmitted ray, or substandard refraction, is caused by large positive M gradients. In terms of dielectric constants, a uniform decrease with height results in standard refraction. Since the refraction normally decreases with height, the upper portions move with higher velocity than the lower portion. Thus the wave path can be represented by rays curved slightly downward toward the earth. As a result, the distance to the radio horizon is some 15 per cent greater than the geometrical line-of-sight distance

from the transmitter to the horizon. This is the condition due to normal refraction of the atmosphere.

The signal at the receiver is the vector sum of the radio waves arriving at the antenna from the direct and any other path. Reflected rays are the result of the earth or large bodies of water acting as a reflecting body. Water and salt flats are very efficient reflectors, while rolling hills and terrain with vegetation may reflect only 10 per cent of the energy striking it at microwave frequencies.

The angles of harmful reflection in microwave propagation are very small. Therefore, it is not too important whether vertical or horizontal radiation is used as long as both the transmitting and receiving antennas are polarized in like manner. Since the reflection angle is very small, the phase lag is nearly 180° between the incident and reflected waves.

The wavefront may be arbitrarily divided into circular zones in the normal propagation of these frequencies. These circular zones are centered on the direct ray line such that the path-length difference from the transmitter to receiver will differ only by one-half wavelength for each zone. These areas are called Fresnel zones. Their radii vary from point to point along the path. Energy from alternate zones either adds to or subtracts from the wave in the first zone, which contains about 25 per cent of the total energy. Therefore, it is imperative that line of sight plus the first Fresnel-zone clearance be obtained between the transmitting and receiving antennas. Figure 2-1 shows the first Fresnel-zone radius at the center of the path for the three microwave bands allocated to TV broadcasters. It also shows the radius at various intermediate points.

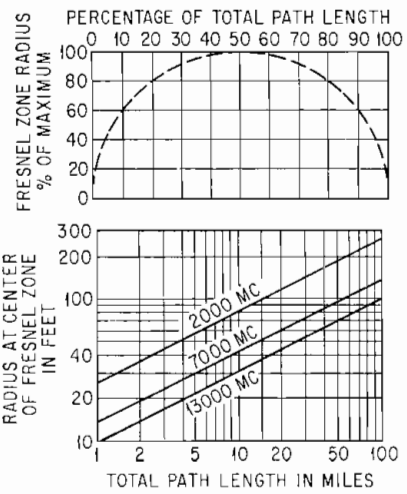

FIG. 2-1. Fresnel-zone radius.

FADING

The path length, frequency, clearance above terrain, and the meterological conditions are the important factors in the consideration of fading. Data on 13,000-Mc fading is not conclusive but is known to be in excess of that occurring at 7,000 Mc.

The variable factor, the refractive gradient, affects the higher frequencies of propagation more than the lower. Fading depths and duration are greater on 13,000 than on 7,000 Mc; while 2,000 Mc, the lowest band available to broadcasters for video use, is the least affected.

Assuming first Fresnel-zone clearance, steady transmission occurs in a microwave link when the air along the path is well mixed or homogeneous. This excellent condition occurs during stormy, windy weather. The refractive gradient M is then nearly standard.

Signal fading occurs in the presence of irregularities in the refractive gradient. A marked change in signal level invariably accompanies refractive gradient irregularities over non-line-of-sight paths or paths without full first Fresnel-zone clearance. For line-of-sight and Fresnel-zone clearance paths, the signal-level change is more diurnal in nature, indicating that fading is of the single-path variety. Generally, a diurnal signal changes from a steady condition at noon to a type characterized by pronounced fading within 2 hr after sunset. It occurs again within 2 hr before sunrise. Diurnal fading is more pronounced in summer than in winter because this type of fading is caused mainly by a change in the humidity gradient. This in turn is caused by

temperature changes, also causing pressure changes. All three atmospheric factors are interrelated.

Extremely stormy conditions may seem to produce the effect of fading by causing antenna alignment variations, but these are not true propagation fades. Correlation between weather conditions and received signal on microwave circuits has been investigated.[3,4] It is interesting to note here that considerable change in refractive-

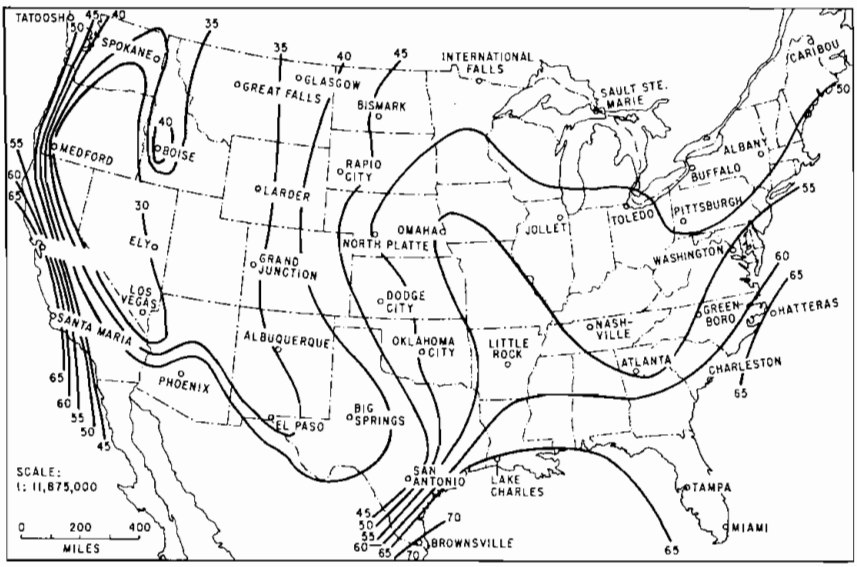

FIG. 2-2. Six-year average of monthly median values of ΔN taken from the surface to 1 km above the surface in August. (0300 GMT)

gradient structure exists at various parts of the United States. The West Coast and the southern Gulf Coast of Texas are areas where abnormal refractive gradients are the general rule throughout the year. The remainder of the United States as shown in Fig. 2-2 has very little change over short path lengths.[5] Delta N, as used in Fig. 2-2, is the simple difference between the value of refractivity at the earth's surface and at 1 km.

Types of Fading

As pointed out earlier, the normal atmospheric conditions cause the microwave beam to be bent downward slightly. This downward bending of the line of propagation has a radius of approximately $\frac{4}{3}$ times the earth's radius, which corresponds to straight-line propagation on a fictitious earth with a radius of $\frac{2}{3}$ the actual earth's radius. Unfortunately, in actual practice, this so-called standard atmosphere varies with time. This in turn varies the downward bending, causing minor fading.

Lines of propagation plotted on true earth curvature paper is usually necessary in television broadcast station microwave siting, since even in long STLs, the receiving antenna, by virtue of the choice location of the TV station transmitter, is usually within line-of-sight. When doubt exists as to line-of-sight conditions, they can be checked out by means of 2-kw Fresnel spotlights, located at the height of the proposed antenna. Visual means of observation should be checked, with caution being taken to make such tests during periods of low humidity to avoid refractivity of the light beams.

[a] Superscript numbers refer to references at end of Part 2.

Greater than Standard Refraction

Sometimes called "superrefraction," this sort of fading is caused by meteorological conditions. The refraction of microwaves may increase until it is equal to the earth's curvature and the waves tend to follow the surface of the earth. This type of superrefraction fading is also called ducting and is common in areas close to large bodies of water. Evaporation of the water will cause an increase in moisture content and a decrease in temperature near the surface. This action then results in what is termed temperature inversion, the temperature being higher at the higher elevation. A quick check of this type of fading is to measure the temperature at the transmitter and the receiver. If the receiver is located at the higher altitude, the temperature should have a decrease of 3.6°F per 1,000 ft of elevation above the transmitter elevation. If this decrease in temperature with height does not exist, temperature-inversion fading may take place. The depth and duration of such fading will depend on frequency, path distance, and the extent of the refractive gradient. It is not only the temperature inversion which causes the abnormal bending but also the large increase in water-vapor content which accompanies the inversion and causes the dielectric constant to change. It is a well-known meteorological fact that the other basic characteristics of the air vary when one (the temperature, humidity, or pressure) varies.

Substandard Refraction Fading

When heavy ground fog covers part of the path, or when the ray travels through fogs to mountain-top receiving sites clear of fog or clouds, substandard refraction fading is likely to occur. Under these conditions the dielectric constant is actually increasing with height. This causes an upward curvature of the microwave radiation. This has the same effect as tilting the transmitting parabola slightly upward. Less signal arrives at the receiver. Since the refractive index changes with time, the received signal varies or fades. In locations where heavy substandard refraction fading occurs, it is recommended that low- to medium-gain antennas be used. This procedure allows more signal during this type of fading because of the large vertical beam angles.

Multipath Fading

It is also possible that the bending may be greater at some point *above* the direct-ray path. This may result in some free-space propagation taking place on two or more paths. Rays arriving at the receiver may have various phase relationships and thus may add or cancel. This multipath condition then will cause fading, even though the path is effectively removed from path obstacles.

Reflected-ray Fading

Interference between the direct ray and the reflected ray must be considered where propagation takes place over smooth earth, a lake, sea water, or salt flats. Energy striking the earth or large bodies of water should be directed away from the receiving antenna, in view of signal cancellation. Another reason for avoiding reflected waves in microwave applications is the fact that this second ray may be subject to more fading because of proximity to the earth and subnormal refractive gradients. Thus, reflected waves may cause fading of the main ray by adding or subtracting in phase relationship.

If a microwave link operating over salt water varies in received-signal amplitude, such variance in signal level can be correlated with tide conditions. If this is found to be the case, then it becomes apparent that reflected-wave interference exists.

Corrective measures for this type of interference can often be devised by a judicious application of plane geometry. Adjustments of tower heights may be possible in some installations. Varying tower heights will place the reflection point upon a rough section of ground, or failing that, the reflection point may be brought as near as

possible to either end of the hop. This latter procedure minimizes phase interference by redueing path-length differences.

Two other ways of avoiding reflected-ray problems have been found satisfactory in TV relay work. The receiving- or transmitting-antenna height can be varied so that an intervening hill or mountain acts as a shield to the reflected wave. The transmitting or receiving antenna or both can be tilted upward slightly in order that normal reflected rays to mid-point reflection points, for example, will be greatly reduced in amplitude.

Reflection coefficients have been measured from 0.2 for very low angles of incidence to 0.9 for angles of incidence of 0.5° over salt water.[6]

Another form of multipath fading or wave interference occurs in over-water TV links. When the transmitting parabola and the receiving parabola are located on land and a great deal of water lies in between, reflection off the water can cause either signal cancellation or addition. The result depends on the distances between dipoles, frequency, and angle of incidence and reflection. A reflection of energy from the surface of the water creates a vertical lobe structure in the antenna pattern. The number of lobes is proportional to the antenna height in wavelengths above the reflecting surface. The depth of the null between lobes depends on the magnitude and phase angle of the reflection coefficient of the water surface.

The gain pattern of the antenna usually makes only the first lobe and first null important. It should be recognized that this lobe shifts vertically only as the transmitting antenna height above the reflecting plane (water in this case) is varied. As pointed out previously, with either vertical or horizontal polarization, the reflection coefficient remains near unity with a phase angle of 180° for all grazing angles of 0.5° or less. Vertical polarization has a slight advantage, producing a somewhat lower reflection coefficient under such circumstances. Therefore, if grazing from water reflections is present, vertical polarization may reduce the effects.

Overland paths do not give reflection coefficients near unity because of the scattering and power-absorption qualities of the earth. Reflection at the right spot and right altitude is seldom encountered, and if it is, the scattering will diffuse the reflected wave.

Nulls can occur in over-water hops. In paths where sea-water tides are present, this cancellation, or nulling, will vary with the time of day at slow rates. Most troublesome fading occurs just before and after a high tide.[8]

Sea-water paths can be easily utilized, provided the usual precautions are taken with establishing first Fresnel-zone clearance throughout the path. In the 2,000-Mc band, the first Fresnel zone usnally will not put the receiving antenna in a null point; therefore 4- to 6-ft variations in tides will not cause nulling. However, with 7,000- and 13,000-Mc systems, it is common to have more than first Fresnel-zone clearances. Here, then, lobes and nulls become common. A 6-ft tide will become a larger per cent of the Fresnel-zone radius, and nulling may take place more readily.

Nulling at the receiving antenna can be checked by varying the height of the receiving antenna and noting the received-signal strength. The antenna should be left at the lowest height consistent with satisfactory RF level. Polarization should be vertical.

Examples of different types of fading common in 2,000- and 7,000-Mc systems are shown in Figs. 2-8*a*, *b*, *c*, and *d*.

Determination of the absolute required path clearances for microwave propagation is a rather complex process. However, two important rules should be followed. In medium and long hops, where signal streugth is a prime consideration, *first Fresnel-zone clearance should exist throughout the path.* The second rule is to maintain at least 25 ft of clearance between the beam center and any obstrnctions throughout the path from parabola to parabola. This means that the center of the antennas should be at least 25 ft higher than any immediate foreground obstructions. In fixed STLs, this procedure will minimize the effects of growing trees, new buildings, and moving vehicles.

SIGNAL-LEVEL CALCULATIONS

In order to predict the performance of a microwave relay system, information is needed regarding the long-term median path losses and the characteristics of the fading to be expected. The median (average normal) path loss can be calculated between the two antennas to within 3 db. This information for the three TV microwave bands can be taken directly from Fig. 2-4. This chart shows the space loss

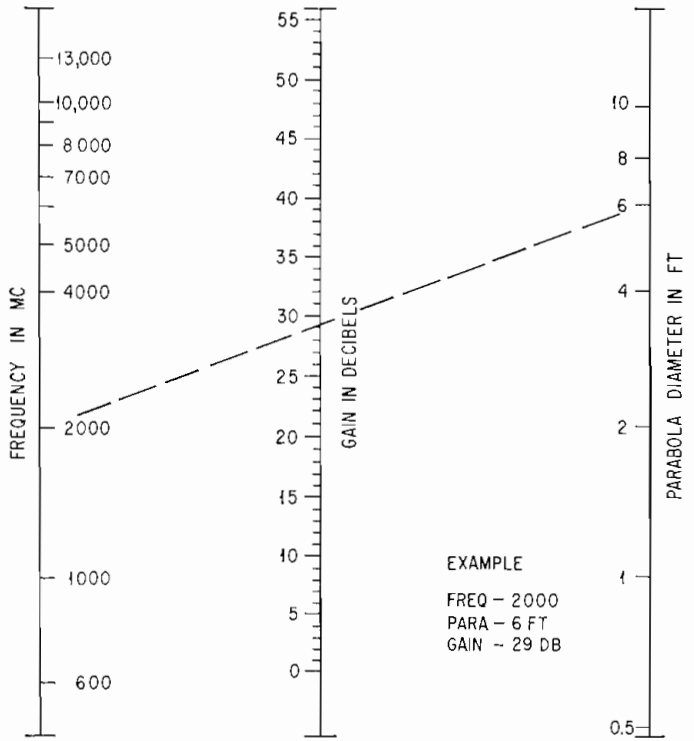

FIG. 2-3. Parabolic antenna gain over dipole.

between two dipole antennas as a function of frequency and the distance between the antennas. Thus the median space path loss can be determined with considerable accuracy. The principel need, therefore, is for statistics on fading depths appropriate to the location involved in a single-hop system or throughout the various legs in a multihop installation.

Free-space attenuation is the greatest loss item in a microwave link. This is the coupling loss between the transmitting and the receiving antenna. The energy radiated from a transmitting antenna is wasted unless it is directed toward the receiving antenna. To obtain this directivity a parabolic reflector, or dish, is ordinarily used to focus the waves. Horn antennas are sometimes used on 7,000 Mc and may become popular on 13,000 Mc because the gain varies directly with frequency. Figure 2-3 shows the gain in decibels of a parabolic antenna as a function of frequency and diameter for highest forward gain. Antenna gain is large in a normal system and tends to overcome part of the free-space loss.

In permanent microwave systems over 20 miles, it is well to make a signal-level calculation before purchase of equipment. The following factors should be considered:

1. Frequency
2. Power output
3. Antenna sizes
4. Reflector requirements
5. Performance expected
6. Fading margin and reliability

Frequencies of Operation

There are currently allocated three microwave bands: 2,000, 7,000, and 13,000 Mc. These bands are for TV broadcast use for video transmission. Audio only can be transmitted in the 940- to 950-Mc band. Sound can be multiplexed in the three bands previously mentioned. Before signal-level calculations can be made, it is well to consider the main characteristics of these microwave bands.

Table 2-2

	2,000 *Mc*	7,000 *Mc*	13,000 *Mc*
Space attenuation, first 10 miles, db	123	135	140
Maximum transmitter power available, watts	10	50	0.1
Over-all receiver noise figure, db	12	14	17
Space attenuation per mile due to 0.5-in. rain per hour, db	0.03	0.5	15
Space attenuation per mile due to 2.3 gm/cu m fog (visibility 100 ft), db	None	0.1	3.0

It can be seen from the table that there are certain physical limitations imposed by characteristics of the various frequencies that can be used. For example, the 13,000-Mc band would not be recommended for a 30-mile STL. Space attenuation plus variable attenuation due to the refractivity gradient, rain, and fog plus the stability required of the parabolas would preclude use of this band for a long hop.*

Signal-level calculations are rather simple. The gains and losses are totaled. Subtracting the losses from the gains gives the signal that is expected at the receiver end of the path. This received signal in an average system may be from 35 to 100 db below the level leaving the transmitter.

Although the normal level of the received signal can be predicted, this level is based on a condition of normal propagation, i.e., without any fading. In practice, only in short hops and in limited parts of the United States can ideal propagation conditions be found. In many parts of the country fading is minor and may go unnoticed, although it occurs throughout the year in various degrees.

Fading depths to be used in signal-level calculations cannot be determined in advance unless information regarding other systems in the area is available. Or it can be determined by setting up a temporary link over the exact path to be used and measuring the fades.

It is suggested that signal-level calculation sheets be used when surveying paths over 20 miles as well as on shorter paths where medium to heavy (10- to 30-db) fading is known to exist. These calculation sheets will give a first approximation of the results to be expected. It will also determine what frequency bands should be used, the size of the parabolas, and the transmitter power output required.

In the signal-level calculations, the margin required for fading should be at least 40 db. This will result in approximately a 53-db signal-to-noise ratio for video (peak signal to rms noise). However, when the received signal fades, say 6 db, the output video will be degraded approximately the same. This reduces the signal to noise in the output video to 53 – 6, or 47 db. To maintain a video signal-to-noise ratio of 53 db at all times, the received signal must be at least 40 db above the deepest fade encountered. This is difficult unless the system has been engineered with an adequate fading margin. It is very important in areas where atmospheric fading is prevalent to ascertain the depth of fades to be encountered and design the microwave

* Current developments are making use of these higher frequencies more feasible.

system to overcome it. This can be done by taking into consideration the following factors:

1. Choosing the frequency band that is least affected by fading
2. Using equipment in this band that has the lowest noise figure and the lowest threshold value
3. Using the largest parabolas consistent with structural limitations (wind, tower stability, etc.)

Propagation-signal Calculations

Where nonstandard propagation conditions exist, a calculation of received signal levels is virtually impossible. Even a calculation of the required fading margin may be arbitrary. Therefore, actual performance measurements of microwave systems operating in the area are extremely helpful. Fading on existing links can be measured by calibrating the receiver limiter current with the aid of a calibrated microwave signal generator. This calibrated limiter current can be used to drive a chart recorder. Examination of these recording charts will reveal the maximum depth and duration of fades. For 100 per cent propagation reliability, the received signal should be 40 db above the deepest fade to be encountered.

Thus, if the deepest recorded fade was 23 db, adding 40-db signal required for 53-db peak rms video S/N ratio makes the RF signal requirement 63 db above the threshold. This would provide 100 per cent propagation reliability. In practice, this signal level is not easily achieved at all times, thereby resulting in somewhat less than 100 per cent reliability.

Instances have been recorded where 43-db fades up to 23 min in duration have occurred in 7,000-Mc STL.[3] Where heavy fading of this nature due to refractive gradients exists, the 2,000-Mc band should be used, since it is less affected by the same conditions. In the case just referred to, a simultaneously operating 2,000-Mc link over the same path experienced a fade of 6 db for a period of 11 min. It has been concluded in tests and operation that the 2,000-Mc band is superior to 7,000 Mc, where heavy fading due to atmospheric refraction exists.[4-6]

SYSTEM EVALUATION

The transmitter power and antenna gains are elements which contribute to the over-all system gain of a microwave link. The important elements that contribute to the over-all system loss are the transmission-line and free-space path losses. System evaluation starts at the video and audio input (if audio is being multiplexed) of the transmitter. It ends at the video and audio output terminals of the receiver.

Table 2-3 shows the no-loss maximum distance between a passive reflector and a parabola in the 7,000-Mc band, which will also serve as a guide for 13,000-Mc use, in the smaller antenna sizes.

Table 2-3. No-loss Maximum Distance between Parabola and Passive Reflector

(F = 7,000 Mc)

Parabola size, ft	*Reflector size, ft*	*Max distance, ft*
4	4 × 6	41
6		65
8	6 × 8	82
6		90
8	10 × 14	125
10		150
8		2,000

It is common practice to use large sheets to reflect energy from a conveniently mounted parabola in the 7,000- and 13,000-Mc bands. The reflector can be mounted at some distance away from the parabola before any coupling loss occurs. The allow-

able distance is a function of frequency and reflector and antenna size. Distances up to 41 ft with 4-ft antennas and 4- by 6-ft reflectors can be used without coupling loss. See Table 2-3 for other antenna and reflector sizes.

Passive reflectors are not ordinarily used for 2,000-Mc systems. Low-loss coaxial cable in both rigid and semiflexible types is available for 2,000 Mc. The separation between transmitter and antenna on 2,000 Mc is limited only by the tolerable loss in the system. Oscillator pulling or nonlinear frequency swing with modulation can be overcome with the use of load isolators when long transmission lines are used with klystron oscillator systems. Load-isolator insertion loss can be kept to approximately 0.5 db or less. When it is desired to mount the antenna on top of the studio or transmitter building and locate RF heads in the normal operating areas, these load isolators can be used between transmission lines and RF heads. Thus oscillator pulling with coaxial or waveguide transmission lines can be reduced or eliminated by inserting these load isolators next to the RF heads in the lines.

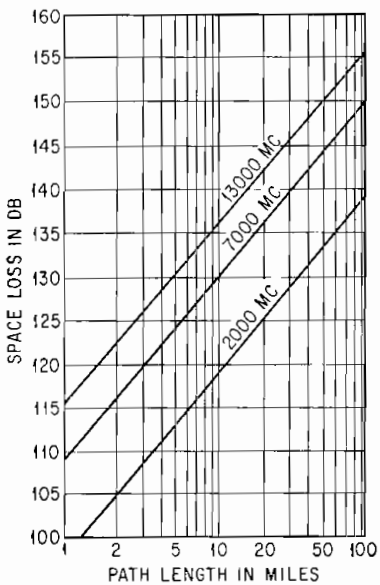

FIG. 2-4. Microwave space loss.

When system evaluations are made, transmitter power output should be converted into decibels above 1 mw (dbm). Dbm is a standard unit of signal level used in microwave engineering. Increases or decreases in power levels are referred to a 1-mw base. The dbm value should be used in the signal calculation sheets. Thus, when 1 watt of power is used in the transmitter, this power is converted into dbm, which would be +30 dbm. Putting this amount of power into an antenna with a gain of 32 db would then raise the radiated power to 30 dbm +32 db, or 62 dbm.

The loss in the antenna transmission line is also expressed in decibels. The actual amount of loss will depend on the line used. In present-day TV microwave relay systems operating on 7,000 and 13,000 Mc, the transmitters and receivers are mounted directly behind the parabolic antennas. Short waveguides used to couple the transmitter or receiver input circuits to the antennas have such negligible loss that they can be omitted in signal-level computations. However, when a waveguide is used to couple a distant antenna, then the length should be determined and the loss in decibels computed from the manufacturer's data.

The energy radiated from a transmitting parabola is wasted unless it is directed toward the receiving parabola. Very high coupling efficiencies can be obtained with carefully orientated large antennas. Table 2-4 shows the gains of typical parabolas and should be used when determining the signal gain in level computations. Figure 2-4 shows the free-space path loss for 2,000, 7,000, and 13,000 Mc as a function of path lengths from 1 through 100 miles. This graph should be used with the signal calculation sheet, a copy of which appears at the end of this part.

Noise Factors in Signal-level Computation

In order to evaluate the performance of receivers and to determine their capability of handling weak signals, the concept of "noise figure" was introduced more than 25 years ago by Dr. H. T. Friis. This concept has been adopted almost universally and is used widely in connection with microwave receiver performance. No other one factor is so important a performance indicator of a TV microwave system.

Table 2-4. Microwave Antenna Power Gains and Beamwidths

Parabola diameter, ft	2,000 Mc		7,000 Mc		13,000 Mc	
	Antenna gain, db	Half-power beamwidth, deg	Antenna gain, db	Half-power beamwidth, deg	Antenna gain, db	Half-power beamwidth, deg
2	19	18	30	5	36	2.5
4	25	9	36	2.5	42	1.5
6	29	6	40	1.75	46	0.875
8	31.5	4	43	1.25	48	0.65
10	33.5	3	44.5	1.00	50	0.50

In the microwave region external noise picked up by the antenna will usually be extremely low. Thus the noise level of the receiver can be determined by the thermal noise generated in the antenna and the noise generated in the receiver itself. This noise masks signals that are lower in level. Random-noise voltages are always present even in the most carefully designed and constructed receivers. These noises sound like hiss on a speaker and look like "grass" on an oscilloscope.

The probability of large noise amplitudes increases as the bandwidth of the receiver is increased. There is a definite rms and average value for all positive and negative noise voltages.

The thermal-noise level in a receiver is a function of the bandwidth of that receiver. It can be plotted from the conversion chart in Fig. 2-5, and is based on the following equation:

$$N_L = -174 + 10 \log_{10} B$$

where B equals the receiver bandwidth in cycles per second.

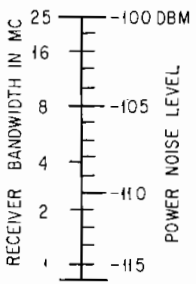

FIG. 2-5. Thermal noise as a function of bandwidth.

Noise fluctuation produced by the microwave receiver is given in terms of the receiver noise figure. The noise figure denotes the amount of deterioration of signal to noise which occurs while signal and noise pass through the receiver. The sensitivity of a receiver cannot be described in terms of thermal agitation noise alone because the receiver noise is several times the pure thermal noise.

The definition of noise figure by the Institute of Radio Engineers (IRE) is: [7]

> Noise factor or noise figure of a linear system at a selected input frequency is the *ratio* of the total noise power per unit of bandwidth available at the output terminals, to the portion thereof engendered at the input frequency by the input termination, whose noise temperature is standard (290°K) at all frequencies.

The method of actually measuring the over-all noise threshold of a receiver is described in this part under Equipment Tests and Measurements.

The over-all noise figures of two different receivers may vary as much as 15 db. This has the effect of requiring 15 db more power in the noisy receiver to get the same performance as the quieter receiver. In view of this, receivers with the lowest noise levels should be used in the longer paths and at all locations where the optimum in performance is required. At the present state of the art, TV microwave receivers with noise figures over 18 db for 2,000 Mc and 20 db for 7,000 Mc are considered poor.

Noise figures in receivers are kept low by utilizing low-noise mixers and low-noise first IF amplifier stages in either grounded grid or cascode circuits. A perfect mixer would have a conversion loss of 3 db. In practice, conversion-loss values from 4 to 9 db are common. This loss results in a reduction of the over-all noise figure.

Utilizing all the above data will give the level of signal required by the receiver.

The calculation sheets also indicate the amount of signal available for fading margins. The specifications for performance are based on a 53-db signal-to-noise ratio. Signal to noise deteriorates at the same rate as the RF signal deteriorates when receiver limiting is taking place. A 2-db fade will result in a 2-db reduction in signal to noise. If the signal is sufficiently strong to provide noise ratios in excess of 53 db, this may be of no concern. It is possible to develop a reliability ratio based on statistical fading amplitudes. This ratio holds for all properly engineered microwave systems where 40-db or more fading margin is available (see Fig. 2-6).

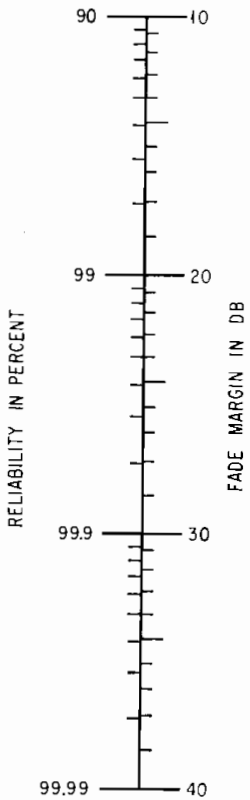

FIG. 2-6. Reliability factor vs. fading amplitudes.

The reliability factor indicates the percentage of time that the system will be normal in operation. If we assume maximum fades of 20 db in a system, Fig. 2-6 shows a reliability of 99 per cent. This means that over a period of, say, one week, the signal would be down 20 db 1 per cent of the time, or 1 hr and 40 min. If only a 40-db fade margin was available in the system, then for a period of 1 hr and 40 min scattered throughout the week, the signal would have a 33-db peak rms signal-to-noise ratio.

Unless a 40-db fade margin exists, the S/N ratio of the video signal will be less than 53 db peak rms. Therefore the fade margin in a well-engineered TV relay link must be over 40 db. Experience will indicate how much over this value it should be. Fading-depth history, deterioration of the receiver and transmitter units, parabola wind stability, etc., are factors to be considered.

A microwave receiver in TV video service will produce a 53-db peak rms video signal if the incoming RF signal is 40 db above receiver noise level. Thus, in theory, if there were no fades in a system and the equipment did not deteriorate for any reason, a fade margin of 40 db would result in a reliability of 100 per cent with a video signal-to-noise ratio of 53 db. However, in practice this is not always possible. Therefore, the amount by which this standard is degraded depends principally on the fading encountered. Equipment failure and outages due to other than signal-level fading are not figured in these reliability-fade margin charts. If the installed system does not perform as calculated, then tests should be undertaken to determine the cause. These tests are detailed in this part under Equipment Tests and Measurements. The RF signal level should be checked. If it is not within 3 db of calculated, then Fresnel-zone clearance should be rechecked. If clearance is indicated but signal level is still low, then the power output of the transmitter, transmission-line losses, and antenna gains should be checked in that order. Where performance does not meet specifications, then detailed checks as indicated later will determine the probable cause of difficulty.

Fading margin as used in these level calculations is the usable signal above the receiver threshold. Fading margins in excess of 40 db raise the reliability of the systems. For example, if the received signal level was 85 db above the receiver threshold, then the system could tolerate a 45-db fade without the 53-db minimum noise value being degraded. Eighty-five-decibels less 45-db fade yields 40 db still above the threshold. This 40-db minimum signal allows the noise value to be met. More signal above this minimum design value will increase the performance, and the system will tolerate deeper fades. A system with a 48-db fading margin will tolerate an 8-db fade and still leave 40 db of signal to yield a 53-db signal-to-noise ratio.

MULTIHOP EVALUATION

The previous discussion was based on single-hop systems. Where more than one hop is used or necessary, several other factors should be considered. The video and audio signal-to-noise ratios decrease with each hop. Fortunately this increase in noise is not destructive. The tendency for sync compression increases.

Off-the-air pickups for TV microwave relays may require as many as three hops. In such a three-hop system the average S/N ratio will be 4.8 db poorer than a single hop, signal strengths being equal. This is shown in Fig. 2-7.

In this analysis the type of repeaters in a multihop installation using demodulated video and audio to modulate the next transmitter is considered. The video and audio signal level, receiver noise level, and threshold level in each repeater are considered to be the same throughout the multihop system. The video and audio noise levels will rise in each successive receiver, starting at the receiver nearest the beginning of the system. The increase in noise level is dependent on the number of hops.

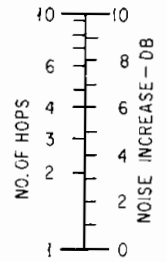

FIG. 2-7. Increase in noise for number of hops.

In addition to noise, fading also should be considered. The multihop reliability compared with a single hop is lower. As the variation in the received signal level occurs in one repeater owing to fading, the automatic-gain-control circuit of the IF amplifiers tends to maintain a constant output level toward the next station in the system. A 20-db fade in one hop would not result in a reduction of total transmitted video in the next leg. Unfortunately, the IF amplifier gain would increase and both the video level and the receiver noise level would be increased by the amount necessary to bring the total up to the nominal level. The result is that the signal-to-noise ratio on the hop next to the low-signal hop is decreased not so much by reduction of signal as by an increase in noise.

For example, the signal-to-noise ratio for a 10-hop system, one hop of which is experiencing a 20-db fade, is only 1 db worse than the signal-to-noise ratio of the fading hop alone. Let us consider the example of a three-hop system when video S/N ratio is being considered:

If the S/N ratio of one hop is 53 db, then the S/N ratio of three hops is 4.8 db less, or 48.2 db.

With a 20-db fade in one leg, the S/N ratio of the hop is 33 db and the over-all three-hop system with one leg going through a 20-db fade will be 32 db.

If fading is occurring in two legs at the same time, there will be a further degradation of noise ratio. Simultaneous fading on two legs of a multihop system is rare except in heavy fading regions as shown in Fig. 2-2.

EQUIPMENT TESTS AND MEASUREMENTS

TV microwave engineering tests can be divided into two parts; (1) tests to prove preliminary engineering in the installation of a system and (2) tests to determine causes of failure to meet predicted performance and reliability. Maintenance techniques can be applied to installed systems for improvement of existing day-to-day operation.

Testing and measuring TV microwave equipment are tasks requiring considerable skill and should not be attempted without proper test equipment and adequate knowledge of the subject. Good knowledge of the microwave equipment design and the use of systematic service methods with suitable test equipment will greatly reduce the possibility of error. Many types of test equipment have been developed for commercial and military microwave systems. Most of it is adaptable to TV microwave equipment.

Commercially available microwave gear for TV broadcast use generally employs unitized construction, permitting rapid and convenient replacement. If routine

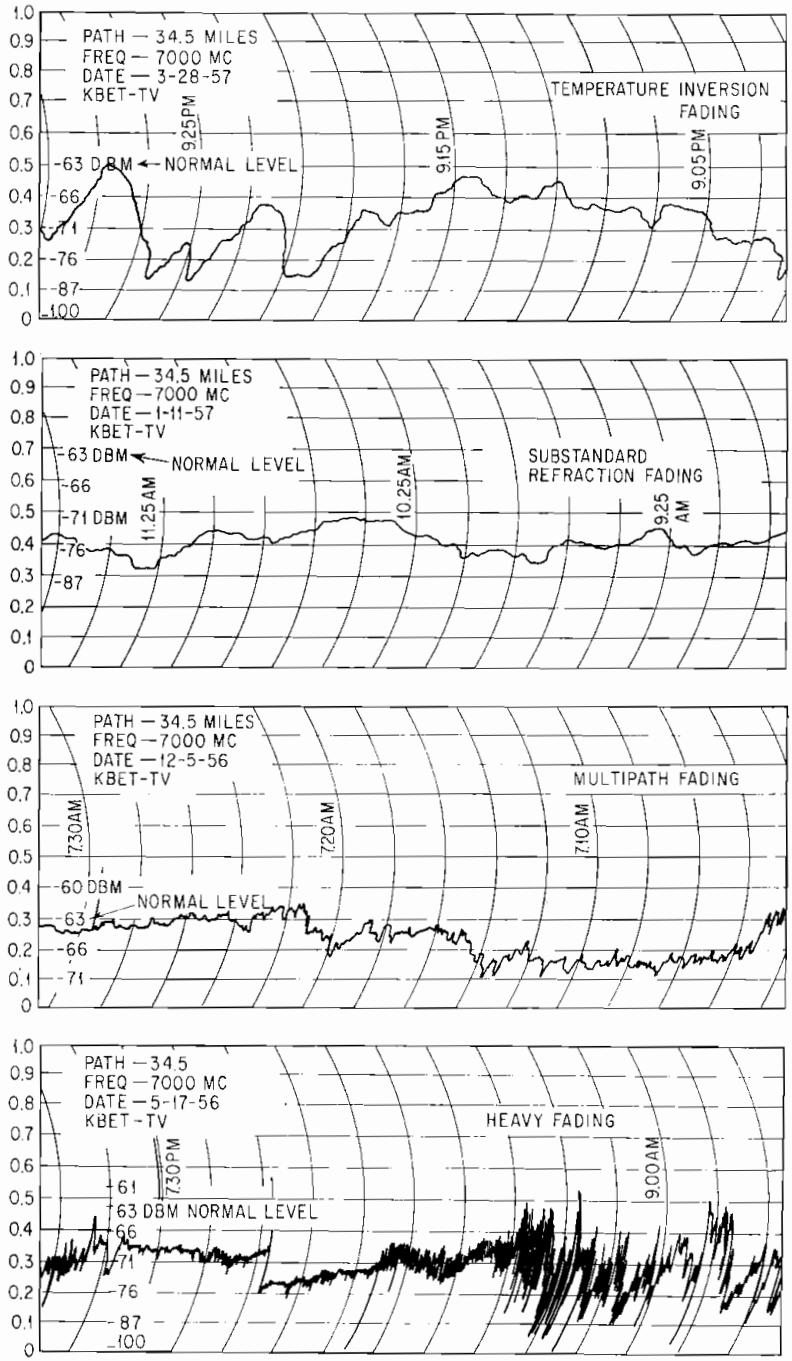

FIG. 2-8. Examples of different types of fading.

measurements are made of all important qualities, and if these measurements are logged, failure of tubes and components can be anticipated. Metering circuits and an ample number of test points strategically located permit checking of tube conditions, circuit voltages, and waveforms without removing associated components.

Previous discussion has referred to planning of over-all microwave systems and methods of utilizing various microwave equipments. Certain guides were detailed which should be followed if the system is to meet performance requirements. In contemplated installations, it is wise to plan the procurement and installation of the several associated items. If the station engineer requires the installation of a complete system, extensive preinstallation planning is necessary and should be done prior to ordering equipment. All supplier data on microwave and accessory equipment should be on hand. These data should include outline drawings with mounting dimensions, terminal connections, identification data, and electrical load requirement. Installation drawings of large items, such as towers and shelters, and of any special mounting and ventilation requirements are advisable. Detailed specifications can be obtained from the equipment manufacturer.

If the entire job is to be done simultaneously with the installation of a television station, elaborate preinstallation planning to the extent of drafting layouts is probably not feasible. The microwave installation is usually rushed along with the station installation. Although the engineer in charge may not actually detail in writing the several items, they can be used as a mental check list.

Suggested Microwave Test Equipment

The average television station has several pieces of test equipment suitable for maintenance of microwave equipment. Other test equipment is unique in that it will be used only for testing and maintaining microwave gear. The following items should be available:

1. *Oscilloscope.* Usually available at any TV station, it should be a wideband unit with a vertical amplifier flat out to at least 6 Mc. It is a valuable tool for locating video troubles in the transmitter modulator as well as checking video in the receiver after demodulation. Scopes are valuable tools in locating sources of hum and distortion.

2. *Multimeter.* A 20,000-ohm/volt meter having various voltage, current, and resistance ranges is another popular item.

3. *RMS voltmeter.* A vacuum-tube voltmeter flat out to at least 6 Mc with 0.001-volt full-scale sensitivity. This is useful in measuring rms values of noise voltages.

4. *IF signal generator.* A variable-frequency signal generator capable of covering the IF of the receiver is recommended. In most equipments, this IF is 120 Mc, although there are some units that have 90 or 130 Mc IF. The frequency should be capable of being swept at least 20 Mc for IF alignment purposes. A signal generator with crystal markers is recommended.

5. *Grid-dip oscillator.* Useful for measuring transmitter deviation, it should be capable of covering the IF with good dial readability.

6. *Microwave test set.* This may be by far the most expensive single piece of test gear found in a TV station. Where outright purchase is not warranted, arrangements should be made to rent or borrow this item. This unit in its common form is a combination microwave RF power meter, frequency meter, and calibrated RF signal generator. It can be used for measuring the level of the received signal.

7. *Audio-signal generator and distortion analyser.* These two items are used to measure audio characteristics.

8. *Frequency meters.* Frequency can be measured with a microwave test set or with one of several types of wavemeters.

9. *Communication facilities.* Two-way radio or telephone facilities should be available at all times between the microwave transmitter and its receiver.

10. *Spare parts.* Needless to say, a certain number of spare tubes should be kept available at all times. Klystrons used in the transmitters and receivers can be pretuned and stored. In this way when a klystron is to be replaced, the time required

is cut to a minimum by inserting a tube already tuned for the proper frequency. Owing to the reliability built into microwave equipment by the manufacturers, spare parts can be held to a bare minimum. Where waveguide equipment is used, spare mica windows and Teflon screws should be stocked. O rings for waveguide and coaxial lines should also be stocked, since water damage to external components cannot be predicted. Mixer crystals, an item not normally stocked by wholesale houses, should be on hand.

Microwave Tests

Before detailing actual tests and measurements, it should be pointed out that certain performance requirements of the system are desirable (see Table 2-1). A good monochrome system may not necessarily provide good color signals. This is because a color microwave system has much more stringent requirements than a monochrome system. The requirements for good color operation are associated with differential phase and gain and envelope delay. Equipment tests can be divided into propagation tests to determine signal levels and performance tests to determine the system characteristics with proper received-signal levels.

Propagation Tests

Before a microwave system is installed, the expected signal level at the receivers should be calculated from the data given previously. After the system is installed, if it does not perform as expected, the received signal should be measured at the receiver input to determine if the measured level approximates the calculated. If the received signal is 3 db or lower than calculated, then the system should be checked out to determine where this RF loss is occurring. In long and medium hops and in multihop installations, less-than-calculated signal strength may be an indication that errors occurred in calculations of power output, line losses, antenna gains, antenna orientation, or Fresnel-zone clearances.

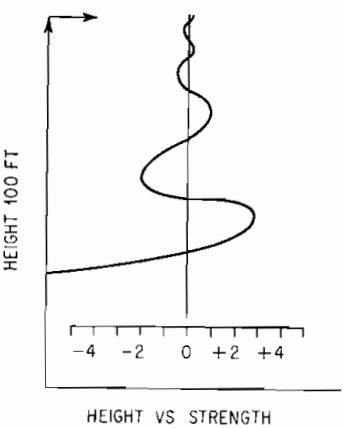

Fig. 2-9. Height-gain relation.

In long hops or in medium hops where low-power transmitters and small parabolas are used, 3 to 6 db of RF level can be gained by "height-gain" adjusting the antennas. This procedure is also helpful in extremely long hops or marginal systems. Height-gain adjustments are easy to make. Starting with the receiving parabola, the entire dish is moved in 12- to 18-in. increments vertically, and the received signal level is noted at each height. Over a vertical run of about 100 ft (for 2,000 Mc) and about 50 ft (for 7,000 Mc) the received-signal strength will usually vary and appear as in Fig. 2-9.

After the first maximum signal-level height has been found from the adjustments, the receiving antenna should be left at that position and secured. Then the transmitting-antenna height can be similarly adjusted vertically in the same manner while the received-signal level is noted. The transmitting dish should be permanently set at the first maximum when measured from the ground up. Since many television STL are located in metropolitan areas, these height-gain adjustments should be made during the months when trees are in leaf. Needless to say, these measurements should be made under steady signal conditions. To ensure that fading is not affecting the antenna being adjusted, it is suggested that another link be operating alongside the link under adjustment.* Then it can be determined that the increase or decrease in received signal level on the adjusted system is not due to fading.

* Usually not feasible.

If the signal strength is still appreciably below the calculated value, the output power of the transmitter should be checked. This can be done by using a microwave RF test set to measure power directly or by substituting for the output of the transmitter the known signal level of an RF test set. The test set is fed into a calibrated attenuation length of line (such as RC 21/U) if a 2,000-Mc system is under test. With 7,000-Mc transmitters, waveguide attenuators can be used while the receiver is used as a detector. Perhaps a simpler and faster way in some instances to check relative output from the transmitter is to change the transmitting klystron.

Another source of signal loss can occur in transmission-line connections. In 2,000-Mc systems where coaxial cable with type-N connectors are used, the actual loss of a male and female connector together could be as much as 1 db. The use of type-N connectors in 2,000-Mc systems should be kept to an absolute minimum. Seven-eighths- and 1⅝-in. flange couplings have lower loss and are suggested wherever usable in 2,000-Mc systems. In 7,000- and 13,000-Mc systems, care should be taken to ensure good physical mating of waveguide flanges in order to keep power loss at a minimum.

Apparent loss of signal from calculated values may result from the use of incorrect gain figures with certain parabolas. Not all parabolas have the same forward gain for a given diameter. Parabolas can be designed and manufactured for maximum forward gain or maximum forward gain consistent with minimum back lobes. The latter types are designed for use in multipath installations where back radiation may present isolation problems. It is advisable to use dishes recommended by the manufacturer for the particular use desired. The dimensions given in Fig. 2-3 are for maximum forward gain.

Polarization of radiation under normal circumstances is not a significant cause of propagation loss. However, cross polarization can be used to reduce cross talk between two links operating in the same band over the same path with isolation from 25 to 30 db.

In the final analysis of propagation tests, the actual signal level arriving at the receiver input terminals is all-important. The actual level of this signal can be determined by the use of a microwave RF test set. The received level as indicated by a meter in the first limiter grid circuit is recorded (under normal propagation conditions). Then the antenna transmission line or waveguide is disconnected and the output of the test set is fed into the receiver. The power from the test set is varied with the calibrated attenuator until the signal level from the test set equals that recorded from the antenna. The power level is read directly in dbm from the attenuator of the RF test set. Care must be taken to ensure that the test set is accurately aligned with the operating frequency of the receiver. Once the receiver is peaked on the received signal, it should not be adjusted when the RF test set is fed into the antenna input. Instead, the RF test set should be adjusted for maximum reading on the receiver. If a matching stub is used on the receiver input, as is sometimes provided in 2,000-Mc units, it should be left in the circuit and adjusted for maximum receiver limiter current under both conditions.

As pointed out previously, if the received signal is not within 3 db of the calculated value, it would be worthwhile to determine the cause.

Equipment Testing

Transmitter Tests

The transmitter should be tested for power output, operating frequency, deviation, noise, and differential gain and phase.

Power Output. The output power of the transmitter should be within 1 db of rated level. If it is not, then the klystron output should be checked by substitution of another tube. If the tube is not at fault, then the beam and repeller voltages should be checked. A good practical check on the power output of the transmitter is to use a small power probe. This consists of a loop at the end of a PL-239 plug connected to a 1N21 crystal (2,000 Mc). 1N23 crystals can be used for 7,000- and 13,000-Mc

systems. This loop is inserted into the antenna field by fastening it to the edge of the parabola. Orienting the loop will give changes in d-c rectified voltage from the power intercepted by the loop. The output current of the rectified crystal is connected to a 0- to 1-ma d-c meter. This meter reading will give an arbitrary power-level indication. Power variations are thus indicated. Aging klystrons and power-amplifier tubes will result in decreasing output power. This probe will also be helpful in peaking repeller voltages for maximum output.

Frequency Measurements. The operating frequency of the transmitter can be measured at the receiver by substituting the known frequency of a microwave test set for that of the transmitter. Operating frequency can also be measured with a calibrated cavity-type wavemeter. This is becoming a standard item supplied with most TV microwave units. Charts are furnished with each wavemeter which indicate the operating frequency corresponding to a given wavemeter dial setting.

Transmitter Deviation. The transmitting klystron deviation can be measured quite accurately with modulation. One method is to use a grid dip oscillator, or an IF signal generator. A sawtooth voltage from a built-in source in the transmitter or a sawtooth waveform obtained from a camera channel may be used as the test signal. This test sawtooth voltage is adjusted in level to approximate normal video modulation. A grid dip oscillator or the IF signal generator is loosely coupled to the IF amplifier of the receiver by removing a tube shield. When the video output is viewed on an oscilloscope, normal sawtooth voltage should be present. The transmitter should be adjusted to give maximum sawtooth voltage out of the receiver without compression. The receiver should be tuned for best signal, taking linearity into consideration. The grid dip oscillator or signal generator is then tuned through the IF of the receiver. A "birdie" will appear in the video presentation, running through the horizontal display. The frequency of the oscillator at the bottom of the sawtooth should be noted. Then the birdie should be run up the sawtooth and the frequency of the oscillator at the top of the sawtooth noted. The difference between these two frequencies is the deviation of the transmitter. If trouble is experience in first seeing the birdie in the scope waveform, the procedure can be practised with 60-cycle sine wave.

The sawtooth signal is then removed, and composite video fed into the transmitter. The video gain control on the transmitter is thus adjusted for maximum video deviation. In general, the amount of deviation is limited by the amount of sync or video compression that can be tolerated. The manufacturer's recommendations should be followed as to the amount of deviation. The noise-reduction qualities of the system are improved by increasing deviation, while extreme levels cause compression. Doubling the deviation yields a 6-db improvement in signal-to-noise ratio.

The deviation of a klystron is limited by several factors, the most important being the standing-wave ratio of the antenna and transmission line or waveguide. Since these loads for the klystron are reactive, they tend to change the oscillator tuning, resulting in the process known as "pulling." These outside reactive components can be isolated from the klystron to a great extent by inserting a load isolator between the klystron and its load.

Ferrite load isolators or gyrators are available for all three television STL bands. They are available in type-N connectors and waveguide flanges of various sizes. Insertion loss in several types is less than 0.5 db in the transmitted direction. Energy going from the load (antenna and coaxial or waveguide) to the klystron is attenuated from 25 to 30 db. In addition to permitting wider deviation of the klystron, these load isolators allow the transmitter to be mounted many feet from the parabola. On 2,000 Mc the parabola can be located as much as 150 ft away from the transmitter, using low-loss coaxial cable and a gyrator. Similar lengths of waveguide can be used to couple a 7,000-Mc antenna to its transmitter.

Checking Transmitted Video. The transmitter should be checked periodically for deterioration of video through its modulator. When a scope probe is placed at the plate of the modulator tube, composite video applied to the modulated klystron is observed. This signal can be checked for compression, noise, differential gain, and

other qualities. One method for checking differential gain is to run 3.58-Mc subcarrier on a stair-step pattern through the modulator and check the linearity through a high-pass filter on the scope.

The modulator can be checked for proper clamping if a clamping circuit is used. The clamping circuit must permit the color subcarrier appearing on the back-porch interval to pass without degradation. This is usually accomplished by the use of a broadly resonant 3.58-Mc circuit in the clamping circuit. Clamping circuits are not usually adjustable, but some manufacturers make the balancing circuit variable. Improper operation of clamping circuits may be caused by defective tubes or changes in resistor values. Clamping circuits are very important to multihop systems in order to maintain proper level. Noise may also creep into the signal. Properly working clamp circuits will ensure proper black level without deterioration of the color subcarrier. Clamping on a line-to-line basis tends to clean up hum or noise appearing during the clamping interval.

Measuring Video Signal-to-noise Ratio. The signal-to-noise ratio of a microwave system, distribution amplifier, or nearly any video amplifier can be determined in the following manner. A video signal, preferably a standard EIA test pattern, is passed through the equipment under test with normal level. The amplitude of this signal is measured at the terminated output of the equipment. This voltage should be measured accurately, from sync tip to video tip, on a peak-to-peak device, such as an oscilloscope which is flat out to at least 6 Mc. The input to the equipment under test should then be terminated (in a microwave system check, the input to the video modulator). The gain controls or any other controls in the equipment should not be touched during this test. The output of the equipment is next measured, with the input thus terminated. The resulting signal is noise or hum. It can be measured on a peak-to-peak basis with the oscilloscope in the high-sensitivity position and then converted into rms values, or it can be directly measured in rms by the use of a sensitive rms voltmeter, flat out to at least 6 Mc.

The noise ratio can be determined by

$$\text{Signal-to-noise ratio} = \frac{\text{peak video voltage}}{\text{rms noise voltage}}$$

$$\text{Signal-to-noise ratio in db} = 20 \log \frac{\text{peak video}}{\text{rms noise}}$$

This, then, would be the signal-to-noise ratio in decibels where the noise voltage is standardized in rms values (normal practice). Unless there is 60- or 120-cycle hum in the equipment, the ratio should be quite large (over 100 to meet the microwave-system specifications set forth in Table 2-1 for video noise, 53db). By the use of the oscilloscope for noise measurements, the nature of the noise can be determined and suitable corrective measures can be taken.

An rms type of meter is recommended for measuring noise, since it is much more accurate than the visual method of reading noise peaks on an oscilloscope.

The noise appearing in most amplifying equipment and microwave systems is high frequency in nature. To evaluate the noise ratio properly, the rms voltmeter and the oscilloscope should have essentially the same high-frequency response. A flat response out to 6 Mc is recommended.

The receiver noise figure plays an important part in the resulting video signal-to-noise value. The signal at the output of the receiver results only from the signal which is applied to the input and is amplified and demodulated by the receiver. However, the noise at the output results from noise which is applied to the input and is amplified and demodulated by the receiver *plus* the noise which is generated within the receiver. The deterioration in signal-to-noise ratio suffered in passing through the receiver is defined in terms of available signal and noise powers at the receiver input and output. It is called the over-all receiver noise figure. Noise figures for individual stages or units in a system such as the transmitter modulator, mixer, first

IF, can be defined in the same manner, but the over-all noise figure is not the simple product of the component figures. The noise figure for an ideal receiver matched to the antenna is 2, and the noise figure for an ideal receiver with infinite input impedance is unity—an improvement of 3 db.

Linearity Measurements. The microwave system for television should be linear in its amplitude-transfer characteristics, especially near 3.58 Mc. Nonlinearity may occur from several causes. The most common are the operation of the transmitter into reactive loads and overdeviating the klystron. Modulated klystrons have limitations on deviation due to nonlinear output vs. frequency.

The recommended testing method and adjustment are the same for both a monochrome and a color microwave system. Test equipment consists of a sweep generator and an oscilloscope. It is suggested that the response of the modulator section of the transmitter be checked first. The sweep is fed into the modulator, and the video appearing on the klystron repeller checked with the scope. The video output level should be flat up through 6 Mc, plus or minus ½ db. The region around 3.58 Mc should be essentially flat without any peaks or dips. The video output level should be equal to that required for normal deviation.

Clamping circuits, if used, should be disabled, which can usually be done by removing the clamping diodes and substituting a suitable resistor. Preemphasis networks, if used, should be removed for this test. If the response is not as expected, then the scope probe should be moved back by stages to find the stage causing the difficulty. If peaking coils are used, these should be adjusted. It may also be helpful to study the suggested method of checking amplitude linearity in the equipment instruction book.

After it has been determined that frequency amplitude response of the transmitter with normal deviation is satisfactory, then the receiver can be checked. The video sweep can be fed into the detector circuits, and the scope connected to the receiver video output. Or the video sweep oscillator can be fed into the microwave test set, which in turn can be fed into the receiver-antenna input. The video section should be flat out to 6 Mc, within 0.5 db. Thus the video circuitry can be examined. The IF bandwidth should be checked and adjusted following instructions contained in the equipment instruction manual. Deemphasis networks should be removed when the receiver is checked and adjusted.

For routine checks on the amplitude linearity, a rapid method is to use a composite video test signal from a stair-step generator or from a slide source. The clamping circuits and the pre- and deemphasis networks should be left in operation. The signal from the stair-step generator is passed through the system and then through a high-pass filter into the scope at the receiving end. If the video is passed through the high-pass filter, only the subcarrier frequency at different amplitude levels appears. Variation in the subcarrier amplitude indicates nonlinearity.

A rapid and easy test for amplitude linearity is to use a sawtooth signal. If a built-in sawtooth signal is not available in the transmitter, a sawtooth waveform can be had from the shading signal output of a live camera chain. This sawtooth voltage is passed through the microwave system, and the signal at the receiver video output is observed for linearity. This method of testing is rapid but will not give the observer the actual linearity response in decibels. It is helpful as a rapid check for amplitnde linearity of the modulated klystron and video systems.

Color Subcarrier Phase Shift. There are two types of phase distortion to be considered in a color microwave system. Phase distortion that results in both color burst and color picture information being shifted together has a small effect in comparison with the errors in color reproduction caused by a variation in the phase of the subcarrier as a function of its position in the amplitude range from burst toward white level. This sort of phase variation results in hue errors.

The phase of the color subcarrier should not be changed when passing through a system. Phase shifting with brightness causes the color signal to cange in hue and brightness. Several causes of phase shifts in a microwave system include diagonal clipping, variable-impedance circuitry, and multipath transmission of a microwave signal.

Phase shifts or differential phase are measured with the aid of a vectorscope, or color-signal analyzer. The process is complicated and beyond the scope of this part. Information on the above test equipment is provided in the instruction books.

Receiver Tests

Measurements of Receiver Threshold Level. The term *noise figure* is a figure of merit. It compares the actual noise threshold of a receiver under consideration with that of a hypothetical noise-free receiver with the same bandwidth and the same frequency of operation. The literature is complete with data on this subject. Here we are interested in the part this threshold level plays in the over-all sensitivity of the receiver. This threshold level largely determines the maximum usable distance of a microwave system. The required signal level at a receiver to provide specified performance can be determined in advance if the threshold level is known. Not all microwave-equipment manufacturers specify a threshold level for their receivers.

The threshold level, recorded periodically, can be used to predict deterioration of over-all receiver operation. Where identical receivers are used in a given location, the most sensitive receiver should be used in the hop where the lowest signal level exists.

Before a method of measurement is given, a brief explanation of how the threshold level is determined may be helpful.[13] A microwave receiver with an IF bandwidth of 16 Mc will be used as an example. The rms KTF for such a bandwidth is -132 db. The symbol K is the Boltzmann constant, T is the temperature (290°), and F is the bandwidth of the IF amplifier in cycles per second. Since the sync peak signal in the receiver has to override the peak noise, this rms KTF is converted to peak KTF. The conversion value of peak noise to rms noise is 13 db. Thus the -132-db peak value $+13 = -119$ db. The excess noise figure of the mixer crystal in the receiver is approximately 13 db. This gives a peak noise level of -106 db. A 6-db difference exists between the FM threshold and the AM threshold, the latter being the lower. Thus the FM threshold is -100 db. This is the level, or point, where an FM signal would override the receiver noise and thus be detected.

At this FM threshold level, the video signal-to-noise ratio is approximately 20 db, which is an extremely poor signal. Video S/N ratios of up to 25 db are classed as unusable. This is 5 db above threshold point. The noise content reaches a point at this level to be too objectionable to a viewer, and home receivers have trouble holding sync.

It might be well to point here how a 20-db rms peak video signal results from a RF signal that is at the threshold of the receiver. Three factors make up this S/N improvement. They are the FM wideband gain of the received FM signal, the conversion from peak to peak to rms to peak, and the 6-db improvement from AM to FM conversion. The wideband gain (WBG) is a function of the modulation index of the transmitter. Six-megacycle video deviated 2-Mc yields about 1.3-db wideband gain. If the 6-Mc video is deviated 6 Mc, then the WBG improvement is about 5 db. The conversion from peak video to peak noise yields a numerical gain of 13 db when changed to peak video and rms noise voltages. The noise ratio isn't improved but the decibel numerical value is owing to the current standard practice of using peak signal to rms noise. Thus the peak signal to rms noise ratio at the threshold is (FM/AM) + (peak noise/rms noise) + WBG $= 6 + 13 + 1 = 20$ db.

This threshold level, then, is the level of input signal required to be detected or noticed in the output noise of the microwave receiver. It can be measured simply with a calibrated microwave signal generator, as shown in Fig. 2-10.

The receiver is tuned up for normal operation with its output connected to an oscilloscope and terminated. Deemphasis networks, if used, should be removed. The signal generator is fed into the antenna input of the receiver through either waveguide or coaxial. If tuning stubs are used, they should be left in. The signal generator is put into operation after careful output-level calibration. The signal from the generator is raised above the noise and carefully adjusted to the normal operating frequency of the receiver. The IF gain control, if variable, is set to normal operating

level, since its position will somewhat affect the noise level. If the receiver has not been installed in a system, the IF gain control can be set at its midrange.

The signal generator should not have modulation on it, since the threshold level should be measured at its AM value. As the output of the signal generator is increased, there will be a decrease in the receiver noise as the limiter and gain-control circuits come into play. A point will be reached where the signal can just be seen in the noise. The dbm level of the signal from the generator is the threshold level of that receiver at the particular frequency and IF gain-control settings.

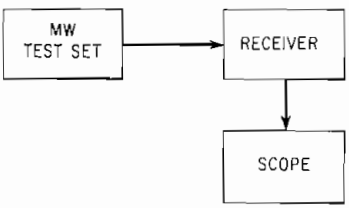

FIG. 2-10. Block diagram of test setup.

If the incoming signal in normal operation falls below the threshold level, then it is obvious that it will be lost in the noise. If the RF signal level is 40 db above the threshold, then in the average receiver, the performance specifications should be met as outlined in Table 2-1. If the signal is somewhat less than 40 db above the threshold, then the signal is degraded. The loss in signal below 40 db can be caused by fading, lack of RF signal due to overextension of paths, inadequate antenna gain, and other losses. It would be excellent practice in television microwave engineering to maintain the incoming RF signal at least 40 db above the threshold value.

Improving the Performance of Older-type Links

If the received signal strength is adequate as specified by the microwave-equipment manufacturer or as determined by the use of the charts included herein, then the performance of the system should meet the specifications shown in Table 2-1. However, there are many instances with older equipment where performance is substandard even with what is considered and calculated to be an adequate signal level. During periods of steady level signals, the system may barely meet these specifications. When a 20-db fade comes along, the performance is substandard for the period of that fade. Therefore, improvement of the existing system is desirable.

There are some installations where the calculated signal level results in submarginal operation. For economic reasons it may be desirable to improve the existing system instead of increasing the received signal by the use of larger antennas or an amplifier on the existing transmitter. As stated previously, it may also be desirable to build greater fading margin into a system.

Equipment improvement may be divided into the following methods of approach, without going into major modifications such as power amplifiers and larger size antennas:

Transmitter:

1. Increasing modulation deviation
2. Decreasing noise generated by the transmitter
3. Improving the modulator video characteristics

Receiver:

1. Improving the threshold level
2. Improving line match between antenna and receiver input
3. Decreasing noise generated by the receiver local oscillator
4. Video preemphasis and deemphasis

It may be possible to incorporate all the above-mentioned improvements in an existing link that is not performing satisfactorily. Obviously there are some equipments where none of the above items can be improved upon. This information can be used as a check list in installations where there is unsatisfactory performance. Present-day equipment is well designed, manufactured, and checked before being shipped to the customer. It should function properly when installed under acceptable engineering conditions.

Increasing Modulation Deviation

If the transmitter will not deviate more than 4 Mc, a worthwhile contribution to performance can be made by increasing this to 6 or 8 Mc. The cause of the deviation limitation should be determined first. It is suggested that the modulator be checked to ensure proper operation at the output level required for 8-Mc deviation. The modulator should be capable of providing the required voltage swing on the repeller for this deviation without degradation. The amount of this voltage can be obtained from tube data sheets for the particular klystron used, and the maximum deviation possible thus determined.

After the modulator has been checked, tests should be made on the modulated klystron. If a dummy load is available, it should be connected to the output of the klystron as closely as possible to eliminate any reactive waveguide or coaxial cable. The klystron deviation should be checked under these conditions. A klystron will deviate many magacycles more into a flat dummy load than into an antenna-line load. There is a natural limitation to deviation, due to the output vs. repeller voltage characteristics which are not linear with frequency. However, it should be possible to deviate up to 8 Mc with presently available klystrons on 2,000 and 7,000 Mc if the antenna is suitably flat.

The klystron should be checked and can be replaced if this amount of deviation is not possible into a dummy load. If this deviation is possible into a dummy but not into the waveguide or coaxial feeding the antenna, the VSWR can be checked to determine if the line is excessively reactive. If the antenna line limits deviation by being reactive, it is suggested that a load isolator be inserted between the klystron and the transmission line. This will prevent reactive components from being reflected back to the klystron. It should be remembered that if the deviation is doubled, the output signal will be 6 db better in signal to noise, assuming that limiting is taking place in the receiver.

Decreasing Noise Generated by the Transmitter

Noise on the transmitter carrier can be caused by hum and noise voltages in the power supplies and in the modulator appearing on the repeller of the klystron. Thermal-type shot noise may also be present. A quick test to determine the presence of noise, as well as its type and magnitude, can be made by looking at the repeller voltage with a scope. The entire transmitter should be adjusted for normal operation with composite video. Then the input to the modulator should be terminated in order that the noise and hum are not masked by video. The noise voltages, including hum, should be at least 1/1,000 of the peak voltage required for normal deviation. Hum and noise can be tracked down with the use of the scope on a stage-by-stage basis.

In addition to checking the repeller, klystron-beam voltage should also be checked. Voltage-regulation circuits and tubes sometimes cause random-noise voltages.

The same technique for determining, measuring, and eliminating noise in the transmitting klystron should be applied to the local oscillator in the receiver. Hum and noise appearing from the receiver klystron can also cause performance impairment by mixing with the incoming signal.

Improving the Video Characteristics of the Modulator

The modulator in the microwave transmitter is designed by the manufacturer to provide the necessary output video level for proper deviation. If the unit does not accomplish this, it probably needs maintenance. As pointed out previously, it should be capable of providing the necessary output voltage to deviate the klystron and still meet all the performance specifications for video. If it does not, a point-to-point check of the modulator circuit may be in order.

The modulator should be checked for differential gain and phase, signal-to-noise ratios, proper clamping, and output level for required deviation.

Video Preemphasis and Deemphasis

Most TV microwave equipments now available utilize preemphasis and deemphasis networks in the video circuits. This scheme improves color performance and reduces video noise in the output of the receiver by approximately 6 db. These networks are now available in type BNC input and output terminals and can be readily inserted into the video line feeding the transmitter modulator and the output line from the receiver. They are passive networks with emphasis starting at about 2 Mc. Their insertion loss is approximately 6 db per unit. Distribution amplifiers are used to build up the video from the receiver, although in most cases the 6-db insertion loss in the modulator input can be overcome by the modulator gain circuitry. This is a very economical method of improving the noise problem in older types of microwave systems that do not have preemphasis and deemphasis circuits.

The theory of operation is the same as frequency-response improvement in FM operation. When the video is built up from 6 to 8 db from 2 to 6 Mc, the deemphasis network in the last receiver brings the *video and noise* down by the same amount. Since most video noise is above 2 Mc, this crossover point is quite effective. In multihop installation, only the first transmitter and the last receiver need have the emphasis networks.

These emphasis networks also improve sound subcarrier operation by increasing the amount of the subcarrier voltage available if the deemphasis network is inserted after the video goes through the subcarrier receiver.

Improving the Threshold Value

Previously it was pointed out that the threshold level is the level at which a signal can be detected in the noise. If limiting in the receiver IF stages is taking place, an improvement of about 6 db can be obtained. If limiting is not taking place because of low signal level in the IF stages, the circuitry can be adjusted to cause signal-amplitude limiting at lower levels.

There are several factors which affect the threshold level of a receiver. In addition to limiting as described above, impedance matching between antenna and receiver, local oscillator injection power, crystal mixer current, the choice of a suitable mixer crystal, and low-noise IF amplifier design in the first two stages are all important factors contributing to the threshold level. Tubes used for the first two stages of the IF amplifier should be selected for low noise when necessary.

The mixer crystal determines requirements for the conversion gain, noise figure, and local oscillator excitation. These factors also determine, in turn, the threshold level. The noise ratio of commercially available crystals for TV microwave use (the 1N21 and 1N23 series) is usually measured at 30 Mc. The injection voltage frequency of the local oscillator has very little effect on the IF noise output resulting from the crystal when used as a mixer.

Currently available are mixer crystals in the 1N21E and the 1N23E series, which are picked crystals from the 1N21B and 1N23B types. These crystals have been selected for their high conversion gain, impedance match, and low noise figure. They may improve the threshold level from 3 to 5 db over the older types, and their use may be warranted to improve threshold levels.

Where balanced mixers are used in receivers, substituting matched pairs of these "low-noise" crystals may be warranted. RF and IF impedance of these crystals are held to closer tolerances, while the older types may vary from 340 to 460 ohms. The impedances are affected by the crystal holder, crystal geometry, and frequency and power level of the local oscillator.

The sensitivity of a crystal mixer is dependent on several factors. It should absorb all the signal power incident upon it, because any power reflected is lost. In order that the mixer can work properly, it is necessary that it have ample local oscillator power. This does not mean, however, that the more oscillator power applied to the crystal the better. Figure 2-11 shows the variation of crystal conversion loss in

decibels and the over-all noise figure of a microwave receiver, as a function of the crystal current.[10]

Figure 2-11 was calculated on the assumption that the IF amplifier has a noise figure of 3.0 db. As can be seen, the best noise figure is obtained with this particular crystal at a crystal current of approximately 0.4 ma. This is a representative case with 1N21 and 1N23 types of crystals. If the crystal current is a little higher than this value, not much sensitivity is lost. If the crystal current is lower, there will be some loss in sensitivity and the noise level increases rapidly. The equipment manufacturer's instructions should be used to set the initial injection voltage from the local oscillator. Then if additional sensitivity is required, the injection level or crystal current can be varied as the noise is observed on a scope or rms voltmeter. The modulator feeding the receiver under adjustment should have its input terminated during this noise adjustment in order not to mask the noise with video.

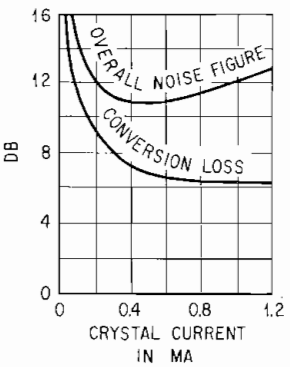

FIG. 2-11. Crystal conversion loss vs. over-all noise figure.

From Fig. 2-11 it can be seen that while the IF amplifier has a noise figure of 3.0 db, the crystal mixer increases this noise figure to approximately 11 db. This is, indeed, a good over-all noise figure and was calculated on a radar microwave receiver. TV video receivers require much more IF bandwidth than radar receivers. Thus the noise figure is higher on video receivers. It is possible to approach this figure with cascode input stages to IF amplifiers, low-noise crystals, and the use of balanced mixers.

Care and Handling of Mixer Crystals

Currently available mixer crystals undergo rugged mechanical electrical and exposure tests in the manufacturing process. The mechanical test consists of a 30-in. drop onto a wooden block and mechanical twisting of the terminals. However, the crystal units can be easily damaged in handling, storage, and use. It has been found that the static accumulated by a person's body is sufficient to damage the crystal when it is inserted into its holder in the mixer. Therefore it is recommended that one's hand be grounded to the receiver chassis before inserting the crystal in or removing it from the receiver. A further step would be to use a well-insulated tool in removing or inserting the crystal in its holder. Crystals may also be damaged when stored in the vicinity of high-power transmitters. In transmitter areas it is advisable to keep the crystals in the metal shielding capsules when not in use.

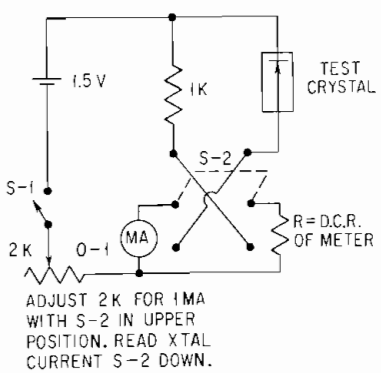

FIG. 2-12. D-c mixer crystal checker.

It is possible to build an inexpensive RF crystal mixer checker which will tell whether the crystal has deteriorated from the time it was known to be acceptable at the factory. The simplest way to check the crystal for deterioration is to measure its back resistance at the standard 1-volt value. A simple d-c mixer crystal checker is shown in Fig. 2-12. The 1N21 C and E series are acceptable if the back current at −1 volt is less than 0.100 ma. The 1N23 C and E

series are acceptable if their back current is less than 0.125 ma. The results of a d-c check of this type depend on the particular crystal, not on the manufacturer. The currents can be logged when the crystal is received, and during routine maintenance checks it can be compared with its original value for deterioration.

Table 2-5. Signal-level Calculation Sheet

Signal path from Sacramento to El Dorado, Calif., Date 7/30/57
Path length, miles, 34.5 Calculated by FLO recommended band 2

	2,000 (example)	7,000	13,000
Transmitting antenna gain, db	+32		
Receiving antenna gain, db	+32		
Free-space path loss, db	−130		
Transmission-line loss, db	−13		
Other losses, db (isolator, etc.)	−2		
Transmitter power gain, dbm	+40		
Calculated RF signal level at receiver	−41		
Calculated receiver threshold level	−81		
Signal level above threshold, db	−40		
Converted into prop. reliability	99.99%		
Video signal to noise peak rms	60 db		
Fading margin, db	40		

Remarks:

NOTE: Calculated RF signal at the receiver is the difference between losses and gains between transmitter and receiver. Signal level above threshold is the difference between the RF signal level at the receiver and threshold level. In the above example, lines total 200 ft, power is 10 watts, receiver bandwidth 25 Mc, noise figure 19 db; 6-ft dishes, S/N ratio is fade margin +20 db.

Transmission-line Tuning Stubs

One make of TV microwave equipment currently available for the 2,000-Mc band utilizes coaxial tuning stubs at the input to the receiver and the output of the transmitter klystron. Adjusting these stubs tends to reduce the VSWR of the line. The matching of the antenna and line to the receiver input raises the received signal level. But what is perhaps more important, it improves the differential gain and phase response of the receiver. This is accomplished by the fact that the signal voltages as a result of FM deviation and demodulation are more nearly constant in level owing to the flatness of the antenna input circuitry.

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Part 3

ELECTRICAL PERFORMANCE STANDARDS FOR TELEVISION RELAY FACILITIES

PROPOSED EIA STANDARD

INTRODUCTION

The intent of this standard is to specify the minimal electrical performance characteristics consistent with good engineering practice of radio relay equipment intended for transmission of NTSC color-television signals from a studio to its associated television broadcast transmitter or for similar applications. (For the purposes of this standard it is assumed that relay equipment meeting the stated requirements is also adequate for monochrome picture transmission.) Pertinent parameters are defined, and standards and methods of measurement have been established for each where practical to do so.

The EIA subcommittee (TR 4.2) responsible for this standard coordinated its efforts with those of the EIA subcommittee (TR 4.1) on Standards for Microwave Transmission Systems and the IRE Committee on Video Techniques to produce a standard of maximum usefulness.

SCOPE

The radio relay systems covered by this standard will generaly be in frequency bands above 1,800 Mc. They will specifically be those used for transmission of TV signals from a broadcasting studio to its associated TV transmitter. The information provided should, however, be useful to a variety of TV relay purposes such as portable-mobile relays, intercity relays, off-air pickups, etc., particularly when the signal being relayed is intended for broadcast purposes.

The relay system may transmit the audio and video portions of the TV program on the same RF channel by any of several multiplexing methods, or they may be transmitted separately. Comment is made only on over-all performance requirements.

The video portion of the TV program may be either a color or monochrome signal. It is recognized that a monochrome signal does not actually require some of the specifications given in the standard. However, it is felt that with the imminence of increased color programming, only the one more rigorous standard should be provided.

DEFINITION OF TELEVISION RELAY SYSTEM

A *television relay system* is a system of two or more stations for transmitting television relay signals from point to point using radio waves in free space as a medium, such transmission not being intended for direct reception by the public.

A *television relay signal* is a radio-freqnency wave modulated primarily by a com-

posite picture signal and may or may not include the accompanying sound, auxiliary, and control signals.

The *composite picture signal* shall consist of the following individual signals:

1. Picture signal (including horizontal and vertical blanking signals)
2. Synchronizing signals (horizontal and vertical)

The *standard composite picture signal* is a composite picture signal having a waveform specified in TR-135 entitled "Picture Line Amplifier Output." This drawing shall be the latest revision of the standard.

Television relay input signals are signals consisting of a standard composite picture signal and, optionally, the accompanying audio, auxiliary, and control signals, available from separate circuits.

Television relay output signals are signals consisting of a standard composite picture signal and, optionally, the accompanying audio, auxiliary, and control signals, available to separate circuits.

Studio-to-transmitter Relay System

A studio-to-transmitter relay system is a television relay system of one or more hops providing service from a television studio to its associated transmitter.

Portable-mobile Relay System

A *portable-mobile relay system* is a system for the transmission of television relay signals from a portable or mobile program source to a fixed control room or a broadcast transmitter. This system may include more than one portable or mobile relay station. *Portable equipment* is defined as being readily transportable and operable in transit.

Intercity Relay System

An *intercity relay system* is a system for the transmission of television relay signals by fixed stations from one metropolitan area to another.

Intracity Relay System

An *intracity relay system* is a system for the transmission of television relay signals by fixed stations between two or more points within the metropolitan area for purposes other than those covered under Studio-to-transmitter Relay Systems.

Off-the-air Pickup Relay System

An *off-the-air pickup relay system* is a system wherein the radiated signal from a television broadcast station is picked up by a suitable receiver and relayed to a point of utilization.

Transmitting Terminal Station

A *transmitting terminal station* is part of a television relay system and is the specific assembly of apparatus which accepts a television relay input signal and radiates a television relay signal.

Receiving Terminal Station

A *receiving terminal station* is part of a television relay system and is the specific assembly of apparatus which accepts a television relay signal and delivers a television relay output signal.

Repeater Station

A *repeater station* is part of a television relay system and is the specific assembly of apparatus which receives and retransmits a television relay signal.

Relay Channel

A *relay channel* is the band of frequencies used in transmission of a single television relay signal and normally includes both the frequency band for the transmission of intelligence and sufficient guard bands.

Relay Band

A *relay band* is composed of a group of contiguous relay channels.

OVER-ALL SYSTEM PERFORMANCE CHARACTERISTICS

This applies to the performance characteristics of a *studio-to-transmitter relay system* from transmitting-station input to receiving-terminal-station output.

Input Impedance

Composite Picture Signal

Definition. The input impedance of a relay system is the complex ratio of voltage to current, expressed in rms, as measured at the input terminals of a transmitting terminal station.

Standard. The standard input impedance of a relay system shall be 75 ohms ± 5 per cent and constant within ± 2 per cent over a frequency range of 0 to 4.3 Mc. This impedance shall be connected for unbalanced line.

Method of Measurement. It is recommended that the input impedance of the relay system be measured by means of an impedance equipment having an accuracy of ± 1 per cent in the vicinity of 75 ohms.

Audio Signal

Definition. The input impedance of a relay system is the complex ratio of voltage to current, expressed in ohms, as measured at the input terminals of a transmitting terminal station.

Standard. The standard input impedance shall be 600/150 ohms, nominal.

Method of Measurement. Standard audio-frequency impedance-measuring equipment shall be used.

Input Level

Composite Picture Signal

Definition. The peak-to-peak voltage of a composite picture signal is the difference in level between its sync tip and reference white expressed in volts.

Standard. The input of the standard composite picture signal to the relay system across its standard impedance shall be a minimum of 0.7 volt and a maximum of 1.4 volts peak to peak. The standard level shall be 1.0 volt peak to peak.

Method of Measurement. It is recommended that the signal voltage input to the relay system be measured by means of an oscilloscope capable of measuring such a signal within an accuracy of ± 2 per cent. The signal may normally occupy the band from 30 cycles to 4.3 Mc.

Audio Signal

Definition. The level of an audio signal is defined numerically as the power ratio in decibels between the audio signal working into a given impedance and a reference signal of 1 mw. It is commonly expressed in dbm.

Standard. The standard audio input level shall be a minimum of 0 dbm and a maximum of +20 dbm. The nominal operating level shall be +10 dbm.

Method of Measurement. The audio input level shall be measured directly across the input terminals of the relay system using a 400-cycle tone.

Load Impedance

Composite Picture Signal

Definition. The load impedance of a relay system is the complex ratio of voltage to current, expressed in ohms, as measured across the two-terminal network which terminates the output of the relay system.

Standard. The standard lead impedance for the relay system shall have a value at zero frequency of 75 ohms ±5 per cent. This impedance shall be connected for unbalanced line operation and shall be constant within ±2 per cent over the frequency range from 0 to 4.3 Mc.

Method of Measurement. It is recommended that the load impedance of the system be measured by means of an impedance-measuring equipment having an accuracy of ±1 per cent in the vicinity of 75 ohms.

Audio Signal

Definition. The load impedance of a relay system is the complex ratio of voltage to current, expressed in ohms, as measured across the two terminal network which terminates the output of the relay system.

Standard. The standard load impedance shall be 600/150 ohms, nominal.

Method of Measurement. Standard audio-frequency impedance-measuring equipment shall be used.

Source Impedance

Composite Picture Signal

Definition. The source impedance of a relay system is a complex ratio of voltage to current, expressed in ohms, of the internal impedance as measured at the output terminals of a receiving terminal station.

Standard. The source impedance of a relay system shall be 75 ohms ±10 per cent over a frequency range of 15.75 kc to 4.3 Mc.

Method of Measurement. It is recommended that the source impedance of a relay system be measured by means of an impedance bridge having an accuracy of ±1 per cent in the vicinity of 75 ohms.

Output Level

Composite Picture Signal

Definition. The peak-to-peak voltage of a composite picture signal is the difference in level between its sync tip and reference white expressed in volts.

Standard. The standard composite picture-signal output from a receiving terminal station across its standard load impedance shall have a level of 1.0 volt peak to peak. The signal level shall be adjustable between the limits of 0.7 and 1.4 volts.

Method of Measurement. It is recommended that the signal voltage output of the relay system be measured by means of an oscilloscope capable of measuring such a signal within an accuracy of ±2 per cent. The signal may normally occupy the band from 30 cycles to 4.3 Mc.

Audio Signal

Definition. The level of an audio signal is defined numerically as the power ratio in decibels between the audio signal working into a given impedance and a reference signal of 1 mw. It is commonly expressed as dbm.

Standard. The standard audio signal output from a receiving terminal station across its standard load impedance shall be 10 dbm ±2 db for 100 per cent modulation.

Method of Measurement. The audio output level shall be measured directly across the output terminals of the relay system using a 400-cycle tone.

Polarity

Composite Picture Signal

Definition. The polarity of a picture signal is the sense of the potential of a portion of the signal representing a dark area of the scene relative to the potential of a portion of the signal representing a light area. Polarity is stated as "black positive."

Standard. The standard polarity of the input or output of a microwave link shall be black negative.

Method of Measurement. It is recommended that signal polarity be measured by means of an oscilloscope of known deflection polarity.

Amplitude vs. Frequency Characteristic

Composite Picture Signal

Definition. An amplitude vs. frequency response characteristic is a description by means of a graph of the variation with frequency of the ratio of sine-wave output voltage applied to a four-terminal network.

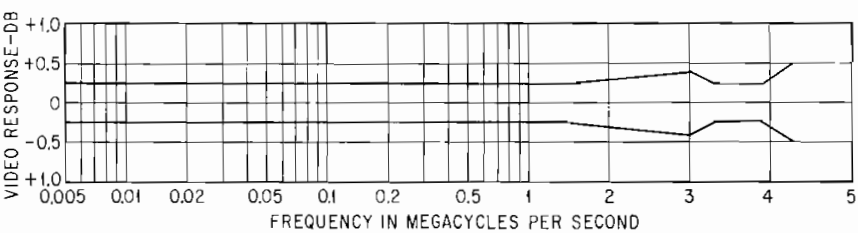


FIG. 3-1. Amplitude vs. frequency-response characteristic.

Standard. The amplitude vs. frequency response characteristics of a microwave link shall be within the limits specified in Fig. 3-1.

Method of Measurement. Deferred.

Audio Signal

Definition. An amplitude vs. frequency response characteristic is a description by means of a graph of the variation with frequency of the ratio of sine-wave output voltage to input voltage applied to a four-terminal network.

Standard. The amplitude vs. frequency response characteristics of a microwave link shall be within the limits specified in Fig. 3-2. If preemphasis and deemphasis are used, it is recommended that it be in accordance with the impedance-frequency characteristics of a series *LR* network having a nominal time constant not greater than 75μsec.

Method of Measurement. The measuring equipment shall terminate the input and output of the equipment under test in pure resistances having values within 5 per cent of the rated source and load impedances. The condition of grounding or balance to ground normally used in operation shall be maintained. The standard input level and deviation to the transmitter shall be established at 400 cycles, and the receiver output

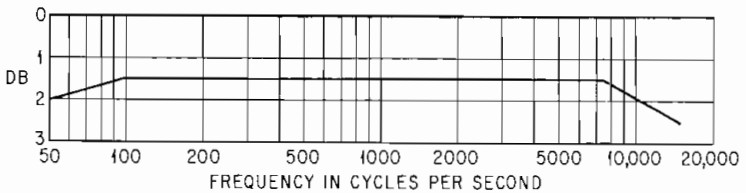


FIG. 3-2. Amplitude vs. frequency-response characteristic—audio signal.

control set for standard output. If *no* preemphasis and deemphasis are used, the frequency response shall be taken under these conditions, maintaining constant input to the transmitter and measuring receiver output variations. If preemphasis and deemphasis are used, after setting up as described, the input to the transmitter shall be dropped approximately 20 db and kept at this level during the frequency-response run. The receiver controls shall *not* be reset. This procedure is used to prevent overload of the audio system at higher audio frequencies due to the "boost" provided by the preemphasis network.

Low-frequency Response

Composite Picture Signal

Definition, Standard, and Method of Measurement. Deferred.

Relative Envelope Delay vs. Frequency Characteristics

Composite Picture Signal

Definition. Relative envelope delay is the variation in the first derivative of the phase shift, measured in radians, with reference to the frequency, measured in radians per second.

Standard. Deferred.

Method of Measurement. Deferred.

Step-function Transient Response

Composite Picture Signal

Definition, Standard, and Method of Measurement. Deferred.

Harmonic Distortion

Audio Signal

Definition. The audio-frequency harmonic distortion is the change in harmonic content of the input signal as a result of passing through the relay system.

Standard. The audio-frequency distortion, including all harmonics up to 30 kc, shall not exceed the values given in the following table at 25, 50, and 100 per cent of full modulation.

Distortion, per cent	*Frequency range, cps*
1.75	50–100
1.25	100–7,500
1.5	7,500–15,000

Method of Measurement. Standard audio-signal generating and distortion-measuring equipment shall be used. A resistor equal to the input impedance of the transmitter shall be connected between an audio oscillator (having less than 0.1 per cent rms distortion) and the transmitter input terminals. The audio-freqnency-level meter shall be connected across the output of the oscillator. The receiving end shall be terminated in a resistor equal to its rated load impedance, and the distortion-measuring equipment connected across this resistor. Measurements shall be taken on at least the following frequencies: 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 cps. It should be noted that if the audio transmitting and receiving equipment employ preemphasis and deemphasis, constant modulation percentage is *not* obtained by constant input voltage but can be obtained only by dropping the transmitter input voltage with rising frequency as many decibels as the preemphasis curve rises. The receiver and transmitter gain controls shall not be readjusted during this procedure.

NOTE 1: Measurements of distortion in the range of 7,500 to 15,000 cps, at 25 and 50 per cent modulation, may not be possible with presently available measuring equipment if preemphasis and deemphasis are employed, and these measurements are not required in such a case.

NOTE 2: For the higher modulation frequencies, it is important to include in the measurements only harmonics of the modulating frequency and to exclude hum and noise components.

Differential Gain and Differential Phase

Composite Picture Signal

Definition. In a video-transmission system, "differential gain" is the difference in gain of the system in decibels for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal on which it is superimposed.

NOTE: In this definition, level means a specified position on an amplitude scale applied to a signal waveform.

In a video-transmission system, "differential phase" is the difference in phase shift through the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal on which it is superimposed.

NOTE: In this definition, level means a specified position on an amplitude scale applied to a signal waveform.

Standards. Maximum differential gain expressed in decibels relative to the maximum gain at 50 per cent average picture level (APL) shall not exceed 0.5 db; at 10 and 90 per cent APL it shall not exceed 0.8 db. Maximum differential phase between blanking level and any other level in the blanking to reference white range shall not exceed $+1.0$, $-1.0°$ at 50 per cent APL; it shall not exceed $+1.5$, $-1.5°$ at 10 and 90 per cent APL. The differential phase shall not exceed a total amount of $1.5°$ at 50 per cent APL and a total amount of $2.0°$ at 10 and 90 per cent APL.

Method of Measurement. The TV relay system shall be operated at standard input and output levels. A test signal consisting of the following components shall be applied to the transmitter input.

1. A low-frequency exploring voltage which varies from blanking to reference white.
2. Sync pulses at the nominal picture line frequency with an amplitude of 0.4 that of the exploring voltage and a nominal width of 5 μsec. Each sync pulse shall be followed by a nominal 5-μsec interval at blanking level.
3. A higher frequency sine wave having a peak-to-peak amplitude of 0.2 that of the exploring voltage. Unless stated otherwise, the sine wave shall he at a nominal frequency of 3.58 Mc.

4. The test signal may also contain such elements of a composite signal (additional sync pulses, color burst, etc.) as may be required for proper operation of clampers or other control devices in the specific equipment under test.

It shall be possible to make measurements at 10, 50, and 90 per cent average picture level. Average picture level is defined as the average signal level during active scanning time, i.e., excluding intervals at blanking and sync, integrated over a frame period. It is expressed as a percentage of the blanking to reference white range. Differential gain is measured by observing the variation in the amplitude of the high-frequency sine wave at the receiver output during a cycle of the exploring voltage at a given APL. Differential phase is measured by observing the variation in the phase of the high-frequency sine wave at the receiver.

Signal-to-noise Degradation

Composite Picture Signal

Definition. The video signal-to-noise ratio for the relay system is the ratio of the peak-to-peak signal voltage to rms noise voltage at the relay output terminals. Noise as referred to herein is random noise and does not include hum components or interfering tones.

Standard. The video signal to rms noise shall be 63 db weighted. The characteristics of the noise-weighting network are shown in Figs. 3-3 and 3-4 (63 db weighted corresponds to approximately 48 db unweighted).

Method of Measurement. The system shall be operated using a standard composite picture signal at standard input and output levels. The modulation shall then be removed, and the output disconnected from the 75-ohm termination and fed to the weighting network which shall be terminated with 75 ohms. The noise output shall be determined at this termination using an appropriate meter. The meter shall be of the rms or average (calibrated in rms) type with a frequency response that is flat ± 1 db to 4 Mc relative to 10 kc.

NOTE: This standard is for nonfading conditions, and it should be noted that the percentage of time during which this standard is maintained is a function of the system fade margin.

Audio Signal

Definition. The signal-to-noise ratio of the relay system is the ratio of rms signal voltage to the rms noise voltage in the relay output terminals. Noise is any extraneous output voltage in the frequency band 50 cycles to 15 kc.

Standard. The rms signal to rms noise ratio shall be at least 58 db.

Method of Measurement:

1. For an AM system the signal-to-noise ratio can be determined by power meters applied to the relay system output with measurements taken with carrier modulation at 100 per cent 400-cycle and at 0 per cent modulation.

2. For an FM system the ratio of signal to noise in the absence of modulation can be determined as follows: The carrier shall be deviated with rated modulation at 400 cycles, and the output determined with an rms indicator. The modulation shall be removed, and the noise output determined with an rms indicator. If preemphasis is used, deemphasis circuits shall be included ahead of the rms indicator.

3. Should the radio relay equipment utilize circuits that are common to the audio and video signals, the audio S/N measurements shall be made while relaying a standard picture signal under standard input and output level conditions.

NOTE: Standard input and output impedance shall be used in all the above measurements. The audio test signal shall be sufficiently free from distortion and noise for the purpose of these measurements.

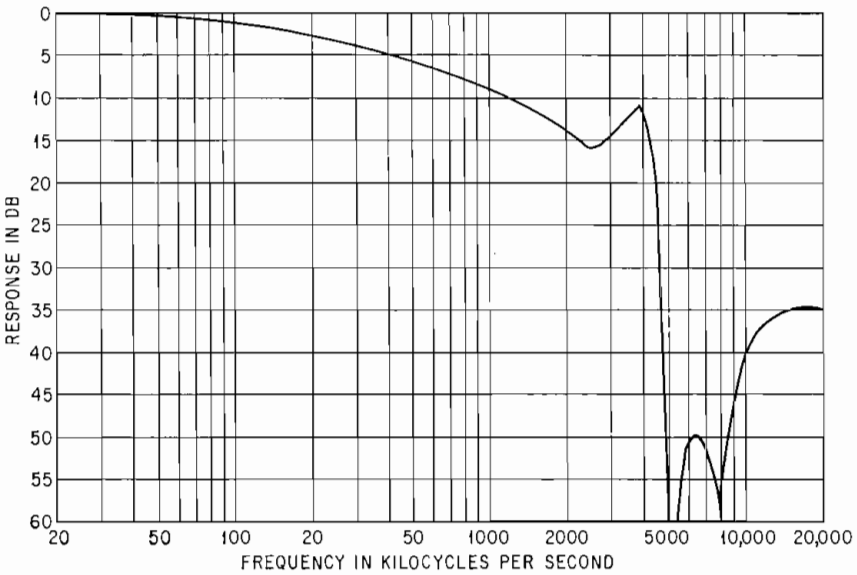
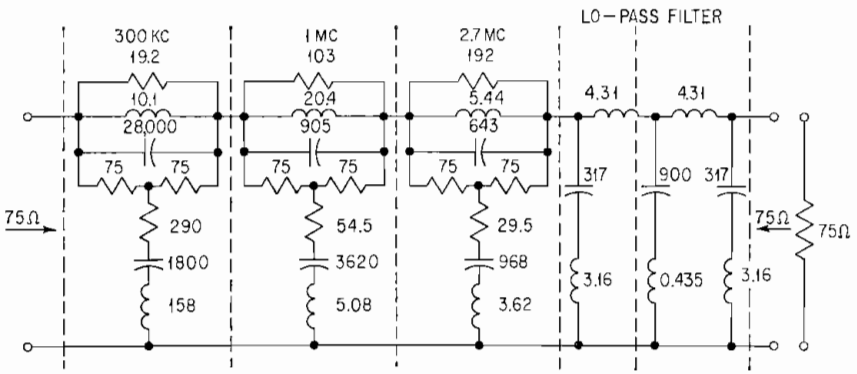


FIG. 3-3. Response of color-TV weighting network.



INDUCTORS IN MICROHENRIES, TYPE 1501 COILS
CAPACITORS IN MMF
RESISTANCE IN OHMS
Q OF ALL COILS — 50
TERMINATING IMPEDANCE 75 OHMS

FIG. 3-4. Television weighting network.

Signal-to-hum Ratio

Composite Picture Signal

Definition. Video signal-to-hum ratio for the relay system is the ratio of the peak-to-peak signal voltage to the rms hum component voltage at the relay output terminals.

Standard. Deferred.

Method of Measurement. The system shall be operated using a standard composite picture signal at standard input and output levels. The modulation shall then be removed, and the hum output shall be determined with an appropriate meter. The meter should be of the rms or average (calibrated in rms) type with a bandwidth sufficiently narrow so that the random noise does not affect the reading.

Power Supplies

Composite Picture Signal

Definition. The rated power supply of the system is described by specifying the voltage, the number of phases, and the frequency of the supply with which the system shall be required to meet all performance standards applying to such apparatus.

Standard. The standard rated power supply shall be single-phase, 117-volt rms ± 5 per cent, 60 cps, ± 2 per cent alternating current.

Method of Measurement. Standard power-measurement practice shall be followed.

Part 4

PLANNING, CONSTRUCTION, AND OPERATION OF A REVERSIBLE INTERCITY MICROWAVE RELAY SYSTEM WITH AUTOMATIC FAULT-REPORTING EQUIPMENT

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INTRODUCTION

Jefferson Standard Broadcasting Company owns and operates two television stations: WBTV in Charlotte, N.C., and WBTW in Florence, S.C. The airline distance between the two cities is 94 miles. Charlotte, N.C., is a metropolitan area with a population of more than a quarter of a million people and is the largest city in the two Carolinas. Florence, S.C., has a population of approximately 26,000. However, there are more than 800,000 Carolinians within the grade B contour of WBTW, which encompasses an area of some 12,292 square miles. Nearly 600,000 of these people reside on farms or in communities with populations under 1,000. Florence, with its population of only 26,000, is the largest community in the entire 12,000-square-mile area served by WBTW.

The Florence station is completely equipped to originate local live productions. However, because of the small population of Florence itself and the wide dispersion of the communities it serves, WBTW has had real difficulty in securing the suitable and salable talent necessary for successful local live productions. Charlotte, with its much larger population, has an abundance of talent which has built up a very high degree of popularity in the Carolinas over WBTV during the past nine years. Florence needed television talent—Charlotte had it—the problem was how to make this talent available to WBTW at a cost which would be compatible with the station's rate card. Economics, of course, ruled out the use of common-carrier facilities. Until recently, Part 4 of the Commission's Rules would not permit licensing of privately owned intercity relay systems where common-carrier facilities were available. In our case such common-carrier facilities were installed and were available. Thus, we were

* The author is deeply indebted to C. I. McDowell, C. A. Runyon, and J. B. Bullock of TCA and T. E. Howard for their valuable assistance in preparing this material.

stymied until the Commission recently relaxed its rules so as to permit privately owned and operated intercity facilities. We promptly applied for and received construction permits for the intercity system. The system has been constructed and has been in operation since Feb. 15, 1959. The system, which is designed to accommodate both color and monochrome programs, will also make available to WBTW the extensive color facilities installed at WBTV. The WBTV studios in Charlotte are equipped for the origination of local slide, film, opaque, and live color or color video tape-recorded programs. Origination of WBTW programs from one of the Charlotte studios enables WBTW to schedule local live color programs, which is not feasible from the Florence studios.

DESCRIPTION OF SYSTEM

The WBTV-WBTW intercity system consists of two terminal stations and three repeater stations (see Fig. 4-1).

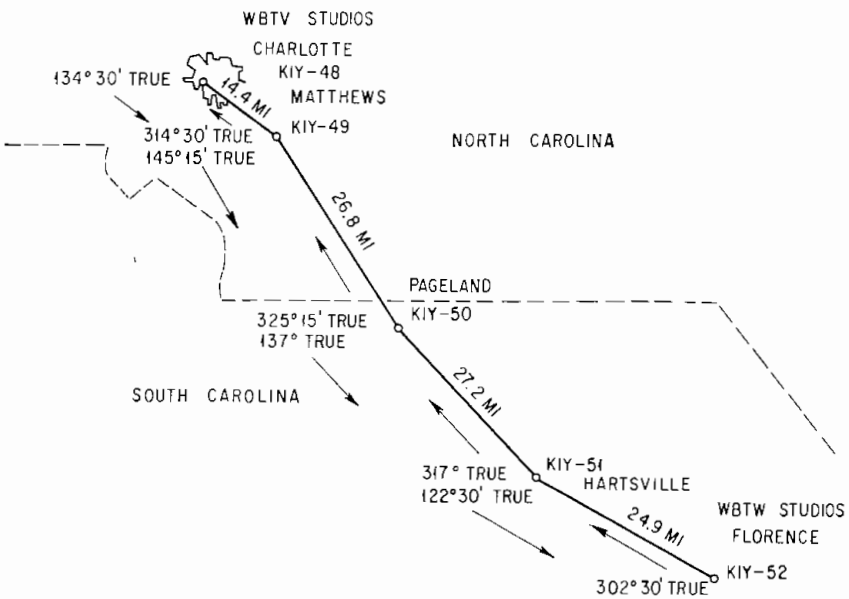


FIG. 4-1. WBTV-WBTW intercity microwave relay system.

The system was designed for remote control, reversible transmission, and automatic fault reporting, and the three repeater stations are unattended. A telephone line is used as the medium for switching signals and for reporting the status of each switched station as well as reporting faults existing at stations other than the controlling terminal. Separate private-line telephone-communication facilities are provided among all locations to facilitate maintenance and adjustments.

All transmitting and receiving equipment are housed in concrete block structures at the bases of the various towers. Plastic domed parabolic reflectors are mounted on these structures and are directed to passive reflectors mounted on the towers. The ground systems consist of 4/0 bare copper wire buried 15 in., extending from the tower base to each guy anchor, and bonded to each guy wire as well as to a copper-clad rod driven in the ground. A similar rod is used as a common-point bond to all three ground wires and connected to the tower and equipment racks to complete the system. A typical repeater installation is shown in Fig. 4-2.

The transmission system is capable of monochrome or color-television video-signal

transmission in either direction, with television audio contained within the channel as a diplexed subcarrier signal. Audio diplexing is provided in both directions.

Automatic frequency control is provided at each of the repeater stations. Monitoring of the transmitter video modulation is also provided at each repeater, the RF signal being demodulated by sampling the same cavity used in the AFC circuit. Thus the output of each repeater transmitter can be locally monitored as an aid to inspection and maintenance of the unattended equipment at the repeater stations.

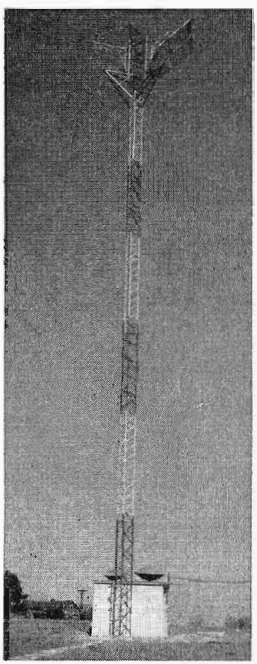


FIG. 4-2. A typical repeater installation.

Two RF channels are used in the system, thus avoiding problems of cross coupling between adjacent receiving and transmitting antennas and passive reflectors on the same tower. Sufficient frequency separation is used to provide adequate isolation between received and radiated signals. The use of two RF channels also minimizes possible problems of overshoot signals causing interference at subsequent receivers.

Path Considerations

In the design of a microwave relay system two types of fading must be guarded against if the system is to have a predictable and a satisfactory propagational reliability. These two types of fades are recognizable by their duration and would be identified as due to what is called "inverse bending" and "multipath" reflection. A third type of fading, due to actual attenuation of the microwave beam by rain or snow, is generally negligible at 7,000 Mc and so will not be considered.

Inverse Bending

The inverse-bending type of fade is prolonged. A fade of this type may last for from a few minutes to several hours as atmospheric conditions change. It is caused by the fact that the trajectory of the microwave beam from transmitter to receiver is not actually a straight line but is, in fact, curved, generally following a path similar to that shown in Fig. 4-3. The path departs from a straight line because the dielectric constant of air generally decreases with altitude. If the atmosphere were perfectly homogeneous, propagation would be along a straight line. If, owing to temperature

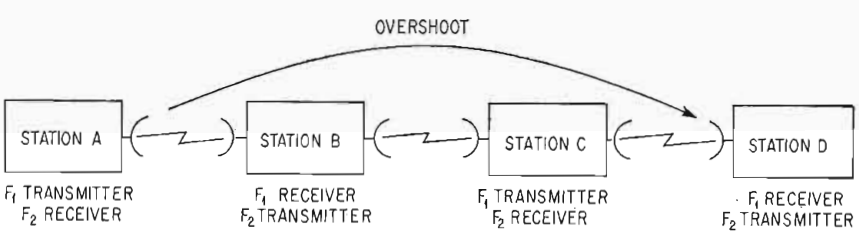


FIG. 4-3. Inverse-bending type of fade.

inversion along the path, the normal conditions become reversed, the beam may then have to follow an "inverse-bend" trajectory, which will result in its being blocked, unless sufficient clearance is provided.

The protection against inverse bending then is adequate clearance. Once this has been provided, the second type of fading, multipath, may be considered.

Multipath

Multipath fading, as the name implies, is caused by the signal arriving at the receiver by two different paths, which become out of phase 180° or nearly so upon arrival. In a multipath fade, one of the paths is, of course, the straight-line antenna-to-antenna path. The second path may be from a ground reflection, from a layer of still air, or maybe from a flat, low cloud base. The second signal, if it is of equal strength to the direct signal and in phase with it, could add only 3 db to the receiver input. However, if equal and out of phase, it could reduce the receiver input to zero. Fortunately, the reflected signal is generally weaker than the direct signal and so reduces it only by some 30 or 40 db when arriving out of phase. Protection against multipath fade is afforded by adequate clearance plus providing sufficient fade margin to maintain the signal through those fades which come from reflections off atmospheric discontinuities. The multipath fade is always of short duration, only a few seconds at the most, but may take place in quick succession as a layer of air shifts so as to provide reflections in sequence.

Proper clearance on the microwave path is assured by providing clearance for the beam during conditions of the maximum amount of inverse bending expected. This varies with the type of terrain and with the generally prevalent weather conditions. Bending is always most severe over smooth earth and in regions where the air is often still and where temperature may vary widely in a short time.

These conditions are most conducive to the accumulation of layers of air in the path which can produce bending. On the other hand, a brisk wind blowing over a broken terrain will assure turbulence in the air which keeps it pretty thoroughly homogeneous, and the beam then tends to travel in a straight path.

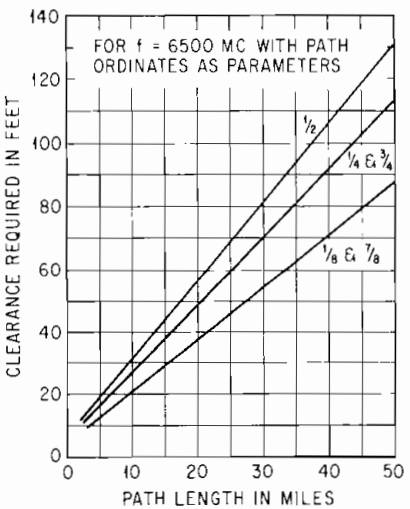


FIG. 4-4. Path-clearance curves.

Fresnel-zone Clearance

For purposes of this part let us say that sufficient clearance protection against both types of fading is provided by allowing full Fresnel-zone clearance over a 4/3 earth on the terrain covered by the WBTV-WBTW system. This clearance is generally equal to about 0.6 full Fresnel zone over a true earth, depending on the distance involved. Figure 4-4 shows the required clearance for a microwave path.

With the use of this rule, antenna heights can be calculated for the case of terrain in which both ends of a hop are roughly equal. Antenna heights thus determined provide line-of-sight clearance *above* all obstructions along the path equal to 0.6 of the Fresnel-zone diameter. In all cases it is, of course, advisable to plot all this on profile.

The Fresnel zone is defined as a region bounded by a fictitious curved surface from which reflection traveling from transmitter to receiver will travel an extra 180° (one-half wavelength) compared with the direct path. Since there is 180° phase change upon reflection, any signal going from transmitter to receiver by this path will arrive as an *aiding* signal. A reflection from a point which penetrates well within the Fresnel zone, however, will not have the benefit of the extra half-wavelength of travel

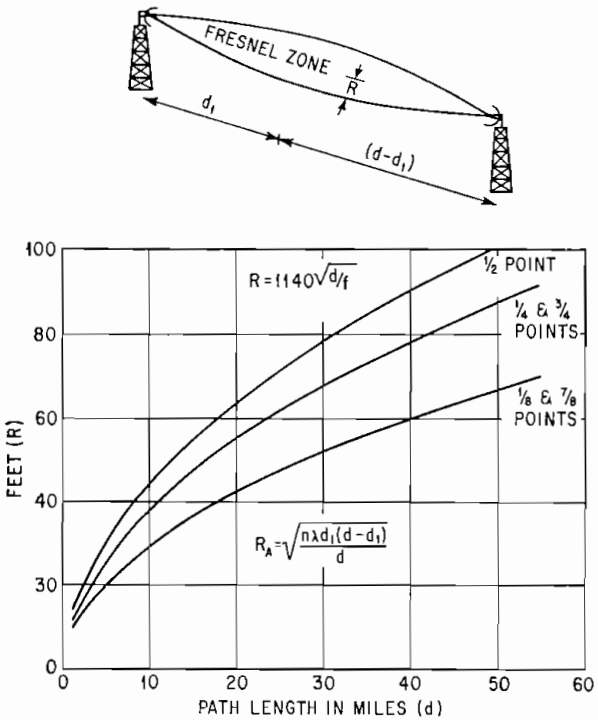


FIG. 4-5. Fresnel zone and radius vs. path length.

and would arrive at the receiver as a canceling signal. Figure 4-5 illustrates the Fresnel zone and radius vs. path length.

Fade Margin

Proper clearance having been provided, it is now necessary to determine the fade margin for protection against those really unavoidable multipath fades which are statistically bound to happen.

In order to provide a fade margin, it is necessary to provide a nonfaded input signal to the receiver which is considerably greater than that required for a usable or even noise-free picture. The required fade margin for a given reliability varies with path length, and this is illustrated by Fig. 4-6.

The fade margin may be defined as the amount by which the nonfaded RF input to the receiver exceeds the RF input which is needed to provide a minimum usable signal out of the receiver. The minimum usable signal is defined—in view of the fact that expected fades are to be of short duration—as existing when the S/N ratio is 28 db. This is a noisy picture. The peak-to-peak signal will be 2.5 times the peak-to-peak noise but by subjective tests is tolerable for short periods (seconds) of time by an average viewer.

Figure 4-7 shows that the RF power to the receiver to produce this minimum usable signal is minus 99 dbw. Every decibel of power above this level is considered fade margin.

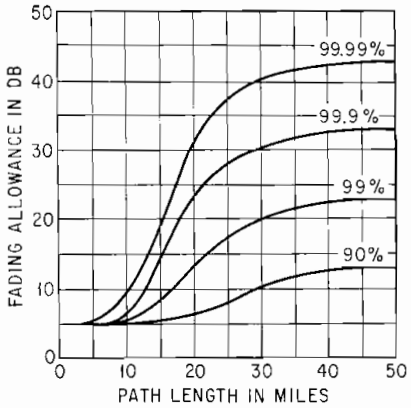


FIG. 4-6. Fading-allowance reliability.

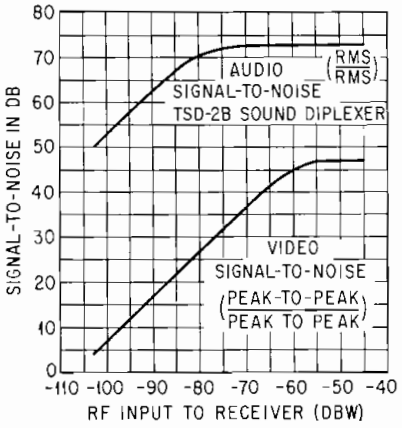


FIG. 4-7. Signal-to-noise ratio.

Reliability Calculations

For example, let us take the Hartsville-Florence hop on the WBTV-WBTW system. The total free-space loss on this 25-mile path is 141.5 db. Figure 4-8 serves to illustrate. Allowing 2.5 db for waveguide losses, the total loss is 144 db. The antenna-reflector combinations at each end of the link have gains of 42.5 db, or a total of 85 db. This makes the net loss between transmitter and receiver 144 – 85, or 59 db, and the power into the receiver is minus 59 dbw (59 db below 1 watt). A fade margin of 99 – 59, or 40 db, has thus been provided. Figure 4-6 shows that the reliability will be slightly greater than 99.99 per cent.

A similar calculation on each of the other hops will also yield a reliability figure of 99.99 per cent.

The over-all reliability can be *conservatively* figured by assuming that none of the fades on the four hops will be coincident. Thus, if each hop is out for 0.01 per cent of the time, the total will be out 0.04 per cent of the time and the over-all reliability will be 99.96 per cent. Figure 4-9 shows the parameters of each path and the over-all system between WBTV and WBTW.

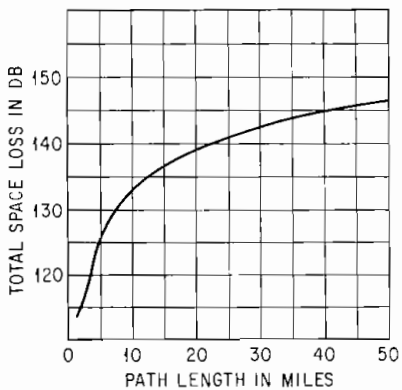


FIG. 4-8. Free-space loss at 6,500 Mc. α (db) = 37 + 20 log f (Mc) + 20 log d (miles).

Equipment and Operation

A basic system diagram for a reversible, two-hop microwave system is shown in Fig. 4-10. There could be N number of repeaters.

Comvor data-transmission and receiver terminal equipments are utilized for reversing control and fault reporting. For fault reporting, the Indicon coder and decoder with delay timer are required.

Fault sensing is accomplished through the use of the low-power–low-signal-level indicator and the video presence detector, while receiver AFC disabling and automatic shutdown is provided for by the application of the AFC radiation switch.

Path Calculations WBTV Five-Station Microwave Relay System	
Charlotte to Matthews	
Free-space loss, 14.4 miles, db	136.0
Waveguide loss, db	2.5
Total loss, db	138.5
Antenna gains:	
4-ft dish and 8- by 12-ft reflector, 150 ft, db	39.5
4-ft dish and 8- by 12-ft reflector, 150 ft, db	39.5
Total antenna gain	79.0
RF input to receiver, dbw	−59.5
Audio S/N ratio, db	73.0
Video S/N ratio, db	65.0
Fading allowance, db	39.5
Predicted reliability, %	99.99 plus
Matthews to Pageland; and Hartsville to Florence	
Free-space loss, 26.8 miles, db	141.5
Waveguide loss, db	2.5
Total loss, db	144.0
Antenna gains:	
6-ft dish and 10- by 15-ft reflector, 150 ft, db	42.5
6-ft dish and 10- by 15-ft reflector, 150 ft, db	42.5
Total antenna gain, db	85.0
RF input to receiver, dbw	−59.0
Audio S/N ratio, db	73.0
Video S/N ratio, db	65.0
Fading allowance, db	40.0
Predicted reliability, %	99.99 plus
Pageland to Hartsville	
Free-space loss, 27.5 miles, db	142.0
Waveguide loss, db	2.5
Total loss, db	144.5
Antenna gains:	
6-ft dish and 10- by 15-ft reflector, 150 ft, db	42.5
6-ft dish and 10- by 15-ft reflector, 150 ft, db	42.5
Total antenna gain	85.0
RF input to receiver, dbw	−59.5
Audio S/N ratio, db	73.0
Video S/N ratio, db	65.0
Fading loss, db	39.5
Predicted reliability, %	99.99 plus
Over-all predicted reliability, %	99.96
Over-all video S/N, db	59.0
Over-all audio S/N, db	67.0
Video S/N is peak-to-peak signal to rms noise Audio S/N is rms signal to rms noise	Random noise only

FIG. 4-9. Path calculations, WBTV five-station microwave relay system.

From the master terminal, switching is accomplished through the activation of a Comvor transmitter. A single Comvor transmitter is required for reversing. It is arranged for the transmission of a carrier-on, mark or space signal (raise-*off*-lower operation). A switching panel arranged to suit the system contains activating controls for the Comvor transmitter and an activating control for the local waveguide switch. Local fault indications appear on each of the units previously mentioned. An Indicon decoder and Comvor receiver are provided for the reception and display of remote faults and answer-backs.

A Comvor receiver is provided at the unattended repeater to receive reversing information. This receiver is equipped with the carrier detector accessory, enabling the receiver to operate in the raise-*off*-lower arrangement. The antenna reversing control provides a junction point for the Comvor receiver and waveguide switch wiring, as well as a remote and local answer-back. It also contains a local reversing control switch. Various fault-finding devices as previously mentioned are included. Remote contacts from the fault devices and the remote answer-back contacts are fed to the delay timer. A closed circuit initiates the timing cycle, and upon completion of the cycle, the Indicon coder transforms closed circuits into coded pulses which key the Comvor transmitter for reporting.

Fault sensing, reversing, and reporting from the final terminal is identical with that of the unattended repeater.

Switching control is shown at a master terminal with reporting to that same terminal. Modifications in arrangement and equipment are made to allow switching and reporting at both terminals.

Basic Reversible System

Figure 4-10 is a block diagram of a basic reversible system with automatic fault reporting.

Operation of a reversing sequence is as follows:

1. To switch the system from that position shown (south-north), activate the system reverse switch at the attended master terminal to the north-south direction.
2. This turns *on* the Comvor tone generator terminal (frequency F_2) and may cause it to transmit a *mark* (or *space*) signal (*raise*).
3. This *mark* (*raise*) tone is then transmitted over the wire line to all unattended stations.
4. The Comvor tone receiver (frequency F_2) at each unattended station then receives the *mark* tone. The output relay and Comvor (tone) detector device will then move to that corresponding position.
5. The output relays of the Comvor tone receiver are then fed to the antenna reversing control.
6. This, in turn, activates the waveguide switch to the north-south position.
7. When the waveguide switch is placed in the north-south position, the microwave receiver and transmitter waveguide connections are reversed. The receivers are then placed on the opposite antenna to that shown in Fig. 4-10.
8. Similarly the transmitter antennas are reversed from the positions shown in Fig. 4-10.
9. Also, on the waveguide switches, answer-back contacts are provided to indicate the positions of the waveguide switches.
10. When the waveguide switches are activated by the antenna reversing control, the answer-back contacts are fed to the Indicon coders.
11. Taking first the unattended terminal, the answer-back contacts on the Indicon coder cause it to report.
12. When this Indicon coder reports, the coded pulses out of it are used to key the Comvor tone generator.
13. These audio tone pulses are then transmitted over the wire line to the attended terminal.
14. At the attended terminal, the audio tone pulses are received by the Comvor tone receiver.

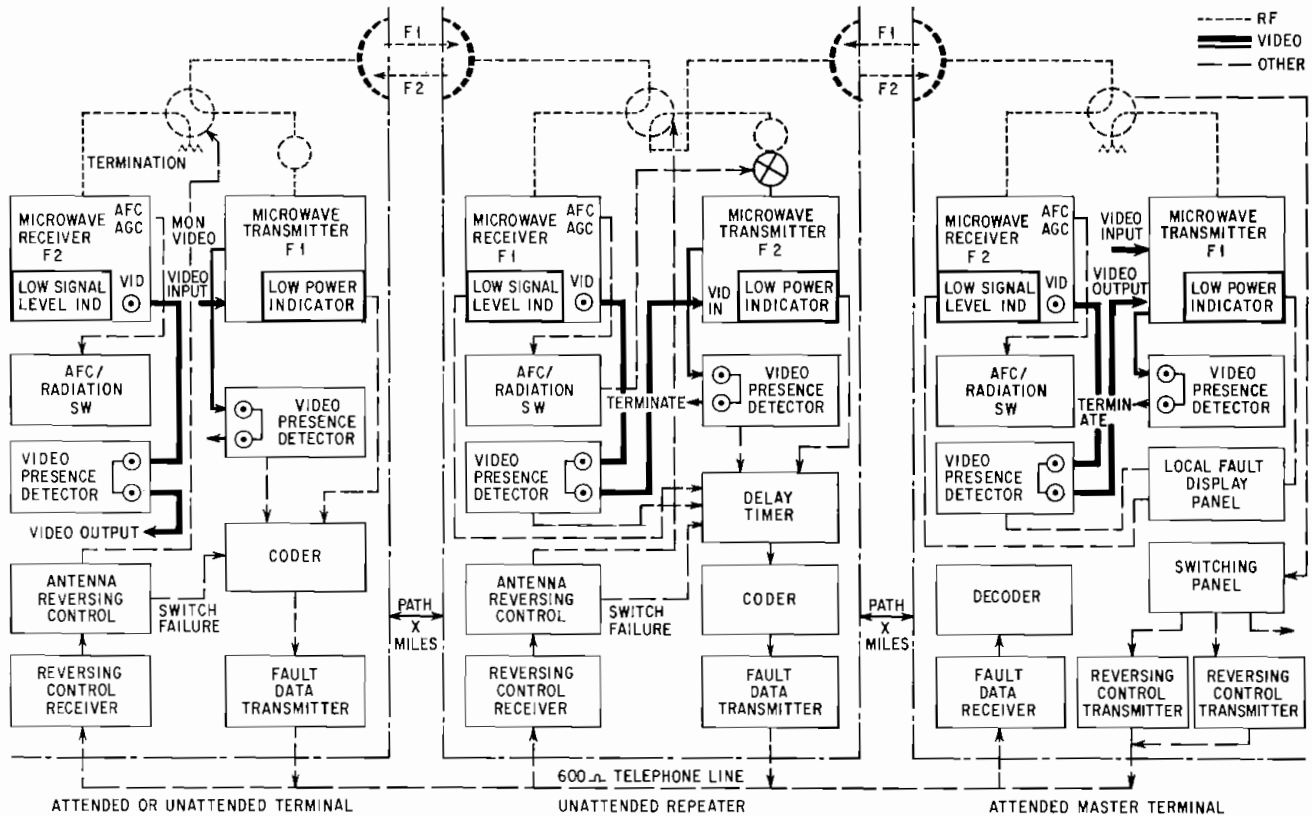


FIG. 4-10. Basic system diagram for a reversible, two-hop microwave system.

15. This tone receiver then keys the Indicon decoder in sequence with the reporting coder. Thus, the answer-back information is indicated on the decoder display. This answer-back information tells what station is reporting and whether or not the waveguide switch is in the proper position.

16. At the unattended repeater, the answer-back information is presented to the delay timer. After a prescribed time delay this station will then report just as the attended terminal did.

It requires about 15 sec for an Indicon coder to transmit its pulses. To arrange that the next station does not report simultaneously, it is necessary to create about 20 sec delay before the second station starts reporting. Similarly, if there is a third station, 40 sec would be required at that location and a fourth station would require 60 sec. This delay is provided by a delay timer at each location. Of course, all stations report in sequence with an arrangement such as this.

17. Thus, for a four-hop system, approximately 2 min would be required to obtain a complete report from all stations.

18. Once all stations have reported or allowing them to report twice, the reversing tone information is turned off. This is accomplished automatically by including a time-delay relay in the system reversing control panel.

When the reversing tone is turned off, the antenna reversing control is deenergized, which removes the answer-back information from the coder. This prevents further transmission of answer-back information and eliminates excessive wear on the coder and decoder equipments.

19. Fault reporting is accomplished exactly as the answer-back information.

When a fault occurs, the coder is activated and sends out pulses. These pulses key a tone generator. The keyed tone is transmitted over a wire line and received at the attended terminal by a tone receiver. The tone receiver keys the decoder, and the fault is thereby displayed.

Delay timers are included to eliminate garbling of fault reporting should simultaneous faults occur at different stations.

Indicon Coder

The Indicon coder is a precision electromechanical device capable of sending 15 digits of binary code for indication purposes. A total of 10 faults or indications can be coded. The first five digits of the binary code are used to identify the reporting station. One of these devices is required at each unattended station. Figure 4-11 is a photograph of the Indicon coder unit.

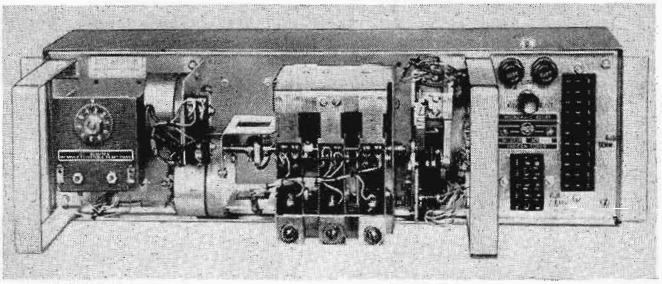


FIG. 4-11. Indicon coder unit.

Fault indications or other information are represented by *closed* relay contacts.

When any one or more of the fault-indicating devices present a closed circuit to the coder, the coding cycle begins.

As the coder is activated, it searches all 15 positions to determine whether or not there is a closure on the circuit. The closures on the first 5 positions are permanent

and are so arranged that a particular code is transmitted for each different station. For the other 10 positions, if there is no closure, another type of pulse is transmitted. A pulse of 360 msec duration (*long*) will repreesnt a closure, while a pulse of 90 msec (*short*) represents no closure.

Assuming that faults 1 and 5 occurred at station 2, the sequence of pulses would be as follows:

Short-long-short-short-short
Long-short-short-short-long
Short-short-short-short-short

These pulses are actually a series of switch and relay contacts which provide a closed circuit to ground for 90 msec on a *short* pulse or 360 msec for a *long* pulse. Approximately 15 sec is required for the complete transmission of 15 digits. A transmission device such as an audio tone generator is then keyed, providing a duration of audio tone equal to the length of the keying pulse or zero audio tone if there is no pulse.

Once a fault has initiated the operation of the coder, it sends out the 15-digit code and then begins a timing cycle during which no code is transmitted. This timing lasts for 10 min, after which the coder again transmits the pulses providing the fault still exists. If the fault (faults) should disappear prior to the completion of the 10-min cycle, only the station identification would be reported and the coder would then rest in the home position. As long as the fault exists, the pulses will be transmitted every 10 min.

Decoder

The decoder operates in response to incoming coded signals from the coder. A bank of five lamps is operated in response to the first five pulses of the coder pulse train for station identification. Ten other lamps operated from relays are used to display the received fault information. Figure 4-12 is a photograph of the Indicon decoder.

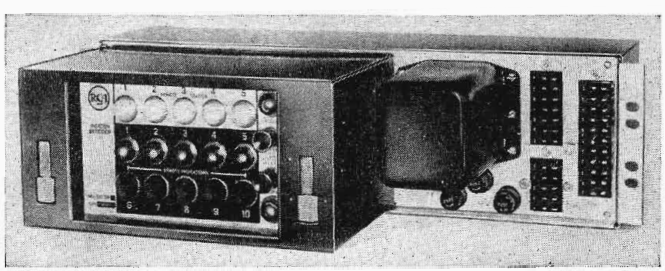


FIG. 4-12. Indicon decoder unit.

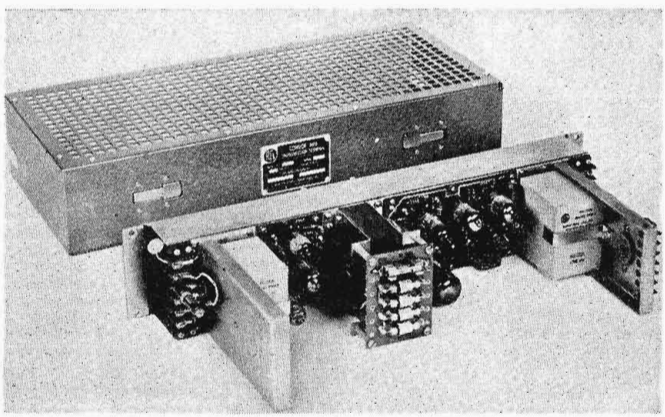
A detailed functional description of the decoder is rather laborious. A simple explanation would be to say that, when a long pulse is received, a lamp *is turned on* and, when a short pulse is received, lamps are not turned on. Each pulse as it is received (long or short) causes an "impulse" relay to step; thus the 15-count sequence is retained. If the decoder should receive an improper number of pulses (15 exactly) as a result of a fault in the fault-reporting system, then the information is cleared from the display of the decoder and it will await the second report.

As the fault information is reported, it is displayed on the decoder and the display is retained until another report is received. When the next report is received, the lamp display is automatically cleared before the new information is displayed.

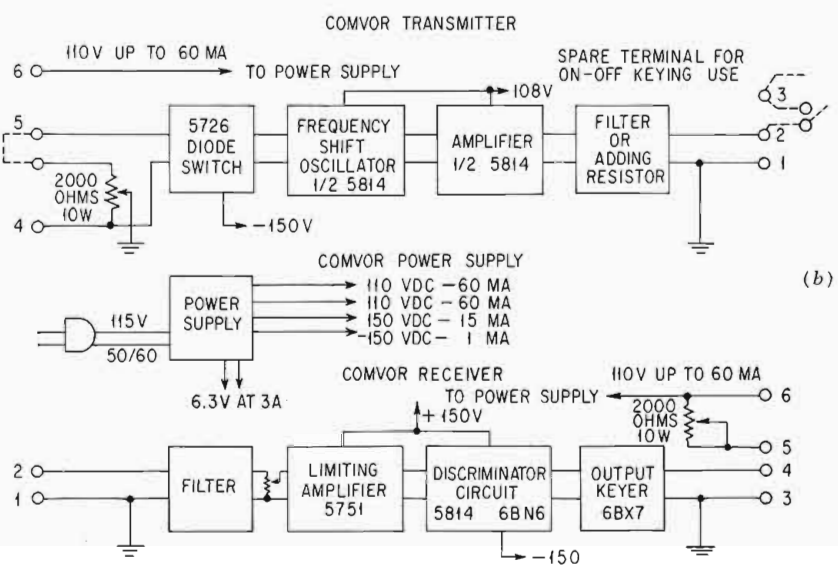
The decoder is operated from closed contacts which are closed in sequence and for the same time duration as those of the Indicon coder pulse output.

A tone generator and tone receiver connected by wire line come between the coder

and decoder. The tone receiver contains a relay in the output, and this relay keys the decoder. A description of the tone transmitter and receiver would be time-consuming and therefore would not be appropriate in this part. However, Fig. 4-13*a* and *b* shows a photograph and a block diagram of the model 912T (transmitter) and model 912R (receiver) used in this system.



(*a*)



(*b*)

FIG. 4-13. Photograph and block diagram of model 912-T (transmitter) and model 912-R (receiver).

Assembly and Installation

In order to minimize field assembly and installation time for this relay system it was felt desirable to install all equipment in the racks, together with required interunit cabling, at the manufacturer's plant. Figure 4-14 is a photograph of one unit. This procedure made it possible to accomplish all wiring and cabling more rapidly and uniformly and permitted complete system tests at a common location by engineering

personnel familiar with system performance requirements. Thus, the equipment was delivered in this manner.

The equipment was given additional operating checks by measurement of video signal-to-noise ratio between transmitter and receiver pairs as they were to be installed in the actual system after delivery in Charlotte and Florence. This check was performed to ensure that all equipment was functioning normally after shipment; all equipment was, in fact, found to be functioning normally.

Upon completion of these checks the equipment was distributed to appropriate

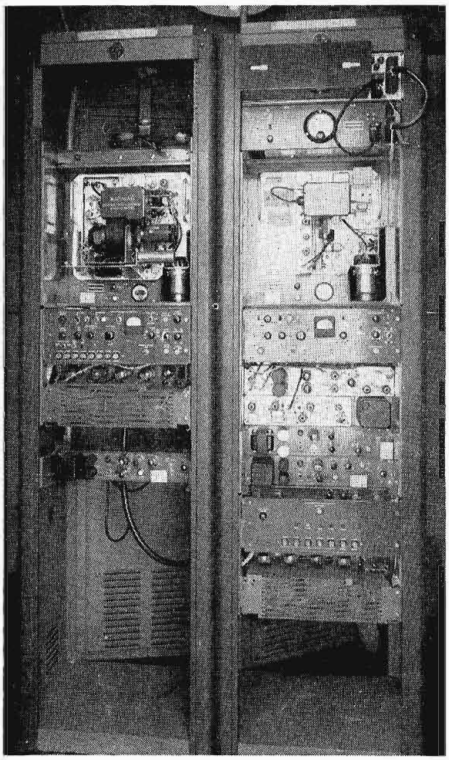


FIG. 4-14. Complete rack-mounted unit (receiver and transmitter).

locations, antennas installed, and the waveguide plumbing connections between equipment cabinets and antennas made. The towers had been previously erected, and passive reflectors installed and approximately oriented for path alignment.

Upon completion of all equipment, antenna, and waveguide installation, alignment of the four paths was begun.

In general, the antenna and reflector alignment proceeded rather rapidly and smoothly, since antenna sizes were such that the beamwidths are not unusualy critical and the terrain traversed is not unusually prone to ground reflection conditions. Typical terrain is shown in Fig. 4-15, which is a profile of the Pageland-Hartsville hop. The reasonably heavy stand of pine-tree vegetation in this area, together with the slightly rolling terrain, is not so likely to aggravate the alignment problem with ground reflections as in some geographical areas. However, even under these conditions considerable care was necessary during alignment to distinguish between maximum

observed from direct main-lobe radiation and maxima which may be encountered owing to alignment on reflections.

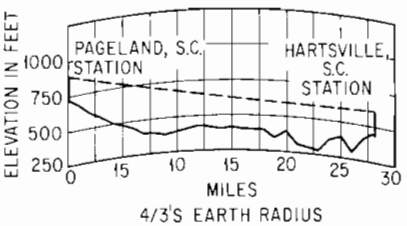
Upon completion of the over-all system the performance was found satisfactory, and program tests commenced on Feb. 15, which carried educational programs for broadcast by WBTW for use in the public school systems of South Carolina.

Maintenance and Personnel

The problem of maintenance and technical personnel is of a twofold nature: (1) regular preventive maintenance and (2) emergency repairs.

One complete set of tubes, crystals, and fuses are kept at each station. A Lambda-Pacific model 7100 microwave test set, a Simpson model 260 Multi-Meter, a vacuum-tube voltmeter, and a tube checker are carried by the maintenance technician on all regular checks.

A regular weekly visit is made to each station to check the performance of all apparatus at that location. A thorough inspection is made of all components to detect excessive heating or other defective functioning. Tubes that are suspected of improper operation are checked and replaced where necessary. A check of the ventilating system is made for proper functioning. A Lambda-Pacific model 7100 test set is used to measure all pertinent characteristics of both transmitter and receivers.



LOCATION	N–LATITUDE			W–LONGITUDE		
	D	M	S	D	M	S
PAGELAND, S.C.	34	45	16.99	80	25	11.971
HARTSVILLE	34	27	54.15	80	05	45.207

BETWEEN CHARLOTTE, N.C.
AND FLORENCE, S.C.

CONTOUR READING BY M. J. MINOR

DATE _____

FIG. 4-15. Profile graph for terrain between Pageland and Hartsville, S.C. (*Jefferson Standard Broadcasting Company: Television Intercity Relay System, Charlotte, N.C., to Florence, S.C.*)

Because of the use of fault-reporting equipment loss of air time will be minimized. Personnel holding first-class radiotelephone licenses are on duty at the terminal stations in Charlotte and Florence during all hours of operation of the system. In case of failure at one of the three unattended repeater stations it will not be necessary to search for the "needle in the haystack" because the location of the repeater in trouble together with an indication of the type of trouble existing is automatically sent to the terminal control station and an engineer can be sent from the nearest terminal.

Part 5

TELEVISION-SIGNAL ANALYSIS *

AMERICAN TELEPHONE & TELEGRAPH COMPANY
LONG LINES DEPARTMENT
NEW YORK, N.Y.

INTRODUCTION

Part 5 of this section was prepared as a general reference for telephone company employees who are concerned with the analysis of television signals transmitted over company lines. Such analysis has as its purpose a determination of the quality of the signal as received at various points along its transmission path and, if signal impairment appears, a diagnosis of its probable cause. This will naturally lead to the taking of such corrective measures as may be indicated.

It is clear that, to have any significance, the observation of signals requires the use of monitoring devices that are always capable of giving a faithful representation of the actual signal on the line. Correct adjustment and proper maintenance of these devices must, therefore, be assumed. Granting this, any observed deficiency in the signal must either be present in the output of the camera equipment or be the result of failure of the transmission system to carry the signal without distortion from its point of origin to the distant monitoring point.

Properly to discharge his responsibilities, the telephone technician must first know what the signal delivered by the camera looks like in comparison with the signal which he is receiving. If this comparison indicates that undue distortion is being introduced by the transmission system, he may wish similarly to compare his received signal with the signals received by other monitors back along the line in order to isolate the section of the transmission system that is at fault.

A single observer, of course, cannot make simultaneous observations of a signal at a number of different points. Comparisons, therefore, depend upon telephone communication among observers who may be located at widely separated points and who may be associated with entirely different communications or broadcasting organizations.

For such communication to be fully effective, it is necessary that the observing devices employed at all points be sufficiently alike to produce signal representations that are directly comparable in kind. It is also necessary that all observers have a common understanding of what constitutes the normal signal representation. Similarly, each should be able to recognize the appearance of the more usual types of signal impairments that may occur from time to time. In addition, skill in diagnosing the probable general cause of any observed impairment is highly desirable as a first step in facilitating the location and correction of the fault responsible.

It is obvious that effective communication among observers further requires that each use a language that is readily understood by the others. As in most new arts, the growing television vocabulary has tended to develop some confusion, with several

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different words or phrases being used for the same thing in many cases. In this part, an attempt has been made to select in each case the particular words or designations that seem to have gained the widest acceptance at this time.

With the principal objective of promoting desirable common understandings of both signal forms and their nomenclature, the following pages first discuss satisfactory monochrome- and color-television signals as they appear in standard oscilloscope and picture-monitor representations and illustrate the generally accepted designations for their several principal components. Following this, various types of test signals are discussed. The major types of video-signal impairments are then listed, and each type is considered separately. Significant features, as they appear to the monitoring observers in both oscilloscope and picture-monitor representations, are illustrated and discussed. Finally, a glossary of video terms is presented.

Much of the photographic and descriptive material included has been prepared with the help of the engineering groups of the American Broadcasting Company, the Columbia Broadcasting System, the Dumont Television Network, and the National Broadcasting Company, all of whom have been extremely cooperative. This part, then, endeavors to represent the viewpoints of both the broadcasting industry and the telephone company.

THE TELEVISION SIGNAL

A picture monitor in a broadcaster's studio or a telephone company television operating center might depict a test pattern as shown in Fig. 5-1. This picture is free of discernible defects as evidenced by the facts that straight lines are straight, circles are round, there is a complete range of grays, and there are no other obvious distortions.

The complete analysis of the picture signal, however, cannot be determined by the picture monitor alone. In the operation and maintenance of network television transmission, it is also necessary to analyze the signal using a cathode-ray oscilloscope (A scope). The A scope permits the display of the voltage-time characteristics of both the horizontal scanning interval and the vertical scanning interval.

Horizontal Scanning Interval

Figure 5-2 is the horizontal video signal presentation of the monochrome test pattern of Fig. 5-1 as seen on the A scope with a sweep rate of about 7,875 cps (one-half the 15,750-cycle line rate). As shown, polarity of the signal generally displayed on A scopes used in broadcasters' master control rooms and telephone company television operating centers is "black negative."

FIG. 5-1. Unimpaired video signal—picture-monitor presentation.

The complete video line signal for one scanning line, included between E and G, requires a time interval of 1/15,750, or 63.5 μsec. The horizontal blanking interval nominally requires 10.05 μsec of this time as indicated between E and F, and the picture information utilizes the balance of the time, or 53.45 μsec. The left side of the picture is indicated at F, and the right side at G.

The horizontal and vertical sync pulses, which synchronize the sweep circuits in the receiver with those of the camera, determine the timing of the scanning lines and thus permit accurate location of each element being scanned. The horizontal synchronizing pulse is shown in the blanking interval, with a voltage level corresponding to D.

The picture-brightness information is carried between A and B, with the peak-

white amplitude of the picture at *A* and the peak-black amplitude of the picture at *B*. In the case of test-pattern signals, these peaks correspond to reference-white and reference-black levels, in which range it is expected that normal program picture information will fall. Any video voltage less than that at *A* will produce an increasingly darker gray until black is reached at *B*. Thus the region between *A* and *B* carries the picture-brightness information in terms of voltage, the instantaneous level of the voltage corresponding to the brightness at that particular instant of time.

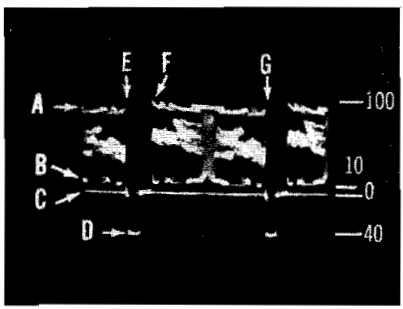


FIG. 5-2. Unimpaired video signal—A-scope horizontal presentation. *A*. White peak. *B*. Black peak. *C*. Blanking level. *D*. Synchronizing level. *E-G*. Complete horizontal interval = 63.5 μsec. *E-F*. Horizontal blanking interval = 10.05 μsec. *F-G*. Picture signal = 53.45 μsec.

The "setup" of the picture is the difference in voltage between the blanking and reference-black levels, as indicated between *C* and *B* in Fig. 5-2. On the IRE voltage scale, which has been adopted for industry-wide use, the setup value for network transmission is normally 10.

It can be seen that if a picture has no black but goes only from white to dark gray, the minimum video voltage will not approach blanking level as closely as it would if the picture contained full blacks. This picture would appear to have a high setup. On the other hand, the video voltage should not extend through reference-black level. Broadcasters attempt to maintain a reference black in all transmissions to obtain the most pleasing effect. Many of their studios are now equipped with electronic devices to maintain proper setup leaving the studio.

Typical proportions for a 1-volt peak-to-peak composite signal as displayed on an oscilloscope with an IRE scale are 40 divisions of sync, 10 divisions of setup, and 90 divisions of picture information, as shown in Fig. 5-2.

Figure 5-3 is an expanded view of the horizontal blanking interval with its component parts, including the horizontal synchronizing pulse and adjacent signal, identified. The nomenclature tabulated here, if universally used, will minimize confusion when a signal impairment is traced to its source.[1]

The front porch isolates the synchronizing pulse from transients or overshoots in the video signal at the end of the scanning line. This is done so that the synchronizing circuits in receivers or customer stabilizing amplifiers will not be triggered prematurely, thus producing a picture with successive horizontal lines displaced in a sporadic manner, which would result in jitter or possible tearing.

[1] The time intervals given in Figs. 5-2 and 5-3 for the front and back porches are approximately the minimum values set by the Federal Communications Commission for radiated signals. In practice, a 630-kc pulse generator frequently is used to time these signals so that the front porch equals one cycle, with the sync and back porch each equaling three cycles.

This basis currently is employed by CBS and NBC, and the nominal intervals become as below. ABC currently generates slightly different timing signals, also listed.

	CBS, NBC	ABC
Front porch	1.59 μsec	1.3 μsec
Sync	4.76 μsec	5.0 μsec
Back porch	4.76 μsec	4.5 μsec
	11.11	10.8

Since the total horizontal interval remains at 63.5 microseconds, the picture information interval varies according to the corresponding lengths of blanking interval.

The leading edge of the sync pulse is used to synchronize the horizontal-sweep oscillators in most monitors and receivers and to trigger some clamping circuits. Excessive slope or curvature of the leading edge of the sync pulse may cause erratic synchronization of a monitor or receiver or even complete failure of synchronization if sufficiently serious. It may also cause clamping failure in transmission equipment.

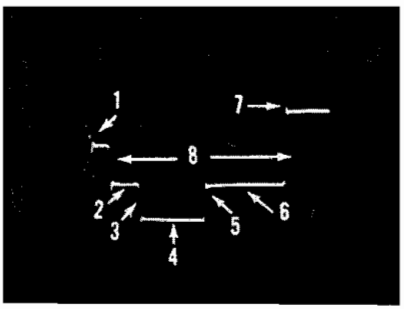


FIG. 5-3. Unimpaired video signal—A-scope expanded horizontal presentation. 1. Video voltages or right-hand side of picture. 2. Front porch = 1.25 μsec. 3. Leading edge of sync. 4. Tip of sync = 5.0 μsec. 5. Trailing edge of sync. 6. Back porch = 3.8 μsec. 7. Video voltages at left side of picture. 8. Horizontal blanking interval = 10.05 μsec.

The tip of the sync pulse is used as the reference point in the d-c restorers of monitors and some oscilloscopes and in the d-c restoration or clamping stages of telephone company equipment.

A pulse derived from the trailing edge of the sync pulse is used to trigger the clamping circuits in most types of stabilizing amplifiers used by broadcasters. Serious slope or curvature of the trailing edge of the sync pulse will cause improper operation of these stabilizing amplifiers, resulting in tearing and rolling in the reproduced picture.

The back porch completes the horizontal blanking interval. If the operation of the sweep circuits of a monitor or receiver is considered, it will be realized that when the electron beam has traversed the picture tube from left to right, it cannot return to the left side of the tube (retrace) instantaneously but requires a small amount of time to do so. If picture voltages were permitted to occur immediately after the horizontal sync pulse, the picture components they represent would be visible during retrace. The duration of the back-porch interval includes the time required for the sweep circuits to retrace completely prior to the occurrence of picture information.

While the broadcasters' stabilizing amplifiers are triggered by the trailing edge of the sync pulse, they clamp on the back porch. This type of clamper amplifier employs a time-delay *RC* circuit which is generally adjusted to delay the start of clamping action until sometime during the first quarter of the back-porch interval. The clamping or reference level is usually the average level over a 1-μsec (one-quarter) position of the back-porch interval. Therefore, if the back porch is seriously deformed or contains a large amount of noise, these amplifiers will clamp improperly, resulting in an impaired or useless picture to the customer, although the picture may appear usable at the serving telephone office.

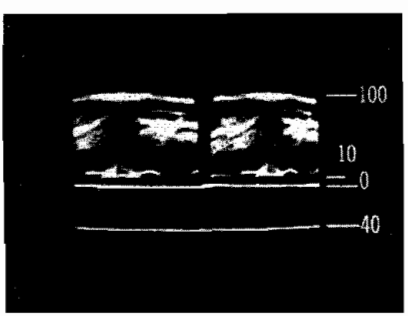


FIG. 5-4. Unimpaired video signal—A-scope vertical presentation.

Vertical Scanning Interval

Figure 5-4 is the video-signal presentation of Fig. 5-1 as seen on the A scope during the vertical scanning interval, using a sweep rate of approximately 30 cps.

The levels of white peaks, black peaks, blanking, and tip of sync indicated in Fig. 5-4 are of the same value on the IRE scale as shown for Fig. 5-2. The vertical synchronizing pulse, with the associated equalizing pulses and blanking pulses, can be seen in the center of the picture. This presentation will reveal many of the common

types of low-frequency trouble such as clamping failures, 60- or 120-cycle interference, or serious signal distortions.

Figure 5-5 is an expanded view of the vertical blanking interval with the component parts identified. Certain signal distortions that cannot be detected in the normal presentation can be seen in the expanded view.

The requirements imposed by interlaced scanning create the necessity for the equalizing pulses. The odd and even fields occur sequentially at the rate of 60 fields per second. The top line of an odd field starts at the top left side of the raster, and the bottom line ends at the bottom center of the raster, while the top line of an even field starts at the top center of the raster, and the bottom line ends at the bottom right side of the raster. Therefore, it can be seen that if the vertical synchronizing pulse occurred immediately following a horizontal scan, the vertical-pulse integrator capacitor in a receiver would have a different residual charge depending upon whether the vertical sync pulse followed an even or odd field. The fact that the vertical synchronizing pulse occurs one-half line nearer a horizontal sync pulse following an odd field than it does following an even field would result in imperfect interlacing if the first group of six equalizing pulses were not provided. The presence of these equalizing pulses preceding every vertical synchronizing pulse interval results in the vertical pulse integrator capacitor in a receiver having the same residual charge at the beginning of the vertical pulse, regardless of whether it follows an odd or even field. These six equalizing pulses occur at one-half horizontal-line intervals, which is at twice line frequency, or at the rate of approximately 31,500 pulses per second.

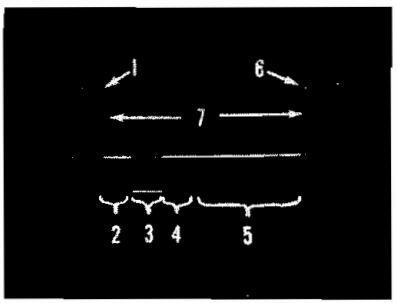


FIG. 5-5. Unimpaired video signal—A-scope expanded vertical presentation. 1. Picture voltages, bottom of picture. 2. First group of six equalizing pulses. 3. Serrated vertical sync pulse. 4. Second group of six equalizing pulses. 5. Horizontal sync pulses. 6. Picture voltages, top of picture. 7. Vertical blanking interval.

The serrated vertical sync pulse has a duration of approximately three full lines and has serrations occurring at the same rate as the equalizing pulses. These serrations are provided to keep the horizontal-sweep oscillators in receivers and monitors synchronized and running smoothly during the vertical synchronizing pulse. Alternate serrations function as horizontal sync pulses.

The second equalizing pulse group follows the serrated vertical sync pulse. These equalizing pulses also occur at twice line frequency. The first and second set of equalizing pulses, along with serrations of the vertical sync pulse, permit stable operation of the horizontal-sweep oscillator for the two different horizontal line conditions between the odd and even and between the even and odd fields.

The portion of the vertical blanking interval between the end of the second set of equalizing pulses and the first video information of the new field (4 and 5 of Fig. 5-5) is provided to allow time for the vertical sweep circuits in receivers to return the electron beam completely to the top of the picture tube before the video information of the new field starts. By adjusting the vertical hold control of the picture monitor and increasing the brightness, a presentation similar to Fig. 5-6 can be obtained. This shows the vertical blanking interval as a wide dark bar. The black bars represent equalizing and vertical sync pulses.

NTSC Color

Figure 5-7 presents the horizontal display of an NTSC color signal on a wideband A scope. This particular signal is shown in black and white by Fig. 5-8. As can be

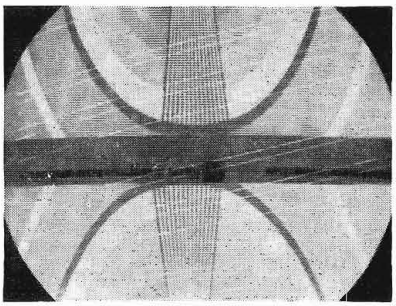


FIG. 5-6. Vertical blanking—picture.

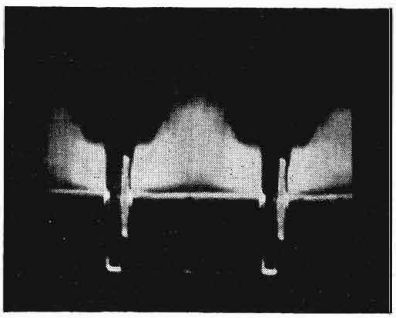


FIG. 5-7. Color signal—horizontal—wide-band.

seen, the A-scope presentation is similar in appearance to that of a monochrome signal in so far as horizontal blanking, sync, and picture information are concerned. The burst of high frequency during the back-porch interval represents the most distinguishing feature of the color signal observed on the A scope. This is the color sync burst, comprising 8 to 11 cycles of 3.6-Mc voltage. The peak-to-peak amplitude of the color burst should be the same as the amplitude of the horizontal sync pulse, i.e., 40 divisions on the IRE scale. The color burst is centered voltage-wise at blanking level, and time-wise it starts about one-tenth of the total back-porch interval from the trailing edge of the sync pulse. Another distinguishing feature is the presence of video information below black level, which varies with the hue and saturation of the colors being televised.

For color transmission the horizontal scanning frequency is 15,734.264 ± 0.044 cps rather than the nominal value of 15,750 cps; the vertical scanning frequency is 59.94 cps rather than the nominal value of 60 cps. The complete video signal for one scanning line requires a time interval of 1/15,734, or approximately 63.6 μsec. The horizontal blanking interval requires approximately 10.5 μsec of this time, and the picture information utilizes the balance of the time, or 53.1 μsec. This compares closely with the nominal intervals shown in Fig. 5-2 for the monochrome signal, the increase in blanking for the color signal being mainly in the back-porch interval.

If the picture content of the signal could be resolved, it would be seen that where color is scanned, the signal includes the 3.6-Mc color subcarrier varying in both amplitude and phase. When the A scope is operated using the IRE roll-off characteristic, the color signal appears as in Fig. 5-9, with practically all the color information removed. Now the scope presentation represents the luminance, or monochrome, portion of the signal only.

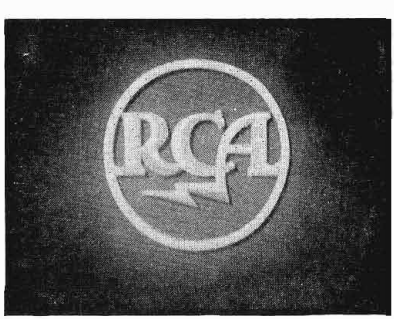


FIG. 5-8. Color signal—monochrome picture.

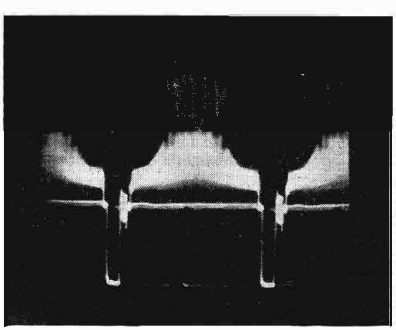


FIG. 5-9. Color signal—horizontal—IRE roll-offs.

A-scope presentations of color signals at vertical sweep rate, using either the wideband or IRE roll-off characteristic, do not differ from monochrome-signal presentations except for the presence of the high-frequency color information. Such a presentation is shown by Fig. 5-10, which was taken on a wideband scope.

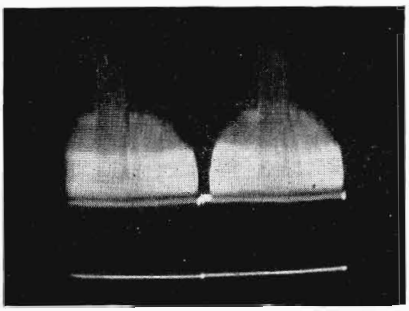


FIG. 5-10. Color signal—vertical—wideband.

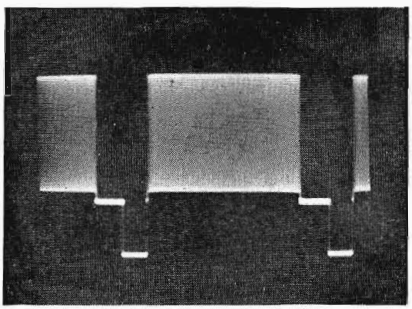


FIG. 5-11. Monoburst signal—horizontal.

TELEVISION TEST SIGNALS

This section describes some of the test signals used in line-up and maintenance of television channels.

Sine Waves

Sine-wave measurements are frequently used to determine gain-frequency characteristics of transmission channels. These signals generally are obtained from the 61B or 61C signal generator. The 70A or 70B power meter, a thermocouple instrument, is used for measuring. To provide accurate measurements at frequencies below 10 kc, clamping circuits along the transmission path must be disabled. Simple sine-wave measurements are not suitable where gating circuits are used, as in certain types of radio relay systems, to set the carrier rest frequency at the time of the horizontal sync pulse. In such cases, synchronizing pulses must be present for faithful reproduction of transmission conditions.

Monoburst

The name "monoburst" has been applied to the resulting composite signal which is illustrated in Fig. 5-11. The complete monoburst signal consists of single-frequency sine waves plus sync pulses at the line rate, a blanking interval, and a means for varying the setup and the amplitude of the sine waves. The presence of the sync enables monoburst signals to operate gating circuits and clampers in normal fashion. Monoburst signals are measured and interpreted using a calibrated oscilloscope.

Window Signal

As viewed on a picture monitor, the window signal is a large square or rectangular white area with a black background. Figure 5-12 is a typical window signal viewed on a picture monitor. Figures 5-13 and 5-14 show the horizontal and vertical presentations on an A scope. The picture signal has but two normal levels, reference black and white. The white level can be adjusted but is usually set at reference white. In order to locate the maximum energy content of the signal in the lower portion of the total frequency band, the white area is adjusted to cover one-fourth to one-half of the total picture width and one-fourth to one-half of the total picture height.

The window signal is useful for a number of checks and tests when observed on picture monitors or A scopes, including:

1. Convenient check for level or continuity. With the use of window of known white level, the peak-to-peak voltage of the signal can be read easily on a calibrated oscilloscope, using the IRE roll-off characteristic.

2. Measurement of sync compression or expansion. Comparison with the office

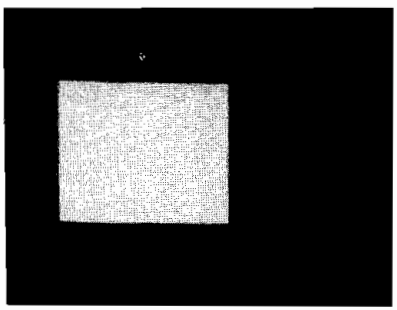


FIG. 5-12. Broadcaster's window signal—picture.

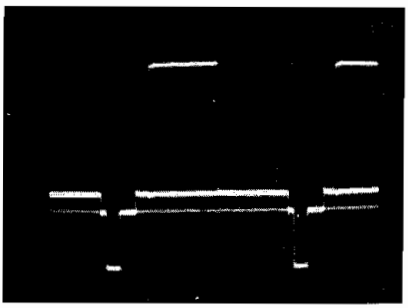


FIG. 5-13. Broadcaster's window signal—horizontal.

transmitting the window signal of horizontal sync and white levels on calibrated scopes using IRE roll-off permits accurate evaluation of these linearity characteristics at the receiving point so that any necessary corrective action can be taken.

3. Minimizing streaking and smearing. Observation of this test signal on scopes using the IRE roll-off characteristic at both vertical and horizontal rates enables evaluation of streaking and smearing and adjustments to be made on clamper amplifiers and low-frequency equalizers to minimize these impairments. When a picture monitor is used for observation of streaking or smearing, it is essential to ensure that it is free from internal defects which might give false results.

4. Observation of ringing. The presence of ringing can be detected using wideband scopes, properly calibrated, and expanding the horizontal presentation to a convenient scale. Ringing amplitude can be measured directly. Its frequency can be calculated by counting the number of ringing cycles occurring during a known time interval. Ringing also can be seen on picture monitors when receiving this signal.

The window signal generally used by the broadcasters contains both horizontal and vertical sync information, as in Figs. 5-12 to 5-14. In this type of signal, the white window is adjustable in size both horizontally and vertically and also is adjustable in position anywhere on the black background.

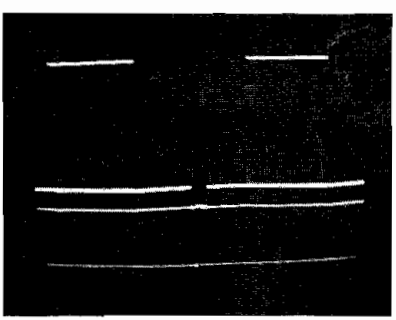


FIG. 5-14. Broadcaster's window signal—vertical.

The window signal provided by most telephone company generators, such as the 61C signal generator, provides a white area adjustable in width from the left edge of the raster, with a black area in the remaining portion as shown in Figs. 5-15 and 5-16. Sync pulses are provided at the horizontal rate (15,750 per second). The window signal provided by the earlier model signal generator (61B) is similar but not so suitable for streaking tests because the black and white areas are reversed, the white area being adjustable in width from the right edge of the raster. There is no adjustment of height for either the 61B or 61C white window, but if these signals are modulated at a 60-cycle rate by means available within the set, a window of approximately one-half the picture height can be obtained, as shown in Fig. 5-17. Horizontal and

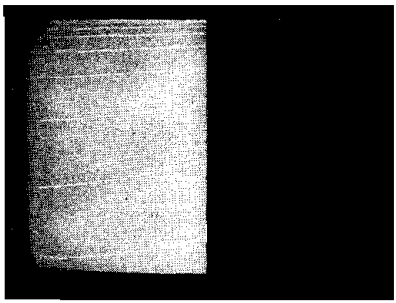


FIG. 5-15. 61C window signal—unmodulated—picture.

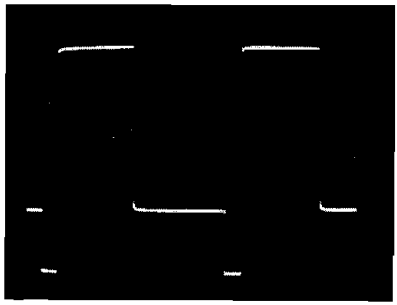


FIG. 5-16. 61C window signal—unmodulated—horizontal.

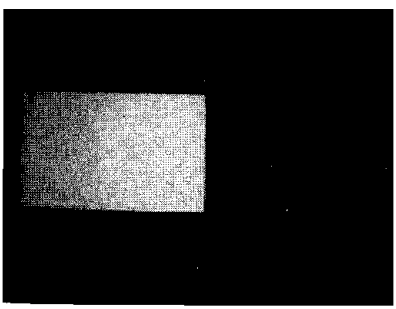


FIG. 5-17. 61C window signal—modulated—picture.

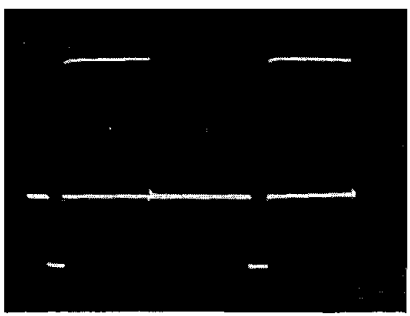


FIG. 5-18. 61C window signal—modulated—horizontal.

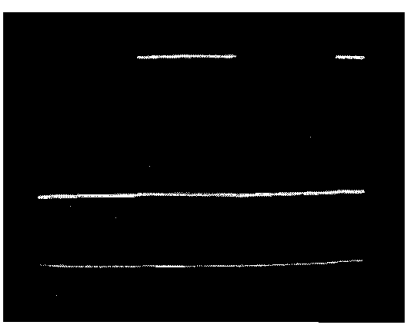


FIG. 5-19. 61C window signal—modulated—vertical.

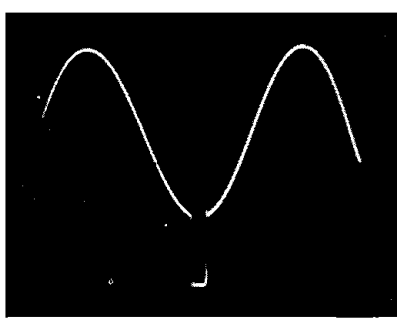


FIG. 5-20. 47A TMS—test signal—unmodulated—horizontal.

vertical presentations on an A scope are shown in Figs. 5-18 and 5-19. Since none of these signals have vertical sync information, the vertical retrace of the monitor is not blanked and the retrace lines are visible. This does not interfere with observation.

47A Transmission-measuring System

The 47A transmission-measuring system is used for measurements of differential phase and differential gain of facilities used for color-television transmission (change in phase or gain at 3.6 Mc as level is varied from black to white). The test signal

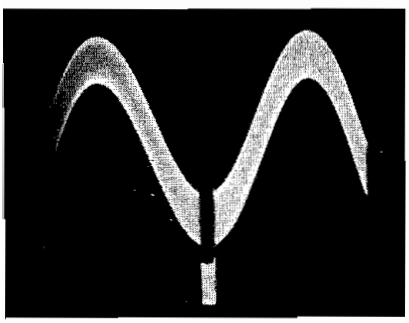


FIG. 5-21. 47A TMS—test signal—modulated—horizontal.

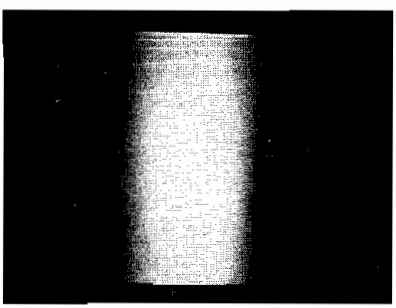


FIG. 5-22. 47A TMS—test signal—picture.

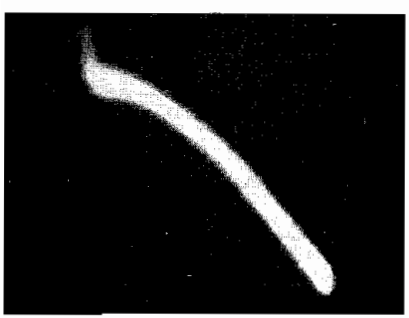


FIG. 5-23. 47A TMS—receiving-unit presentation—minus 27° differential phase.

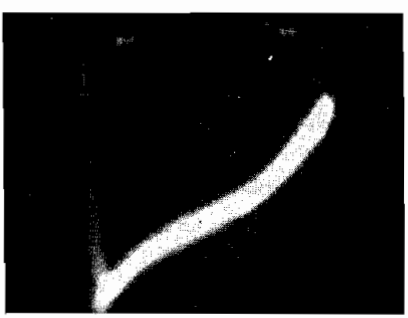


FIG. 5-24. 47A TMS—receiving-unit presentation—plus 27° differential phase.

consists of a 15.75-kc sine wave with positive peaks at reference-white level and negative peaks at blanking level, plus horizontal sync pulses inserted at negative peaks. On this sine wave, which corresponds to the luminance signal, there is superimposed a lower level 3.6-Mc (3579.545 kc) sine-wave signal corresponding to the chrominance signal. The 3.6-Mc signal is thus periodically raised and lowered through the region between blanking and white levels. At the receiving locations, instantaneous differential phase or differential gain at 3.6 Mc is displayed and measured on a low-frequency high-gain oscilloscope.

The 47A system consists of a transmitting unit (47B) and a receiving unit (47C). Test signals and presentations on receiving sets are illustrated by Figs. 5-20 through 5-25.

For comparison, Fig. 5-26 illustrates a staircase signal transmitted over the layout having a 2-db differential gain.

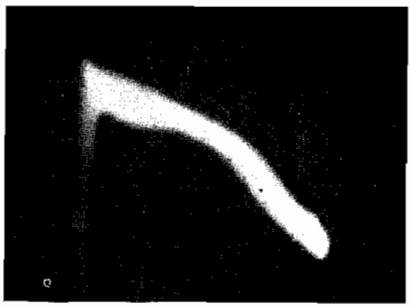


FIG. 5-25. 47A TMS—receiving unit presentation—2-db differential gain.

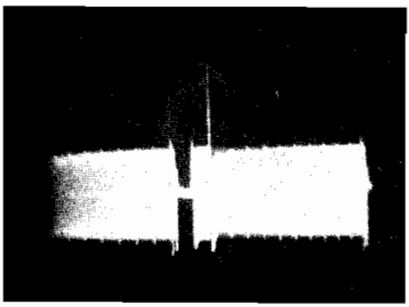


FIG. 5-26. Staircase signal—horizontal—2-db differential gain.

Multiburst

A multiburst signal is used for rapid measurements of gain at a few predetermined frequencies.

One form of multiburst signal, illustrated in Fig. 5-27, consists of a burst of peak white (white flag) followed by bursts of six sine-wave frequencies from 0.5 to 4.2 Mc, plus a horizontal sync pulse, all transmitted during one line interval. The white flag provides white level reference signal. Figure 5-28 indicates the burst frequencies normally used, but these may be varied. Vertical sync information is also provided in some types of multiburst generators.

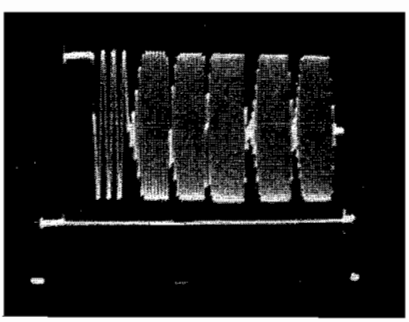


FIG. 5-27. Multiburst signal—horizontal.

Some of the earlier models of multiburst generators do not include the white flag; that is, six sine-wave bursts occupy the entire interval bethween sync pulses.

At the receiving point the signal is observed on an oscilloscope. For gain measurements, the peak-to-peak amplitudes of the individual bursts are measured and compared. The accuracy of measurement is subject to the limitations of the oscilloscope. The principal uses are to observe:

1. Quick check of amplitude-frequency response
2. Changes in setup
3. Black or white compression
4. Compression which may be selective with frequency

Figures 5-29 and 5-30 illustrate, respectively, gradual dropping and rising gain-frequency characteristics. These figures should be compared with the normal signal illustrated in Fig. 5-27. For information, the picture-monitor presentation is shown in Fig. 5-31 and the A-scope vertical presentation is shown in Fig. 5-32.

Test Pattern—RETMA [2]

Standard test patterns are valuable in determining the performance of video systems because the distant viewer knows what the original picture looks like and can therefore readily detect distortions. The test pattern illustrated in Fig. 5-33 is a reproduction of a test chart developed by the RETMA Data Bureau. It is used mainly as source material for local test of broadcasters' equipment, such as cameras, etc.

The following is a description of the use of the pattern in checking the quality of

[2] Now Electronic Industries Association (EIA).

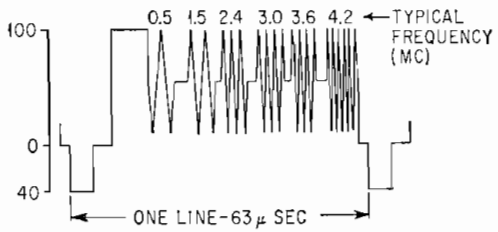


FIG. 5-28. Multiburst signal–frequencies normally used–horizontal.

FIG. 5-29. Multiburst signal–gradual loss –horizontal.

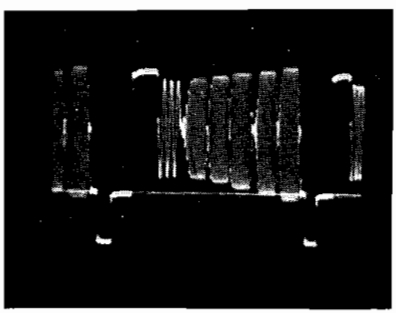


FIG. 5-30. Multiburst signal–gradual gain –horizontal.

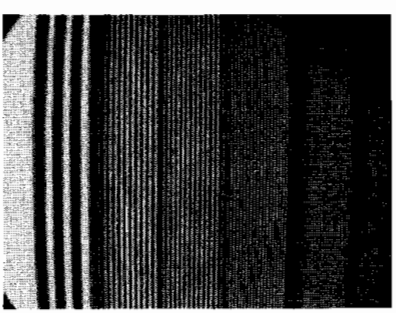


FIG. 5-31. Multiburst signal–picture.

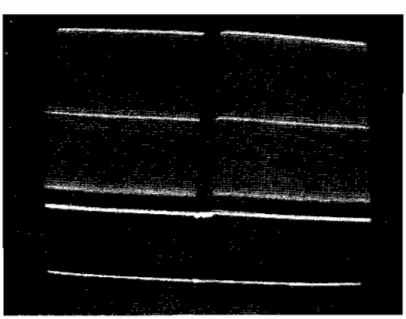


FIG. 5-32. Multiburst signal–vertical.

the picture and interpreting the results. In all cases it is assumed that the picture monitor has been properly adjusted.

Horizontal Linearity. This can be determined by checking the large circle, the four corner circles, and the three squares of "200-line" vertical bars, one on each side of the picture and one in the center. The circles should show no distortion, and the horizontal length of all squares should be equal.

Vertical Linearity. The circles plus the six sets of short "200-line" horizontal bars can be used to check linearity of the vertical sweep. The circles should show no distortion, and the over-all height of the sets of bars should be equal.

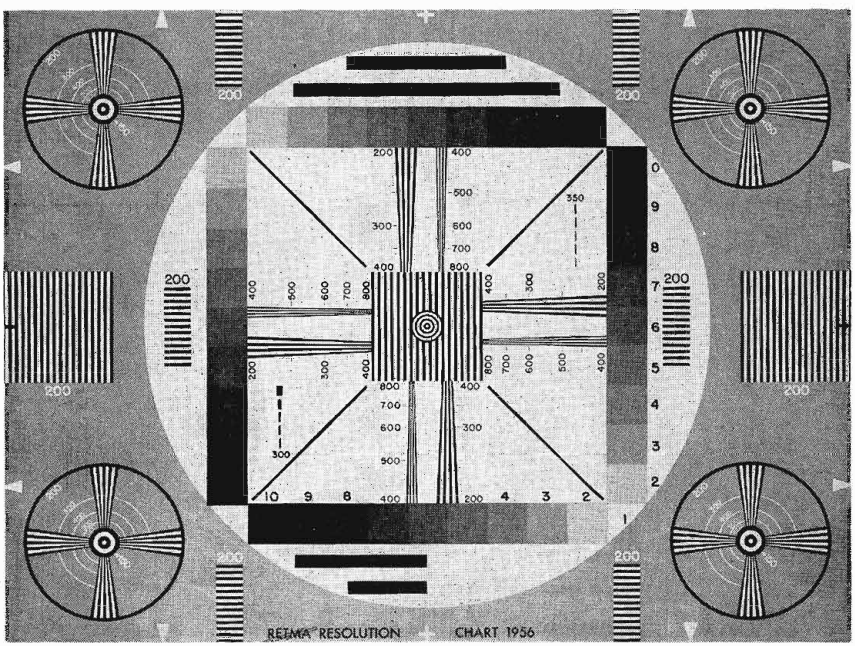


FIG. 5-33. RETMA test pattern—picture.

Contrast. The four bars at the ends of the central wedges are the gray scales. Each is composed of 10 squares varying from maximum white brightness to approximately one-thirtieth of this value. If the received signal has the proper distribution of grays, it will be possible to distinguish all squares in the scales. Loss of distinction among the individual squares is an indication that the gain of the over-all system is not constant over the full range of the input voltages.

Aspect Ratio. The four gray-scale bars should form a perfect square.

Interlace. The quality of interlace can be checked by noting the condiiton of the four diagonal lines in the center. A serrated or jagged line indicates pairing of the interlace lines.

Streaking. Streaking following any one of the two horizontal black bars, at the top and bottom of the large circle, indicates low-frequency phase and/or amplitude distortion. The bars represent half cycles of square-wave signals ranging from about 30 kc for the longest to 100 kc for the shortest. They help to locate the frequency range within which the phase distortion takes place. For instance, if it is near 100 kc, the short bar will have more intense streaks than the others.

Ringing. The vertical wedges and the short vertical lines or ringing bars, marked

50 to 300 in the lower left quadrant of the circle along with those marked 350 to 600 in the upper right quadrant, are used to check ringing. The frequency of the ring will be indicated on the vertical wedges by the vertical position at which the strongest ring is indicated to the right or left of the wedge. Similarly, the short vertical line that gives the strongest ring will also indicate the ringing frequency.

Resolution. Resolution is measured in terms of "lines."

Vertical resolution, the resolution from top to bottom of the picture, is expressed in the number of horizontal lines that can be resolved. Therefore, the horiozntal wedges in the test pattern are used to measure vertical resolution. Vertical resolution depends primarily on the size and shape of the picture-tube scanning beam spot rather than the high-frequency response or bandwidth of the receiver or transmission path. Therefore, vertical-resolution measurements are omitted from network operating tests.

Horizontal resolution is based upon the number of distinct black and white dots (vertical lines) that can be reproduced by the picture monitor in three-quarters of the usable (visible) length of a horizontal scanning line. This length of three-quarter width is selected because it equals the height of the picture and, therefore, gives a basis for direct comparison between horizontal and vertical resolutions. The vertical wedges are used to determine horizontal resolution.

Vertical or horizontal resolution can be measured in terms of lines by determining the point on the horizontal or vertical wedges, respectively, up to which it is possible to distingnish distinct lines.

The wedges in the center and the four corners are calibrated in lines. They all vary from 200 at the large end to 600 at the small end. The vertical and horizontal linearity bars are all spaced for 200-line resolution. The concentric circles in the centers of the corner circles are at 150-line spacing. Those at the center of the large circle are at 300-line spacing.

Test Pattern—Typical Broadcasters

Various types of test patterns are employed by the different broadcasters for alignment of their circuits and monitors and for use by servicemen in the adjustment of home receivers. The test pattern illustrated in Fig. 5-34 is a typical pattern and employs many of the features included in the standard RETMA pattern.

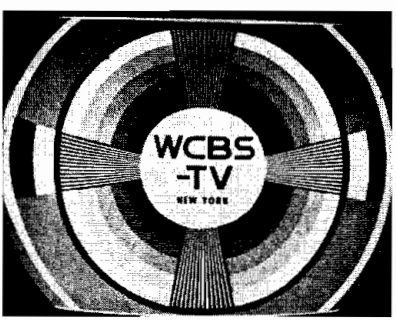


Fig. 5-34. Unimpaired picture—typical test pattern.

The following is a description of the use of this test pattern:

Linearity. The circles and the horizontal and vertical wedges can be used to check both the horizontal and vertical linearity. The circles should be round, and the wedges of equal length.

Contrast. The five circles extending from black to white offer a check of the grays in the received signal. If the signal has the proper distribution of grays, all circles will be seen in varying shades of gray from black to white.

Streaking and Smearing. Streaking following any of the letters in the center of the test pattern indicates low-frequency distortion. Echo, smear, following whites, etc., can also be noted at these points. Streaking can also be seen at the right outside edge of the horizontal wedge.

Resolution. Resolution can be determined by noting the point to which the lines can be distinguished on the vertical and horizontal wedges. The resolution of the vertical wedges on the test pattern illustrated extends from 150 to 320 lines and on the horizontal wedges from 150 to 350 lines. This value will differ among the various broadcasters' patterns, depending upon the width of the wedge lines.

Ringing. Ringing can be noted on the sides of the vertical wedges. Ringing frequency will be indicated by the vertical position at which the strongest ring is observed.

Color Bars

The broadcasters use various color-bar signals for the adjustment of their equipment including color monitors. They may also transmit this signal over transmission facilities for test purposes.

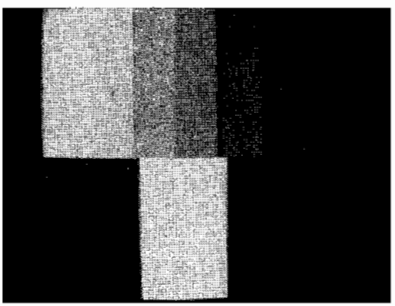


FIG. 5-35. Color-bar signal—monochrome picture.

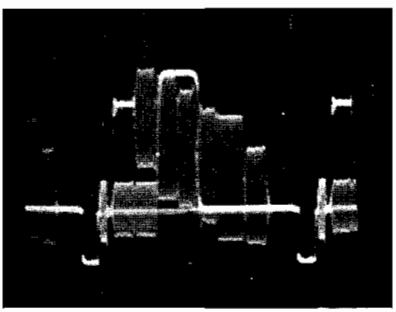


FIG. 5-36. Color-bar signal—horizontal—wideband.

As shown in Fig. 5-35, on a monochrome picture monitor, the color-bar signals will appear as corresponding bars in various densities of gray, the densities depending upon the individual values of luminance. The wideband A-scope horizontal presentation can indicate whether or not the white reference of the luminance signal and the color

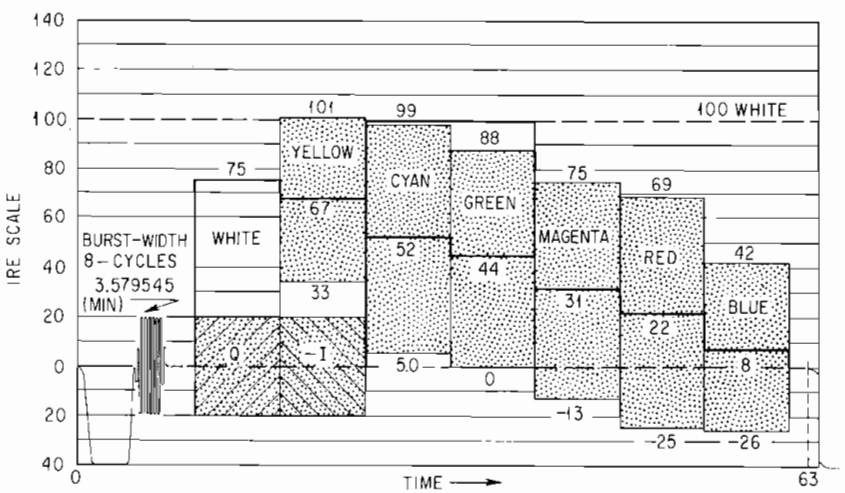


FIG. 5-37. Color-bar signal—typical color information.

information have the proper amplitude relations. Figure 5-36 illustrates a typical presentation, the colors for this particular pattern being identified in Fig. 5-37. For this color-bar signal, if the color burst signal is of correct amplitude, and if the positive excursion of the cyan bar is at 99 per cent of white level, with the negative excur-

sion of the green bar at black level, it can be assumed that the over-all signal is in good condition from an amplitude standpoint. Figures 5-38 and 5-39 show vertical and expanded horizontal presentations of this signal.

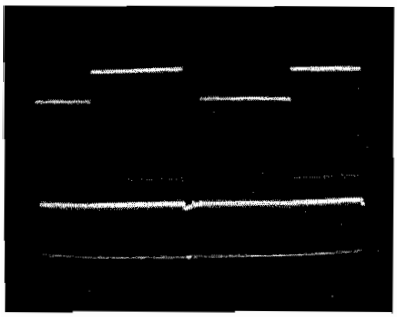


FIG. 5-38. Color-bar signal—vertical.

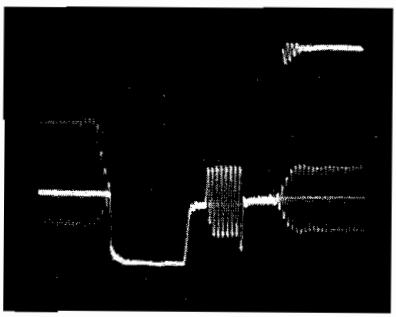


FIG. 5-39. Color-bar signal—expanded horizontal.

The broadcaster can observe the color-bar signal on a vector display oscilloscope (variously known as a vectorimeter, vectorscope, chromascope, etc.) to measure absolute amplitudes and phase angles for equipment adjustments. Differential phase and gain measurements of limited accuracy can also be made by this means.

Staircase

The techniques most commonly used by the broadcasters at present for the measurement of differential phase and differential gain involve the transmission of a staircase signal, as in Fig. 5-40. A sine wave, usually at 3.6 Mc, is superimposed on 10 steps extending progressively from black to white level. At the receiving point, the high-frequency sine wave is separated from the low frequencies of the steps by a high-pass filter and displayed on the oscilloscope as in Fig. 5-41. Any difference between the amplitudes of the blocks represents differential gain. By means of a color-signal analyzer used in conjunction with the receiving oscilloscope, differential phase can be measured.

The staircase signal, without sine wave added, is also used in some cases as a linearity check, as shown in Fig. 5-42. In this case, the relative height between steps is used as an indication of compression or nonlinearity. Figure 5-43 illustrates for information the picture-monitor presentation of a staircase signal.

In some forms of the staircase signal, a single scanning line of stairsteps may be followed by several lines of adjustable amplitude. The amplitude is adjusted to permit changes in the over-all duty cycle, principally for tests on television broadcast transmitters. Figure 5-44 illustrates a signal with a duty cycle having 90 per cent window and 10 per cent staircase.

SIGNAL-IMPAIRMENT ANALYSIS

Television-network facilities are designed to transmit picture signals so that they will be received at the distant connection in a condition to give a satisfactory reproduction of the signal furnished by the customer. The network transmission facility is only part of the transmission path from camera to receiver. The other elements contributing to the faithfulness of the reproduced scene are:

1. Performance of camera and other studio equipment
2. Performance of local loop facilities not included as part of the network facilities, i.e., studio-to-transmitter link
3. Performance of the broadcaster's transmitting facilities

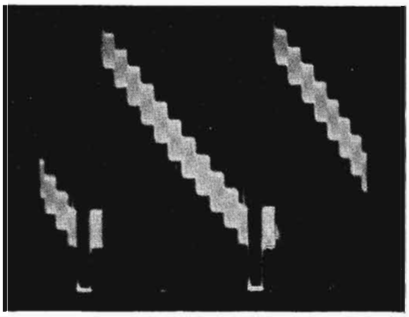


FIG. 5-40. Staircase signal—modulated—horizontal.

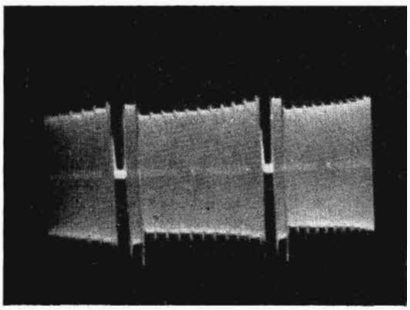


FIG. 5-41. Staircase signal—modulated—horizontal—through high-pass filter.

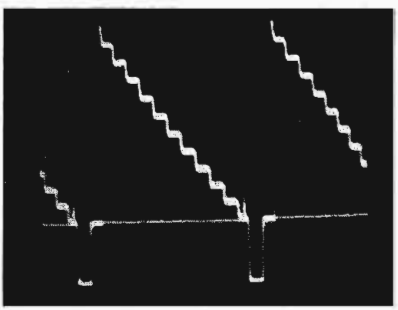


FIG. 5-42. Staircase signal—unmodulated—horizontal.

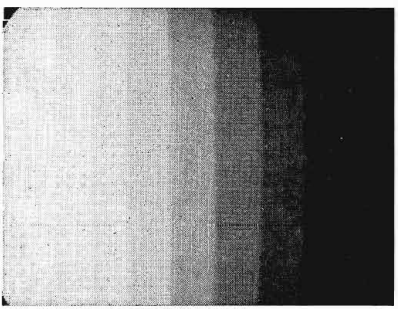


FIG. 5-43. Staircase signal—picture.

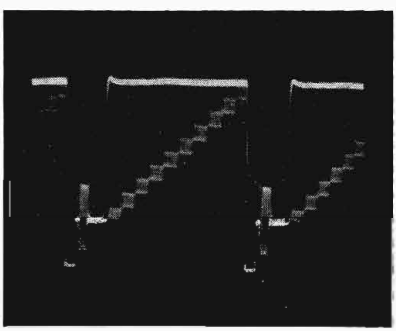


FIG. 5-44. Staircase signal—variable overall duty cycle—horizontal.

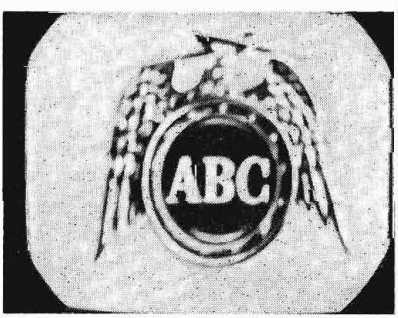


FIG. 5-45. Blooming.

4. Radio path between broadcast transmitter and the receiver, i.e., distance, obstructions, interference

5. Ability of the receiver to reproduce a picture from the signals received

Since all the above elements must work together, discrepancies occurring in any of the individual units will affect the received picture adversely. The broadcaster and the telephone company have no control over the last two links in the chain—the path from the transmitter to receiver and the home receiver. However, network transmission from camera to the broadcaster's transmitter generally involves close cooperation. Because of the necessity of using different pickup points and cameras or of rearranging the network facilities to meet customers' requirements, it is essential that each transmission element be engineered and maintained with this flexibility in mind.

The composition of a television signal, as discussed previously, determines the objectives for network facilities. Compared with telephone transmission, the bandwidth is of the order of 1,000 times as great, the amplitude distortion requirements are about 10 times as severe in spite of the wider band, and interference requirements are about 3 times as severe. In addition, delay distortion requirements are more severe. Since color-television signals are more complex than monochrome signals, they are correspondingly more difficult to transmit.

Distortion of video signals during transmission may be the result of trouble conditions or inherent limitations of the facilities in the transmission path. This distortion in general will be apparent in the oscilloscope presentation of the signal and will show in the picture monitor as an impairment. The A-scope signal distortions and picture-monitor impairments fall into several categories. The following pages illustrate a number of typical distortions as observed on picture monitors and A scopes, together with an explanation of the causes. In many instances it has been found necessary for photographic-reproduction reasons to introduce impairments beyond the degree to which it would be expected to find them under actual conditions. This is particularly true of the picture-monitor photographs where a given impairment generally has greater effect upon the eye under actual conditions than is evident in the photographs.

Level Irregularities

General

An essential factor in good television operation is the maintenance of correct video levels at both broadcasters' and telephone company locations. The observed effect of incorrect levels as seen on picture monitors and A scopes is dependent upon the magnitude of error, whether the level is constant or varying, and whether all or only part of the frequency range is affected. This discussion is concerned with level errors that affect the entire frequency range in a relatively uniform manner. Such level irregularities can be caused by improper amplifier gains or pad losses along the transmission path, defective electron tubes or other components, or change in camera level from broadcasters' studios or pickup points.

Long-duration Level Changes

High Levels. Small increases in level cause an increase in the over-all picture brightness and a general loss of contrast. Larger changes may result in more serious defects. Blooming, bleeding whites, clipping, and sync compression are long-duration impairments generally caused by an increase in level sufficient to cause some degree of overloading.

Blooming (Fig. 5-45). This is an increase in the size of the scanning spot with resultant loss of detail in white areas due to overloading the picture tube. The A-scope presentation will appear normal when the difficulty is due to high-gain setting of the monitor itself.

Bleeding Whites (Figs. 5-46 to 5-48). As the level is increased on the network to an extent where overloading occurs, the A scope, in addition to indicating too high

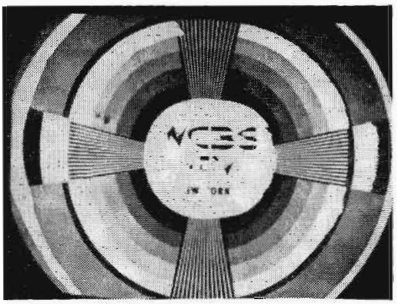


FIG. 5-46. Bleeding whites.

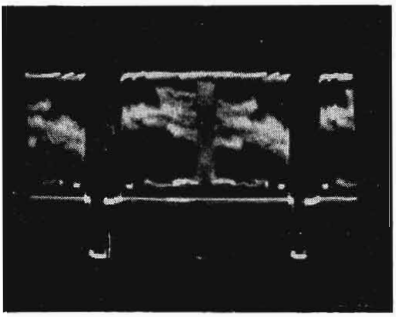


FIG. 5-47. Bleeding whites—horizontal.

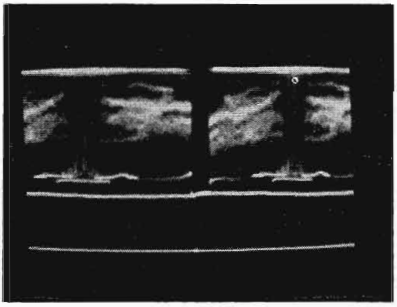


FIG. 5-48. Bleeding whites—vertical.

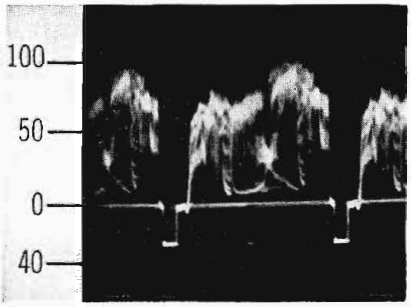


FIG. 5-49. Sync compression—horizontal.

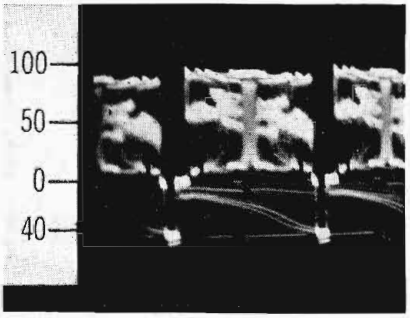


FIG. 5-50. Partial clamping failure—horizontal (A-scope presentation expanded to normal height).

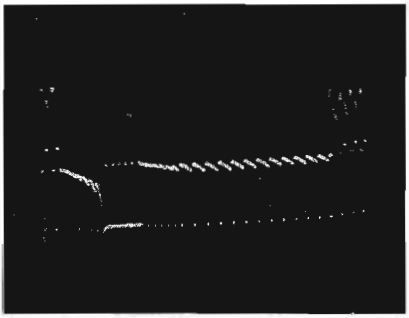


FIG. 5-51. Partial clamping failure—expanded vertical.

level, will also show evidence of clipping, or compression, as indicated by the square tops of the waveforms of Figs. 5-47 and 5-48. The picture (Fig. 5-46) as observed will have lost contrast and may appear to have white areas "bleeding" into black, although the defocusing found under blooming conditions may not exist. The effects shown in Figs. 5-46 to 5-48 were obtained by overloading an amplifier.

Black or Sync Compression (Fig. 5-49). High-level conditions sufficient to cause overloading may also result in black peak or sync compression. Here the sync-pulse amplitude is reduced and loss of contrast may be noticeable in the black region. If the sync signals are sufficiently compressed, difficulty will be experienced in keeping pictures in step. Figure 5-49 illustrates sync compression as seen on the oscilloscope at horizontal rate. The sync level in this case reads approximately 30 on the IRE scale, or about 10 divisions lower than normal. The picture monitor, in this case, showed no evidence of trouble.

Low Levels (Figs. 5-50 and 5-51). Lower than normal levels cause a decrease in average picture brightness and make the signal more susceptible to interference. When the television signal level is reduced by only a small amount, ill effects are not likely to be noticed. As the signal is transmitted through clamping or stabilizing circuits at still lower levels, clamping action will be partially or completely lost. Streaking, smearing, and loss of synchronism may occur. Figures 5-50 and 5-51 illustrate a signal transmitted through a clamper amplifier at about one-half normal level. Partial failure of clamping is seen on the A scope at horizontal and vertical rates. The picture was not affected appreciably. The impairments observed when clamper failure occurs will depend upon the amount of low-frequency distortion present in the signal. The results of complete clamping failure are discussed at a later point.

Short-duration Level Changes

Intermittent level changes, at either regular or irregular intervals, may have several causes. Fluctuating a-c line voltage and hunting regulators in power supplies or on transmission facilities are some of the possible sources for this type of trouble. These usually give short changes in picture brightness, evident on A scopes as momentary voltage changes. If of sufficient magnitude, frame rolls, momentary tearing, etc., can be observed.

Bounce and Breathing. In operating parlance bounce is the condition where there are sudden irregular changes in level while breathing is the condition where the changes occur more slowly and at a regular rate.

Transmission-frequency Irregularities

General

Uniform amplitude response and linear phase shift throughout the passband of the transmission system of a television network are characteristics to be desired. In addition, the shape of these two characteristics beyond the passband, usually at the high-frequency end, should be such that the gain characteristic gradually rolls off without affecting the phase characteristic. A large family of impairments to picture transmission is caused by inability to attain these conditions or by adjustments or troubles affecting them. Some of these impairments differ from one another so greatly in manifestation that they do not appear related. In this discussion the impairments resulting from distortions in various parts of the video band are grouped together, that is, those affecting field rate and harmonic frequencies, those affecting line rate and its first 10 or so harmonics, and those affecting frequencies above about 200 kc.

Figures 5-52 to 5-59 show some of the relationships between low- and high-frequency distortion. A telephone company window signal was used for test signal for reference. In the remaining figures both attenuation and related phase distortion are present. Minimum phase-shift networks were used to vary the gain-frequency characteristic.

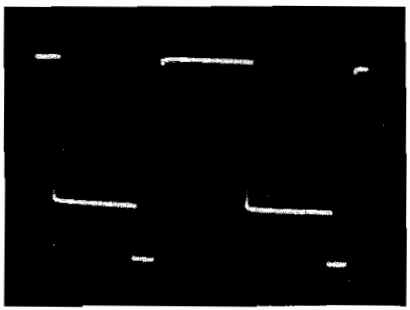


FIG. 5-52. Window signal—unimpaired—horizontal.

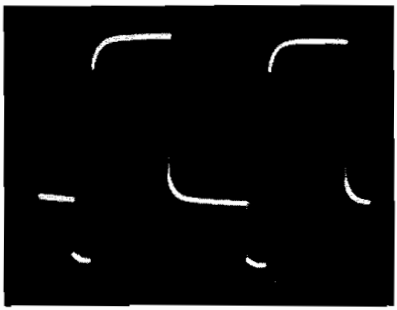


FIG. 5-53. Window signal—lows raised—horizontal.

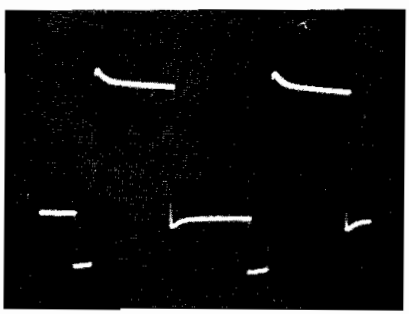


FIG. 5-54. Window signal—lows depressed—horizontal.

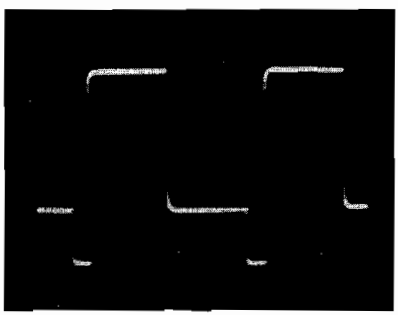


FIG. 5-55. Window signal—highs depressed—horizontal.

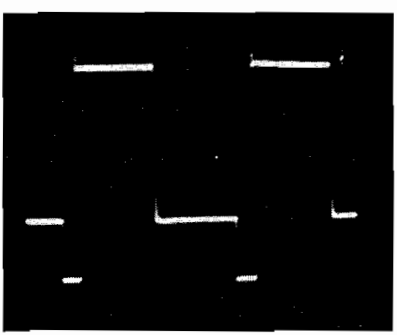


FIG. 5-56. Window signal—highs raised—horizontal.

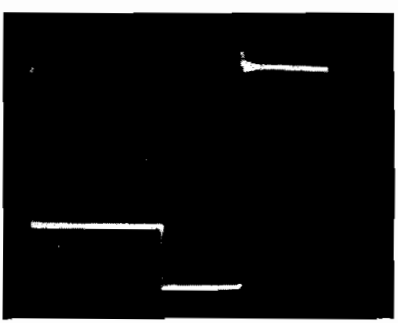


FIG. 5-57. Window signal—ringing—horizontal.

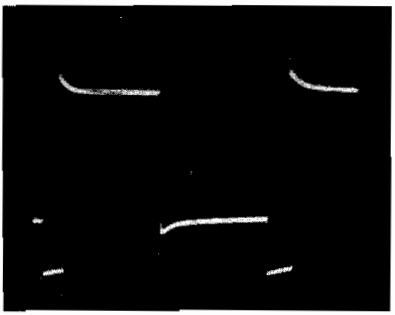


FIG. 5-58. Window signal—lows depressed, highs raised—horizontal.

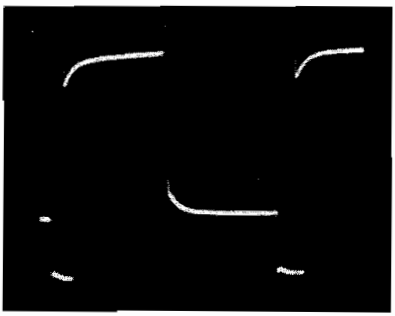


FIG. 5-59. Window signal—lows raised, highs raised—horizontal.

Low-frequency Gain Changes (Figs. 5-53 and 5-54). Figures 5-53 and 5-54 illustrate a relative 1.0-db increase or decrease, respectively, of frequencies below about 100 kc. With the low frequencies increased, there is illustrated the case of positive streaking in which the length of time for the streak to disappear is determined by the shape of the curve at the transition from white to black. The reverse case, with low frequencies decreased causing long-duration overshoots at transitions, illustrates negative streaking.

High-frequency Gain Changes (Figs. 5-55 to 5-57). Figures 5-55 and 5-56 show results when frequencies above about 100 kc are affected. The networks used give a gradual modification of characteristics with frequency, so that at 3.0 Mc the gain-frequency characteristic is changed by minus and plus 1.5 db, respectively. Figure 5-55, with the high frequencies depressed, shows some loss of sharpness or rounding-off of transitions, much less and of shorter duration than Fig. 5-53. The fine detail in a picture would thus be impaired in this transmission. The small overshoot, or spike, evident in Fig. 5-56 is the result of raising 3.0 Mc by only 1.5 db. This spiking is similar to that in Fig. 5-54 but of much shorter duration. Carried far enough, and possible at a somewhat lower frequency, this sort of thing will result in "edge effect"—a distinct outline following an object of a tone opposite to that of the object itself.

Figure 5-57 goes one step further by increasing the 3.0-Mc gain to +3.0 db and then cutting off rather abruptly. The result shows that an oscillatory transient, or ringing, has developed. With minimum phase shift, the ringing should be about equal on each side of the transitions. This was not the case here.

Both Low- and High-frequency Gain Changes (Figs. 5-58 and 5-59). Figures 5-58 and 5-59 illustrate cases where the gain-frequency characteristic is not flat at either end of the spectrum. In each case there is a 3.0-db rise at approximately 3.0 Mc. At the lower frequencies, Fig. 5-58 has a 1.0-db loss and Fig. 5-59 a 1.0-db gain. It can be seen that the individual characteristics previously illustrated are still recognizable and that adjustments at one end of the band do not compensate, in general, for maladjustments at the other end. The short duration spike, for example, is evident regardless of the lower frequency adjustment.

It should be noted that the sync pulse itself shows evidence of all these distortions. In the usual case, clamper action will tend to minimize these effects on tips of sync pulses. However, transitions between porches and sync and in the vertical interval are always available for observation and have been found to be sensitive indicators of the troubles described. Further detail on specific types of impairments is given below.

Streaking and Smearing

Streaking is caused by transmission distortions in the frequency region up to about 200 kc. Smearing generally is caused by distortions at somewhat higher frequencies.

Streaking and smearing affect both color and black-and-white signal transmission almost equally.

Distortions that cause streaking and smearing can occur in any part of the transmission system, from the camera to the television receiver. Prevention of these de-

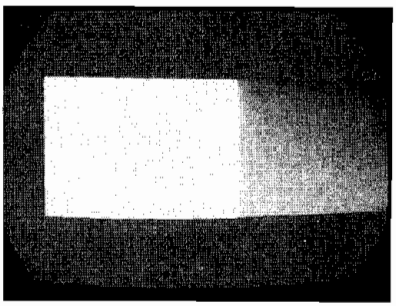


FIG. 5-60. Positive streaking—window signal.

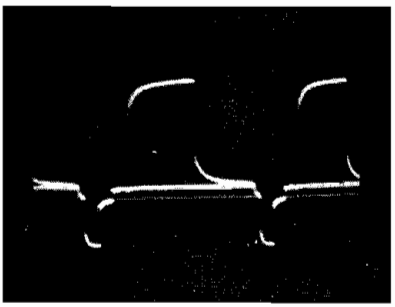


FIG. 5-61. Positive streaking—window signal—horizontal.

fects requires very close control of transmission characteristics in the lower frequency portion of the video band.

The amplitude and phase-characteristic tolerances at the very low end of the frequency band, say below half-line frequency, are probably not so critical but have not been evaluated accurately. When the signal is clamped, the amplitude characteristic at 60 cycles can be allowed to vary considerably. Furthermore, it can be deliberately adjusted to depart from a uniform response at 60 cycles or other points below half-line frequency in order to provide phase correction at line frequency and its harmonics.

Streaking (Figs. 5-60 to 5-71). Streaking is the appearance of an error luminance in the picture, extending horizontally toward the right edge of the picture from some point in the picture marked by a sharp transition in luminance. Streaking is most prominent for a change from a high luminance to a low luminance or vice versa. Since this type of impairment generally is caused by transmission irregularities in the region of the 15,750-cycle line scanning rate or its first few harmonics, the horizontal size of the object also affects the amount of streaking. Streaking is especially apparent when the objects move vertically in the scene and the streaking moves with them.

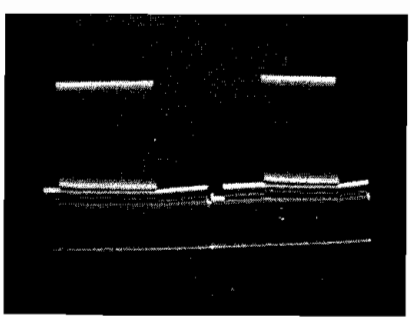


FIG. 5-62. Positive streaking—window signal—vertical.

If the streaking is the same shade as the original figure (white following white or black following black), it is called positive. If the streaking is the opposite shade, it is called negative. Figures 5-60 to 5-71 illustrate picture-monitor and A-scope presentations of positive and negative streaking.

In Fig. 5-61, the leading edge of the white window aprpoaching white level is heavily rounded while the trailing edge of the white window approaching black level rolls off gradually, indicating black following black and white following white, or positive streaking. The vertical presentation in Fig. 5-62 reveals in the signal region below the white level, a heavy trace above black level, the height of this trace being a measure of the streaking or

FIG. 5-63. Positive streaking—window signal—expanded vertical.

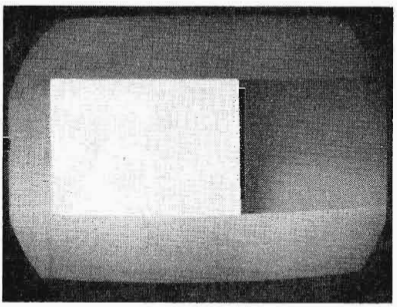


FIG. 5-64. Negative streaking—window signal.

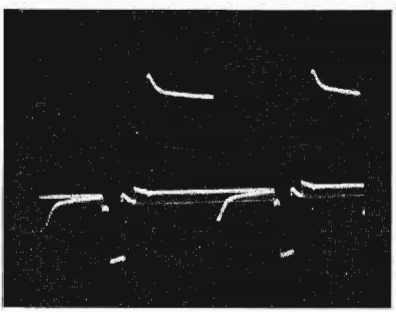


FIG. 5-65. Negative streaking—window signal—horizontal.

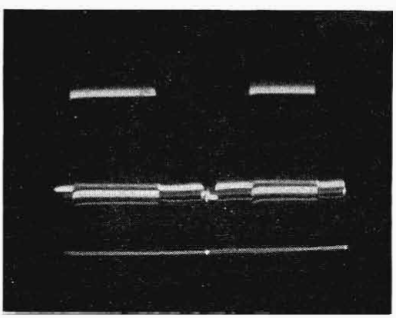


FIG. 5-66. Negative streaking—window signal—vertical.

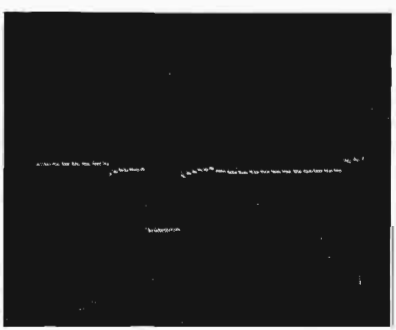


FIG. 5-67. Negative streaking—window signal—expanded vertical.

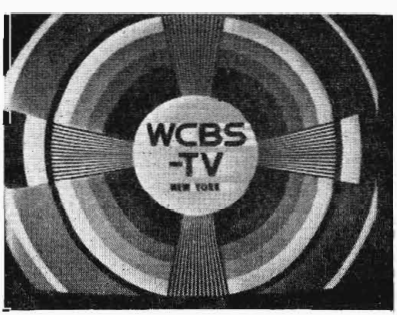


FIG. 5-68. Negative streaking—test pattern.

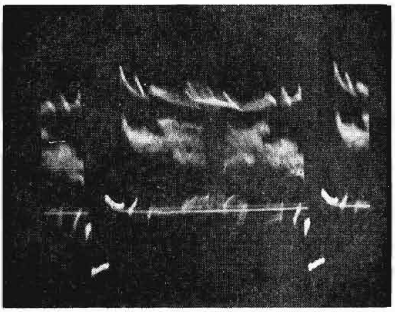


FIG. 5-69. Negative streaking—test pattern—horizontal.

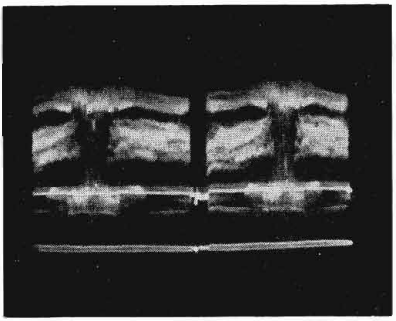


FIG. 5-70. Negative streaking—test pattern—vertical.

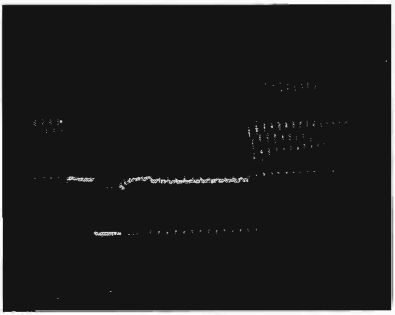


FIG. 5-71. Negative streaking—test pattern—expanded vertical.

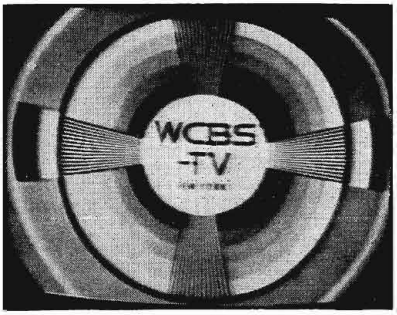


FIG. 5-72. Smearing—test pattern.

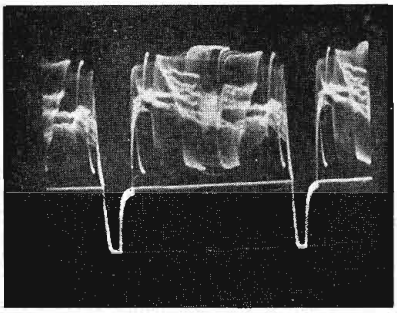


FIG. 5-73. Smearing—test pattern—horizontal.

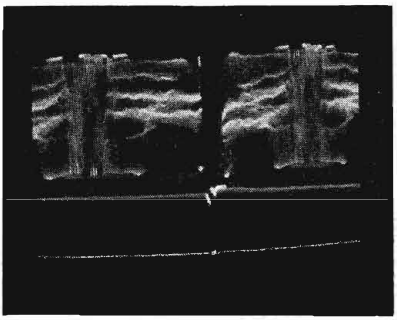


FIG. 5-74. Smearing—test pattern—vertical.

white following white. In like maner, Fig. 5-65 is the horizontal presentation for negative streaking, or black following white and white following black. Here the manifestations are just the opposite from Fig. 5-61; that is, there is a high peak, or white level, on the transition from black to white, while the trailing edge of the white window dips below blanking and gradually restores to reference-black level. The vertical presentation in Fig. 5-66 shows a heavy trace, or following black, in the window signal region, which is the opposite to Fig. 5-62. The picture-monitor presentations (Figs. 5-60, 5-64, and 5-68) show this streaking; however, in practice a comparison of A-scope presentations using suitable signals is preferred because of the possibility of streaking caused by the picture monitors.

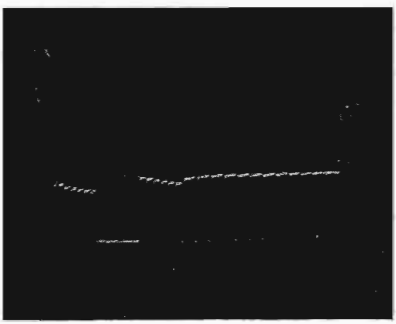


FIG. 5-75. Smearing—test pattern—expanded vertical.

In addition to the foregoing, comparison of the A-scope presentations for positive and negative streaking reveals opposite tilts of front and back porches and tip of sync for the horizontal presentations (Figs. 5-61, 5-65, and 5-69) and of the trace between the first and second sets of equalizing pulses for the vertical presentations (Figs. 5-63, 5-67, and 5-71).

Smearing (Figs. 5-72 to 5-75). Smearing is a distortion similar to streaking. The impairment is a blurring of the vertical edges of objects in the televised scene, and the whole picture looks as if it had been smeared along the horizontal axis. The smearing-error luminance may also be of the same or opposite sign as the luminance it follows.

Change of Setup (Figs. 5-76 to 5-81)

The setup of the picture is the difference between the blanking and reference-black levels as viewed on the A scope using IRE roll-off. For normal operation this is 10 divisions on the IRE scale. Setup variation along network facilities is mainly affected by the lower portion of the frequency band, excessive transmission-frequency loss in this region causing too little setup and excessive transmission-frequency gain in this region causing too much setup.

Loss of Setup (Figs. 5-76 to 5-78). Low setup results in pictures having more contrast than normal. The whites in the scene will be unchanged, but some of the normal grays may become almost black. Some streaking may also occur owing to the deviations in the gain and phase characteristics at low frequencies. When loss

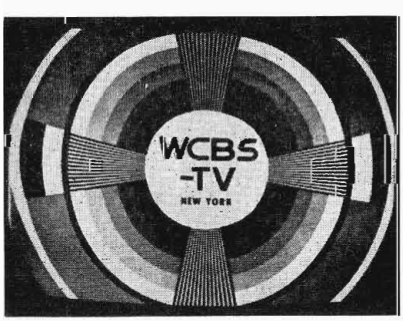


FIG. 5-76. Low setup—test pattern.

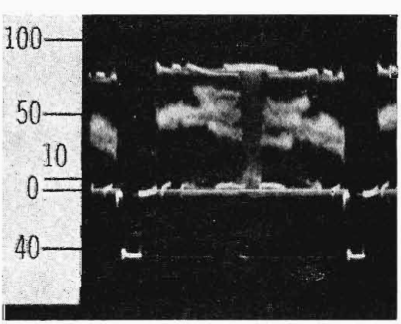


FIG. 5-77. Low setup—test pattern—horizontal.

of setup occurs to the point where the picture signal punches through the blanking level, normal clipping functioning of the customer's stabilizing amplifier will cause loss of this picture information. In severe cases, erratic operation of the customer's stabilizing amplifier may occur and the picture will be unusable.

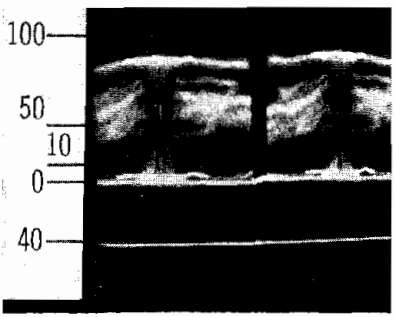


FIG. 5-78. Low setup—test pattern—vertical.

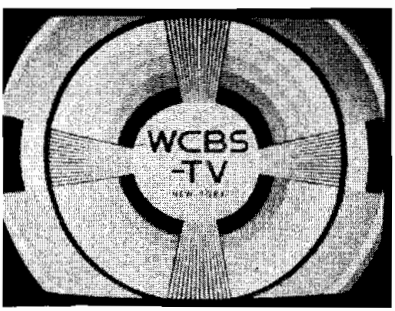


FIG. 5-79. High setup—test pattern.

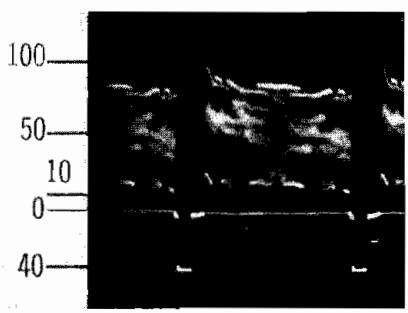


FIG. 5-80. High setup—test pattern—horizontal.

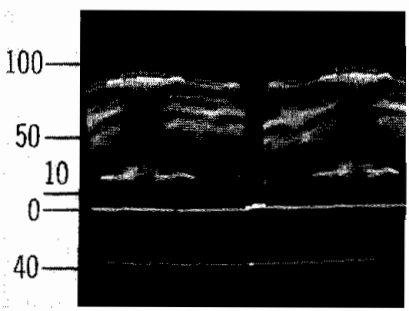


FIG. 5-81. High-setup—test pattern—vertical.

Increase in Setup (Figs. 5-79 to 5-81). High setup resnlts in reduced contrast range and reduced signal-to-noise ratio.

Ringing (Figs. 5-82 to 5-86)

Ringing geuerally results from the transmission of sudden tonal transitions over a system that has a finite passband with a sharp cutoff at the upper end of the frequency range. It may also result from a marked transmission discontinuity at some frequency below cutoff. When a signal containing a sudden transition is applied to such a circuit, damped oscillations or ringing will occur at approximately the frequency of cutoff or other discontinuity, the duration of the ringing depending upon the sharpness of the discontinuity. Ringing will be accentuated by a rising gain characteristic preceding the discontinuity.

The RETMA test pattern and the typical broadcaster's test pattern shown in Figs. 5-33 and 5-34 are sensitive indicators of ringing. The phenomenon will be apparent as additional lines on either or both sides of the vertical wedges. These lines will be strongest at the vertical position correspondiug to the frequency of cutoff or other discontinuity of the circuit elements causing the ring.

Ringing can also be detected by using the A-scope horizontal presentation to uote

the presence of damped oscillations following sharp transitions in the signal. It is possible to observe the transitions during the blanking interval, such as sync pulse to back porch. The window or other square-wave type of signal is also suitable for

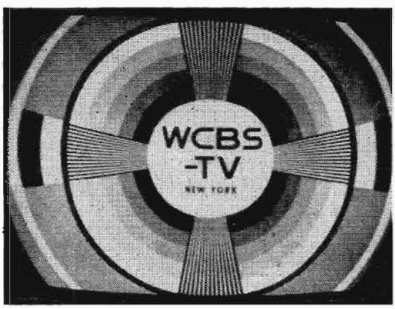


FIG. 5-82. Ringing (3 Mc)—test pattern.

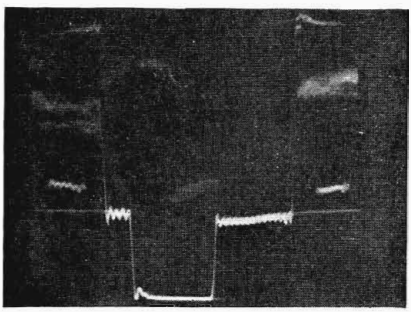


FIG. 5-83. Ringing (3 Mc)—test pattern—expanded horizontal.

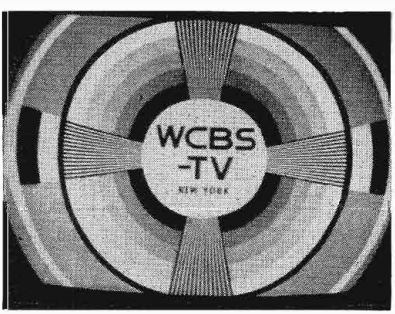


FIG. 5-84. Ringing (4 Mc)—test pattern.

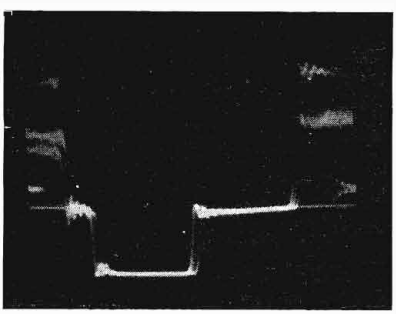


FIG. 5-85. Ringing (4 Mc)—test pattern—expanded horizontal.

noting this type of distortion. The ringing frequency can be determined by counting the number of complete oscillations appearing in a known time interval and converting to frequency by using the following formula:

Ringing frequency = number of oscillations $\times$ 10^6 $\div$ time interval, μsec

$$f = n \frac{10^6}{t(\mu\text{sec})}$$

The accompanying illustrations were produced by introducing sharp cutoff at approximately 3 Mc (Figs. 5-82 and 5-83) and 4 Mc (Figs. 5-84 and 5-85). Close observation of Fig. 5-86 will reveal to the lower right of the necktie that there is in succession a trailing white, a trailing black, and a second lower level trailing white, indicating a damped transient or ringing. Had this following signal been damped to the extent that only one white edge trailed the necktie, the impairment might be described as "edge effect" as covered in Overshoots, following.

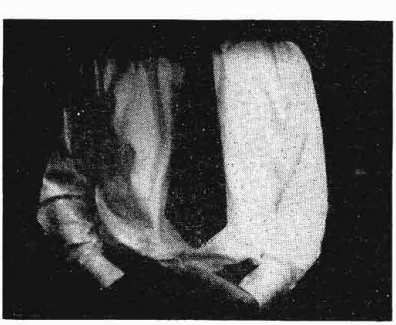


FIG. 5-86. Ringing.

Overshoots (Figs. 5-87 and 5-88)

In a television signal, an overshoot is an excessive response to a sudden change in signal. A sharp overshoot is commonly referred to as a spike. An overshoot is generally caused by excess gain at high frequencies. In vestigial sideband systems, another possible cause is insufficient carrier-to-sideband ratio.

Following Whites or Blacks (Fig. 5-87). Overshoots within the picture area result in impairments to the picture called following white or black (edge effect).

FIG. 5-87. Edge effect.

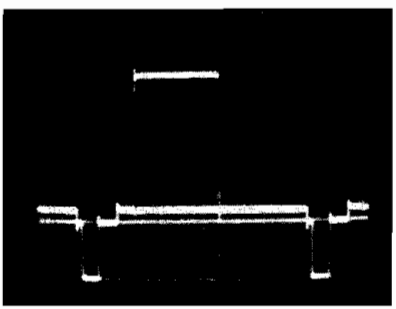


FIG. 5-88. Overshoots—window signal—horizontal.

These appear as a black outline to the right of white objects and a white outline to the right of black objects. In Fig. 5-87 this is most evident as a white edge following the man's head. A black edge follows the white of the handkerchief. Wide following whites or blacks are similar to negative smear.

Overshoot on Back Porch. An overshoot of the trailing edge of the sync pulse is called a "positive spike on the back porch." If this extends above black level, it may be visible in the picture as a gray vertical bar due to illuminating portions of the horizontal return traces. Figure 5-88 illustrates a slight overshoot on the back porch.

Overshoot on Front Porch. An overshoot of the transition from picture to blanking is called a "negative spike on the front porch." Since this is below black level, it will not be visible in the picture. However, if the overshoot is of sufficient magnitude, it may cause improper triggering of stabilizing amplifiers, monitors, or clampers, with serious tearing or complete loss of picture. Figure 5-88 also shows a slight overshoot on the front porch.

Resolution (Figs. 5-89 to 5-91)

Resolution is the ability to reproduce detail in a transmitted picture. Resolution is measured in lines, as discussed under the descriptions of the RETMA and broadcasters' test patterns. The degree of resolution can be affected by the dimensions of camera and receiver scanning beams. Horizontal resolution is also a function of bandwidth. A rule of thumb is that 1.0 Mc of bandwidth corresponds to 80 lines of resolution. For maximum resolution with a given bandwidth, a flat amplitude and linear phase characteristic up to the point of cutoff would be favored. However, the resulting sharp cutoff would cause ringing. Assuming a transmission system having the same passband but rolled off gradually with frequency, the resolution will become poorer as lower and lower frequencies are selected as the start of the roll-off, but transient effects in the region of cutoff will be reduced. The actual shape of a passband, then, is a compromise between transient effects in the region of cutoff and the distortion introduced at lower frequencies (loss of resolution) by the extent and shape of the roll-off.

In addition to frequency response, excessive noise also can mask fine picture detail and result in apparent loss of resolution.

Figures 5-89 and 5-90 show test-pattern transmissions when the high frequencies are strongly rolled off starting at about 1 Mc. The A-scope expanded presentation shows loss of sharpness at transition points. Figure 5-91 illustrates loss of both horizontal and vertical resolution caused by too large a receiver scanning spot.

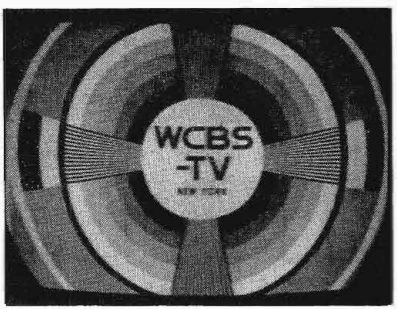


FIG. 5-89. Low resolution—roll-off from 1 Mc.

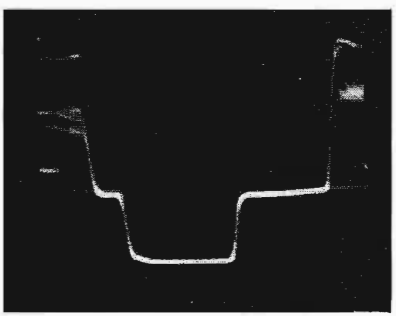


FIG. 5-90. Low resolution—roll-off from 1 Mc—expanded horizontal.

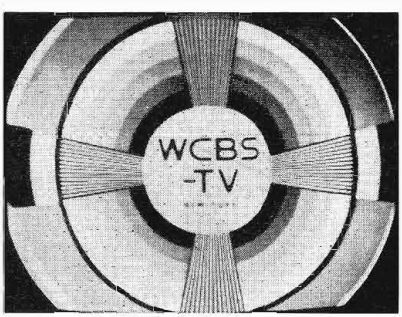


FIG. 5-91. Low resolution—receiver scanning spot too large.

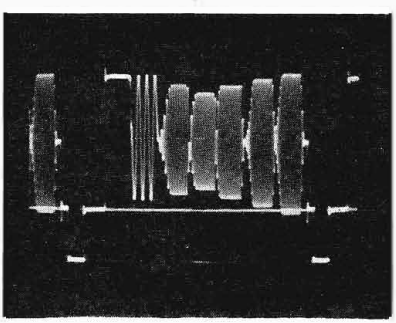


FIG. 5-92. Hourglass effect.

Hourglass (Fig. 5-92)

When multiburst signals are transmitted over a video facility having a transmission-frequency-response characteristic such that the middle multiburst test frequencies are attenuated with respect to both the lower and higher test frequencies, the resulting A-scope presentation of the multiburst test signal has been referred to as the "hourglass" effect. The frequency characteristic usually results from partial equalization, such as would occur when compensating for a facility having a gradually increasing loss with frequency, using an equalizer effective only in the upper portion of the frequency band. As improvement is made in the facility having increased loss with frequency, less compensation is required from the high end equalizers eliminating the hourglass.

Echoes (Figs. 5-93 to 5-105)

An echo signal or ghost can be defined as a duplicate of the original video signal displaced horizontally from the original signal. A complete reproduction of the original signal is called a ghost, while a partial reproduction is called an echo or

reflection. Ghosts and echoes are due to impairment in the transmission path which causes the signal pulses to reach the viewer at two or more discrete times. Generally, the echo signal is weaker than the original signal, so the echo picture is also weaker than the main picture. When two or more echo patterns are present, one pattern usually predominates and the others are relatively weak.

The impairment effect of the echo picture varies not only with echo signal strength but also with the time offset and the nature of the original video signal. This is illustrated by Fig. 5-93.

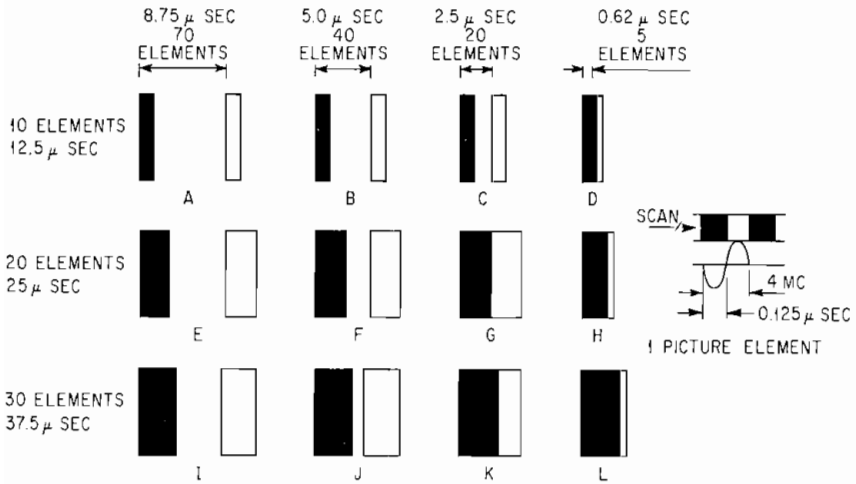


FIG. 5-93. Echo impairment effect vs. image size and echo displacement.

As a practical matter, echo signals are generally not true reproductions of the original signal, since the conditions that give rise to echo signals are usually not linear throughout the band. This adds still another variable factor, since distorted echo signals result in a lesser picture impairment than undistorted echo signals. Echoes may be either leading or lagging, and they may be either positive (same tonal range) or negative (reverse tonal range). Figures 5-94 to 5-101 show positive lagging echoes; Figs. 5-102 to 5-105 show negative lagging echoes.

The most usual cause of ghosts and echoes seen on home receivers is two transmission paths from the broadcast station to the receiving location—the direct path and a second path produced by a reflection from some tall building or high point of terrain. The ghost is offset to the right of the direct image by an amount of time equivalent to the difference in length of transmission time of the two paths. Transmission over the reflected path is generally attenuated as compared with the direct path, so the ghost appears weaker than the direct signal. When FM radio signals are used, as in radio relay systems, an impairment from a reflected path generally does not result in a television picture with a distinct echo, since its echo-producing signal would be smothered by the FM capture feature of the radio relay receivers.

Ghosts and echoes may also be produced in transmission facilities as a result of troubles or unsatisfactory adjustments. A trouble such as impedance irregularity in a cable section or an improperly terminated cable will produce electrical reflections which are delayed in transmission compared with the original signal and thus produce ghosts or echoes. Ghosts will be produced if the irregularity affects substantially the whole video frequency band, and echoes when only a part of the frequency band is affected.

The same effects can also be caused by nonuniformity of gain- and delay-frequency characteristics. In particular, a gain-frequency characteristic having periodic peaks

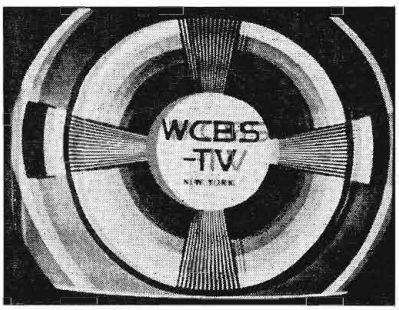


FIG. 5-94. Positive echo—test pattern.

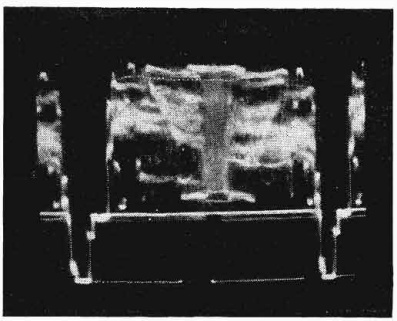


FIG. 5-95. Positive echo—test pattern—horizontal.

FIG. 5-96. Positive echo—test pattern—expanded horizontal.

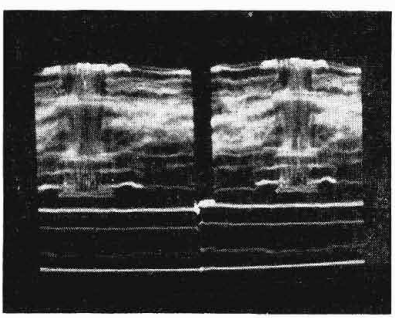


FIG. 5-97. Positive echo—test pattern—vertical.

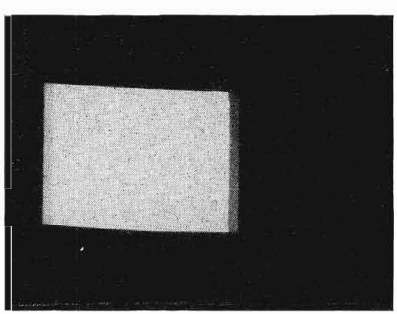


FIG. 5-98. Positive echo—window signal.

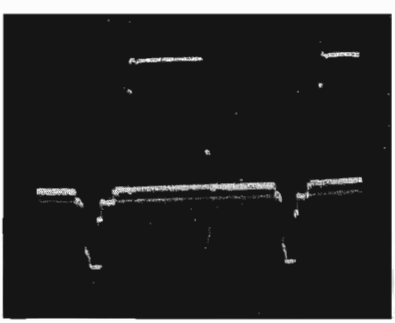


FIG. 5-99. Positive echo—window signal—horizontal.

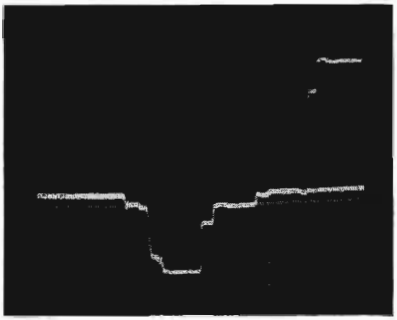


FIG. 5-100. Positive echo–window signal –expanded horizontal.

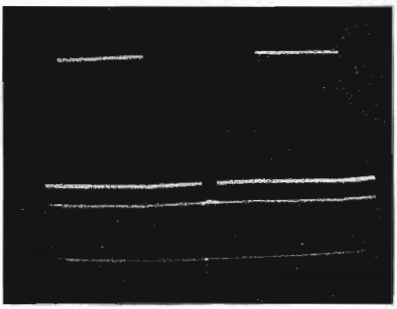


FIG. 5-101. Positive echo–window signal –vertical.

FIG. 5-102. Negative echo–test pattern.

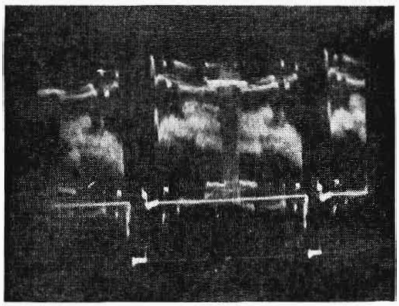


FIG. 5-103. Negative echo–test pattern–horizontal.

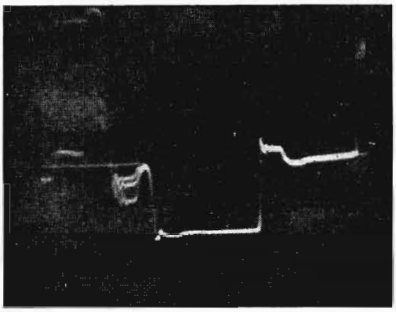


FIG. 5-104. Negative echo–test pattern–expanded horizontal.

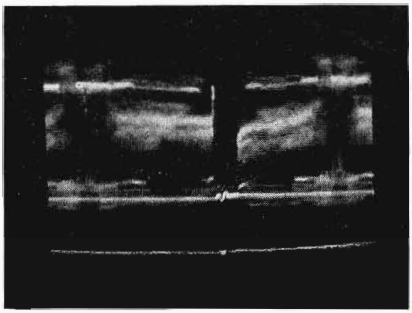


FIG. 5-105. Negative echo–test pattern–vertical.

and valleys across the frequency band will act the same as an impedance irregularity on cable affecting a broad band of frequencies.

The spacing of the reflected image or images from the original object and from each other is determined by the location of the irregularity in the frequency spectrum and usually can be calculated by the relationship that the reflection displacement in seconds is equal to the reciprocal of the frequency in cycles at which the irregularity occurs. For example, an irregularity occurring at 500 kc will produce reflections displaced from the original and from each other by 2 μsec. Remembering that one line in a television picture (exclusive of blanking) is equal to about 53 μsec, we can then see that in this case the reflections will be displaced by a fraction of the total picture width equal to $\frac{2}{53}$, or about $\frac{3}{8}$ in. in the case of a 10-in. picture tube. Where carrier-type facilities are involved, it should be remembered that this is a video-frequency calculation and that further conversion to carrier frequencies may be required. The number of reflections is dependent upon the sharpness of the irregularity, being only one for a broad irregularity and increasing in number with irregularity sharpness.

Interference

General

Interference is the introduction of extraneous signals into the desired signal. In the case of television transmission, the resulting picture impairments may be in the form of bars, moving spots, salt-and-pepper effect, or erratic synchronizing. One form of interference is called noise, this term being used generally to describe natural phenomena such as thermal noise in electronic components, whereas "interference" generally refers to man-made signals, such as extraneous single-frequency voltages, cross talk from another video channel, and the like. The term *noise* is a carry-over from audio work. In television the effects are visual rather than aural.

Interference can be simply added into the path of the desired signal, or it can modulate the signal itself. Signal modulation by interference may occur in nonlinear circuit elements such as vacuum tubes and results in the whole picture-signal amplitude changing at the interfering rate. The two types of interference are difficult to distinguish in a television picture. Treatments that will minimize additive interference, such as filtering, use of clamper amplifiers for low-frequency interference, etc., will not affect modulation products. Additive interference is the case discussed and illustrated in this section.

Single-frequency Interference

The appearance on a television picture of extraneous regularly spaced bars or lines indicates the presence of an interfering frequency. At low levels of interference the amount of single-frequency interference that can be tolerated varies quite widely, depending on the part of the spectrum in which it is operative.

Low-frequency Interference (Figs. 5-106 to 5-113). A particularly sensitive portion of the spectrum is the immediate region of the field rate, 60 cycles. It has been found that as the level of such an extraneous frequency is increased from a very low value, flicker is much more objectionable than the brightness distortion corresponding to a broad bar pattern. The flicker effect is accordingly controlling in this level region. The tolerable level of interference varies with the flicker frequency (difference between the extraneous and field frequencies), a flicker rate of about 5 cycles being the most objectionable. This holds for frequencies either side of the field rate; that is, the most critical frequencies are 55 and 65 cycles. To be tolerated, the peak-to-peak amplitude of these interfering frequencies has to be about 54 db less than the peak-to-peak amplitude of the television signal.

Figures 5-106 and 5-109 are cases of 120- and approximately 1,000-cycle interference. For low-frequency interference which is an exact multiple of the field rate (60 cycles) the extraneous bars will be horizontal and will remain stationary. The interfering frequency can be determined by multiplying 60 cycles by the number of

white or the number of dark bars observed. Two horizontal white bars can be distinguished in the first instance, and 16 or 17 for the 1,000-cycle picture. When the extraneous frequency differs slightly from the 60-cycle field rate or its multiples, the bars will remain horizontal but will move vertically through the picture, the rate of motion increasing with the difference in frequency. Interference at 60 cycles and its first few harmonics is frequently called "hum," as it is often caused by defects in power supplies—similar to the audio case.

Low-frequency interference shows on the A-scope horizontal presentation as thickened horizontal lines, the thickness indicating the relative amplitude of the interference, as in Figs. 5-107 and 5-110 for the 120- and 1,000-cycle cases, respectively. The vertical presentation shows no thickening of the trace. The interference may appear as a waveform on the blanking line, horizontal sync tips, and sometimes the picture signal, as in Figs. 5-108 and 5-111 for the same two examples.

Clamper amplifiers effectively reduce interference at 60 cycles by about 33 db. This figure reduces progressively as the interfering frequency is increased, and the clamper is not effective on interference above about 2 kc. (This varies somewhat with the clamper time constant.) Figures 5-112 and 5-113 show the 120-cycle interference of Figs. 5-107 and 5-108 after passing through a clamper amplifier. No impairment is visible in the pictures.

Glitch (Figs. 5-114 and 5-115). A type of low-frequency interference, which has been commonly referred to by the broadcasters as a "glitch," is observed as a narrow horizontal bar moving through the picture (Fig. 5-114). Simultaneous observation of the A scope at field or frame rate will indicate one or more extraneous voltage pips moving along the signal at approximately reference-black level. The pip in Fig. 5-115 was moving rapidly from right to left.

This may be present in the signal from the customer's pickups as a result of a difference in frequency between a remote camera power supply and the customer's local 60-cycle power supply. When some types of radio relay equipment are used, the impairment also may result from spiking on the positive and negative sine-wave peaks of commercial power supplies. The speed of movement of the dark bar depends on the difference between the frequency of the picture field rate and the frequency of the commercial power supply. Such spiking is sometimes introduced from mercury-vapor rectifiers or similar systems feeding back voltage pips at a 60-cycle rate into the commercial power supply. Thus, this is not pure single-frequency interference but has many similar characteristics. It is possible to observe this spiking from such power supplies through use of an oscilloscope bridged on the power line. Effects are eliminated through filtering, either at the source of interference or at the point of connection of the radio relay equipment.

High-frequency Interference (Figs. 5-116 to 5-127). In the region above the line rate, 15,750 cycles, the most critical frequency is found to be in the ½- to ⅓-Mc range. The maximum tolerable interference level at this point in the spectrum is about 65 db below the signal. High-frequency interference will appear as regularly spaced diagonal or vertical bars which become finer as the frequency increases. If this frequency is an exact multiple of the line rate, the pattern will be stationary and vertical. The interfering frequency can be determined by multiplying the line rate by the number of white or the number of dark bars observed cutting a horizontal cross section of the picture. Figures 5-116 to 5-119 are samples, respectively, of 31.5-kc, 311-kc, 1.0-Mc, and 3.6-Mc interference. The first picture contains light vertical areas just to the left of center and on the right side of the pattern which are difficult to distinguish. The bar patterns on the other three pictures are quite evident, and a count of the bars will give the interfering frequency accurately.

The A-scope presentations are shown by Figs. 5-120 to 5-123 at horizontal rate and Figs. 5-124 to 5-127 at vertical rate, respectively. It will be noted that, on the horizontal display, the interference shows as a wave whose frequency can be determined by counting the cycles appearing in the scanning interval. If the frequency is very high, expanding the scope presentation may be necessary to resolve the individual wave shapes. The vertical trace shows thickening as illustrated.

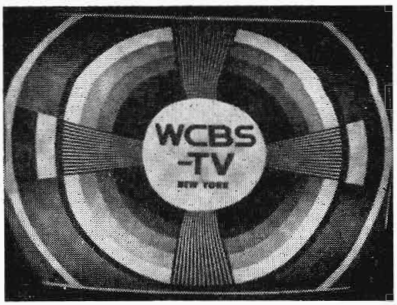


FIG. 5-106. Interference—120 cycles.

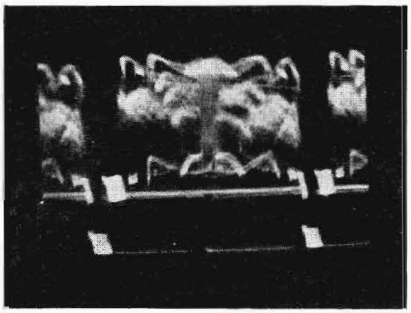


FIG. 5-107. Interference—120 cycles—horizontal.

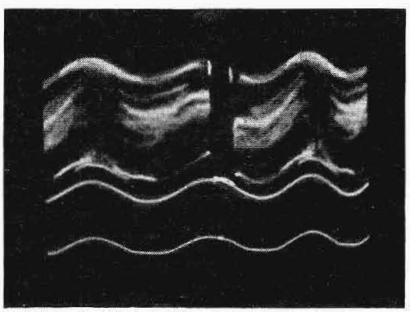


FIG. 5-108. Interference—120 cycles—vertical.

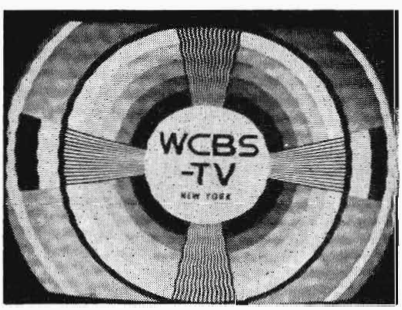


FIG. 5-109. Interference—1,000 cycles.

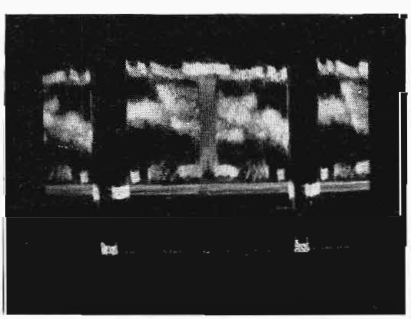


FIG. 5-110. Interference—1,000 cycles—horizontal.

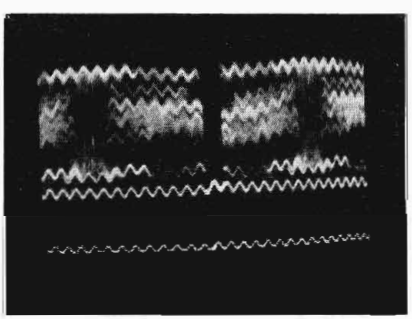


FIG. 5-111. Interference—1,000 cycles—vertical.

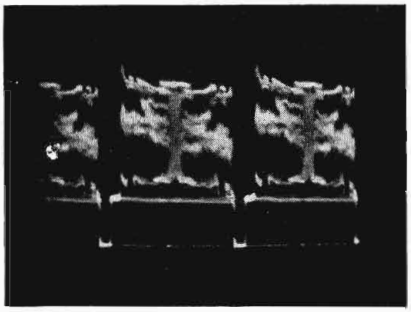


FIG. 5-112. Interference—clamped—120 cycles—horizontal.

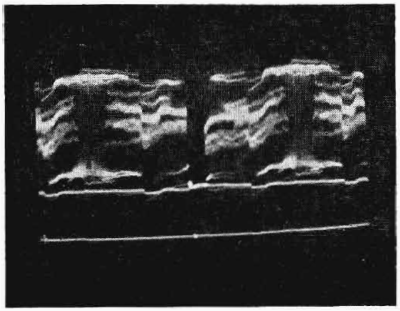


FIG. 5-113. Interference—clamped—120 cycles—vertical.

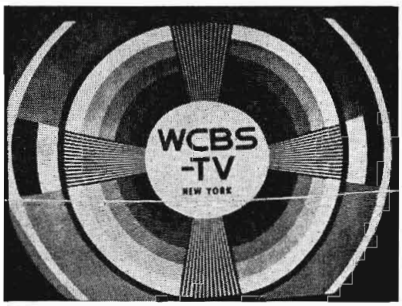


FIG. 5-114. Glitch.

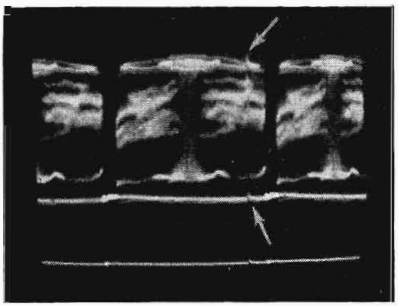


FIG. 5-115. Glitch—vertical.

FIG. 5-116. Interference—31.5 kc.

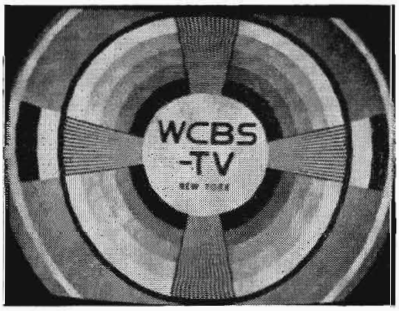


FIG. 5-117. Interference—311 kc.

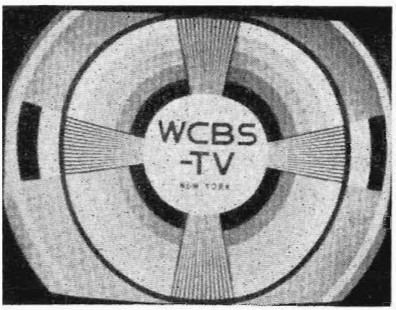


FIG. 5-118. Interference—1 Mc.

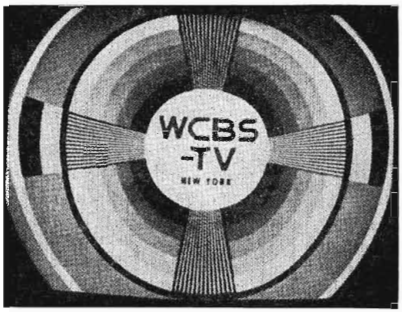


FIG. 5-119. Interference—3.6 Mc.

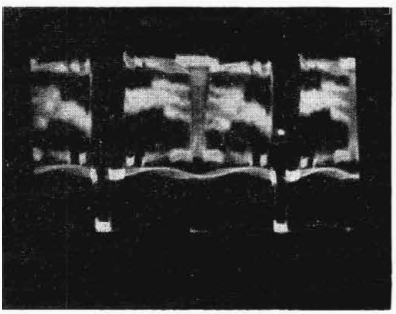


FIG. 5-120. Interference—31.5 kc—horizontal.

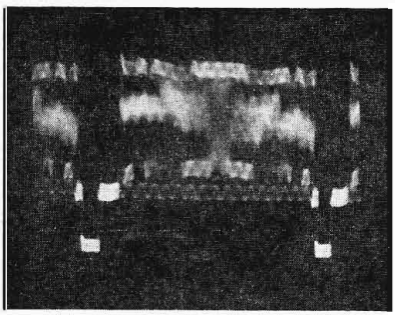


FIG. 5-121. Interference—311 kc—horizontal.

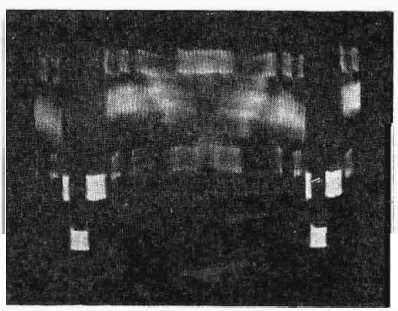


FIG. 5-122. Interference—1 Mc—horizontal.

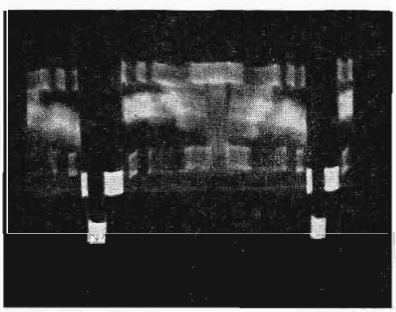


FIG. 5-123. Interference—3.6 Mc—horizontal.

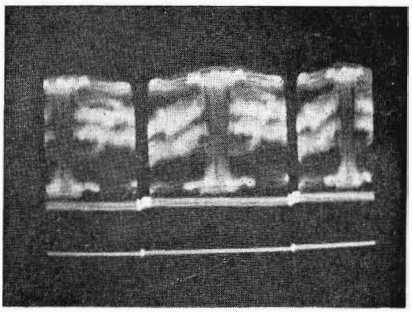


FIG. 5-124. Interference—31.5 kc—vertical.

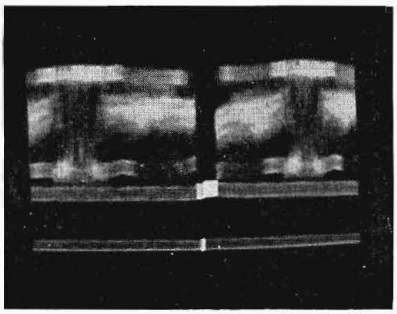


FIG. 5-125. Interference—311 kc—vertical.

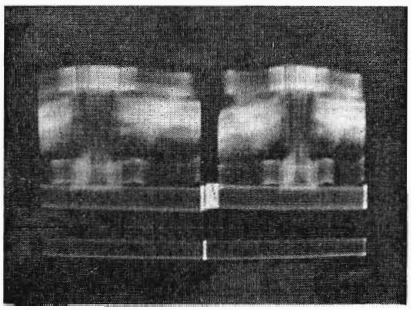


FIG. 5-126. Interference—1 Mc—vertical.

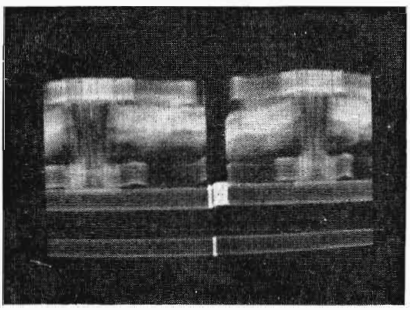


FIG. 5-127. Interference—3.6 Mc—vertical.

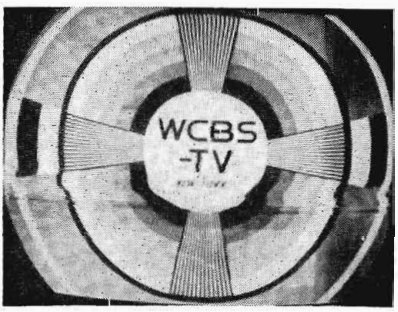


FIG. 5-128. Interference—cross talk.

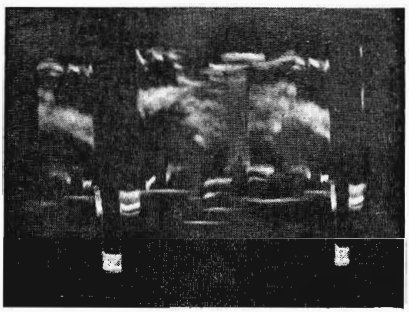


FIG. 5-129. Interference—cross talk—horizontal.

Cross Talk (Figs. 5-128 to 5-130)

Cross talk, as considered herein, is the effect of coupling between two television channels. If the coupling is strong enough, the result is a weak extraneous image, usually somewhat distorted, superimposed on the main image similar to Fig. 5-128. Since different video systems normally are not exactly synchronized, rather violent horizontal motion of the cross-talking image usually occurs. Vertical motion is not likely to be so violent, since the field rates usually will be closer together than the line rates.

FIG. 5-130. Interference—cross talk—vertical.

The most prominent feature of the cross-talking image will be the line and field synchronizing interval. These are, of course, blacker than black, and they effectively frame the cross-talking image. As cross-talk coupling is reduced, the cross-talking image is no longer visible, but the horizontal interval which appears as a wide black vertical bar and the vertical interval which appears as a wide black horizontal bar will be visible moving through the picture. The rate of horizontal and vertical motion will vary with the differences between the sync rates of the two signals. The horizontal interval is usually the most disturbing, since it extends the whole height of the raster as a wide black bar, with appreciable motion. The vertical interval is not usually so noticeable.

It would appear that the limiting loss in the coupling path should be 58 db or higher for equal-level circuits.

Depending upon the strength of the unwanted signal, the interference may or may not be seen on the A scope. In the example used, it was necessary for photographic reasons to introduce the cross-talking signal only about 10 db below the desired signal. Therefore, the interfering signal is evident as modulation on both the horizontal and vertical presentations (Figs. 5-129 and 5-130).

Random Noise (Figs. 5-131 to 5-136)

This type of noise is of the general type obtained by vacuum-tube amplification of thermal noise but is not necessarily confined to that source. It covers a wide band of frequencies without too much energy variation. The over-all rms amplitude is reasonably stable over time intervals corresponding to one line scan. Experience to date indicates that, assuming noise peaks to run around three times the rms value, peak random noise should be limited to approximately 30 db below the picture signal for a 4-Mc bandwidth system. It appears that "noise per megacycle of bandwidth" rather than total noise in the band determines the impairment. An 8-Mc system, for example, would be 3 db more tolerant to noise than a 4-Mc system.

The visual effect of random noise is that the picture acquires a pronounced graininess. When noise is strong enough, this may be called "snow" as shown in Fig. 5-131. Thickening of the blanking lines and tips of sync pulses is usually evident, as in Figs. 5-132 and 5-133, which show the horizontal and vertical scanning intervals of the picture of Fig. 5-131. These three illustrations are of noise caused by transmitting low level into a microwave repeater and restoring the signal to normal amplitude at the receiving terminal, thus amplifying the thermal noise in the equipment.

Figure 5-134 illustrates another type of random noise. This is the result of a microwave message channel, with a large number of busy circuits, interfering with the picture channel.

Light random noise (Figs. 5-135 and 5-136), visible only in the background of the picture has been referred to sometimes as "busy background," since variations in

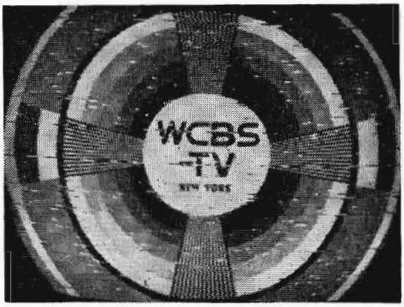


FIG. 5-131. Random noise.

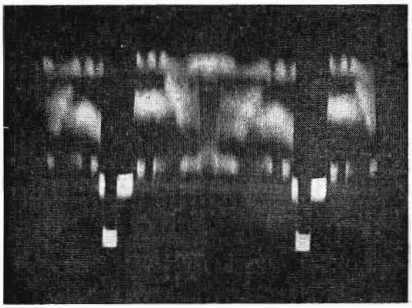


FIG. 5-132. Random noise—horizontal.

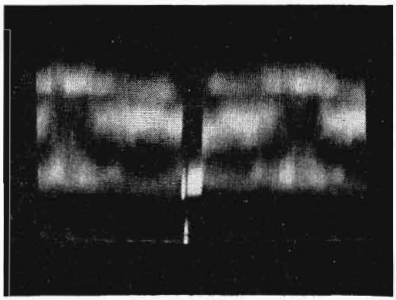


FIG. 5-133. Random noise—vertical.

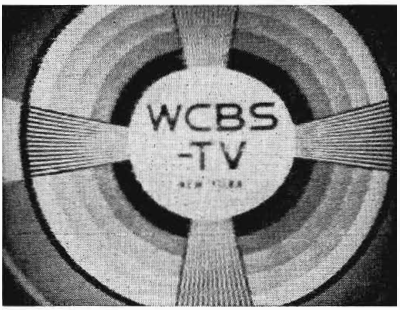


FIG. 5-134. Message-channel interference.

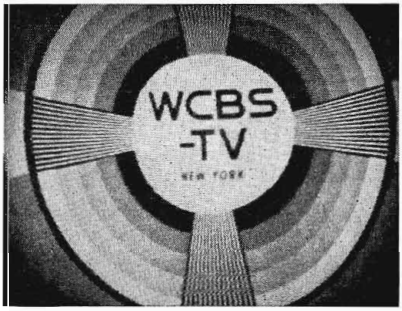


FIG. 5-135. Light random noise.

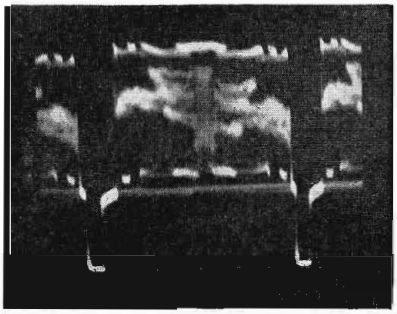


FIG. 5-136. Light random noise—horizontal.

intensity of the noise peaks usually cause the appearance of movement of the gray background, with minor thickening of the A-scope traces. This term is used with a different meaning by other groups connected with television and theatrical work, and its use is not recommended for description of television-signal impairments. "Light noise" or "light high-frequency noise" are preferred terms.

Impulse Noise (Fig. 5-137)

The effect of impulse noise, which is composed usually of intermittent bursts or pulses, is difficult to evaluate. Assuming noise peaks at one per minnte, one objective thought to be reasonable is to limit the peak noise to 20 db below the signal level. The division between impulse noise and random noise is not sharp; as the rate of occurrence of noise pulses increases, the more nearly it approaches random noise. Picture impairments resulting from impulse noise, as shown in Fig. 5-137, are sometimes called "pigeons," since the spots seem to fly across the picture. The picture was obtained by reducing levels on a microwave system just enough to allow a few noise peaks to act on the picture, infrequently and unpredictably enough to be called impulse noise. Unless observation is made of the A scope at the time of occurrence of the noise pulse, or unless the pulses occur frequently, thickening of blanking lines or other signal indications will not be observed.

Microphonics (Fig. 5-138)

When some vacuum tubes are physically disturbed by vibrations due to nearby machinery, shocks from installation operations, or even loud noises, their elements may vibrate, usually at a rate below 15,750 cps. The varying tube characteristics

FIG. 5-137. Impulse noise.

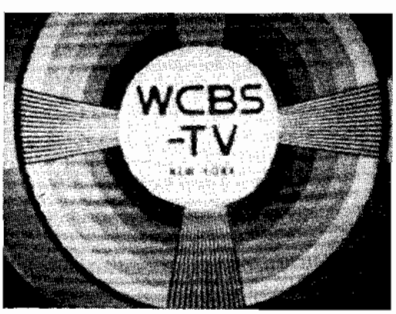


FIG. 5-138. Microphonics.

will cause any signal being handled to be modulated at the vibration rate. Since this ean be considered as low-frequency interference, the effect on pictures is to add a scries of horizontal bars, usually moving and changing in size in accordance with the amplitude and frequency of the vibration. Figure 5-138 was obtained by lightly tapping a tube in microwave terminal equipment.

Miscellaneous

Clamping

The effect on a composite video signal of low-frequency distortion is the same as though a low-frequency signal were added to the video signal. Thus low-frequency interference and low-frequency transmission deviations produce similar distortions of the video waveform. Clamping is a process whereby the effects of low-frequency interference and low-frequency transmission deviations are removed from the video

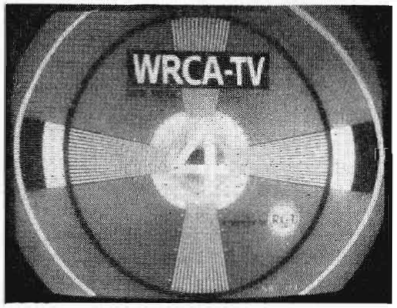


FIG. 5-139. Clamping failure.

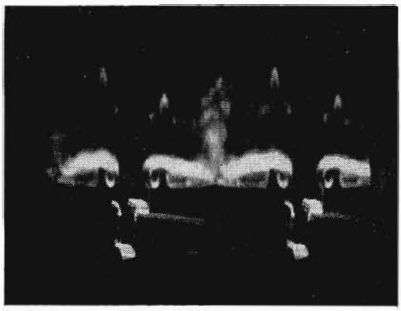


FIG. 5-140. Clamping failure—horizontal.

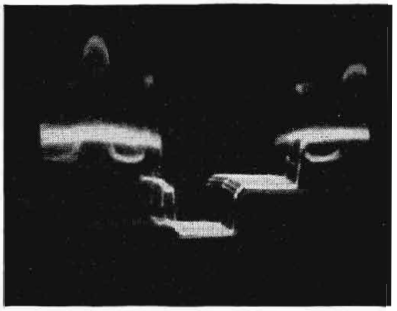


FIG. 5-141. Clamping failure—expanded horizontal.

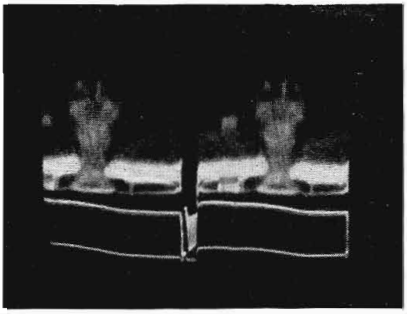


FIG. 5-142. Clamping failure—vertical.

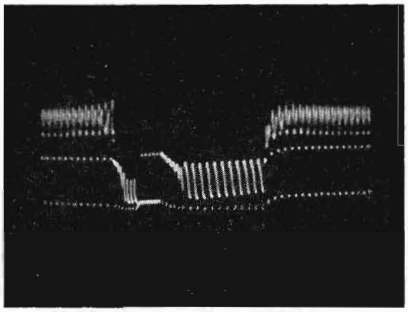


FIG. 5-143. Clamping failure—expanded vertical.

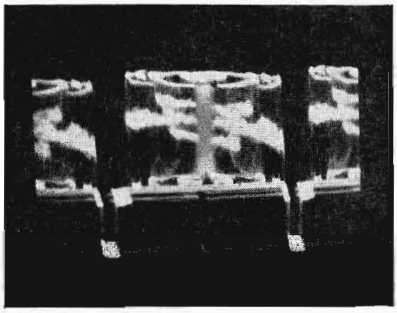


FIG. 5-144. Lack of clamping—horizontal.

signal. Telephone company clamper amplifiers are designed so that a correcting bias voltage is added to the signal at the start of each horizontal synchronizing pulse, the magnitude and polarity of this correcting voltage being sufficient to keep the tips of the horizontal sync pulses at a fixed reference level.

Since the back porch immediately follows the tip of the synchronizing pulse which has been adjusted to a fixed reference voltage, it is subjected to approximately the full clamper correction. The front porch, however, occurs at the end of a line signal, and its level is displaced by the over-all frequency distortion change during the preceding line interval. Since the clamper is triggered by the leading edge of the sync pulse, the front porch is unaffected by any subsequent correction that is applied by the clamper. Therefore, if the levels of the front and back porches were equal except for the low-frequency impairment experienced, the correcting voltage supplied by the clamper would be equal to the difference in the level of the two porches. However, porches are frequently displaced owing to other causes, such as transmission over a vestigial sideband carrier system where front-porch level may vary depending upon the signal level at the end of each scanning line. In general, therefore, porch displacement should not be depended upon as a measure of clamper correction voltage except under known conditions.

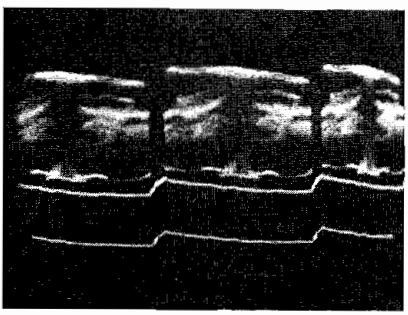


FIG. 5-145. Lack of clamping—vertical.

Loss of Clamping (Figs. 5-139 to 5-145). Loss of clamping results when the output level of the clamper amplifier drops to such a low level as to exceed the range of the clamping amplifier and thus make the clamping action ineffective. Figures 5-139 to 5-145 show the result of loss of clamping due to low level. Loss of clamping also may be caused by defective tubes or other defective components within the amplifier. Erratic or no clamping action may also result from an overshoot on the leading edge of the front porch sufficiently large to cause the clamper to be falsely triggered, resulting in complete tearing of the picture. In the examples, only a few lines of tearing are visible at the top of the pictures; however, the A scope reveals an erratic horizontal interval and serious distortion of the vertical blanking interval.

FIG. 5-146. Serrations.

Loss of clamper action on a signal transmitted through a coil is illustrated in Figs. 5-144 and 5-145. As previously discussed, the impairments observed as a result of low-frequency distortion are the same as though a low-frequency interfering signal were introduced and, therefore, will vary depending upon the nature and amount of low-frequency impairment present in the signal being observed. This is shown on the horizontal presentation (Fig. 5-144) by the thickening of the traces and in the vertical presentation (Fig. 5-145) by the varying tilts during vertical blanking and picture intervals.

Serrations (Fig. 5-146)

Serrations are jaggedness in the vertical and diagonal structure of images as seen in a picture monitor. They result from horizontal displacement of some of the

scanning lines due to nonuniformity in the triggering time of the horizontal-sweep oscillator. This condition may be caused by a distortion of the leading edge of the sync pulse as a result of interference, streaking, etc. Figure 5-146 shows serrations of vertical and diagonal lines in the center of the test pattern.

Tearing (Figs. 5-147 and 5-148)

Tearing is a horizontal displacement of the scanning lines to the extent that the picture appears torn. Tearing of the picture on the receiver or monitor may be caused by distortion or lack of horizontal sync pulses. It also may be caused by

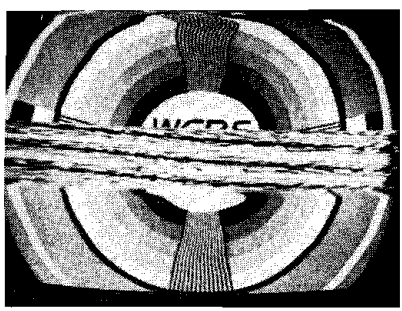


FIG. 5-147. Tearing.

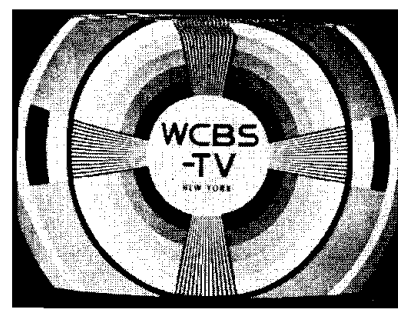


FIG. 5-148. Tearing.

video black peaks or spikes which drop below blanking level near the horizontal sync pulse. Any other form of interference whose amplitude is such as to cause false triggering of the horizontal scanning circuit of a receiver or monitor will give similar effects. One illustration of such tearing is shown in Fig. 5-147.

Tearing at only the top of a picture, as in Fig. 5-148, is usually caused by impairment or loss of some equalizing pulses. This may be due to sync generator trouble or improper clamping action due to defective clampers or improper levels.

Nonlinearity (Figs. 5-149 and 5-151)

The requirement in most transmission circuits and amplifiers that the output be directly proportional to the input over the working range of voltages or power means that these circuits must be "linear." Operation outside the range of linearity may occur when exceeding ratings of equipment, when maladjustments occur, when components such as vacuum tubes age, or owing to improper design. The departure from linearity that can be tolerated varies over wide ranges. For example, sync expansion circuits have been built into some telephone company clamper amplifiers deliberately to "expand" the sync part of the video signal relative to the picture signal to compensate for unwanted compression which may accumulate in transmission. This illustrates that the results of nonlinearity may be either "compression," which is the more usual, or "expansion."

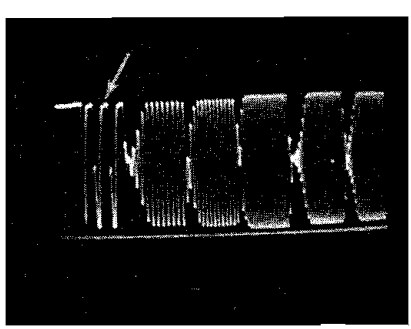


FIG. 5-149. Harmonic distortion—500 kc.

As discussed in the section on Level Irregularities, is it possible to compress either the negative or the positive peaks of a signal passing through an amplifier. The

resulting video signal will contain either "black compression" or "white compression." In analyzing the effects of compression on a sine wave, it can be shown that the compressed signal, in addition to containing the fundamental sine wave, may include a d-c component and other components made up of harmonics of the original sine-wave frequency. When all these components can be transmitted, the received wave is distorted and limited, as in Fig. 5-149, showing harmonic distortion on the 500-kc burst of a multiburst test signal. Other examples of compression effects are shown in the portion of this part dealing with level variations such as blooming, bleeding whites, etc. When compression becomes severe, it sometimes is called clipping and is observed as a sharp line of demarcation in level beyond which no signal is found.

If the nonlinearity is not equal for different impressed frequencies, combinations of effects may result which may be difficult to analyze. Such unequal distortions may occur in feedback amplifiers, where the feedback is a function of frequency in order to maintain over-all flatness, or in circuits such as those of video cable amplifiers, where the high frequencies are transmitted at somewhat greater levels than the

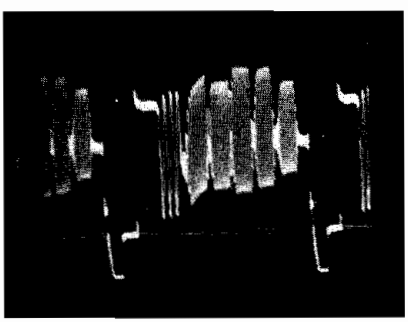


FIG. 5-150. Axis shift.

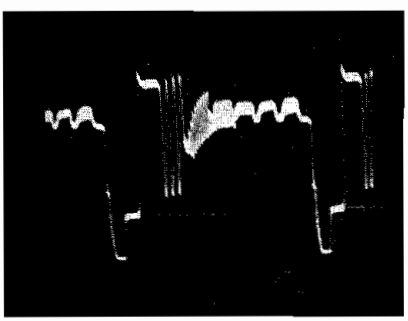


FIG. 5-151. Axis shift—through low-pass filter.

lows in order to compensate partially for succeeding cable loss. Compression of higher frequency compouents of a signal compared with the lows has been noted fairly frequently.

The multiburst test signal has proved to be a good indicator for this selective type of compression and may sometimes detect this condition when differential-gain measurements indicate no trouble. When this distortion is present, close observation of the higher frequency burst will reveal that the axes of some or all of these bursts are shifted vertically by varying amounts, as in Fig. 5-150. As mentioned above, the distorted wave contains a d-c or, in the case of a video-type signal because of the horizontal scanning frequency, a 15,750-cycle component and harmonics of the distorted burst. For frequencies above about 2.5 to 3.0 Mc, most transmission facilities cut out the burst harmonics, leaving only the 15,750-cycle component and the fundamental frequency. This 15,750-cycle component will shift the axis of the multiburst through the burst in question. For frequencies whose second or higher harmonics are passed by the system, the axis shift is not so pronounced, but an expansion of the wave will show distortion, as on the 500-kc burst illustrated in Fig. 5-149. This shiftiug of the axis of the bursts has sometimes been called "rectification" because of the production of the effective d-c component. Figure 5-151 is the same signal as Fig. 5-150, but in this case the signal has been put through a low-pass filter which effectively eliminates the higher frequency bursts and makes the axis shift more evident.

Halo (Fig. 5-152)

Halo usually is the appearance of a black border around unusually bright objects in a televised scene. As shown in Fig. 5-152, the border may be irregular in size and shape but is easily distinguished from streaking and smearing. It is caused by overloading of the pickup tube in scanning bright objects. While the accompanying figure indicates halo around an object occupying a large part of the viewing screen, it also is commonly noticed when stage lights are reflected from jewelry, eyeglasses, and other small objects. With certain camera tube operating adjustments, a white area may surround dark objects.

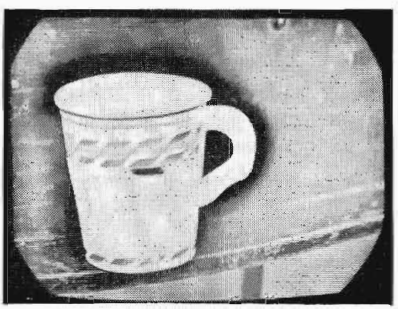


FIG. 5-152. Halo.

Moiré (Figs. 5-153 and 5-154)

Mesh beat, or moiré effect, is the appearance of vertical or diagonal lines on a picture which resemble high-frequency interference. In Fig. 5-153, these lines are most noticeable across the top and bottom of the kitchen cabinet close-up. This difficulty may be caused by image-orthicon cameras where a beat is obtained between the scanning signal and the screen, or mesh, associated with the target plate.

Moiré pattern is also a natural optical effect when scanning closely spaced picture lines which are almost horizontal. It is evident on the horizontal wedges of the test pattern shown in Fig. 5-154 (which is a reprint of Fig. 5-137, Impulse Noise).

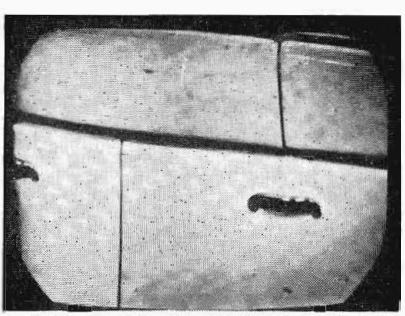


FIG. 5-153. Moiré.

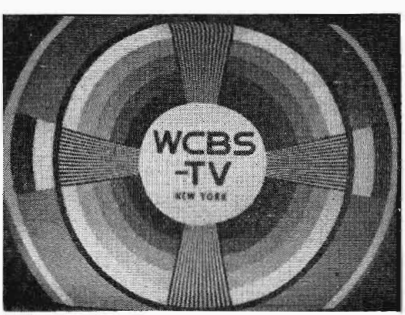


FIG. 5-154. Moiré.

Burned-in Image (Figs. 5-155 and 5-156)

A burned-in image is one which persists in the camera output signal when the camera has been focused on another scene. Figure 5-155 illustrates the case of a camera having been shifted to one side of a prompting chart, with the original image still visible to the right of the new one. Figure 5-156 shows a burned-in image of the RETMA test pattern, originally being viewed, superimposed on a close-up of a stove top and grillwork. This phenomenon is associated with orthicon camera tubes where the persistence of the burned-in image depends upon the length of time that the camera is focused on the original scene and the brightness of the scene. It may last as long as several minutes in extreme cases.

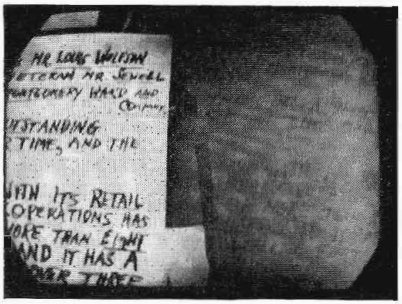


FIG. 5-155. Burned-in image.

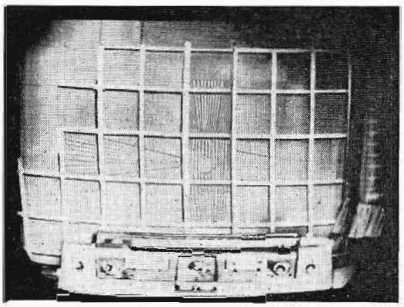


FIG. 5-156. Burned-in image.

Color-signal Impairments

In general, color-television signals are subject to the same impairments as monochrome transmissions. However, color-television signals may be impaired seriously by additional conditions that might not affect a monochrome picture.

High or Low Chrominance-signal Level

When the chrominance-signal component of a color-television signal is received at too high a level, colors will increase in saturation; when this component is received at too low a level, colors will tend to wash out. So long as overloading or differential gain is not controlling, the proper relationship in saturation between various hues will be maintained.

A high or low chrominance-signal level occurring when luminance-signal levels are normal would result from excess gain or loss at the upper portion of the video-signal frequency spectrum.

Since the color burst has the same frequency as the color subcarrier, any transmission characteristic affecting the amplitude of the chrominance signal will usually also affect the amplitude of the color burst (Figs. 5-157 and 5-158). For rapid location of large deviations it is possible, using an A scope with a wideband characteristic, to observe the color-signal waveform for comparison of color burst and sync pulse amplitudes, which should be the same. However, a comparative measurement of color-burst amplitudes is necessary for more precise locations.

Because results can be expressed quantitatively, A-scope location of impairments can usually be made more accurately and rapidly than would be possible using color monitors, although color monitors can be used also for verification.

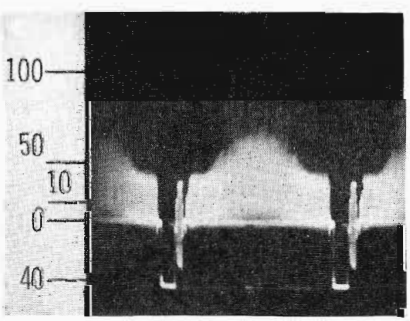


FIG. 5-157. High-level chrominance signal—horizontal.

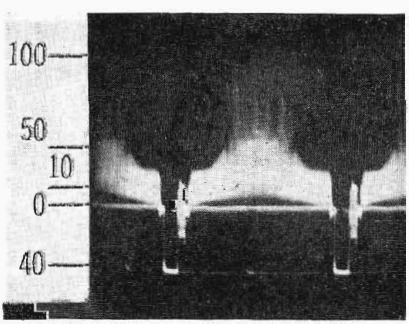


FIG. 5-158. Low-level chrominance signal—horizontal.

Loss of Color

In the general case this is caused by very low chrominance-signal level. However, such a condition has occurred with an apparently normal color burst, as viewed on an A scope. In this case, the frequency of the apparent color burst has been shifted from the normal 3.6-Mc value during transmission. Color monitors are required for quick location in such cases.

Differential Phase Distortion (Figs. 5-159 and 5-161)

Differential phase is the change in phase of the 3.6-Mc color subcarrier as the level of the luminance signal on which it rides is varied from blanking to white. It causes error in portrayal of hues. Figures 5-159 and 5-161 illustrate large amounts of differential phase of opposite signs, as compared to Fig. 5-160 which is a "normal" picture.

In FM radio relay systems, this distortion is usually caused by a nonuniform delay-frequency characteristic in the IF equipment, where varying amplitudes of input signal are represented by varying frequencies. The color burst is always at blanking level and, therefore, will always swing about the same frequency on the radio relay system. Color components of the signal generally are not at blanking level; therefore, the FM swing will be about a different frequency and any difference in delay between the two results in differential phase. In telephone company systems, delay equalizers in IF paths are used to correct for differential phase.

In addition to FM radio systems, differential phase distortion may be experienced in any equipment having transmission paths that vary in phase with level. Hue impairments are observable in color picture monitors, but are not apparent in either monochrome picture monitors or in A scopes. Color monitors are neither sufficiently precise nor stable to use as a basis for correction of differential phase, and it is therefore necessary to release facilities from service in order to make differential phase measurements. The 47A transmission-measuring system is used for proper adjustment of differential phase equalizers.

Differential Gain Distortion

In color-television transmission, differential gain is the change in gain of the 3.6-Mc color subcarrier as the level of the luminance signal on which it rides is varied from blanking to white. It causes error in color saturation of the received picture.

Differential gain is generally observed as signal compression as luminance levels are increased, although expansion can be experienced. The effects of differential gain may be observable in color monitors, depending upon degree. Severe cases of such signal impairment should be evidenced in the A-scope presentation of a color-bar test signal as an overloading or expansion condition of the chrominance components. Other than for severe conditions of this type, the facility or equipment to be tested must be released from service for differential-gain tests to enable location of causative facility sections.

When excess differential gain is experienced, the first step is to assure that proper amplitude levels have been maintained. Further investigation would include location of the portions of the layout or piece of equipment contributing appreciably to this condition. Clearance is then generally accomplished by replacement of tubes or other defective components.

Leading or Lagging Chrominance

When the chrominance signal is not received at the same time as the luminance signal, colors will appear in the color-picture monitor to either one side or the other of the image. For example, a blob of red may occur at lip level to one side or the other of a face. Since the synchronizing of the color signal is governed by the color

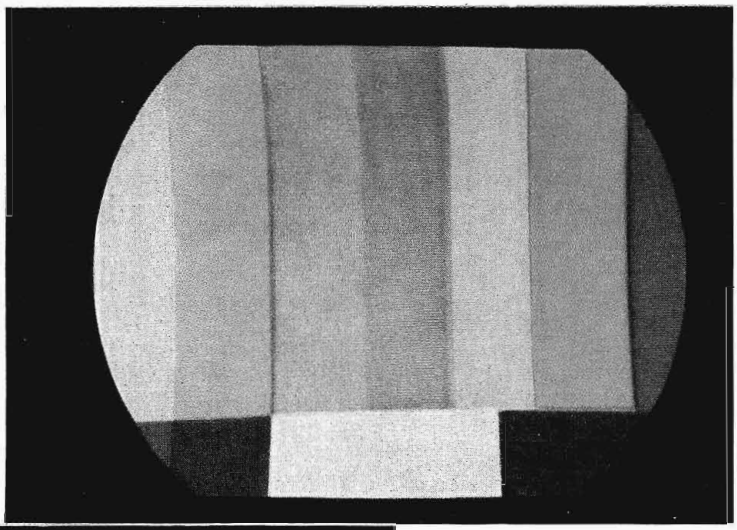


FIG. 5-159. Color-bar signal—yellow shifted toward red.

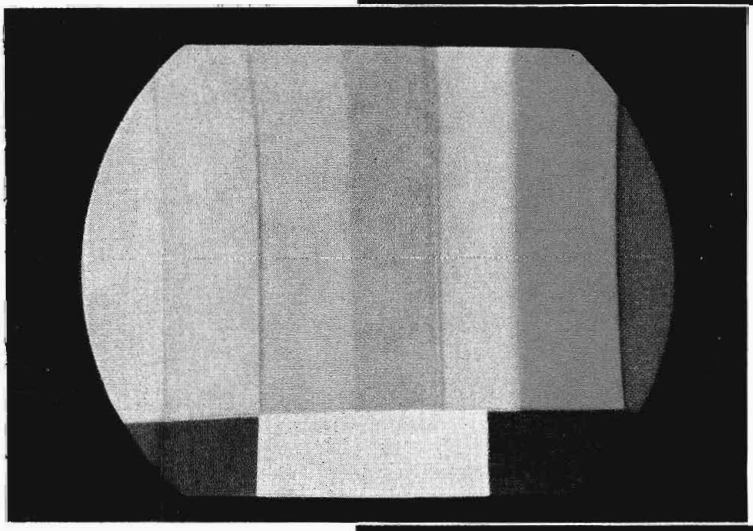


FIG. 5-160. Color-bar signal—normal phase.

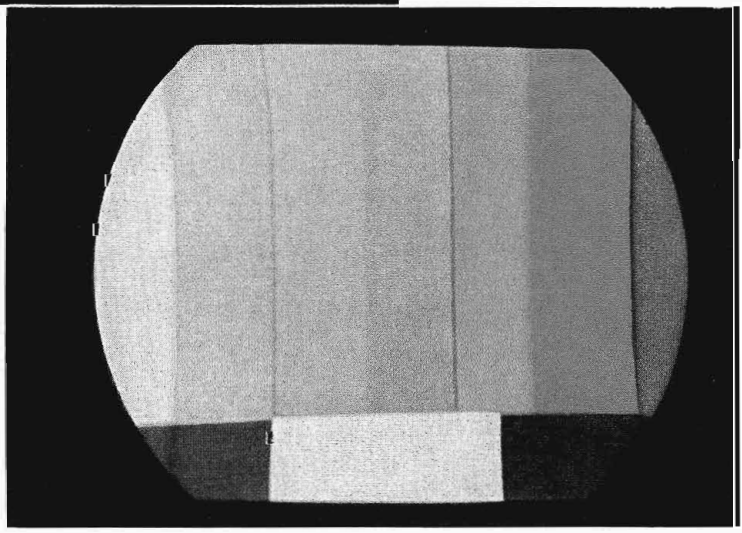


FIG. 5-161. Color-bar signal—yellow shifted toward green.

burst, observation of an A scope having wideband characteristic will reveal whether the color burst has been shifted from normal position in the back-porch interval. A shift to the left results in leading chrominance information. When severe, this impairment might be observed as edge effect on monochrome pictures transmitted over the same facility.

This condition can result from improper delay relationship between the lower and the upper portions of the frequency spectrum over transmission facilities or through equipment. Therefore, envelope-delay characteristics of television layouts in color condition should be checked if leading or lagging chrominance is experienced.

GLOSSARY OF TELEVISION TERMS

General

This glossary defines various terms presently used in the line-up, operation, and maintenance of video transmission systems. Experience in providing video service has indicated that a common understanding and use of the terms outlined in this section by the telephone companies and the broadcasting companies is desirable. Because these terms are intended for practical use by operating personnel, they may differ somewhat in wording from published standards, which are not so well suited for the intended purpose.

Terms and Definitions

ASPECT RATIO: The numerical ratio of picture width to height.

BACK PORCH: That portion of the composite picture signal which lies between the trailing edge of the horizontal sync pulse and the trailing edge of the corresponding blanking pulse.

BACK-PORCH TILT: The slope of the back porch from its normal horizontal position. Positive or negative refer, respectively, to upward or downward tilt to the right.

BANDWIDTH: The number of cycles per second expressing the difference between the limiting frequencies of a frequency band. For example, the 2.5- to 3.5-Mc band has a width of 1 Mc.

BLACK COMPRESSION: Amplitude compression of the signals corresponding to the black regions of the picture, thus modifying the tonal gradient.

BLACK PEAK: The maximum excursion of the picture signal in the black direction at the time of observation.

BLACKER-THAN-BLACK: The amplitude region of the composite video signal below reference-black level in the direction of the synchronizing pulses.

BLANKING (PICTURE): The portion of the composite video signal whose instantaneous amplitude makes the vertical and horizontal retrace invisible.

BLANKING LEVEL: The level of the front and back porches of the composite video signal.

BLEEDING WHITES: An overloading condition in which white areas appear to flow irregularly into black areas.

BLOOMING: The defocusing of regions of the picture where the brightness is at an excessive level owing to enlargement of spot size and halation of the fluorescent screen of the cathode-ray picture tube.

BOUNCE: An unnatural sudden variation in the brightness of the picture.

BREATHING: Amplitude variations similar to "bounce" but at a slow regular rate.

BREEZEWAY: In NTSC color, that portion of the back porch between the trailing edge of the sync pulse and the start of the color burst.

BURNED-IN IMAGE: An image which persists in a fixed position in the output signal of a camera tube after the camera has been turned to a different scene.

CAMERA TUBE: See Pickup Tube.

CATHODE-RAY TUBE: An electron-tube assembly containing an electron gun arranged to direct a beam upon a fluorescent screen. Scanning by the beam can produce light at all points in the scanned raster.

CHROMINANCE SIGNAL: That portion of the NTSC color-television signal which contains the color information.

CLAMPER: A device which functions during the horizontal blanking or sync interval to fix the level of the picture signal at some predetermined reference level at the beginning of each scanning line.

CLAMPING: The process that establishes a fixed level for the picture signal at the beginning of each scanning line.

CLIPPING: The shearing off of the peaks of a signal. For a picture signal this may affect either the positive (white), or negative (black) peaks. For a composite video signal, the sync signal may be affected.

COLOR BURST: In NTSC color, normally refers to a burst of approximately 9 cycles of 3.6-Mc subcarrier on the back porch of the composite video signal. This serves as a color-synchronizing signal to establish a frequency and phase reference for the chrominance signal.

COLOR SUBCARRIER: In NTSC color, the carrier whose modulation sidebands are added to the monochrome signal to convey color information, i.e., 3.6 Mc (3.579545 Mc).

COLOR TRANSMISSION: The transmission of a signal which represents both the brightness values and the color (chrominance) values in a picture.

COMPOSITE VIDEO SIGNAL: The complete video signal. For monochrome, it consists of the picture signal and the blanking and synchronizing signals. For color, additional color-synchronizing signals and color-picture information are added.

COMPRESSION: An undesired decrease in amplitude of a portion of the composite video signal relative to that of another portion. Also, a less than proportional change in output of a circuit for a change in input level. For example, compression of the sync pulse means a decrease in the percentage of sync during transmission.

CONTRAST: The range of light and dark values in a picture or the ratio between the maximum and minimum brightness values. For example, in a high-contrast picture there would be intense blacks and whites whereas a low-contrast picture would contain only various shades of gray.

CROSS TALK: An undesired signal interfering with the desired signal.

CUTOFF FREQUENCY: That frequency beyond which no appreciable energy is transmitted. It may refer to either an upper or lower limit of a frequency band.

DAMPED OSCILLATION: Oscillation which, because the driving force has been removed, gradually dies out, each swing being smaller than the preceding in smooth, regular decay.

DEFINITION: See Resolution (Horizontal) and Resolution (Vertical).

DELAY DISTORTION: Distortion resulting from nonuniform speed of transmission of the various frequency components of a signal; i.e., the various frequency components of the signal have different times of travel (delay) between the input and the output of a circuit.

DETAIL: Refers to the most minute elements in a picture which are distinct and recognizable. Similar to definition or resolution.

DIFFERENTIAL GAIN: The amplitude change, usually of the 3.6-Mc color subcarrier, introduced by the over-all circuit, measured in decibels or per cent, as the subcarrier is varied from blanking to white level.

DIFFERENTIAL PHASE: The phase change of the 3.6-Mc color subcarrier introduced by the over-all circuit, measured in degrees, as the subcarrier is varied from blanking to white level.

DISPLACEMENT OF POUCHES: Refers to any difference between the level of the front porch and the level of the back porch.

DISTORTION: The departure, during transmission or amplification, of the received-signal waveform from that of the original transmitted waveform.

DRIVING SIGNALS: Signals that time the scanning at the pickup device.

ECHO (OR REFLECTION): A wave which has been reflected at one or more points in the transmission medium with sufficient magnitude and time difference to be perceived in some manner as a wave distinct from that of the main or primary transmission. Echoes may be either leading or lagging the primary wave and appear in the picture monitor as reflections, or "ghosts."

EDGE EFFECT: See Following or Leading White and Following or Leading Black.

EQUALIZING PULSES: Pulses of one-half the width of the horizontal sync pulses which are transmitted at twice the rate of the horizontal sync pulses during the blanking intervals immediately preceding and following the vertical sync pulses. The action of these pulses causes the vertical deflection to start at the same time in each interval and also serves to keep the horizontal-sweep circuits in step during the vertical blanking intervals immediately preceding and following the vertical sync pulse.

EXPANSION: An undesired increase in amplitude of a portion of the composite video signal relative to that of another portion. Also, a greater than proportional change in the output of a circuit for a change in input level. For example, expansion of the sync pulse means an increase in the percentage of sync during transmission.

FIELD: One-half of a complete picture (or frame) interval, containing all the odd or even scanning lines of the picture.

FIELD FREQUENCY: The rate at which a complete field is scanned, nominally 60 times a second.

FLASH: Momentary interference to the picture of a duration of approximately one field or less and of sufficient magnitude totally to distort the picture information. In general, this term is used alone when the impairment is of such short duration that the basic impairment cannot be recognized. Sometimes called "hit."

FLYBACK: See Horizontal Retrace.

FOLLOWING (OR TRAILING) BLACKS: A term used to describe a picture condition in which the edge following a white object is overshaded toward black. The object appears to have a trailing black border. Also called "trailing reversal."

FOLLOWING (OR TRAILING) WHITES: A term used to describe a picture condition in which the edge following a black or dark gray object is shaded toward white. The object appears to have a trailing white border. Also called "trailing reversal."

FRAME: One complete picture consisting of two fields of interlaced scanning lines.

FRAME FREQUENCY: The rate at which a complete frame is scanned, nominally 30 frames per second.

FRONT PORCH: That portion of the composite picture signal which lies between the leading edge of the horizontal blanking pulse and the leading edge of the corresponding sync pulse.

FRAME ROLL: A momentary roll.

GAIN-FREQUENCY DISTORTION: Distortion which results when all the frequency components of a signal are not transmitted with the same gain or loss. A departure from "flatness" in the gain-frequency characteristic of a circuit.

GHOST: A shadowy or weak image in the received picture, offset to either the left or right of the primary image, the result of transmission conditions which create secondary signals that are received earlier or later than the main or primary signal. A ghost displaced to the left of the primary image is designated as "leading," and one displaced to the right is designated as "following" (lagging). When the tonal variations of the ghost are the same as the primary image, it is designated as "positive," and when it is the reverse, it is designated as "negative."

GLITCH: A form of low-frequency interference appearing as a narrow horizontal bar moving vertically through the picture. This is also observed on an oscilloscope at field or frame rate as an extraneous voltage pip moving along the signal at approximately reference-black level.

HALO: Most commonly, a dark area surrounding an unusually bright object, caused by overloading of the camera tube. Reflection of studio lights from a piece of jewelry, for example, might cause this effect. With certain camera tube operating adjustments, a white area may surround dark objects.

HEIGHT: The size of the picture in a vertical direction.

HIGH-FREQUENCY DISTORTION: Distortion effects which occur at high frequency. Generally considered as any frequency above the 15.75-kc line frequency.

HIGH-FREQUENCY INTERFERENCE: Interference effects which occur at high frequency. Generally considered as any frequency above the 15.75-kc line frequency.

HIGHLIGHTS: The maximum brightness of the picture, which occurs in regions of highest illumination.

HIT: See Flash.

HORIZONTAL BLANKING: The blanking signal at the end of each scanning line.

HORIZONTAL DISPLACEMENTS: Describes a picture condition in which the scanning lines start at relatively different points during the horizontal scan. See Serrations and Jitter.

HORIZONTAL RETRACE: The return of the electron beam from the right to the left side of the raster after the scanning of one line.

HORIZONTAL (HUM) BARS: Relatively broad horizontal bars, alternately black and white, which extend over the entire picture. They may be stationary or may move up or down. Sometimes referred to as a "venetian-blind" effect. Caused by approximate 60-cycle interfering frequency or one of its harmonic frequencies.

HUE: Corresponds to "color" in everyday use, i.e., red, blue, etc. Black, white, and gray do not have hue.

ICONOSCOPE: A camera tube in which a high-velocity electron beam scans a photoemissive mosaic which has electrical-storage capability.

INTERFERENCE: In a signal-transmission path, extraneous energy which tends to interfere with the reception of the desired signals.

INTERLACED SCANNING (INTERLACE): A scanning process in which each adjacent line belongs to the alternate field.

ION: A charged atom, usually an atom of residual gas in an electron tube.

ION SPOT: A spot on the fluorescent surface of a cathode-ray tube which is somewhat darker than the surrounding area because of bombardment by negative ions which reduce the sensitivity.

ION TRAP: An arrangement of magnetic fields and apertures which will allow an electron beam to pass through but will obstruct the passage of ions.

IRE: The Institute of Radio Engineers.

IRE ROLL-OFF: The IRE standard oscilloscope frequency-response characteristic for measurement of level. This characteristic is such that at 2 Mc the response is approximately 3.5 db below that in the flat (low-frequency) portion of the spectrum and cuts off slowly.

IRE SCALE: An oscilloscope scale in keeping with IRE Standard 50, IRE 23.S., and the recommendations of the Joint Committee of TV Broadcasters and Manufacturers for Coordination of Video Levels.

JITTER: A tendency toward lack of synchronization of the picture. It may refer to individual lines in the picture or to the entire field of view.

KINESCOPE: Frequently used to mean picture tubes in general. However, this name has been copyrighted.

KINESCOPE RECORDING: A motion-picture-film recording of the presentation shown by a picture monitor. Also known as television recording (TVR), Vitapix, etc.

LEADING BLACKS: A term used to describe a picture condition in which the edge preceding a white object is overshaded toward black. The object appears to have a preceding or leading black border.

LEADING WHITES: A term used to describe a picture condition in which the edge preceding a black object is shaded toward white. The object appears to have a preceding or leading white border.

LINE FREQUENCY: The number of horizontal scans per second, nominally 15,750 times per second.

LOW-FREQUENCY DISTORTION: Distortion effects which occur at low frequency. Generally considered as any frequency below the 15.75-kc line frequency.

LOW-FREQUENCY INTERFERENCE: Interference effects which occur at low frequency. Generally considered as any frequency below the 15.75-kc line frequency.

LUMINANCE SIGNAL: That portion of the NTSC color-television signal which contains the luminance or brightness information.

MESH BEAT: See Moiré.

MICROPHONICS: In video transmission, refers to the mechanical vibration of the elements of an electron tube resulting in a spurious modulation of the normal signal. This usually results in erratically spaced horizontal bars in the picture.

MICROSECOND: One-millionth of a second.

MOIRÉ: A wavy or satiny effect produced by convergence of lines. Usually appears as a curving of the lines in the horizontal wedges of the test pattern and is most pronounced near the center where the lines forming the wedges converge. A moiré pattern is a natural optical effect when converging lines in the picture are nearly parallel to the scanning lines. This effect to a degree is sometimes due to the characteristics of color picture tubes and of image-orthicon pickup tubes (in the latter termed "mesh beat").

MONOCHROME TRANSMISSION (BLACK AND WHITE): The transmission of a signal wave which represents the brightness values in the picture but not the color (chrominance) values in the picture.

MULTIPLE BLANKING LINES: Evidenced by a thickening of the blanking-line trace or by several distinct blanking lines as viewed on an oscilloscope. May be caused by bum.

NEGATIVE IMAGE: Refers to a picture signal having a polarity which is opposite to normal polarity and which results in a picture in which the white areas appear as black and vice versa.

NTSC: National Television System Committee.

NOISE: The word "noise" is a carry-over from audio practice. Refers to random spurts of electrical energy or interference. May produce a "salt-and-pepper" pattern over the picture. Heavy noise sometimes is called "snow."

ORTHICON (CONVENTIONAL): A camera tube in which a low-velocity electron beam scans a photoemissive mosaic on which the image is focused optically and which has electrical-storage capability.

ORTHICON (IMAGE): A camera tube in which the optical image falls on a photoemissive cathode which emits electrons that are focused on a target at high velocity. The target is scanned from the rear by a low-velocity electron beam. Return beam modulation is amplified by an electron multiplier to form an over-all light-sensitive device.

ORTHICON EFFECT: One or more of several image-orthicon impairments that have been referred to as "orthicon effect" as follows:

1. Edge effect
2. Mesh beat or moiré
3. Ghost

4. Halo
5. Burned-in image

It is obviously necessary to indicate specifically the effect or effects experienced, and therefore, it is recommended that use of this term be discontinued.

OVERSHOOT: An excessive response to an unidirectional signal change. Sharp overshoots are sometimes referred to as "spikes."

PAIRING: A partial or complete failure of interlace in which the scanning lines of alternate fields do not fall exactly between one another but tend to fall (in pairs) one on top of the other.

PEAK TO PEAK: The amplitude (voltage) difference between the most positive and the most negative excursions (peaks) of an electrical signal.

PEDESTAL: This term is obsolete.

PEDESTAL LEVEL: This term is obsolete; "blanking level" is preferred.

PERCENTAGE SYNC: The ratio, expressed as a percentage, of the amplitude of the synchronizing signal to the peak-to-peak amplitude of the picture signal between blanking and reference-white level.

PHOTOEMISSIVE: Emitting or capable of emitting electrons upon exposure to radiation in and near the visible region of the spectrum.

PICKUP TUBE: An electron-beam tube used in a television camera where an electron current or a charge-density image is formed from an optical image and scanned in a predetermined sequence to provide an electrical signal.

PICTURE MONITOR: This refers to a cathode-ray tube and its associated circuits arranged to view a television picture.

PICTURE SIGNAL: That portion of the composite video signal which lies above the blanking level and contains the picture information.

PICTURE TUBE: A cathode-ray tube used to produce an image by variation of the intensity of a scanning beam.

PIGEONS: Noise observed on picture monitors as pulses or bursts of short duration at a slow rate of occurrence—a type of impulse noise.

POLARITY OF PICTURE SIGNAL: Refers to the polarity of the black portion of the picture signal with respect to the white portion of the picture signal. For example, in a "black negative" picture, the potential corresponding to the black areas of the picture is negative with respect to the potential corresponding to the white areas of the picture, while in a "black positive" picture the potential corresponding to the black areas of the picture is positive. The signal as observed at broadcasters' master control rooms and telephone company television operating centers is "black negative."

PREEMPHASIS (PREDISTORTION). A change in level of some frequency components of the signal with respect to the other frequency components at the input to a transmission system. The high-frequency portion of the band is usually transmitted at higher level than the low-frequency portion of the band.

RASTER: The scanned (illuminated) area of the cathode-ray picture tube.

REFERENCE BLACK LEVEL: The level corresponding to the specified maximum excursion of the luminance signal in the black direction.

REFERENCE WHITE LEVEL: The level corresponding to the specified maximum excursion of the luminance signal in the white direction.

REFLECTIONS OR ECHOES: In video transmission this may refer either to a signal or to the picture produced.

1. Signal:
   a. Waves reflected from structures or other objects
   b. Waves which are the result of impedance or other irregularities in the transmission medium
2. Pictures: "Echoes" observed in the picture produced by the reflected waves.

RESOLUTION (HORIZONTAL): The amount of resolvable detail in the horizontal direction in a picture. It is usually expressed as the number of distinct vertical lines, alternately black and white, which can be seen in three-quarters of the width of the picture. This information usually is derived by observation of the vertical wedge of a test pattern. A picture which is sharp and clear and shows small details has good, or high, resolution. If the picture is soft and blurred and small details are indistinct, it has poor, or low, resolution. Horizontal resolution depends upon the high-frequency amplitude and phase response of the pickup equipment, the transmission medium, and the picture monitor as well as the size of the scanning spots.

RESOLUTION (VERTICAL): The amount of resolvable detail in the vertical direction in a picture. It is usually expressed as the number of distinct horizontal lines, alternately black and white, which can be seen in a test pattern. Vertical resolution is primarily fixed by the number of horizontal scanning lines per frame. Beyond this, vertical resolution depends on the size and shape of the scanning spots of the pickup equipment and picture

monitor and does not depend upon the high-frequency response or bandwidth of the transmission medium or picture monitor.

RESTORER: As used by the telephone company, a network designed to remove the effects of predistortion or preemphasis, thereby resulting in an over-all normal characteristic.

RETMA: Abbreviation for Radio Electronic Television Manufacturers Association.

RETRACE (RETURN TRACE): See Horizontal and Vertical Retrace.

RF PATTERN: A term sometimes applied to describe a fine herringbone pattern in a picture. May also cause a slight horizontal displacement of scanning lines resulting in a rough or ragged vertical edge of the picture. Caused by high-frequency interference.

RINGING: An oscillatory transient occurring in the output of a system as a result of a sudden change in input. Results in close-spaced multiple reflections, particularly noticeable when observing test patterns, equivalent square waves, or any fixed objects whose reproduction requires frequency components approximating the cutoff of the system.

ROLL: A lack of vertical synchronization which causes the picture as observed on the picture monitor to move upward or downward.

ROLL-OFF: A gradual attenuation of gain-frequency response at either or both ends of the transmission passband.

SATURATION (COLOR): The "vividness" of a color described by such terms as pale, deep, pastel, etc. The greater the amplitude of the chrominance signal, the greater the saturation.

SCANNING: The process of breaking down an image into a series of elements or groups of elements representing light values and transmitting this information in time sequence.

SCANNING LINE: A single continuous narrow strip of the picture area containing highlights, shadows, and half tones, determined by the process of scanning.

SCANNING SPOT: Refers to the cross section of an electron beam at the point of incidence in a camera tube or picture tube.

SERRATED PULSES: A series of equally spaced pulses within a pulse signal. For example, the vertical sync pulse is serrated in order to keep the horizontal-sweep circuits in step during the vertical sync-pulse interval.

SERRATIONS: This is a term used to describe a picture condition in which vertical or nearly vertical lines have a sawtooth appearance. The result of scanning lines starting at relatively different points during the horizontal scan.

SETUP: The separation in level between blanking and reference-black levels.

SMEAR: A term used to describe a picture condition in which objects appear to be extended horizontally beyond their normal bonndaries in a blurred, or "smeared," manner.

SNOW: Heavy random noise.

SPIKE: See Overshoot.

STREAKING: A term used to describe a picture condition in which objects appear to be extended horizontally beyond their normal boundaries. This will be more apparent at vertical edges of objects when there is a large transition from black to white or white to black. The change in luminance is carried beyond the transition and may be either negative or positive. For example, if the tonal degradation is an opposite shade to the original figure (white following black), the streaking is called negative; however, if the shade is the same as the original figure (white following white), the streaking is called positive. Streaking is usually expressed as short, medium, or long streaking. Long streaking may extend to the right edge of the picture and, in extreme cases of low-frequency distortion, can extend over a whole line interval.

SYNCHRONIZATION: The maintenance of one operation step with another.

SYNC: An abbreviation for the words "synchronization," "synchronizing," etc. Applies to the synchronization signals, or timing pulses, which lock the electron beam of the picture monitors in step, both horizontally and vertically, with the electron beam of the pickup tube. The color sync signal (NTSC) is known as the color burst.

SYNC COMPRESSION: The reduction in the amplitude of the sync signal, with respect to the picture signal, occurring between two points of a circuit.

SYNC LEVEL: The level of the tips of the synchronizing pulses.

TEARING: A term used to describe a picture condition in which groups of horizontal lines are displaced in an irregular manner. Caused by lack of horizontal synchronization.

TELEVISION RECORDING (TVR): See Kinescope Recording.

TRANSIENTS: Signals which endure for a brief time prior to the attainment of a steady-state condition. These may include overshoots, damped sinusoidal waves, etc., and therefore, additional qualifying information is necessary.

VERTICAL BLANKING: Refers to the blanking signals which occur at the end of each field.

VERTICAL RETRACE: The return of the electron beam from the bottom to the top of the raster after completion of each field.

VESTIGIAL-SIDEBAND TRANSMISSION: A system of transmission wherein the sideband on one side of the carrier is transmitted only in part.

VIDEO: A term pertaining to the bandwidth and spectrum position of the signal which results from television scanning and which is used to reproduce a picture.

VIDEO BAND: The frequency band utilized to transmit a composite video signal.

VIDEO-IN-BLACK: A term used to describe a condition as seen on the waveform monitor when the black peaks extend through reference-black level.

WAVEFORM MONITOR: This refers to a cathode-ray oscilloscope used to view the form of the composite video signal for waveform analysis. Sometimes called "A scope."

WHITE COMPRESSION: Amplitude compression of the signals corresponding to the white regions of the picture, thus modifying the tonal gradient.

WHITE PEAK: The maximum excursion of the picture signal in the white direction at the time of observation.

WIDTH: The size of the picture in a horizontal direction.

Degrees of Impairments

Television picture impairments may be present in varying degrees. In the case of oscilloscope presentations, most impairments can best be described to remote points by indicating the IRE scale readings of the various signal components. In the case of picture-monitor presentations, however, impairments generally must be described in qualitative terms rather than quantitative terms, and the exchange of intelligence between remote observers is more complicated. The following descriptive terms, without a sharp line of demarcation being possible, are in common usage for indicating the magnitude of impairments:

DETECTABLE: Impairment is not readily noticeable in a normal picture or oscilloscope display but can be discerned by a minute inspection of the signal, it sometimes being necessary to vary picture-monitor brightness or expand oscilloscope presentations.

NOTICEABLE: Impairment is readily observed.

OBJECTIONABLE: Impairment interferes with the viewing of the picture.

UNCOMMERCIAL: Impairment is present to such degree that the program or portion of the program is not broadcast.

Section 5

COLOR-TELEVISION FACILITIES

INTRODUCTION TO SECTION 5

This section of the handbook has been reproduced through the courtesy of the Radio Corporation of America who kindly permitted us to use portions of their "Color Television, Manual for Technical Training."

Obviously, the material contained herein is not a complete treatment of the subject but covers only the aspects which are considered to be of fundamental importance to an understanding of the system. Further reference to the RCA "Manual for Technical Training," as well as such publications as "Color Television Engineering," by John W. Wentworth, Manager, Television Terminal Engineering, RCA Engineering Products Division, and other worthy treatises on the subject, is recommended.

In view of the deletion of certain portions of the reference material, minor editorial changes have been made to provide continuity.

Part 1

COLOR FUNDAMENTALS

Color is a new dimension that has been added skillfully to black-and-white television. To the engineering fraternity as a whole it signifies one of the most dramatic technological achievements of this age.

Nearly every branch of science including chemistry and psychology contributes in some way to the reality of color television. Through chemistry, improved phosphors are continually being found for use in color-picture tubes. Psychology enters into the selection of lighting arrangements and picture composition to obtain desirable interpretations by the viewer. But physics plays the leading role with intense application in optics and illumination as well as in the design of electronic circuitry and components for the complete television system.

Two specialized branches of physics, namely, radio and television engineering, are responsible for the electronic techniques which make color television "compatible" with black-and-white, or monochrome, television, marking what is probably the greatest technical advance in television in the past decade.

COMPATIBILITY

The compatible color system offers tremendous economic advantages to the home viewer as well as to the television broadcaster. Because of compatibility, color telecasts can be seen (in monochrome) on existing television receivers without any changes or added devices. Also, color receivers can receive monochrome as well as color telecasts. Since compatible color is transmitted over the same channels as monochrome and within the same framework of standards, the television broadcaster can utilize his monochrome system as the transmitting nucleus when installing equipment to broadcast color. Moreover, he can utilize his color equipment to produce monochrome telecasts.

Another important advantage of the compatible color system is the part it plays in the conservation of the radio-frequency spectrum. Compatible color requires no additional space in the spectrum. However, it employs techniques which make much more efficient use of the standards originally set up for monochrome television.

A brief review of the fundamentals of monochrome television, particularly the areas wherein specialized color methods are employed, is presented in the next few paragraphs as an aid in describing the basic color concepts.[1]

TELEVISION—A SYSTEM OF COMMUNICATIONS

Basically, television is a system of communications consisting of the television station at one end of the system and the television receiver at the other. As such, it is actually one of the highest capacity systems in use today, being able to transmit from station to receiver more than five million "bits" of picture information every second.

[1] For detailed information on the theory and operation of monochrome television broadcast equipment, reference should be made to the RCA "Manual for Television Technical Training," Form No. 2J 8172.

Very simply, the function of the television station is to divide and subdivide the optical image into over 200,000 picture elements, each of different light intensity; convert these light elements to electrical equivalents; and transmit them in orderly sequence over a radio-frequency carrier to the television receiver.

Reversing this process at the receiver, these electrical signals are each converted to light of corresponding brightness and reassembled to produce the transmitted image on the face of the picture tube.

Scanning

Picture elements to be transmitted in sequence are selected by a process of image scanning which takes place in the television camera focused on the studio scene at the station. Within the camera, an electron beam in a pickup tube scans a sensitive

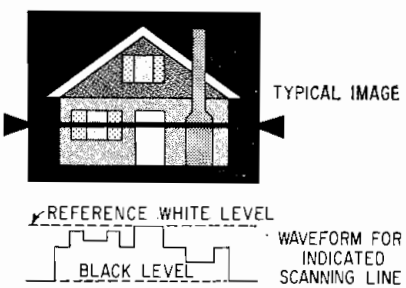


FIG. 1-1. Typical image and camera output waveform produced by light and dark areas during one scan along line indicated by arrows.

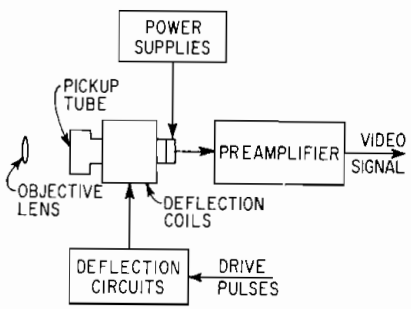


FIG. 1-2. Block diagram of monochrome-camera circuits.

surface containing an "electrical image" of the scene of action. The electron beam successively scans the image at great velocity, beginning at the upper left corner and continuing from left to right in a series of parallel lines to scan the image completely. Movement of the electron beam, which is controlled magnetically by vertical- and horizontal-deflection coils surrounding the tube, is analogous to that of the eye in reading a printed page. The speed of movement is such, however, that 30 complete image frames of approximately 500 lines each are scanned every second. Of course,

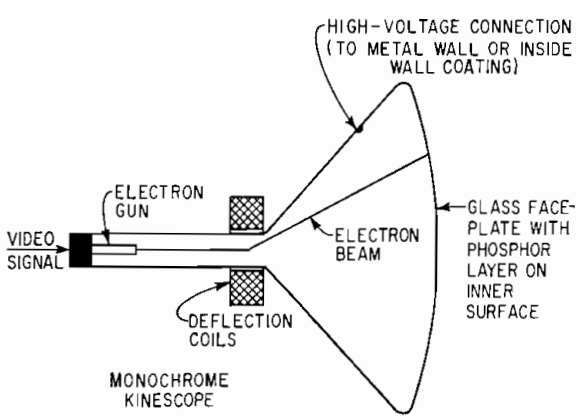


FIG. 1-3. Diagram showing principal elements of the monochrome kinescope picture tube.

at the receiver, an electron beam in the kinescope, or picture tube, moves with the same speed and in synchronism with the camera-tube beam so that the corresponding picture elements appear in the proper relative position on the television screen.

Owing to "persistence of vision" and the speed of scanning, these elements appear to be seen all at once as a complete image rather than individually. Thus, the impression is one of continuous illumination of the screen and direct vision.

Scanning standards have been established in this country to assure that all television receivers are capable of receiving programs broadcast by any television station within range. The scanning pattern adhered to by manufacturers in the design of television receivers and broadcast equipment consists of 525 lines with odd-line interlaced scanning. Interlaced scanning, effective in eliminating perceptible flicker, is a method whereby the electron beam scans alternate rather than successive lines.

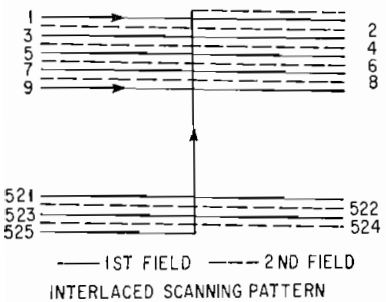


FIG. 1-4. Diagram showing paths of the electron beam in both the pickup tube and kinescope to produce the interlaced scanning pattern.

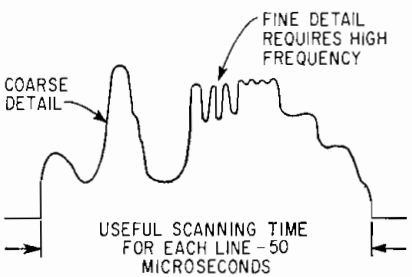


FIG. 1-5. Diagram illustrating the relationship between picture detail and signal bandwidth.

For example, the beam begins by scanning the odd-numbered lines (1, 3, 5, 7, etc.) until it reaches the bottom of the image, whereupon it returns to the top of the image to scan the even-numbered lines (2, 4, 6, 8, etc.). Thus, each scan, or field, comprises only half the total number of scanning lines, and two fields are required to produce the 525-line frame. Each field is completed in one-half the frame time. The vertical scanning frequency is 2×30 or 60 cps, and the horizontal scanning frequency is 30×525, or 15,750 cps.

Resolution and Bandwidth

The degree of resolution, or fine detail, that can be seen in a televised image depends upon the number of scanning lines used and the bandwidth of the transmitting and receiving system.

The relationship between resolution and bandwidth can be seen by considering the number of picture elements that can be transmitted each second.

The standard 6-Mc broadcast channel provides a video bandwidth of approximately 4.1 Mc (the remaining bandwidth being required for a vestigial sideband plus the sound signal). Since each cycle of a sine wave is capable of conveying two picture elements (one black and one white), the maximum rate at which picture elements can be transmitted is $4{,}100{,}000 \times 2$, or 8,200,000 per second. Since 30 complete frames are transmitted per second, the number of picture elements per frame would be $8{,}200{,}000 \div 30$, or 273,333, if it were not for the retrace blanking problem, which requires interruption of the picture signal periodically by blanking pulses. Since the combination of horizontal and vertical blanking pulses requires nominally 25 per cent of the total time, the maximum number of picture elements per frame is reduced in practice to $0.75 \times 273{,}333$, or approximately 205,000.

Synchronizing

In addition to the picture information, or video signals, blanking and synchronizing signals are transmitted by the television station to control the intensity and movement of the scanning beam in the kinescope of the television receiver. Both these signals are in the form of rectangular pulses. Moreover, their polarity and amplitude are such that they are received as "black" signals and therefore do not appear on the receiver screen.

Blanking pulses eliminate the "retrace" lines which would otherwise appear between scanning lines and at the end of each field from the bottom of the picture to the top. Horizontal blanking pulses, transmitted at the end of each line, or at intervals of 1/15,750 sec, blank the beam during retrace periods between lines. Vertical blanking pulses, transmitted at the end of each field, or at intervals of $\frac{1}{60}$ sec, blank the beam during the time required for its return to the top of the picture. Because the vertical retrace is much slower than the horizontal, the vertical blanking periods are longer than the horizontal blanking periods. Vertical blanking pulses are about 20 lines duration, while horizontal blanking pulses have a duration of only a fraction of a line.

Synchronizing signals keep the scanning beam of the kinescope in step with that of the camera tube. These signals consist of horizontal and vertical pulses which are transmitted within the respective blanking periods. Although the sync pulses are of the same polarity as the blanking pulses, they are of greater amplitude ("blacker than black") and thus easily separated in the receiver and fed to the deflection circuits of the kinescope.

Since the vertical sync pulses are quite long compared with the horizontal sync pulses and the two are of the same amplitude, separation at the receiver is accomplished through frequency discrimination. Serrations, or slots in the vertical pulses, prevent loss of horizontal sync during the vertical blanking period.

THE MONOCHROME-TELEVISION SYSTEM

The major equipment in a typical television station consists of the aural and visual units illustrated in the block diagram of Fig. 1-6. In the visual channel, the video signal leaving the camera is passed through processing equipment which inserts the

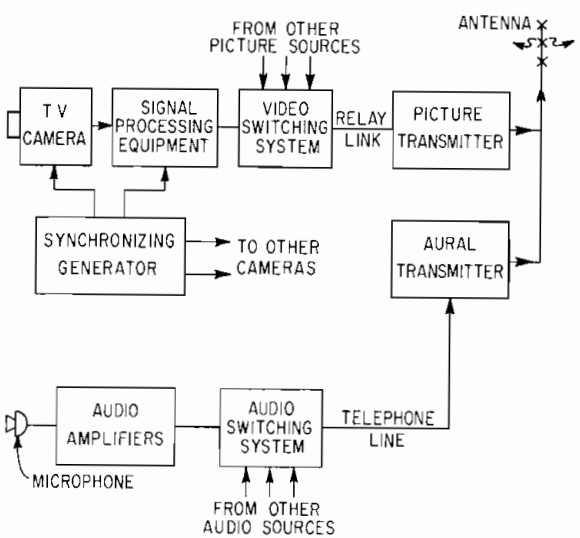


FIG. 1-6. Simplified block diagram of the monochrome-television station.

blanking and synchronizing signals and performs other functions such as aperture compensation and gamma correction. From the processing chain, the video signal is fed to a switching system which provides for selection from a number of video sources. The selected signal is then sent to the visual transmitter through coaxial cable or over a microwave relay link, depending upon the distance between the television studio and transmitter. In the transmitter, the composite video signal amplitude-modulates a carrier in the VHF or UHF range, which is radiated by the television antenna.

In the aural channel, the audio signal is fed from the microphone or other sound source through the switching system and to the aural transmitter. Frequency-modulated output from the aural transmitter is combined with the visual output and radiated from the same antenna.

The Radiated Picture Signal

Amplitude relationships between the synchronizing pulses and the tonal gradations from white to black in the picture are represented in the waveform of the radiated picture signal. From the illustration, it can be seen that modulation takes place in such a way that an increase in the brightness of the picture causes a decrease in carrier output power. Note that the reference-white line indicated on the sketch is relatively close to zero carrier level. Also, the synchronizing pulses are in the "blacker than black" region, representing maximum carrier power. Use of a widely different range of amplitude for the sync pulses makes it possible for home receivers to separate them by a simple clipping technique.

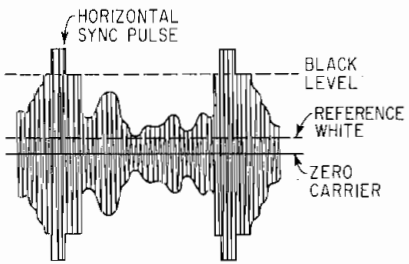


FIG. 1-7. Waveform and radiated picture signal.

Receiver

The basic elements of the television receiving system are illustrated in the block diagram of the television receiver. The radiated television signal is picked up by an antenna and fed to a tuner which selects the desired channel for viewing. Output from the tuner is passed through an intermediate-frequency amplifier which provides the major selectivity and voltage gain for the receiver. A second detector then recovers a video signal which is essentially the same as that fed to the visual transmitter.

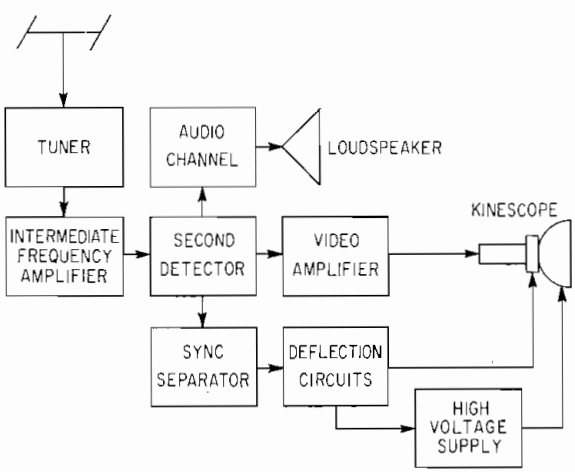


FIG. 1-8. Block diagram of monochrome-television receiver.

The sound signal is usually taken off at the picture second detector in the form of a frequency-modulated beat between the picture and sound carriers. The sound signal is further amplified in a special IF stage, detected by a discriminator or ratio detector, and applied to the speaker through an audio amplifier.

Picture output from the second detector is fed to two independent channels. One of these is the video amplifier which drives the electron beam in the kinescope, and the other is the sync separator, or clipper, which separates the sync pulses from the picture information. The separated pulses are then used to control the timing of the horizontal and vertical deflection circuits. The high-voltage supply, which is closely associated with the horizontal deflection circuit, provides accelerating potential for the electron beam.

THE THREE VARIABLES OF COLOR

Color is the combination of those properties of light which control the visual sensations known as brightness, hue, and saturation. Brightuess is that characteristic of a color which enables it to be placed in a scale ranging from black to white or from dark to light. Hue, the second variable of a color, is that characteristic which enables a color to be described as red, yellow, blue, or green. Saturation refers to the extent to which a color departs from white, or the "neutral" condition. Pale colors, or pastels, are low in saturation, while strong or vivid colors are high in saturation.

The monochrome system is limited to the transmission of images that vary with respect to brightness alone. Thus, brightness is the only attribute of a color that can be transmitted over a monochrome-television system. To produce a color image, therefore, provision must be made for the transmissiou of additioual information pertaining to all three of the variables of color. However, since the primary-color process can be employed, it is not necessary to transmit information in exactly the form expressed by the three variables.

Primary Colors in Television

Experiments have proved conclusively that virtually any color can be matched by the proper combination of no more than three primary colors. While other colors could be used as primaries, red, green, and blue have been selected as the most practical for color-television use. A few of the many colors that can be made by mixing lights of red, green, and blue are illustrated in Fig. 1-9. Red and green combined produce yellow, red plus blue gives purple, and green plus blue gives cyan or blue-green. The proper combination of all three of the primary colors produces white, or neutral, as shown at the center of the illustration. By relatively simple optical means, it is possible to separate any color image into red, green, and blue, or RGB, components, as shown by Fig. 1-10.

Generating RGB Signals

Major compouents of the color-television camera are shown in block-diagram form in Fig. 1-11. Whereas the monochrome camera contains only one pickup tube, the color camera coutains three separate pickup tubes mounted in three separate deflection-coil assemblies. An objective lens at the front of the camera forms a real image within a condenser lens which is located where the pickup tube is usually mounted in a mononchrome camera. A relay lens transfers this real image to a system of dichroic mirrors which shunt the red and blue light to the red and blue pickup tubes and permit the green to pass straight through to the green tube. In this manner, the three pickup tubes produce three separate images corresponding to the RGB components of the original scene. These images are scanned in the conventional manner by common deflection circuits.

A single scanning line through the typical color image at the point shown (Fig. 2-6) produces three separate waveforms. It is important to note the correlation be-

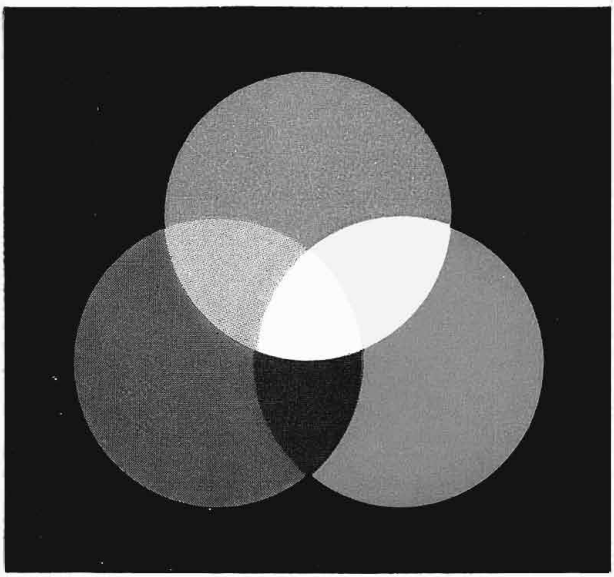


FIG. 1-9. The primary colors of television are red, green, and blue. Virtually any color can be matched by combining proper amounts of these primaries. White is produced by a combination of all three.

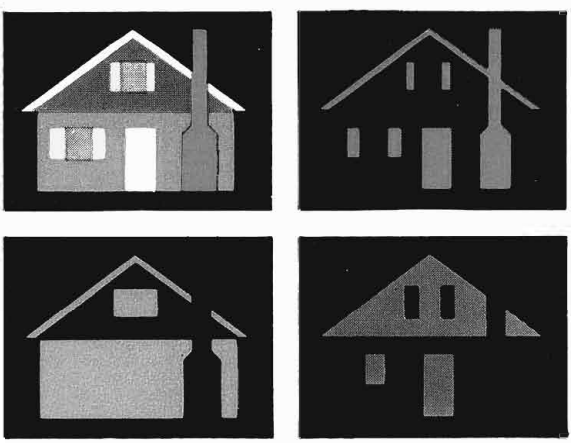


FIG. 1-10. Illustrating how a typical color image (upper left corner) can be separated by optical means into red, green, and blue counterparts.

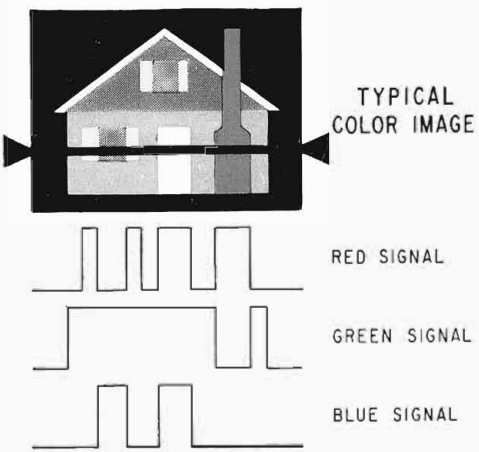


FIG. 2-6. Typical color image and RGB waveforms.

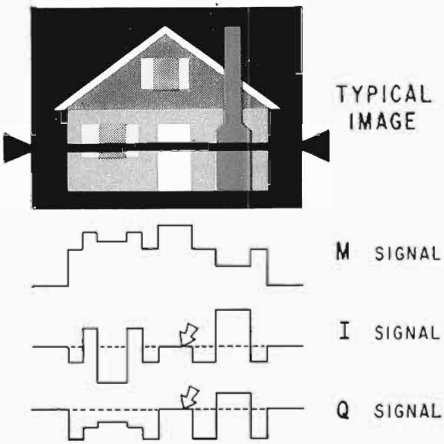


FIG. 2-7. Typical color image and MIQ waveforms.

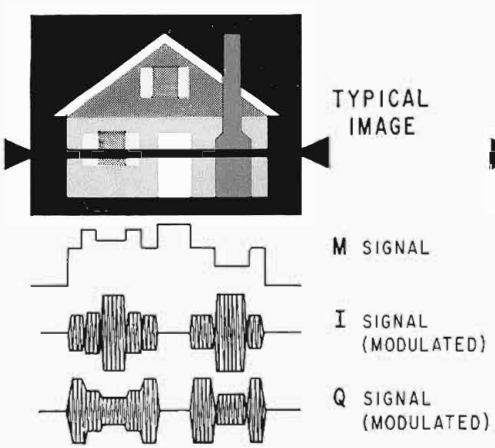


FIG. 2-15. Typical color image and waveforms of the M signal and modulated I and Q signals.

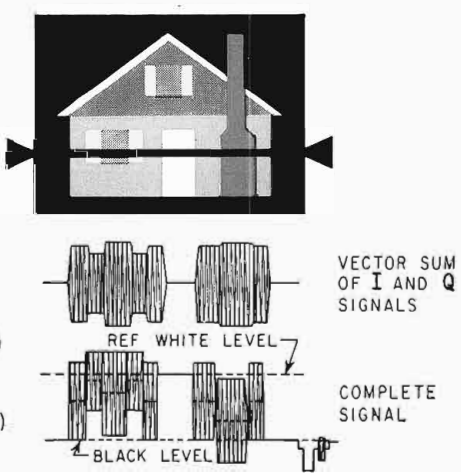


FIG. 2-16. Typical color image with vector sum of I and Q signals together with composite waveform produced by adding all signal components.

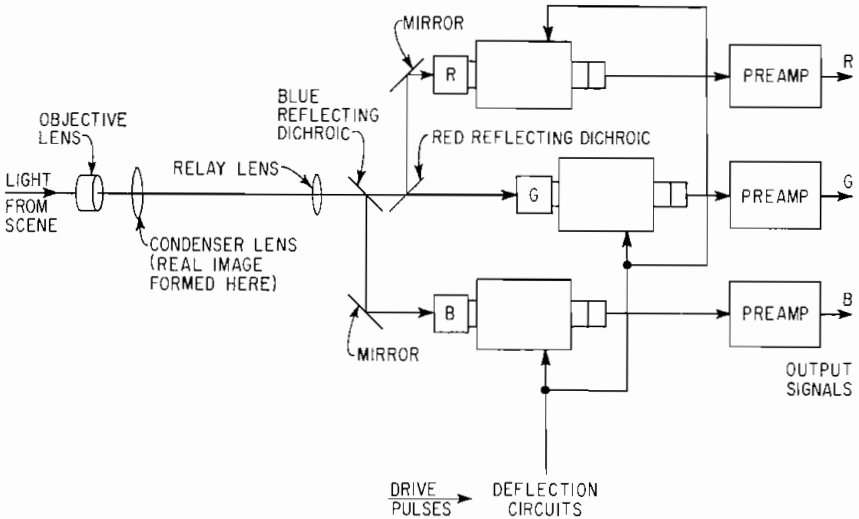


FIG. 1-11. Simplified block diagram of the optical and electrical components of the color camera.

tween these waveforms and the image at the top. The yellow shutters in the image, for example, must be produced by a mixture of red and green, and the blue signal is not required. Thus, at this interval of scanning, the red and green signals are both at full value and the blue signal is at zero. The white door utilizes all three color signals. Of course, similar correlations can be seen for other parts of the image along the scanning line.

Displaying RGB Signals

RGB signals are displayed in color by the tricolor kinescope, the basic components of which are shown in the diagram of Fig. 1-12. Three electron guns produce three beams which are independently controlled in intensity by the red, green, and blue signals. These three beams are all made to scan in unison by deflection coils around the neck of the tube. The three beams converge at the screen owing to the magnetic field produced by a convergence yoke.

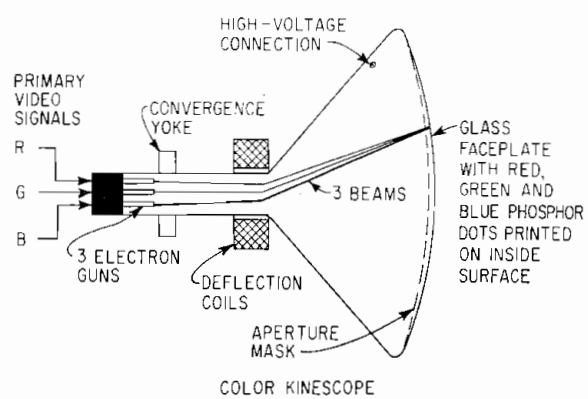


FIG. 1-12. Diagram showing components of the three-gun kinescope picture tube.

The phosphor screen of the color kinescope consists of an array of very small primary-color dots. Approximately ½ in. behind the phosphor screen is an aperture mask which has one very small opening for each group of red, green, and blue phosphors. Alignment of this aperture mask and screen is such that each beam is permitted to strike phosphor dots of only one color. For example, all the electrons emitted by the red gun must strike red phosphor dots on the aperture mask; they cannot strike either the green or blue dots because of the "shadow" effect of the mask. Likewise, the beams emanating from the other two guns strike only green or blue dots.

In this way, three separate primary-color images are produced on the screen of the tricolor tube. But since these images are formed by closely intermingled dots too small to be resolved at the normal viewing distance, the observer sees a full-color image of the scene being televised.

Part 2

ELECTRONIC ASPECTS OF COMPATIBLE COLOR TELEVISION

To achieve compatibility with monochrome television, color-television signals must be processed in such a way that they can be transmitted through the same channels used for monochrome signals, and they must also be capable of producing good monochrome pictures on monochrome receivers. Since color television involves three variables in contrast to the single variable (i.e., brightness) of monochrome television, an encoding process is required to permit all three to be transmitted over the one available channel. Likewise, a decoding process is required in the color receiver to recover the independent RGB signals for control of the electron guns in the color kinescope. Moreover, the process used must enable existing monochrome receivers to produce a monochrome picture from the color information.

Encoding and decoding processes used in compatible color television are based on four electronic techniques known as matrixing, band shaping, two-phase modulation, and frequency interlace. It is these processes which make the color system compatible with monochrome and enable the color system to occupy the existing 6-Mc channel.

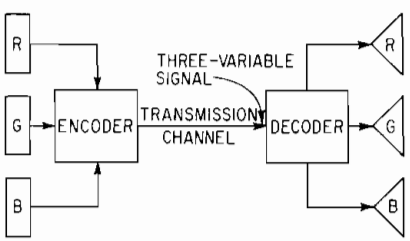


FIG. 2-1. Encoding of the RGB signals provides a three-variable signal which can be transmitted over existing monochrome channels.

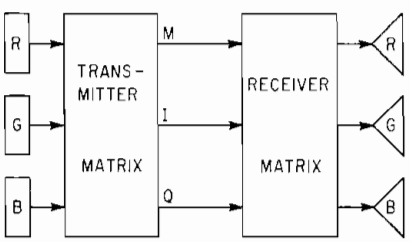


FIG. 2-2. A part of the encoding process is the matrixing of R, G, and B signals to provide M, I, and Q signals.

MATRIXING

Matrixing is a process for "repackaging" the information contained in the red, green, and blue output signals from a color camera to permit more efficient use of the transmission channel. The matrix circuits which perform this function consist of simple linear cross-mixing circuits. They produce these signals, commonly designated M, I, and Q, each of which is a different linear combination of the original red, green, and blue signals. Specific values for these signals have been established by FCC standards.

The M-signal component, or *luminance* signal, corresponds very closely to the signal produced by a monochrome camera, and therefore is capable of rendering excellent service to monochrome receivers. The M component is obtained by combining red,

green, and blue signals in a simple resistor network (Fig. 2-3) designed to produce a signal consisting of 30 per cent red, 59 per cent green, and 11 per cent blue.

The I and Q signals are *chrominance* signals which convey information as to how the colors in the scene differ from the monochrome, or "neutral," condition. The component I is defined as a signal consisting of 60 per cent red, −28 per cent green, and −32 per cent blue. Minus values are easily achieved in the matrix circuits by use of phase inverters to reverse the signal polarity (see Figs. 2-4 and 2-5). The Q signal is defined as 21 per cent red, −52 per cent green, and 31 per cent blue.

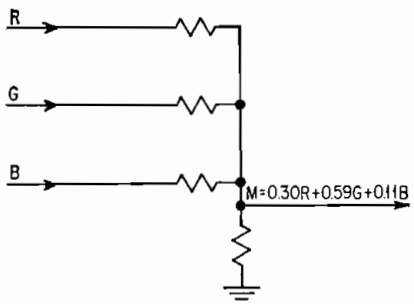


FIG. 2-3. Diagram of resistance matrix circuit used to produce the M luminance signal.

It can be seen that the quantities are related so that when red, green, and blue are equal, corresponding to a neutral condition, both I and Q go to zero. Thus, when the color camera is focused on an object having no color information, such as a monochrome test chart, the I- and Q-signal components are absent, leaving only the M component, or monochrome signal.

The matrix circuits, therefore, produce a new set of waveforms corresponding to the M, I, and Q components of the image. A comparison of the MIQ and RGB waveforms (Figs. 2-6 and 2-7 *) obtained from the image illustrates the correlation among the types of signals. It will be seen that the M signal remains in the region between black level and reference white. It is identical with the monochrome signal derived from the monochrome version of the image. The I and Q signals, on the other hand, swing positive and negative around a zero axis.

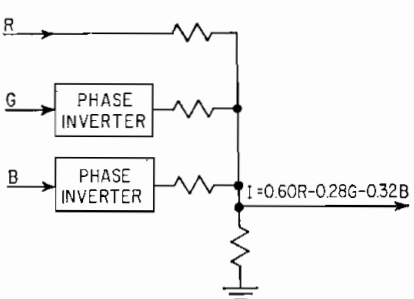


FIG. 2-4. Diagram of I matrix showing phase inverters to produce minus green and blue quantities.

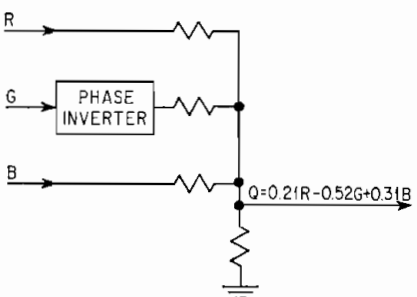


FIG. 2-5. Diagram of the Q matrix showing phase inverter to produce required minus green signal.

BAND SHAPING

The eye has substantially less acuity in detecting variations in color than it has for resolving differences in brightness. This important characteristic of human vision was considered in setting up the I and Q equations because it permitted a significant reduction in the bandwidth of these signals through use of low-pass filters. A bandwidth of approximately 1.5 Mc was found to be satisfactory for the I signal, which corresponds to color differences in the range extending from orange to blue green. For color differences in the range from green to purple, as represented by the Q signal, the eye has even less acuity and the bandwidth was restricted to only 0.5 Mc. The M-signal component, which conveys the fine details, must be transmitted with the standard 4-Mc bandwidth.

* For Figs. 2-6 and 2-7 see the illustrations in color between pages 5-8 and 5-9.

TWO-PHASE MODULATION—GENERATION OF COLOR SUBCARRIER

Two-phase modulation is a technique by which the I and Q signals can be combined into a two-variable signal for transmission over a single channel. This is accomplished by adding the sidebands obtained through modulation of two 3.6-Mc carriers separated in phase by 90°. The resultant waveform is the vector sum of the components. Elements of the transmitting and receiving system are shown in Fig. 2-8. The two

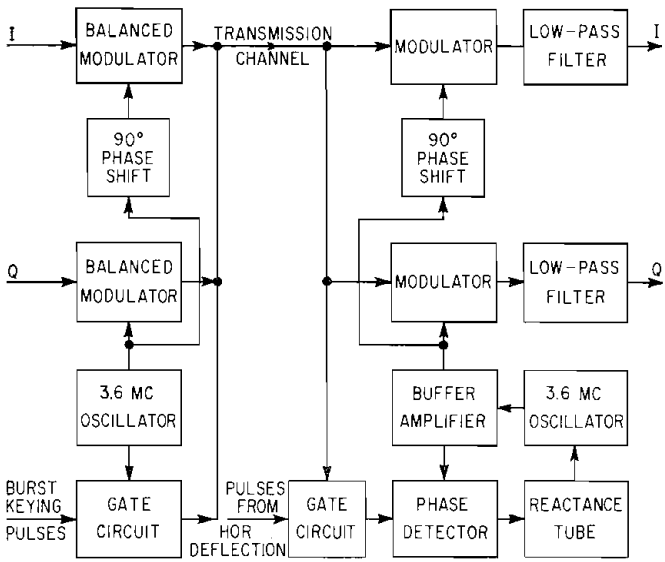


FIG. 2-8. Simplified block diagram showing elements for transmitting and receiving the I, Q, and burst signals.

carriers, which are derived from the same oscillator, are suppressed by the balanced modulators. Thus, only the two amplitude-modulated sidebands, 90° out of phase, are transmitted. At the receiving end of the system, the I and Q signals are recovered by heterodyning the two-phase wave against two locally generated carriers of the same frequency but with a 90° phase separation and applying the resultant signals through low-pass filters to the matrix circuits. Typical signal waveforms are illustrated in Fig. 2-9.

The 3.6-Mc oscillator at the receiver must be accurately synchronized in frequency and in phase with the master oscillator at the transmitter. The synchronizing information consists of 3.6-Mc "bursts" of at least 8-cycle duration transmitted during the "back-porch" interval following each horizontal sync pulse. The bursts are generated at the transmitter by a gating circuit which is turned "on" by burst keying pulses derived from the synchronizing generator. At the receiver, the two-phase modulated signal is applied to another gating circuit, known as a burst separator, which is keyed "on" by pulses derived from the horizontal deflection circuit. The separated bursts are compared in a phase detector with the output of the local 3.6-Mc oscillator. Any error voltage developed is applied through a smoothing filter to a conventional reactance tube which corrects the phase of the local oscillator.

FCC Standard phase relationships between the I and Q signals and the color synchronizing burst are shown in the vector diagram of Fig. 2-11. The I and Q signals are transmitted in phase quadrature, and the color burst is transmitted with an arbitrary 57° phase lead over the I signal.

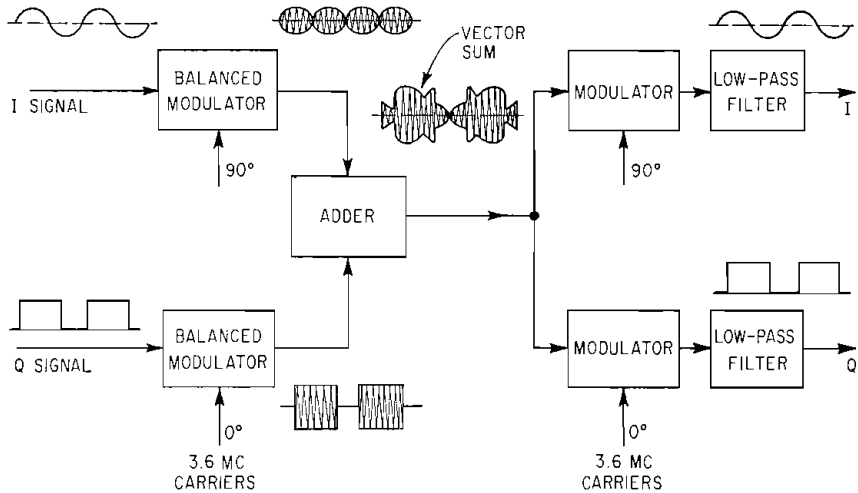


FIG. 2-9. Representative waveforms of the separate I and Q signals and the vector sum of the suppressed carrier sidebands at the modulator output. Original I and Q signals are recovered by heterodyning in balanced modulators at receiver.

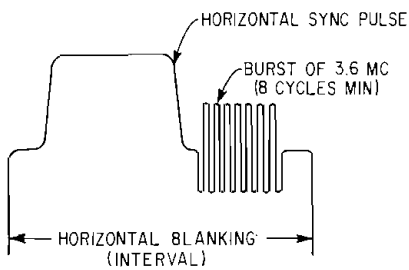


FIG. 2-10. Diagram showing position of subcarrier burst during horizontal blanking interval.

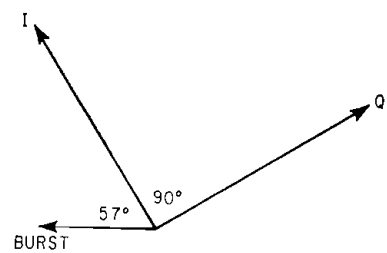


FIG. 2-11. Diagram showing phase relationship of I, Q, and burst signals.

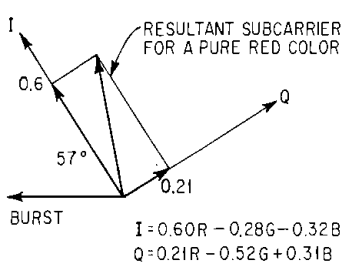


FIG. 2-12. Vector diagram showing phase and amplitude of subcarrier for a pure red signal.

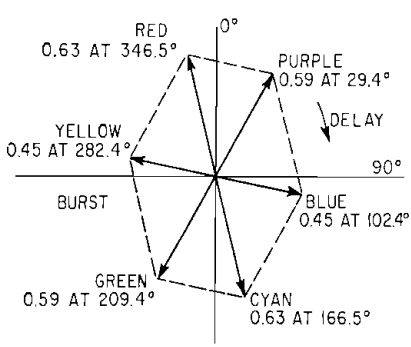


FIG. 2-13. Composite vector diagram showing subcarrier phase and amplitude for each of six colors.

Several interesting properties of the two-phase modulated signal are illustrated by the vector diagrams which represent the resultant signal under known transmission conditions. For example, when a pure red color of maximum amplitude is being transmitted, the green and blue components are at zero and the I and Q signals have levels of 60 and 21 per cent, respectively. When modulated upon their respective carrier, these signals produce the resultant shown in Fig. 2-12. The phase and amplitude shown are characteristic of pure red of maximum relative luminance. Figure 2-13 is a composite vector diagram showing the phase and amplitude characteristics of all three primaries and their 1-to-1 mixtures. This composite diagram indicates that there is a direct relationship between the *phase* of the resultant two-phase modulated signal and the *hue* of the color being transmitted. There is also a relationship (although indirect) between the *amplitude* of the resultant signal and the saturation of the color being transmitted. If the phase of the resultant subcarrier and the level of the monochrome signal both remain constant, then a reduction in the amplitude of the subcarrier indicates a decrease in color saturation. The composite vector diagram also shows an interesting symmetry between complementary colors (colors are complementary if they produce a neutral when added together); the resultants for any two complementary colors are equal in amplitude but opposite in phase.

FREQUENCY INTERLACE

Since the 3.6-Mc carriers, consisting of the I and Q sidebands, fall within the video passband as shown in the diagram of the television channel (Fig. 2-14), they become

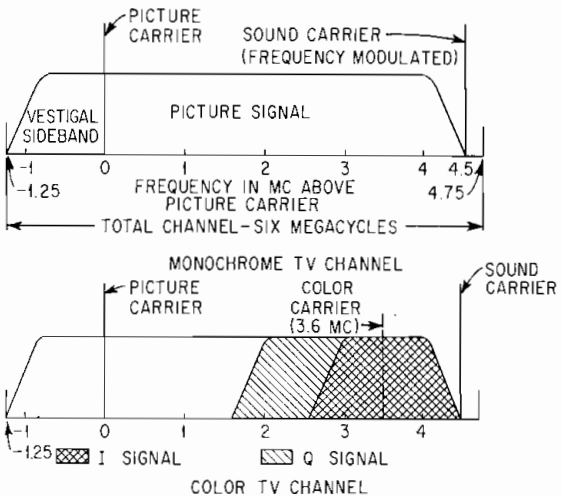


FIG. 2-14. Diagram of television channel showing portions occupied by color and monochrome signal components.

subcarriers and can be handled in many respects like unmodulated video signals. By use of *frequency interlace* it is possible to add the several components of the chrominance and monochrome signals together without causing objectionable mutual interference.

The significance of the straightforward addition of signal components made possible by frequency interlace may be brought out by a study of waveforms derived from a simple color image. Figure 2-15 shows M, I, and Q signals after the latter two have been modulated upon 3.6-Mc subcarriers. Note that both the I- and Q-signal components are at zero during the scanning of the white door, a neutral area. Figure 2-16 * shows the vector sum of the I and Q signals and also the complete compatible

* For Figs. 2-15 and 2-16 see the illustrations in color between pages 5-8 and 5-9.

color signal formed by adding together all the components, including synchronizing pulses and color-synchronizing bursts. The most significant fact about this signal is that it is still capable of providing good service to monochrome receivers, even though a modulated wave has been added to the monochrome-signal component. Although the modulated wave is clearly a spurious signal with respect to the operation of the kinescope in a monochrome receiver, its interference effects are not objectionable because of the application of the frequency-interlace principle.

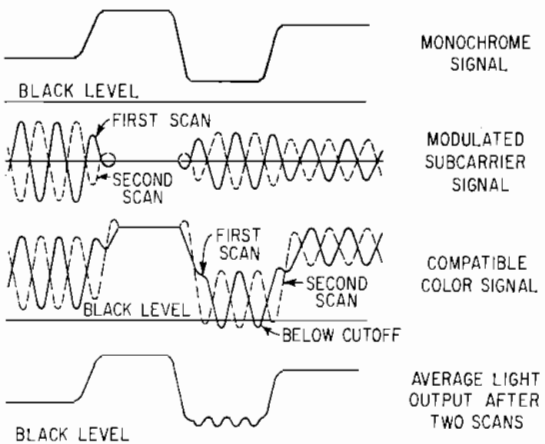


FIG. 2-17. Waveforms showing superposition of modulated subcarrier on scanning signals, compatible color signal, and effect of subcarrier on average light output.

The frequency-interlace technique is based on two factors—a precise choice of the color subcarrier frequency and the familiar "persistence-of-vision" effect. If the color subcarrier is made an odd multiple of one-half the line frequency, its apparent polarity can be made to reverse between successive scans of the same area in the picture. Since the eye responds to the average stimulation after two or more scans, the interference effect of the color subcarrier tends to be self-canceling, owing to the periodic polarity reversals (see Fig. 2-17).

COLOR-FREQUENCY STANDARDS

The relationships among the various frequencies used in a compatible color system are illustrated in the block diagram of Fig. 2-18. The actual frequency of the color subcarrier, which has been referred to as 3.6 Mc, is specified by FCC Standards as 3.579545 Mc, or exactly 455 multiplied by ½ the line frequency.

In broadcast practice, the frequency of the color subcarrier provides a frequency standard for operation of the entire system. A crystal oscillator at the specified frequency provides the basic control information for all other frequencies. Counting stages and multipliers derive the basic frequencies needed in the color studio. A frequency of nominally 31.5 kc is required for the equalizing pulses which precede and follow each vertical sync pulse and for the serrations in the vertical sync pulse. A divide-by-2 counter controlled by the 31.5 kc signal provides the line-frequency pulses at nominally 15.75 kc needed to control the horizontal blanking and synchronizing waveforms. Another counter chain provides the 60-cycle pulses needed for control of the vertical blanking and synchronizing circuits.

The synchronizing waveform adopted by the Television Committee of the Radio Electronics Television Manufacturers Association [1] is illustrated on page 1-233.

[1] Now known as Electronic Industries Association.

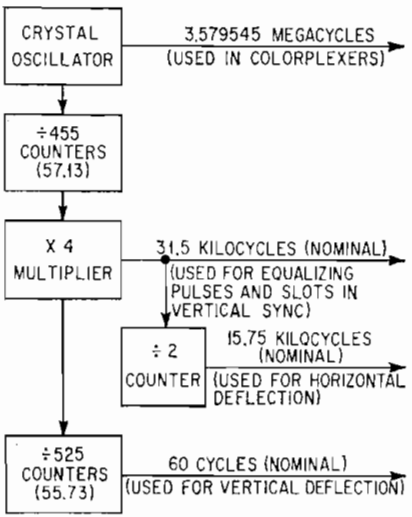


FIG. 2-18. Block diagram showing relationship between various frequencies used in color-television station.

THE OVER-ALL COLOR SYSTEM

The major functions performed in transmitting and receiving color are shown in the over-all block diagrams of the transmitting and receiving systems (Figs. 2-19 and 2-20).

At the transmitting end, camera output signals corresponding to the red, green, and blue components of the scene being televised are passed through nonlinear amplifiers (the gamma correctors) which compensate for the nonlinearity of the kinescope elements at the receiving end. Gamma-corrected signals are then matrixed to produce the luminance signal M and two chrominance signals I and Q. The filter section establishes the bandwidth of these signals. The 4.1-Mc filter for the luminance channel is shown in dotted lines because in practice this band shaping is usually achieved by the attenuation characteristics of the transmitter and the filter is not required.

The bandwidths of 1.5 and 0.5 Mc shown for the I and Q channels, respectively, are nominal only—the required frequency-response characteristics are described in more detail in the complete FCC signal specifications. Delay compensation is needed in the filter section in order to permit all signal components to be transmitted in time coincidence. In general, the delay time for relatively simple filter circuits varies inversely with the bandwidth. The narrower the bandwidth, the greater the delay. Consequently, a delay network or a length of delay cable must be inserted in the I channel to provide the same delay introduced by the narrower band filter in the Q channel, and still more delay must be inserted in the M channel.

In the modulator section, the I and Q signals are modulated upon two subcarriers of the same frequency but 90° apart in phase. The modulators employed should be of the doubly balanced type, so that both the carriers and the original I and Q signals are suppressed, leaving only the sidebands. Some sort of keying circuit must be provided to produce the color-synchronizing bursts during the horizontal blanking intervals. To comply with the FCC signal specifications, the phase of the burst should be 57° ahead of the I component (which leads the Q component by 90°). This phase position was chosen mainly because it permits certain simplifications in receiver designs. Timing information for "keying in" the burst can be obtained from a "burst flag generator," which is a simple arrangement of multivibrators controlled by horizontal and vertical drive pulses.

In the mixer section, the M signal, the two subcarriers modulated by the I and Q chrominance signals, and the color-synchronizing bursts are all added together. Provision is also made for the addition of standard synchronizing pulses, so that the output of mixer section is a complete color-television signal containing both picture and synchronizing information. This signal can then be put "on the air" by means of a standard television transmitter, which must be modified only to the extent necessary to assure performance within the reduced tolerance limits required by the color signal.

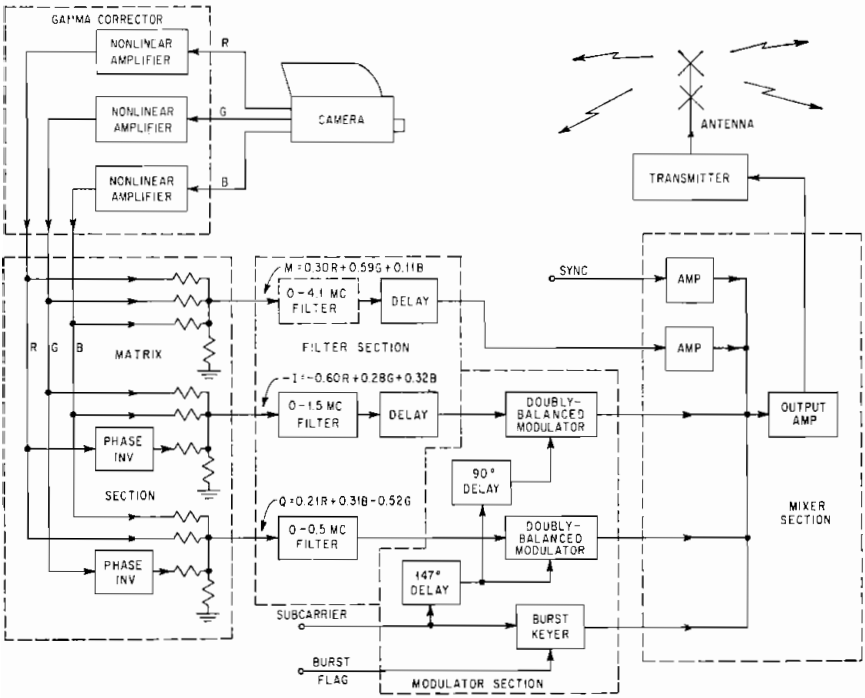


FIG. 2-19. Block diagram showing major functions of color-transmitting system.

(Since the color signal places more information in the channel than a black-and-white signal, the requirements for frequency response, amplitude linearity, and uniformity of delay time are stricter.)

THE COLOR-RECEIVING SYSTEM

In a compatible color receiver, the antenna, RF tuner, IF strip, and second detector serve the same functions as the corresponding components of a black-and-white receiver. Thus, up to the second detector, the color receiver is no different from a black-and-white receiver except that the tolerance limits on performance are somewhat tighter.

The signal from the second detector is utilized in four circuit branches. One circuit branch directs the complete signal toward the color kinescope, where it is used to control luminance by being applied to all kinescope guns in equal proportions. In the second circuit branch, a bandpass filter separates the high-frequency components of the signal (roughly 2.0 to 4.1 Mc) consisting mainly of the two-phase modulated subcarrier signal. This signal is applied to a pair of modulators which operate as synchronous detectors to recover the original I and Q signals. It should be noted

that those frequency components of the luminance signal falling between about 2 and 4.1 Mc are also applied to the modulators and are heterodyned down to lower frequencies. These frequency components do not cause objectionable interference, however, because they are frequency-interlaced and tend to cancel out through persistence of vision.

The remaining two circuit branches at the output of the second detector make use of the timing or synchronizing information in the signal. A conventional sync separator is used to produce the pulses needed to control the horizontal- and vertical-deflection circuits which are also conventional. The high-voltage supply for the kinescope can be obtained either from a "flyback" supply associated with the horizontal

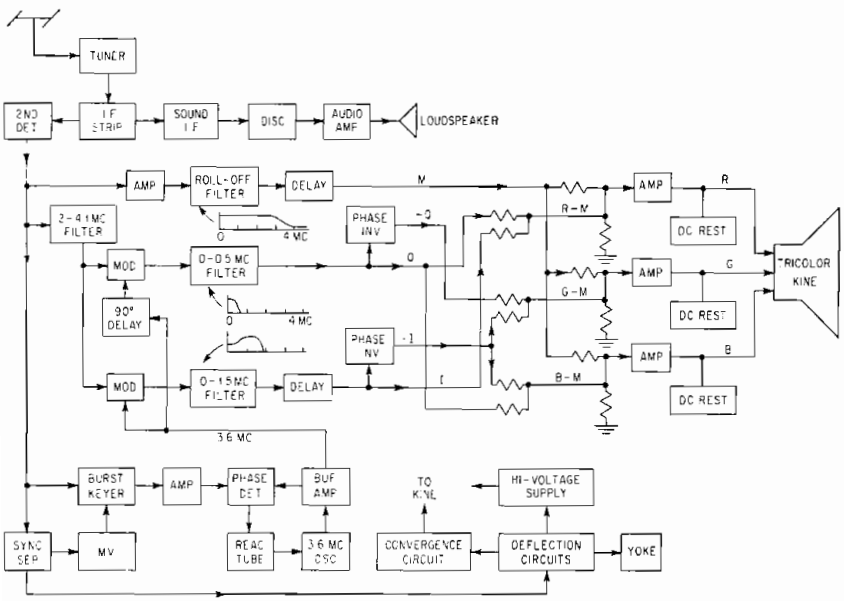


FIG. 2-20. Block diagram showing major functions of color-receiving system.

deflection circuit or from an independent RF power supply. Many color kinescopes require convergence signals to enable the scanning beams to coincide at the screen in all parts of the picture area; the waveforms required for this purpose are readily derived from the deflection circuits.

The final branch at the output of the second detector is the burst gate, which is turned "on" only for a brief interval following each horizontal sync pulse by means of a keying pulse. This pulse may be derived from a multivibrator controlled by sync pulses, as illustrated, or it may be derived from the "flyback" pulse produced by the horizontal output stage. The separated bursts are amplified and compared with the output of a local oscillator in a phase detector. If there is a phase difference between the local signal and the bursts, an error voltage is developed by the phase detector. This error voltage restores the oscillator to the correct phase by means of a reactance tube connected in parallel with the tuned circuit of the oscillator. This automatic-frequency-control circuit keeps the receiver oscillator in synchronism with the master subcarrier oscillator at the transmitter. The output of the oscillator provides the reference carriers for the two synchronous detectors; a 90° phase shifter is necessary to delay the phase of the Q modulator by 90° relative to the I modulator.

There is a "filter section" in a color receiver that is rather similar to the filter section of the transmitting equipment. The M, I, and Q signals must all be passed through filters in order to separate the desired signals from other frequency components which,

if unimpeded, might cause spurious effects. The I and Q signals are passed through filters of nominally 1.5- and 0.5-Mc bandwidth, respectively, just as at the transmitting end. A step-type characteristic is theoretically required for the I filter, as indicated in Fig. 2-14, to compensate for the loss of one sideband for all frequency components above about 0.5 Mc. Actually, this requirement is ignored in many practical receiver designs, resulting in only a slight loss in sharpness in the I channel. A roll-off filter is desirable in the M channel to attenuate the subcarrier signal before it reaches the kinescope. The subcarrier would tend to dilute the colors on the screen if it were permitted to appear on the kinescope grids at full amplitude. Delay networks are needed to compensate for the different inherent delays of the three filters, as explained previously.

Following the filter section in the receiver there is a matrix section in which the M, I, and Q signals are cross-mixed to recreate the original R, G, and B signals. The R, G, and B signals at the receiver are not identical with those at the transmitter because the higher frequency components are mixed and are common to all three channels. This mixing is justifiable, because the eye cannot perceive the fine detail (conveyed by the high-frequency components) in color. There are many possible types of matrixing circuits. The resistance mixers shown provide one simple and reliable approach. For ease of analysis, the matrix operations at the receiver can be considered in two stages. The I and Q signals are first cross-mixed to produce R-M, G-M, and B-M signals (note that *negative* I and Q signals are required in some cases), which are, in turn, added to M to produce R, G, and B.

In the output section of the receiver, the signals are amplified to the level necessary to drive the kinescope and the d-c component is restored. The image which appears on the color kinescope screen is a high-quality full-color image of the scene before the color camera.

It should be made clear that the block diagram of Fig. 2-20 is intended only to illustrate the principles used in color receivers and does not represent any specific model now on the market. Design engineers of color receivers have shown great ingenuity in simplifying circuits, in combining functions, and in devising subtle variations in the basic process which have made possible significant cost reductions while maintaining excellent picture fidelity. The principles of compatible color television are firmly established, and it is to be expected that steady progress will be made in the practical application and requirement of those principles.

Part 3

COLOR FIDELITY

"Color fidelity," as used herein, is the property of a color-television system to reproduce colors which are realistic and pleasing to the average viewer.

Although perhaps not apparent at first, color fidelity is analogous to "high fidelity" as applied to sound reproduction. Just as a high-fidelity audio system faithfully reproduces sounds reaching the microphone, the color-television system is capable of faithfully reproducing colors as seen by the television cameraman. In fact, the color-television system is capable of reproducing colors more accurately than techniques presently used in color printing and color photography.

Tests have shown, however, that color-television pictures are generally more pleasing to the viewer when deliberate modifications are made in the reproduced colors to compensate for the surroundings in which they are reproduced. The situation is similar to that experienced in the art of sound reproduction in the case of a symphony orchestra recorded at high sound levels in a large hall and reproduced at lower sound levels in a small room. In this case, a more pleasing effect is obtained if the ear's new environment is taken into consideration and the reproduction modified accordingly. Similarly, in color television, the changed environment of the eye must be considered and the reproduced colors modified accordingly.

Color fidelity, therefore, is a term used to indicate a color reproduction which pleases the viewer esthetically and convinces him that he is viewing an accurate reproduction of the original colors in the scene being televised.[1]

The following describes possible distortions in the color system and their effect on the picture and prescribes amounts or degrees of distortion that can be tolerated without adverse effects on picture quality.

COLOR-SYSTEM ANALYSIS

Individual elements or areas of the complete color system are discussed in the following paragraphs with the aid of the diagrams shown in Figs. 3-1 through 3-5.

Figure 3-1 is a theoretical color system in that it assumes linear camera tubes and kinescope interconnected by a distortionless wire system. The only distortion that can result from this system is a flaw in colorimetry.

Figure 3-2 introduces linearity correctors to compensate for color errors produced by nonlinearities in the transducers.

Figures 3-3, 3-4, and 3-5 successively introduce the complexities of matrixing, band limiting, delay compensation, and the transmission system (shown dotted in Fig. 3-5). These diagrams, each representing a possible color system, introduce techniques used in compatible color television and permit the study of color distortions peculiar to each technique.

The systems diagramed in Figs. 3-1 and 3-2 are described under Possible Distortions

[1] A detailed discussion of colorimetry and perception, and how these factors affect the viewer, is presented in "Color Television Engineering" by John W. Wentworth, McGraw-Hill Book Company, Inc., New York, 1955.

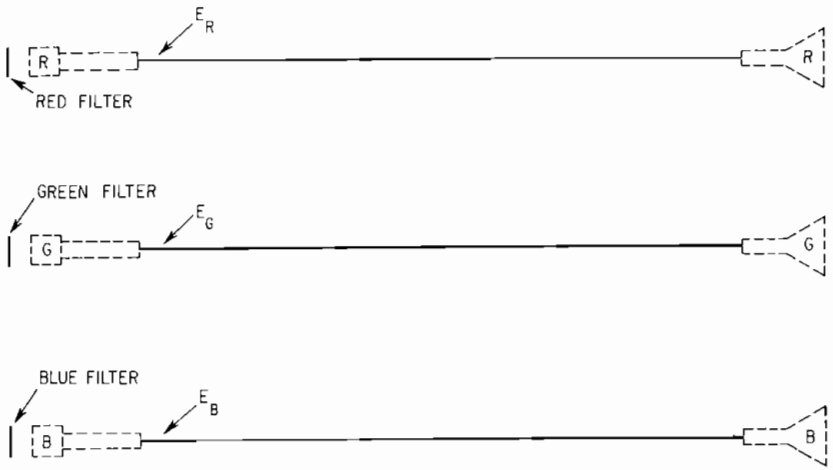


FIG. 3-1. Diagram of a theoretical color system showing linear RGB pickup tubes and kinescopes interconnected by wire.

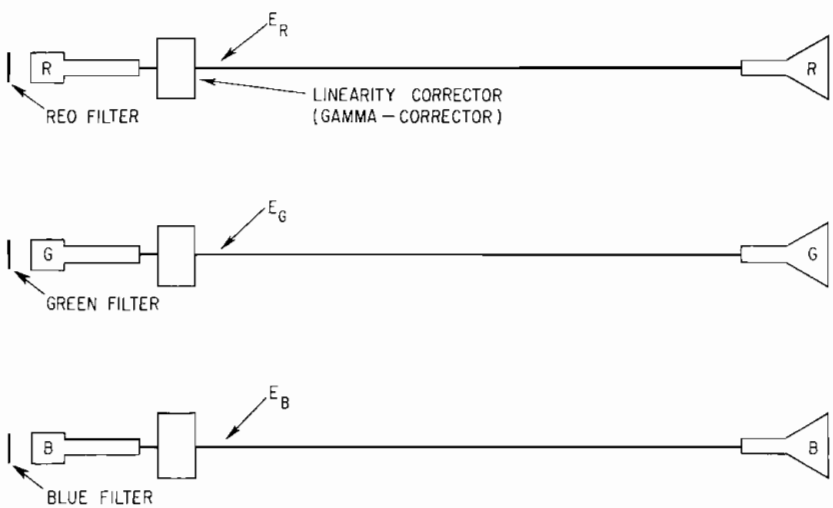


FIG. 3-2. The basic color system shown with necessary linearity correctors to compensate for color errors introduced by the nonlinear transducers.

in Transducers, and those in Figs. 3-3, 3-4 and 3-5 under Possible Distortions in Encoding and Decoding Processes. The system shown in Fig. 3-5 is discussed under Distortions in the Transmission System.

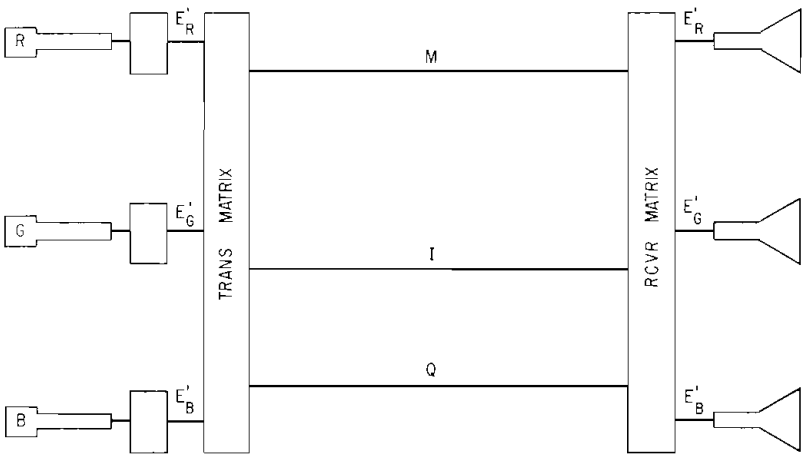


FIG. 3-3. Diagram showing transmitter and receiver matrix functions in the color system.

CHARACTERISTICS OF THE EYE

To appreciate fully the significance of color fidelity, it is helpful to consider some of the characteristics of the eye associated with color perception and to analyze such terms as color adaptation, reference white, and primary colors and determine their relationship to a color-television system.

Color Adaptation

One amazing characteristic of the eye is the phenomenon known as color adaptation. It is this adaptation which enables one to describe accurately the color of an object under "white" light while viewing it in nonwhite light. That is to say, recognition of color is surprisingly independent of the illumination under which an object is viewed. For example, if sunlight at high noon on a cloudless day is taken as "white" light, then, by comparison, the illumination from a typical 100-watt incandescent bulb is very yellow light. Yet it is known that an object viewed under sunlight looks very little if any different when viewed under incandescent light. Moreover, it is obvious to the observer, after a very few minutes in a room illuminated with incandescent lights, that the light is not yellow at all; it is really "white."

It is apparent, then, that the color seen by an observer is dependent upon the illumination to which that observer has been exposed for the past several minutes. This ambient illumination will have a marked effect on his choice of what color he is going to call "white."

This phenomenon can cause a loss of color fidelity under certain conditions. Consider, for example, a theoretically perfect color system with camera viewing an outdoor scene under a midday sun while the reproduced picture is being viewed in a semidarkened room, with what little light is in the room also being derived from the midday sun. Under these conditions, the ambient illuminations at both camera and receiver are identical, so a man standing alongside the camera and a man viewing the receiver would both see the same colors. Now, if a change in the weather at the camera location should cause a cloud to cover the sun, the ambient illumination at the camera location would shift toward a bluer color. This shift would not disturb

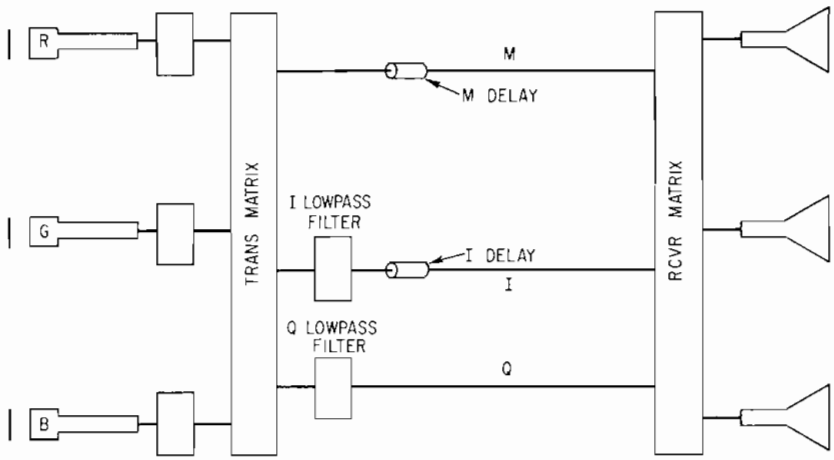


FIG. 3-4. Basic color system with band limiting and delay compensation.

the viewer standing alongside the camera, because his eyes, bathed in the new ambient light, would rapidly adapt to the new viewing conditions and he would perceive the scene as being unchanged.

The man viewing the receiver would not be so fortunate. Assuming that he is far enough away that this same cloud would not affect his ambient, he would observe that everything on his screen had suddenly and inexplicably taken on a bluish cast, which he would certainly find most disturbing.

Such errors in color fidelity can always be corrected by making the camera imitate the human eye in adaptation. The eye adapts to changes in ambient illumination by changing its sensitivity to a certain color. For example, if a light source changes from white to blue-white (as in the above example), the eye reduces its blue sensitivity until the light again appears to be white to the observer. Likewise, a camera operator can correct for the same situation by decreasing the gain of the blue channel of the

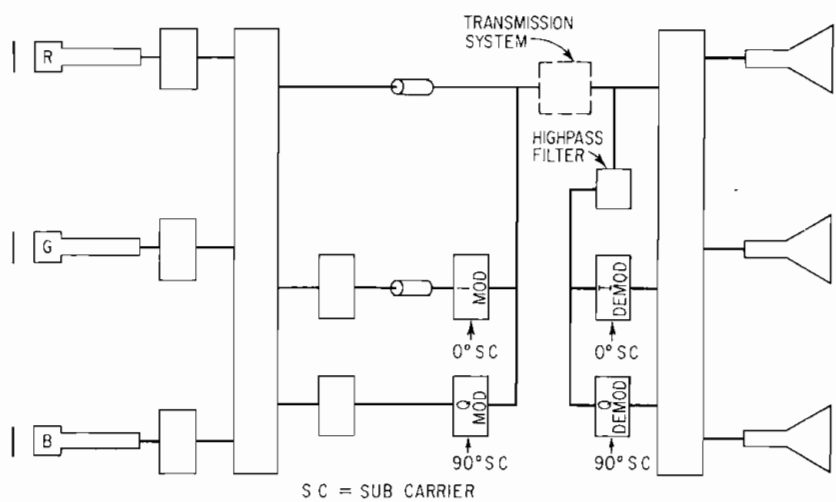


FIG. 3-5. Basic color system showing all major elements, including the transmission system.

camera or by attenuating the light reaching the blue camera tube. In this way, the camera is made to "color-adapt," and the reproduced picture on a receiver loses its bluish cast.

Reference White

Although color adaptation can generate a problem such as the one just described, it also simplifies certain requirements. Specifically, it eases the requirement that white be transmitted as a definite, absolute color, for there clearly can be no absolute white when almost any color can be made to appear subjectively white by making it the color of the ambient illumination to which an observer's eye has adapted.

In color television, we take advantage of this characteristic in the following manner: A surface in the studio which is known by common experience to be white—such as a white shirt or a piece of paper—is selected to be reproduced as white on a home receiver. The relative sensitivities of the three color channels of the camera are then adjusted so that the camera "adapts" to this white regardless of the studio illumination. The home receiver can then be adjusted to reproduce the surface as any "white" which the home viewer prefers, depending upon his surroundings. In the average home-viewing situation, a strong viewer preference has been shown for a bluish-white at the receiver; a subjective effect of freshness, newness, and crispness is conveyed by this white. Therefore, a hue of this type is the common choice for reference white in the home.

It is interesting to note that the studio illumination is commonly the yellow-white of incandescent lighting; hence, a white object in the studio would appear considerably different from its image in the home. It would be possible to adjust the home receiver to reproduce the object with its "proper" whiteness, but this adjustment would result in a yellowish reference white which the viewer would find displeasing. The surprising fact appears, therefore, that absolute color fidelity in a reproduced picture is usually undesirable.

The change in reference white between studio and home must inevitably produce errors in all reproduced colors, but the errors are small and, more important, tend to be subjectively self-correcting, so that any given object will tend to produce the same color sensation whether viewed in relation to the studio reference white or the home reference white.

Consequently, a viewer may become familiar with an object such as a sponsor's packaged product and will recognize it on his television screen, under the fluorescent lighting of his supermarket, or under the incandescent lighting of his home and, furthermore, will note no difference in the colorimetric values of the package under the three conditions, even though the absolute colorimetric values would be appreciably different in the three situations.

Primary Colors

Of all the characteristics of the eye, there is perhaps none more fundamental to practical color television than that characteristic which allows us to choose certain colors, called primary colors, and from these synthesize almost any other desired color by adding together the proper proportions of the primary colors. If it were not for this characteristic, each hue in a color system would have to be transmitted over a separate channel; such a system would be too awkward to be practical. Because of the eye's acceptance of synthesized colors, it is possible to provide excellent color rendition by transmitting only the three primary colors.

POSSIBLE ERRORS IN TRANSDUCERS

The block diagram of Fig. 3-1 shows a fundamental color-television system using red, green, and blue primaries and three independent transmission channels. The camera tubes and kinescopes are shown dotted to indicate that any inherent nonlinearities in these devices are to be disregarded, for the moment, in order to simplify the discussion of the colorimetry of the system.

The general plan in a system such as that of Fig. 3-1 is to provide the three kinescopes with red, green, and blue phosphors, respectively, and to allow the corresponding camera tubes to view the scene through an appropriate set of red, green, and blue filters. If a phosphor and a filter have the same dominant wavelength, that is, if they appear to the eye to be the same color, it might be mistakenly supposed that they would be colorimetrically suited to be used as a filter and phosphor set for the channel handling that color. Actually, the basis for choosing filters and phosphors is much more complex and is based on the shape of the response curve of the filter, plotted against wavelength, and the shape of the light-output curve of the phosphor, also plotted against wavelength. The following paragraphs will discuss briefly a

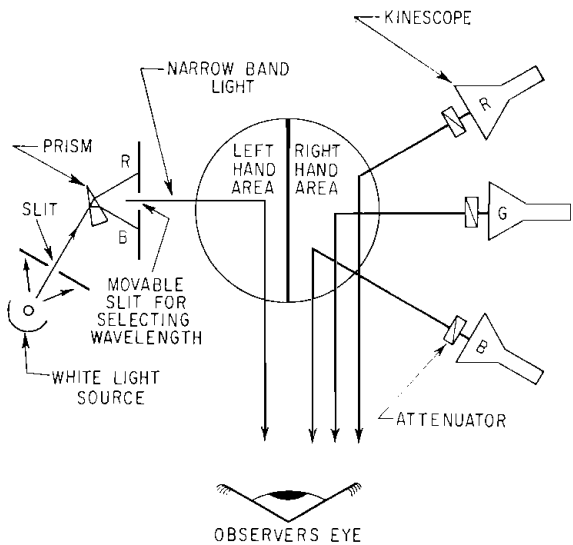


FIG. 3-6. Diagram showing laboratory setup arranged to compare narrow-band light source and R, G, and B light produced by kinescopes to determine proper camera-filter color characteristics.

technique which might be used to determine the required relationship between the phosphor curves and the filter curves.

The color characteristics of the phosphor are generally less easily changed than are filter characteristics; for this reason characteristics of phosphors are taken as the starting point, and characteristics of the filters are determined from them. A laboratory setup which could be used to determine these characteristics is shown in Fig. 3-6. In this figure, an observer (who must have "normal" vision) is viewing simultaneously two adjacent areas, one of which is illuminated by a source of single-wavelength light which can select any wavelength in the visible spectrum, the other of which is illuminated by a red kinescope, a green kinescope, and a blue kinescope. The phosphors of these kinescopes are the phosphors which are to be used in the color system. Starting at, say, the red end of the spectrum, a single-wavelength red is selected to illuminate the left-hand area, and the light from each of the three phosphors is varied until a color match is obtained between the left-hand and right-hand areas. The respective amounts of red, green, and blue lights needed to accomplish this match are recorded. Then another wavelength is chosen, the kinescope outputs varied to produce a match, and the new amounts of red, green, and blue needed for a match are recorded. Similarly, points are obtained throughout the entire spectrum, and a graph is plotted showing the various required outputs vs. wavelength. The

shapes of these three curves—one for red, one for green, and one for blue—are the required shapes for the three camera-filter response curves. The resulting curves would in general resemble Fig. 3-7.

(To simplify the above discussion it was assumed that the camera tubes responded equally well to all wavelengths. In practice, camera tubes show higher output at certain wavelengths than at others. The filter-response curves derived by the above technique would have to be modified so that the combined response of filter and camera would be correct.)

Certain practical difficulties could result in errors in the above procedure. For example, if the observer had any deviations from normality in his color-vision characteristics (as most people do), these deviations would result in "nonstandard" matches and, hence, improper camera-filter characteristics. Also, if the phosphors were contaminated in any way during their manufacturing process (as most phosphors are, at least to some small degree), the resulting phosphor characteristics would not be the proper ones and hence would give rise to improper camera-filter characteristics. The observer errors can be normalized out by standard colorimetric procedures, but phosphor errors represent a basic error which may possibly be present not only in the above experiment but also in varying degrees in a large number of receivers. Quality control of phosphor manufacture is sufficiently good, however, to make the net effect unnoticeable in home receivers.

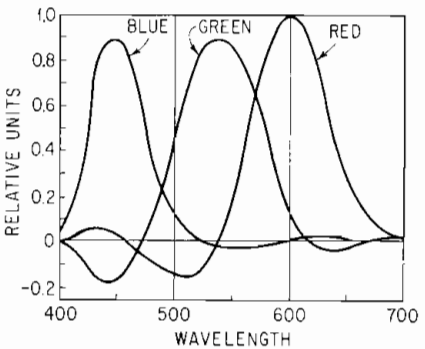


Fig. 3-7. Curves showing relative quantities in camera output required to produce correct kinescope colors over the visible spectrum.

A striking practical difficulty would also arise regardless of observer or phosphor errors. For most wavelengths, no combination of red, green, and blue kinescope outputs could be found which would produce a match. In order to obtain a match at these wavelengths, it would be necessary to move one or two of the kinescopes over to the other side so that they could add their light to the single-wavelength light being matched. This procedure can be described mathematically, for graphing purposes, by saying that adding light to the left-hand area is the same as subtracting that light from the right-hand area. Therefore, the amount of light added on the left would be considered as a negative quantity and would result in a point below the axis on the graph. Since this condition would be found to exist for several successive wavelengths, the resulting graph would show one or more minor lobes below the axis. These are called negative lobes.

These negative lobes represent a need for filters with negative light-transmission characteristics at certain wavelengths. Simple attenuating filters cannot yield such a characteristic; much more elaborate means would be required. However, it has been shown that excellent color fidelity can be obtained by ignoring the negative lobes and using filters which yield the positive lobes only. Positive-lobe processes such as color photography have gained wide acceptance for years. The RCA TK-41 color camera, which also ignores the negative lobes, has shown by its widespread use and approval that this approach to the problem is both practical and sensible. In short, the contribution of the negative lobes is so small that any means for giving effect to them must be comparatively inexpensive to justify its use. Further advances in the art may provide such a device.

Nonlinearities in the Transducers

The assumption made in Fig. 3-1 that a system comprised of perfectly linear devices and circuits was convenient for the discussion of colorimetry, but since any

practical system is always found to be more or less nonlinear, further discussion must take into account this nonlinearity. In this section we shall discuss the inherent nonlinearities of camera tubes and kinescopes, the effects of these nonlinearities on the

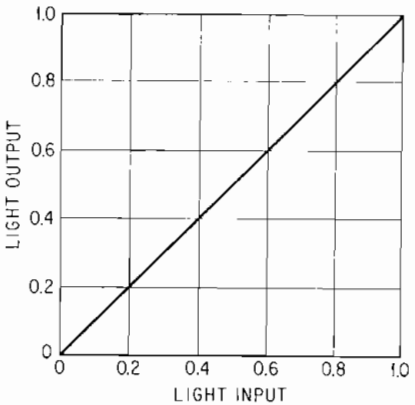


FIG. 3-8. Curve showing light-transfer characteristics of a perfectly transparent piece of window glass.

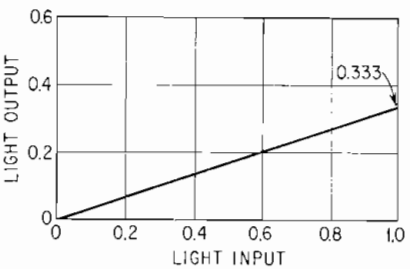


FIG. 3-9. Curve showing transfer characteristic of a neutral density filter with 3-to-1 light attenuation.

reproduced picture, and the use of conversely nonlinear amplifiers to correct for the camera-tube and kinescope characteristics.

Transfer Characteristics

A piece of window glass is perhaps the nearest approach to a perfect video system. For a piece of glass, the light output (to the viewer) is essentialy identical with the light input (from the scene). This fact is shown graphically in Fig. 3-8. This plot could be called the "transfer characteristic" of a piece of glass, since it describes the way that light is transferred through the system.

If the window glass is replaced by a neutral-density filter which attenuates light 3 to 1, the transfer characteristic will then be given by Fig. 3-9. The difference between Figs. 3-8 and 3-9 can he described by these simple relationships:

For the glass:

$$\text{Light output} = \text{light input}$$

For the neutral-density filter:

$$\text{Light output} = k \times \text{light input}$$

where $k = \frac{1}{3}$ in this case.

Both systems are linear; that is, doubling the light input of either will double its light output; tripling input will triple output; etc. A nonlinear system does not exhibit this simple proportionality. For example, consider a system described by

$$\text{Light outut} = k \times (\text{light input})^2$$

Doubling the input to this system will quadruple its output; a threefold increase in input will result in a ninefold increase in output; etc. The transfer characteristic

for this type of system is shown in Fig. 3-10. Note that the characteristic is definitely nonlinear; that is, it is not a straight line as were Figs. 3-8 and 3-9.

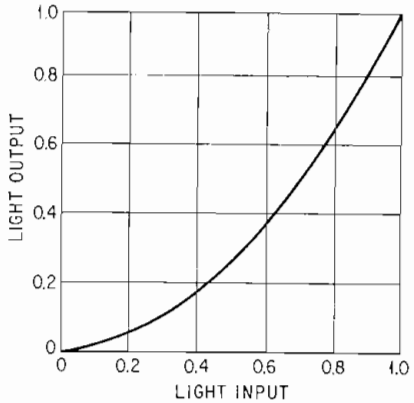


FIG. 3-10. Curve showing a nonlinear transfer characteristic.

In television and photography, nonlinearity is more common than linearity. For example, an ordinary kinescope is a nonlinear device, having a transfer characteristic which can be approximated by the expression

$$\text{Light output} = k\ (\text{voltage input})^{2.2}$$

Camera tubes also are usualy nonlinear devices. For example, the characteristic of a vidicon is approximately

$$\text{Current output} = k\ (\text{light input})^{0.65}$$

The general expression for nonlinear transfer characteristic can be given approximately as

$$\text{Output} = k\ (\text{input})^{\gamma}$$

where the exponent is the Greek letter gamma.

Graphical Displays of Transfer Characteristics

Linear Plots

The first reaction of any person asked to display two variables (like light input and light output) on a set of XY coordinates is to divide X and Y coordinates into eqnal increments and plot the variables in this manner. A typical result of such a plot has already been described (Figs. 3-8 and 3-9). Such a plot has the advantage of showing at a glance the linearity of the device described by the variables. If the plot is a straight line, we say the device is linear; if curved, we say the device is nonlinear. Moreover, the slope of the line describes the attenuation (or gain) of the device. If the slope is unity (which occurs when the plot makes a 45° angle with the X axis), there is no attenuation; we are dealing with a very good piece of glass. For the neutral-density filter described above, which has the equation (light output) = ⅓ (light input), the line has a slope of one-third (see Fig. 3-9).

Such are the advantages of plotting transfer characteristics with equal-increment divisions of the X and Y axis. However, other advantages—very important ones—can

be obtained by dividing up the X and Y coordinates logarithmically. Such a plot is called a log-log plot.

Log-Log Plots

Consider a system which has a transfer characteristic given by $L_0 = (L_{in})^{2.2}$. If this equation is plotted on axes which are divided logarithmically, the resulting plot

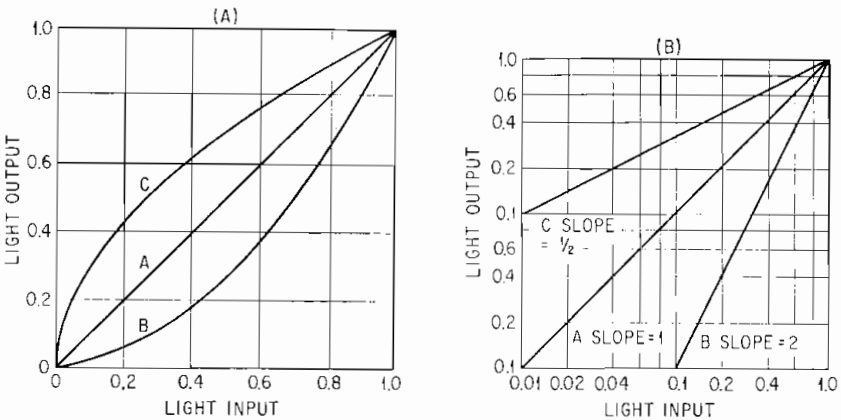


FIG. 3-11. Graphs showing the curves obtained by platting A, B, and C types of transfer characteristics on linear coordinates (A) and on log-log coordinates (B).

is the same as though the logarithm of both sides of the equation were plotted on equal-increment axes. Taking the logarithm of both sides, we obtain

$$\log L_0 = \log (L_{in})^{2.2}$$

Since $\log (L_{in})^{2.2}$ is the same as $2.2 \log (L_{in})$, then

$$\log L_0 = 2.2 \log L_{in}$$

Comparing the form of this equation with an earlier equation, light output = $\frac{1}{3}$ light input, we can see that just as the attenuation, $\frac{1}{3}$, was the slope of the earlier equation, so 2.2, the exponent, is the slope of the latter equation. We see, then, that the use of logarithmically divided coordinates yields a plot in which the exponent is given by the slope of the line. Therefore, this plot will show at a glance the magnitude of the exponent and will also show whether or not the exponent of the system is constant for all light levels. It also is advantageous in showing the effects of stray light.

Figure 3-11*a* and *b* compare the two types of plotting for three types of transfer characteristics.

The Effect of a Nonlinear Transfer Characteristic on Color Signals

Effect of Identical Nonlinearities in Each Channel

In monochrome television, some degree of nonlinearity can be tolerated, but such is not the case for a color-television system. It can be shown that a system exponent different from unity must inevitably cause a loss of color fidelity. For an example, consider a situation in which signals are being applied through linear amplifiers to the red and green guns of a perfectly linear (theoretical) kinescope. The green amplifier is receiving 1.0 volt; the red amplifier, 0.5 volt. If everything is perfectly

linear, the proportions of the light output should be 1.0G + 0.5R = a greenish yellow. However, if the kinescope has an exponent of 2.0, the light output will be $(1.0)^2G + (0.5)^2R$ = 1.0G + 0.25R = greenish yellow with an excess of green.

From the above specific case, it may be correctly inferred that in general, a system exponent greater than 1 will cause all hues made of the combination of two or more primaries to shift toward the larger or largest primary of the combination. Conversely, a system exponent less than 1 will shift all hues away from the largest primary of the combination.

In the above example, an exponent of 0.5 would yield $(1.0)^{0.5}G + (0.5)^{0.5}R$ = 1.0G + 0.707R = a greenish yellow which is just a shade off pure yellow.

In addition, the reader can correctly conclude that white or gray areas, in which all the primaries are equal, will not be shifted in hue by a nonunity exponent.

Effect of Differing Exponents in Each Channel

The preceding discussion assumed that all three channels (in Fig. 3-2) have the same exponent, whether unity or not. In practical systems, however, there is always the possibility that the exponents of the channels may differ from one another. This

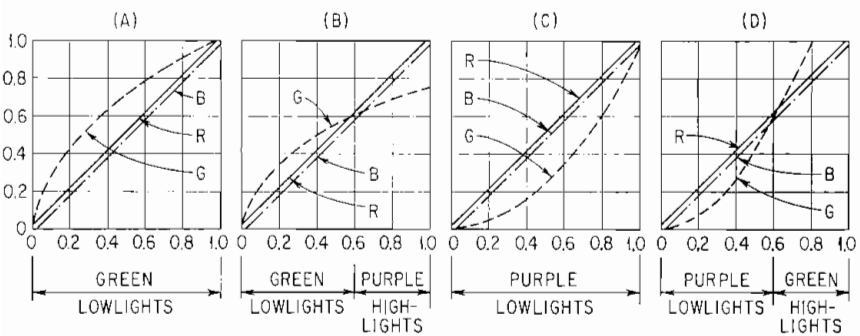


FIG. 3-12. Linear plots showing graphically the effect of unequal exponents in the R, G, and B channels. In all four graphs the R and B exponents are taken as unity. In (*A*) and (*B*) the green exponent is taken as less than 1, and in (*C*) and (*D*), as greater than 1.

situation will produce intolerable color errors if the differences become even moderately large. In general, the requirements for "tracking" among the light-transfer characteristics of the individual channels are even more stringent than the requirement for unity exponent.

Figure 3-12*a*, *b*, *c*, and *d* shows graphically the effects of unequal exponents in the three channels. In all four figures, the red and blue exponents are taken as unity; in Fig. 3-12*a* and *b* the green exponent is taken as less than 1, and in Fig. 3-12*c* and *d*, as greater than 1. In Fig. 3-12*a*, the transfer characteristics are shown for the system adjusted to produce peak white properly. It can be seen that the bowed characteristic of the green channel will cause all whites of less than peak value to have too much green. A gray-scale step tablet before the camera would be reproduced properly only at peak white; the gray steps would all have a greenish tinge. Relative channel gains could be readjusted to reproduce one of the gray steps properly (Fig. 3-12*b*), but then all highlight steps would be purplish while lowlight steps would still be greenish.

A green-channel exponent greater than unity would reverse the above results (Fig. 3-12*c* and *d*). With gains adjusted to reproduce peak white properly (Fig. 3-12*c*), lowlights would be purplish; with gains readjusted to provide proper reproduction for one of the lower steps (Fig. 3-12*d*), highlights would be green and lowlights purple.

The Effect of Stray Light

If a kinescope is viewed in a lighted room, there will always be some illumination on the faceplate. Therefore, the eye will always receive some "light output" from the kinescope, regardless of the magnitude of the signal input voltage. Under this condition, a true black is impossible to obtain.

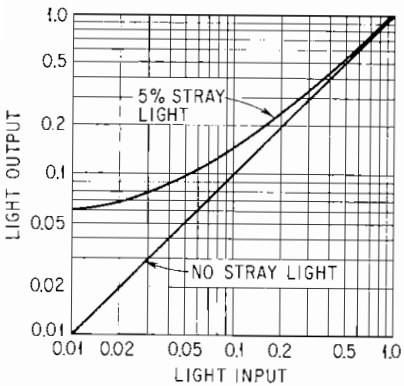


FIG. 3-13. Log-log plot of system with stray light, illustrating change of slope in the low-light regions.

This condition is reflected in the transfer characteristic of the system. If, for example, the stray light were 5 per cent of the peak highlight brightness of the picture, a linear plot of light output vs. light input would have the entire transfer characteristic shifted upward by 5 per cent. However, the most interesting change is found in the log-log plot, where, as seen in Fig. 3-13, the stray light causes a change in the slope in the lowlight regions. Since the slope is eqnal to the exponent, this change shows that stray light causes an effective exponent error in the lowlight regions of the picture and hence will cause color-fidelity errors which will be most marked in the low-light regions.

These errors will be noted by an observer as improper hues and saturations, with the saturation errors—a "washing out" of the more satnrated lowlight areas—being the more objectionable to a viewer.

Stray light is not the only cause of errors of this type. Similar effects will be noted whenever the kinescope bias ("brightness") is set too high, if camera pedestal is set too high, or if stray light enters the camera (whether through lens flare or any other source). In general, any condition which prevents the light output of the system from becoming zero when the light input is zero will cause errors similar to those caused by stray light.

Linearizing a System

It can be shown that a system using a vidicon with an exponent of 0.65 to drive a kinescope with an exponent of 2.2 will have an over-all exponent given by the product $0.65 \times 2.2 = 1.43$, assuming that all devices in the system are linear. In general, the over-all exponent of a system is the product of the exponents of the cascaded elements.

This knowledge provides an excellent tool for linearizing a system. For example, a system with an over-all exponent of 1.43 could be linearized by inserting somewhere (in a video path) an amplifier having an exponent of $1/1.43$ ($= 0.7$) so that the product becomes unity: $1.43 \times 1/1.43 = 1$.

In Fig. 3-2, a nonlinear amplifier, or gamma corrector, is shown inserted in each of the three paths.

POSSIBLE ENCODING AND DECODING DISTORTIONS

The second of the two systems discussed in the preceding section bordered on being a practical system but still required three independent 4-Mc/sec channels. A fortunate characteristic of the human eye—the inability to see colored fine detail—allows us to modify this requirement to one 4-Mc/sec channel for monochrome fine detail and two much narrower channels for color information. Before this modification can be made, the red, green, and blue signals must be combined to form three other signals,

usually called M, I, and Q, such that the M signal alone requires a 4-Mc/sec channel, and the I and Q channels, which contain the color information, are confined to narrower channels. This rearrangement of red, green, and blue to form M, I, and Q is called matrixing and was described in the previous part. A system which uses a matrix is block-diagramed in Fig. 3-3. The illustration also shows that to recover the original red, green, and blue signals at the receiving end, a "rearranging" device is needed. This device is usually called the receiver matrix.

Matrixing alone offers no advantage unless steps are taken actually to limit the I-signal and Q-signal channels to the narrow bandwidths allowed. Figure 3-4 shows a system employing such band shaping. The band-shaping filters themselves always introduce delay, which must be compensated for by placing delay lines in the wider band channels, as shown in the diagram.

To put both color and monochrome information in the spectrum space normally occupied by monochrome only requires that the color information overlap the monochrome. This overlap can be allowed for both I and Q signals, without incurring visible cross talk, if two techniques, known as frequency interlace and two-phase modulation are employed. A system using these techniques, which were described in Part 2, is block-diagramed in Fig. 3-5.

Possible Errors in the Matrixing Process

The entire matrixing process can be summed up in two sets of equations, the first set describing how the transmitter matrix takes in red, green, and blue and turns out M, I, and Q:

$$\begin{aligned} M &= 0.30R + 0.59G + 0.11B \\ I &= 0.60R - 0.28G - 0.32B \\ Q &= 0.21R - 0.52G + 0.31B \end{aligned}$$

and the second set describing how the receiver matrix takes in M, I, and Q and recreates red, green, and blue:

$$\begin{aligned} R &= 0.94I + 0.62Q + M \\ G &= 0.27I + 0.65Q + M \\ B &= 1.11I + 1.7Q + M \end{aligned}$$

Both matrices can therefore be considered as analogue computers which continuously compute the desired output from the given input. The coefficients in the above six equations are usually determined in the "computers" by precision resistors or, in the case of negative numbers, by precision resistors and signal-inverting amplifiers. The basic error that can occur, therefore, is a change in a resistor value or an amplifier gain, resulting in a change in one or more coefficients. In general, the resulting picture error resembles cross talk among the primary colors.

More specifically, the transmitter matrix can have two distinct types of errors. The first type involves the coefficients of the equation for M; the second type, the coefficients for I and Q. An error in an M coefficient will brighten or darken certain areas. In a monochrome reproduction of a color signal, such an error, if small, would not be noticed; if large, it would still probably be tolerated by the average viewer. In a color reproduction, however, even a small error would be objectionable. For example, a reduction of the red coefficient from 0.3 to 0.2 would cause a human face to be reproduced with an unnatural ruddy complexion and dark-red lips.

Note that the sum of the M coefficients is 1. An error in one coefficient would change this sum, so that peak white would no longer occur at 1 volt. An operator could mistake this condition for a gain error and adjust either M gain or over-all gain in an effort to obtain the correct peak-white voltage. Changing M gain would cause errors to occur in all M coefficients; changing over-all gain would put errors in all coefficients. Although such an error is rare in well-engineered equipment, it is a possible source of color error which can be compounded by misdirected attempts at correction.

Note that the sums of the Q and I coefficients are each zero, which means that

when R = G = B (the condition for white or gray), Q and I both equal zero. An error in a Q or I coefficient would cause color to appear in white or gray areas and, in addition, would cause general errors in colored areas resembling cross talk among the primaries. Controls are usually provided in the Q and I matrices, called Q white balance and I white balance, respectively, which allow the operator to adjust the sum of the Q or I coefficients by changing the value of one of the coefficients. If the coefficient controlled is the one in error, adjusting white balance restores proper operation. If the controlled coefficient is not the one in error, then adjusting white balance restores the condition that the sum of the coefficients is zero, that is, it removes the color from white and gray objects, but it does so by giving the controlled coefficient an error which just counteracts the error of a nonadjustable coefficient, so that two coefficients are wrong instead of one. Again, such an error is rare in well-engineered equipment, for the adjustable coefficient is usually the one in error. However, the possibility of an error compounded by adjustment should be kept in mind.

A far more likely cause of white-balance error is an error in input level, that is, a discrepancy between the peak white levels of input red, green, or blue. In such a case, an operator can still achieve white balance (Q and I = 0 for white input) but the entire system will be in error. The starting point for all investigations of the cause of white-balance errors should be the levels of the red, green, and blue colorplexer inputs.

In the receiver matrix, only one general type of error can occur instead of two as in the case of the transmitter matrix. This type of error, a general coefficient error, results in cross talk among the primary colors. For example, a change in the I coefficient for the red equation from 0.94 to 0.84 would yield about a 7 per cent reduction in the peak red output available and would also result in unwanted red light output in green or blue areas at about 3½ per cent of the green or blue level.

Gain Stability of M, I, and Q Transmission Paths

In the system of Fig. 3-3, every gain device or attenuating device in the three transmission paths must maintain a constant ratio between its input and output in order to maintain the proper ratios among the levels of M, I, and Q at the input to the receiver matrix. A variation in the gain of one of these paths will result in a loss in color fidelity.

For example, a reduction in M gain must obviously cause a reduction in the viewer's sensation of brightness. Not quite so obvious are the effects of I and Q gain. Since these are color signals, their amplitude would be expected to influence the sensation of saturation, but the manner of this influence is not intuitively obvious until the factors which influenced the selection of I and Q compositions are recalled. It previously was pointed out that the eye has the greatest need for color detail in the color range from orange to blue-green (cyan) and the least in the range from green to purple. Hence I, the wider band signal, conveys mainly orange and cyan information, and Q, the narrower band signal, conveys principally the greens and purples. Therefore, a reduction in I gain could be expected to reduce the saturation sensation for colors in the orange and cyan gamut, leaving the greens and purples virtually unaffected. Conversely, Q gain will influence the greens and purples without causing much change in the appearance of orange and cyan objects.

Modulation and Demodulation

The system of Fig. 3-4, which introduced bandwidth limiting of the I and Q signals in accordance with the capabilities of the eye to see colored fine detail, is a fairly practical and economical system, except for the fact that three individual transmission channels are employed. If we are to have a compatible system, however, these three channels must be reduced to one through some multiplexing technique. The technique used has already been described, and a system employing this technique is blocked-diagramed in Fig. 3-5.

Possible Errors in Modulation

Burst Phase Error

Perhaps the most fundamental error in the multiplexing process would be an error in the phase of the main timing reference, burst. Since the entire system is based on burst phase, an error in burst phase will appear as an opposite error in every phase except burst, because the circuits will insist that burst phase cannot be wrong. The general result will be an over-all hue error in the reproduced picture. This effect can be better visualized by referring to Fig. 3-14.

A phase error in burst produces the same result as holding burst phase stationary and allowing all other phases to slip around the circle an equal amount (but in a direction opposite to the burst-phase error). Each color "vector" then represents a hue other than the one intended.

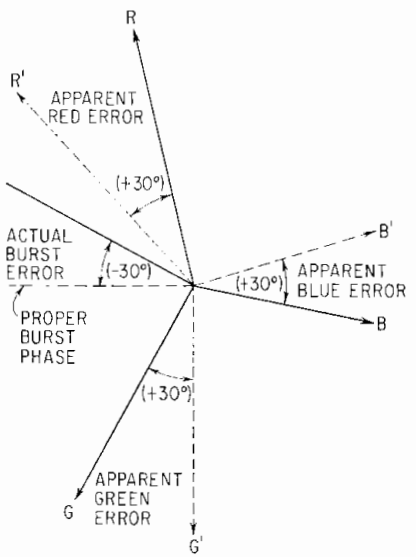


FIG. 3-14. Vector diagram showing how error in subcarrier phase becomes an opposite error in all other phases.

Burst Amplitude Error

In theory, the receiver circuits which extract timing information from the burst are insensitive to variations in burst amplitude as long as the burst is large enough to maintain a respectable signal-to-noise ratio and not so large that some type of clipping or rectification upsets the burst circuitry. But practical receivers always exhibit some degree of sensitivity to burst amplitude, the amount of this sensitivity depending mainly upon the error in the subcarrier oscillator in the receiver. If the free-running frequency of the receiver oscillator is very different from burst frequency—particularly if the difference is so great that the burst is in danger of losing control of the oscillator—then a fairly appreciable amplitude sensitivity will be noted. This sensitivity will take the form of a phase error, and the net result will be indistinguishable from a burst phase error, as discussed above.

Some receivers have a circuit which automatically adjusts the gain of the color-information channels so that the viewer always sees the proper saturations, regardless of errors which might tend either to "wash out" or to oversaturate the picture. Such a circuit, called an automatic chroma control (ACC), derives its control information from the amplitude of burst, which is presumed to bear a constant ratio to the amplitude of chroma. Transmission distortions, for example, might decrease the amplitude of both burst and chroma, but since the ratios of their amplitudes would be preserved, an ACC receiver could automatically modify its chroma-channel gain to compensate for the decreased chroma amplitude. However, if a colorplexer error should cause burst alone to decrease in amplitude, the ACC circuits would increase chroma gain just as in the above case, with the result that a viewer would receive an oversaturated picture.

Two-phase Modulation Errors

The fidelity of color reproduction can be seriously affected if the phase separation of the Q and I subcarriers is not maintained at 90°. It can be shown that a "slip"

in the angular position of the Q axis, for example, will result in cross talk of Q and I. The final result will be the same as cross talk among all the primary colors.

Likewise, in a receiver, the phase relationship between the reference subcarriers must be maintained to avoid a similar error. Any deviation from the proper phase relationship will have a result similar to the above, that is, cross talk of I into Q or Q into I, with the net picture result resembling cross talk among all the primary colors.

Carrier Unbalance

In a properly operating doubly balanced modulator, the carrier component of the signal is suppressed in the modulator circuit. If some error in components or operation causes this suppression to be imperfect, the carrier will appear in the output. This condition is known as carrier unbalance.

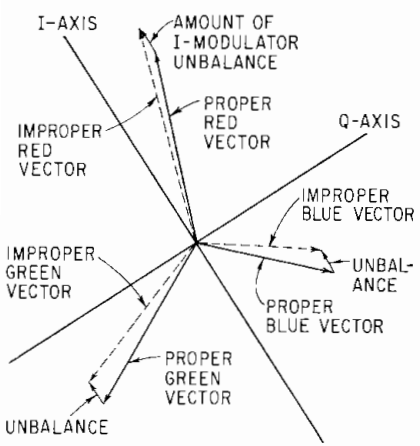


FIG. 3-15. Vector diagram of subcarrier phase and amplitude with positive vectors added to represent carrier unbalance in the I modulator.

The effect of carrier unbalance can be evaluated by considering the unwanted carrier as a vector of constant amplitude which adds itself vectorially to every vector present in the colorplexer output. In general, such a vector will shift all vectors and hence all hues seen in the picture toward one end or the other of the color axis represented by the unbalanced modulator. For example, a positive unbalance in the I modulator would shift all colors toward the color represented by the positive I axis, that is, toward orange. A negative I unbalance would shift all colors toward cyan.

To visualize this effect, refer to Fig. 3-15, in which has been added to each color vector a small positive vector which is parallel to the I axis. This small vector represents the amount of carrier unbalance. The resultant vectors will all be rotated toward the positive I axis and changed in amplitude as well. Such changes represent errors in both hue and saturation.

Another error from carrier unbalance occurs in white and gray areas of the picture. In a normally operating colorplexer, a white (or gray) area in the scene causes the Q and I signals to become zero and thereby causes the modulator outputs to become zero. Hence, a white or gray area will normally appear in the signal as an interval of zero subcarrier amplitude. If one of the modulators begins to produce a carrier-unbalance vector, however, a white or gray area will become colored because of the subcarrier which will be added in this interval. Moreover, certain areas which are normally colored may have their subcarrier canceled by the carrier-unbalance vector and become white. Such white-to-color and color-to-white errors are very objectionable.

Video Unbalance

A doubly balanced modulator derives its name from the fact that it balances out or suppresses both the carrier (as described above) and the modulating video (Q or I). If, for any reason, the video suppression becomes less than perfect, the resulting condition is called video unbalance.

Video unbalance will cause unwanted Q or I video to appear in the modulator output, in addition to the desired sideband outputs. This unwanted video signal will be

added to the luminance signal, thereby distorting the gray scale of the picture. For example, a slight positive unbalance in the Q modulator would slightly brighten reds and blues and slightly darken greens. A negative unbalance would have the opposite effect.

Subcarrier-frequency Error

The color subcarrier frequency is specified by the Federal Communications Commission to be 3.579545 Mc ±10 cycles. Deviations within this specified limit are of no consequence (provided they are slow deviations). Large deviations, however, can affect color fidelity. The effect does not usually become serious within the possible frequency range of a good crystal-controlled subcarrier source driving a properly designed receiver.

In receivers, the subcarrier timing information is extracted from the burst on the back porch and used to control the frequency of a subcarrier-frequency oscillator in the receiver. As long as the unlocked frequencies of the burst and the receiver oscillator remain the same, the locked phase relationship between the two will remain the same. But if either the burst frequency or the receiver-oscillator frequency becomes different (and the difference between them is not so large that lockup is impossible), then the locked error, which obviously cannot be a frequency error, manifests itself as a phase error. This error can become as large as ±90° before the AFC circuit can no longer hold the receiver oscillator on frequency. The frequency range over which this phase shift occurs depends upon the receiver design.

POSSIBLE DISTORTIONS IN THE TRANSMISSION SYSTEM

Preceding sections have described the processes involved in the generation and display of a color-television signal. Errors in these processes are not the only possible source of distortion; when the signal is transmitted over great distances, the transmission system itself may contribute errors. This section discusses parameters which specify the behavior of a transmission system and describes the effects that errors in these parameters can have on the reproduced picture.

This section is divided into two parts. The first relates to the parameters of a perfectly linear transmission system, while the second part discusses the additional parameters required to describe the nonlinearities that are inevitable in any practical system.

The Perfectly Linear Transmission System

A perfectly linear and noise-free transmission system can be described by its gain and phase characteristics plotted against frequency as the independent variable.[2] Typical plots are shown in Figs. 3-16 and 3-17, respectively. These two characteristics known, it is possible to predict accurately what effect the transmission system will have on a given signal.

Gain Characteristic

Figure 3-16 is usually known as the frequency response or gain characteristic of the system. Ideally, it should be perfectly flat from zero to infinite frequency, but this, of course, is impossible to attain. An amplifier has a definite gain-bandwidth product, depending upon the transconductance of its active elements (tubes or transistors), the distributed capacity shunting these elements, and the types of compensation (peaking) employed. The bandwidth of a given combination of tubes, transistors, stray capacitances, and peaking networks can be increased only by decreasing its gain, or conversely, its gain can be increased only by decreasing its bandwidth.

[2] If the filters in the system are of the minimum-phase type, only one of the plots is needed, for either plot can be derived from the other for this type of filter. Almost all common interstage coupling networks are of the minimum-phase type.

There is a limitation, therefore, to the actual bandwidth than can be obtained. For a given scanning standard, the bandwidth required in a monochrome-television system is determined by the desired ratio between the horizontal resolution and the vertical resolution. Although nominally a 4.0-Mc/sec bandwidth is required for the monochrome standards, the requirement can be relaxed to the detriment of only the horizontal resolution. The subjective result is a "softening" of the picture in proportion to the narrowing of the bandwidth (neglecting the influence of the phase characteristic in the vicinity of the cutoff frequency). As pointed out in preceding sections, the entire chrominance information of the color system is located in the upper 1.5 Mc of the prescribed 4.0-Mc channel; hence, any loss of response in this part of the spectrum can have a marked effect on the color fidelity of the reproduced picture.

One of the most serious forms of distortiou inflicted on a color picture by band-

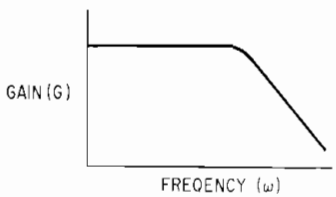


FIG. 3-16. Typical curve showing gain of a system plotted against frequency to determine its gain characteristic.

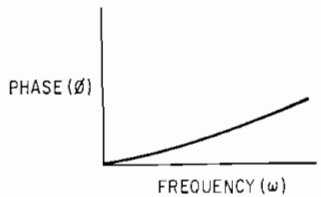


FIG. 3-17. Curve showing phase characteristic of a system plotted vs. frequency.

width limiting is loss of *saturation*. Consider a case in which the bandwidth is so narrow as to result in no gain at the color subcarrier frequency. The output signal then contains no color subcarrier and hence reaches the color receiver as a monochrome signal, producing zero saturation. Nearly as poor results can be expected from an amplifier with response such that the gain at 3.58 Mc is one-half the low-frequency gain. Since the saturation depends chiefly on the amplitude of the subcarrier, the saturation will be correspondingly reduced. The resultant color picture will have a "washed-out" look.

Loss of high-frequency response, which can be expected to contribute to loss of fidelity, is usually accompanied by phase disturbance, depending on the type of networks employed in the system. The intent in this section, however, is to treat each variable separately. Therefore, discussions are based on the effects of varying only one parameter of a system. It is suggested that the reader can determine the combined effect of two or more variables by comparing the results shown for the individual variables.

Phase Characteristic

An ideal system has a *linear* phase characteristic, as in Fig. 3-18*a*. Such a characteristic implies that all frequencies of a signal have exactly the same *time* delay in passing through this system, since the time delay is given by the phase angle divided by the (radian) frequency. It can be seen in Fig. 3-18 that if three frequencies are chosen arbitrarily, then the corresponding phase angles must have values proportional to their corresponding frequencies (because of the geometric properties of a right triangle). To state it another way, if $\phi_1/\omega_1 = 0.2$ μsec, then ϕ_2/ω_2 also equals 0.2 μsec and ϕ_3/ω_3, too, is 0.2 μsec. Plotting these three values and drawing a straight line through them as in Fig. 3-18*b* will show that the time delay for all frequencies is 0.2 μsec.

A signal is not distorted by delay as long as all parts of it are delayed by the same amount. However, when the phase characteristic is nonlinear (as in Fig. 3-19*a*),

the time delays for all parts of the signal are no longer equal (see Fig. 3-19*b*). For example, if a complex waveform is made up of a 1-Mc sine wave and its third harmonic, these two components will suffer unequal delays in passing through a system having the characteristics of Fig. 3-19. The resultant distortion can be seen by comparing Fig. 3-20*a*, *b*, and *c*.

Such distortion is detrimental to both the luminance and chrominance of a composite signal. The luminance signal will have its edges and other important details *scattered*, or *dispersed*, in the final image. Such a transmission system is said to

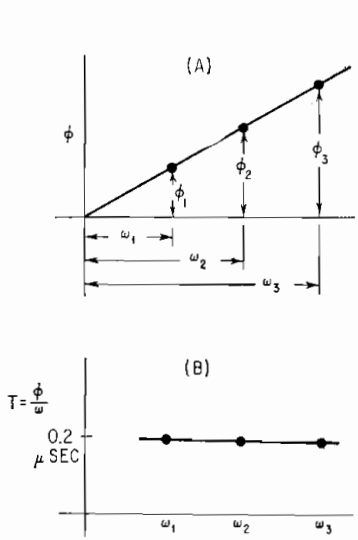


FIG. 3-18. Curves illustrating a system with linear phase characteristics, which will give the same time delay for signals of all frequencies.

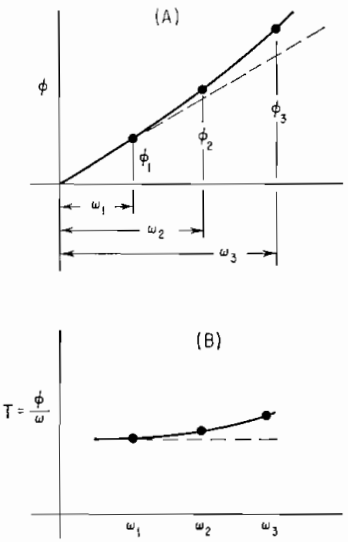


FIG. 3-19. Curves showing the effect of nonlinear phase characteristic on the time-delay characteristic.

introduce *dispersion*. (Conversely, if a system does not scatter the edges and other high-frequency information, it is said to be dispersionless.) The effect of phase distortion on the chrominance information is of a rather special nature and can best be explained by introducing the concept of *envelope delay*.

Envelope Delay

In the preceding discussion, the time delays ϕ_1/ω_1, ϕ_2/ω_2, and ϕ_3/ω_3 were always determined by measuring the frequencies and the phases from $\omega = 0$ and $\phi = 0$. It might be said that the delay at zero frequency is commonly taken as the reference point for all other delays. This method is usually adequate for determining the performance of systems that do not carry any signals which have been modulated onto a carrier. But a carrier, with its family of associated sidebands (Fig. 3-21*b*), can be thought of as a method of transmitting signals in which the zero-frequency reference is translated to a carrier-frequency reference. This translation can be understood by referring to Fig. 3-21*a* and *b*. To calculate the delay of the carrier-borne signals *after* they have been demodulated, measurements of ϕ and ω must be referenced, not from zero frequency, but from *carrier* frequency.

In Fig. 3-22*a*, an impossible phase characteristic has been drawn to aid in further

discussion of this subject. Such a characteristic, consisting of two perfectly straight lines, is never met in practice but makes a very simple system for developing the subject of envelope delay.

First, pass two frequencies ω_1 and ω_2 through this system. Let ω_1 be a carrier and ω_2 a sideband which might be, for example, 1,000 cycles higher. If ω_1 and ω_2 fall on the characteristic as shown in Fig. 3-22*a*, the delay which the 1,000 cycles will show after demodulation can be found putting new reference axes (shown dotted) with ω_1, the carrier, at zero on these new axes. Now, when ω_s and ϕ_s are measured

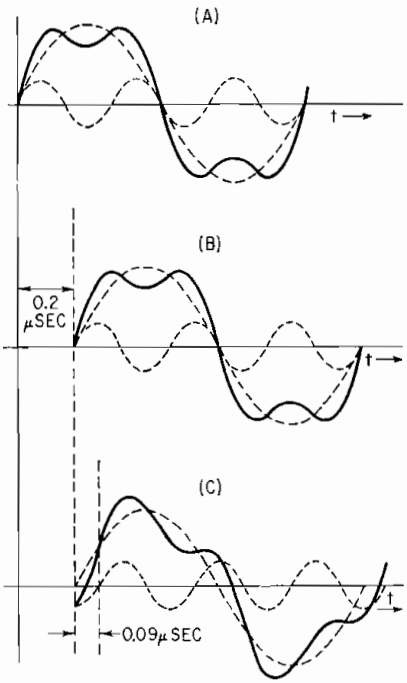


FIG. 3-20. Curves showing that a complex wave (*A*) is not distorted by time delay (*B*) when both components (shown dotted) are delayed by the same amount. Unequal delays (*C*), however, cause distortion.

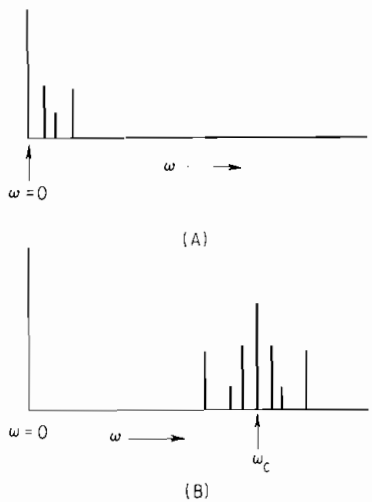


FIG. 3-21. Sketch showing how a group of frequencies near $\omega = 0$ [see (*A*)] can be translated by modulation onto a carrier to a group of sidebands near ω_c – *a* carrier frequency (*B*).

as shown, the time delay after demodulation is ϕ_s/ω_s. In this case, the delay of the 1,000 cycles after demodulation is the same as it would have been had it been passed through the system directly.

Second, pass two other frequencies ω_3 and ω_4 through this system as redrawn in Fig. 3-22*b*. This time drawing in the new axes at ω_3, it can be seen that although ω_s is still 1,000 cycles, ϕ_s' is larger than ϕ_s. Therefore, it can be concluded that the time delay ϕ_s'/ω_s for this second case is greater than for the first case. The 1,000 cycles, when demodulated, will show a considerable error in timing.

Stressing the phrase "delay after demodulation" should not be taken to mean that the demodulation process produces this delay or even makes it apparent where it was previously not detectable. Any delay that a demodulated wave shows was also present when the wave existed as a carrier having an envelope. In short, the delay of the demodulated wave appears first as a delay of the envelope, hence the phrase "envelope delay."

Envelope delay does not constitute a distortion. If a system such as the one shown in Fig. 3-22*a* introduces a delay of 0.2 μsec to the 1,000-cycle wave (measured after demodulation), then the *envelope delay* of the system is 0.2 μsec. However, it was shown that a 1,000-cycle signal passed directly through the system (without first being modulated into a carrier) would also suffer a delay of 0.2 μsec. As long as the envelope delay ϕ_s/ω_s is the same as the time delay ϕ_1/ω_1, the envelope delay introduces no timing errors. But in the second system (Fig. 3-22*b*) the demodulated 1,000-cycle wave suffered a *larger* delay, say 0.29 μsec. A 1,000-cycle signal passed directly through this system, however, would still be delayed only 0.2 μsec. Therefore, the second system has an *envelope delay* of 0.29 μsec and an *envelope-delay distortion* of 0.09 μsec.

It is probably wise to point out that the time delay ϕ_3/ω_3 in Fig. 3-22*b* is considerably less than the 0.29 μsec estimated for the value of envelope delay. Although ϕ_3/ω_3 would be greater than 0.2 μsec (say, for example, that ϕ_3/ω_3 is 0.22 μsec), the value would be optimistic about the amount of timing error that would be shown by the demodulated 1,000-cycle signal. The need for a knowledge of the envelope delay ϕ_s/ω_s of the system is therefore obvious.

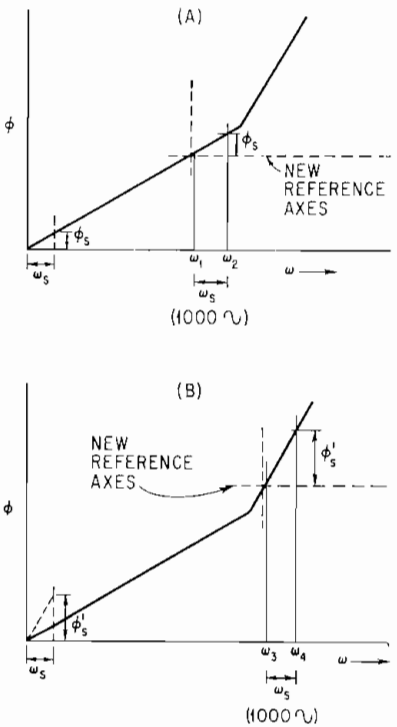


FIG. 3-22. Idealized straight-line phase characteristics showing how a carrier-borne 1,000-cycle signal can be delayed excessively when the carrier and sideband fall on a steeper portion of the phase characteristic.

Effect of Envelope-delay Distortion on a Color Picture

A transmission system which exhibits envelope-delay distortion will destroy the time coincidence between the chrominance and luminance portions of the signal. This will result in misregistration between the color and luminance components of the reproduced picture. The following paragraph explains briefly how envelope-delay distortion causes this error.

Any colored area in a reproduced picture is derived from two signals—a chrominance signal and a luminance signal. Since these two signals describe the same area in the scene, they begin and end at the same time. The chrominance signal arrives at the receiver as a modulated subcarrier; the luminance signal does not. Therefore, as shown above, the delay of the chrominance signal is determined principally by the envelope delay of the system and the delay of the luminance signal is determined principally by the ordinary time delay ϕ/ω. If the two delays are not identical (that is, if there is envelope-delay *distortion*), then the chrominance signal does not coincide with the luminance signal and the resultant picture suffers *color-luminance misregistration* in a horizontal direction.

For example, in a system having the characteristic of Fig. 3-22*b*, the luminance signal is delayed by 0.2 μsec but the chrominance signal is delayed by 0.29 μsec. The error in registration then amounts to 0.09 μsec, or about 0.2 per cent of the horizontal dimension of the picture, which is about 0.3 in. on a 21-in. (diagonal) picture.

Although the subject of compatibility is outside the scope of this part, it is worth noting in passing that envelope-delay distortion adversely affects compatibility, since it causes wideband monochrome receivers to display a misregistered dot-crawl image in addition to the proper luminance image.

General Method for Envelope Delay

The specific cases described above (Fig. 3-22*a* and *b*) made use of simple, idealized straight-line approximations to develop the concept of envelope delay. Practical circuits are not so simple. For example, a simple *RC* network has a ϕ vs. ω plot as in Fig. 3-23. Finding the envelope delay of this curved-line plot will clarify what is meant by envelope delay.

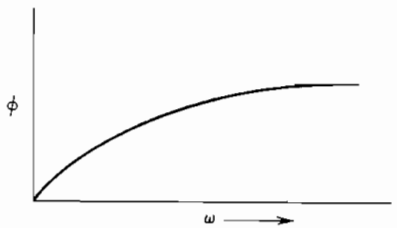


FIG. 3-23. Phase characteristic of an *RC* network.

Referring back to the plots of Fig. 3-22*a* and *b*, it can be seen that the characteristic of the plot that determines the value of envelope delay is its *slope*. The larger envelope delay, which was suffered by the ω_3-ω_4 pair (Fig. 3-22*b*), was a result of their lying on the steeper slope. The envelope delay of *any* system is equal to the slope of the phase-vs.-frequency characteristic. If this characteristic is a curved line (as for the *RC* network, Fig. 3-23), then the slope is different at every frequency and, therfore, the envelope delay is different at every frequency.

The slope of a curved line can be found by the methods of the differential calculus or to a good approximation by breaking up the line into a number of straight-line segments, as in Fig. 3-24. If the slope of each of these straight lines is then plotted against its corresponding frequency (that corresponding to the center of the line), the resulting curve will be approximately the envelope-delay characteristic.

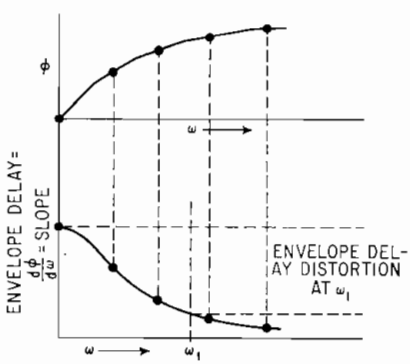


FIG. 3-24. Graphs showing how a series of straight-line segments can be used to approximate the smooth curve of Fig. 3-23 (top) and how the slopes of these segments may be plotted to approximate the envelope delay characteristics (bottom).

Nonlinearities of a Practical Transmission System

It is important to emphasize that the effect of nonlinearities in a color-television system depends upon whether these nonlinearities precede or follow the matrixing and modulation sections of the system. Nonlinearities in transfer characteristics detract from color fidelity; the same degree of nonlinearity after matrixing and modulation also affects color fidelity although in a different way. The purpose of the following paragraphs is to discuss how a nonlinear transmission system affects a *composite* color signal. It is assumed that all other nonlinearities in the entire system either are negligible or have been canceled by use of nonlinear amplifiers such as gamma correctors.

The major sources of nonlinearity in a transmission system are its amplifying devices.[3] These devices—tubes and transistors—have a limited dynamic range. For example, if too much signal is supplied to them, an *overload* results. The transfer characteristic of such a system can be sketched as in Fig. 3-25*a*.

[3] FM systems can have nonlinearity as a result of *passive* networks, but this case is not considered here.

Such a nonlinearity is one of three types commonly encountered in video transmission systems. These three types are:

1. Incremental gain distortion
2. Differential gain
3. Differential phase

The paragraphs below will show that type 2 is merely a special case of type 1.

Incremental Gain

The concept of the slope of a plot, developed in the discussion of envelope delay, will be useful here as well. Consider a plot as in Fig. 3-25*a* which shows output voltage of an amplifier plotted against input voltage. Idealized straight-line plots are shown for simplicity. It can be seen that the amplifier has a maximum output of 3 volts for 1-volt input. Larger input voltages result in no more output; the amplifier *clips* or *compresses* when inputs larger than 1 volt are applied.

The gain of the amplifier is

$$\text{Gain} = \frac{E_0}{E_{in}} = \frac{3 \text{ volts}}{1 \text{ volt}} = 3$$

The gain is obviously constant below the clip point. For example, an input voltage of 0.5 volt gives

$$\text{Gain} = \frac{1.5 \text{ volts}}{0.5 \text{ volt}} = 3$$

But at an input of 1.5 volts, the output is still 3 volts, so the "gain" is only 2. (The word "gain" is of doubtful use here because of the clipping involved.) The gain, defined as E_0/E_{in}, is plotted against E_{in} in Fig. 3-25*b*. It can be seen in this figure that the gain is constant only as long as the *slope* of Fig. 3-25*a* is constant.

It is useful, then, to establish a new term, called *incremental gain,* which will be defined as the *slope* of a plot such as Fig. 3-25*a*. For the particular plot of Fig. 3-25*a*, the slope is constant up to $E_{in} = 1$ volt and then suddenly becomes zero. The corresponding plot of slope vs. E_{in} is shown in Fig. 3-25*c*.

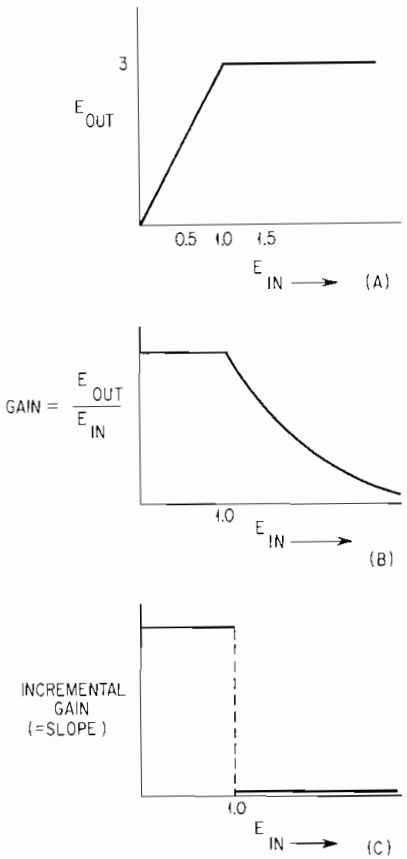


FIG. 3-25. Idealized straight-line plots showing (*A*) output voltage of an amplifier vs. input voltage, (*B*) gain of the amplifier vs. input voltage, and (*C*) incremental gain of the amplifier vs. input voltage. Curve (*C*) is the slope of curve (*A*).

The importance of incremental gain in color television can be assessed by applying the input signal shown in Fig. 3-26 to the distorting system of Fig. 3-25*a*. Before being applied to the distorting system, such a signal could be reproduced on a monochrome receiver as a vertical white bar and on a color receiver as a pastel-colored bar, say, for example, a pale green. After passing through the distorting system, the signal would still be reproduced as a white bar on the monochrome receiver with the only apparent error being a luminance distortion, that is, a slight reduction in brightness, which, for the magnitudes shown here, would probably pass unnoticed. The color receiver, however, would receive a signal completely devoid of any color information and would reproduce a white bar in place of the former pale-green one.

A less extreme case is shown in Fig. 3-27. For the system represented by this characteristic, the slope (incremental gain) does not become zero for inputs above 1

volt but instead falls to one-half its below-1-volt value. The color signal of Fig. 3-27 would not lose all color in passing through this system, but the amplitude of the subcarrier would become only one-half of its proper valne. Since saturation is a function of subcarrier amplitude, the pale green of the undistorted reproduction would, in this case, become a *paler* green. The luminance distortion would also be less than in the extreme (clipping) case.

It can be seen, then, that unless the incremental gain of a system is constant, that system will introduce compression, which will distort the saturation and brightness of reproduced colors. Usually, the error is in the direction of *decreased* luminance and saturation. For certain systems, however, exceptions can be found. For example, the effect that the system represented by Fig. 3-27 will have on a signal depends on

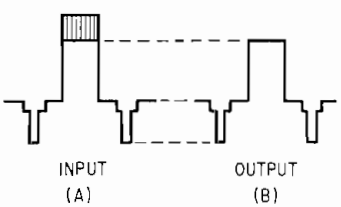


FIG. 3-26. Extreme case of distortion resulting from passing signal at left (*A*) through the amplifier represented by Fig. 3-25. The output (*B*) has no color information remaining.

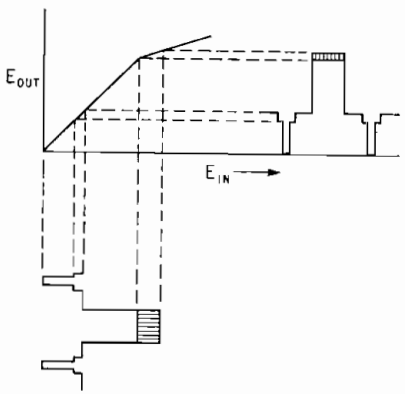


FIG. 3-27. Diagram showing effect of incremental gain distortion in reducing amplitude of color portion of signal.

the polarity of the signal. For the signal as shown, the usual *decrease* in luminance and saturation is exhibited. For an inverted signal, however, the subcarrier amplitude would not be reduced, but the luminance signal would still be diminished. The subjective result of this distortion would be an *increase* in saturation. The unusual behavior of this particular system is attributable to its peculiar transfer characteristic, which was drawn with curvature at one end only to simplify the discussion. Most practical system-transfer characteristics exhibit curvature at both ends and therefore have an effect on the signal which is essentially independent of polarity.

Incremental gain can be measured in two ways, the first of which stems from its contribution to luminance distortion and the second, from its contribution to chrominance distortion.

In the first method, an equal-step staircase waveform such as shown in Fig. 3-28*a* is applied to the system to simulate a signal having equal luminance increments. If the system has constant incremental gain, the output will, of course, also have equal-step increments. But if the system does not have constant incremental gain, certain of the steps will be compressed, as in Fig. 3-28*b*. If the compression is as in the figure, the *incremental gain distortion* (IGD) is indicated by the distorted amplitude of the last step. Numerically, it can be stated as a percentage:

$$\text{IGD} = 1 - \frac{S_{\text{distorted}}}{S_{\text{undistorted}}} \times 100\%$$

where S is a step amplitude.

For example, if an undistorted step is 0.1 volt and the distorted one is 0.075 volt, then the incremental gain distortion would be 25 per cent.

Using the other (chrominance distortion) technique, an input signal consisting of the step wave plus a small, high-frequency sine wave, as shown in Fig. 3-28*c*, is applied to the system. After the signal has passed through the system, it is fed through a high-pass filter which removes the low-frequency staircase. The incremental gain distortion then is indicated by the differences in the amplitude of the high-frequency sine waves (see Fig. 3-28*d*). In this case, the high-frequency sine wave associated with the top step is shown as having 75 per cent of the amplitude of

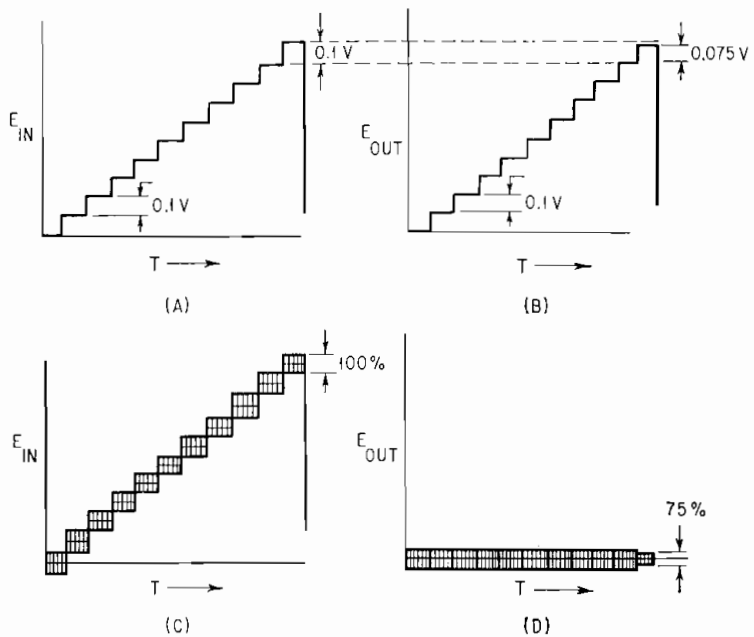


FIG. 3-28. Diagrams showing two methods of measuring incremental gain distortion, namely, in (*A*) and (*B*) by its contribution to luminance distortion and in (*C*) and (*D*) chrominance distortion.

the sine waves associated with the lower steps, which are assumed to be undistorted. Again, the incremental gain distortion is 25 per cent.

A most important point must be made regarding the equivalence of these two techniques. Certain systems which show incremental gain distortion when tested by the luminance-step technique may or may not show the same distortion when tested by the high-frequency and high-pass-filter technique. Moreover, a system which shows distortion by the second technique may or may not show distortion by the first. In other words, the incremental gain distortion may be different for different frequencies. Such differences are frequently found in staggered amplifiers, feedback amplifiers, or amplifiers having separate parallel paths for high and low frequencies, such as might be found in stabilizing amplifiers.

A thorough test of a system, therefore, should include tests of its incremental gain by both techniques. The staircase-plus-high-frequency waveform can be used to provide *both* tests by observing the system output (for this test waveform input) first through a low-pass filter and then through a high-pass filter. The first test will show low-frequency distortions; the second, high-frequency distortions.

Differential Gain

On the basis of the above discussion of incremental gain distortion, the extremely important concept of *differential gain* can be presented merely as a simple definition. Differential gain is identical with incremental gain distortion when the latter is measured by observing ". . . the difference in the gain of the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal upon which it is superimposed."[4] In other words, differential gain is a special form of incremental gain distortion which describes the IGD of a system for the superimposed high-frequency case only.

One of the reasons for selecting the high-frequency aspect of incremental gain distortion for the IRE definition of differential gain was applied in Fig. 3-26, when the ". . . high-frequency sine wave . . ." of the definition was made equal to color subcarrier. This special case of differential gain explores the system gain linearity in the vicinity of this particularly important frequency. The definition of differential gain was purposely made in the broad terms of a ". . . high-frequency sine wave . . ." to allow the greatest possible versatility in devising methods of measurement. In present color-television practice, however, the ". . . high-frequency sine wave . . ." is always color subcarrier and the low-frequency signal mentioned in the definition is a 15,750-cycle staircase, sine-wave, or sawtooth. The complete specifications for the signal presently used in this measurement will be found elsewhere in this manual.

Another reason for emphasizing high-frequency IGD was implied previously by the sentence ". . . the signal . . . would . . . be reproduced . . . with the only apparent error being a luminance distortion . . . which, for the magnitudes shown here, would probably pass unnoticed." The magnitude shown was a 25 per cent IGD, which is passing unnoticed, indicating that large incremental gain distortions usually cause no detectable luminance errors. Incremental gain distortion is almost too sensitive a tool to measure luminance distortions. For this purpose, simple gain distortion (compression) is more useful. Therefore, the luminance-distortion aspect of IGD was deliberately omitted from the definition of differential gain.

Incremental Phase and Differential Phase

The phase characteristic sketched in Fig. 3-17 indicates that the system described by this plot will introduce a certain amount of phase shift for any given frequency. For example, it might be found that a certain system would introduce a phase shift

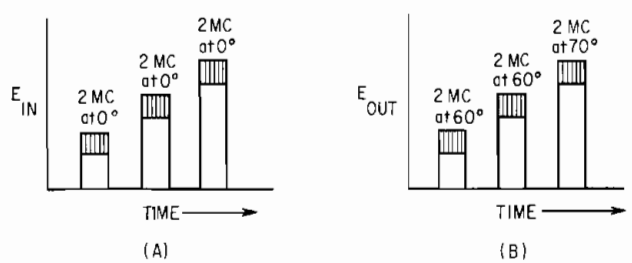


FIG. 3-29. Graphs illustrating how a signal (*A*) may undergo different phase shifts (*B*) depending upon where the zero axis at the sine wave falls on the system transfer characteristic. This distortion is called differential phase.

of 60° at 2 Mc/sec. If the system in question were perfectly linear, this 60° phase shift would be produced regardless of how the 2-Mc/sec signal might be applied to the system.

It can be shown, however, that some systems, when presented with a signal of the type shown in Fig. 3-29, will introduce a delay *different* from 60°, depending on where the zero axis of the sine wave falls on the transfer characteristic of the system. For

[4] From the definition of differential gain by IRE Subcommittee 23.4.

the case sketched in the figure, a phase shift of 70° is drawn for the largest zero-axis displacement.

By analogy with the incremental gain and differential gain arguments above, it is possible to define three quantities which pertain to this type of distortion. These quantities are *incremental phase, incremental phase distortion,* and *differential phase.* It can also be shown that of the three, differential phase is the most important quantity.

Incremental phase is the least exact analogue, since it is not very similar in form to incremental gain. Incremental *gain* is a *slope;* incremental phase is simply the absolute value of phase shift. In the above system, the incremental phase was 60 or 70° (or somewhere in between), depending upon the location of the zero axis.

Incremental phase distortion, like its analogue *incremental gain distortion,* depends upon the magnitude of the error. It should be zero for a perfect system. In the system of Fig. 3-29 the 2-Mc/sec signal with 70° incremental phase would be said to have 10° incremental phase distortion, so it is clear that the difference between two phases (one of which is assumed to be "correct") gives the incremental phase distortion.

As previously stated, *differential gain* is identical with *incremental gain distortion* for the superimposed-high-frequency case only. Similarly, *differential phase* is identical with *incremental phase distortion,* but there is no need to limit the definition to the superimposed-high-frequency case, since there is no other case which is meaningful for phase distortion. Without the superimposed sine wave, no phase measurement is possible. Therefore, differential phase is identical with incremental phase distortion. In practical work, the first two terms are seldom used, for the last, differential phase, has been found completely adequate to describe this aspect of a system.

In summary, the differential phase of a system is ". . . the difference in phase shift through the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal ou which it is superimposed." [5]

It is important that the phrases "differential phase *distortion*" and "differential gain *distortion*" be avoided because differential phase *is* distortion as is differential gain, since they are defined as being identical with incremental phase distortion and incremental gain distortion, respectively. To add the word *distortion* to either is redundant. A sample of proper usage is "this amplifier has a differential gain of 1.5 per cent and a differential phase of 0.5°."

Effect of Differential Phase on a Color Picture

The phase of subcarrier in a composite signal carries information about the *hue* of the signal at that instant. If the signal passes through a system which introduces differential phase, the subcarrier phase (and hence, the hue) at the output will become dependent upon the amplitude of the luminance associated with the hue, since it is the luminance signal which determines the location of the zero axis of the subcarrier. For example, a system introducing 10° of differential phase might be adjusted to reproduce properly a low-luminance hue such as saturated blue or a high-luminance hue such as saturated yellow, but *not both.* One or the other would have to be in error.

STATE OF THE ART

The preceding portions of this part have discussed in general terms the possible sources of color errors in a color-television system. In no practical system can any of these errors be reduced to zero; therefore, anyone working with practical systems should know how nearly perfect any given parameter should be to be considered acceptable according to the present state of the art.

System Colorimetry

Talking qualitatively about colorimetric accuracy is one thing; assigning numbers and magnitudes is quite another. For the practical purposes of this part, however,

[5] From the definition of differential phase by IRE Subcommittee 23.4.

we are spared the need of digging deeply into the quantitative aspects of colorimetry by one simple fact: At the present time, color errors attributable to phosphor errors, filter errors, and other basic colorimetric errors are negligible in comparison with other sources of error.

System Exponent

At the present state of the art, adjusting a system to precompensate for a kinescope exponent of 2.2 is not enforced by the Federal Communications Commission, since this parameter is not yet well established. Adjusting the system to precompensate for this median value, however, can be done with precision. A gamma corrector which uses four or five diodes to make a series of straight-line approximations to a 0.7 exponent can be made so as to have a maximum error of less than 2 per cent of the peak signal amplitude. The exponents of the three channels can be made to match within 1 per cent of the peak signal amplitude.

Matrix Coefficients

A high-quality matrix, such as would be found in a well-engineered colorplexer or studio monitor, uses 1 per cent precision resistors for all resistances which will influence the values of the coefficients, while inverters and amplifiers are either stabilized by feedback or made adjustable. Errors of greater than 2 per cent are rare in such circuits.

White balance in the transmitter matrix, which is a special case of the subject of matrix coefficients, can usually be adjusted and held to a tolerance of the order of ½ per cent of peak white.

Phase Accuracies

Adjustment of Q subcarrier, I subcarrier, and burst to within 1° of their proper relative phases is easily accomplished using standard commercial equipment and techniques. This accuracy is ten times that required by the Federal Communications Commission.

Subcarrier-frequency Accuracy

Subcarrier frequency can be easily adjusted to within ± 1 cycle, the real limit on the accuracy of the adjustment being in the inherent accuracy of the standard used for frequency comparison. Long-term stability of well-engineered equipment should be easily within the required limits of ± 10 cycles.

Transmission Characteristics

A single amplifier should have a gain characteristic with less than $\pm ½$-db variation out to 8 Mc. Its envelope-delay error should be of the order of 0.001 μsec at 3.58 Mc, relative to 200 kc. Differential gain of ½ per cent and differential phase of 0.25° represent good performance.

TOLERABLE COLOR ERRORS

The eye's sensitivity to color errors depends upon the manner in which two colors—the original and the reproduction—are compared. For example, if the two colors are placed side by side, the eye becomes a very sensitive indicator of color errors. However, if the comparison is made only by color memory, the eye is far more lenient in its requirements of perfect reproduction. Furthermore, if the reproduced color is one that the eye has never viewed before, the eye requires only that the color relayed to the brain be plausible, that is, that it be a reasonable color for the object concerned.

Fortunately, side-by-side comparison of colors never occurs in home viewing of color television. However, the system is frequently called upon to reproduce objects whose colors may be well known to the viewer, such as flesh tones or a sponsor's

packaged product. The reproductions of these objects must be accurate enough to satisfy the viewer's color memory. And if the system can satisfy the color memory of the viewer, the color-plausibility requirement will be easily met.

Several investigations have been made to determine the sensitivity of the eye to color errors expressed as burst phase errors, Q amplitude errors, etc. The results of two of these investigations [6] are summarized briefly in the following paragraphs:

Above all, it must be borne in mind that the following information represents the effect of changing only the parameter specified while every other parameter in the system remained constant and as nearly perfect as possible. In all cases, the data resulted from subjective tests of a fairly large number of viewers, and almost every viewer used flesh-tone reproduction as the criterion of acceptability. All but the phase data below are from the second reference. The error magnitudes indicated resulted in marginal pictures; larger errors caused the average viewer to class the pictures as "not quite passable."

The amplitudes of the three primary colors themselves proved to be the most critical, in general, of all the variables measured. A -27 per cent change in green could be tolerated; a -28 per cent change in red was found allowable. The permissible positive changes in these colors were 40 and 32 per cent, respectively. Tolerable blue changes were -35 and $+53$ per cent. Subcarrier amplitude, it was found, could vary ± 45 per cent before the pictures were objectionably degraded. A comparatively small negative change in M amplitude, -30 per cent, raised viewers' objections, but a fairly large position error, -72 per cent, could be tolerated. The amplitude of I could fall only 34 per cent before the pictures were rejected, but it could rise 70 per cent before the reproductions were classed as definitely below par. The least sensitivity was shown by Q (namely, -94 and $+135$ per cent), but the reader should again be reminded that observers admitted using flesh-tone reproduction as the criterion of acceptability, and Q contributes very little to flesh tone.

Also of interest are the approximate variations allowed before the reproductions were downgraded from "excellent" to "good." The three primaries were allowed approximately a ± 20 per cent variation: subcarrier amplitude, about a ± 30 per cent variation; M and I both about $+40$, -20 per cent; and Q about $+60$, -55 per cent.

Both of the investigations referred to agree that the maximum phase error for tolerable picture reproduction was about $\pm 20°$ for the average observer. The first investigation reported, in addition, that although this figure represented the numerical average, a phase tolerance of about $\pm 11°$ was all that could be tolerated by 90 per cent of the observers.

If the reader finds these tolerances to be large in comparison with the magnitudes discussed before, he is reminded that a number of cascaded elements in a system may provide an appreciable fraction of these magnitudes and that furthermore, the errors in a typical operating system will include simultaneously *several* of these degrading factors. Also, the subcarrier amplitude and phase in the receiver are under the control of the viewer, who sets them without the aid of any measuring device other than his eyes' judgment. Therefore, careful attention to all parameters at the point of origin is essential to the production of good pictures in the viewer's home.

Conclusion

Although this part may appear to be negative in its approach to the subject of color fidelity, the reader should bear in mind that, in spite of these seemingly unfavorable descriptions of what *might* happen in a system, the picture quality at the output of a *properly adjusted* color-television system is excellent. The apparent pessimistic attitude results, of course, from the need for defining the boundaries of system performance. Therefore, in conclusion, let it never be forgotten that, within these boundaries, there lies one of the best commercial color-reproducing systems that has ever been devised.

[6] Pritchard, "Visibility of Hue Change versus Overall Phase Error in N.T.S.C., Proposed Color Television Specifications," RCA Internal Report. Weiss, Significance of Some Receiver Errors to Color Reproduction, *Proc. IRE*, vol. 42, no. 9, September, 1954.

Part 4

THE COLORPLEXER

The RCA colorplexer performs the required encoding and processing of RGB signals emanating from the color camera and produces a color video signal conforming to FCC specifications.

As the "heart" of the color system, the colorplexer centralizes a number of very important operating adjustments. Figure 4-1 shows the functional location of the equipment in the basic color-television system.

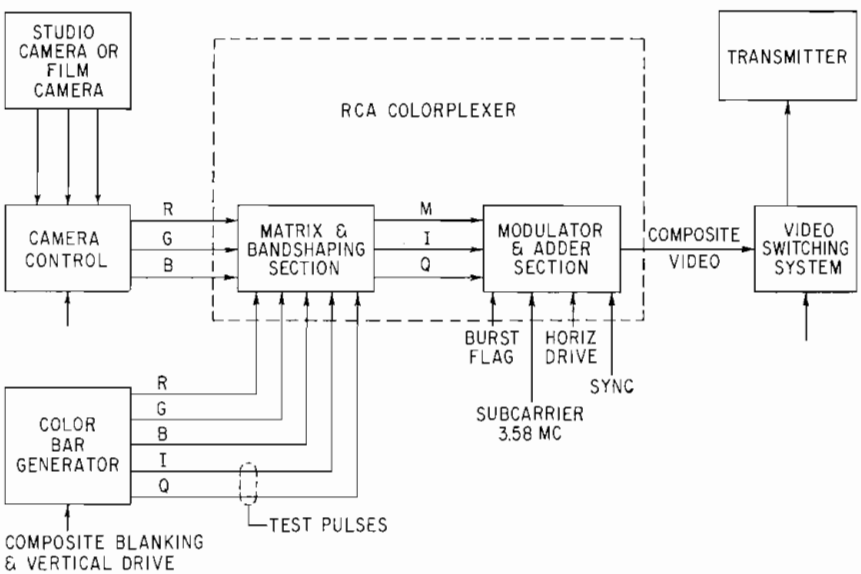


FIG. 4-1. Basic color-television system showing functions and major components of the colorplexer.

BASIC FUNCTIONS

The principal operations and functions performed by the colorplexer include:

1. Matrixing of RGB video signals to produce luminance and chrominance signals
2. Filtering of chrominance signals to required bandwidth
3. Delay compensation to correct for band limiting
4. Modulation of 3.58-Mc carriers by chrominance signals
5. Insertion of color sync burst

6. Aperture compensation of luminance signal
7. Optional insertion of sync
8. Addition of signal components to form a complete color signal

Derivation of luminance and chrominance signals and the principles of matrixing, bandwidth limiting, and color subcarrier modulation are described in Part 2. Aperture compensation is employed to boost the amplitude of the high-frequency component of the video signal, improving the over-all video-response characteristic. This technique is desirable because the finite size of the camera scanning beams, together with the limited resolving power of lenses, produces a video signal with deficient contrast range in picture areas with fine detail. The aperture compensation circuit, which is described in later paragraphs, is of a type that boosts high-frequency components without distorting their phase.

DESIGN FEATURES

The RCA colorplexer, type TX-1, consists of three chassis units designed for installation in a standard 19-in. rack, requiring a total height of only 26 in.

Several features are incorporated in the colorplexer circuits to facilitate operation and to enhance picture quality.

Provision is made for shifting the phase of the incoming 3.58-Mc carrier through 360° to permit signals from several colorplexers to be lined up with respect to subcarrier phase at some common point, such as the output of the switching system.

An automatic-balance-control circuit for the carrier provides instantaneous correction voltages for maintaining carrier balance in the modulators at all times, although manual balance adjustments are provided in the modulators to permit both differential gain and a-c impedance measurements to be made.

A selector switch in the colorplexer gives the operator a choice of two inputs—camera signals or test signals from a color-bar generator. The color-bar generator provides a total of five signals. These signals consist of the RGB video signals plus special test pulses which are very useful in checking phase adjustments of the I and Q modulators. I and Q test pulses are inserted directly into the I and Q channels as shown.

Operating controls for the various functions are mounted on the front of the chassis. Test jacks installed at several points in the circuits provide for observation of waveforms. A few of these waveforms are discussed later, under Colorplexer Operation.

Circuit Description

To aid in describing the circuits, the colorplexer has been divided into two sections in accordance with their functions. In the matrix and band-shaping section, the red, green, and blue signals are transformed into M, I, and Q signals, which are then adjusted with respect to bandwidth and delay. The multiplexing operations required to produce a composite signal from the M, I, and Q signals take place in the modulator and adder section.

Matrix and Band-shaping Section

With reference to the basic circuit arrangement for the matrix and band-shaping section of the colorplexer, RGB signals at 1-volt levels are fed through coaxial jacks and applied through the matrix resistor network to the grids of separate M, I, and Q pentode amplifiers.

In the M amplifier, sync is combined with the matrixed RGB signals to form the composite monochrome signal, which is fed through a coaxial delay line to amplifiers in the modulator-adder section.

The I signal is developed in the I amplifier by application of a red signal to the control grid and blue and green signals to the cathode. This I signal is then fed through a coaxial delay line, a 1.5-Mc band-limiting filter, and a phase splitter to the I modulator tubes. It so happens that the signal produced by the I channel is inverted

in polarity relative to the M and Q signals, but this poses no problem in view of the fact that the polarity is readily corrected by proper connections in the modulator which follows.

The Q signal is obtained by applying the green signal to the control grid of the Q amplifier and the red and blue signals to the cathode. The Q signal then passes through an 0.5-Mc filter, amplifier, and phase splitter to the Q modulators. Delay networks, which compensate for band-limiting of the chrominance signals, consist of specified lengths of high-impedance delay cable. A sync delay line is not required, since sync is added to the monochrome signal ahead of the delay line.

Aperture Compensation

As previously mentioned, the aperture compensator is employed to compensate for the finite size of the electron scanning beam in color studio or film cameras. The aperture compensator is connected electrically to the colorplexer, and no other aperture compensation is necessary in the system.

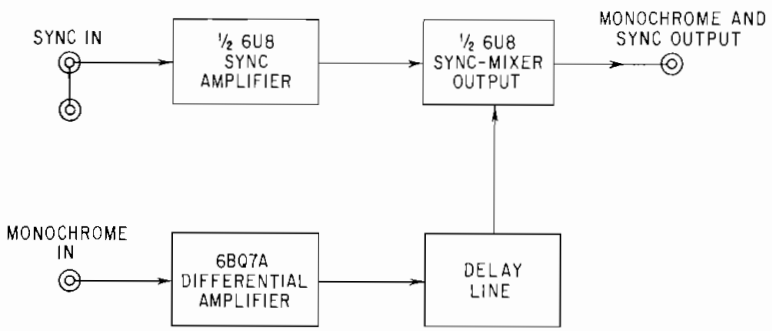


Fig. 4-2. Simplified block diagram of aperture compensator.

Since the monochrome channel is a wideband channel and the I and Q channels are narrow band, it is necessary to apply compensation to only the monochrome channel. It is not desirable to aperture-compensate the sync signal; therefore provision is made for adding sync after compensation.

Circuitry of the aperture compensator is shown in the simplified block diagram of Fig. 4-2. The circuit consists of a differential amplifier which feeds an open-circuited delay line. The open-circuited end of the delay line is connected to the grid of an output amplifier which drives the monochrome delay line. Part of the plate load of the output amplifier is common to the sync amplifier; thus sync can be added at this point if desired.

Modulators and Automatic Carrier Balance

Circuits required to produce the I and Q color subcarrier, insert the color burst, and multiplex the monochrome and color video signals are shown in simplified form in Diagram B. The basic components consist of two pairs of balanced modulators, amplifiers for the 3.58-Mc carrier with provision for 90° phase displacement, "adder" stages for combining the composite M signal with the color and burst signals, and automatic-balance-control circuitry for the carrier to maintain complete 3.58-Mc carrier suppression in the output of the modulators.

I and Q signals developed in the matrix and band-shaping sections of the colorplexer are applied through tube-type phase splitters (in phase opposition) to the control grids of the balanced modulators, while 3.58-Mc carrier voltages with a 90° phase difference are applied to the suppressor grids. Since the plates of the modulators are in parallel,

the carrier voltages in each pair of modulators cancel out, leaving only the signal which is the vector sum of the I and Q sidebands in phase quadrature.

The composite color signal from the output of the adders is applied to a two-stage gate in the automatic-balance-control unit for the carrier (see Fig. 4-3). This gate is normally biased in the "off" condition, but it is keyed by horizontal drive pulses, which make it conduct only during the horizontal blanking time (prior to color sync burst) so that only the signal components of the unbalanced subcarrier are amplified. Output from the gated amplifier is fed to two bridge-type diode discriminators through tuned circuits. Reference subcarrier signals are applied in phase quadrature to the two discriminators in such a way that each develops an output voltage proportional to

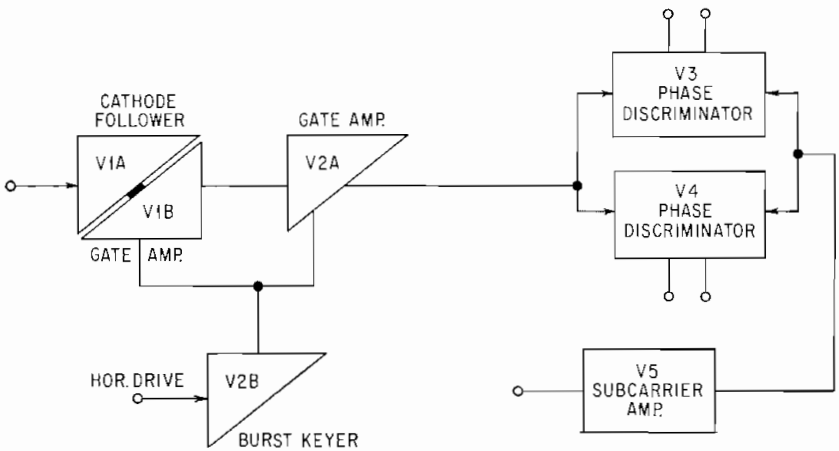


FIG. 4-3. Block diagram of automatic carrier-balance control circuits.

the carrier unbalance in either the I or the Q channel. These correction voltages are then applied as bias voltages to the I and Q modulators to maintain a state of proper balance.

Adders and Output Amplifiers

The complete color signal is formed in the common plate circuits of the monochrome, chroma, and burst adder stages. From these stages the color signal is passed through two feedback amplifiers. The first of these provides most of the required voltage gain and contains a low-impedance video gain control. The second feedback amplifier is the output stage which has sufficiently low output impedance to permit the connection of three separate 75-ohm outputs with a high degree of isolation. The composite color signal is clamped at the proper level in the first feedback amplifier by a clamp tube driven by horizontal drive.

The subcarrier signal, supplied from a frequency standard operating at 3.579545 Mc, is applied through an amplifier and adjustable phase-shifting network to phase-displacement networks that provide subcarrier signals of correct phase displacement for the burst gate, modulators, and automatic carrier-balance circuits. A keying signal from the burst flag generator is applied through an inverter tube to the suppressor of the burst gate. The 57 and 33° delay elements shown in the block diagram provide the necessary phase relationship between burst and I and Q signals as described previously.

OPERATION OF THE COLORPLEXER

Correct settings for the operating controls of the RCA colorplexer are obtained by following a step-by-step procedure described in the "Colorplexer Instruction Book."

Thereafter, tests verifying proper adjustment are usually made at the beginning of each operating day. Personnel soon become familiar with the controls and their effects on the output signal, and the detailed initial adjustment procedure then resolves itself to a few routine steps.

Colorplexer setup involves adjustment of signal amplitudes and phase with the aid of test equipment, some of which is designed especially for color use. Actual reproductions of waveforms displayed by an oscilloscope connected to significant points in the circuitry are presented in this section to assist the reader in visualizing colorplexer operation (see Fig. 4-6).

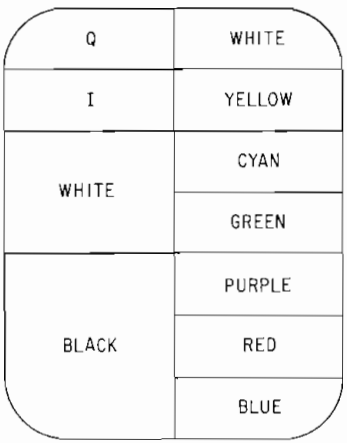


FIG. 4-4. Diagram showing color monitor display of color and test bars electronically produced by RCA color-bar generator.

Test equipment required to produce these waveforms consists of a color-bar generator and an oscilloscope. The color-bar generator is capable of producing on the screen of a color monitor all the signal bars illustrated in Fig. 4-4. Colors in the top portion of the pattern are arranged from left to right in their order of luminance. The lower portion of the pattern contains, from left to right, a special I signal, a special Q signal, a white signal, and a black signal. The special I and Q signals simplify subcarrier phase adjustments, and the white signal facilitates white-balance adjustment. Limiting action assures constant level output of 1 volt, peak to peak, for all signals. The generator requires input signals consisting of composite blanking and vertical drive, both at standard 4-volt peak-to-peak levels. The oscilloscope should have a bandwidth of 10 Mc together with excellent transient response which is required in making accurate waveform analyses.

Waveforms

The composite color waveform obtained at the output jack of the colorplexer can serve to verify all adjustments of the colorplexer excepting the phase of the color burst. Colors from left to right, in descending order of luminance, are white, yellow, cyan, green, purple, red, and blue. Correct amplitudes for these bars and other signal components in the waveform, expressed in IRE scale units (1 volt peak to peak equals 140 IRE scale units), are given in the corresponding line diagram of Fig. 4-5. The photograph shows only the waveforms corresponding to the sequence of color bars shown on the top half of the raster in Fig. 4-4, but the line diagram in Fig. 4-5 also shows the test bursts produced by the special I and Q test pulses adjacent to the color sync burst. As seen, the yellow and cyan bars should be adjusted to coincide at 133

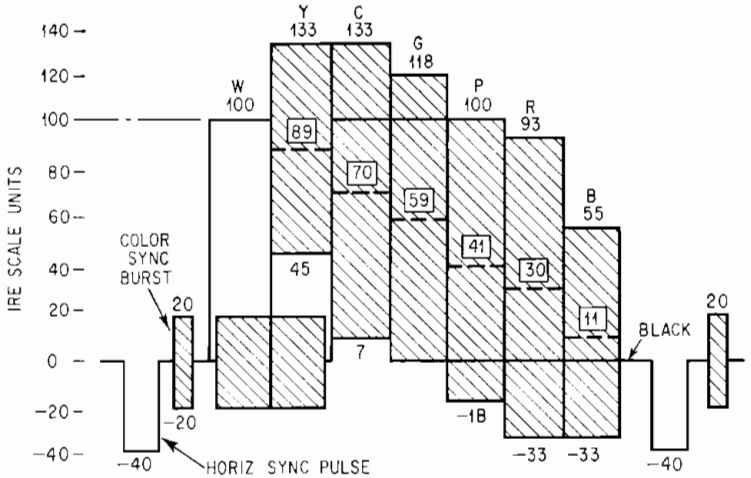


FIG. 4-5. Correct relative amplitudes for color bars, burst, and sync pulses, expressed in IRE scale units (1 volt peak to peak equals 140 IRE scale units).

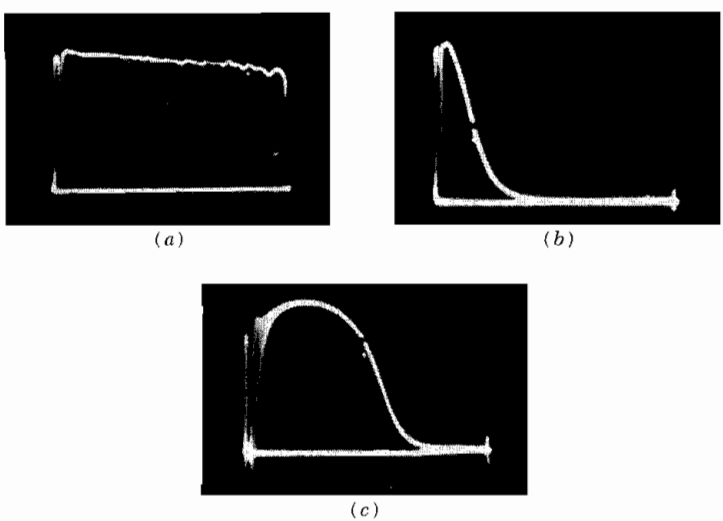


FIG. 4-6. Waveforms showing response characteristics of colorplexer monochrome, I and Q channels. (*a*) Response of monochrome channel without aperture correction, marker at 8.0 Mc; (*b*) outpnt of I filter, marker at 2.0 Mc; (*c*) output of Q filter, marker at 500 kc.

units, and the red and blue bars should coincide at −33 units. The bottom edge of the green bar should just touch the black level, and the top of the purple bar should meet the reference-white level.

Other output waveforms include that of the monochrome signal, obtained by switching out the I and Q amplifiers, and the separate I and Q waveforms obtained with the monochrome switched out. The monochrome signal contains the luminance information of the color-bar signal and hence produces the descending step pattern shown. The I and Q waveforms are useful in setting the proper peak amplitudes for these signals as well as the 90° phase separation. The slow rise time apparent in components of the Q waveform is due to the 0.5-Mc Q-channel filter. The effects of the I filter are not so pronounced and are barely visible in the I waveform.

The special I and Q test bursts shown in Fig. 4-5 can be used to check phase adjustments of the I and Q modulators relative to each other and the burst gate. The instrument used for the purpose is a color-signal analyzer.

Bandpass characteristics of the colorplexer are illustrated by the waveforms shown in Fig. 4-6. These waveforms are typical for a properly adjusted colorplexer and were obtained at the output jacks of the colorplexer.

Part 5

FACTORS AFFECTING COLOR-CAMERA PERFORMANCE

The following general principles underlying proper alignment and operation of the color camera, as they differ from those for monochrome cameras, are presented to assist the station engineer in understanding the effect that each adjustment can have on the composite picture. No attempt is made to present step-by-step alignment procedures.

Although the controls for the three image orthicons in the color camera are similar to those of the monochrome camera, a few additional controls and new alignment techniques are required to permit registration of the images and proper level control of the three signals.

It is important to point out that color-camera setup should be made by viewing the proper test chart. This is the only tool for a true indication of the required camera adjustments. The practice of making indiscriminate adjustments during a scene to "paint" a pleasing picture should be avoided in color-camera setup. It is successful for only the specific scene, and there is too little time during programming to make the required readjustments for subsequent scenes. Also, certain controls of the camera when improperly set give false indications that other controls are misaligned. Therefore, maximum effort should be given to correct alignment of the controls before program time. During operation, a properly aligned camera requires no more than routine adjustments of the master gain control and an occasional adjustment of the master pedestal.

"Q" AND "SKEW" CONTROLS

The "Q" controls, one for the horizontal and one for the vertical, are interconnected to the individual deflection circuits and are utilized to affect the linearity in order to match the scans over the entire raster. A change in the settings of the individual height and width controls changes the reactance-to-resistance ratio in the deflection circuits, affecting the linearity of the channel. Adjustment of the Q control keeps the ratio and linearity the same in each channel.

The "skew" controls, which are connected in the red and blue channels, introduce a small amount of sawtooth waveform at a vertical rate into the horizontal deflection yoke to center the horizontal scan by different amounts at the top and bottom of the raster. This serves to compensate for normal manufacturing tolerances in the axial placement of the yokes. This variation results in a slightly rhomboidal-shaped raster, different in each channel. This amounts to only a degree or two and is not noticeable in monochrome cameras, where only one signal is used. The need for skew adjustment is seen on the kinescope when the vertical lines of two superimposed channels are not parallel after the horizontal lines have been made parallel with yoke rotation.

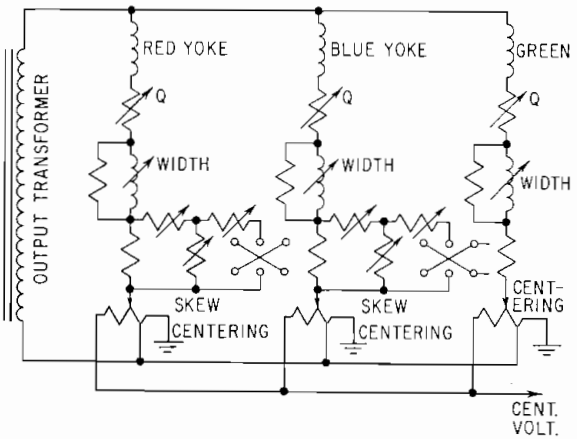


FIG. 5-1. Schematic diagram of horizontal scanning circuit showing location of Q and skew controls.

TEST-CHART LIGHTING

It is already apparent to monochrome-television broadcasters that good lighting techniques are of utmost importance in obtaining good picures. This holds true for color operation, where requirements are even more stringent. A very important phase of aligning television cameras, often overlooked by the engineer, is that of lighting the test pattern. The amount of light is not important provided the level is at least high enough to bring the highlights a little above the "knee" of the image-orthicon transfer characteristic when the remote iris is wide open. Of utmost importance, however, is the placement of lights.

An evenly lighted pattern with a minimum of surface reflectance can be obtained with two equal-size scoops equidistantly placed at 45° angles to the chart. For angles less than 45°, a large amount of surface or direct reflection may enter the camera lens. The image on the photocathode then contains excessive ambient light that gives a distorted gray scale and upsets the true black level. The scoops should also be at the same height as the chart. Direct light from all other scoops and spots should not be allowed to fall on the chart. If the pedestals are first matched with the lens capped, and if no surface reflectance is present, very little adjustment of the individual pedestals should be required to match the black levels of the test chart. If the knees and pedestals have been matched when an improperly lighted test chart was viewed, the color balance will be distorted in both highlights and lowlights when the scene is shifted to the studio set.

OBJECTIVE-LENS IRIS SETTING

When more than one lens iris is contained in an optical system, the over-all aperture and depth of field are defined by the lens that is stopped down to the greatest f number. Since the remotely controlled iris is in the relay lens, which has a speed of f-4, the objective lens should be set to f-4 so it will not limit the maximum over-all aperture. Opening the objective lens greater than f-4 will only add flare light to the picture.

IMAGE-ORTHICON OPERATION

The color image orthicon is designed especially for color work. The alignment techniques for this tube follow very closely in accordance with best monochrome practice using the type 5820 image orthicon; however, the nature of the color signal,

composed of the mixed outputs of three image orthicons, requires a more precise degree of signal uniformity and freedom from spurious signals. Manufacturing tolerances have therefore been tightened for the color tube, and each image orthicon is system-tested to rigid specifications in order to assure uniform characteristics of the tubes. This eliminates the necessity of buying image orthicons for the color camera in matched sets of three and allows any tube to be replaced by another without replacing the entire set.

It is common monochrome practice to operate the image orthicon above the knee of its transfer characteristic, since this offers a better signal-to-noise ratio and partially corrects gamma in the signal; also the redistribution effect of secondary electrons on the target preserves the fine detail in the highlights. For color operation, however, the image orthicon must be free of any random redistribution that will distort the color information. Furthermore, it must also be operated below the knee over a constant gamma range.

The capacity of the target assembly has been increased in the color version over that of the 5820 by reducing the screen-to-target spacing. This extends the contrast range and improves the signal-to-noise ratio below the knee. The closer spacing allows the screen to collect more of the secondaries from the target. This eliminates random secondary redistribution of the target and "ghost" and "halo" effects. It has been found that the color tube is difficult to handle for large changes of light level reaching the photocathode, so the 5820 is still preferred for monochrome operation where the highlights are allowed to extend above the knee.

An important consideration when a color camera is initially aligned is that all image orthicons should be operated at about the same conditions. Targets should be maintained at 2 volts above cutoff, and the G-4 (Orth Focus) potentials set about equal.

Shading

Extreme care should be taken to obtain the best shading characteristics from the image orthicons rather than correcting later in the system with the shading signals

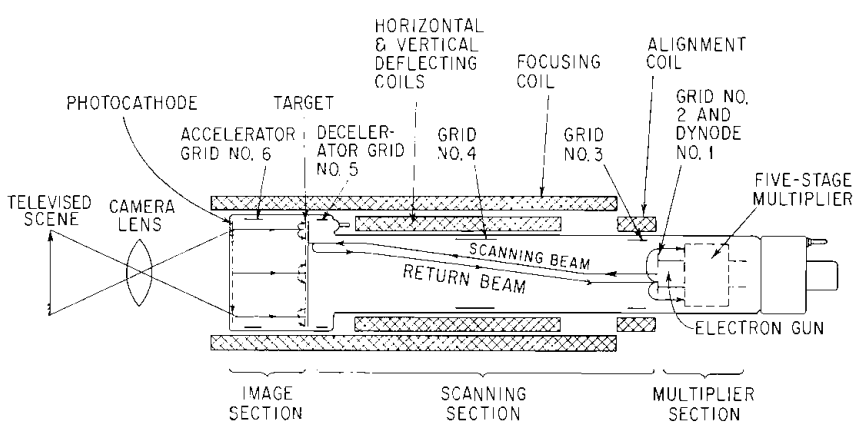


FIG. 5-2. Diagram showing elements of the image-orthicon pickup tube.

provided in the processing amplifier. These shading signals superimposed on the video signal are fixed-amplitude waveforms and therefore can correct properly at only one video-amplitude level. At other video-amplitude levels the same amount of shading signal is superimposed, but the shading component originating in the image orthicon may vary as a function of the video amplitude.

The shading component is due mainly to a change in the current amplification in the multiplier section as the return beam scans a small area of the first dynode. The

effect of any variations of the secondary-emission ratio over the first dynode will be amplified in the other dynode sections. Therefore, special care is taken in manufacturing the color tube to assure the most uniform and stable secondary-emission characteristics of the first and second dynodes and uniform collection of the secondary electrons.

The color camera requires careful adjustment for best shading because slight differences in the shading components from the three image orthicons will result in severe color distortion, especially in the lowlights. This is seen as spurious changes of hue superimposed over the dark areas of the color picture.

The amplitude of the shading component is a function of the return beam. Therefore it is greatest in the dark areas, where the return beam is maximum, and decreases toward the highlight areas, where the return beam is decreased. All operation on the shading characteristics of the image orthicon should be made with the lens capped. This represents the worst case of shading, since the beam is then completely returned to the first dynode.

The shading generator in the processing amplifier inserts a constant wave shape into the video signal which adds the same amplitude to the dark areas as to the highlight areas, so that the shading-generator signal does not completely cancel the shading component over the entire gray scale. For this reason the best shading possible should first be obtained out of the image orhicon with the shading generator cut off. The necessary shading-generator signal should then be added to give the flattest waveform as seen on the CRO. This adjustment is also made with the lens capped, since in dark areas of the picture a given shading component represents a larger percentage of the signal than in the highlight areas.

G-5 Control

Reducing the potential on G-5 (decelerator grid) decreases the area scanned by the return beam on the first dynode. This potential should be set as high as possible in order to avoid burning the first dynode. G-5 also serves to cause the beam to approach the target perpendicularly at the edges. This eliminates "portholing" a dark ring around the edges. Portholing is introduced as the G-5 potential is reduced. The proximity of G-5 to the target corners causes the potential on G-5 to influence the scanning geometry at the corners of the picture.

Because of the three effects mentioned above, G-5 should be run as far clockwise as possible consistent with good shading. It is decreased to reduce any shading component in the corners due to variation in the secondary-emission ratio over the first dynode. It is also decreased to scan the first dynode inside any burned areas which appear as "clouds" or white streaks when the lens is capped. If difficulty is experienced in registering the corners of the three image orthicons, it may be necessary to decrease the G-5 potential on one or both of the other image orthicons if the third G-5 has been reduced for shading considerations.

The area of the first dynode scanned by the return beam is also directly controlled by the deflection field. The centering and over-all size controls can therefore be used to improve shading, but it is usually desirable to set these controls to scan as large an area of the target as possible.

Multiplier Focus

The potential on G-3 (multifocus) influences the shape of the electrostatic field between the first and second dynodes. This field, in combination with the magnetic focus field, serves to collect the secondary electrons emitted from the first dynode and attract them toward the second dynode. It is essential for good shading characteristics that this field be uniform over the area scanned on the first dynode by the return beam. The G-3 potenital will affect the peak video amplitude by collecting more or less of the total secondary electrons. In the case of the color camera the G-3 potential should be set for best shading rather than for maximum amplitude.

Beam Alignment and Landing

The alignment controls are initially set with the lens capped in order to cause the first dynode aperture spot to go in and out of focus without swirling when the orth focus control is rocked back and forth slightly. This orth focus adjustment indicates that the beam is leaving the electron gun along the axis of the tube normal to the target. As the beam scans across the target, the decelerator grid (G-5) serves to keep the beam normal to the target over the entire raster; the variation in angular velocity of the beam as it approaches the target is therefore held to a minimum. The electrons drawn from the beam to the target should then be entirely a function of the stored charge and not of the angular velocity.

The principle of the return beam being partially a function of the angle at which the beam approaches the target can be utilized by displacing the beam from scanning symmetrically about the tube axis. This displacement can compensate for any slight nonuniformity of target sensitivity or for slight angular assembly of the target. The need for correcting the beam landing is seen on the color monitor when the color balance in the highlights is not uniform over the entire raster. When a resolution chart or a gray card is viewed, the amplitude of the video signal in the highlights as viewed on the CRO will slope to one side or the other at either a horizontal or vertical rate. This should not be corrected by the shading generator for reasons pointed out earlier. This slope can be corrected without affecting the shading in the lowlights by displacing the alignment controls slightly from optimum.

Image Accelerator

The image accelerator (G-6) is set in the same manner as in monochrome operation. However, like the other controls, it is more critical for the color camera, because the result must be matched by all three image orthicons. G-6 should be set for minimum S distortion of horizontal lines when viewing the registration chart. S distortion can be more critically detected by superimposing a grating generator signal of horizontal bars or by panning the camera slowly back and forth. If S distortion of horizontal lines cannot be eliminated entirely in all three channels, the final criterion for setting the image accelerator should be for best registration of the horizontal lines.

Registration

Final registration adjustments should be made only after all image orthicons have been individually aligned for best picture. Besides those controls already mentioned that affect the geometry of the picture, there are several others that the operator may have a tendency to touch up that would cause misregistration. These are orth focus, image focus, and the alignment controls. These are adjusted in much the same manner as in monochrome-camera operation. If any of these are changed after the camera has been registered, registration should be rechecked.

The best registration of the three images occurs when both the electrical and optical registration adjustments are individually set to optimum conditions. The operator should avoid using one adjustment to compensate for misalignment of another. It is difficult to set the front surface mirrors properly in the blue and red channels if the electrical images are not of approximately the same size and linearity, and likewise it is sometimes impossible to match the three scans if the mirrors are not aligned.

Centering

It is important to remember that it is always desirable to scan the largest possible area of proper aspect ratio within the target ring. After this is done, the electrical centering controls are then held fixed and the centering positioning of the red and blue picture to match the green is achieved with the front surface mirrors. The tilt adjustment of the mirrors (for vertical optical centering) should always be set before the rotational adjustment of the mirror (for horizontal optical centering) because a

tilt of the mirror also produces some effective rotation of the image. Any image rotation introduced by tilting the mirrors can be corrected by rotating the deflection yokes.

Focus Tracking

The three yoke assemblies are positioned after the mirror adjustment to cause proper focus tracking. This should be done with the remote iris control set wide open (*f*-4) for minimum depth of field, or the most critical focus to be encountered. To be able to make optical focus from extreme close-in shots to infinity for all objective lenses, it is necessary that the image stay in focus at both the focal plane of the field lens and the photocathode of the image orthicons. It is possible when viewing a distant object to position the yoke assemblies to obtain focus on the photocathodes without the image being in focus exactly at the focal plane of the field lens. However, under these conditions, a point may be reached as the camera is moved very close to the subject where it will become impossible to make optical focus.

Amount of Scan

The individual heights and widths should be matched, and the over-all height and width set for proper size and aspect ratio. The proper amount of scan for new image orthicons is that which will just show the target corners when in the OVERSCAN position. All corners should disappear when the overscan switch is thrown to NORMAL. The overscan position does not apply maximum scan but is designed to increase the preset amount of scan by about 15 per cent. When looking for the target corners care should be taken not to confuse corners that may be inserted owing to misalignment of the field lens mask or to excessive compression of the sponge-rubber light-shield bellows. As the image orthicons age, it may be desirable to reduce the scan in order to obtain better shading characterisics.

After the sizes have been matched and the individual linearities adjusted (with the Q controls) for an approximate match over the entire raster, the superimposed pictures will be in better condition to see the need for finer mirror adjustments. Again set the electrical centering controls to scan the center of each target, and then make final adjustments on the front surface mirrors.

In order to see the amount and direction of electrical misregistration more clearly, the two superimposed pictures of the registration chart should be displaced slightly by electrical centering, because a difference in line separation is easier to detect than differences in overlapped lines. The individual height and width controls can then be operated to make the separation of the lines equal around the edges of the raster, and the horizontal Q and vertical Q used to separate the lines in the center by an amount equal to that at the edges. The horizontal lines should be made to be parallel with yoke rotation before paralleling the vertical lines with the skew controls.

Color Balance

The *shapes* of the spectral responses in the color camera are fixed by dichroic mirrors and trimming fitters to conform to the color-mixture curves for the primaries standardized by the FCC. However, the relative *amplitudes* of the primary colors can be controlled by use of the individual gain controls and individual pedestals. The relative amplitude of each primary-color signal to be transmitted is established by the fact that reference white must be transmitted with no color information; i.e., the subcarrier must vanish during the transmission of a neutral color. Since the colorplexer is designed to cancel out the color subcarrier when all three inputs are equal, the gains and pedestals on the camera should be set for equal outputs from all channels when a neutral surface is viewed. Since a neutral object reflects light into the camera of the same spectral quality as the illuminant, it is apparent that the relative gains to which the three channels are adjusted will depend on the spectral quality of the illuminant being used. The pedestals are, of course, set for equal black-level information. When gain and pedestal are properly set for highlights and lowlights, re-

spectively, maintenance of a proper gray scale in between these two levels depends on how well the transfer characteristics are matched.

The transfer characteristic of the kinescope is for all practical purposes assumed to be fixed. However, that of the image orthicon is a function of the potential above cutoff on the target. A potential of 2 volts above cutoff on the target gives the most constant gamma characteristics. The gamma-corrector amplifiers are therefore designed to correct for image orthicons operated at 2 volts above cutoff on the target. The target test switch on the control panel is provided for setting the target at 2 volts above cutoff. When the target is set to cutoff with the switch in TEST position, the pedestal should be raised and the brightness on the monitor increased so that the signal is not clipped. When all targets are operated at 2 volts above cutoff, they all have the same gamma characteristics below the knee. Therefore, in order to match the three transfer characteristics, it is necessary, then, to match the knees.

Matching Transfer Characteristics

If the iris is opened from a closed position when viewing the gray scale chart, three factors will determine which image orthicon reaches the knee first: the spectral quality of the illuminant, the relative light-transmitting efficiencies of the three channels, or the relative image section sensitivities of the image orthicons. In order that all three image orthicons can be operated over the same portion of their transfer characteristics, neutral density filters are inserted in the "hottest" channels just ahead of the image orthicons. This reduces the peak highlights to a point on the transfer characteristic of the hottest channels to that of the least sensitive channel.

It is desirable to attenuate the incident light with the least possible amount of neutral density filters in order to keep the over-all sensitivity of the camera as high as possible. The least sensitive image orthicon should be placed in the most sensitive channel, and vice versa.

When looking for the knee care should be taken to have the beam sufficiently high that a fold-over due to the target not being completely discharged is not mistaken for a compression due to the knee. Too much beam, of course, will add noise and shading to the signal, and the highlights will not be clearly defined. The dynode gains should be held so the highlights do not exceed about 0.3 volt on the master monitor CRO when the "input" signal is punched up on the processing amplifier. This is to be sure that no amplifiers are overloading.

A suggested method that will reduce the trial-and-error time required for selecting the proper neutral density filters when viewing the gray scale chart is as follows:

1. Consider only one channel at a time.
2. Set the iris so the highlight of one channel is at the knee.
3. Set the dynode gain of that channel so the highlight falls at about 0.3-volt input to the processing amplifier.
4. Set the processing amplifier gain of that channel so the highlight falls right at the 0.7-volt calibration mark when the processing amplifier is on the OUTPUT position. (The 0.7-volt level then marks the knee for that channel regardless of where the iris is set, provided the pedestal is not changed.)
5. Repeat the above for each of the other two channels.
6. Set the iris so the highlight in the least sensitive channel falls at the knee, or 0.7-volt-output level.
7. Hold neutral density filters in front of the objective lens to determine the amount required for each of the more sensitive channels, so that highlights can be brought to the 1-volt level, the knee for that channel.
8. Remove the light shield, and insert the neutral density filters into their proper channel.

Gain Controls

The importance of operating with an over-all linear system in order to reproduce colors faithfully over the entire luminance range stresses the fact that the image orthicons must not be operated above the knee of their transfer characteristics. For

the greatest contrast range and best signal-to-noise ratio, the brightest highlight should be allowed to fall just at the knee by operation of the remote iris control (master gain). Since the colorplexers are designed for a peak input signal of 0.7 volt, it would be desirable to have the knee represent 0.7 volt out of the processing amplifier. If the gains of each channel are adjusted for 0.7 volt out of the processing amplifier when the highlight is just at the knee, the 0.7-volt calibration mark on the master monitor CRO will then serve as a reference for the position of the knee.

Pedestals

The 0.7-volt level at the knee is set with the individual gain controls after the pedestals have all been adjusted to about a 5 per cent setup. If the pedestal is changed after the 0.7-volt output level has been set, the reference black will be changed from its 0.7 volt below the knee position and the 0.7-volt calibration on the CRO will no longer represent the knee. For this reason the gray-scale chart should have a contrast range similar to that of the scene to be televised, or about 30 to 1. Standard gray-scale charts fulfill this requirement. In order to keep the knee at the 0.7-volt output position, the master pedestal should be touched as little as possible during operation.

It is often necessary to adjust the master pedestal for a more pleasing picture, however, such as in extreme close-ups where the darkest video level may actually be quite high; but it should be kept in mind that if the pedestal is lowered (blanking decreased), the knee will fall below the 0.7-volt level and, if the pedestal is raised (blanking increased), the knee will fall above the 0.7-volt level. During operation of the camera the iris is adjusted so that the highlight in the channel with the greatest peak video amplitude is held as high as possible, for best signal-to-noise, without exceeding either the knee or the 0.7-volt-output level.

Final Color Balance

When the output of the colorplexer is observed on a CRO when viewing the gray-scale chart or the resolution chart, no subcarrier should be present (seen as a thickening of the lines) if the transfer characteristics of the three channels are perfectly matched and the colorplexer is perfectly balanced. The individual pedestals and gains on the processing amplifier should be touched up to cancel the subcarrier in the lowlights and highlights, respectively. Another check for proper color balance is to switch the CHROMA on the color monitor on and off while viewing the signal from the camera focused on the gray-scale chart or the resolution chart. No change in the color balance of the monitor should take place if the camera chain is properly balanced.

LIGHTING AND SUBJECT MATERIAL

The most carefully aligned camera chain cannot give an accurate reproduction from a poorly lighted scene or from a poor selection of subject material. The most important aspect of studio lighting and material selection peculiar to color television is to restrict the reflected light contrast of the scene to the contrast capabilities of the system. For an average scene being reproduced on the kinescope under typical viewing conditions, the contrast between the brightest and darkest areas cannot exceed about 20 or 30 to 1. This is restricted at the high end owing to the limited luminance capabilities of the kinescope and at the low end owing to stray light and "spillover" in the kinescope and the ambient illumination.

Since the iris at the camera is adjusted so the brightest area in the scene is set at the knee, or the maximum transmitted level, the areas with luminance values less than one-twentieth the luminance of the brightest area will become desaturated or be lost in the black level. Very bright areas allowed in the scene may therefore cause some critical colors, such as flesh tones, to be forced far down in the luminance range with the result of color distortion at the kinescope. If the iris is opened to improve the flesh-tone reproduction, then the highlights will extend over the knee,

the brightest colors will become desaturated, and some amplifiers will overload. For large, dark areas in a scene where the contrast range exceeds 20 to 1, the shading component of the image orthicons becomes an appreciable amount of the signal and the reproduced colors will be distorted in the lowlights.

Flourescent lights should not be used where color fidelity is important. The spectral distribution is broken by excessive radiation over certain narrow bands of the spectrum.

The amount of light entering the camera lens depends, of course, on both the illumination on the subject and its reflectance value. All material to be used in the scene that has excessive reflectance and very low reflectance should be screened out before going on the air. A light gray shirt, for instance, will be reproduced as a white, when the iris is properly set, without forcing the other colors down in luminance value. The white areas in show cards that contain color should also be grayed down. Observation of the CRO waveform will give an indication of which subjects are exceeding the desired contrast range. The scene contrast can also be checked with a comparison-type light meter such as the Luckiesh-Taylor brightness meter, or the McBeth illuminometer.

Part 6

COLOR TEST EQUIPMENT

High-quality test and monitoring facilities are important and necessary to the color-television station in maintaining desirable standards of performance and to ensure compliance with FCC regulations.

Equipment used for *monitoring* color transmission is almost the same as that used for monochrome, except for the color monitor and the high-quality demodulator needed for color. The color monitor sets the standard of system performance, serving not only in monitoring functions but also as a vital unit of test equipment. In contrast to modest monitoring requirements, however, color operation has introduced new *test and measuring* techniques, as well as a number of test equipments developed especially for color use.

Test equipment for the color station can be listed in two general categories: (1) equipment needed to evaluate the studio installation and (2) equipment required to test transmitter performance. Since requirements differ still further, depending upon whether the station originates color or merely participates in color-network shows, two additional lists are possible. To assist the reader in visualizing the equipment in each case, typical test equipment lists are presented in Tables 6-1 and 6-2. Equip-

Table 6-1. Studio Test and Measuring Equipment

Equipment	*Purpose*
	For Network Participating Stations
Linearity checker	Differential gain measurement
Color signal analyzer	With linearity checker provides differential phase measurement
Color stripe generator (optional)	Provides color test signal for home-receiver adjustment
	For Color Originating Stations (All items listed above plus the following equipment)
Color bar generator	Provides standard color signal for aligning colorplexers and monitors
Calibration pulse generator	Provides standard signal voltage for calibration of waveform monitors and setup of processing amplifier

Table 6-2. Transmitter Test and Measuring Equipment (For Color Originating and Network Participating Stations)

Equipment	*Purpose*
Linearity checker Color signal analyzer	Measuring transmitter amplitude and phase response
VHF or UHF sideband response analyzer	Measuring frequency response of transmitter
VHF or UHF sideband demodulator	Checking and monitoring characteristics of transmitted RF signal
Square-wave generator	Adjustment of phase equalizer
Dummy load and wattmeter	Power-output measurements

ment groups selected for these tables are capable of providing sufficient information to ensure that the installation will meet the operating standards established by the FCC.

COLOR STUDIO TEST EQUIPMENT

Most color video signal tests can be performed by use of standard monochrome test items such as wideband oscilloscope, sweep generator, and suitable test charts, in conjunction with a linearity checker, color-signal analyzer, and color-bar generator. Detailed information on the use of this equipment in measuring the transfer characteristics of color-television equipment is contained in the equipment manuals. Reference should be made to them for actual procedures to be followed in making measurements.

WA-9 Calibration Pulse Generator

The WA-9 calibration pulse generator produces a precise video signal voltage of either 0.7- or 1.0-volt amplitude. These voltage standards can be used for setup of the processing amplifier in film and live camera chains, as well as for accurately calibrating waveform monitors so that video signal amplitudes can be established. The 0.7-volt output serves as a reference standard for noncomposite video signals, and the 1.0-volt output for composite signals. It is common practice to make these voltages available at jack panels and in switching systems so that the entire distribution system can be aligned conveniently for proper levels.

The WA-9 provides a square pulse at horizontal frequency. The output impedance of approximately 0.6 ohm is sufficiently low to permit feeding several circuits with negligible change in level. In addition, the square wave is timed so that it appears as a positive half cycle centered between horizontal sync pulses. Thus, the signal will readily pass through any clamp circuits in the system without disabling them. Horizontal drive from the sync generator is amplified and used to trigger a stabilized, cathode-coupled multivibrator which places the calibrated pulse between the horizon-

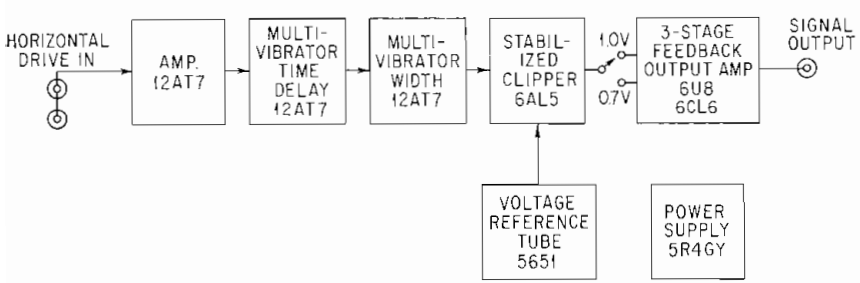


FIG. 6-1. Block diagram of WA-9 calibration pulse generator.

tal sync pulses. The output pulse is produced by a square-wave multivibrator. Output of this stage is clipped by a current-regulating circuit controlled by a voltage reference tube, and the resultant calibrated pulse drives a feedback amplifier with highly stabilized gain.

Circuits of the generator, shown in the simplified block diagram of Fig. 6-1, feature extreme stability. With line voltage changes from 110 to 125 volts, output level will vary no more than 1 per cent. Output voltage variations are held to 0.5 per cent in changing from no termination to one 75-ohm termination or from one to two 75-ohm terminations. Pulse width is 31.75 μsec, with a rise time of less than 1 μsec and tilt less than 1 per cent.

All components of the WA-9 are mounted on a recessed-type chassis designed for standard rack mounting. Controls are located on the front of the chassis for the fol-

lowing functions: pulse position, pulse width, voltage calibration, 0.7/1.0-volt selector, and power switch. Output can be controlled by a locking-type screwdriver adjustment.

WA-1 Color-bar Generator

The WA-1 color-bar generator supplies a synthetic signal which permits precise alignment of the colorplexer and provides a standard for measuring color-camera performance. Use of this signal in the color system is analogous to the use of the monoscope camera in monochrome operations.

The WA-1 generates rectangular pulses which when fed to the red, green, and blue input circuits of the colorplexer produce a color-bar test signal at the output of the colorplexer. In addition, the generator is capable of providing a split-field color-bar pattern on the color monitor, displaying standard color bars in the upper half of the raster and a white bar together with the Q and I test bars in the bottom half of the raster, as recommended by the Electronics Industries Association.

Circuits of the color-bar generator are shown in the simplified block diagram of Fig. 6-3. All components are mounted on a recessed-type chassis designed for standard rack mounting. An integral regulated power supply and conservative circuit design assure stability in operation. Limiting action ensures constant outpnt level of 0.7 or 1.0 volt peak to peak for all the color-bar signals.

In operation, the trailing edge of the horizontal blanking pulse triggers the green multivibrator which is adjusted to produce a pulse long enough to include the first four bar intervals. The green multivibrator triggers the red multivibrator from both its leading and trailing edges, so there are two red pulses per line period, each one-half as long as the green pulses. The red multivibrator in turn triggers the blue multivibrator from both its leading and trailing edges to produce four pulses, each one bar interval wide.

Formation of the Q, I, and white pulses is as follows: The trailing edge of the horizontal blanking pulse initiates the I pulse, the trailing edge of the I pulse triggers the white pulse, and the trailing edge of the white pulse triggers the Q pulse. The manner of triggering as well as the amplitude and time relationships of these pulses are shown in the diagrams of Fig. 6-2.

WA-6 Color-signal Analyzer

The WA-6 color-signal analyzer is designed to permit the study of the composite color video and subcarrier signal. The WA-6 facilitates adjustment of the colorplexer and, when used in conjunction with the color-bar generator and an oscilloscope, permits accurate measurement of phase relationships existing between the subcarrier hurst reference and various components of the composite color signal. The instrument is also used in conjunction with the linearity checker for making differential-phase (phase intermodulation) measurements.

In all cases a source of snbcarrier is required in the operation of the color-signal analyzer. This can be obtained from the linearity checker which contains a generator for this purpose, or it can be obtained from the output of the frequency standard. The color-signal analyzer is a null-indicating-type instrument for measuring phase at subcarrier frequency. It contains self-calibrating facilities and is capable of measuring phase differences of the order of 0.5°.

WA-8 Color-stripe Generator

The WA-8 color-stripe generator is an inexpensive color-signal generator designed to produce a color test stripe on color home receivers. Use of the generator makes it possible for the viewer or receiver service personnel to determine that a particular color-receiver installation is capable of reproducing color programs, even though at the time only monochrome programs are being broadcast.

Any station which is equipped to transmit network color can use the color-stripe generator to add a narrow color stripe to the monochrome signal. The stripe signal

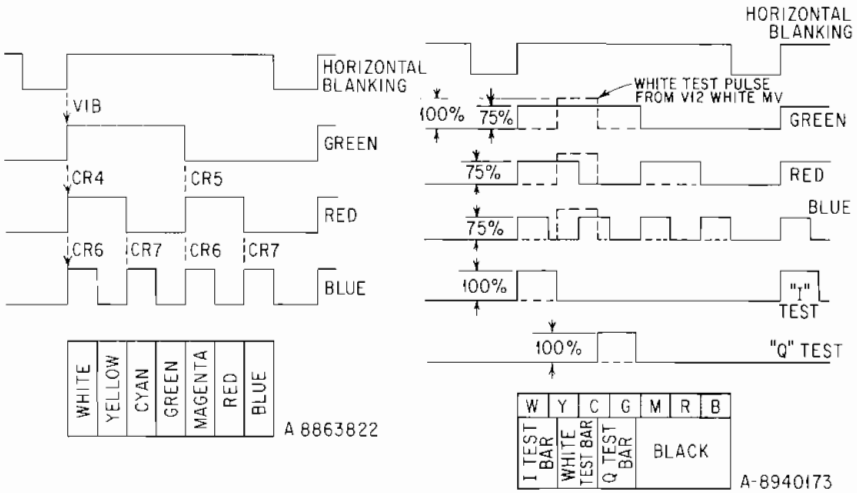


FIG. 6-2. Diagram showing derivation of R, G, and B color bar pulses and time and amplitude relationships in the composite bar signal.

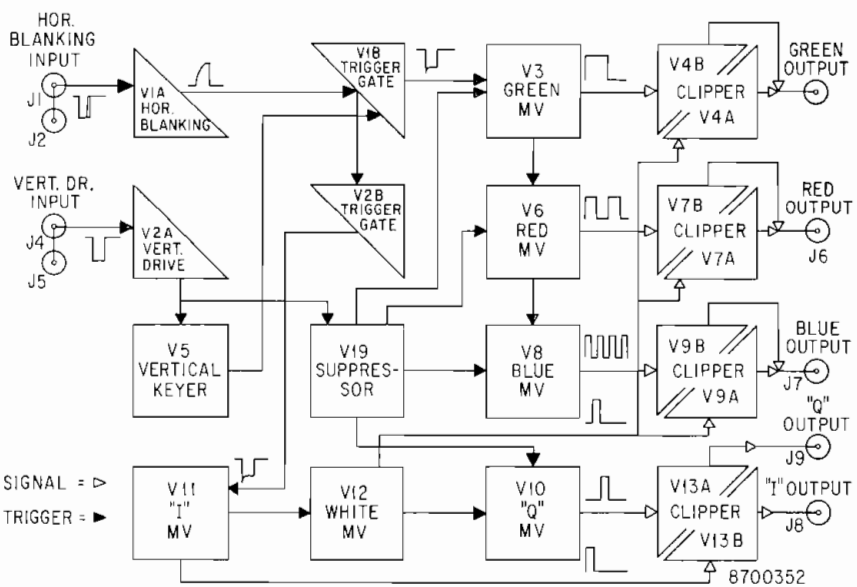


FIG. 6-3. Simplified block diagram of WA-1 color-bar generator.

is normally unnoticeable on either monochrome or color reeeivers, but the technician installing a color recciver can use the signal to produce a stripe of yellow-green color (when color reception is normal) by making a deliberate temporary misadjustment of the horizontal-deflection oscillator. The geuerator is loosely coupled to the video liue feeding the transmitter in such a way that normal system operation is not changed.

Information added by the stripe generator to the composite monochrome signal consists of two bursts of 3.58-Mc subcarrier frequency. The first burst is positioned immediately following horizontal blanking, or 9.2 μsec $(+0.6, -0.0)$ following the

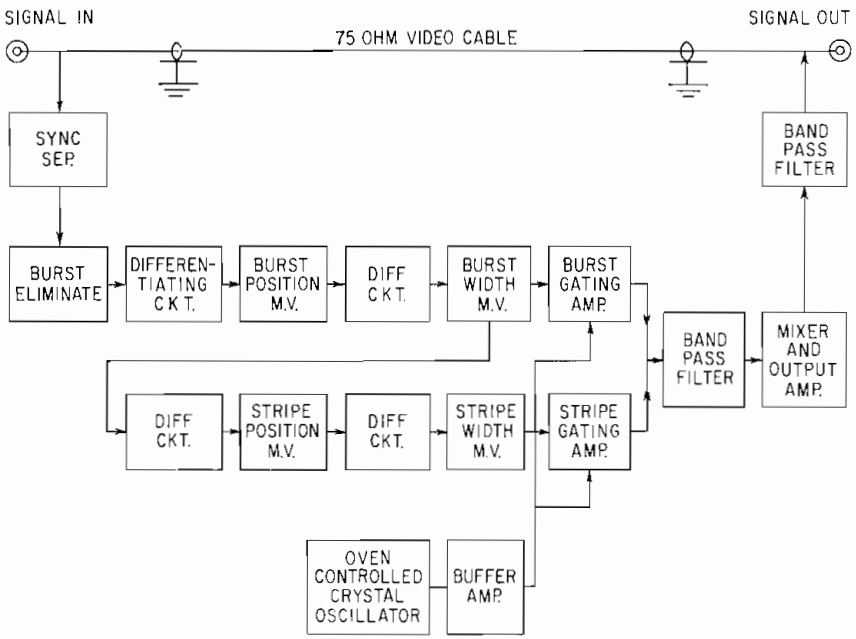


FIG. 6-4. Block diagram of color-stripe generator.

leading edge of horizontal sync. In this location, it is just outside the period normally "sampled" by the burst gate of a receiver, so it does not activate the color circuits in the receiver. If the horizontal phasing circuits of the receiver are deliberately misadjusted, however, the burst sampling pulse can be moved over to pick up the first burst of the stripe signal. When this happens, the color receiver responds as if the signal had a normal color sync burst (i.e., the color circuits are activated). The second burst is positioned so that its leading edge is 3 μsec preceding the leading edge of horizontal picture blanking. This burst produces the color on the kinescope of a properly adjusted color receiver. Since these signals are devoid of any luminance component, they are positioned on the average of the luminance value present in the monochrome signal at the time. When a color program is broadcast, however, the stripe generator should be turned off so as not to cause color interference.

Circuitry of the color-stripe generator is shown in the block diagram of Fig. 6-4. The purpose of the sync separator is to strip sync from the composite monochrome signal. The "burst-eliminate" circuit prevents the separation of pulses during the vertical sync and equalizing pulse intervals. No bursts or stripes should appear for nine lines during the vertical blanking interval. The output of this stage, therefore, is a series of pulses at horizontal rate with a nine-line gap during the vertical interval. This information is differentiated and applied to the burst-position multivibrator,

which, in turn, drives the burst-width multivibrator. Its output is the positive pulse necessary to trigger the burst gating amplifier. A second output drives the stripe-position multivibrator, which, in turn, drives the stripe-width multivibrator. Its output is also a positive pulse necessary to trigger the stripe gating amplifier. The subcarrier signal at 3.579545 Mc is produced by a stable oven-controlled crystal oscillator. Its output is supplied to the gating amplifiers. The gating amplifiers feed the mixer and output stage, which, in turn, feeds back to the video line. Thus, the video line is never broken. If failure of the stripe generator should occur, the monochrome signal would not be affected. Coupling of the output signal to the video line is so loose that the monochrome signal is essentially unaffected, but the color bursts or envelopes are added or superimposed on it.

All controls for the generator are accessible from the front. Front-panel controls

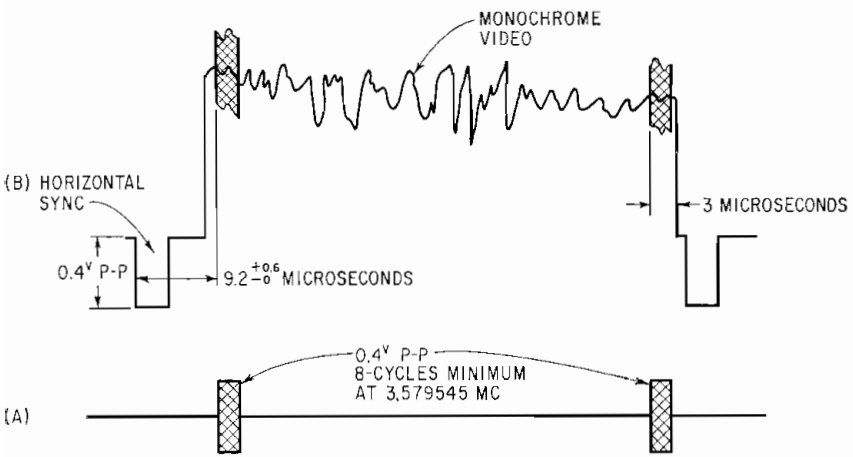


FIG. 6-5. Diagram showing signal produced by the color-burst generator. Line (*A*) represents color bursts of subcarrier frequency, and line (*B*) is the composite signal from the color-stripe generator.

consist of the REMOTE-OFF-LOCAL switch which applies +B to the subcarrier oscillator and mixer output tubes in the remote and local positions and removes it from the tubes in the off position; pulse discriminator bias pot for adjusting the clipping level so that under all values of picture information nine lines of bursts are eliminated during the vertical blanking interval; subcarrier frequency control—a trimmer to adjust the oscillating frequency of the oven-controlled crystal to exactly 3.579545 Mc; subcarrier output control—a level-setting control common to both burst and stripe for adjusting their amplitudes with respect to the monochrome signal; three separate controls associated with the color burst for adjusting its width, its amplitude, and its position with respect to sync; envelope-shaper control—essentially a control to adjust a bandpass filter (a low-*Q* resonant circuit) for best shape of the burst and stripe envelopes; oscillator plate tuning—an inductance control for adjustment of the crystal oscillator plate circuit for maximum stability; and the on-off power switch.

WA-7 Linearity Checker

The WA-7 linearity checker generates a test waveform consisting of a staircase signal with provisions for superimposing a 3.58-Mc sine wave on the steps and for varying the average picture level of the signal. Differential gain measurements can be made in video amplifiers, transmitter circuits, and transmission systems by use of the linearity checker alone. Differential-phase measurements can be made by employing the linearity checker together with the color-signal analyzer to serve as a

phase detector to analyze the signal after it passes through the device under test. Another important use of the linearity checker is in the adjustment of white stretch to compensate for the nonlinear transfer chraacteristics of grid modulation in the transmitter.

The linearity checker includes a Hi-Lo filter which is used at the input to the oscilloscope. When the filter is switched between high, low, and normal positions, the subcarrier, step wave, or composite signal can be viewed separately and the waveforms interpreted accordingly. The instrument incorporates a subcarrier-freqnency generator.

Burst-controlled Oscillator

The burst-controlled oscillator is an accessory for the color-signal analyzer for use in special cases where differential-phase measurements are to be made over a studio-to-transmitter link or in any other circumstances where the test-signal source is at a distance from the point of measurement. The oscillator provides a continuous subcarrier frequency of 3.579545 Mc. Output is locked in frequency and phase to the color-synchronizing bursts which are part of the incoming signal being measured.

This item is not necessary if the studio and transmitter are at the same location or if test procedures are not carried out at a point remote from subcarrier signal sources.

Signals for Grating and Dot Patterns

Signals to produce grating and dot patterns useful in the adjustment of scanning linearity and beam convergence can be obtained from the TG-2 sync generator. Circuits built into the TG-2 provide a stable pattern of 13 by 17 bars, white on black background with blanking added. A selector switch in the grating circuits allows choice of horizontal bars, vertical bars, both horizontal and vertical bars, dots at the intersections of the bars, or a test position where sync and blanking are mixed for observation of the front porch.

TRANSMITTER TEST EQUIPMENT

Equipment required for test and monitoring of the color transmitter is listed in Table 6-2, which appears at the beginning of this part. The burst-controlled oscillator, although not listed, may be required if the studio and transmitter are not at the same location, as previously stated.

In addition to the linearity checker and color-signal analyzer, transmitter tests require use of the BW-5 sideband-response analyzer, BW-4 visual sideband demodulator, and a suitable RF load and wattmeter.

The sideband-response analyzer provides for the display on an oscilloscope of the entire frequency and sideband-response capability of the transmitter and sideband filter without laborious point-to-point curve plotting. The unit is used in the adjustment of video amplifiers and modulators as well. The analyzer includes a video sweep oscillator, making it unnecessary to provide separate video sweep generators for measurement purposes.

The visual sideband demodulator produces a signal for monitoring and checking transmitter output. It provides information on waveform characteristics such as wave shape, sync percentage, depth of modulation, resolution, and transient response, as well as a composite picture of the signal for checking compliance with FCC standards.

Section 6

STUDIO FACILITIES

Part 1

PLANNING AM/FM STUDIO FACILITIES

NAB Engineering Department *

GENERAL PLANNING CONSIDERATIONS

The early planning of a radio station usually involves consideration of the market to be served, site selection, transmitter power, tower height, station policies, personnel, the extent of programming, the hours of operation, and available capital. In this part we confine ourselves mainly to the selection and arrangement of equipment to achieve the desired results. First and foremost of the decisions to be reached is whether the studio and transmitter are to be combined under one roof or to be in separate locations.

In the past few years there has been a trend toward combined studio and transmitter facilities rather than separated facilities. More recently, however, there has again been a trend toward separated installations, with the transmitter operated by remote control from the studio where permissible.

It is generally agreed that wherever practical it is most economical to combine the studio and transmitter facilities. The initial equipment requirements are less, and more important is the fact that day-to-day operating expenses are lower. With the plant "all under one roof" there are savings in heating and air conditioning, building maintenance, and travel time, and in addition, less technical personnel is required. A "combined" operation, however, is not always practical. There are several important considerations:

1. Is the combined location the best spot for the transmitter site? (By that we mean is there sufficient room for installation of tower or towers and an adequate ground system? Furthermore, is it more advantageous from a standpoint of providing the desired coverage?)

2. Is the combined location convenient and accessible for station personnel and for clients? (A combined location is generally more practical in smaller cities, since an accessible and satisfactory location for both studio and transmitter can usually be obtained near the city limits.)

When a combined operation is not practical, the second most economical approach, where permissible, is to operate the transmitter by remote control from the studio. Then one can select a transmitter site that is most advantageous from a radiation and coverage standpoint, and the studio could logically be placed at its most convenient location. The building requirements at the transmitter can be the very minimum, requiring only space for the equipment, a small work area, and a small room-heating unit. The studio contains conventional equipment and a remote-control unit. This type of installation is one of the most desirable for larger cities.

* Compiled from sources listed in this part.

Control Room

All control-room installations, large or small, are alike in many respects. The differences are mainly a matter of the number of microphones, turntables, tape recorders, and other program sources to be served. This, in turn, will dictate the type of consolette or control console that is most suitable. Beyond this, there are various arrangements of facilities to suit special conditions and personal tastes. For economic reasons, most stations locate the control console in front of the studio viewing window. They locate the turntables on either side of the operator's position at the console, a microphone over the console for control-room announcing, and tape-recording equipment within easy reach of the operator.

House Monitoring

A house-monitoring system is an important function, and proper planning before construction begins will provide a much neater installation. Provisions should be made to carry audio to several locations throughout the building, the lobby area, offices, clients' room, etc. Besides normal program material, it provides a convenient closed-circuit system for auditions and special monitoring.

Ductwork

The careful planning and layout of trenches and ducts for wiring is essential to economical installation and efficient operation. Once the technical equipment has been accurately determined, it is then time to plan trench runs. These should provide for some measure of future expansion.

Studio Considerations

As we examine present-day operations, we find the studio receiving less consideration because fewer live programs are being originated. However, we have further discovered that neglect in the planning of the studio places a later handicap on the average operation, which could have been prevented with only a small additional expense and a little careful consideration at the time of construction. Hence in this article we present plans that provide for normal expansion without undue expense.

EQUIPMENT PLANNING *

The next most logical step after early plans have been completed is the careful and considered planning for the technical equipment. This goes hand in hand with the building design and construction. Equipment planning is the proper selection and layout of technical equipment to satisfy contemplated programming requirements.

We are going to cover three versatile plans for radio station equipment, which do not uecessarily represent any existing stations but do illustrate several ways in which the very latest equipment can be arranged to perform efficiently with a minimum of capital and personnel.

Since programming requirements vary, we present three plans, which represent three specific categories of operation:

1. Plan *A* covers a typical "combined" studio-transmitter operation, with programming requirement of records and transcriptions, control-room announce, one studio, tape facilities, network, and remotes. This is a small station, requiring minimum investment.

2. Plan *B* also covers a "combined" operation but incorporates additional facilities to allow for an announce booth and other local program material. It is a typical community station of moderate size.

* The following material was based on an article entitled, "Planning a Radio Station," contained in *RCA Broadcast News*, vol. 97, October, 1957.

3. Plan *C* covers a fairly large two-studio station with separate studio and transmitter locations but with optional remote operation of the transmitter. It is designed for large-city operation, providing a high degree of flexibility and facilities for extensive programming.

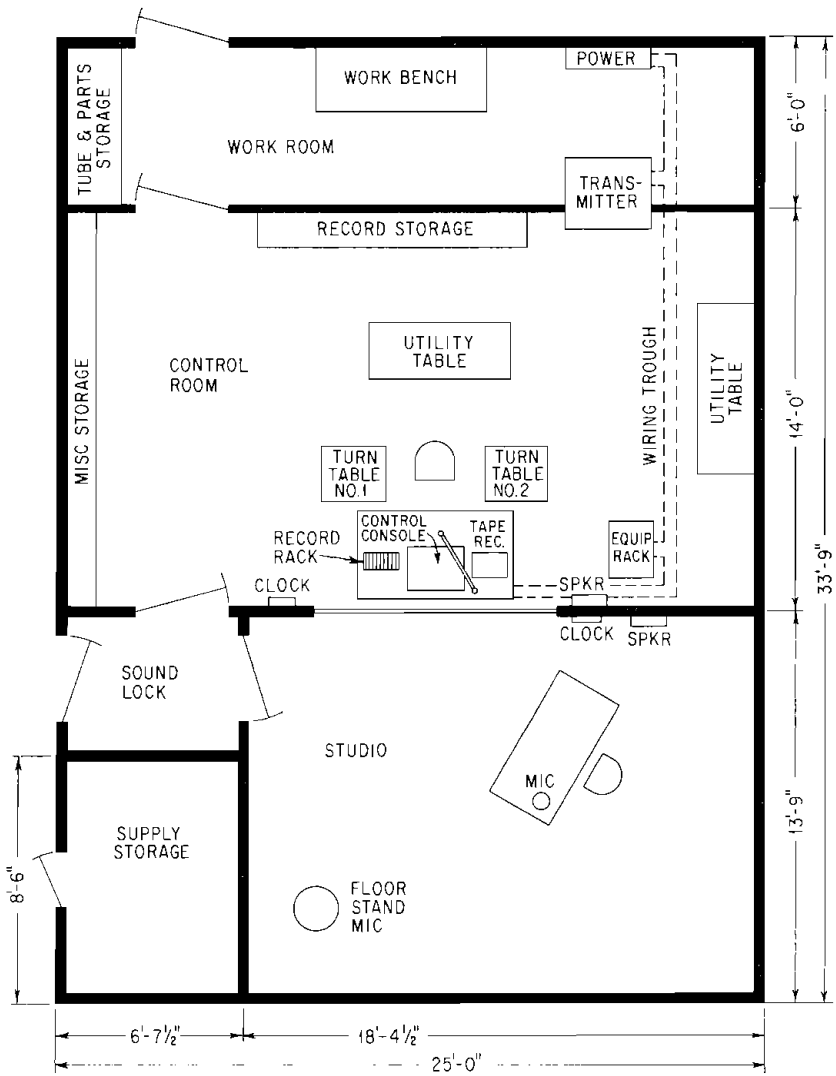


FIG. 1-1. Floor plan *A*: location of major equipment items. Observe the convenient location of the wiring through (dotted lines) for accessibility to the necessary equipment.

The three plans are considered adequate for the majority of cases, and each is so arranged that the plan can be modified to suit individual requirements. The choice of the equipment layout will depend to a large extent on factors which are already determined: type of programming, area to be served, station policies, and personnel.

Plan A

Plan A is a desirable layout for the small station that proposes to start operation at minimum investment. It includes the necessary technical equipment for handling the following programs: (1) announcements, (2) record and tape shows, (3) network, (4) remotes, and (5) local live originations such as interviews and newscasts.

It will be noted in Fig. 1-1 that the floor plan is separated into combined transmitter and control room, small studio, engineering workroom and parts storage, supply storage, and a sound lock.

The major items of equipment required to perform the programming operation are identified on the floor plan. A block diagram and rack layout (Figs. 1-3 and 1-4) show how the system is connected. An equipment list itemizes the requirements, including the miscellaneous small items necessary to complete the system.

Table 1-1. Plan A Equipment List *

(Providing the facilities for handling records and transcriptions, announcements from the control room, one studio, tape facilities, network and remote programming.)

Quantity	*Control room*
1	Audio consolette with tubes
1	Dual headphone
1	Microphone
1	Microphone mounting
1	Microphone plug
1	Microphone receptacle
2	"On-air" lights
2	Three-speed turntables
2	Transcription tone arms
2	Pickup heads
2	Transcription equalizers or filters
1	Tape recorder
1	Input transformer for tape recorder
1	Output transformer for tape recorder
1	20-db 600-ohm fixed pad
1	Monitor speaker
1	Monitor-speaker housing
1	Speaker matching transformer
1	16-in. sessions clock
100 ft	Interconnecting cable No. 22 AWG shielded pair, with cotton-braided outer cover
	Studio
2	Ribbon microphones
1	Desk stand
1	Floor stand for microphone
3	Microphone plugs
3	Microphone receptacles
2	"On-air" lights
1	Studio monitor speaker
1	Monitor-speaker housing
1	Speaker matching transformer

Quantity	*Studio (Continued)*
1	16-in. clock
100 ft	Interconnecting cable No. 22 AWG shielded pair, with cotton-braided outer cover
	AM transmitter input and monitoring
1	Cabinet rack
1	AM frequency monitor
1	Modulation monitor
1	40-db 600-ohm fixed pad
1	Program amplifier with tubes
1	Mounting shelf for BA-25 amplifier
1	20-db 600-ohm fixed pad
1	Limiting amplifier with tubes
1	Mounting shelf for amplifier
1	Double-jack panel
1	Single-jack panel mat
400 ft	Interconnecting cable for audio rack wiring, No. 20 shielded pair, solid conductor
200 ft	Interconnecting cable for a-c and filament circuits, No. 18 shielded pair, stranded conductor
1	Terminal board mounting bracket
1	Terminal power strip
1	Terminal audio block
4	Audio patch cords, 2 ft in length
1	Switch and fuse panel
1	$3\frac{15}{32}$-in. blank panel
1	$1\frac{23}{32}$-in. blank panel
2	$8\frac{23}{32}$-in. blank panels
1	$5\frac{7}{32}$-in. blank panel

* Transmitter and antenna equipment are not listed here, since they are specified in accordance with power and pattern.

The choice of transmitter, of course, depends upon the power of the individual station. Regardless of power, all other items included in plan A remain the same.

TAPE OUT	NET	REM 1	REM 2	REM 3	EXT PGM OUT	EXT AUD OUT	CON-SOLE OUT	40 DB PAD OUT	AGC AMP OUT	20 DB PAD OUT	LIMIT-ER OUT
TAPE IN	NET IN	REM 1 IN	REM 2 IN	REM 4	TAPE REC IN	SPARE	40 DB PAD IN	AGC AMP IN	20 DB PAD IN	LIMIT-ER IN	XMIT-TER IN

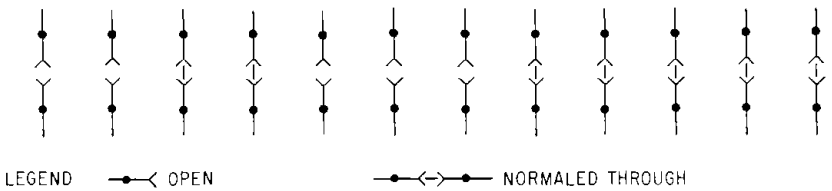


FIG. 1-2. Jack panel for plan A.

Plan A incorporates many features to permit operation with a minimum of personnel. It is designed for a single operator-announcer to work directly from the control room. The equipment location makes this practicable, since turntables, tape recorder, control console, and record rack are all within easy reach of the operator. The equipment rack is situated for convenient reading of the frequency and modulation monitor meters without leaving the operating position. Record-storage racks are easily accessible within the control room. Furthermore, the small utility storage rack and table, located directly behind the operating position, provides a handy place for keeping the daily program material ready for use.

Entrance to the control room or the studio is via the common sound lock. The small engineering workroom with storage cabinet and workbench is sometimes neglected in planning but will prove its worth many times over. The wiring trough shown by dotted lines in Fig. 1-1 makes the wiring readily accessible for service or making additions to the system.

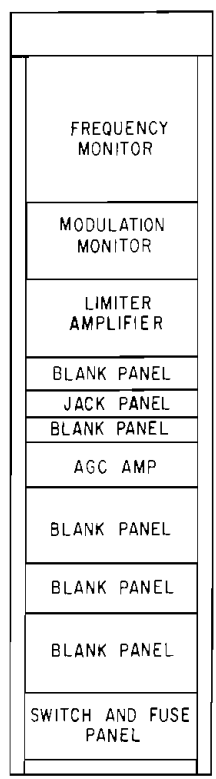


FIG. 1-3. Rack layout for plan A equipment. Note blank panels which allow for future expansion.

Technical Facilities of Plan A

The control console is the heart of the audio system. Because of its operational simplicity, it makes possible smooth and successful performance. This is owing to proper location of important controls. Both from a system standpoint and from the physical standpoint all controls are easily accessible to the operator. An examination of the block diagram (see Fig. 1-4) shows the functional location of the console in the system. Note the capabilities, especially the number of inputs and outputs.

Turntables are next in importance. They are three-speed units: 33⅓, 45, and 78 rpm. These utilize a simplified speed-changing mechanism, proved and reliable, driven by a hysteresis synchronous motor. The turntable starts very smoothly, which is so necessary with microgroove recordings.

A tape recorder is located on the table within easy reach of the operator. (This may be rack mounted, if desired.) It is a dual-track, two-speed (3¾ and 7½ ips) unit, driven

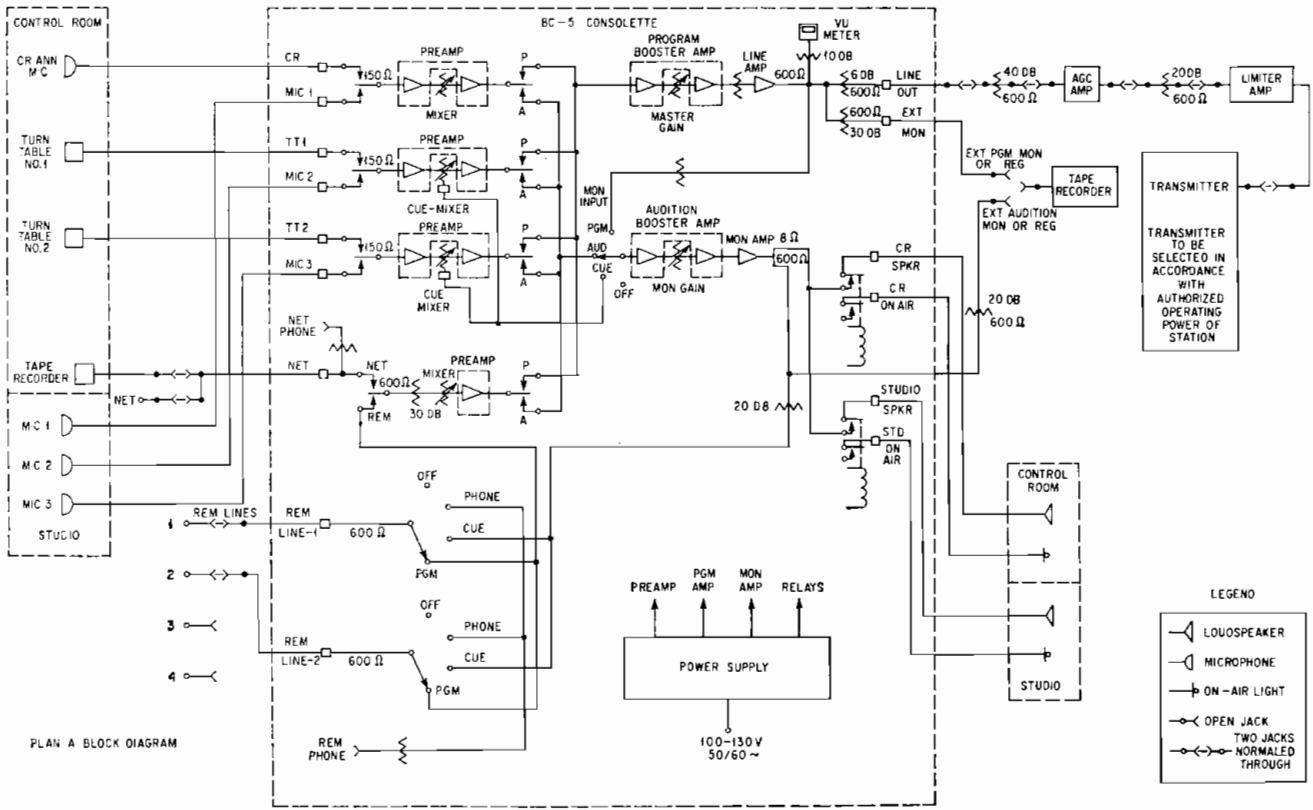


FIG. 1-4. System diagram for plan A.

direct by a synchronous motor. It utilizes the latest circuit techniques: transistor amplifiers and electrodynamic-tape tensioning and braking.

An automatic-gain-control amplifier and a limiting amplifier are located in the equipment rack. The functions of these two units in the system are related, and a description of their importance follows.

It is a well-known fact that station coverage, regardless of power, is definitely

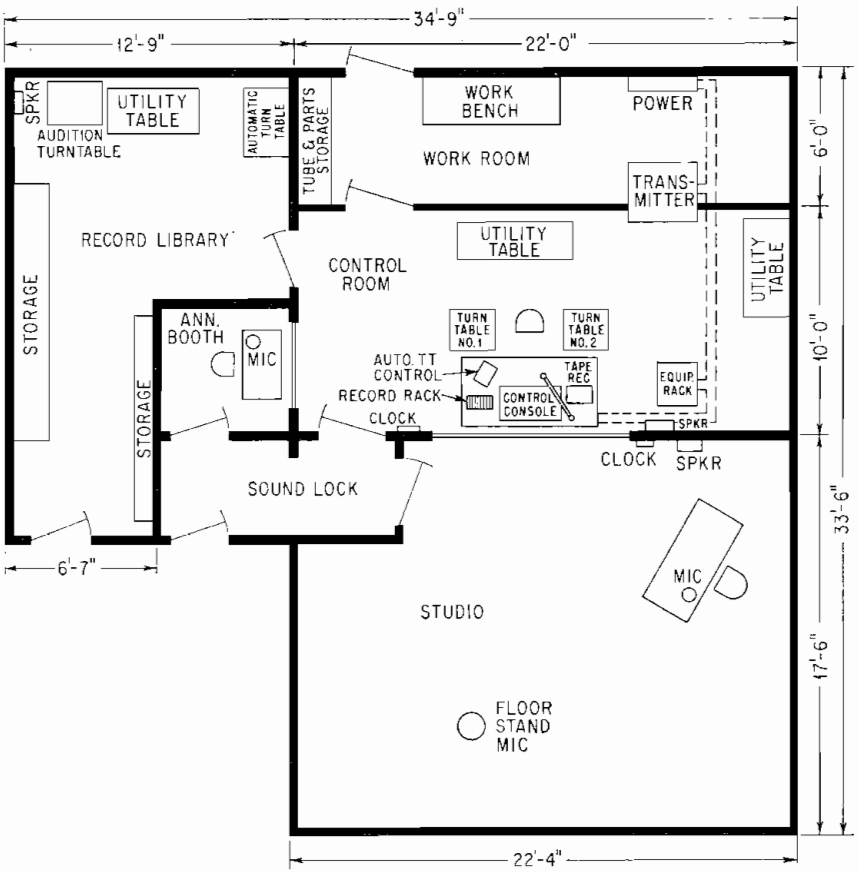


FIG. 1-5. Floor plan *B*: location of all major equipment items. Note the addition of an announce booth and a record library.

related to the ability to maintain the highest possible average level of modulation without distortion. The use of a limiting amplifier has been common for several years with reasonably good results; however, it has some limitations. In a limiting amplifier, the gain is constant up to a certain output level. Above this level, there is so much gain reduction that the output level will be maintained virtually constant. Thus, a limiting amplifier is effective only on high levels of program material.

On the other hand, the automatic-gain-control amplifier (AGC) will serve to maintain a relatively constant output, much in the same manner that an operator might, by carefully and constantly "riding gain" on the program. The characteristics of the AGC amplifier and the limiting amplifier supplement each other ideally when connected in a system feeding a transmitter. This combination permits a higher

average level of program material and prevents overmodulation on sudden program peaks, which effectively improves reception in fringe areas and extends coverage without increasing transmitter power.

Other major equipment items located in the equipment rack are the frequency and modulation monitors (required by the FCC) and a jack panel. The complete rack layout is shown in Fig. 1-3.

Plan *B*

Plan *B* typifies the most desirable arrangement for the community-type radio station. This plan fulfills all the requirements, from a space and facility point of view, for handling a very diversified program schedule. It incorporates technical features that make for an adequate yet economical operation. The following equipment list itemizes the equipment including the miscellaneous small items necessary to complete the system.

While plan *B* is identical in many respects with the plan *A* station, it includes larger and additional facilities (see Fig. 1-5). The major difference is a larger studio, the addition of an announce booth, and a record-library room. Additional

Table 1-2. Plan *B* Equipment List *

(Providing the facilities for handling records and transcriptions, announcements from the control room, one studio, announce booth, tape facilities, network and remote programming.)

Quantity	*Studio and announce booth*
2	Ribbon microphone
2	Desk stands
1	Floor stand
1	Uniaxial microphone
4	Microphone receptacles
4	Microphone plugs
4	"On-air" lights
2	Studio monitor speakers
2	Monitor-speaker housings
2	Speaker matching transformers
2	16-in. clocks
150 ft	Interconnecting cable No. 22 AWG shielded pair, with cotton-braided outer cover
	AM transmitter input and monitoring
1	Cabinet rack
1	AM frequency monitor
1	Modulation monitor
1	40-db 600-ohm fixed pad
1	AGC program amplifier with tubes
1	Mounting shelf for amplifier
1	20-db 600-ohm fixed pad
1	Limiting amplifier with tubes
1	Mounting shelf for amplifier
1	Double-jack panel
1	Single-jack panel mat
400 ft	Interconnecting cable for audio rack wiring, No. 20 shielded pair, solid conductor
200 ft	Interconnecting cable for a-c and filament circuits, No. 18 shielded pair, stranded conductor
1	Terminal board mounting bracket

Quantity	*AM transmitter input and monitoring (Continued)*
1	Terminal power strip
1	Terminal audio block
4	Audio patch cords, 2 ft in length
1	Switch and fuse panel
1	Monitor amplifier with tubes for house monitoring system (speakers to be selected as required)
1	Plug-in transformer for amplifier
1	Mounting shelf for monitor amplifier
1	$3\frac{15}{32}$-in. blank panel
1	$1\frac{23}{32}$-in. blank panel
1	$5\frac{7}{32}$-in. blank panel
1	$8\frac{25}{32}$-in. blank panel
	Record library
1	Automatic turntable with remote control
1	Turntable
1	Transcription tone arm
2	Pickup heads
2	Transcription equalizers and filters
1	Utility amplifier
1	Monitor amplifier for audition
1	Plug-in transformer for amplifier
1	Selector switch for input of amplifier
1	Bridging pad for automatic-turntable audition
1	Monitor speaker for audition
1	Monitor-speaker housing
100 ft	Interconnecting cable No. 22 AWG shielded pair, with cotton-braided outer cover

* Transmitter and antenna equipment are not listed here, since they are specified in accordance with power and pattern.

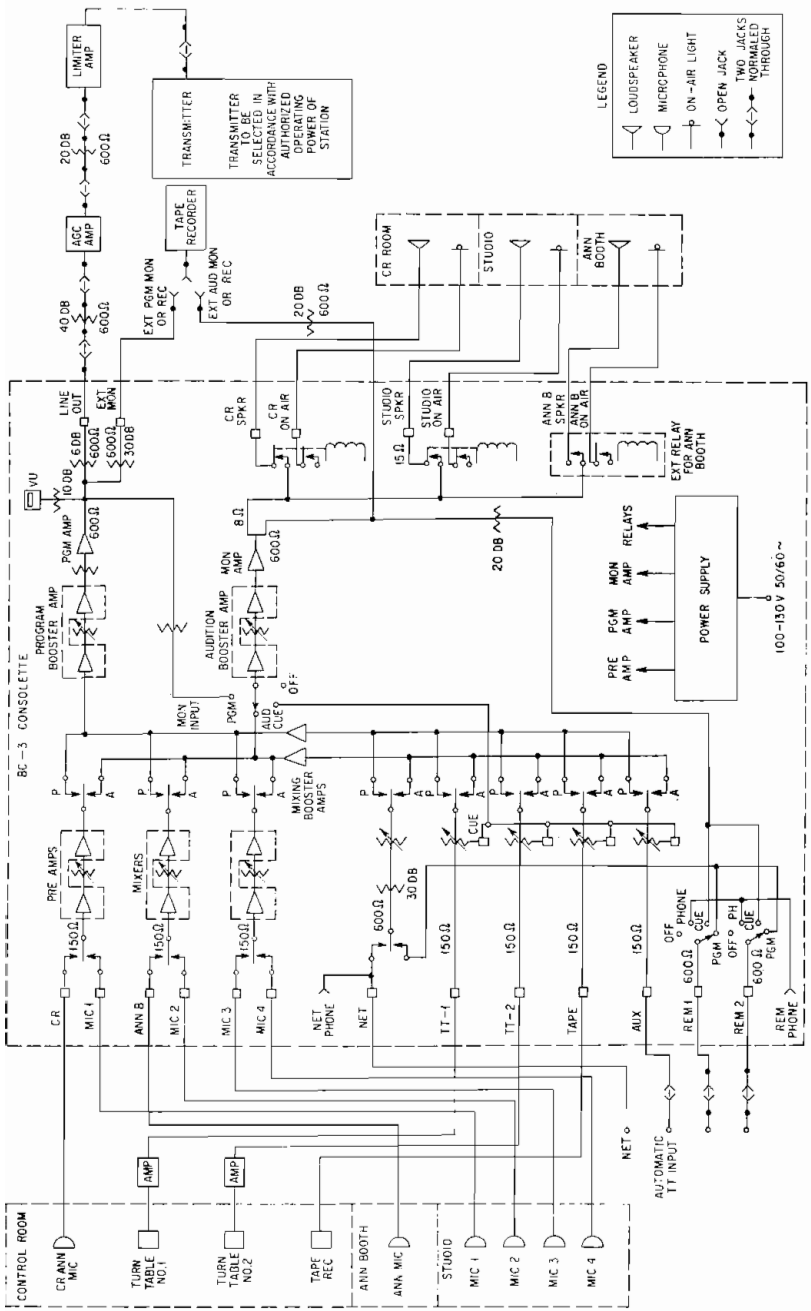


FIG. 1-6. System diagram for plan *B*.

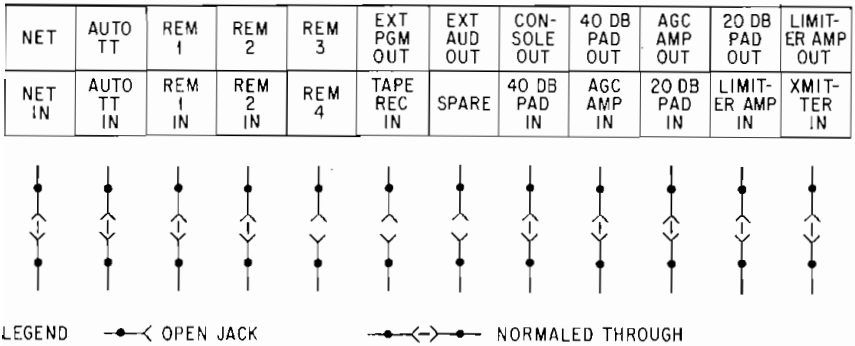


FIG. 1-7. Jack panel for plan *B*.

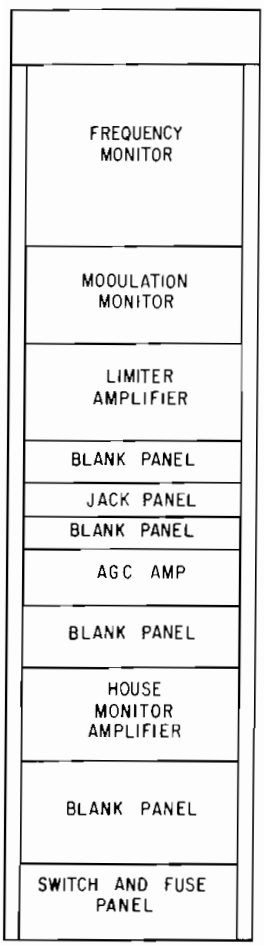


FIG. 1-8. Rack layout for plan *B* equipment.

equipment consists of an automatic turntable, another microphone, a monitor speaker, and associated items.

Now programming can be expanded to include the origination of a fairly substantial live studio show. Another important aspect of this plan is that with the announce booth serving as another point of origination, it becomes very practical to record announcements and other program material while on the air.

Again we have utilized a common sound lock, in the interest of economy, with the announce booth, studio, and control room all accessible from this area. The separation of the record library from the point of program origination makes it possible, with the facilities provided, to carry on auditioning of records, building of shows, cataloguing, filing, etc., without interruption during the program day.

It will be noted that the automatic turntable is located in the record library bnt controlled remotely from the operator's desk. This is convenient and further isolates the unit from the control room, so that any noise created while it goes through the change cycle will not go out on the air when the control-room announce microphone is open.

Technical Facilities of Plan B

The control console offers the additional system and operational functions required for Plan *B*. It retains, however, the operational simplicity of the console employed in plan *A*. As a matter of fact, it is simply an expanded version of plan *A*, just as plan *B* is essentially an expansion of plan *A*. An examination of the block diagram, Fig. 1-6, verifies this, showing the function of the consolette in this system.

The jack panel for plan *B* is shown in Fig. 1-7, and the rack layout in Fig. 1-8.

Three turntables are specified in the equipment list for plan *B*. The additional turntable, along with some accessory equipment, makes up a small system for

auditioning records. Figure 1-9 gives the details as to how this system goes together.

A first step toward automatic, or unattended, programming is provided by the automatic turntable. It can be used at some later time as one of the building blocks in a complete, unattended programming system. The automatic turntable, in conjunction with a tape recorder, can be utilized at the present time for more effective programming. For example, taped commercials and announcements can be pre-recorded at any convenient time. Then the desired records are loaded into the automatic turntable. This, in conjunction with a cue sheet, will enable an operator to select and direct, simply and easily, the function of the units. Plans for unattended operation will, by necessity, require some changes in programming concept. A transition will be required from the old way to the new, and all stations will not find unattended programming operation applicable in the same way. Here, however, is the opportunity to gain experience and guidance for future planning.

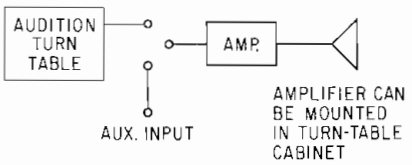


FIG. 1-9. Block diagram of record-audition system.

An automatic-turntable system (block diagram, Fig. 1-10) serves to provide necessary information for planning.

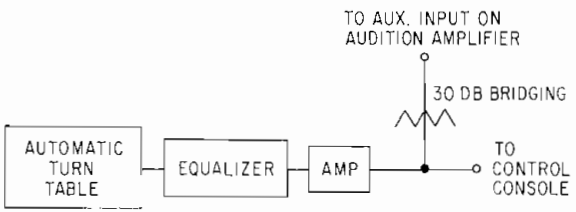


FIG. 1-10. Block diagram of automatic-turntable system.

Plan *C*

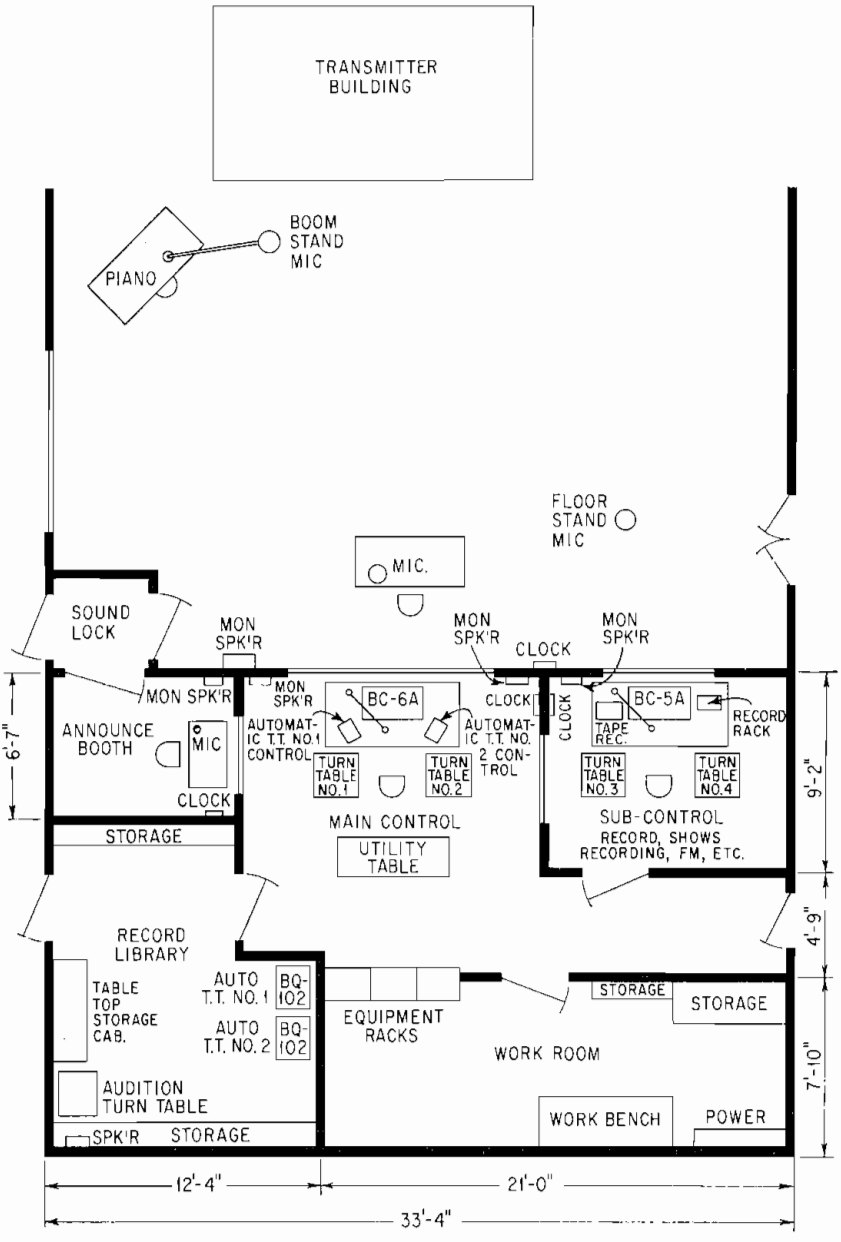
Plan *C* approaches the ultimate for the "larger" type of radio station as we know it today. From the floor plan (Fig. 1-11), it will be apparent that a high degree of flexibility is maintained, offering facilities for handling very extensive programming. Furthermore, it will be noted that plan *C* incorporates many of the same general considerations described for the other layouts but with several additions. There is also one significant deletion—the transmitter. In this plan we have assumed that the transmitter would be located separate from the studio, with its own building, at its own site.

First there is a large studio, the size to be determined by just what type of programs one wants to originate. The associated technical facilities suggested will handle choral groups, full orchestra, audience-participation programs, etc.

Then there is the main control room equipped with a dual-channel control console. These two full channels, each with its own monitoring amplifier and power supply, provide maximum flexibility and reliability. Two three-speed turntables and two automatic turntables are employed. Two remote-controlled tape recorders and two monitor speakers together with miscellaneous amplifiers and accessory items are included.

A highlight of this plan is the inclusion of a multipurpose room. It may be a small studio or, as it is shown equipped (Fig. 1-11), may serve many purposes as follows:

1. A subcontrol room serving the main studio for regular programming auditions or recording (see Fig. 1-12)
2. For disc-jockey-type shows



FLOOR PLAN C

FIG. 1-11. Floor plan C: location of all major equipment items. Note that the transmitter is separated from the studio location.

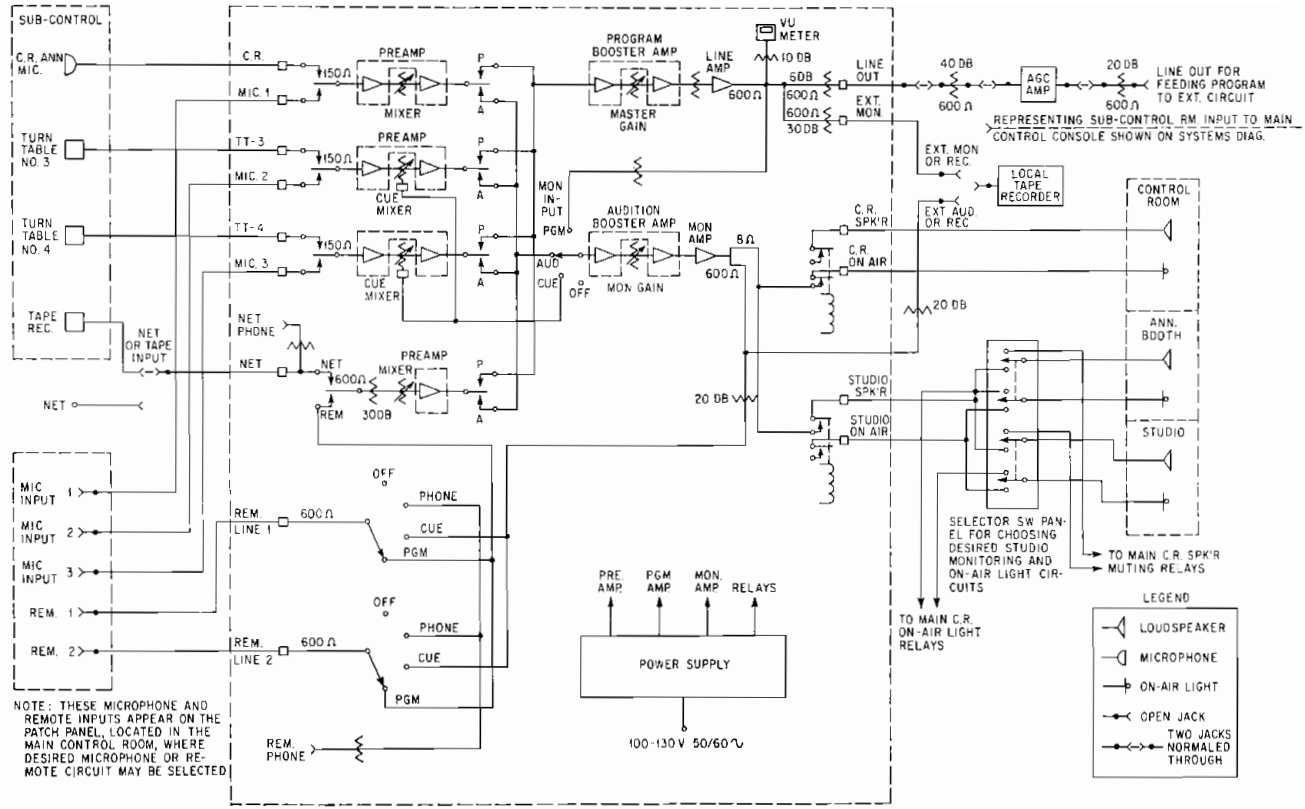


FIG. 1-12. Subcontrol block diagram for plan *C*.

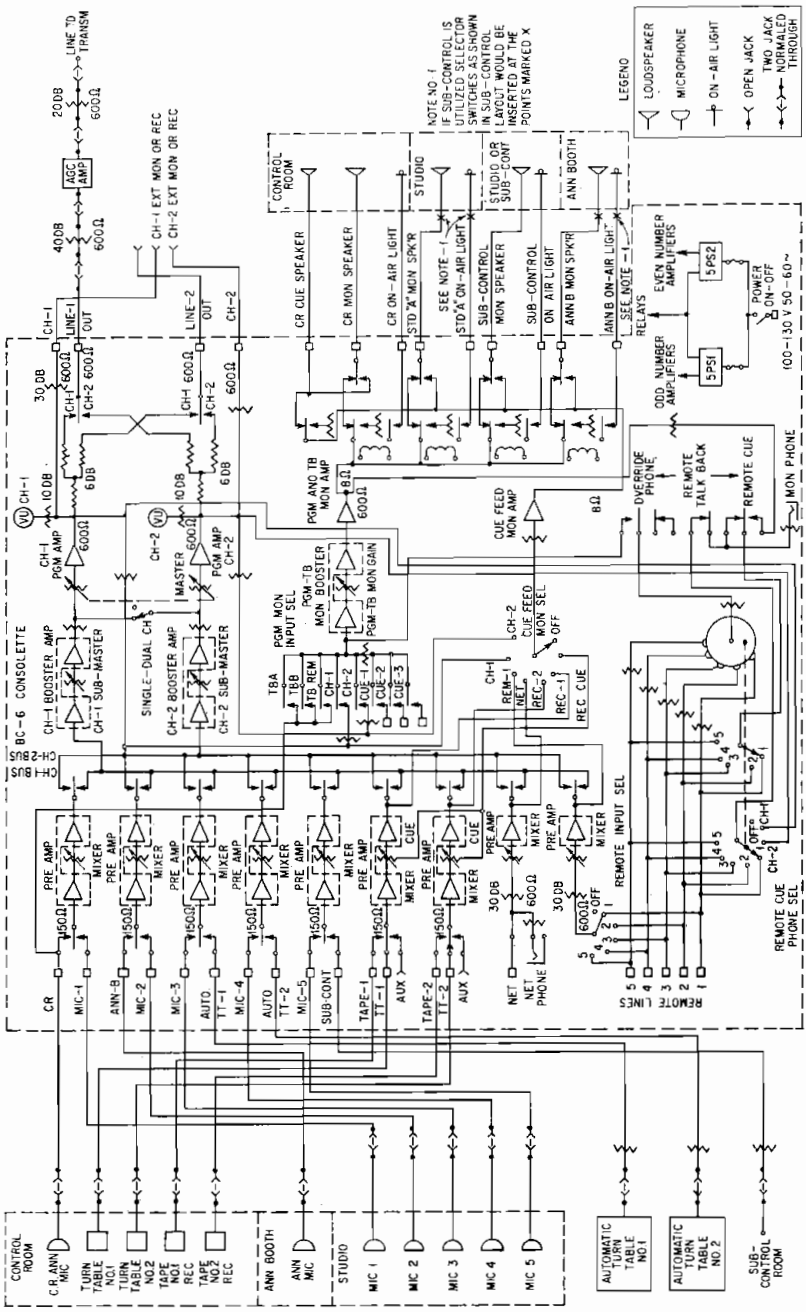


FIG. 1-13. Main control room of plan C and associated equipment.

3. For separate programming of another channel such as FM or to another AM station
4. As a recording control room
5. Announce booth
6. Auditioning special programs
7. Standby
8. As a program "make-up" facility for automatic program utilization in the future.

The announce booth, record library, engineering workroom, and storage area follow closely the preceding plans.

Technical Facilities of Plan C

The major equipment item new to this plan is the dual-channel control console. A block diagram of the unit is shown within the system diagram in Fig. 1-13. It has 22 inputs available, a "split-mixer" fader system, and two VU meters.

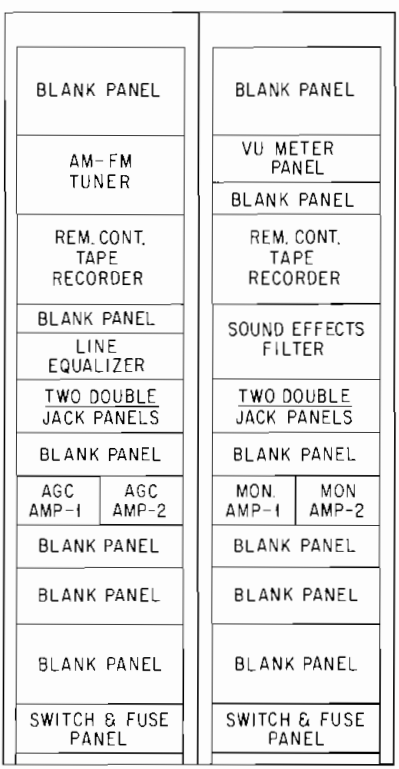
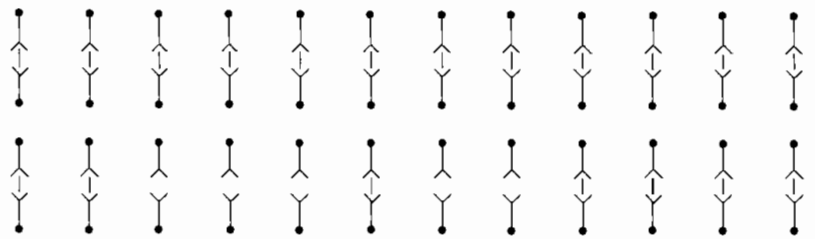


FIG. 1-14. This shows the necessary rack equipment for plan C with several desirable optional items: AM-FM tuner, line equalizer, VU meter panel, and sound-effects filter.

As used in plan C system this consolette is made to serve on command as a master control; a "combo," or operator-announcer's control board; and a program on one channel while running an audition or recording on the other. Figures 1-14 and 1-15 show that the rack layout for Plan C is as given in Table 1-3.

At the beginning of this part it was stated that the plans did not necessarilly represent any existing stations but that they illustrated several ways in which the equip-

CR MIC	ANN B MIC	MIC 1	MIC 2	MIC 3	MIC 4	MIC 5	TT 1	TT 2	TAPE 1 OUT	TAPE 2 OUT	SUB CONT OUT 1
PRE AMP 1-A	PRE AMP 2-A	PRE AMP 1-B	PRE AMP 2-B	PRE AMP 3-A	PRE AMP 4-A	PRE AMP 5-A	PRE AMP 6-B	PRE AMP 7-B	PRE AMP 6-A	PRE AMP 7-A	PRE AMP 5-B
AUTO TT 1	AUTO TT 2	SPARE	SUB CONT PRE-AMP 1-B	SUB CONT PRE-AMP 3-B	TAPE 3 OUT	SUB CONT REM-1 IN	SUB CONT MON OUT	SUB CONT CONSOLE OUT	40 DB PAD OUT	AGC AMP OUT	20 DB PAD OUT
PRE AMP 3-B	PRE AMP 4-B	SPARE	SUB CONT PRE-AMP 2-B	NET LINE	SUB CONT NET IN	SUB CONT REM-2 IN	SUB CONT AUD OUT	40 DB PAD IN	AGC AMP IN	20 DB PAD IN	TAPE 3 IN



REM LINE 1	REM LINE 2	REM LINE 3	REM LINE 4	REM LINE 5	NET LINE	LINE EQ-ZR 1-IN	LINE EQ-ZR 2-IN	CON-SOLE LINE-1 OUT	40 DB PAD OUT	AGC AMP OUT	20 DB PAD OUT
REM INPUT 1	REM INPUT 2	REM INPUT 3	REM INPUT 4	REM INPUT 5	NET IN	LINE EQ-ZR 1-OUT	LINE EQ-ZR 2-OUT	40 DB PAD IN	AGC AMP IN	20 DB PAD IN	LINE TO XMTR
SPARE	AM FM TUNER OUT	HOUSE MON 1-OUT	SPARE	SPARE	SPARE	SPARE	SPARE	HOUSE MON 2-OUT	SPARE	EXT MON 1	CON-SOLE LINE-2 OUT
SPARE	HOUSE MON 1-IN	HOUSE MON CKT	SPARE	CUE 1-IN	CUE 2-IN	CUE 3-IN	HOUSE MON 2-IN	HOUSE MON CKT	SPARE	EXT MON 2	SPARE LINE TO XMTR

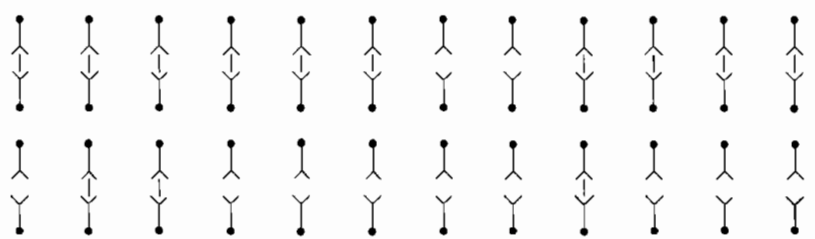


FIG. 1-15. Jack panels for plan C.

ment could be arranged and that the plans or combinations of them would satisfy a majority of cases. As plan C is examined, it becomes evident that some of these features would readily adapt themselves to Plan B. With the cross-application possibilities of these plans, practically all programming requirements can be met.

Table 1-3. Plan C Equipment List *

Quantity	*Main control room*
1	Dual-channel audio consolette with tubes and additional speaker light relay
1	Dual headphone
1	Microphone
1	Microphone mounting
1	Microphone plug
1	Microphone receptacle
2	"On-air" lights
2	Three-speed turntables
2	Transcription tone arms
2	Pickup heads
2	Transcription equalizers or filters
2	Tape recorders, remote control, rack mounting
2	Cabinet racks
2	40-db 600-ohm fixed pads
2	AGC program amplifiers with tubes
2	Monitor amplifiers with tubes
2	Mounting shelves
2	Monitor speakers
2	Monitor-speaker housings
2	Speaker-matching transformers
1	16-in. sessions clock
4	Double-jack panels
2	Double-jack panel mats
8	Audio patch cords, 2 ft in length
1	AM-FM tuner
2	Line equalizers
1	VU-meter panel
1	Sound-effects filter
2	Terminal board mounting brackets
2	Terminal power strips
2	Terminal audio blocks
2	Switch and fuse panels
4	$10\frac{15}{32}$-in. blank panels
1	$1\frac{23}{32}$-in. blank panel
4	$5\frac{7}{32}$-in. blank panels
2	$8\frac{23}{32}$-in. blank panels
2	$3\frac{15}{32}$-in. blank panels
200 ft	Interconnecting cable No. 22 AWG shielded pair with cotton-braided outer cover
400 ft	Interconnecting cable for audio rack wiring No. 20 shielded pair, solid conductor
200 ft	Interconnecting cable for a-c and filament circuits No. 18 shielded pair, stranded conductor

Quantity	*Studio and announce booth*
1	Pressure microphone
2	Ribbon microphones
1	Floor stand
1	Microphone boom stand
2	Uniaxial microphones
4	Desk stands
8	Microphone receptacles
8	Microphone plugs
3	"On-air" lights
2	Studio monitor speakers
2	Monitor-speaker housings
2	Speaker matching transformers
1	16-in. clock
300 ft	Interconnecting cable No. 22 AWG shielded pair, with cotton-braided outer cover
	Record library
2	Automatic turntables with remote control
1	Turntable
1	Transcription tone arm
3	Pickup heads
3	Transcription equalizers and filters
2	Utility amplifiers
1	Monitor amplifier for audition
1	Plug-in transformer
1	Selector switch for input of amplifier
1	Monitor speaker for audition
1	Monitor-speaker housing
150 ft	Interconnecting cable No. 22 AWG shielded pair, with cotton-braided outer cover
	Multipurpose room equipped as studio
1	Pressure microphone
1	Microphone mounting
2	Microphone plugs
2	Microphone receptacles
2	"On-air" lights
1	Monitor speaker
1	Monitor speaker housing
1	Speaker matching transformer
1	16-in. clock
50 ft	Interconnecting cable No. 22 AWG, shielded pair, with cotton-braided outer cover

* Transmitter and antenna equipment are not listed here, since they are specified in accordance with power and pattern.

Quantity	*Multipurpose room equipped as a subcontrol room*
1	Single-channel audio consolette with tubes
1	Dual headphone
2	Three-speed turntables
2	Transcription tone arms
2	Pickup heads
2	Transcription equalizers and filters
1	Tape recorder
1	Input transformer for tape recorder
1	Output transformer for tape recorder
100 ft	Interconnecting cable No. 22 AWG, shielded pair, with cotton-braided outer cover

HOW TO DESIGN THE COMBINATION CONTROL ROOM-ANNOUNCE BOOTH TO GIVE GOOD ACOUSTICAL PERFORMANCE [1]

Many present-day radio control rooms are not only used for this purpose but also act as announce booths where most of a station's announcing is carried on. In many cases the control room may be the only studio area in a station, and it will contain all the audio equipment of the station. Frequently, a transmitter and a record library will also be located in the control room. This makes the problem of acoustics more complex, but since radio sells with sound, good acoustics are a must when the best sound possible is desired.

Design Factors

Combination control rooms are at best a compromise of the several design factors. In the design of this control room, consideration must be given to the following:

1. Location of the control room within the studio building
2. Isolation—elimination of unwanted sound and noise, both internal and external
3. Construction—dual wall, floating wall, single wall
4. Reverberation control, elimination of unwanted reflections, and floor treatment
5. Ventilation and air conditioning
6. Size and arrangement of equipment

Location

The combination control room must be located so that it is convenient to the office areas, but traffic in and out of the room should be minimized in order to reduce distractions to the announcer. The location selected must have as little external acoustical and electrical noise as possible. The control room should be located away from street noise or noise that may be generated in other parts of the building, because it may become difficult and costly to reduce unwanted noise that enters through the floor and walls. Air-conditioning compressors and other rotating machinery should be well isolated and kept as far away from the control room as possible.

It is not wise to locate a control room next to a power-transformer vault or other large electrical equipment that may produce strong electrical fields. These strong electrical fields may cause noise problems in audio equipment. If the control room contains the transmitter, great care should be given to the grounding of all audio equipment, including equipment racks, consolettes, turntables, pickup arms, and other metal objects. In some cases, it may be desirable to shield the control room with copper screen to reduce noise generated from high-power RF fields of the nearby transmitters and antennas.

[1] *RCA Broadcast News*, vol. 100, April, 1958.

Isolation

Ideally, a control room should be a sound-isolated room within a room. Cost considerations in a small station may make such construction impractical, but it should be considered when possible. The floors and walls should be built from materials that will minimize the transfer of sound into the control room. Many new stations use concrete block walls and concrete slab floors that are isolated from the building walls with asphalt-impregnated glass fiberboard. This type of floor construction is very practical, since it reduces outside vibration in the control room floor.[2] A stable floor will improve turntable operation by reducing vibration that enters the pickup system from external sources.

Construction

The ideal control-room wall would consist of either a dual masonry wall or a masonry wall with a sound-isolated floating inner wall.[3] In the smaller stations, cost considerations usually preclude this type of construction. A single wall of masonry, cement, gypsum, or pumice block is a good compromise, which is completely satisfactory where external noise is reasonably low.

Wood-wall construction should not be used unless double walls are used. Staggered 2- by 4-in. studs can be set on 16-in. centers on a 2- by 6-in. plate for the double-wall construction (see Fig. 1-16). Rock-wool bats can be interlaced between the studs for additional sound isolation. There should be at least 2 in. of rock wool or other sound-absorbing material above the ceiling surface, and if external noise is of large magnitude, the ceiling should be sound isolated.

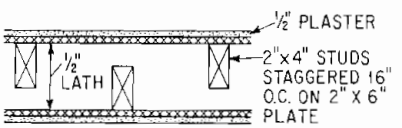


FIG. 1-16. A cross section of a sound-insulating partition. Wooden walls should be constructed in this manner to reduce external noise.

If care has been given to the location of the control room in a given building, the offices and other quiet areas surrounding the control room may screen it from unwanted sound. Control-room doors should be the heavy soundproof type (see Fig. 1-17), or double doors should be used. Observation windows should be kept to a minimum. Each such window should consist of two panes of heavy plate glass of different thicknesses to break up resonance conditions. The glass plates should be set in rubber or felt gaskets, and usually the glass plates are set about 10° off vertical (see Fig. 1-18).

Reverberation Control

Some form of reverberation control should be employed within the studio. If a studio has too long a reverberation period, the sound may blur and speech may lack intelligibility. Such sound characteristics are not pleasing to the listener. Generally a studio should have an approximate reverberation time of 0.4 sec for a volume of 1,000 cu ft rising to 0.6 sec for 10,000 cu ft[4] (see Fig. 1-20). The reverberation time should be about the same from 100 to 5,000 cycles, but it may rise slightly at 5,000 cycles (see Fig. 1-19). This type of studio characteristic helps eliminate low-frequency boominess.[5] An acoustical consultant should design the studio and supply the proper materials.

[2] Impact Noise Isolation in Television Studios, *Broadcast News*, vol. 97, October, 1957.
[3] Michael Rettinger, "Applied Architectural Acoustics," Chemical Publishing Company, Inc., New York.
[4] NBC Studio Design, *J. Acoust. Soc. Am.*, vol. 8, p. 31, 1936.
[5] Edward J. Content and Lonsdale Green, Jr., Acoustical Design and Treatment for Speech Broadcast Studios, *Proc. IRE*, vol. 32, no. 2, February, 1944.

Consideration should be given to all wall and equipment surfaces in the control room in order to eliminate unwanted reflections. Perforated hardboard or Transite can be used for wall coverings with rock or glass wool placed behind it for sound absorption (see Fig. 1-21). Hardboard may be painted, and it is easily maintained with occasional washing. The hardboard can be used for wall panels set at various small angles of 5 to 10° to produce greater diffusion of sound.

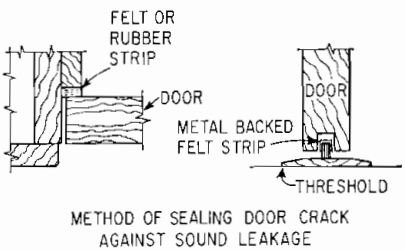


Fig. 1-17. Normal methods for sealing the control-room door. The door itself should be of a heavy type to improve isolation of the control room.

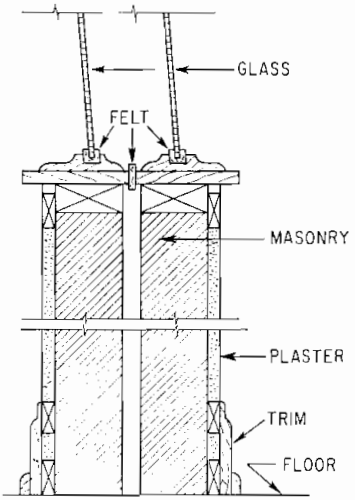


Fig. 1-18. Sound-insulating window construction showing structural separation of double wall. Glass windows in studios and control rooms should be offset about 10°, and they should be mounted as shown on a double wall.

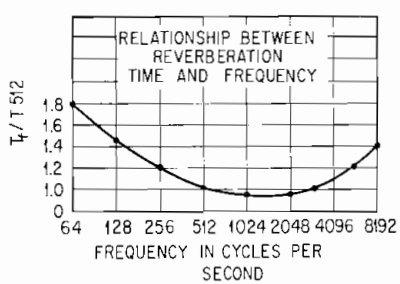


Fig. 1-19. Morris-Nixon curves showing the relationship between reverberation time and frequency. Reverberation time should remain fairly constant between 100 and 5,000 cycles.

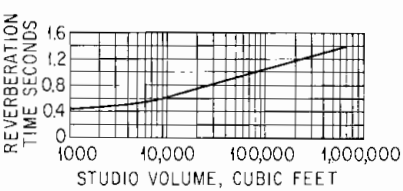


Fig. 1-20. Variations in reverberation time as the size of the room increases with a 512-cycle reference signal.

All glass surfaces should be set on an angle to reflect sound into the sound-absorbing surfaces of the ceiling. Glass surfaces should be kept to a minimum, and large corner areas of glass should be avoided. The floor covering should be of a soft material, such as cork or vinyl tile, to reduce surface noise. A rug may be necessary to produce the required deadening in control rooms having many glass surfaces and other reflecting areas. The surface of the operating table should be made of a soft material such as linoleum or vinyl. This will reduce table-top noise.

Microphone Requirements

A good microphone with proper directional characteristics is important in the control room. A 77-DX microphone operated in a unidirectional pattern has excellent properties (see Fig. 1-22). The BK-5A microphone is also an excellent microphone for the control room. The distance between the speaker and the microphone will be determined by the acoustics of the control room; however, good microphone technique is important for all personnel if natural reproduction is desired.

Ventilation

To do a good selling job, an announcer must sound alive. It is important to provide air conditioning and ventilation so that announcers have a good environment in which to work. A central air-conditioning system is recommended. The air is brought in through ducts from the coolers. The air ducts should be lined with a sound-absorbing material for a distance at least twenty times the average width of the duct. A separate duct should be run to each studio and to each control room to avoid sound transfer through the ducts. Low-velocity air should be used to prevent air noise from the duct openings.

If the control room contains a transmitter, it is usually possible to exhaust hot transmitter air to the outside and to cool the transmitter with spent room air. If this is not possible, the transmitter should be partitioned off from the control room, and a separate source of air should be used to cool the transmitter. The transmitter can be remotely controlled if it is in another room some distance from the control operation. Such a procedure will save many dollars in construction costs and also eliminate a source of noise in the control room.

Equipment Arrangement

The equipment selected will, to a large extent, determine the physical aspects of the control room. The control room should be large enough to contain all required personnel and equipment. At the same time thought should be given to possible future expansion, and extra space should be provided with this in mind. A control room that is a little larger than necessary at the outset makes it easily expanded later. Furthermore, it is always more difficult to treat a small room acoustically than a large room.

Planning It Right

A good architect should be consulted when planning a studio-control room. After a general station plan is formulated and equipment selected, the architect and the consulting engineer should work out the specific construction details for the station. Careful acoustical planning combined with good equipment will enhance the sound of any station and make its sound sell more.

ROOM ACOUSTIC DESIGN

Foreword

The third edition of the "NAB Engineering Handbook" contained a reprint of a paper presented by Mr. John E. Volkmann before the Acoustical Society of America in New York, entitled "Polycylindrical Diffusers in Room Acoustical Design." Mr. Volkmann prepared another paper entitled "Acoustic Recommendations for Small Combined Studio, Scoring Stage and Review Room" which although it was prepared originally for motion-picture studios provides data of interest in the construction of television studios.

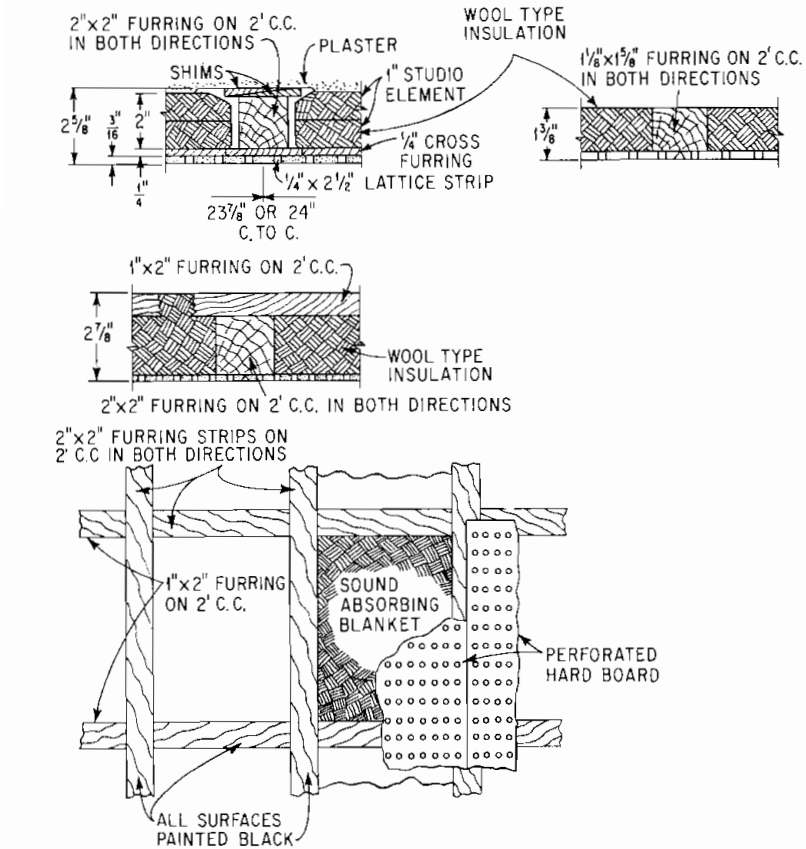


Fig. 1-21. Typical acoustical panels and how they are mounted. Excellent isolation can be obtained if this type of wall material is backed up with glass or rock wool.

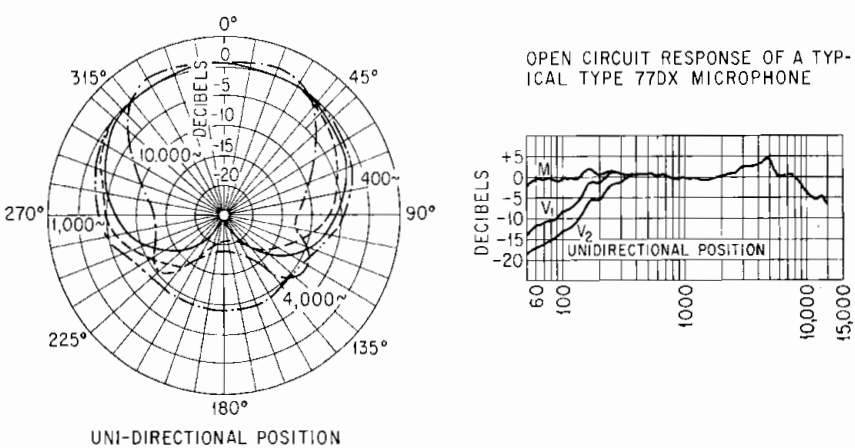


Fig. 1-22. Response curve for the RCA type 77-DX microphone. A good microphone is necessary for combination control rooms.

The NAB Department of Engineering, with the permission of Mr. Volkmann and RCA, has combined the two papers to provide informational data useful in the design of studios used for AM and FM broadcasting as well as for television broadcasting and recording.

Basic Requirements and Definitions

Although large-scale recording and projection operations usually require separate rooms for optimum acoustic results, economic considerations frequently necessitate the combining of these facilities into one studio and the primary purpose of these recommendations is to provide the basic information necessary to accomplish this objective. The proper planning and acoustic design of a studio before construction have received ever-growing attention by architect and engineer and have eliminated much of the necessity for the curative treatment of acoustic defects.

Good Acoustics

The requirements for good acoustics have been stated by Wallace Clement Sabine, pioneer in architectural acoustics, in his book referenced in the bibliography. The criterion most frequently used for judging the acoustic excellence of a room is its optimum reverberation time. Other factors and acoustic phenomena with which the scientist or acoustical engineer is concerned in determining the acoustical performance of a room include the following: echo, resonance, interference pattern, sound absorption, reflection, transmission, diffuse sound, rate of decay, intensity distribution, sound level, and noise level.[6]

Experience in rooms with wood paneling and sound-diffusing surfaces indicates that the manner in which the reverberant and other aftersounds in a room are distributed has possibly as much to do with the acoustical excellence of a room as the actual time of decay in the room, and from time to time we have heard discussions on the diffusion of sound in rooms not only in regard to fulfilling the assumptions in the Sabine reverberation formula but in regard to its subjective effect.

Physical Design Factors

The major physical factors with which the architect is concerned in the acoustical design of a studio are as follows:

1. Choice of site
2. Size of studio
3. Shape and proportions of studio
4. Selection and placement of absorbing materials
5. Sound and vibration isolation

The broadcasting and recording engineers are also interested in the placement of microphones and loudspeakers and in variable reverberation control.

General Considerations

Since most room acoustic difficulties occur due to reverberation and other reflection phenomena, a brief discussion of these general factors and their control is considered important to a proper understanding of acoustical design.

Reverberation

The action of sound when confined in an enclosure is much more complex than its action in free air. In free air only the direct sound from the source can be heard. In a room, however, the sound one hears is composed of both the direct and the reflected waves. The sound wave generated in the room proceeds or expands spheri-

[6] See Appendix A for definitions of acoustic terms.

cally from its source until it meets the boundary surfaces, where it suffers partial reflection, absorption, and transmission. The reflected wave from each surface continues its travel inside the room only to suffer again partial reflection, absorption, and transmission each time it strikes a boundary surface. This process is repeated until the sound energy is completely dissipated. In an ordinary room with plaster walls and ceiling, an ordinary sound may undergo from 200 to 300 such reflections before its energy is completely dissipated by absorption or transmission. If we recall that sound travels 1,120 fps, it is readily seen that the duration of this prolonged aftersound, called the reverberation time of the room, may be several seconds for a large room where the mean free path is long. The effect of excessive reverberation is to blur speech and music owing to the overlapping of successive sounds.

The reverberation time of a room, which is the time required for a sound of given initial intensity to die away to the threshold of minimum audibility, depends directly on the intensity level of sound and the size of the room and depends inversely on the absorption in the room. The standard reverberation time of a room is the time obtained when using an initial intensity of 1,000,000 times the intensity at minimum audibility. Increasing the size of a room increases the reverberation period owing to the fewer number of reflections which occur in it during a unit interval of time.

Optimum Size of Studio

Just as tradition and experience have taught that an optimum reverberation time exists for each size of room, so we have learned that an optimum size of studio exists for each type and size of orchestra. The data in Table 1-4 are based on com-

Table 1-4. Size of Orchestra vs. Room Size

Volume of room, cu ft	*Auditorium practice*	*Optimum*	*Broadcast practice*
10,000	–	6	12
20,000	6	9	25
50,000	9	21	50
100,000	19	38	130
200,000	31	70	250

mercial practices and subjective listening tests. The column labeled "auditorium practice" shows the minimum number of orchestral instruments recommended for auditoriums, while the column labeled "broadcast practice" gives the maximum number of instruments sometimes crowded into broadcast studios. The recommended practice for recording and scoring studios is shown in the column labeled "optimum." Experience in Hollywood indicates that a volume of 50,000 cu ft constitutes about the minimum requirements for scoring studios. Another acoustical factor which, in the case of sound-picture projection, is related to the size of room is the acoustical power required for proper sound reproduction. Most sound motion-picture reproducing equipment is more than adequate for the ordinary-size review room; however, in those cases where the picture is reviewed in a theater, the reproducing equipment should meet the "Minimum Power Requirements for Theatres" established by the Academy Research Council.

From the standpoint of reverberation time, minimum power requirements, air-conditioning-system requirements, etc., the theater which is used for reviewing purposes should be made a minimum in size compatible with its seating capacity and architectural treatment. Small review rooms and scoring rooms on the other hand should be made as large as possible to most nearly approximate auditorium and hall conditions. For normal theater sizes the Academy of Motion Picture Arts and Sciences recommends 125 cu ft per seat. For small rooms, say with a seating capacity of only 20, this figure can be increased to as much as 500 cu ft per seat.

Room Resonances—Effect of Parallel Reflecting Surfaces

When sound is generated between two parallel reflecting surfaces, "standing waves" are set up at certain frequencies depending on the distance between the surfaces. The lowest frequency at which the standing-wave resonance will be set up is that frequency for which its wavelength equals twice the distance. The parallel surfaces will likewise cause resonance for harmonic frequencies. Thus, for a flat reflective ceiling whose height is 11.2 ft above floor level, resonance may occur at 50, 100, 150 cycles, etc. (frequency equals 1,120 divided by wavelength, that is, by twice the ceiling height).

The effect of these resonances is twofold: First, it introduces frequency discrimination in the form of peaks and dips in the response characteristic, and second, it introduces a persistence, or hanging-on effect, in the sound for frequencies at or near resonance. This frequency discrimination and persistence gives a hollow-sounding characteristic, especially if the resonance frequencies are widely separated (surfaces close together), which is generally the case in small rooms.

The effects of standing-wave resonances can be minimized or controlled by any or all of three methods: (1) by absorption treatment, (2) by changing the position or spacing of the surfaces, and (3) by changing the shape of the reflecting surfaces. In general, the first method is not satisfactory in small studios, since the absorption required for damping the resonances is too great from the viewpoint of optimum reverberation and hence causes the room to sound "dead" and, if the absorption material is selective, may cause it to sound "bassy." The other two methods will be discussed under separate paragraphs later.

Structural Resonance

The phenomenon of resonance, or the ability to vibrate most easily at certain frequencies, may occur in structures as well as in the air in rooms. Structural resonance usually is not harmful unless the resonant body is closely coupled mechanically to the source of sound. As discussed later, structural resonance is sometimes a virtue; for example, the resonance of wood paneling in an auditorium is often a factor which improves its acoustic excellence, especially for music. In this case, however, the fundamental and harmonic resonances do not occur at any one frequency but rather over many different frequencies owing to variations in size and construction of the individual wood panels.

Shape of Studio—Preferred Proportions

To minimize the frequency-discrimination effect caused by the standing-wave systems set up between parallel surfaces in a room, it is desirable to choose major dimensions which are not integral to one another. By proportioning the three major dimensions of a room in the ratio of the cube root of 2 (or in ratio of multiples of the cube root of 2), a good distribution of the natural resonance frequencies is obtained. For small rooms the preferred ratio of height to width to length is 1 to 1.25 to 1.6 as shown in Fig. 1-23. For the studio of average size and shape the preferred dimensions should be in the ratio of 1 to 1.6 to 2.5. In all cases the dimensions shown are derived from the ratio of the 3/2. Stating it another way the major dimensions should be separated 1/3 octave with respect to one another, or other ratios derived from this fundamental ratio by shifting any or all of the dimensions by one or more integral octaves can be used. Other preferred proportions for less common shaped rooms are also shown in Fig. 1-23.

We next deal with the shape and treatment of individual surfaces.

Shape of Reflecting Surfaces—Sound Diffusion

A pleasing reverberation characteristic depends not only on the proper reverberation time but on a uniform rate of decay of sound. This requires a diffuse distribu-

tion of the aftersound in a room and can be obtained by shaping and paneling the walls, ceiling, and other surfaces so as to disperse their reflections in all directions. Many rooms and halls known for their acoustic excellence have such wood paneling and sound-diffusing surfaces. For example, in the Philadelphia Academy of Music, which has several tiers of boxes and wood paneling throughout the auditorium, the dimensions of the projecting surfaces, being comparable to the wavelength of sound, tend to disperse the reflections and give a more diffuse distribution of sound. An important point regarding sound diffusion is that it does not lessen the total energy in the room but merely tends to increase the number of reflections which occur per unit time and hence lessens the intensity level of the individual reflections. Because

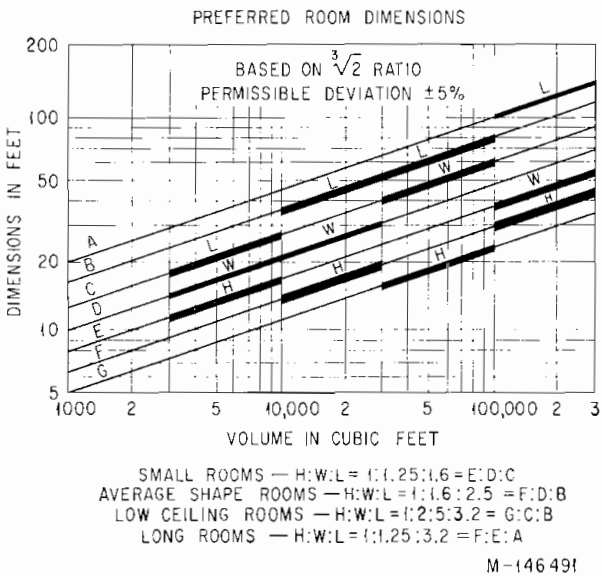


FIG. 1-23. Preferred studio dimensions.

the difference in intensity level between reflections is less, the decay of sound in the room tends to be smoother and more uniform and hence more pleasing to a listener. This factor is also of practical importance in making the placement of microphones less critical.

A second factor of importance in these famous music rooms is that the wood paneling also helps to give a diffuse distribution of sound by virtue of the fact that the energy incident on its surface which is not absorbed is reradiated.

This reradiated energy does not follow the regular law of equal angle of incidence and reflection but, owing to panel vibration, acts more like a loudspeaker diaphragm and, therefore, for most frequencies either disperses the incident energy over a wide angle or changes its direction. A third important factor in these rooms is that the radiation from the wood paneling occurs farther owing to direct mechanical or "telephonic" transmission from the original sound sources on the stage through the wood flooring and panel-mounting structure. Since the wood panels are more or less of different sizes and shapes, the panel resonance frequencies are not selective. Two other interesting facts to note here are that panel radiators have a decay time of their own and that the transmission time in wood is much shorter than in air.

This "diffuse" distribution of energy coming from many random directions and from a great number of small sources of sound in the room has, in addition to giving a more uniform distribution and decay of sound, the important psychological effect

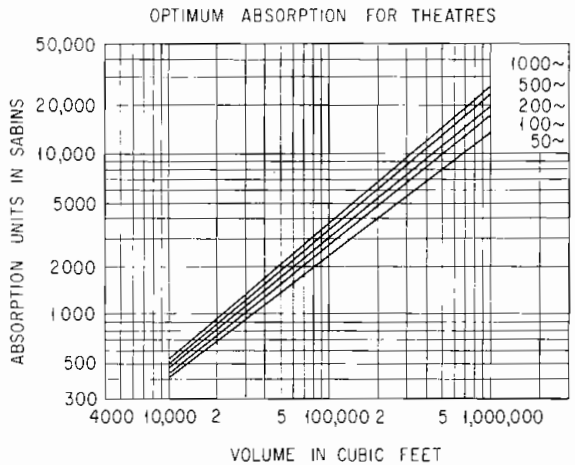
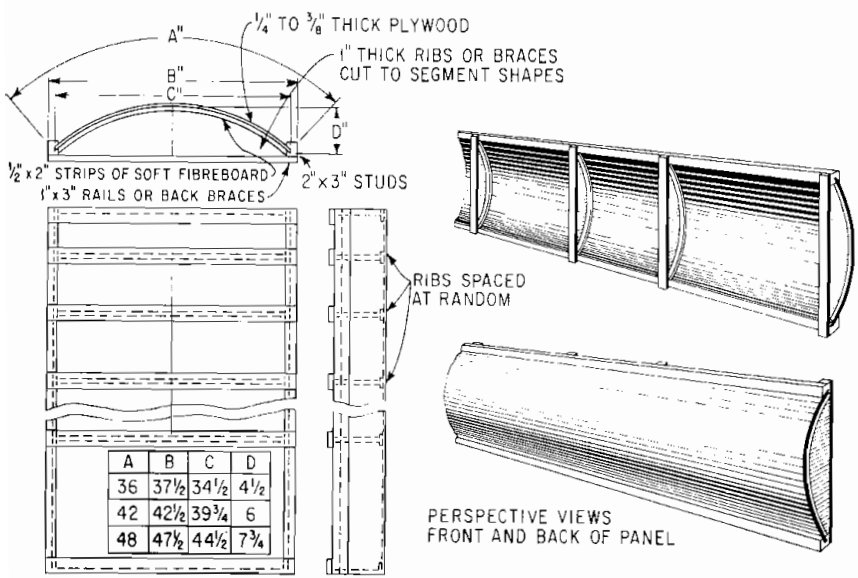


Fig. 1-24. Optimum absorption.



A	B	C	D
36	37½	34½	4½
42	42½	39¾	6
48	47½	44½	7¾

Fig. 1-25. Convex wood panel.

created by enveloping the listener with sound, which gives a certain feeling of body or depth to the sound. This "feeling" effect of sound is further enhanced by the transmission of sound through the wood floor to the seats and from other structures in the room.

Sound-absorption Characteristics

The sound-absorbing materials used for the control of reverberation and delayed reflections should have adequate efficiency at the low frequencies to give the optimum reverberation characteristic for the specified room size (see Fig. 1-23).

The optimum sound-absorption units vs. frequency corresponding to the optimum reverberation times for various room volumes is shown in Fig. 1-24.

Convex Wood Panels

Figure 1-25 shows a typical curved wood panel consisting of 4- by 8-ft plywood formed over curved segment braces and fitted at the edges with 2- by 3-in strips which have been routed and held together with 1- by 3-in. back braces. The segment braces, which must be spaced at random, have strips of ½-in. Celotex or other soft fiberboard placed between them and the paneling to prevent rattles. It is felt that convex cylindrical wood paneling is particularly suited to meet the aforementioned requirements of a good sound diffuser because it disperses sound energy not only by reflection from its curved surface but by radiation due to its resonance action or panel vibration which, as already mentioned, is set up either by direct transmission from the original source of sound or by partial absorption and reradiation of the aerial sounds impinging on its surface.

Dispersion by reflection depends on the size and curvature of the panels and their relation to the wavelength. Dispersion characteristics for a curved and flat panel plotted on polar coordinates are shown in Fig. 1-26. This shows clearly the diffusing action of convex curved surfaces and was obtained by rotating the panel about its long axis while keeping the source and directional pickup constant.

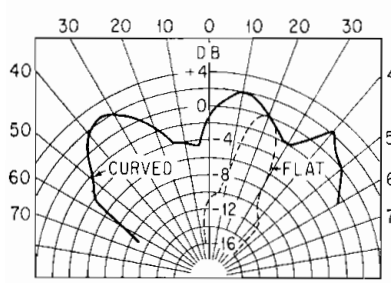


FIG. 1-26. Polar distributions from convex and flat panels.

It should be noted here that the apparent source for convex reflectors is always behind the surface. The value of such surfaces in reducing the interference effect of first reflections as compared with flat surfaces is shown in Fig. 1-27. Note that the aiding effect at some frequencies and the cancellation at others is less for the convex panel. The relative intensity levels of the direct and reflected waves used in obtaining the interference curves are shown in Fig. 1-28. The reduction in interference effect is significant when we remember that the total energy content of the reflected wave from either surface remains the same. As mentioned earlier, the reduction of the interference effect of first reflection is important in studio microphone pickup in allowing greater freedom of placement. For remote surfaces in large rooms a similar diffuse reflection can be obtained by means of concave reflectors providing the focus point or the apparent source of sound, which in this case is in front of the reflector, is not within or near the seating area or any other critical area.

Dispersion of sound by means of panel resonance depends on the modes of vibration set up. For areas of motion small compared with the wavelength radiated, the distribution will tend to be nondirectional. For vibrations normal to the surface, a convex cylindrical panel would tend to set up a cylindrical wavefront as compared with the plane wavefront in the case of flat panels. The resonance frequencies and response of a panel depend on a great number of factors such as the damping co-

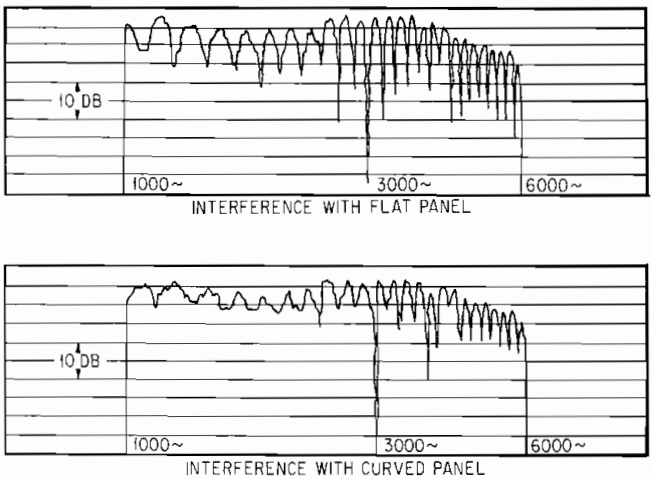


FIG. 1-27. Interference between direct and reflected waves for convex and flat panels.

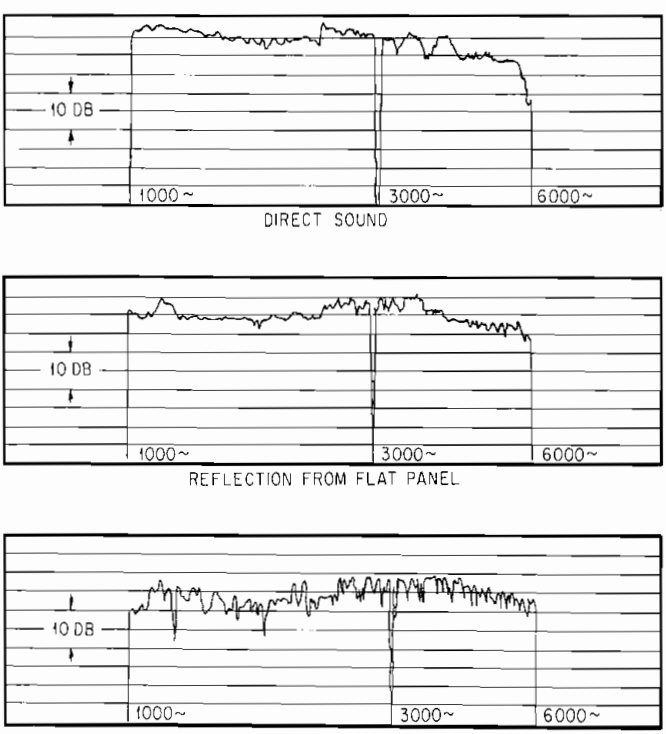


FIG. 1-28. Direct and reflected response of panels used in interference measurements.

efficient of the material, thickness, spacing of braces, method of mounting of the entire panel, etc. It is interesting to note that because of the added stiffness introduced by bending, a smaller panel thickness can be employed for curved panels for the same frequency. The decay time, or "resonance time," of a typical panel excited at one of its modes of vibration is shown in Fig. 1-29. In addition to the

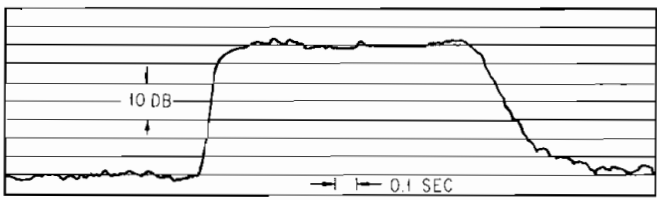


FIG. 1-29. Growth and decay curve of vibrating convex panel.

dispersion and radiation action, the vibration of the wood paneling aids the absorption efficiency over more rigid materials. Preliminary data indicate a coefficient of approximately 0.18 over a considerable band of frequencies.

This absorption characteristic in conjunction with its dispersing action makes convex wood paneling ideal for small studios.

Objectionable Shapes—Interference Phenomena

Flat, untreated surfaces, if very extended in area or if close to the recording microphone, may give rise to objectionable interferences due to the phase difference between the direct and reflected sounds. The "loud" and "dead' spots caused at various frequencies when the direct and reflected waves are comparable in intensity level can become very pronounced and, owing to frequency discrimination, give a hollow-sounding effect. In view of this effect it is desirable that all flat surfaces in the studio have some absorption or else be shaped to disperse the reflection.

Concavely curved surfaces, even though treated with absorbing material, should be avoided. Because of their focusing effect, such surfaces accentuate the interference problems already discussed.

In larger rooms, reflections from concave surfaces and from large untreated flat areas give further trouble due to the echo or time-delay effect and therefore should definitely be avoided.

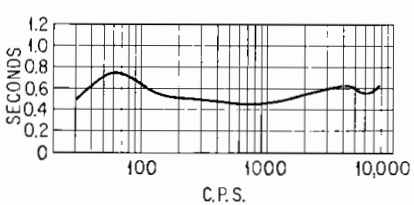


FIG. 1-30. Reverberation time of listening studio.

Studio with Polycylindrical Wood Panels

In addition to the cylindrical wood diffusers already mentioned, such studios have several other features of interest in room acoustic design.

In order to obtain maximum diffusion in three orthogonal planes, axes of the polycylindrical surfaces are placed mutually perpendicular to each other. Three different-sized panels and curvatures are used further to obtain asymmetry in the pattern of diffused sound. The high degree of diffusion obtained in this type of room is evidenced in the smoothness of decay curves. The reverberation curve for one such studio is shown in Fig. 1-30, which conforms reasonably well with published optimal times.

Another feature of the reference studio is the choice of the major dimensions (12.5 by 20 by 32 ft) which progress in two-third octave steps in order to avoid the "piling up" of room resonances. This is especially important as already pointed out

for small rooms where the frequency gap between fundamental and harmonic resonances is oftentimes great and unless guarded against may lead to a room response with wide hollows in the audible range. In the present case this consideration was important because the use of large convex diffusers effective in the range below approximately 300 cps was not considered practical. In large rooms consideration should be given to the use of low-frequency diffusers as well as for the mid-range and high frequencies.

Orchestra Shell

Occasionally regular sound stages (usually treated over the entire wall area with 4-in. rock wool and over the entire ceiling area with 2-ft rock wool to eliminate all reflections) are employed for musical recordings, in which case it is necessary to "liven" the stage.

In an application of polycylindrical design to an orchestra shell the multiplicity of dispersing surfaces and resonant panels not only minimizes the microphone placement problem but gives a more pleasing reinforcement of sound to the conductor and musicians. The platforms can be used for elevating and reinforcing the bass instruments in the orchestra.

Exclusion of Noise

A review room with good acoustics has its walls insulated against the transmission of outside noises into the studio. The transmission of sound is of two kinds: (1) aerial and (2) structural. Small openings due to doors, windows, portholes, etc., transmit sound to a great degree. Thus, all the joints between walls, doors, windows, etc., should be made as airtight as possible.

Likewise, transmission of sound through structures, such as the noise from vibrating motors and machinery, should be minimized by using massive walls and floors and by separating all vibrating bodies from their supporting structures by sound-insulating materials such as cork, lead, or rubber.

Massive walls are not always necessary to obtain sufficient sound insulation. A double wall of fairly light construction will give good sound insulation provided the two walls are not closely coupled mechanically by nails or cross members, that is, provided the walls are kept isolated or separated from each other.

Projection Booth

Treating of ceilings and walls inside the projection booth lowers the noise level, permitting more accurate control of volume and quality.

Treating ceilings and walls by lowering the noise level reduces the sound transmitted into the studio. Insulation of machines from the floor by heavy blocks mounted on cork or Keldur is often necessary to reduce transmitted sound.

Double or triple optical glass in ports is generally used to reduce the sound conducted by the air through these ports.

The projection booth walls either should be very heavy (12-in. brick walls) or should be constructed with double walls which are isolated from each other so as not to conduct sound by supporting them on some such material as felt and avoiding any construction which will tie the walls rigidly together.

Figure 1-31 shows a cross section of a typical projection-booth window of the sound-retarding type in accordance with principles outlined by National Broadcasting Company engineers and others. Figure 1-32 shows a cross section of a typical sound-retarding door such as the Riverbank door used by broadcasting stations and other sound studios. Figure 1-33 illustrates construction of a typical sound-insulating wall in accordance with principles stated by Bagenal and Wood in their book "Planning for Good Acoustics."

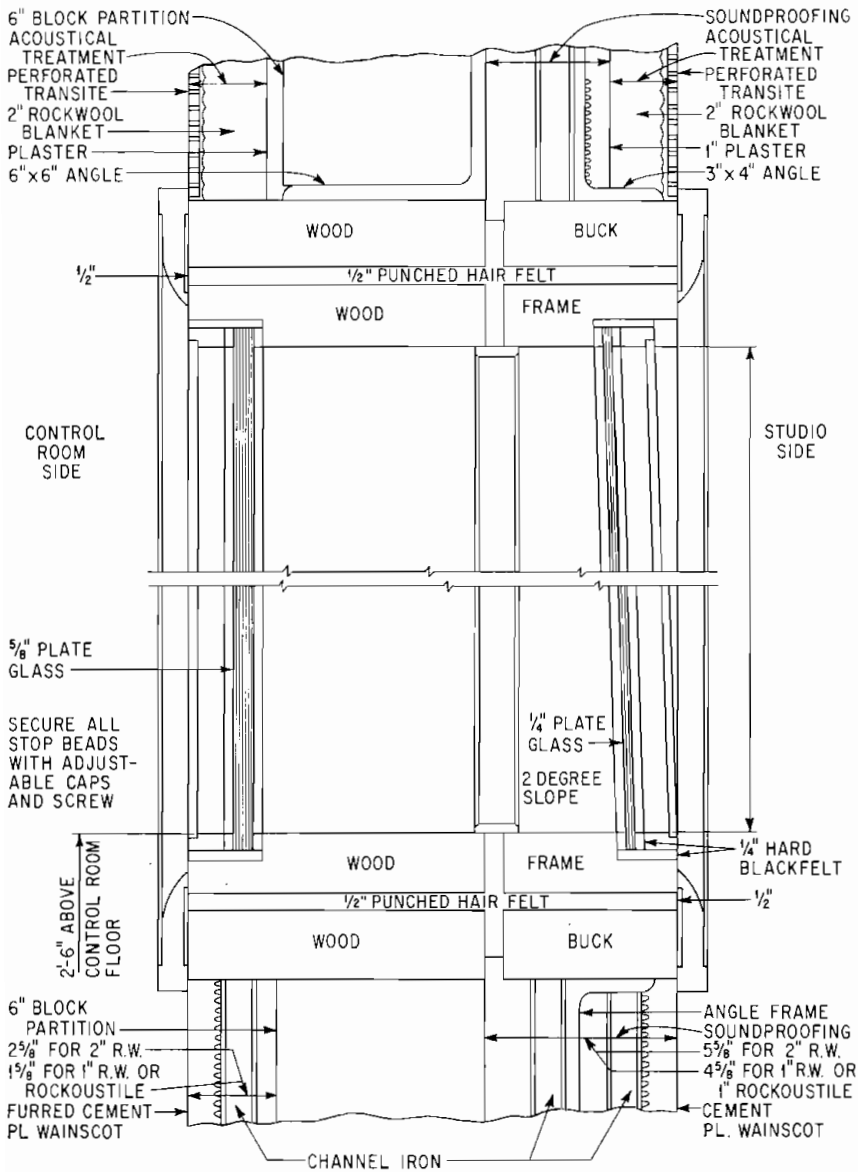


Fig. 1-31. Sound-insulated window.

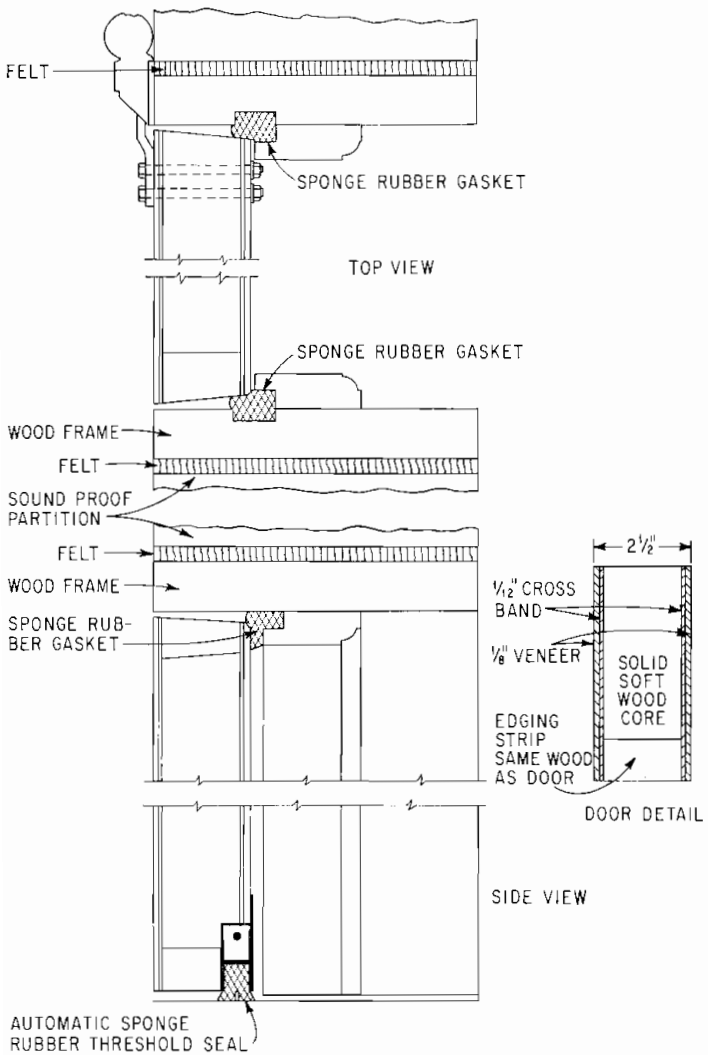


Fig. 1-32. Sound-retarding door.

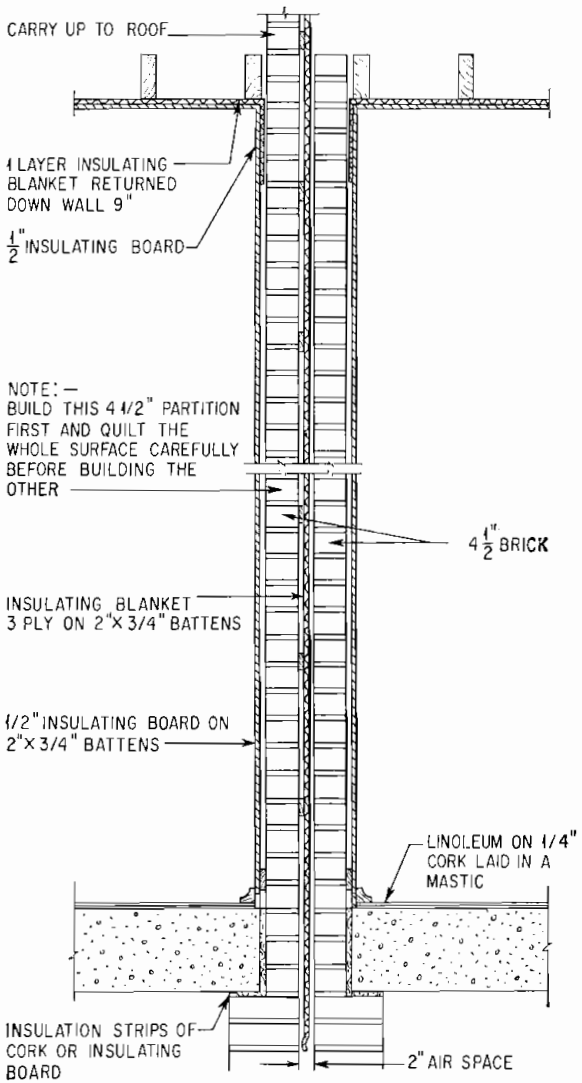


FIG. 1-33. Sound-insulating wall construction.

Acoustic Design of a Typical Small Combination Studio

The following specification covers, in accordance with the principles already outlined, recommendations on the acoustic treatment of a typical small combination studio.

Purpose of Studio

The general purpose of this studio is to provide the following recording functions:

1. Straight recording (voice or music)
2. Pre- or postscoring of small orchestras
3. Rerecording
4. Reviewing and projection
5. Monitoring and control

A plan view showing the general arrangement of rooms and equipment to serve these functions is given in Fig. 1-34.

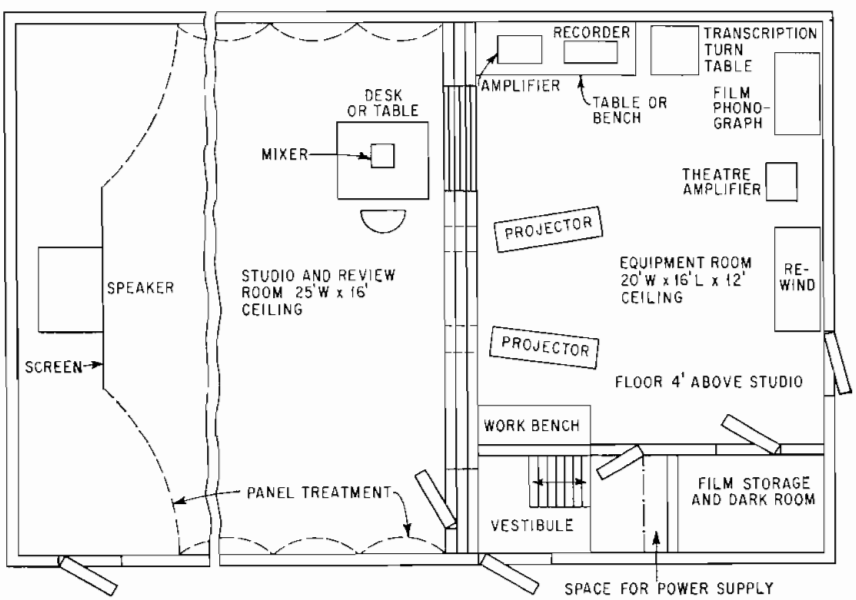


FIG. 1-34. Proposed arrangement of a small studio.

Size and Proportions of Studio

The studio proper shall have a minimum volume of 16,000 cu ft and shall have its average height, width, and length proportioned in the ratio of 1 to 1.6 to 2.5, namely,

Height, 16 ft
Width, 25 ft
Length, 40 ft

A deviation in average dimension not greater than plus or minus five per cent is permissible (see Fig. 1-23).

It should be noted that this studio constitutes the very minimum requirements commercially acceptable with regard to size and will produce optimum results for orchestras of 10 pieces or less. When larger size orchestras are contemplated, the minimum requirements of 50,000 to 65,000 cu ft (25 by 40 by 65 ft) as practiced in Hollywood should be adhered to.

Shape of Studio

The general shape of the studio shall be such that all reflecting surfaces in the room shall be convexly curved to disperse the sound in random directions. The proposed design with polycylindrical surfaces shown in Fig. 1-35 is recommended for this purpose.

Walls

All walls shall be treated with convex wood panels, general specifications for which are given in Fig. 1-25. The panels on the rear wall should be disposed horizontally, while the front and side-wall panels should be vertical as indicated in Fig. 1-35. All

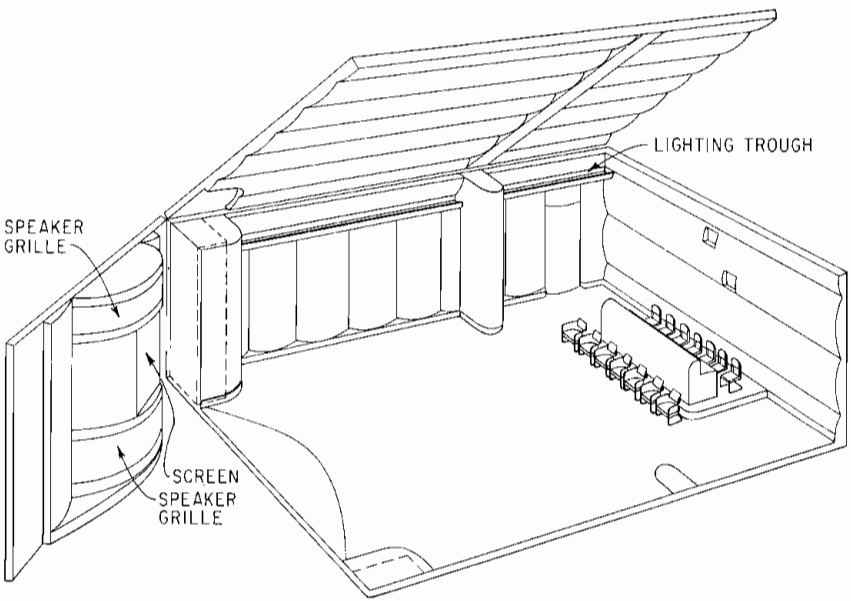


FIG. 1-35. Proposed design of a small film-recording studio and review room.

walls shall be insulated as specified later. Double-wall construction is particularly important between the projection booth and studio. A blanket of 1-in rock wool or other sound-absorbing material should line the entire back of the wood paneling.

Ceiling

The entire ceiling shall be treated with convex wood panels which are disposed lengthwise to the room as shown in Fig. 1-35. The attic side of the ceiling should receive a granulated fill of rock wool or similar acoustical material to "load" the ceiling and to afford partial sound insulation against external noises.

Floor

The entire floor area (except in orchestra or band-shell area) should be covered with a good grade of reinforced carpeting with padding underneath. All seats should be of the heavily upholstered type.

Loudspeaker Chamber and Screen

The loudspeaker preferably should be mounted flush with the screen wall, and all openings between them caulked to give a sealtight chamber. The ceiling and back side of the screen wall forming the loudspeaker chamber should be lined with 4 in. of rock wool.

Sound-absorption Treatment

No additional absorption is required for reviewing and scoring purposes to that provided inherently by the wood paneling and floor treatment. For dialogue recording it is desirable to furnish adjustable draperies on any nearby wall in the microphone area.

Exclusion of External Noise and Building Vibration

A noise survey of the proposed studio site should be made by a qualified acoustical engineer before plans are drawn. From the viewpoint of excluding outside noises and building vibrations it is essential that during erection all joints and openings between panels, etc., shall be fully caulked to give a continuous and sealtight enclosure and furthermore that the entire wall structure shall be floated on cork, rubber, or other suitable material in order to isolate the walls completely from the main building structure. This precaution is extremely important, since a single mechanical bridge or solid connection between the inner and outer shells caused by nails, pipes, ducts, etc., can almost completely nullify the sound insulation by setting the inner structure into vibration. Any bracing between inner and outer walls which may be necessary for structural reasons should receive individual isolation treatment to break the continuous mechanical connection. The various methods employed in building practice and patented methods for vibration isolation are too numerous to treat in these specifications. The underlying principle for preventing transmission through solids is to avoid a continuous medium (reinforced concrete, brick, etc.) or solid connection (wood, metal, etc.) by interposing a resilient or less dense material (cork, rubber, felt, air, etc.) in the link between the source of vibration and the reception point. In general the greater the number of such discontinuities (dense to less dense medium and vice versa), the greater the isolation effect. The ceiling and floor structure should receive similar caulking and vibration-isolation treatment.

Exclusion of Air-borne Noises—Ventilation Ducts

In addition to caulking all openings around pipes, ducts, etc., entering the studio with a mastic felt or other soft material, it is essential to line all ventilator ducts on the inside with an efficient sound-absorbing material and on the outside with a sound deadener for a sufficient distance from the point where they enter the studio so that the ambient noise level in the studio is not greater than 30 db above the standard reference level of 10^{-16} acoustic watt per square centimeter, using a noise-level meter set on the 30-db loudness contour characteristic. In general this represents a distance equal to at least ten times the duct diameter. Extra precaution should be taken at the point where the duct enters the studio that outside noise does not leak through owing to the canvas or other isolation coupling.

Recording and Projection Booth

The size of the projection and recording equipment booth should be 20 by 16 ft with a 12-ft ceiling height as indicated in the floor plan in Fig. 1-34. The booth floor should be elevated 4 ft above the studio floor level and should be properly insulated according to the principles already outlined. (Either the entire booth floor or the areas under all vibrating equipment or both should be isolated from direct connections to the main building structure with 1-in. felted asphalt mastic.)

The ceiling and exposed wall areas above wainscot level should be treated with a fireproof sound absorbent.

Vestibule

Entrance to the studio should be made only through double sound-insulating doors or a sound lock. Details of a typical sound-insulating door are shown in Fig. 1-32. The vestibule or sound-lock area can be used for storage or other non-noise-producing purposes as shown in the proposed studio floor plan.

Summary

Acoustic Treatment Guide

The main design features and considerations essential to good acoustics in small studios can be summarized as follows:

1. The size of the studio should be commensurate with the number and kind of musical instruments to be recorded. For a 10-piece orchestra the minimum volume would be 16,000 cu ft. (For orchestras of other sizes refer to Table 1-4.)
2. The major dimensions of the studio should be proportioned to give a preferred ratio of average height, width, and length of 1 to 1.6 to 2.5. For a volume of 16,000 cu ft this would represent a studio 16 by 25 by 40 ft.
3. Large parallel surfaces should be avoided.
4. All reflecting surfaces should be shaped, preferably convex, to give a diffuse distribution of sound and to minimize the effects of standing-wave resonances.
5. If polycylindrical surfaces are used, their size and shape should be varied and their axes disposed to be mutually perpendicular in the three orthogonal planes.
6. The characteristics of convex wood paneling are particularly well suited for supplying the necessary absorption and diffusing properties for studios. The panel bracings should be spaced at random distances to avoid selective resonance. The panels should be varied in size, and backs lined with rock wool or other absorbing blanket.
7. The floor should be covered with a good grade of reinforced carpeting with padding underneath.
8. Seats should be of the upholstered type.
9. Adjustable draperies should be provided on wall surfaces in the microphone area for speech recordings.
10. Studio walls, ceiling, and floor should possess sufficient sound isolation to prevent the transmission of extraneous noises into the studio.
11. The projection booth should be treated with a fireproof sound absorbent on ceiling and exposed wall areas above wainscot level.
12. All machinery and vibrating equipment such as arc generators, voltage regulators, ventilators, etc., should be acoustically isolated from the studio.
13. Air-conditioning equipment should be of the low-velocity type and preferably operated to give full volume at half speed. All ducts should be provided with acoustic baffling and lined for a distance of at least 10 diameters from the studio.

The foregoing general recommendations on the acoustic treatment for studios are offered merely as a guide. The services of a qualified acoustic engineer should be relied upon for the exact specifications relative to the proper type, amount and location of acoustic treatment, shape of studio, and type and amount of sound insulation required. The trend today is toward close cooperation between architect and engineer and toward functional styling based on the acoustic design. In the case of new studios, a noise survey of the proposed site and complete acoustic specifications for the studio are desirable and worth while.

In illustrations or references to acoustical insulating materials in this book, specific materials mentioned are listed only as an example of a material suitable for the purpose described. Any equivalent acoustical material can be used with similar results.

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Appendix A

Definitions in Architectural Acoustics from ASA Standards Z24.1

ACOUSTIC ABSORPTIVITY (ABSORPTION COEFFICIENT): The acoustic absorptivity of a surface is equal to 1 minus the reflectivity of that surface.

ACOUSTIC REFLECTIVITY (REFLECTION COEFFICIENT): The acoustic reflectivity of a surface not a generator is the ratio of the rate of flow of sound energy reflected from the surface, on the side of incidence, to the incident rate of flow. Unless otherwise specified, all possible directions of incident flow are assumed to be equally probable. Also, unless otherwise stated, the values given apply to a portion of an infinite surface, thus eliminating edge effects.

ACOUSTIC TRANSMITTIVITY: The acoustic transmittivity of an interface or septum is the ratio of the rate of flow of transmitted sound energy to the rate of incident flow. Unless otherwise specified, all directions of incident flow are assumed to be equally probable.

CYCLE ($\sim$): One complete set of the recurrent values of a periodic quantity comprises a cycle.

DIFFUSE SOUND: Sound is said to be in a perfectly diffuse state when, in the region considered, the energy density, averaged over portions of the region large compared with the wavelength, is uniform and when all directions of energy flux at all parts of the region are equally probable.

ECHO: An echo is a wave which has been reflected or otherwise returned with sufficient magnitude and delay to be perceived in some manner as a wave distinct from that directly transmitted.

FLUTTER ECHO: A flutter echo is a rapid succession of reflected pulses resulting from a single initial pulse. If the flutter echo is periodic and if the frequency is in the audible range, it is called a musical echo.

FREQUENCY (f): The number of cycles occurring per unit of time or which would occur per unit of time if all subsequent cycles were identical with the cycle under consideration is the frequency. The frequency is the reciprocal of the period. The unit is the cycle per second.

INTENSITY LEVEL (IL) (SOUND ENERGY FLUX DENSITY LEVEL): The intensity level, in bels, of a sound is the logarithm to the base 10 of the ratio of the intensity I of this sound to the reference intensity I_0. Intensity level can also be expressed in decibels.

INTERFERENCE PATTERN: An interference pattern is the resulting space distribution of pressure, particle velocity, energy density, or energy flux when sound waves of the same frequency are superposed.

MEAN FREE PATH: The mean free path for sound waves in an enclosure is the average distance sound travels in the enclosure between successive reflections.

MULTIPLE ECHO: A multiple echo is a succession of separately distinguishable echoes from a single source.

NOISE: Noise is any undesired sound.

RATE OF DECAY (OF SOUND ENERGY DENSITY) (S): The rate of decay of sound energy density is the time rate at which the sound energy density is decreasing at a given point and at a given time. The practical unit is the decibel per second.

REVERBERATION: Reverberation is the persistence of sound due to repeated reflections.

REVERBERATION TIME (T): The reverberation time for a given frequency is the time required for the average sound energy density, initially in a steady state, to decrease after the source is stopped to one-millionth of its initial value. The unit is the second.

SABIN: The sabin is a unit of equivalent absorption and is equal to the equivalent absorption of one square foot of a surface of unit absorptivity, i.e., of one square foot of surface which absorbs all incident sound energy.

SOUND: (1) Sound is an alteration in pressure, particle displacement, or particle velocity propagated in an elastic material or the superposition of such propagated alterations. (2) Sound is also the sensation produced through the ear by the alterations described above.

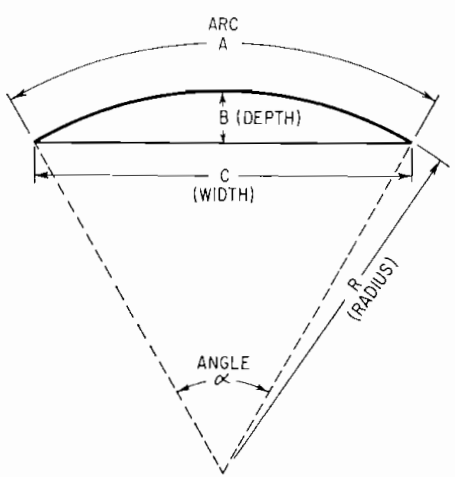
NOTE: In case of possible confusion, the term *sound wave* can be used for concept (1) and the term *sound sensation* for concept (2).

WAVELENGTH (λ): The wavelength of a periodic wave in an isotropic medium is the perpendicular distance between two wavefronts in which the displacements have a phase difference of one complete cycle.

Appendix B

Sectional Dimensions in Inches for Convex Cylindrical Panels

α	60°			90°			120°			180°
Arc (a)	Width (c)	Depth (b)	Radius (r)	Width (c)	Depth (b)	Radius (r)	Width (c)	Depth (b)	Radius (r)	Radius (r)
16	15¼	2	15¼	14⅜	3	10⅜	13⅛	3⅞	7⅜	5⅛
32	30⅝	4⅛	30⅝	28¾	6	20¾	26¼	7⅜	15¼	10⅛
48	45⅞	6⅛	45⅞	43¼	9	31¼	39½	11½	22⅞	15¼
64	61⅛	8¼	61⅛	57⅝	12	41⅝	52⅝	15¼	30½	20⅜
80	76⅜	10¼	76⅜	72	15	52	65¾	19⅛	38⅛	25½
96	91⅝	12¼	91⅝	86⅜	18	62⅜	78⅞	23	45¾	30½
112	107	14⅜	107	100¾	21	72¾	92⅛	26¾	53⅜	35⅝
128	122¼	16⅜	122¼	115¼	23⅞	83¼	105¼	30⅝	61	40¾
144	137½	18⅜	137½	129⅝	26⅞	93⅜	118⅜	34⅜	68⅜	45¾



LIVENESS IN BROADCASTING *

When your friend tells you the news, do you prefer to have him sit comfortably in your home with you or to talk at you from a box? When yon attend a concert, do you prefer to be in the audience and hear the sweep of the music through the hall or to have the sound shot at you from a cabinet? Your radio can now bring your favorite newscaster, in living reality, to your home or can transport you to the best seats in the concert hall. This article tells you how it is done.

Under normal conditions, you listen to an orchestra, to a singer, or perhaps to someone telling you the latest news with two ears. The binaural sense which resnlts from the use of the two ears enables you to pay attention to the sound arriving from any desired direction and partially to exclude the sound from other directions. Similarly, yon easily separate nearby sounds from the more distant ones. You have, therefore, two means of accentuating, at will, certain parts of the sound.

If, however, the sound has been picked up by one or more microphones and reproduced through a single loudspeaker, your binaural ability to pay attention to the sound from any desired direction is completely lost. This results in an apparent increase in the "liveness," or reverberation, present and also in the intensity of the incidental noises. However, your ability to distinguish between nearby and distant sounds is in no way impaired but is frequently enhanced.

Therefore, the situation can be summarized as follows:

1. You have lost all ability to accentuate at will certain parts of the sonnd, snch as solo artist, by the help of the direction from which that particular sound comes.
2. You still maintain your ability to accentuate by the distinction between nearby and distant sounds.
3. The liveness, i.e., the apparent amount of reverberation, has been automatically accentnated.

Any studio technique which is to reproduce lifelike and realistic programs must (1) provide the studio engineer with a means of supplying the necessary accentuation lost by the failnre of the binaural sense, (2) provide the engineer with means of making full use of the distinction between nearby and distant sounds, (3) eliminate the undesired accentuation of the apparent liveness.

This is particularly true, as the sense of realism experienced by the listener is as much dependent on the microphone placement and the studio acoustics as it is on his home conditions.

Greater Coverage

The purpose of this article is to describe a technique of studio and anditorinm sound pickup which fulfills the above requirements and which places control of the desired accentuations on the dials of the studio mixer panel. Fortunately, the correction for the increased apparent reverberation can be accomplished by the initial placement of the microphones used.

One of the important advantages of this live type of pickup is as much as 6-db gain in coverage at no extra expense to the sponsor or the broadcasting company.

This unexpected gain is a result of the manner in which the ears of the listener perform. For a given power supplied to the loudspeaker, the loudness of a program picked up with this new technique can be 6 to 8 db greater than the loudness of programs from "dead" pickups. Since this gain in loudness permits the listener to operate his receiving set with a correspondingly lower electrical gain, static and other noises are reduced by this amount. Thus, this effect is a real gain in coverage.

In view of this apparently complicated situation, a search was made for some simple acoustic constant which would clarify the studio problems. Such a constant has been derived mathematically and checked by practical application to studio practice.

This constant is called *liveness* and represents the acoustic properties of an enclosed

* By J. P. Maxfield, Bell Telephone Laboratories, Inc., New York.

space, such as a studio or auditorium, including the effect of the distances from the artists to the pickup microphones. The properties of this constant are such that the formula can be readily applied to the use of one general, or "over-all," microphone in combination with the necessary additional microphones for accentuation purposes.

The liveness formula is

$$L = \frac{1{,}000T^2D^2}{G_pV} \tag{1-1}$$

where L = liveness
T = reverberation time, sec
D = distance from sound to microphone, ft
V = volume of studio, cu ft
G_p = directivity of pickup microphone from source to microphone

The value of T used for the practical application of this technique to broadcast pickup is an average of the values over the frequency range from 500 to 2,000 cps. Where this average is unknown, the value at 1,000 or even 500 cps can be used as a guide.

The range of the limits of liveness for satisfactory binaural listening is very great but is quite narrow for monaural, or single-channel, reproduction. However, experience has shown that with single-mike pickup the limits of the value of liveness selected for best monaural pickup always lie within those acceptable for direct listening. This means that in the concert hall, for example, the microphone position is always farther from the sound source than the front row of acceptable seats but nearer to the sound source than the rear row. The center of the monaural range is always closer to the source than that position generally rated as best for direct listening. This increased closeness of the monaural microphone automatically removes the accentuation of the apparent excess reverberation present.

The full useful range of liveness for monaural pickup varies materially from one type of sound to another as, for instance, from symphony orchestra to solo singing to speech. Table 1-5 shows the values of the monaural liveness range for several different types

Table 1-5

Type of sound	*Liveness range*
Piano	4–16
Symphony orchestra	5–20
Small orchestra	3–12
Solo violin, cello, etc.	1–4
Solo singing	½–3
Speech	1/6–⅔

of sound when picked up for reproduction in average living rooms. It may be of interest to know that where the reproducing space is abnormally live, both limits of the useful range are moved upward, not downward. Where the listening space is abnormally dead, the values must be decreased accordingly.

Increased Sense of Reality

If sound is reproduced from a pickup in which the liveness is controlled within the useful range as shown in Table 1-5, the subjective effect might be described as the acoustic recreation of the pickup space around and behind the loudspeaker position. This effect adds greatly to a sense of reality and renders music or speech both natural and "easy to listen to." Under these circumstances, it is difficult to locate the position of the loudspeaker laterally, the sound appearing to flood in from behind it through an opening completely across the room. In other words, the effect is that of adding the studio space behind the plane of the loudspeaker without any intervening wall.

When the liveness is near the lower limit of the useful range, you get the impression that the sound is situated in the near end of this added space. In the case of a person speaking, there is the illusion of a real person speaking from the position of the loudspeaker.

When, however, the liveness is near the upper limit of the useful range, the source of sound appears to be considerably behind the plane of the loudspeaker as if it were coming to the hearer from a position in the remote end of the added space. In the case of broadcasting large symphony orchestras, this control of liveness enables one so to broadcast a concert that the listener in his home may seem to occupy any seat from the front to the back row of the auditorium. Since most auditoria have seats which music critics consider to be best, it is desirable to control the liveness of the broadcast so that the listeners are placed acoustically in that portion of the auditorium.

When pickups are made with a liveness value well below the useful range, this effect of added space disappears and one is aware of the sound being projected from the box containing the loudspeaker. Under these conditions, it has an artificial quality which could never be mistaken for the presence of a real person or a real orchestra. This effect might be called "absence" as opposed to the much desired "presence" of good broadcast pickup.

Under these dead conditions, the lateral position of the loudspeaker can be accurately located by ear and the interpretation of quality is quite sensitive to one's position with respect to the high-frequency beam of the loudspeaker and to the volume at which the sound is being reproduced.

On the other hand, when the liveness value is well above the upper limit of the useful range, one can again locate with ease the position of the loudspeaker. However, instead of feeling that the sound is being projected from a point source, the hearer experiences the effect of the sound reaching him through an open window from a room which is much more reverberant than the one in which he is listening.

Considerable evidence has been obtained that the public much prefers recordings made well within the useful range and in the case of orchestral music near its upper limit.

The advantages of this type of pickup can be summarized as follows:

1. The 6-db gain in coverage previously mentioned.
2. When operating within the useful liveness range, the amount of manual volume control normally necessary with dead pickup is markedly decreased without either overloading the equipment or causing the sound to sink into background noise and therefore permits a higher average per cent modulation.
3. For a given volume range as indicated by the VU meter, reproductions from monaural sound pickups made within the useful range have an apparent volume range nearly twice that of similar reproductions from dead pickups.
4. The change in quality of the monaurally reproduced sound as a function of the loudness of reproduction is materially reduced. This characteristic can be best illustrated by two contrasting cases.

Case 1

Assume that the sound from an orchestra, for instance, has been picked up under conditions of liveness well below the useful range and that this sound has been balanced for reproduction at an average intensity level of 75 db at the ear.

If this sound is now reproduced at an average ear level substantially lower than 75 db, marked distortion of the balance takes place. The lower notes and the high harmonics appear to be greatly attenuated. A similar effect in the reverse direction occurs if the sound is reproduced at a level substantially higher than that for which it was balanced. An equalizer introduced into the reproducing circuit will correct this unbalance if its characteristics correspond to the differences in the loudness contours of the Fletcher-Munson curves.

Case 2

Assume that the sound referred to in Case 1 has been picked up under conditions of liveness well within the useful range and, as before, has been balanced for reproduction at an average ear level of 75 db.

If this sound is reproduced at an average ear level either substantially lower or substantially higher than 75 db, very little, if any, apparent change of quality is noticeable. This advantage is of great value to the listening audience, as it enables the listener to reproduce a sound in his living room at any desired level without a corresponding loss of quality.

Two or More Microphones *

The pickup technique being described consists basically of the use of (1) a microphone situated at some distance from the performers to pick up the general blend of

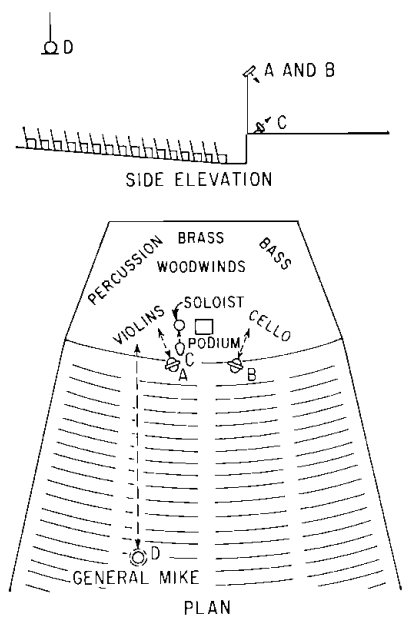


FIG. 1-36. Large auditorium with a symphony orchestra. *A* and *B*, accentuation microphones; *C*, solo microphone; *D*, general microphone. Dotted lines show distances which can be computed as described elsewhere.

sound and (2) one or more accentuation microphones for accenting desired portions of the orchestra, soloists, etc. This accentuation is obtained by controlling the liveness instead of the loudness.

The general microphone preferably has nondirectional characteristics as typified by the Western Electric 640AA or the 633 type. The accentuation microphones are usually of the bidirectional or of the cardioid type typified by the Western Electric 639 type. Any high-quality microphone, having the proper characteristics, will operate in an entirely satisfactory manner.

Figure 1-36 shows a qualitative arrangement for a symphonic broadcast with soloist

* The manufacture of the Western Electric microphones mentioned in this article has been discontinued.

and some orchestral accentuation, while Fig. 1-37 shows a typical studio setup for orchestra with vocals. It should be realized, of course, that all the accentuation microphones are not necessarily used simultaneously.

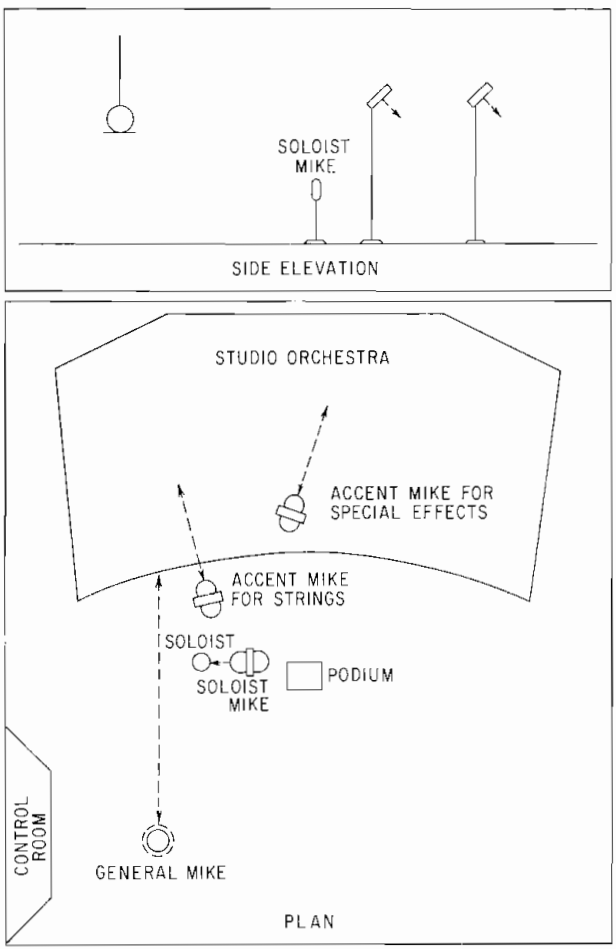


FIG. 1-37. Plan and side elevation of normal studio set up for orchestra with vocals. It should be noted that all the accentuation microphones in this arrangement are not necessarily used at the same time.

Arrangements such as these ensure the fulfillment of the following requirements:

1. Over-all liveness control is available to the sound engineer at all times during the broadcast.
2. Accentuation control is similarly available at all times.
3. The loss, by failure, of any one microphone does not render the pickup unsuitable for broadcast.
4. The arrangement is versatile and capable of rapid adjustment during rehearsal.

The employment of this technique requires studios with acoustic properties of a "pleasing" nature, i.e., studios of good acoustic properties. It also requires that studios shall not be overcrowded.

Figure 1-38 shows the relation between the number of artists and the studio size. Curve *A* represents good studio practice, while curve *B* represents the maximum crowding possible without loss of realism. Curve *C* is given for comparison only and represents auditorium conditions for symphonic music.

Figure 1-39 shows the optimum reverberation time with artists in place, as a function of studio or auditorium size. Any values within 30 per cent of those shown can be compensated for by a proper choice of microphone positions.

Placement and Control of Microphones

Positioning the General, or Over-all, Microphone

1. Choose from Table 1-5 the maximum value of liveness necessary for any part of the program. For instance, for a studio pickup of a dance orchestra with vocals the maximum value of L is 12 for small orchestra.

2. Choose a value 1.5 times this ($L = 18$) as suitable for the over-all microphone. The increase of one and one-half is to allow you margin for leaving some accentuation microphones in circuit at all times without reducing the general liveness too much.

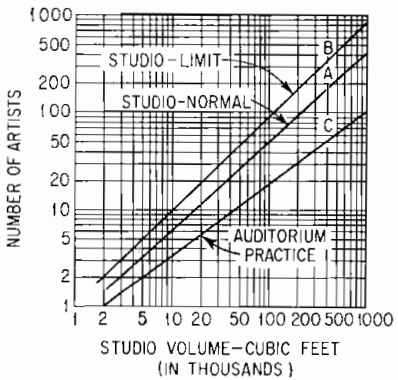


FIG. 1-38. Relation between number of artists and studio size. *A* shows good studio practice; *B*, maximum crowding without loss of realism; *C*, for comparison, shows auditorium conditions for symphonic music.

3. Determine the distance D from Eq. (1-2) below. D represents the distance of the microphones from the front of the orchestra.

Equation (1-1) can be solved for D and we get

$$D = \frac{\sqrt{LVG_p}}{31.6T} \tag{1-2}$$

Where studios are in active use, a set of curves as shown in Fig. 1-40 can be prepared. To aid you in preparing such a chart the following typical case is worked out in detail.

Assume a studio whose volume V is 30,000 cu ft and whose reverberation time T, with musicians in place, is 1.2 sec. For nondirectional microphones $G_p = 1$, and for bidirectional or cardioid type $G_p = 3$ for sound sources on their beams. Assume a range of L from 0.3 to 30.

From Eq. (1-2) for a nondirectional microphone we get

$$D = \frac{\sqrt{30 \times 30{,}000 \times 1.0}}{31.6 \times 1.2} = 24.6 \text{ ft for } L = 30$$

Similarly $D = 2.46$ ft for $L = 0.3$.

Plot these two points (A and B of Fig. 1-40) and connect them with a straight line. From this chart the distance D corresponding to any desired value of liveness can be obtained for a nondirectional microphone.

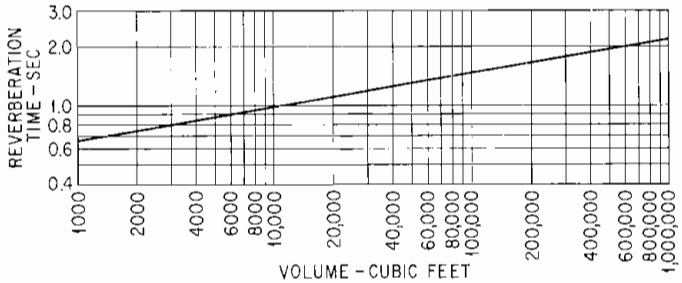


FIG. 1-39. Curve showing optimum reverberation time with artists in place as a function of studio or auditorium size. Any values within 30 per cent of above can be compensated for by microphone placement.

To obtain the plot for bidirectional or cardioid microphones proceed in a similar manner letting $G_p = 3$. Then we obtain the points M and N, Fig. 1-40. Connect these with a straight line.

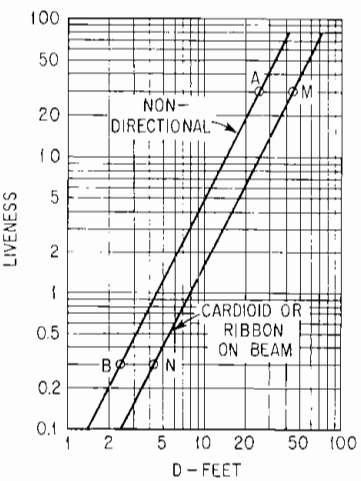


FIG. 1-40. Typical chart used for positioning general and accentuation microphones in active studios.

This completed chart is now available for use in positioning the general microphone and, as described in the next section, for positioning the accentuation microphones also.

Positioning the Accentuation Microphones

1. Choose from Table 1-5 the minimum liveness for the portion of the orchestra, the soloist, or other course to be accentuated. For instance, for solo parts in the string section choose $L = 1.0$ (solo violin, etc.) or for a vocalist choose $L = \frac{1}{2}$ (solo singing).

2. Choose a value which is two-thirds of that obtained from Table 1-5 as the practical operating liveness for the accentuation microphone. This decrease to two-thirds

is to allow you margin for the increase in liveness due to the over-all microphone, which is always in circuit.

3. Choose a suitable type of microphone—cardioid, bidirection, or nondirectional. One of the directional types is usually preferred as the accentuation microphone, since it can be "beamed," i.e., partially limited to the sound sources on or adjacent to the high-sensitivity axis.

4. Determine the distance D from Eq. (1-2) or from the studio chart typified by Fig. 1-40. If you are using this microphone for accentuation of the string section or any other group of artists, D represents the distance from the microphone to the nearest artist in that group.

5. Proceed in a similar manner for any other accentuation microphones which may be necessary.

Determination of Approximate Mixer Dial Settings

No hard-and-fast rules can be given for control of the amount of accentuation necessary. This amount depends upon the type of program and upon the nature of the esthetic or dramatic illusion you are trying to create for the listener.

However, there are some general considerations which will help you acquire experience more rapidly than is possible with mere "cut-and-try" methods. In the first place, make it a rule to start your rehearsal with the general microphone only—all others being out of circuit. Then slowly fade in the accentuation microphones until the desired result has been obtained. When in doubt, use less accentuation than appears desirable over your monitor. This is due to the fact that most monitoring rooms are both smaller and acoustically more dead than the average living room.

The details of this mixing technique are described in Appendix A. General adherence to the methods outlined there will result in the production of acceptable programs with very little rehearsal.

Important Applications

There are three broad classes of programs to which this technique has been successfully applied: namely, (1) large concert-hall pickup, such as symphony orchestra, opera, choral singing, etc.; (2) studio music programs with or without vocals; (3) speech only, such as news, lectures, announcements, etc.

The Large-concert-hall Type of Program

The most pleasing broadcast of a symphonic or operatic program is the one which creates for the listener the illusion that he is actually present in the auditorium. That effect is obtained when the liveness of the orchestra, including accentuation of any section such as strings, woodwinds, etc., lies between 8 and 20. A good average value for heavy music is 16, while for light delicate music a value of 10 is often preferable.

If the orchestra is accompanying a soloist, for instance, a violinist, a singer, or a pianist, the liveness value for the soloist should never be less than one-quarter of the orchestral liveness and should preferably be between one-half and one-third. When the one-half of orchestral liveness is used, the soloist is well out in front of the orchestra. As the solo liveness is increased, the voice or solo instrument seems to move back and finally becomes merely an accentuated part of the orchestra itself.

The method of determining the dial settings to obtain these effects will be described in detail in Appendix A. If you will use the quantitative method for setting the dials on your first few rehearsals with this new technique, you will soon find that you easily recognize the desired effects by ear and no longer require the computed values except for an approximate check.

Table 1-6 shows the liveness value for each of the three microphones and the power used, expressed in decibels above (+) or below (−) the power supplied by the over-all microphone D, Fig. 1-36.

Table 1-6

Mike	*L*	*Decibels*
D (general)	21	0
A (violin section)	0.6	−18 to −12
B (cello section)	0.6	−18 to −12
C (soloist)	0.5	Not used

The effective liveness of this arrangement is about 13, which value is well within the useful liveness range shown in Table 1-5.

Studio Music Programs with or without Vocals

As before, the most pleasing result is obtained when the listener feels that he is present in the studio. A liveness between 6 and 12 for the orchestra yields this effect. Solo voices should have a value one-half to one-third of the orchestra value, while crooners may operate as low as one-sixth of it. These values are easily obtainable in a good studio which is not overcrowded much beyond curve *B* in Fig. 1-38.

Figure 1-37 shows a typical studio setup. The method of setting the distances and choosing the types of microphone has already been described. However, a sample computation may be helpful.

Assume a 20-piece orchestra and a crooner in a studio crowded to the curve marked *B*, Fig. 1-38. Therefore, the studio volume is about 22,000 cu ft, and it should have a reverberation time of about 1.1 sec (see Fig. 1-39) with orchestra.

Assume that

1. The desired liveness *L* for the orchestra is 10.
2. The desired liveness *L* for the crooner is about 1.6.
3. The general microphone has nondirectional characteristics.
4. The microphone for the crooner and any accentuation microphones for parts of the orchestra have bidirectional characteristics.

Proceed as follows:

1. Set the liveness of the general microphone at a value $1.5 \times 10 = 15$.
2. Set the liveness of the crooner microphone at a liveness not greater than $1.6 \times \frac{2}{3} = 1.0$ approximately. Use 0.5 if in doubt, as slightly more flexibility is assured.
3. Set the orchestral-accentuation microphone at a liveness not greater than $2.0 \times \frac{2}{3} = 1.3$. Use 1.0.

From Eq. (1-2) you get the values in Table 1-7.

Table 1-7

Microphone	*Type*	G_p	*L*	*Distance, ft*
General	Nondirect	1.0	15	16–17
Crooner	Bidirect	3.0	0.5	4–6
Accentuation	Bidirect	3.0	1.0	7–9

If the distance of 4 to 6 ft for the crooner worries you, cut it down to any value not less than 2 ft and mix accordingly (see Appendix A).

Speech Such as Announcers, Newscasters, Lecturers

These programs usually originate in small rooms of 1,000 to 2,000 cu ft with reverberation times of the order of ½ sec.

They get the full benefit of the extra coverage and naturalness due to liveness for values of *L* greater than ⅛ to ¼. From Eq. (1-2) the distance for a nondirectional microphone for a 2,000-cu-ft studio, having a reverberation time of ½ sec, would be 1¼ ft and for a ribbon or cardioid microphone on beam would be 2 ft.

Appendix A. Method of Setting Relative Gain for General and Accentuation Microphones

Let L_a = liveness for accentuation mike
L_g = liveness for general mike
L_e = effective liveness of combination
P_r = ratio of power contributed by accentuation microphone to power contributed by general microphone

then

$$\text{db} = 10 \log P_r$$

It can be shown that

$$P_r = \frac{1 - L_e/L_g}{L_e/L_a - 1} = \frac{L_a L_g - L_e}{L_g L_e - L_a} \tag{1-3}$$

and

$$L_e = \frac{L_a L_g (1 + P_r)}{L_a + P_r L_g} \tag{1-4}$$

For example, if $L_a = 1.0$ and $L_g = 20.0$, we can use Eq. (1-3) and compute the data shown in Table 1-8.

Table 1-8

L_e	P_r	*Decibels*	*Approx. decibels*
1.25	3.75	+5.8	+6
1.50	1.85	+2.7	+3
2.0	0.90	−0.5	0 or −1
3.0	0.43	−3.7	−4
4.0	0.27	−5.7	−6
6.0	0.14	−8.5	−8 or 9
8.0	0.086	−10.7	−10 or 11
12.0	0.036	−14.4	−14
16.0	0.013	−18.8	−19

Where a studio or auditorium is in regular use, it is worth the time to plot this data as a curve. Figure 1-41 shows such a plot.

In Table 1-8 and Fig. 1-41, negative values of decibels mean that the level of the accentuation mike is below that of the general mike by the number of decibels shown.

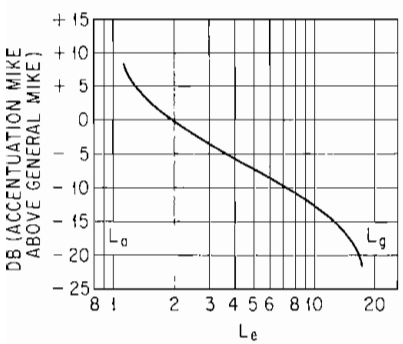


FIG. 1-41. Chart showing effective liveness of two-microphone combination as function of relative level.

Since the sensitivities of the various microphones are not equal, the following procedure must be used to determine this relative gain value.

During rehearsal, set the general microphone attenuator control and master gain control as if the broadcast were to be made on this microphone alone. Read the attenuator dial setting for maximum peaks on the VU meter.

Then turn off the general microphone and turn up the accentuation microphone until the maximum peaks have the same VU reading. Read the attenuator dial for the accentuation mike. This becomes the zero of the decibel scale illustrated in Table 1-8 or in Fig. 1-41.

For example, assume that the general microphone had an attenuator dial setting of 10 db and the accentuation microphone had a dial setting of 14 db for the same maximum peaks as read by the VU meter. This means that with a setting of 14 db the accentuation microphone is contributing the same power as the general microphone.

Then if the desired over-all liveness is 9, we find from Fig. 1-41 that the accentuation microphone should be operated at −12 db. Therefore, the setting would be 26 db on the attenuator dial of the accentuation mike.

It sometimes happens that this low setting of the accentuation microphone causes a blend of the sound which does not seem to have given the accentuation to the desired instruments. This usually indicates that the general mike has been placed in a poor spot and that the accentuation mike is being used to mask this trouble.

Therefore, seek a new location for the general mike as a first step of correction.

Appendix B. Music Programs in Overcrowded Studio

Under these conditions it is usually impossible to place the general microphone at a sufficient distance from the front row of the orchestra. Therefore, a trick must be resorted to.

1. Place a bidirectional microphone, such as 1, Fig. 1-42, with its insensitive direction pointing toward the orchestra. In practice this microphone will act as if G_r [see Eqs. (1-1) and (1-2)] had a value of ¼ to ⅓.

2. Place the necessary accentuation microphones in the standard manner except that bidirectional microphones must not be placed too close to the studio wall. Where the crowding is extreme, the use of cardioid microphones for accentuation purposes is preferred.

3. Use the minimum contribution from the accentuation microphones necessary to obtain the desired effect. Too much accentuation does more damage under overcrowded than under normal conditions and can easily push the pickup into the region below the useful liveness range. You then obtain "absence" instead of "presence."

This discussion has attempted to describe a semiquantitative sound-pickup technique. If it is followed as a general guide, experience has shown that these methods can almost ensure programs with a new realism—programs that can give your station as much as 6-db gain in coverage and your listeners the sense of being in the presence of the living artists.

HOW TO IMPROVE PROGRAM PICKUPS *

Make it good. Then make it better. This is the creed of radio engineers. Over a period of 35 years, broadcasting has been made good. Broadcast equipment has reached the state of design where the noise level is negligible and the complete spectrum of audible frequencies is available for transmission and reproduction.

Yet it is apparent to all concerned that the techniques of coordinating and operating this equipment are as confused and almost as varied as the number of stations and the number of operating personnel at each station.

What has not been so apparent is the fact that this situation can spell the success or failure of a well-designed, well-maintained layout. There is extensive literature covering the theory, design, construction, and repair of the equipment, but the importance of using such equipment properly is just beginning to gain recognition of its true worth.

Microphone Facts and Fancies

The microphone is a mechanical extension of the human ear. How often have you heard that one? The fault in this definition lies not so much in its literal meaning as in the implications involved. If it were true, even though you had only one ear, you could walk into a studio and place the microphone at the spot where your one good ear could hear the orchestra, the soloist, the chorus, and the announcer. Only it doesn't work that way in practice. Yet this conception is probably the basic factor in the reasoning of the operator who just sticks up the mike in a studio and

* By Harold E. Ennes, WTAE, Pittsburgh, Pa., from *FM and TV Magazine,* Sleeper Publications, Inc.

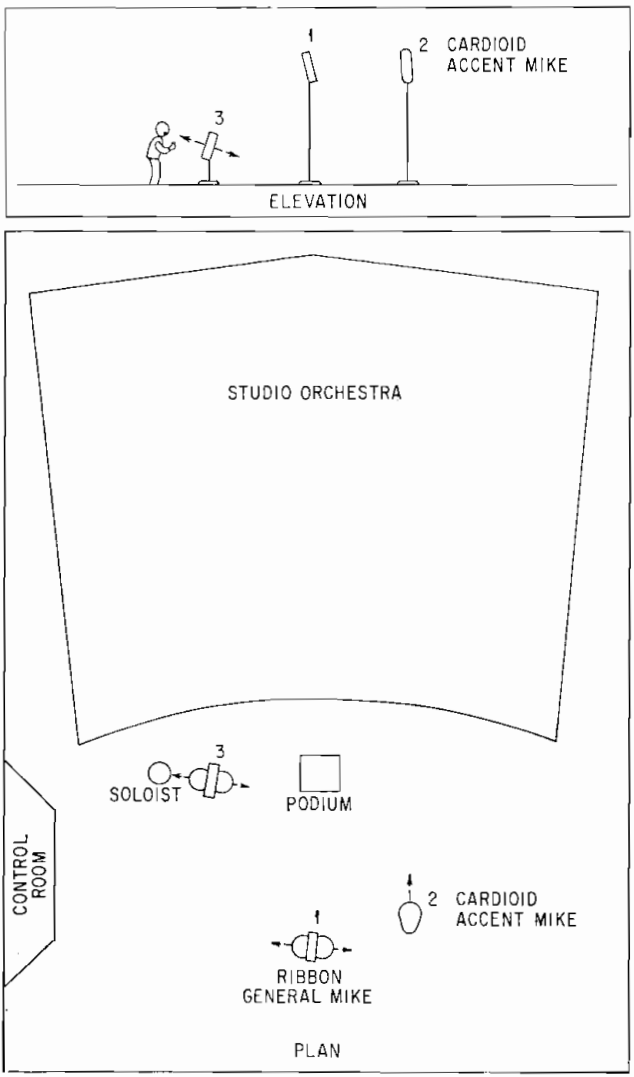


FIG. 1-42. Plan and elevation of overcrowded studio.

proceeds to broadcast the show by riding gain. And there is the more ambitious type who spots a microphone for each section of the orchestra and one for the soloist and announcer and several for the chorus and then becomes very indignant when the conductor reports that his musician friends listened to the show and thought someone else had been on the podium.

To understand why a microphone cannot be considered an extension of the human ear, it is necessary to review the fundamental theory. It is an old story, but absolutely essential to understanding the mike from an operational point of view.

Unlike the human hearing system, which is binaural (two-eared), the microphone is monaural (one-eared). It should be emphasized that this is true regardless of the number of microphones used, since the sound is collected into one channel and reproduced by one loudspeaker while each of our two ears has a separate channel to the brain. Physically, the difference is that in a monaural system the sense of direction is lost while reverberation is somewhat more noticeable, making the apparent distance to the sound source seem greater than when listening binaurally. Any operator who has set up a microphone in a particularly live hall has experienced this phenomenon.

The conversation between two people anywhere in the hall can be heard quite clearly when listening with two ears, but when listening with headphones connected to an amplifier and microphone, the sounds seem much more distant while the extraneous noise is high. This brings up an all-important psychological factor closely linked to the physical effect just explained.

This is the focusing power exerted unconsciously when listening binaurally or even with one ear plugged up as much as is possible. The association of the ear with the nervous system and the brain tends to exclude recognition of the extraneous noise and to focus attention on particular sounds. The microphone, as a mechanical device not associated with any means of concentration, exercises no discrimination between wanted and unwanted sound sources.

A practical example of this difference is to be found in any restaurant where there is dinner music. Despite the high level of ambient noise, you can carry on a conversation or listen to the music and enjoy doing either one but not both at the same time. But imagine the result if a microphone were placed on your table for a broadcast! Very little of the music would be heard, and the few strains coming through would sound far, far away. The radio listener would hear a hopeless hodgepodge of voices, noise, and confusion.

First, then, let's do away with the idea that the microphone is an extension of the human ear. This applies equally to microphone techniques for AM and FM. In practice, every effort must be made to utilize the possibilities and limitations of the mike in order to deliver an exact replica of the original program content to the ears of the radio listeners.

Frequently we hear it said that microphone techniques are different for AM and FM. As to this, there are ample grounds for disagreement. Discussions with control-room operators and production men seem to indicate that they do not know how to set up for optimum on FM. Therefore, they adopt the attitude that FM and AM techniques are different and, since the AM audience is larger, AM practices should be favored.

Actually, experience shows that the rule should be: "Precise or sloppy techniques show up more on FM than on AM." In other words, the difference between careful and careless handling of a program is disclosed on AM to only a limited degree, but FM listening shows up the difference very clearly, even with a set of no more than average audio capabilities.

In this connection, there is another point that calls for revision of control-room practice at many stations. It is not unusual to find three speakers in one control room, for the operator may be called upon to keep up with the program on the air, another under rehearsal, and a third being aired by a local competitor. Under such conditions, critical listening by the operator is impossible!

All this leads up to the fact that FM has set new and very high standards of studio practice. Haphazard program setups that "get by" on AM may prove to be poison

for FM. This is no exaggeration. On the other hand, the employment of high-fidelity methods for FM results in improved quality on AM. This will be explained in detail.

Understanding Response Patterns

In so far as program setups are concerned, the foremost characteristic of a broadcast microphone is its response pattern. There are several important factors which must be considered when using a microphone pattern to obtain a desired result.

The basic point to keep in mind is that a response pattern as illustrated for a given mike is plotted in a perfectly dead room, to avoid all reflections of sound waves. But when a microphone is set up in a studio room, although the theoretical response pattern does not change, the mike is acted upon by reflections which vary in direction and magnitude according to the shape of the walls and the ceiling and their ability to absorb or reflect sound waves. This will be made clear by the hypothetical case of a setup involving two sound sources and a bidirectional microphone.

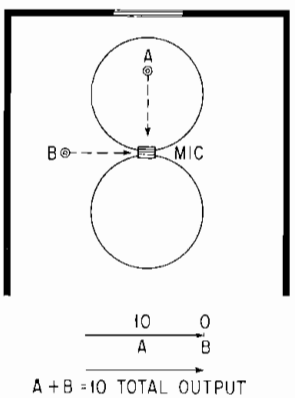


FIG. 1-43. Bidirectional pattern in dead room.

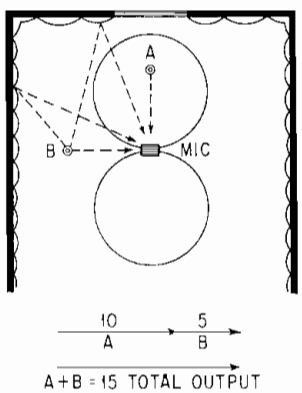


FIG. 1-44. Results are modified in live studio.

Figure 1-43 illustrates the ideal response curve of a bidirectional mike in a completely dead room. Sound sources *A* and *B* are of the same intensity and the same distance from the mike, but *B* is directly on the zero-response axis. Let us say that each source represents 10 units of sound. Since sound source *B* will excite both sides of the ribbon equally, no movement of the ribbon will result from this source and no output voltage will be created in the microphone. Therefore, the total output voltage will be 10 units and consist only of the impulses received from *A*. Thus the pattern holds true.

Figure 1-44 shows the same setup in a live room. It is still true that *B* will excite both sides of the ribbon equally, resulting in no response to the direct wave, but now we have reflections. Sound will be reflected from the walls back into the sensitive side of the mike and, although reduced in intensity, will add to the 10 units of sound from source *A*. The difference now between the two sound sources is not only one of intensity but ratio of reflected to direct sound. Naturally this ratio is greater for sound source *B* than for source *A*.

It is, of course, obvious that there is no such thing in broadcasting as a perfectly dead studio. This example is, therefore, rather crude but serves to illustrate the basic idea of how acoustical treatment influences the polar action upon a microphone. This understanding is imperative from an operational point of view.

While we are on the subject of response patterns, it is well to be sure that it is clear as to just what information they are meant to convey. Figure 1-45 shows the

polar response pattern of a particular cardioid mike, plotted for four different frequencies against the ideal cardioid curve. This shows that there is a narrower response angle at higher frequencies than at lower ones because high frequencies tend to travel in beams.

The curves at the left in Fig. 1-45 illustrate, for example, that on 50 cycles the response is down about 5 db at 90° with respect to its response for the same distance at 0°. It will also be noted that for 9,000 cycles the response at 90° is down about 6 to 7 db. Also, at 90° the 9,000-cycle response is about 11 db lower than the zero-axis 50-cycle response. Since, in broadcasting, we are concerned not only with wanted and unwanted sound, but all shades in between, the individual response patterns of a mike prove extremely useful if utilized properly. From this discussion we have four fundamental operating points for the microphone:

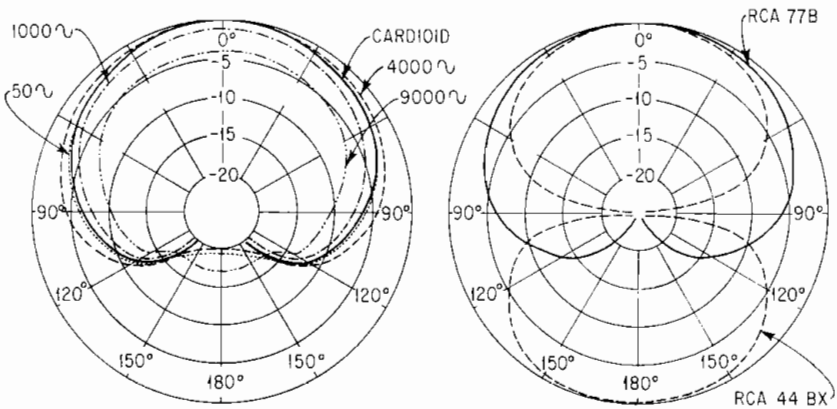


FIG. 1-45. *Left:* Cardiod. *Right:* Unidirectional and Bidirectional RCA types.

1. If a sound source must be moved about the mike, loss or response can be compensated for, if desired, by moving the mike closer to the source.
2. The ratio of reflected to direct sound can be raised in a sufficiently live studio by using greater angles from the zero axis of the mike. This is especially true of bidirectional microphones.
3. The more live the studio, the greater will be this effect.
4. High-frequency sound sources must be more nearly on beam for a given distance to achieve the same intensity of response as lower frequency sound sources.

To this latter point should be added the note that a bidirectional microphone has a greater deviation in angular response between high and low frequencies. Also, the cardioid, or unidirectional, instrument has a much wider angle of response at all frequencies than a bidirectional mike.

This is shown in Fig. 1-45, where the 1,000-cycle curve of an RCA 77 B unidirectional mike (solid curve) is superimposed on the 1,000-cycle curve of an RCA 44 BX velocity (bidirectional) microphone. It should be observed that at 60° the relative response of the 77 B is down only about 2.5 db whereas the 44 BX at 60° is down about 6 db. The very great difference at 90° is clearly shown. This is typical of all makes of broadcast microphones when comparing the unidirectional and bidirectional patterns.

Studio Acoustics

The nonstandard acoustical characteristics of broadcast studios are the outstanding factor that has prevented any establishment of definite standards in microphone setups. If there were such a thing as a standard studio, designed to approach as nearly as

practicable the ideal condition of sound dispersion, the setup for any particular musical organization would be a simple matter anywhere when once worked out. Naturally, such is not the case. It is probably safe to say that there are no two studios anywhere in the world that are acoustically alike.

Right here, the author feels it advisable to bring out a point so far neglected in the scanty literature on mike technique. This point is that a great number of operators and producers (alas, even in FM) do not have adequately designed and acoustically controlled studios in which to work.

Since it is the purpose of this material to present practical information, the author will attempt to show some definite rules that can be used to meet any acoustical conditions. High-fidelity techniques for a good modern studio cannot be applied to most of the studios in use around the country. We shall have to plant our feet squarely on the ground and face the situation as it really exists.

In the modern studio, the walls are live to musical sounds but are broken up acoustically in some manner to avoid standing waves while still achieving a maximum response to diffused, polyphased high-frequency sound. Under those conditions, good tonal brilliance can be obtained with a minimum of microphone and control-board manipulation. This is the type of design we need really to practice proper microphone technique.

The Single Announcer

The single announcer is the logical starting point for our discussion of mike technique. It must be understood that we are not concerned at present with announcing over a background of music or any form of dramatic presentation. You may ask: "What is there to discuss, then? The announcer just steps up to the mike or sits down in front of one and talks!"

You're right. He does. But the fact of an error does not justify it.

Announcing alone occupies a considerable portion of the broadcaster's schedule. Correct voice transmission is so very important to radio because we do not have the sense of sight to help our impressions; the voice is the complete medium of expression. The intake of the breath, the most subtle inflections, the style of delivery, the original voice timbre, all are necessary to the listener. Any or all of them may be severely affected by the announcer's relation to the mike.

Those of us in the technical end of radio must at some time of our careers realize that engineering training does not develop an appreciation of artistic values or sense of showmanship. We are very apt to lose sight of the real reasons behind the keys, faders, and perfectly matched impendances of the control system. They are designed this way so that the electrical impulses may correspond to the thunderous crescendos of Wagner's *Die Walkiire* or the light, delicate strings of Debussy's *Festivals*. It is with the intangible qualities of human experience, expressed by great artists through the moods of music, that the wires and switches and dials and knobs of the technical department are concerned. As we grow ever more conscious of this, we come to see our work in its true relation to the service of radio to the listening audience.

But to get back to the announcer and our starting point in high-fidelity microphone techniques. Mugging the mike is a strongly entrenched and deeply rooted habit. But the announcer must be kept away from the microphone. He will probably object. He may refuse. Some announce desks have microphones permanently mounted on them, and if the announcer moves back, he must hold his script in an uncomfortable position, without an armrest. This is plainly and simply an engineering error. Like fingerprints, there are no two voices exactly alike. For every voice there is a definite relationship to the microphone which allows the most natural and pleasing reproduction.

For voice work alone, 2 ft is the minimum distance from the face to the microphone that will assure naturalness of that voice! A distance of 2 ft, incidentally, should be used only for the softest voices. Compare this with your own studio-operating practice. What is the distance your announcers use? Probably somewhere between 4 and 12 in. Voice waves at this distance from the mouth and throat

cavities do not create electrical impulses that correspond to the natural character of that particular voice.

Do this as an experiment: On rehearsal, set up microphones (in addition to the regular announce mike) 3, 6, and 9 ft away. Stagger them enough so that no mike will be in front of another. If the regular microphone is immediately in front of the announcer's face, you will have to move it lower or to one side. Don't tell him what you are doing. Just say you are testing mikes. If he is told to start reading at a distance from one microphone and then to move closer, he will subconsciously alter his volume and you will not get a natural check.

Now turn only one microphone on at a time. Start with the farthest mike. Unless you are so conditioned to hearing the mugging voice that you can accept no other, you will find a new experience in naturalness of voice transmission. A distance will be found where the voice begins to sound hollow in a live studio or thin in a dead one. Use the distance just a shade closer than this point.

FIG. 1-46. Setup for interview in small room.

In small announce booths, where space is at a premium and where distance would create a barrel effect owing to the proximity of the studio wall to the microphone, the mike should be suspended over the announcer's head at a distance of several feet. We are borrowing this technique from television, where the mike must be kept out of the range of the camera and is often as much as 15 ft from a performer. It should be borne in mind, however, that the sound in television is only a secondary expression to the picture. In other words, all the intent and meaning need not be embraced in sound, as in audio broadcasting.

This same technique is most convenient when two persons are seated at a table and using a single mike as illustrated in Fig. 1-46. The table top should be deadened by acoustical treatment or by the use of a heavy cloth cover to prevent reflected sounds from entering the mike.

How Many Microphones?

In an approach to the study of specific types of program setups, the question of the number of mikes will invariably arise, especially on a large show. Keep always in mind the previous discussion on the monaural character of the system and the lack of focusing power unless it is deliberately used as a means of concentrating the attention.

The greatest weakness in mike setups for large shows has always been the use of too many microphones. There is bound to be some distortion, however slight, in multiple-mike setups due to the time lag of sound waves which create phase additions and subtractions at the various pickup positions. This source of distortion, however, is only minor compared with the other faults of this technique. Aside from the operational difficulties of handling a large number of channels on the mixing panel, with greatly increased chances of error, the control man and his board take the place of the conductor. All the dramatic interest, the emotional pattern written into the original score, plus even the conductor's interpretation are placed in the ratio of fader adjustments and the reactions and psychological temperament of the operator. In other words, too many variables are injected between the performers and the listeners.

Let's establish a foundation upon which we can build a workable structure to determine the correct number of microphones for a given show. Let's also be practical and realize that many operators have neither the very latest studios nor an adequate amount of rehearsal time.

1. Whenever it is possible in the time allotted for setting up, arrange your performers about a single microphone (following suggestions given later for each type of show) so that the over-all balance is correct. If you do this, you achieve balance by proper positioning rather than by mixing various sources on the control board.

2. Perhaps your time is running out and you are still having trouble with a particular section in obtaining balance. This is more apt to occur in a dead studio than in one which is acoustically live. Another mike will have to be used on the troublesome section. However, use of the second pickup can probably be limited to particular spots in the show, such as rhythm-section accentuation of an orchestra as required by the score.

3. Some of the more complex shows do require more than one microphone. Take, for example, a variety show consisting of a drama cast, a chorus, and an orchestra. Remember that the microphone does not focus attention as your ears do in the studio. Of course, it is likely that a program of this type will originate at one of the larger stations having modern studios. The more rehearsal time you have, the less the number of microphones necessary, to the point where the absolute minimum is reached. So much for the basic theory of microphone technique. Let's go on with more specific program setups.

Picking up the Piano

The single-piano pickup is the simplest setup, since it is perhaps the least affected by acoustical nature of the room. No matter how softly the pianist plays, as long as he is unaccompanied by other instruments, the microphone should not be placed up under the lid. The distortion arising from the close proximity of large physical objects to the microphone is well known. It should then be obvious that a pickup under the lid and close to the sounding board will not allow natural transmission of the piano tones. Close-miking almost any instrument makes it necessary to hold down the volume, with great loss of musical brilliance. It is true that many operators have become so accustomed to this type of piano setup that, as is the case with the close-talking announcer, the sound may be familiar, but it is not natural reproduction. We must remember that it is the business of the broadcaster to transmit the natural sound of the original program content.

Here is the best method of determining the setup for a single piano: Start with a distance of 20 ft, head high. In a dead studio, this distance will probably result in a thin response, especially on low passage. In live studios, the sound may be too reverberent for clear-cut transmission. Move the microphone in on a line drawn through the center of the sounding board until the tones are full-bodied, with just the right amount of reverberation. This distance is seldom less than 8 ft and will allow tonal brilliance and balance between lows and highs that is sacrificed in close-up technique.

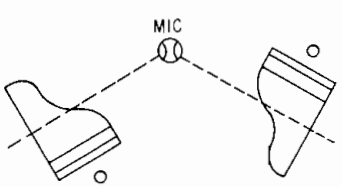


Fig. 1-47. Orientation for a two-piano team.

Now comes the final check for balance between bass and treble, in other words, the check of the player's left- and right-hand pressures. If the pianist has a heavy right hand and bass response is somewhat weak in relation to the highs, keep the mike at the same distance but swing it toward the tail of the piano. This method increases the response from the bass strings. If the pianist has a heavy left hand, with a relative loss of highs (this lack of highs is also apt to occur in dead studios), the mike should be moved toward an imaginary extension of the keyboard. This will increase response to the treble strings and decrease that from the bass strings.

The twin-piano team imposes only slight additional requirements. Figure 1-47 illustrates the most satisfactory orientation. The temperaments of the pianists must, of course, be considered, and the lead piano given prominence by moving the mike closer to that piano if the accompanist is heavy-handed. The procedure for bass

and treble balance should be followed, not by moving the microphone, but the piano itself.

Vocalist and Piano

The distance of the vocalist from the mike, the distance of the mike from the piano, and the distance of the vocalist from the piano must be considered in this setup. There is no excuse for using more than one microphone unless the time allowed for rehearsal is zero.

The first requirement is to listen to the vocalist in the studio. Does he or she sing out with the chest muscles, using a large volume and dynamic range? Or is the vocalist the crooner type, using only the larynx and throat for emphasis? Every vocalist is in one or the other general category.

One who sings out with full volume should be placed 12 to 6 ft from the microphone when a piano alone is used as background. On rehearsal, always start with the greatest distance. The goal is to use the lowest volume and the highest volume without having to ride gain on the fader control. This part of the balance can always be achieved by careful rehearsal checks. The balance between vocalist and piano accompaniment is not always so simple. A good pianist or one familiar with a particular vocalist's style will automatically adjust his volume to the pianissimo and crescendo of the singer.

A bidirectional mike should be placed about 8 ft from the piano, with the vocalist on the opposite side at the distance determined by trial. It is well to point out here that a very common error is in taking a vocal solo too literally. The presence of the piano must always be there, with only slight emphasis on the voice. It should be a blend with, of course, the voice always a little predominant, but not with a weak background of piano tones, as is often heard.

When the pianist insists on playing so loudly that the accompaniment smothers the vocalist (some pianists cannot alter their volume and still play well), the dead side of the vocalist's microphone must be turned toward the piano. This is almost always the only adjustment necessary from the 8-ft distance between mike and piano. If the studio is very live and the piano tones are still too prominent, turn the piano around so that the lid opens toward a wall of the studio. Don't at any time move the vocalist closer to the mike if it is necessary to ride gain on the natural dynamic range of the voice.

Setup for Small String Groups

Small salon groups, string quartettes, or hillbilly groups, playing in intimate style, require good instrumental definition. This calls for comparatively close mike setups, but not too close! The author is always hesitant about using the word "close," since the reader is apt to take it as meaning directly into the face of the instrument.

Consider a small salon orchestra, generally consisting of several violins, a viola, a cello, a string bass, and sometimes a piano. Because of their comparative volume they are usually placed in that order from the microphone. Figure 1-48 illustrates the general orientation of such a group with the mike.

Now assume that the approximate distances are violins 4 ft, viola 6 ft, cello 8 ft, and string bass 10 ft, with piano somewhat off mike at 10 ft. If the violins are too predominant for proper sectional balance, usual practice is to move the violins farther back or to one side in a less sensitive zone or else to bring the other instruments in closer.

However, remembering the focusing-power principle, it is clear that quite a range of sectional balance can be obtained by the simple expedient of adjusting the microphone height and tilt, as shown in Fig. 1-49. If the violins are too predominant, raise the mike and focus on the other instruments. If the violins are weak, the mike should be lower and focused on them. This is a better method than moving the predominating instruments to one side in a less sensitive area of the

mike, since the higher frequencies containing the overtones are very important for wide-range pickups.

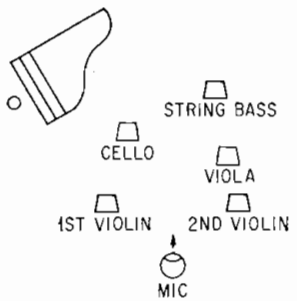


FIG. 1-48. Orientation for a salon orchestra.

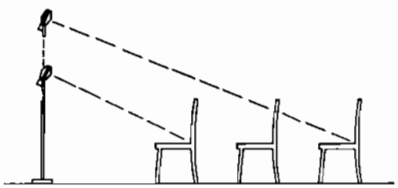


FIG. 1-49. Adjusting microphone for balance.

There is little difference in pickup for this type of musical organization between dead and live studios, since the setup must be intimate in character, with high direct-to-reflected sound ratio, minimizing the effect of the acoustical nature of the studio.

Setups for Small Orchestras

A large number of organizations presenting popular, serious, or variety music comes within the small-orchestra category. There may be a combination of brass, strings, and reeds, numbering anywhere from 4 to 15 musicians.

Again the first step is to visualize the instruments in comparative power output. From softest to loudest, they are:

1. Violins, trumpets or trombones (muted), guitar
2. Clarinets, saxophones, xylophone, vibraphone
3. String bass
4. Piano
5. Trombone (open belled), trumpets (open belled).
6. Traps, bass drums, guitar (electrically amplified)

These are the most likely instruments to be encountered in such a setup. As before, the conventional approach is to arrange them in the order listed from the single microphone.

Look now at Fig. 1-50. This is a live-studio practice, starting with the violins at about 8 ft. When initially checking the balance of sections, remember the height and tilt adjustment for focusing power to obtain proper blend. Then, and not until then, try moving a troublesome section.

If you think it necessary to move instruments, keep these principles in mind: A predominating section may be too loud, not because the relative distances between instruments are incorrect, but because the microphone is too close to the entire outfit. Move the mike back.

A weak section may be too soft, not because it is too far from the mike, but because all instruments are too close to the microphone. Move the mike back.

In other words, the farther back a microphone is placed (within the limits of acoustically allowable distance), the better the chance of a good balance between all sections.

Another very important item is the treatment afforded muted trumpets or trombones. When their bells are muted, the instruments must be very close to the microphone. This means really close, about 2 ft. If the players cannot or will not step from their regular positions to one immediately in front of the mike, a separate

microphone must be spotted just in front of that section. Obviously it is to be used only when the instruments are muted.

Now consider a studio of older design with dead characteristics. When the musicians number around 12 to 15, it is often difficult to get good sectional balance with the plan shown in Fig. 1-50. Even though the farther instruments may contribute about the same number of volume units, the pickup may be thin, because the dead studio does not reinforce the harmonics and overtones. Also the mike must be a little closer in a dead studio, emphasizing the discrepancy in sectional presence.

In nearly every case, however, best results are obtained with one mike and by using the setup illustrated in Fig. 1-51. The mike is a bidirectional ribbon type. The instruments must be more nearly on beam, owing to the narrower angle of response in comparison with the unidirectional mike employed in Fig. 1-50 and with

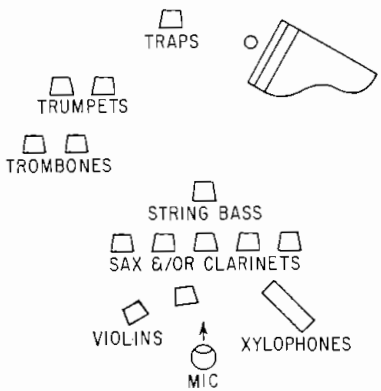


Fig. 1-50. Conventional one-microphone plan.

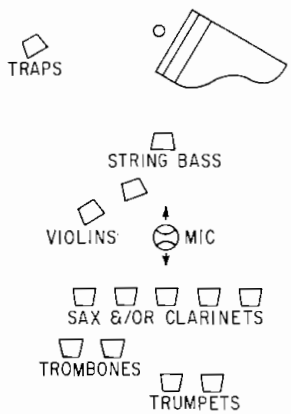


Fig. 1-51. Improved pickup location.

the dead acoustics of the studio. More time and movement of players will be necessary to get this setup exactly right, but it is far better than the usual procedure of using additional microphones.

How to Add a Vocalist

A vocalist with the type of musical program just described imposes special problems unless the organization is thoroughly trained in prior broadcast-production technique.

The ideal arrangement would be for the vocalist to stand in front of the orchestra, facing the mike at a distance of several feet. This arrangement, however, is often not practical as, for instance, when the mike is raised and slanted so as to obtain proper balance of instrumental tones.

Where such a situation occurs, there is no alternative but to use a second microphone for the vocalist, preferably a unidirectional type, with the dead side toward the orchestra. This mike can be used for the announcer also.

Symphony Orchestras

The setup for a large symphony orchestra should be based upon exactly the same principles as heretofore discussed, except that the grouping of instruments, the use of a chorus, and the type of musical score make the problems much broader in scope. Fortunately, such programs are not usually attempted in an inadequately designed studio.

Generally, the usual physical arrangement of the orchestra for regular audience listening will be satisfactory for broadcast purposes. On the initial trial of the main orchestra microphone, several mikes should be suspended at the most likely pickup positions in order to avoid the confusion of moving mikes. The general area for these microphones is 15 to 20 ft high and 15 to 25 ft in front of the violin section. Figure 1-52 illustrates a typical grouping of a large symphony orchestra.

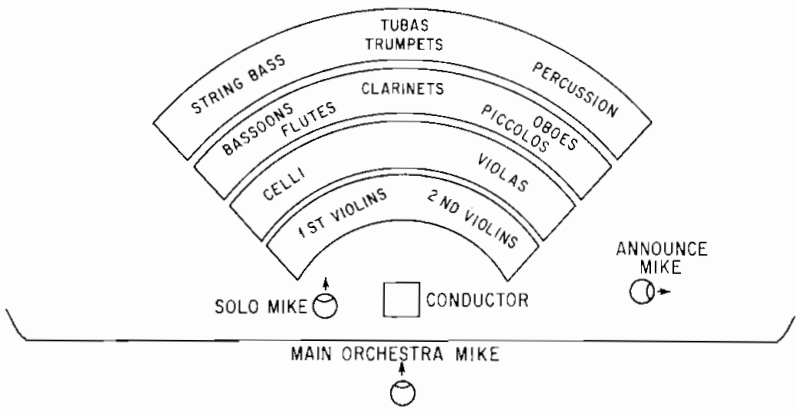


FIG. 1-52. Symphony orchestras may require solo and section mikes for highest fidelity.

If a vocalist or instrumental solo is called for, it is almost always necessary to use a second mike to achieve proper sound perspective. Remember that vocal or instrumental solos are not to be entirely predominant; the orchestral accompaniment must be very much present. Always try to get the conductor to listen to a monitor speaker for a final check on balance, or get some responsible member of the organization to pass on it. The very best control and production men do this simply because every symphony organization has its own arrangement of score or possibly a distinct interpretation of the original score. This individuality must be conveyed to the listeners. Thus, many times, a slight rearrangement of instruments in relation to the microphone is found necessary.

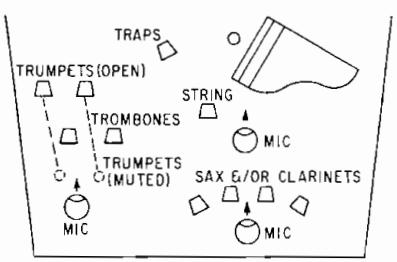


FIG. 1-53. Mike setup for dance orchestra.

In spite of the usually superior results obtained with a single, well-orientated microphone, it is often necessary to deviate from this practice for true high-fidelity pickup. The main orchestra microphone, back far enough to obtain the proper blend of all instrumental tones, will faithfully pick up the delicate, distant tonal beauty of the violin passages in *Clair de Lune,* for example. Most music lovers, however, criticize this same microphone setup for such numbers as the Strauss waltzes, where the tonal perspective of the strings should be closer and more strident in quality.

Many leading conductors and producers of symphony broadcasts insist on an added mike suspended directly over the strings or other sections to be turned up only on cue. This procedure supplies the missing psychological factor of microphone-to-sound perspective. When a choir is used with a symphony orchestra, it is also necessary to use a separate mike because of the spread of the total combination in order to obtain focusing power.

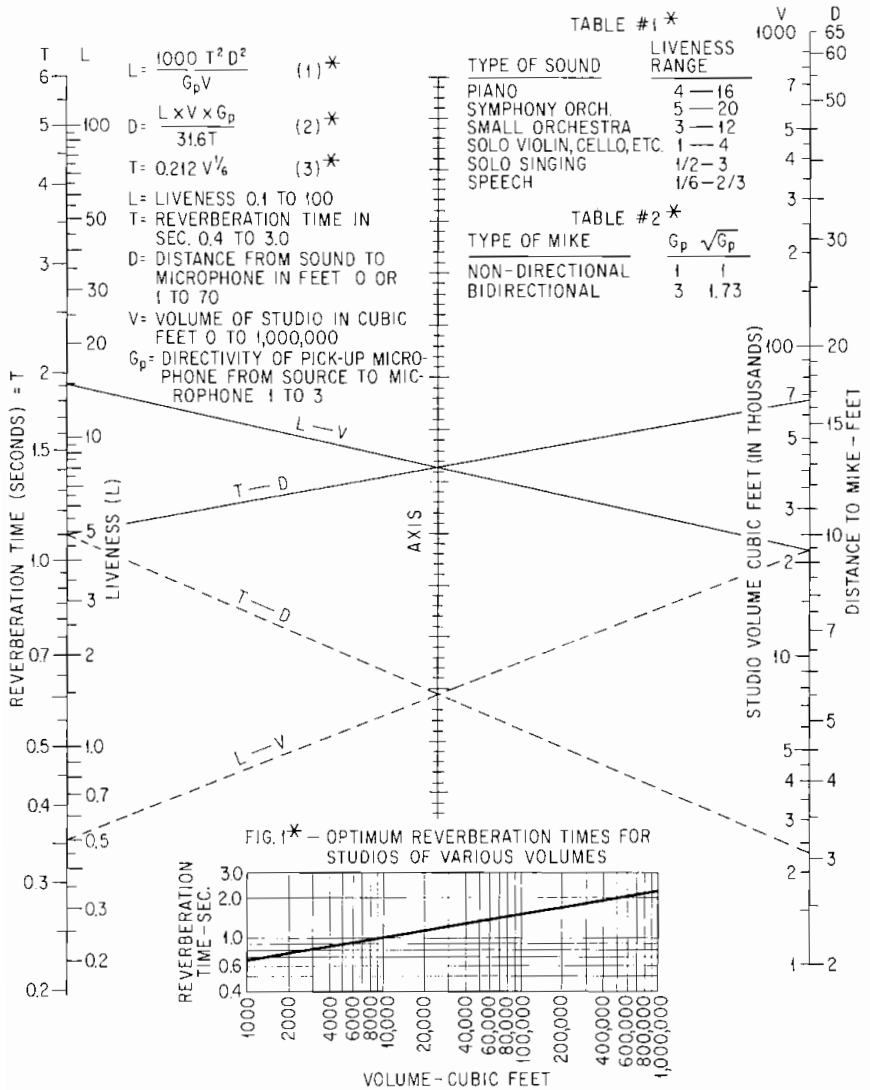


FIG. 1* — OPTIMUM REVERBERATION TIMES FOR STUDIOS OF VARIOUS VOLUMES

*COURTESY OF WESTERN ELECTRIC CO.

FIG. 1-54. Nomograph for microphone distances in liveness broadcasting. (*Reprinted by permission from Tele-Tech magazine.*)

Constants V = 22,000 cu ft; T = 1.1 sec.

Example 1: (solid lines) placement of general microphone. From Table 1 use liveness of 15. Connect 22,000 on V and 15 on L. Mark reference on the axis. Then extend a line from 1.1 on T through reference on axis to 16.5 ft on D. Answer: 16½ ft from mike to sound source.

Example 2: (dash lines) placement of solo vocal microphone. From Table 1 use liveness of ½. Connect 22,000 on V and ½ on L. Mark reference on the axis. Then extend line from 1.1 on T through this reference to 3 ft on D. For bidirectional mike multiply 3 ft by $\sqrt{3}$ or 1.73. This yields 5 to 6 ft for actual distance.

Notes on Field Setups

Field setups are an entirely different matter. The musical instruments must usually be placed more in a straight line owing to lack of depth of the platform. Added to this is the inevitable noise and confusion about the point of origin. It may be argued that really high-fidelity transmission is impossible from such a broadcast, and this is true. But FM listeners especially will appreciate any pains taken to improve the pickup.

Multiple-microphone arrangements are absolutely necessary for such an orchestra of even medium size.

Figure 1-53 illustrates a three-microphone treatment of a typical dance orchestra playing in the open. Always strive to obtain a good balance with the minimum number of mikes, taking into consideration the usually heavy background noise. It is almost always necessary to use a microphone for each group of instruments, as shown in Fig. 1-53, to give the section playing the lead or melody at any particular time the highest intensity. But remember that the presence of the other sections is important.

Conclusion

It is apparent to the experienced broadcast man that many types of program setups have not been treated in this article. Indeed, such a treatment would require a full-size book. The author has attempted to take up only those situations most commonly encountered.

There will, no doubt, be some who have honest disagreements with parts of this discussion. The author extends an invitation of correspondence to any reader who may care to offer comment or criticism. Progress in any line of endeavor can be achieved only by the inquisitive mind and earnest doubts of traditional practices. Microphone-setup techniques in particular and operational engineering in general are in need of exhaustive, wide-open discussion.

Part 2

COST ESTIMATING FOR TELEVISION FACILITIES

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ITT Communication Systems, Inc.

INTRODUCTION

The following information is for preliminary estimating only and is based on costs in the Northeastern part of the United States. When using this information, make sure that all concerned realize that these are quick estimates of relatively good accuracy but should not be considered exact costs. Final pricing can be determined after consultation with the architect or engineer and obtaining contractor's quotations.

Cost-estimating factors will vary with current labor rates, location, union jurisdiction, climate, etc. The cost factors shown herein can be adjusted to suit these local conditions. Make sure that you know your own local situation in so far as these items are concerned.

Where there are improvements to land, make sure that you have enough basic information to include all necessary items. Certain property might require drilling and blasting, special provisions for drainage, etc.

These cost factors presuppose good construction materials and methods. In some circumstances cheap construction may be warranted. However, it is believed that good construction pays in the long run and that it is better to save on operating and maintenance costs rather than on capital expenditures.

The following information does not include equipment or tower costs, which are covered:

Table 2-1. Construction-cost-estimating Factors—TV Plants

Total Estimates	
New transmitter buildings	$21/sq ft
New studios and offices	$32/sq ft
Studio conversions (shell available)	$17/sq ft
Component Estimates	
Studio flooring	$0.55/sq ft floor area
Office flooring	$0.35/sq ft floor area
Studio acoustic treatment	$0.90/sq ft area covered
Other acoustic treatment	$0.55/sq ft area covered
Studio lighting and rigging	$10/sq ft floor area
General electrical work	$2.25/sq ft floor area
Audio/video wiring	$1.50/connection
Air-conditioning plant	$1,000/ton of refrigeration

Table 2-1. (*Continued*)

Improvements to Land

Land–clearing and grubbing	$600/acre
Excavating:	
Power (use on large jobs)	$1/cu yd
Hand (use on small jobs)	$5/cu yd
Grading:	
Rough	$0.35/cu yd
Finish	$0.15/sq yd
Roadway and parking area	$2.50/sq yd
Fencing	$3/ft

SAMPLE PROBLEMS

Example 1. Conversion—Studios and Offices

Existing building is 200 by 110 ft, seven stories high.

$$110 \times 200 \times 7 = 154{,}000 \text{ sq ft}$$

Deduct 28,000 sq ft for studios that are two stories high.

$$154{,}000 - 28{,}000 = 126{,}000 \text{ sq ft}$$
$$126{,}000 \times \$17 = \$2{,}142{,}000 \text{ estimated cost}$$

NOTE: In 1953 this actual job priced out at $1,731,000. Multiply 1,731,000 by the increase in cost from 1953 to 1959 to get $1{,}731{,}000 \times 5.1/4.2 = 2{,}100{,}000$.

Example 2. New Studio—Office Building

To be built on property already cleared. Building is to be 90 by 80 by 20 ft and will house two studios, one 60 by 40 by 20 ft, the other 40 by 20 by 20 ft, with the remaining area (two floors) devoted to offices, technical space, program space, etc.

Total area: $90 \times 80 = 7{,}200$ sq ft

Studio area: $60 \times 40 = 2{,}400$
$40 \times 20 = 800$
$3{,}200$ sq ft

$7{,}200 - 3{,}200 = 4{,}000$ sq ft
$4{,}000 \times 2$ stories $= 8{,}000$ sq ft other space
3,200 sq ft (studio) + 8,000 sq ft (other) = 11,200 sq ft
$11{,}200 \times 32 = \$358{,}400$

Example 3. Transmitter-plant Estimate

Land:	
Size, cost: 20 acres at $1,200	$24,000
Improvements to land:	
Clearing 5 acres at $600	3,000
Grading and excavating negligible	—
Roadway and parking lot, 400 sq yd at $2.50	1,000
Fence 500 ft at $3	1,500
Miscellaneous, drainage, etc.	2,500
	$32,000
Balance brought forward	$32,000
Transmitter building:	
$70 \times 35 = 2{,}450$ sq ft	
2,450 sq ft × $21	51,450
	$83,450

Example 4. Flooring Cost Estimate

Same studio and office building described in Example 2.

Studio area:	
3,200 sq ft at $0.55	$ 1,760
Other area:	
8,000 sq ft at $0.35	2,800
Total	$ 4,560

Example 5. Acoustic-treatment Cost Estimate

Studio 60 by 40 by 20 ft with wall surfaces not treated from floor to 5 ft above floor.

$$\begin{aligned}\text{Area covered} &= 60 \times 40 + 2(40 \times 15) + 2(60 \times 15)\\ &= 2{,}400 + 1{,}200 + 1{,}800\\ &= 5{,}400 \text{ sq ft}\\ 5{,}400 \times \$0.90 &= \$4{,}860\end{aligned}$$

Totals for building described in Example 2:	
Studio 60 by 40	$ 4,860
Studio 40 by 20	2,340
	$ 7,200
Balance brought forward	$ 7,200
Office ceilings:	
8,000 sq ft × $0.55	4,400
Total	$11,600

Example 6. Air-conditioning Cost Estimate

Method:

1. Determine heat load in kilowatts (see Table 2-2).
2. Determine volume of space in cubic feet.
3. Based on six air changes per hour, divide volume by 10 to give cubic feet per minute to be cooled.
4. Allow 1 ton of refrigeration per 400 cfm plus 1 ton per 4 kw.[1]

Table 2-2. Heat Loads

	Watts
General lighting	4/sq ft
Studio lighting (monochrome)	25/sq ft
Studio lighting (color)	100/sq ft
Persons	150/each
Equipment radiation	600/rack

NOTE: For the studio and office building described in Example 2:

Monochrome studio lighting: 3,200 sq ft × 25 watts/sq ft =	80 kw
Other lighting: 8,000 sq ft × 4 watts/sq ft =	32 kw
Staff and audience: 150 × 150 watts =	22.5 kw
Equipment: 25 racks × 600 watts/rack =	15 kw
	149.5 kw

[1] These factors are based on Northeastern United States. There will be changes for different design conditions in different areas. See "ASHAE Handbook."

Table 2-2. (*Continued*)

$$\text{Volume of building} = 90 \times 80 \times 20 = 144{,}000 \text{ cu ft}$$

$$\frac{144{,}000}{10} = 14{,}400 \text{ cfm}$$

$$\frac{149.5 \text{ kw}}{4} = 37.4 \text{ tons}$$

$$\frac{14{,}400}{400} = 36 \text{ tons}$$

$$37.4 + 36 = 73.4 \text{ tons approx.}$$

$$73.4 \text{ tons} \times 0.70 \text{ diversity factor}^{2} = 52 \text{ tons}$$

$$52 \text{ tons at } \$1{,}000^{3} = \$52{,}000$$

Example 7. Lighting and Rigging Cost Estimate [4] ***(per Square Foot of Studio)***

Table 2-3. Cost Factors

Item	*Monochrome (100 fc)*	*Color (400 fc)*
Connector strips	1.20	1.40
Fixtures	1.40	2.20
Light control	2.30	2.75
Installation	2.50	2.75
Subtotal	7.40	9.10
Rigging (installed)	2.50	2.50
Subtotal	9.90	11.60
Add for 10 scene preset board	3.50	5.25
Total	13.40	16.85

For the studios described in Example 2: 60- by 40- by 20-ft studios complete with rigging and adjustable battens, lit for monochrome, using autostat board and patch panel for light control.

$$60 \times 40 \times 9.90 = \$23{,}760$$
$$40 \times 20 \times 9.90 = \quad 7{,}920$$
$$\$31{,}680$$

Table 2-4. Power-service Estimates

	Watts
1. General service	4/sq ft
2. Studio lighting, monochrome	25/sq ft
3. Studio lighting, color	100/sq ft
4. Camera chains, orthicon	1,500
5. Camera chains, vidicon	650
6. Equipment racks	1,500
7. Air conditioning	1,000/ton
8. Miscellaneous *	

* Don't forget to include office equipment, cleaning equipment, shop tools, elevators, electric signs, and other applicable items.

Advances in equipment design, the use of transistorized equipment, etc., are reducing these loads from year to year. For some applications, fluorescent lighting has been used with success. Ultimately, there will be considerable reduction in power service and air-conditioning requirements.

[2] Allow 0.70 diversity factor on the basis of a few large audience programs and limited back-to-back studio operation.

[3] Some areas in the United States may be as little as $600 per ton.

[4] Based on New York City electrical costs of approximately $6 per man-hour.

In the building described in Example 2:

	Kilowatts
Studio lighting	80
Other lighting	32
4 orthicon chains at 1,500	6
2 vidicon chains at 650	1.3
25 racks	37.5
Total	156.8
Balance forward	156.8
52 tons air conditioning	52
Miscellaneous and reserve	50
Total	258.8

Table 2-5. Building-trades Wage Scales [*]

Geographical Variations (1957)

Middle Atlantic	1.00
New England	0.86
Southeast	0.77
Great Lakes	0.95
Middle West	0.90
Southwest	0.83
Mountain	0.83
Pacific	0.91

[*] Source: Bureau of Labor Statistics.

Table 2-6. Building-cost Indices [*]

Year	*Labor*	*Material*	*Total*
1940	1.0	1.0	2.0
1945	1.1	1.3	2.4
1950	1.6	2.0	3.6
1955	2.3	2.4	4.7
1957	2.5	2.6	5.1

[*] Source: *Engineering News-Record.*

Part 3

STUDIO LIGHTING FOR MONOCHROME AND COLOR TELEVISION

NATHAN J. SONNENFELD

New York Sales Manager
Century Lighting, Inc.

PLANNING TV STUDIO-LIGHTING FACILITIES

Television is essentially a visual art. High priority, therefore, must be given to the planning of the lighting facilities. Proper planning will result in a high-quality picture at a moderate operating cost. Improper planning will result in excessive operating costs and an inferior picture.

In TV lighting, as in all planning, the requirements should determine the space and the facilities. Therefore, it is strongly recommended that the operations people be part of the planning group and be represented at all meetings related to studio planning and facilities. The cost of the studio-lighting equipment and its installation represents only about 10 per cent of the total cost of the facilities. Lighting is such an important factor in picture quality, however, that due consideration must be given to it in planning. Money spent wisely in the initial design will greatly influence the profit picture later.

The responsibility for designing and building the studio should be vested in a planning group. The planning group should include, but not be limited to, the production supervisor, chief engineer, sales manager, personnel manager, and general manager. This group will work with the architects and consulting engineers in designing and building the studio and transmitting facilities.

The planning group will have all available information regarding the present and future scope of the operation. The group should know which facilities should be built immediately and what provisions should be made for future expansion. The planning group should operate before pencil is put to drafting paper.

Based on surveys by management, facilities can be planned for the live telecast of weather, news, variety shows, disc jockey, dramatic shows, live local commercials, and choral and orchestral groups.

The planning group then converts these decisions into space requirements. The requirements should determine the space, not vice versa.[1] The lighting representative on the planning group will recommend the studio size, ceiling height, location in relation to other facilities, and budget. He will be the most important single influence in deciding the lighting-suspension system, the lighting-control system, and the lighting-fixture complement. He will advise management of the latest developments in these areas and examine the economics of the newer, more advanced systems.

[1] Not always possible.

LIGHTING FACILITIES FOR A TV STUDIO

Let us analyze some of the requirements for lighting facilities for a TV stndio. The aim is to provide proper lighting facilities for the telecast of a high-quality picture with an optimum signal-to-noise ratio in a minimum amount of setup time with limited personnel. To do this, the following recommendations are made based on the use of the image-orthicon tube type 5820 and monochrome-broadcast operations. Additional information is provided to plan for future or immediate color broadcast using the type 1854 tube. When costs are cited, they are for average budget consideration and will vary in different labor and freight areas.

Where the phrase "studio area" is used, it is defined as "useful set area," or any part of the studio which can be used to televise from. Generally speaking, this is the complete studio floor.

In planning the lighting facilities for the TV studio, the designers must

1. Provide a safe and rapid means of energizing the lighting instruments and controlling them
   a. By installing ample wiring devices, outlets, and feeders and locating them properly
   b. By providing a properly designed lighting-control center for grouping and dimming lights
2. Specify equipment that is reliable, easily installed and moved
   a. To assure dependable operation
   b. To keep maintenance and time-consuming improvisations to a minimum
   c. To obtain the most favorable casualty, compensation, and fire insurance rate
3. Fixtures should be specified that are
   a. Lightweight for easy handling yet durable to withstand the handling
   b. Easily adjusted, repositioned, and focused
   c. Safely constructed and wired
   d. Adequate in number
   e. Equipped with accessories such as barn doors, diffusers, etc., designed for the fixtures
   f. Able to provide maximum light effectiveness per dollar invested
4. Lighting-control center specified should be
   a. Of sufficient capacity to handle the complete studio-lighting system including patching and dimming
   b. Designed to provide maximum flexibility with a minimum of operations personnel
   c. Safely constructed and wired

SUSPENSION SYSTEMS

Today's lighting practice dictates that, if possible, all lighting equipment should be mounted overhead (Fig. 3-1). This is necessary to permit freedom of camera movement for the multiple cameras used in the average set. From this requirement developed a number of different mounting systems.

The most universal method of mounting lighting equipment is to clamp the fixtures to 1¼- or 1½-in. pipe battens running across the studio. The battens are generally 4 to 6 ft apart. Two additional back-light rails are mounted about 3 ft from the walls, which are at right angles to the main battens (Fig. 3-2).

The pipes should be mounted from the ceiling by chain and S hooks to permit some flexibility as to height adjustment between 12 and 16 ft from the floor level.

Many studios have installed counterweight systems (Figs. 3-3*a* and *b*) to permit rapid and easy raising and lowering of lights in groups or to permit rapid change of equipment. Lateral movement of lights is also facilitated, since the equipment is made easily accessible. Studios having counterweight systems claim that they have paid for themselves in a few years in labor saved and in improved picture quality. Improved picture quality results from the ease of putting a key (or other) light exactly where required.

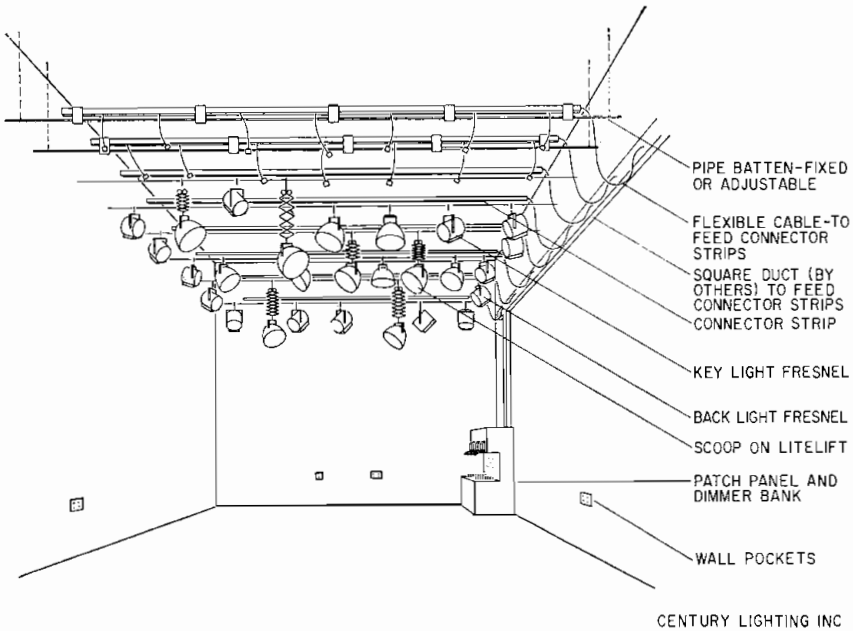

FIG. 3-1. Studio with pipe suspension system.

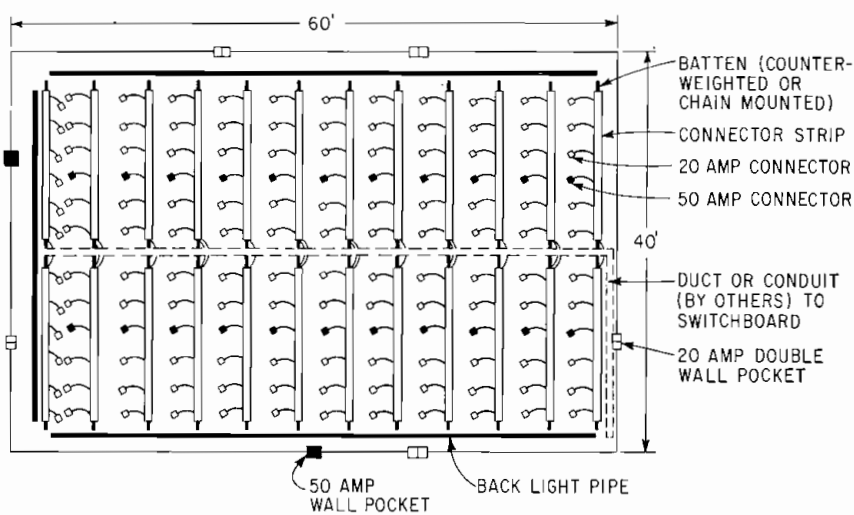

FIG. 3-2. Typical layout for 40- by 60-ft TV color studio.

A few studios have installed motor-operated pipe grids. This system is expensive, but in high-labor-cost areas of extensive studio use, it has proved economical.

Some large studios in New York and Hollywood have installed a complete overhead catwalk system. The lights are set, focused, and serviced from the catwalk. This system, used in conjunction with slide poles, practically eliminates the need for ladders. This is the most expensive suspension system.

Another system gaining in popularity is the mobilrail system (Figs. 3-4*a*, *b*, and *c*). Mobilrail is a system of utilizing pairs of tracks approximately 6 ft apart running across the studio. By the use of double-roller carriers, additional floating mobilrail tracks 12 ft long are carried at right angles to the main tracks. The floating rails can thereby be

FIG. 3-3*a*. WRGB–TV. Showing counterweighted pipe batten in lowered position.

moved forward and back along the fixed rails. The lighting instruments are in turn mounted on single carriers which run on the floating rails. This permits complete horizontal movement of all lighting instruments singly or in groups. This system when used in conjunction with pantograph light lifts is one of the most flexible available. The price of the mobilrail system is about $1.25 per square foot of studio area. Counterweights cost approximately $250 to $325 per set of lines installed.

All lighting instruments should be carried from the suspension system by pantograph light lifts (Fig. 3-5). The light lifts permit height setting of the lighting instruments from the floor (by the action of negator springs).

When planning for color, the pipes should be mounted closer together than 6 ft (generally 4 to 5 ft). A higher percentage of light lifts should be provided to permit a greater amount of flat light.

ELECTRICAL DISTRIBUTION

We now have the lights up off the ground. The most usual system for providing current to the lights is the connector strip (or wireway) method (Fig. 3-6). A sheet-steel wireway with pigtail connectors is mounted onto the pipe batten. The pigtails are evenly spaced along the connector strip. The connector strip is held above the

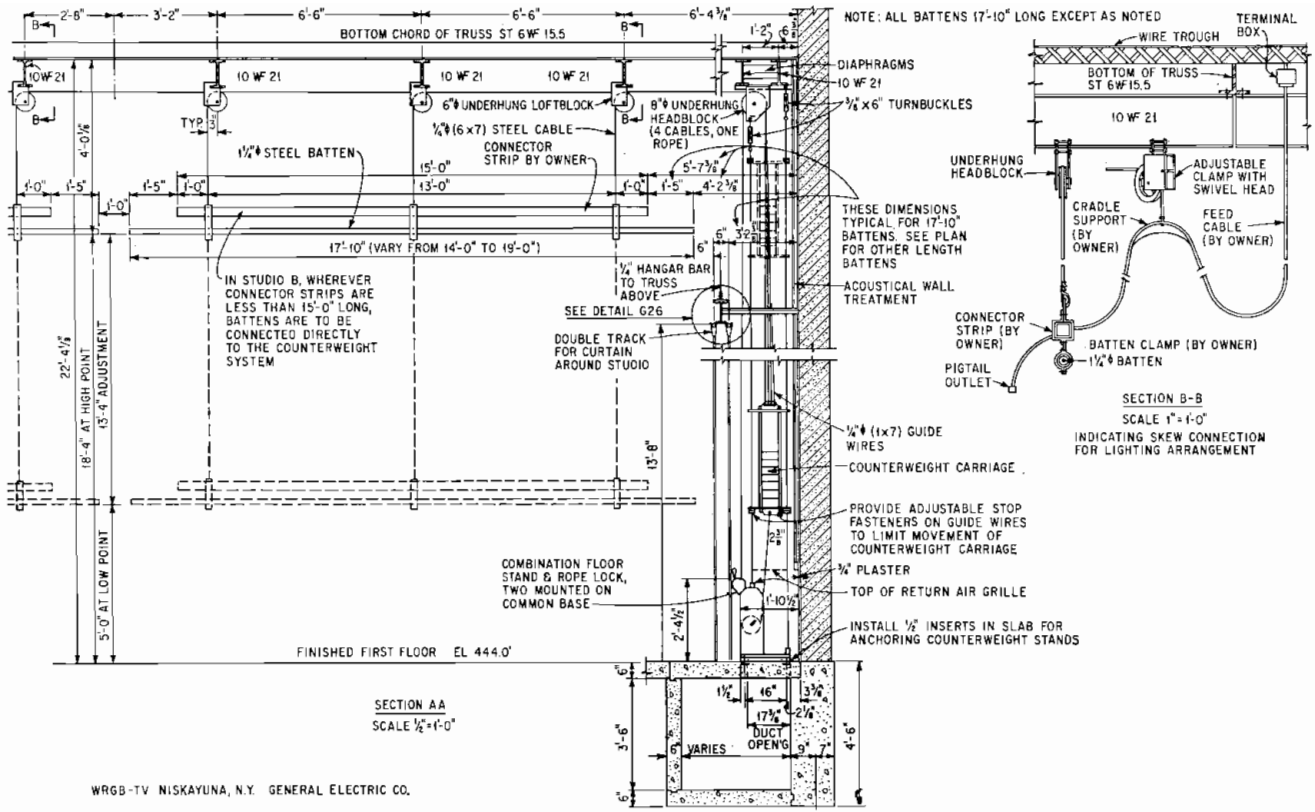

FIG. 3-3*b*. WRGB–TV. Showing details of counterweight system.

pipe batten by brackets so that the lights can still be clamped onto the pipe and the unit plugged into the pigtail connector. At one end of the strip a terminal box is provided. From this terminal box multiconductor flexible cable is carried to a square duct. The duct in turn carries the connection back to the patch panel or lighting-control center. A separate two-wire 20-amp circuit should be carried back from each pigtail connector to the lighting-control center. For safety, it is recommended that grounded pigtail connectors and lighting units be used. Some studios carry a ground wire throughout their entire electrical system.

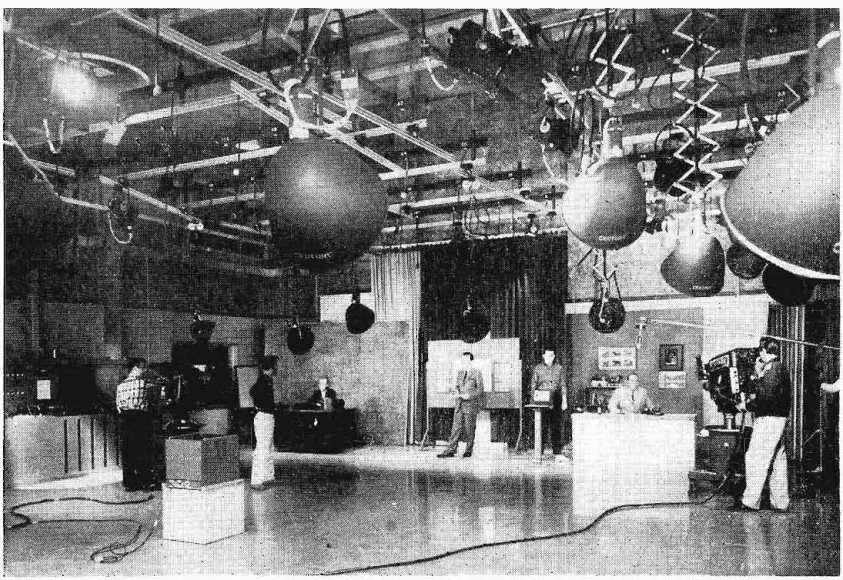

FIG. 3-4*a*. WPST—TV. Showing mobilrail system in use.

Connector strips should be laid out to provide one outlet for every 14 to 20 sq ft of studio space. This means that if pipe battens are used on 5-ft centers, pigtails should be spaced 3 or 4 ft apart. When provisions are made for color broadcast, the area for each outlet should be closer to the 14-ft spacing. In addition to this approximately one outlet in five or six should be a 50-amp circuit.

In addition to the overhead outlets, some provision must be made for floor units. General practice is to provide one duplex 20-amp wall receptacle for every 20 to 40 running feet of wall. Also provide half as many wall receptacles with a single 50-amp receptacle. This will take care of rear screen projectors, follow spots, wall and table lamps, fireplace, and other effects and provide current for the occasional floor spot or scoop when required. These receptacles should be provided with the same connectors as the overhead connector strips. For color telecast make all the wall outlets 50 amp.

LIGHTING-LOAD REQUIREMENTS

Note that although one 20-amp outlet is provided every 14 to 20 sq ft of studio space, the load requirement is not 120 to 170 watts/sq ft. Some of the outlets will feed 500-watt fresnels, some 750-watt scoops, and some will not be in use at all on many occasions. The recommended lighting-load requirement is 25 watts/sq ft of studio area. This value will provide sufficient current for a quality picture with a minimum fixture movement.

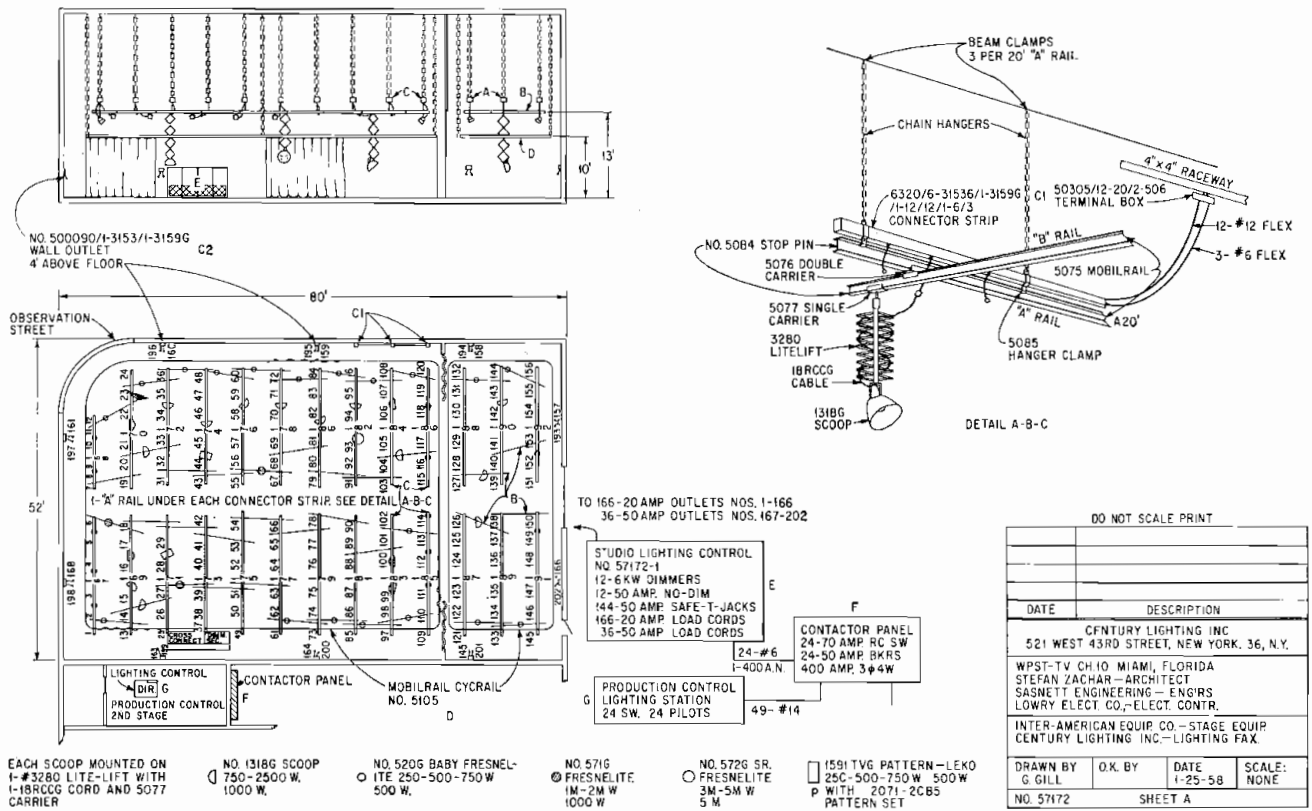

FIG. 3-4*b*. WPST—TV. Showing installation details.

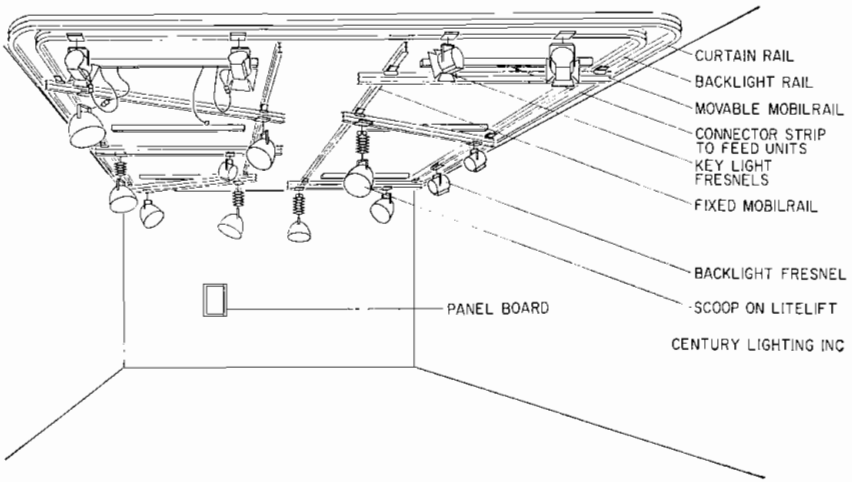

FIG. 3-4c. Typical mobilrail layout for a small TV studio.

In figuring the feeder requirements, use 25 watts/sq ft. The minimum diversity factor to consider would be 80 per cent. Many engineers figure 100 per cent utilization. In the design of the air-conditioning system, a diversity factor of 50 to 60 per cent is used. Most engineers use 50 per cent or 12.5 watts/sq ft. This figure seems to satisfy most factors of good engineering practice, economics, and actor comfort.

In the design for color, provisions must be made for 80 to 100 watts/sq ft. The same factors for feeder utilization and air-conditioning apply: 80 to 100 per cent feeder utilization and 40 to 50 watts/sq ft for air-conditioning.

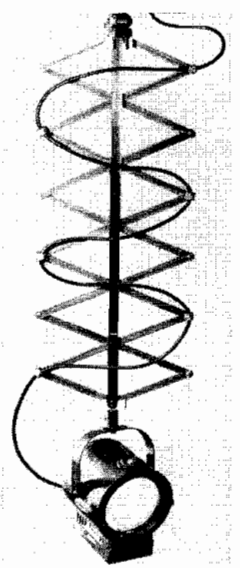

FIG. 3-5. Pantograph or light lift.

BUDGET

Listed in Table 3-1 are two typical schedules of connector strips and lighting equipment for monochrome and color. Scheduled is a 25- by 40-ft and a 40- by 60-ft studio.

Table 3-1. Cost Estimate for Lighting Equipment

Description	*Monochrome*	*Color*	*Monochrome*	*Color*
	25 by 40 ft		*40 by 60 ft*	
Connector strips and wall receptacles . . .	$1,400	$ 1,600	$ 3,500	$ 3,900
Lighting instruments and accessories . . .	$3,400	$ 5,100	$ 6,700	$10,500
Patch panel	$1,900	$ 2,100	$ 4,000	$ 4,500
Dimmer bank	$1,200	$ 2,000	$ 2,000	$ 3,700
Electronic dimming with presetting	$8,000	$14,000	$14,000	$20,000

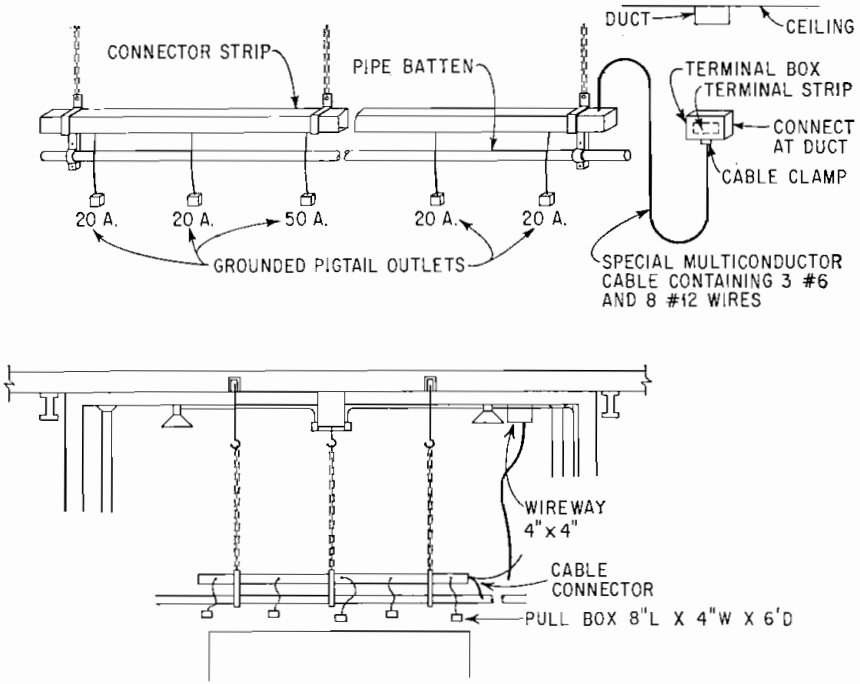

FIG. 3-6. Typical detail of connector strip installation.

Table 3-2. Electrical System for a 25- by 40-ft Studio *

(1,000 sq ft of studio area, 56 overhead and 7 wall circuits, 17.9 sq ft per overhead circuit)

Description	*Quantity* Black and white	Color
20-ft connector strip: seven 3-ft pigtails, each with 20-amp capacity, terminating in three-pole, female pin connectors	8	
20-ft connector strip: seven 3-ft pigtails, six with 20- and one with 50-amp capacity, terminating in three-pole female pin connectors		8
Note: Above type numbers refer to a three-wire, grounded system. To specify a two-wire, ungrounded system, change the type number from the 63 to the 62 series.		
Wall receptacle: double 20-amp three-pole pin connector	3	3
Wall receptable: single 50-amp three-pole pine connector (Nos. 3046 and 3048 for equivalent two-pole units)	1	1
Cyclorama rail: aluminum 1-beam rail with snspension straps and 93 ball-bearing rollers and curtain hooks, ft	93	93
Switchboard: 72 load, circuit-breaker control panel (62- to 20- and 10- to 50-amp circuits)	1	1
Switchboard: patch panel with 72 load cords (62- to 20- and 10- to 50-amp)	1	1
39 control jacks, six group master preset switches. Plus:		
Dimmer bank: three 6-kw transformer interlocking dimmers, one master interlocking handle, three 50-amp primary breaker switches	1	
Dimmer bank: six 6-kw transformer interlocking dimmers, one master interlocking handle, six 50-amp primary breaker switches		1

* For information and prices about more advanced lighting control systems, refer to the separate heading entitled Control Systems.

Table 3-3. Equipment List for a 25- by 40-ft Studio

(Load power, watts/sq ft. Monochrome: 31. Color: 107)

Description	*Quantity* Black and white	Color
3-in. 75- to 150-watt fresnelite	3	3
Two-way barn door for No. 523	3	3
6-in. 250- to 750-watt fresnelite	18	6
Four-way barn door for No. 520	10	3
8-in. 1,000- to 1,500-watt fresnelite	6	
Four-way barn door for No. 526	4	
8-in. 1,000- to 2,000-watt fresnelite		16
Four-way barn door for No. 571		8
12-in. 1,000- to 2,000-watt fresnelite		4
Four-way barn door for No. 572		2
16-in. 5,000-watt fresnelite		2
Four-way barn door for No. 576		2
18-in. 750- to 2,000-watt scoop	15	18
18-in. diffuser frame for No. 1318	15	18
6-in. 250- to 750-watt pattern projector with shutters and gobo slot	3	2
Gobo holder for above	3	2
Gobo slides for above −6/set	3	2
8-in. 1,000- to 2,000-watt pattern projector with shutters and gobo slot		1
Gobo holder for above		1
Gobo slide for above −6/set		1
6-in. 1,500-watt follow spot	1	1
6-ft striplight, 12-lamp unit with a 3-ft pigtail and three-pole male pin connector	2	
6-ft striplight, 12-lamp unit on three circuits with three pigtails at each end		2
12-ft extension light lift, support 12 to 15 lb	9	12
18-ft jumper, 12/3 cable, 20-amp pin connectors	9	12
24-in. three-legged castered stand, 5- to 8-ft extension	3	3
25-ft jumper, 12/3 cable, 20-amp pin connectors	3	3

Table 3-4. Electrical System for a 40- by 60-ft Studio *

(2,400 sq ft of studio area, 144 overhead and 9 wall circuits, 16.6 sq ft per overhead circuits)

Description	*Quantity* Black and white	Color
18-ft connector strip: five 3-ft pigtails, each with 20-amp capacity, terminating in three-pole, female pin connectors	24	
18-ft connector strip: five 3-ft pigtails, four with 20- and one with 50-amp capacity, terminating in three-pole female pin connectors		24
Note: Above type numbers refer to a three-wire, grounded system. To specify a two-wire ungrounded system, change the type number from the 63 to the 62 series.		
Wall receptacle: double 20-amp three-pole pin connector	4	4
Wall receptacle: single 50-amp three-pole pin connector (Nos. 3046 and 3048 for equivalent two-pole units)	1	1
Cyclorama rail: aluminum 1-beam rail with suspension straps and ball-bearing rollers and curtain hooks, ft	148	148

* For information and prices about more advanced lighting control systems, refer to the separate heading entitled Control Systems.

Table 3-4. (*Continued*)

	Quantity	
	Black and white	*Color*
Switchboard: patch panel with 153 load cords (one hundred and thirty-four 20-amp and nineteen 50-amp), 144 control jacks, 12 3-position selector switches each with three 50-amp breaker switches, three sub-master relay switches, 36 pilot lights	1	1
Dimmer bank: six 6-kw transformer interlocking dimmers, one master interlocking handle, six 50-amp primary breaker switches	1	
Dimmer bank: twelve 6-kw transformer interlocking dimmers, one master interlocking handle, twelve 50-amp primary breaker switches		1

Table 3-5. Equipment List for a 40- by 60-ft Studio

(Load power, watts/sq ft. Monochrome: 24, color: 90)

	Quantity	
Description	*Black and white*	*Color*
3-in. 75- to 150-watt fresnelite	4	4
Two-way barn door for No. 523	4	4
6-in. 250- to 750-watt fresnelite	30	8
Four-way barn door for No. 520	16	5
8-in. 1,000- to 1,500-watt fresnelite	8	
Four-way barn door for No. 526	4	
8-in. 1,000- to 2,000-watt fresnelite		30
Four-way barn door for No. 571		16
12-in. 1,000- to 2,000-watt fresnelite	4	9
Four-way barn door for No. 572	2	5
16-in. 5,000-watt fresnelite		4
Four-way barn door for No. 576		4
18-in. 750- to 2,000-watt scoop	30	40
18-in. diffuser frame for No. 1318	30	40
6-in. 250- to 750-watt pattern projector with shutters and gobo slot	3	1
Gobo holder for above	3	1
Gobo slides for above −6/set	3	1
8-in. 1,000- to 2,000-watt pattern projector with shutters and gobo slot	1	3
Gobo holder for above	1	3
Gobo slide for above −6/set	1	3
6-in. 1,500-watt follow spot	1	
12-in. 3,000-watt follow spot	1	2
6-ft striplite, 12-lamp unit on three circuits, with three pigtails at each end		4
6-ft striplite, 12-lamp unit with a 3-ft pigtail and three-pole 20-amp pin connector	4	
12-ft extension light lift, support 12 to 15 lb	15	20
18-ft jumper, 12/3 cable, 20-amp pin connectors	15	20
24-in. three-legged castered stand, 5- to 8-ft extension	6	6
25-ft jumper, 12/3 cable, 20-amp pin connectors	6	6

LIGHTING CONTROL

In TV-studio-lighting practice, the multiplicity of scenes and fluidity of light movement require an ever-increasing number of lighting units and in turn an increasing number of dimmer-control circuits. The producer, director, and viewer are demanding and getting a more artistic lighting result. The planning groups are putting more modern control tools in the hands of the operating personnel. The lighting director and engineers are utilizing these facilities and are asking for more dimmers.

To achieve superior professional and artistic results as well as to get a competitive sales advantage, many studios use electronic control boards in their lighting systems. These boards include multiscene electronic dimming systems with ON-OFF and intensity

memory and scene-to-scene fading. The savings in setup and rehearsal time together with the superior results warrant the consideration and use of these systems.

This emphasizes the importance of the lighting-control center. A simplified system must be provided for normal operations. Yet it must be flexible enough and advanced enough to provide artistic results and handle complicated shows. The lighting-control center has been called "the heart of the art."

This area of the facility requires careful study. Here one can spend $5 per load circuit for a circuit-breaker panel or $125 per load circuit for a multiscene preset electronic, magnetic amplifier or silicon-controlled rectifier control board. Fully automatic punch-card systems are now available at a cost of about 20 per cent over that of a 10-scene preset board in a large system.

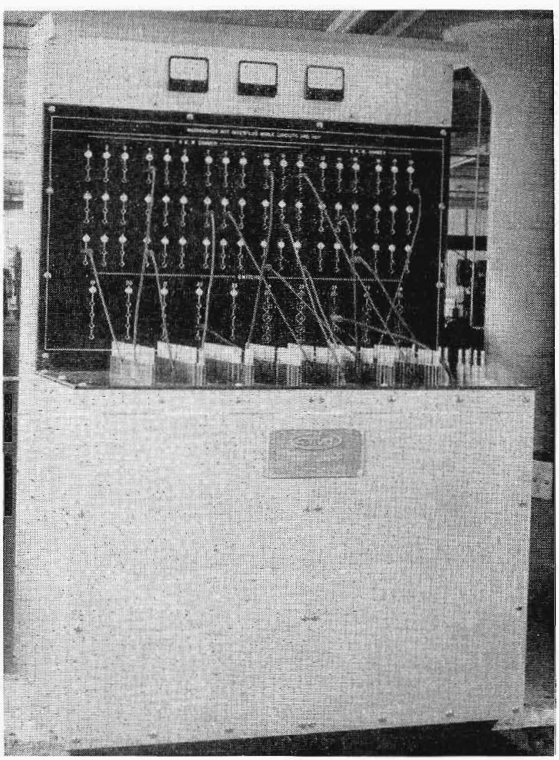

FIG. 3-7. Patch panel with retractable cords.

The lighting-control center should be designed so that maximum control can be exercised. Every light should be controlled singly or together with any other light or group of lights, and each light and each group should be adjustable to varying intensities desired by the lighting director. Lights should be able to be preset as to ON-OFF and intensity. Ultimately they should be able to be preset as to color, direction, and even movement. The industry still has far to go toward expanding yet simplifying the light-control center.

The importance of dimmers should not be underrated. They are essential for balancing light composition. Dimmers are useful in handling subtle time changes during a scene. Dimmers are important to increase or decrease light intensities in certain areas of a set to heighten dramatic intensity. They permit slow "bringing in" of set areas or people. Silhouette effects are artistically handled with dimmers. Many other special and intricate effects are accomplished with dimmers.

Since each lighting unit comes to the lighting-control center as a single circuit, some means of grouping lights by set area and function should be provided. Where circuit-breaker switches alone are used in a small studio, generally no means of grouping is provided. In a larger studio, breakers may be grouped and mastered. The most common system of grouping is the patch panel with retractable cords. In this system, each load circuit is represented by a cord and plug (similar to a telephone switchboard). Then four or six female receptacles are grouped together and controlled by dimmers or nondim contactors. A modified version of this is the wall-mounted nonretractable patch panel (Fig. 3-8). Another popular means of grouping lights is the rotary-switch panel. Here, each load circuit is represented by a rotary switch. The load can then be grouped into any one of 12 or 24 dimmer or nondim circuits.

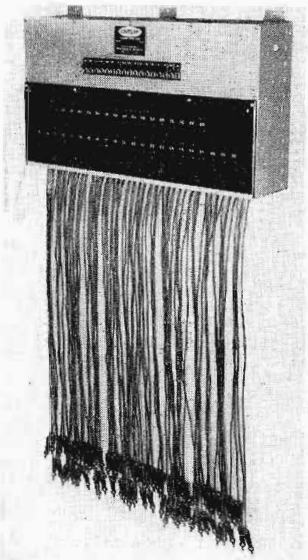

FIG. 3-8. Wall-mounted patch panel.

When circuit-breaker panels are provided, they should be located on the studio floor along a wall which will not be covered by scenery or within camera view. When a patch panel is used, it should be located on the studio floor for speed in setting and grouping lights during rehearsal. It is desirable to have a remotely located contactor panel to control the main control groups, i.e., one for each dimmer and one for each nondim section. One control station for the contactors should be placed at the dimmer board. A second station should be located in the control room. This way, during rehearsal, the patching and dimmer settings can be made by the electrician on the studio floor. During the show, if no changes in setup are required, the switch-

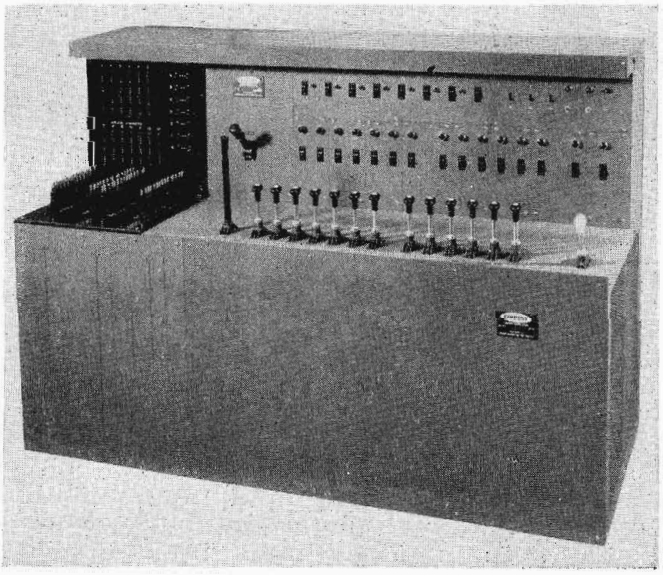

FIG. 3-9. Autotransformer dimmer board.

ing of lighting groups can be accomplished from the control room. The most commonly used dimmers are the 6,000-watt autotransformer (Fig. 3-9), the all-electronic thyratron tube (Fig. 3-10), and the magnetic amplifier (Fig. 3-11*a*). The autotransformer is a durable, efficient unit. It is generally provided with a mechanical-interlock handle. No presetting or memory is included. Contactors can be provided for remote on-off control. Generally one 6,000-watt dimmer is provided for each 6 to 10 lighting-load circuits.

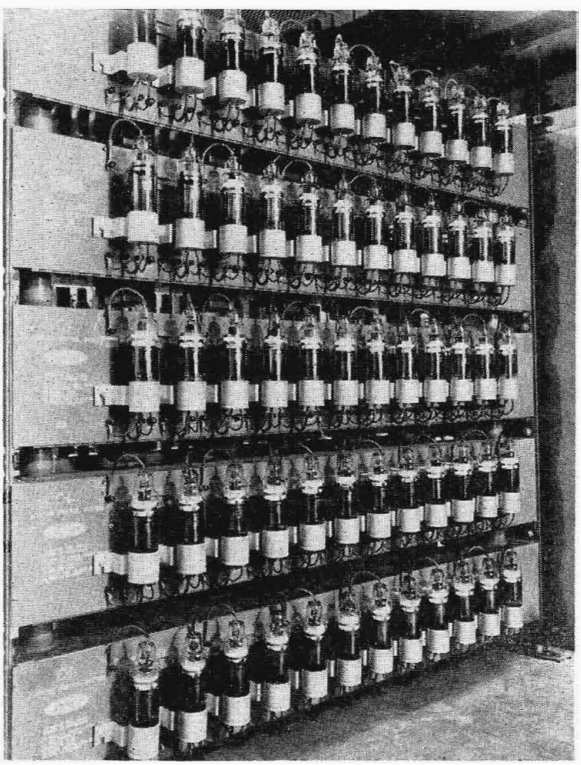

FIG. 3-10. Tube bank of thyratron dimmers.

The thyratron tube sparked the acceptance of the multiscene preset lighting-control board (Fig. 3-12). Ten-scene preset boards are in use in studios of all the major networks. They permit the operator always to be nine "light scenes" ahead of the action on camera. The lights are preset as to ON-OFF and intensity. Complete setup of lights can be instantly switched or slowly and subtly changed by the movement of one handle. Loading ratio of the tube is infinite (within its rated capacity), response is instantaneous, cross fading is linear, and maintenance excellent.

The magnetic amplifier also lends itself to presetting and remote operation. It is available in many capacities and has long life.

The silicon-controlled rectifier dimmer (Fig. 11*b* and *c*) is the newest member of the electronic dimmer group. When utilized as the heart of the dimmer circuit, the dimmer becomes small in size, light in weight, high in efficiency, cool in operation, and moderate in price. It will make obsolete the magnetic amplifier and thyratron-tube dimmer. The silicon-controlled rectifier dimmer is available in capacities of 2,500, 4,000, and 5,000 watts. It will soon be available in 6,000-, 8,000-, and 10,000-

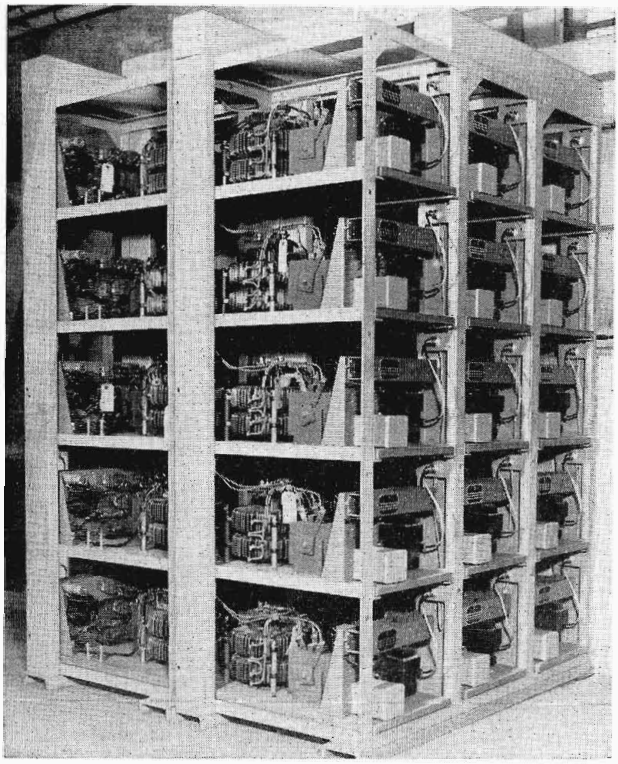

FIG. 3-11*a*. Magnetic amplifier dimmer bank.

watt capacities. As production of the rectifier increases, the price will decrease. It is hoped that the price will one day compete with the autotransformer dimmer.

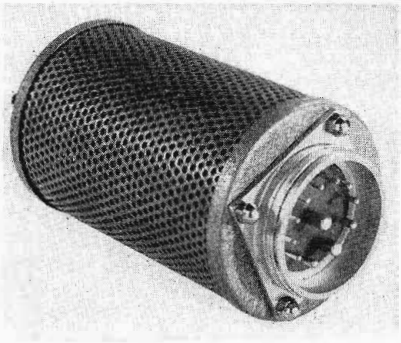

FIG. 3-11*b*. Silicon-controlled rectifier dimmer.

A great step forward in the automation of TV lighting is the Century Lighting development of "Punch" (Fig. 3-11*d*), the first all-automatic infinite preset system for control of light intensities. This system permits the lighting director to adjust the light intensities for each "scene," then automatically record them on a punch card. When the show is completely lighted, the cards are stacked in rotation and the operator fades or switches from one light scene to the next at any desired speed. The cards are fed into the binary memory system automatically.

Provisions are made to "override" the memory, skip cards, duplicate cards, black out, and repeat cue. This system completely eliminates all mechanical operations with the exception of setting up the proper lighting conditions for each scene or preset and the timing of each change or fade. This system allows more time for artistic

perfection by providing more time during rehearsal for the proper setting of light and gives more "stage" time to the actors and director. "Punch" can be used with thyratron-tube dimmers, magnetic amplifiers, or silicon-controlled rectifier dimmers.

When preset memory systems for on-off control are provided, the control console can be placed in the control room, and the memory bank and the circuit breaker and contactor panels can be placed in any adjacent off-studio space. They should be sound-isolated from the studio.

When multiscene preset boards incorporating thyratron tubes, magnetic amplifiers, or silicon-controlled rectifiers are used, the light circuits go back to a patch panel located on the studio floor (or in a large studio on a balcony). The dimmers are located remotely. The control console and preset panel can be located in any convenient location, i.e., control room, etc.

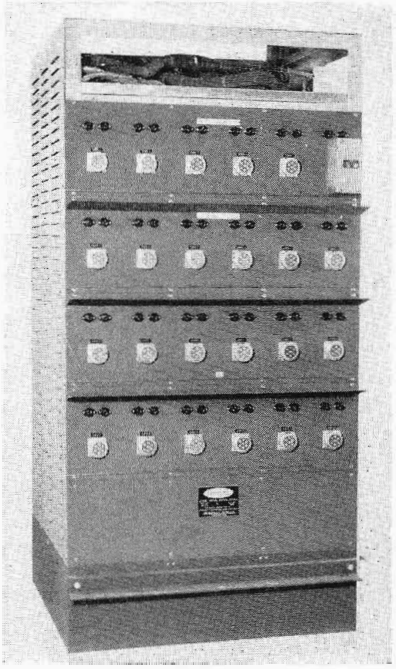

FIG. 3-11*c*. Silicon-controlled rectifier dimmer bank.

BUDGET PRICES FOR LIGHTING-CONTROL SYSTEMS

Note that these prices vary widely because of variations in size of systems, special features, and personal preferences of the designing engineers. They can be used as a guide. When designing for a particular studio, equipment manufacturers should be called in for more exact prices and recommendations.

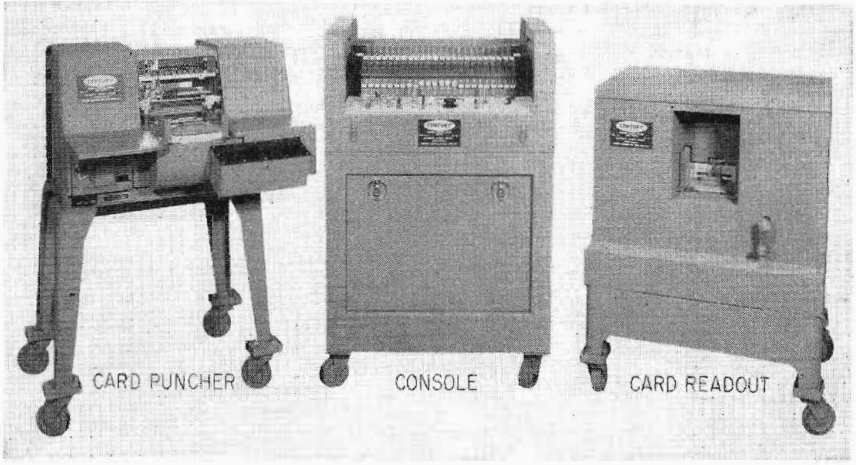

FIG. 3-11*d*. Fully automatic infinite preset system for controlling light intensities.

Circuit-breaker panel	$5–$8 per circuit
Patch panel, no dimmers	$20–$40 per circuit
Rotary-switch panel, no dimmers	$40–$60 per circuit
6,000-watt autotransformer dimmers mounted in a system	$250–$350 per circuit
10-scene preset dimmer board with 6,000-watt thyratron tubes, or 5,000-watt silicon-controlled rectifiers including patch panel	$700–$900 per dimmer crt.
10-scene preset dimmer board with 6,300-watt magnetic amplifier dimmers including patch panel	$750–$950 per dimmer crt.
2-scene preset dimmer board with 5,000-watt thyratron tube, 5,000-watt silicon-controlled rectifiers, or 6,300-watt magnetic amplifier dimmers	$350–$450 per dimmer
5-scene selector ON-OFF memory system	$80–$100 per load circuit

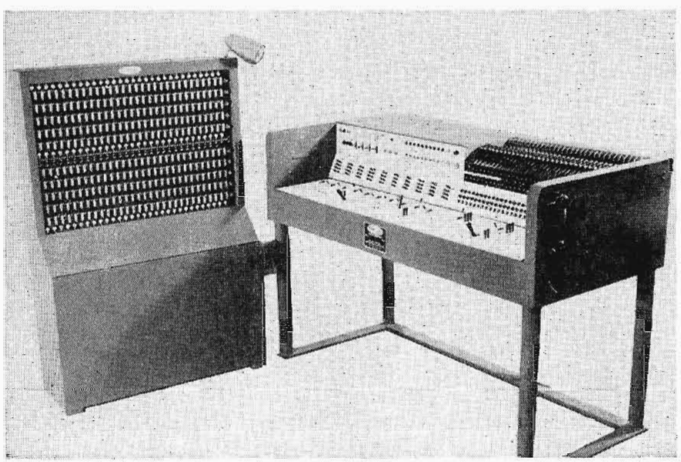

FIG. 3-12. 10-scene C-1 all-electronic control board.

Fully automatic infinite preset systems add 20 per cent to the cost of a large 10-scene preset system.

In some of the existing major studios, the complexity of the lighting is such that the dim and no-dim circuits are all in use and an operator is required to replug the patch panel during the show. To eliminate the need to replug, present reloading facilities have been designed by CBS Television and Century Lighting, Inc., by the use of mercury relays and programming boards.

Dimmers are receiving greater use in color-TV lighting work than in monochrome use. This is partially due to the selection of the top lighting directors (they are generally also the more artistic) to handle the color shows. Another factor is that the added cost of dimmers is small in relation to the over-all cost of the facility. Dimmers are good insurance for a quality picture.

TV LIGHTING PRACTICE

Rudy Bretz in his book "Techniques of Television Production" clearly points out the objectives which should always be kept in mind by lighting and engineering personnel. They call for understanding and cooperation among engineers, scenic designers, lighting directors, directors, and producers.

Directors have been learning about *f* stops, brightness contrasts, key lights, etc., to control the dramatic effect of the picture desired. For instance, if an actor is "shot" with a dark background and then the camera angle is switched to a light background, the actor's face will suddenly go dark as the contrast between his face

and the background changes. It is almost impossible and generally impractical to correct with lights the shift in contrast. The knowledgeable director will try to keep his camera angles such as to get similar background brightness. His familiarity with the possibilities and limitations of lighting facilities will help him to avoid demanding the impossible. One of the finest procedures ever published to give direction to the new lighting director appears in "Television Broadcasting" by Howard A. Chinn of CBS Television Network, published by McGraw-Hill Book Company, Inc. We abstract here "General Lighting Techniques and Procedures" by permission of the author.

GENERAL LIGHTING TECHNIQUES AND PROCEDURES FOR MONOCHROME OPERATION

Lighting Practice 1. The standard lighting procedure should be (*a*) to establish first a uniform over-all base light which will ensure proper camera-operating conditions for technically good-quality pictures and (*b*) then to add carefully balanced effects light to obtain the desired artistic results.

Lighting Practice 2. Base light should be obtained from large-area diffuse sources arranged to produce a uniform illumination level throughout the set and from the viewpoint of all camera angles. The lighting-levels requirements will depend upon the camera tube. For example, with a type 5820 image-orthicon camera tube, a lighting intensity of 75 ± 10 lumens/sq ft, measured in a horizontal plane, is usually satisfactory. The vertical light intensity should be less than (½ to 1 times) the horizontal intensity.

Lighting Practice 3. To provide depth, to separate objects, and to add artistic interest to a picture, several types of effects lights should be added to the base light. Effects light may include key light, back light, modeling light, eye light, and special-effects light. In general these are best supplied from directional sources (usually incandescent) which can be conveniently adjusted in intensity, character, and coverage. Initial adjustments may be made with the aid of a photocell meter but final judgments should be made on a picture monitor.

Lighting Practice 4. Back light should be directed from the lowest possible rear angle with intensity between 1 and 1½ times the base-light level. The light meter should be pointed toward the source of back light for this measurement, and all other sources of light should be turned off. Vertical top light is not back light and is to be avoided.

Lighting Practice 5. Modeling light should be directed from a side-front position and can be adjusted in intensity just to produce shadows. In general the amount of light required will not exceed ½ to 1 times the base-light intensity.

Lighting Practice 6. Key light used to give the effect of a predominant source of light may be from 1 to 2 times the base-light level, with any base light from the same direction as the key light reduced accordingly.

Lighting Practice 7. Eye light can be added to brighten up a performer's eyes and to supplement the base light on close-ups. A small spotlight, mounted on the front of the camera and having an intensity of not more than ½ to 1 times the base light, is useful for this application.

Lighting Practice 8. Special lighting effects, such as spotlights, moonlight, and lights-out sequences, can be obtained by reducing the base light to approximately one-quarter its normal value, and any special-effects lights then adjusted to bring the total illumination level up to 1 or 1½ times the normal base-light intensity (light meter aimed at camera positions).

Lighting Practice 9. Effects light directed to backgrounds to create window and similar shadows should not exceed 1½ times the normal base light incident upon the background in question.

Lighting Practice 10. Self-luminous objects or areas such as exposed lamp bulbs, lanterns, and near lighted windows should not produce a light-meter reading in excess of ¾ to 1 times the normal base-light reading when the meter is held a few inches from the light source and directed toward it.

Lighting Practice 11. In monochrome transmission, incandescent light sources can be dimmed to one-quarter normal light intensity without impairing spectral response because of change in color temperature.

Lighting Practice 12. Lighting plans should be prepared in detail for all repetitive productions to ensure reproducibility of established lighting conditions.

By carefnlly following these procedures, it is almost impossible to get a bad picture.

The following adjustments should be made for lighting for color broadcasting: Base light plus key light should be increased from 100 to 300 to 400 ft-c. It is also essential that the entire background which is presented to the camera be evenly lighted. This is more critical in color work than in monochrome broadcast. Key and modeling light must be used from much flatter angles to minimize shadows under eyes, nose, and chin.

Pantographs are useful to eliminate mike boom shadow, to correct the angle of a motivating source, etc. In actual practice, generally about 50 per cent of the scoops and 40 per cent of the key lights are provided with pantographs. Pole slide carriers are generally used in studios equipped with a catwalk.

LIGHTING ROUTINE ON THE SHOW

Generally the show is in a studio where the lighting director has worked previously. Most of the equipment is more or less hanging in the right places owing to the physical limitations in most plants. The sets have to be in the same general locations such as along the studio walls, and it follows that the cameras, actors, and lights will also be in approximately the same areas as in the last show.

SYMBOL	COLOR PLAN
	NO. 526 8" 1000–1500 W FRESNEL
	NO. 572 12" 1000–2000 W FRESNEL
	NO. 576 16" 5000 W FRESNEL
	NO. 1315 16" 750–2500 W SCOOP
	NO. 1568 8" 1000–2000 W LEKO
	BLACK & WHITE PLAN
	NO. 520 6" 250–750 W FRESNEL
	NO. 526 8" 1000–1500 W FRESNEL
	NO. 572 12" 1000–2000 W FRESNEL
	NO. 1315 750–2500 W SCOOP
	NO. 1581 TV 4½" 250–750 W LEKO

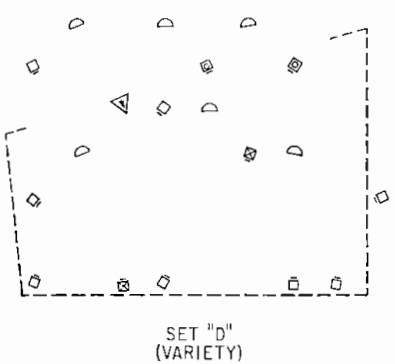

FIG. 3-13*a*. Layout of 1,000 sq ft area TV studio.

The lighting director meets with the scenic designer, director, and producer for a script review. Notes are made as to mood, time of day, special effects, etc. Camera angles and mike boom locations are plotted. Working from the floor plan, the lighting director then will lay out his lighting plan, keeping in mind what equipment is already hung. A few lights may not be accurately located until the sets are up aud the mike booms brought in. Now the lighting director goes into the studio with 95 per cent of his lights plotted and most of them where he wants them.

Lights are now added or shifted by the electricians. After the sets are in place, the last few lights are decided upon and placed. Generally, the first lights set are used by the actors as work lights. While the actors continue their rehearsals, additional sets are being erected.

The lighting director starts lighting with "key light." This will be set at a level high enough for the camera to operate with a high signal-to-noise ratio. This is a departure from the old accepted practice of starting with base light and adding key, etc. (Note this change from Chinu's procedures.) By starting with key light, the lighting director can get a more artistic picture at lower foot-candle levels. Fill light is then added. Then pattern projectors,

eye lights, and specials are added as required. Lights are all focused accurately, barn doors adjusted, and minor corrections carried out. While this is happening, the lighting director checks the light levels with a meter and the over-all result in the monitor. The monitor check is the one that really counts.

The electrician generally has the responsibility for grouping the lights at the patch panel and dimmer board. He also provides his own cue sheet, generally in his own fashion. On an extremely complicated show, the lighting director may lay out the patching and dimming control. For a color show, he will lay out the colors and select the cinemoids before setting up, so the electrician can be sure to have sufficient quantities on hand.

In lighting a simple "milk-run" show, the lighting director might not even prepare a light plot but simply direct the hanging and focusing of lights as the sets go up (Fig. 3-13).

CENTURY LIGHTING, INC. T. V. PLANNING AID

Set *A*, panel or small dramatic
B, dramatic
C, small variety, dramatic
D, variety
E, kitchen
F, news, interview, commercial
G, weather, commercial

Studio Set Plans
Equipment List

Type	Description	Quantity													
		Black and White							Color						
		A	*B*	*C*	*D*	*E*	*F*	*G*	*A*	*B*	*C*	*D*	*E*	*F*	*G*
520	6-in. 250- to 750-watt fresnelite	4	4	3	8	3	2								
2570	Two-way barn door for No. 520	1			2										
2580	Four-way barn door for No. 520	1	2	1	2	1	1	1							
526	8-in. 1,000- to 1,500-watt fresnelite	3	4	4	2	3	1	2							
2571	Two-way barn door for No. 526	1				1									
2581	Four-way barn door for No. 526	2	2	2	1	1	1	1							
571	8-in. 1,000- to 2,000-watt fresnelite								4	4	3	8	3	3	2
2567	Two-way barn door for No. 571								1			2			
2585	Four-way barn door for No. 571								1	2	1	2	1	1	1
572	12-in. 1,000- to 2,000-watt fresnelite		2	2	2				3	4	4	2	3	1	2
2573	Two-way barn door for No. 572								1				1		
2583	Four-way barn door for No. 572		2	2	2				2	2	2	1	1	1	1
576	16-in. 5,000-watt fresnelite									2	2	2			
2559	Two-way barn door for No. 576														
2586	Four-way barn door for No. 576									2	2	2			
1318	18-in. 750- to 2,000-watt scoop	4	4	5	6	3	3	2	6	6	8	9	4	4	3
3236	18-in. diffuser frame for No. 1318	4	4	5	6	3	3	2	6	6	8	9	4	4	3
1542	12-in. 3-kw follow spot			1	1						2	2			
1591TV	6-in. 250- to 750-watt pattern projector		1	1	1		1								
1557TV	8-in. 1,000- to 2,000-watt pattern projector									1	1	1		1	
3286	12-ft extension light-lift pantograph	2	2	3	3	2	2	1	3	3	4	5	2	2	2
18RCC	18-ft jumper cable for No. 3286	2	2	3	3	2	2	1	3	3	4	5	2	2	2
3216	24-in. castered, 5- to 8-ft extension stand	1	1	1	2	1	1	1	1	1	2	2	1	1	1
25RCC	25-ft extension cable	1	1	1	2	1	1	1	1	1	2	2	1	1	1

NOTES: 1. Type numbers are given for a two-wire ungrounded system. To specify a three-wire grounded system add G to the type number.

2. Portable floor stands are used on all sets and are listed above but are not shown in the diagrams. Additional fixtures for use with these stands are included in above list but are also not shown in diagram.

FIG. 3-13*b*. Equipment list for typical set areas.

There is no universal plan for setting lights in the studio so that they can be used for all situations without being moved. There is not enough ceiling space for that, and probably no one could afford it. However, in most studios, the majority of the lights will remain where set from one show to the next. For instance, most of the back lights will remain where they are, though some may have to be added where wings are set. This generally follows with the base lights, key lights, etc.

After a show is over, the light plot, plugging plot, and cue sheets are generally discarded, since the conditions for that show (script, director, scenic designer, lighting director, and studio) will almost never repeat themselves. For repeat shows, this information is recorded and kept.

Generally, very little consideration is given to the lighting for kinescope recording. Since live shows demand a high standard of lighting, the producer cannot afford the compromise of the flat light most desirable for kinescope recording. The range of video tape is well within the range of the camera tube. Therefore no special adjustments have to be made for VTR.

Some additional proceedures and practices are:

1. The practical brightness contrast range for operational use is considered to be 30 or 40 to 1 even though "the book" says 20 to 1; *f* stops between *f*-8 and *f*-16 are generally used. This gives good depth of focus. As the *f* stop is decreased, depth of focus decreases and the background loses sharpness. As the *f* stop is decreased, lower light levels should be used. Put differently, where only low levels of light are available, reduce the *f* stop, being careful to remember that depth of focus will also be reduced.

2. When more light is required on an actor's face, it is simpler to reduce the intensity of the background. This will improve the contrast between the actor and the background and create the same effect as more light.

3. Whenever foot-candle levels are given, they are for incident light, i.e., with the light meter turned toward the camera tube.

4. Lighting adjustments should normally be checked with the video-control operator. Often carefully created lighting effects are nullified by a video shader who is unaware of what a production crew is attempting to create. Coordination between production and video personnel saves considerable time and often results in otherwise unobtainable effects.

5. Barn doors should be used on all back and side lights to prevent glare into the camera lens. Lens hoods are essential for complete camera mobility without the danger of lens flare.

6. Pattern projectors are often used to make unnoticed a difficult mike boom or subject shadow.

7. Endeavor to keep the subjects as far away from the background as space permits. This reduces shadows on backgrounds and aids the back lights to provide desired depth to the picture.

8. Specific personnel should be responsible for lighting and lighting-facilities maintenance. A light meter should always be available.

9. Time should be allowed for the proper lighting of a show.

10. A safe inexpensive picture can always be obtained by simply directing 100 ft-c of flat light on the set. However, this is a dull picture, which will tend to lose audience interest.

Where the type 7038 vidicon tube is used, 100 ft-c must be provided for card lighting. Where movement takes place, 200 to 300 ft-c are necessary to help overcome "lag."

It is important to spend as much time training personnel as possible. Every dollar spent for lighting training will come back manyfold. A definite lighting training program should be started before moving into any new studio. A continuing educational program should be planned and kept in operation always. As new lighting instruments and techniques become known, all operation and artistic personnel should be made aware of these developments. Good lighting techniques should become SOP for all.

LIGHTING INSTRUMENTS

The range of available TV lighting instruments is large and varied. Each unit has its usefulness and is another tool in the hands of the skilled lighting director. The tools should be understood and used properly. It is recommended that new personnel be given the opportunity to examine, light, check, and study each type of unit in the studio.

A description of each type of fixture follows.

The Scoop (Figs. 3-14*a* and *b*)

This wide-angle floodlight is one of the two most used lighting instruments in TV. The other is the fresnel. It is used for base and fill light. The scoop provides a great deal of soft diffuse light in a wide beam from a lightweight compact instrument (Fig. 3-14*a*). The finish is matte-finish Alzak. Accessories include glass cloth diffusers, clamps, cinemoid color media, and light lifts.

Scoop sizes and wattages are:

Inches	*Watts*
10	250–400
14	300–500
16	750–1,000–1,500–2,000–2,500
18	750–1,000–1,500–2,000–2,500

FIG. 3-14*a*. 18-in. 750- to 2,500-watt scoop.

The 2,500-watt lamp tends to overheat the unit and is not recommended except for short periods of time.

For monochrome broadcasting, the 1,000-watt lamp is most often used. In studios with very high pipes sometimes 1,500-watt lamps are installed. In color telecasting, the 1,500- and 2,000-watt lamps are used.

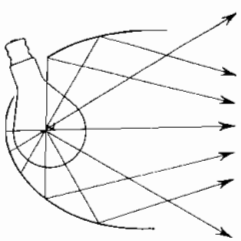

FIG. 3-14*b*. Optics of the scoop.

The Fresnel (Figs. 3-15*a*, *b*, and *c*)

The second most used unit in TV is the fresnel spotlight. Gradually this versatile unit is becoming the most important single lighting instrument. The fresnel provides a variable focus or beam spread. The field is smooth, even, and soft edged. The fresnel on flood focus is the most efficient of all the spotlights (Fig. 3-15*b*). It is available in a large variety of sizes and wattages as listed below. Accessories include barn doors, diffusing screens, cookies, color media, and light lifts.

A variety of lenses are available for wide-angle or narrow-beam distribution. Rectangular beam spreads are available.

Units are manufactured with rear access for relamping without disturbing barn-door setting.

Some units are equipped with "pole-op" provisions so that the fresnels can be "spotted-down" or "flooded" from the floor. "Sticky-joint" units are available which can be tilted and panned from the floor.

The units being offered for sale today by the major manufacturers have been specifically designed for TV use. The lenses have black ceramic risers to reduce

spill light. They have been designed to give specific distributions and to work effectively with barn boors.

Century Lighting has designed a system for remote-control operation (Fig. 3-15*c*). This system includes remote control raise-lower, pan, tilt, spot-flood, and mechanical bright-dim. The system is expensive, and it is difficult to justify the cost of installation. However, in areas of high rent, high labor cost, and intensive studio use, this system can justify its cost.

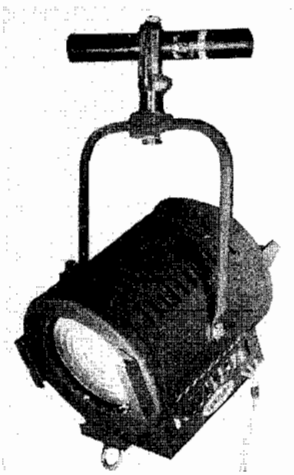

FIG. 3-15*a*. 12-in. 1,000- to 2,000-watt fresnel with "pole-op," rear access, "sticky-joint."

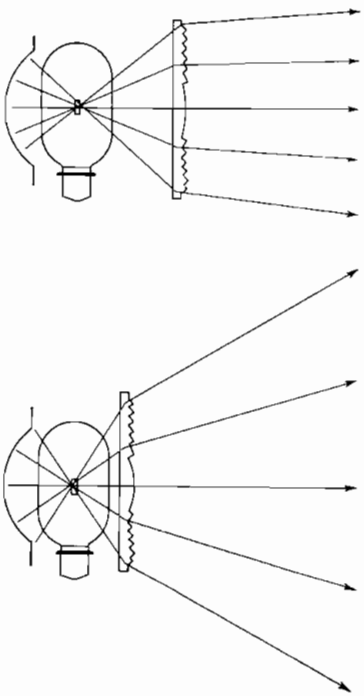

FIG. 3-15*b*. Optics of the fresnel spot.

In black-and-white broadcasts, the 6-in. 500-watt unit is generally used for back light, with the 6-in. 750-watt and 8-in. 1,000-watt units doing the key lighting.

When telecasting in color, the back lights are generally the 8-in. 1,000- to 2,000-watt units with 1,000-watt lamps. For key lighting, the 8- and 12-in. 1,000- to 2,000-watt units are necessary with some 16-in. 5,000-watt units used for high key.

Lens, in.	*Wattage*	*Beam spreads, deg*
3	75–100–125–150	15–40
6	250–500–750	15–60
8	1,000–1,500	15–45
8	1,000–2,000	15–60
10	1,000–2,000	15–60
12	1,000–2,000	15–70
14	3,000–5,000	15–45
16	3,000–5,000	15–70
20	10,000	15–60

The 6-, 8-, 12-, and 14-in. units are also available with lenses which give a rectangular soft-edge distribution.

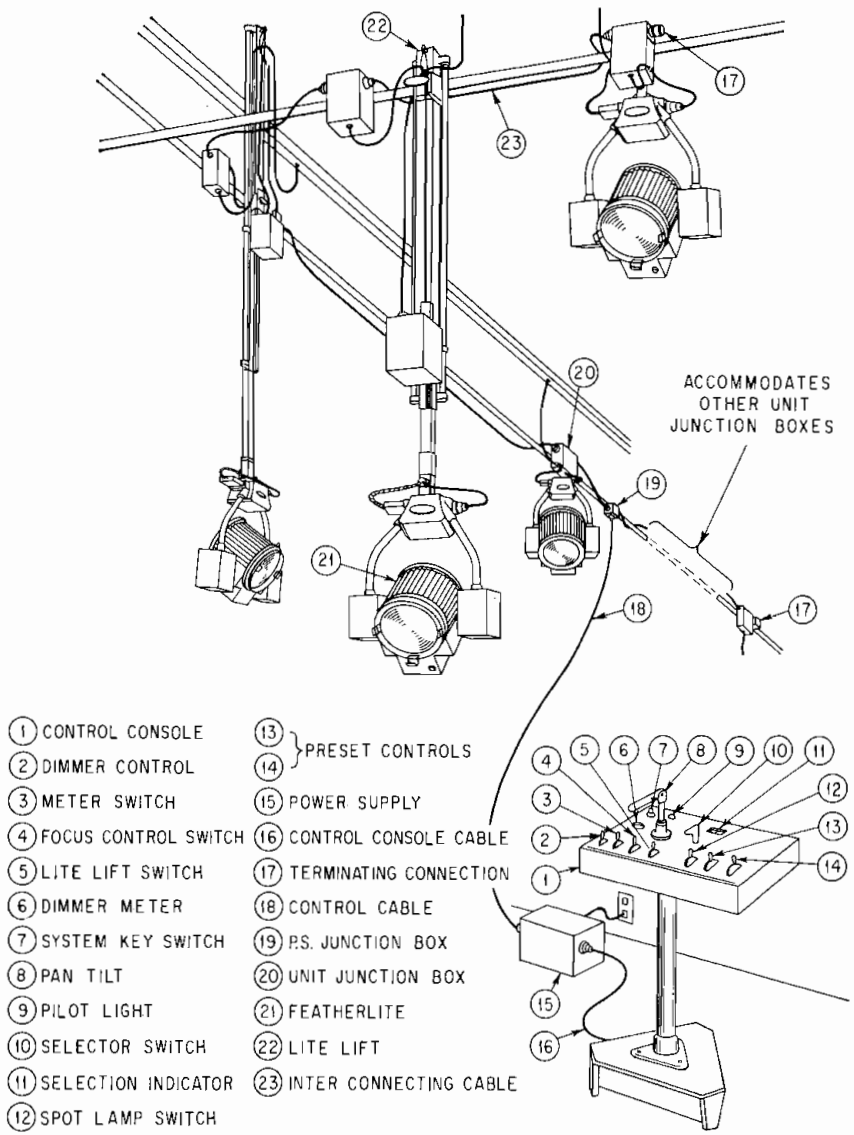

Fig. 3-15*c*. Remote-control fresnel.

Pattern Projectors (Lekos) (Figs. 3-16*a*, *b*, and *c*)

This ellipsoidal reflector spotlight (Fig. 3-16*a*) has built-in framing shutters for giving rectilinear shapes to a round beam. A built-in gobo slot permits the use of

FIG. 3-16*a*. 6-in. 750-watt pattern projector Leko.

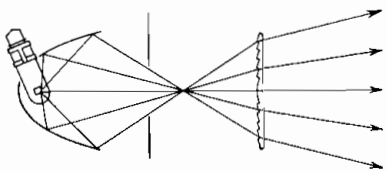

FIG. 3-16*b*. Optics for the pattern projector.

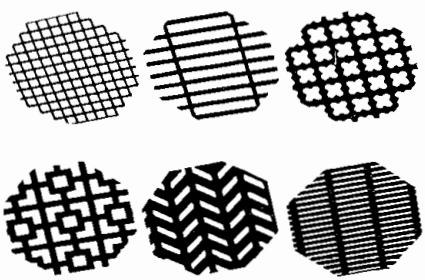

FIG. 3-16*c*. Gobos for insertion in pattern projectors.

a wide variety of pattern effects (Fig. 3-16*c*) to be projected onto a background. The efficiency is as high as 40 per cent. The beam edge can be hard or soft depending on whether the lens is in or out of focus.

Pattern projectors are also used as slash lights and for projecting circles, squares or rectangles on floors or walls.

The 6-in. 750-watt units are most used for monochrome work. The 1,000- to 2,000- and even 3,000-watt units are necessary for color work.

Lens, in.	*Wattage*	*Beam spread, deg*
4½	250–500	50
6	250–500–750	40
8	250–500–750	30
6	1,000–1,500–2,000	60
8	1,000–1,500–2,000	40
6	3,000	60

Reflector Lamp Banks

This unit consists of a square or rectangular sheet-metal or cast pan equipped with 4 to 12 medium screw sockets, yoke, clamp, and lead. The sockets take 150- to 300-watt reflector (R) or 150-watt projector (PAR) lamps. These lamps have a long (2,000-hr) life and are available in spot or floor distribution. Their low cost and long life made them useful in early television. As the art of TV lighting advanced, a higher degree of control of distribution became necessary, and the reflector lamp bank is disappearing in favor of scoops and fresnels. The inability to barn-door

the bank, the inability to change the spread of the unit, and the bulk of the unit all contributed to its demise.

Short life, high-output 375-watt photoflood lamps are sometimes used for a very short scene where little or no space is available. They are sometimes used on remotes. A word of caution is appropriate to their use. When the filament fails, it sometimes strikes the glass lamp jacket and causes it to shatter. Therefore, if photoflood lamps are used, a protective screen should be used in front of them. Some studios discard them after they have burned for 4 hr of their rated 6-hr life.

The Follow Spot (Fig. 3-17)

For variety shows, the follow spot still retains a certain dramatic quality that is irreplaceable. Arc lights have been used until very recently. Their disadvantage has been color and flicker. Recently 3,000- and 5,000-watt (Fig. 3-17) narrow-beam

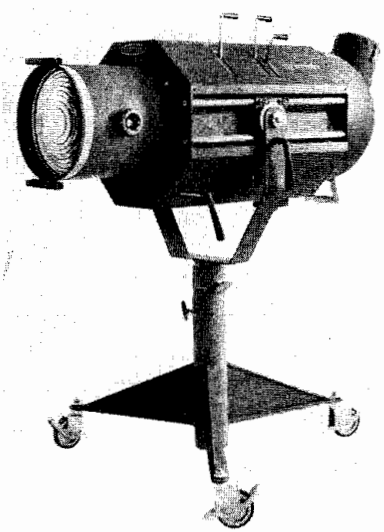

FIG. 3-17. 5,000-watt follow spot.

high-intensity follow spots were placed on the market. These are replacing the arc for network variety shows. The units have built-in iris, shutters, blowers, stands, and "chorus line" spread lenses. For black-and-white shows the 5-in. 1,500-watt unit is popular. Sizes and wattages are:

Inches	*Wattage*
8	750
5	1,500
6	1,000
8	1,000–1,500–2,000
12	3,000
12	5,000

The Strip Light (Fig. 3-18)

The strip light is a wireway with reflectors and sockets mounted in a sheet-metal housing. Generally the reflectors alternate between specular and matte finish, matte

for the near throw and specular for the far projection. They are used to light eyes, backings, windows, etc.

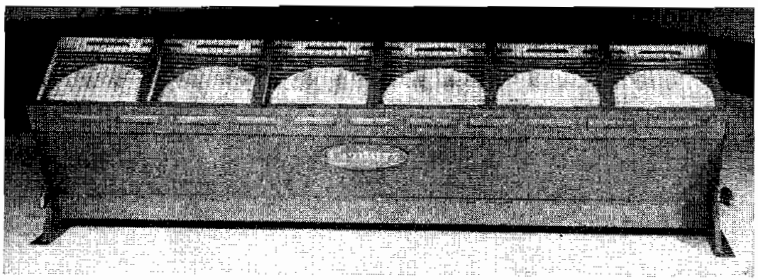

FIG. 3-18. Strip light with specular-finish reflectors.

The Punch Scoop

This unit has the same general characteristics as the scoop, except that it has a narrower beam of higher intensity. The beam spread can be varied slightly. In theatre studios, the punch scoop is used on the balcony front. The new larger unit is finding many specialized uses in color-television work. Punch-scoop sizes and wattages are 14-in., 750- to 1,000-watt size and 30-in., 3,000- to 5,000-watt size hot spot. The beam spread is 40° in spot focus and 100° in flood focus.

The Rear Screen Projector

This is an effective instrument for projecting scenic effects on a background. Placed behind a translucent screen, it throws the image of a slide on the screen. Care must be taken to keep the foreground lighting at as low a level as possible. Light falling on the screen should be kept to a practical minimum.

Rear screen projectors are available in wattages of 2,000, 2,100, 3,000, and 5,000. The one most frequently used is the 2,100-watt 60-volt unit. Many are equipped with magazine loading for 70 slides or drum loading for 5 slides. The RP's deliver between 4,000 and 6,000 screen lumens. Some studios have used carbon-arc RP's. These units, because of the point light source and high amperage, deliver sharp resolution and a high quantity of light to the scene. The color should be filtered for color-television use. The size, noise, and operation problems limit the popularity of the arc. For motion-picture clips, the arc is very popular.

The maximum effective spread for RP's is 8 ft in a 10-ft throw. Century Lighting has developed a 5,000-watt unit that gives a 15-ft spread in a 10-ft throw but has some distortion in the corners.

The Fluorescent Bank

The fluorescent bank, so popular in the earlier days of television, is gradually disappearing from the studio. The older camera tubes required 600 to 1,000 ft-c, and the highly efficient fluorescent lamps easily achieved these high levels. As the tubes became more sensitive and the art of lighting improved, the fluorescent bank became obsolete.

Other factors leading to obsolescence of the fluorescent bank were its bulk and consequent difficulty of moving or adjusting the unit, the noise factor of the ballasts, the inability to control its intensity or spread at the unit, and the inability to dim without complicated circuitry.

The Lighting "Igloo" or "Tent"

To light highly specular objects such as a watch, silverware, or a car, the ideal method is to surround the object with soft diffuse light and punch through with one single high-wattage spot. The "igloo" or "tent" consists of screen, gauze, or muslin surrounding the object. The tent is then lighted from all sides with scoops, etc., till it literally glows. One hole is cut into the tent for the camera, and one for the high-wattage spot. The resultant quality of light is excellent.

EQUIPMENT

Color-value Wall

A recent development in lighting is the color-value wall. This consists of a series of fluorescent and incandescent lamps spaced behind a translucent plastic diffusing screen. The lamps are on four-color circuits and are controlled by dimmers. By means of the additive method of color mixing, any color background can be obtained. Also any tone or tint of white light can be mixed. The color-value wall takes advantage of the phenomenon of "simultaneous contrast," and if the background color is changed, the foreground can be made to shift. Many other uses of this unit will be discovered as it gains wider usage.

The screen is available in sizes up to 45 by 85 ft. Lamp spacing can be as close as 16 in. per lamp per color in a 14-in. depth.

Lamp Replacement

The practice generally is to make a quick visual check of the lamps before use. Lamps which are dark and which look as if they have been burning for a long time should be replaced and discarded. For insurance, some lighting directors double-hang all important key lights, particularly in dramatic shows.

A method of extending lamp life is to bring the lights up on the dimmer rather than the full switch-on procedure. "Dimming-on" eliminates the initial surge of current which causes the filament to fail at its weakest spot. Most often a lamp failure occurs when the lamp is switched on rather than when it is burning.

To increase the amount of light available in existing studios without providing completely new facilities, some studios have devised a specialized practice. They operate 110-volt lamps on 120-volt service. This increases the light 30 per cent, decreases the lamp life 70 per cent, and increases the current consumption 15 per cent. This will give a studio a 30 per cent increase in light levels and may be the method used to go to color from black and white without greatly increasing studio lighting facilities.

LIGHTING-CONTROL-SYSTEM TERMINOLOGY

BOARD: The general term applied to a control board or switchboard. The various types are discussed in a later section of this chapter.

CONSOLE: A compact control face resembling an organ console in terms of size and arrangement of parts, generally placed so that the operator can see the studio.

DIMMER: A means of reducing the current or voltage in a circuit and thereby the intensity of light given off by the lamp in an instrument. It can be had in five general types: the resistance dimmer, the autotransformer, the magnetic amplifier, electronic tube, and the silicon-controlled rectifier. This is the most essential element in a switchboard. The dimmer is connected in series with the lamp, generally on the neutral side so that the current must trace through the lamp first, although with a cross-connecting or interplugging type of board it can be connected on the hot side and equipped with a disconnect, or low-end, limit switch.

EXTENDED OR FOREIGN CONTROL: A single-throw push-button switch on the end of a long lead which can close or open the grand master contractor pilot from a remote point.

FADER: A means of blending a lighting effect from one set of dimmer readings to another, manually or by automatic timer.

INDEPENDENT: Any circuit which is routed directly from the feed past the master or submaster so as to leave a circuit hot even when the master is thrown. This sometimes refers also to an undimmed circuit pocket or a constant potential circuit.

INTERCONNECTING: The ability to connect any load circuit to any line or control circuit by means of an interplugging or cross-connecting apparatus permits the grouping of widely separated instruments on adjacent, easily handled controls. The ordinary portable board is essentially of the interconnecting type. In permanent installations, a cross-connecting panel is installed. Generally the dimmers feed vertical bus bars and the load circuits are connected to horizontal bars which run across the face of the dimmer bars, forming a cross grid separated by proper insulating space. The connection can be made at any juncture by means of a plug. This is a cross-metering panel. The simplest form is the telephone-switchboard type using a jumper between the various line and load pockets.

INTERLOCKING: The individual dimmer handles can be twisted to drop a plunger into a slotted cam mounted rigidly on a shaft, which is connected solidly to the master interlocking handles.

MASTER CONTROL: The means for grouping a number of individual controls under a master switch or dimmer. Most boards have submaster control for each section with master control over each submaster. Most master switches are of the double-throw type which permits independent operation on the upthrow and grand-master operation on the downthrow.

PRESET: Any switch or dimmer arrangement which permits predetermining the lighting effect for a following scene or scenes, previous to its use, even while the circuit is in operation during a scene.

By the use of a contactor switch for each individual control unit, the routing of the current to the pilot can be controlled through any one of five or ten master preset switches. The same number of small toggle switches under each control unit can be thrown to determine in which of the scenes the circuit will be used. This is valuable only for presentation houses, where intensity balance is not important.

Preset dimming, however, enables the operator to anticipate a number of group actions. A fading mechanism generally blending from one hot feed to another, preset 1 to 2, can change the light effect proportionally from one setup to another. Some circuits go up; others go down; some remain constant with one movement. This requires a double- or multiple-dimmer control for each circuit. It is primarily practical only with remotely controlled dimmers where there are a number of intensity controllers associated with each individual circuit. This system is particularly useful in handling the complications of sunset effects.

Eventually, it is desirable for all switchboards where a smooth flow of lighting effect is created by more instruments than the operator can handle effectively with his two hands.

SETUP: A definite interconnecting arrangement between load circuits and feed pockets. Sometimes this is extended to include the switch arrangements and dimmer readings for a scene.

PRESET PILE ON: The ability to add one preset on top of the other; i.e., while the operator is in preset 4, he can add or "pile on" preset 6 (or any other preset or presets) on top of preset 4. The higher dimmer reading always takes over.

PRESET RELOADING: Consists of a system using mercury relays and programming cards located between the male plugs and female receptacles in the patch panel. This permits intensive loading of dimmers without replugging the patch panel.

CROSS-CONNECT MULTIPLIERS: These are devices to permit the operator to plug two load cords into one female receptacle in the patch panel. Similar to a "two-fer."

LANGUAGE OF LIGHTING

HIGH-KEY LIGHTING: A type of lighting which, applied to a scene, results in a picture having gradations falling primarily between gray and white; dark grays and blacks are present but in very limited areas.

LOW-KEY LIGHTING: A type of lighting which, applied to a scene, results in a picture having gradations from middle gray to black with comparatively limited areas of light grays and whites.

KEY LIGHT: The apparent principal source of directional illumination falling upon a subject or area.

BASE LIGHT: Uniform, diffuse illumination, approaching a shadowless condition, sufficient for a television picture of technical acceptability and which can be supplemented by other lighting.

FILL LIGHT: Supplementary illumination to reduce shadow or contrast range.

CROSS LIGHT: Equal illumination in front of the subject from two directions at substantially equal and opposite angles with the optical axis of the camera and a horizontal plane.

BACK LIGHT: Illumination from behind the subject in a direction substantially parallel to a vertical plane through the optical axis of the camera.

SIDE BACK LIGHT: Illumination from behind the subject in a direction not parallel to a vertical plane through the optical axis of the camera.

EYE LIGHT: Illumination on a person to produce a specular reflection from the eyes (and teeth) without adding a significant increase in light to the subject.

SET LIGHT: Separate illumination of background or set other than that provided for principal subjects or areas which may be composed of items 3 to 8 above.

(Copies are available from the SMPTE.)

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Part 4

MAGNETIC RECORDING ON DISC AND TAPE

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The material presented in this part is essentially a review of magnetic recording practices and the reasons for some of them. It is gathered from the many available sources and compiled into a general guide for the operating, maintenance, and installation engineer. While it may not answer specific questions, perhaps it will give an over-all picture that will help the engineer determine the answer he requires.

THEORY OF MAGNETIC RECORDING

The basic theory of magnetic recording is relatively simple. A magnetic material is moved through the field of a magnet, and the varying currents in the magnet are recorded on the material as varying degrees of magnetization. The magnetic material may be in the form of wire, tape, oxide-coated tape, oxide-coated discs, cylinders, etc. This discussion will be confined to oxide-coated discs and tape.

The magnet is usually called a "head" and consists of magnetically "soft" iron structures, known as "pole pieces," wound with coils of wire through which flows the signal current. This current generates the magnetomotive force which is conveyed to the magnetically "hard" recording medium by the pole pieces.

To reproduce the signal, the material is moved over the poles of a similar head and the magnetic impulses in the material generate a varying voltage in the coil which is then raised to the required level by a suitable amplifier.

The material which is magnetized consists of a nonmagnetic base which supplies the strength and an iron oxide coating which furnishes the magnetic properties. For tape recording, the base may be of paper, acetate, or polyester (mylar). For disc recording, the iron oxide particles are held to an aluminum plate by a binder material.

Bias

For the same reason that a vacuum tube must be biased for proper operation, the recording head of a tape recorder must also be biased for operation without excessive distortion. If the tape is biased with a steady d-c magnetic field, the audio magnetization will vary about this fixed point rather than zero. This is similar to a d-c bias voltage on a tube. Although this method corrects the distortion problem, the tape (where no signal is recorded) is left in a magnetized condition. Unfortunately, a magnetized tape is noisier than an unmagnetized one. In fact, the signal-to-noise ratio is degraded at least 10 db. Therefore, d-c bias has become obsolete, except in some battery-operated portable tape recorders.

To overcome this problem, it has become standard practice to use an a-c bias with the frequency sufficiently high to avoid being recorded on the tape. This leaves the tape in an unmagnetized condition when no audio modulation is being applied and correspondingly quieter. This bias frequency is usually selected to be five times the upper frequency limit of the recorder to prevent any beat between it and the harmonics of the audio signal. This is usually called supersonic bias and is in the 60- to 100-kc range. The current through the recording coil is always many times as great as that of the signal being recorded. Using the correct value of bias current is very important, for this affects the frequency response, distortion, and signal-to-noise characteristics of the recording.

A bias value that is too low may result in high distortion and a low signal-to-noise ratio, while too high a value causes a loss of high-frequency response (due to partial erasure). This adjustment can be readily made on a professional machine which has separate recording and playback heads and amplifiers. The best adjustment is made by recording a low-level tone in the range of 400 to 1,000 cycles and gradually increasing the bias current to the point of maximum reproduced signal. Further increase in bias will reduce the reproduced signal. The best adjustment is somewhere between the maximum signal and the point of 1-db reduction on the higher bias side of the curve. Machines which do not have simultaneous playback while recording can be adjusted in a similar manner by repeated recording and playback tests.

Erase

When the usefulness of the recording is over, it is general practice to erase the signal so that the tape or disc can be reused. Both d-c and a-c methods are possible, but the a-c method is almost always used. In a-c erasing, the tape or disc is subjected to an a-c magnetic field of decreasing intensity, caused either by an erase head preceding the recording head or by a large magnet powered from an a-c power line. The latter is used for the bulk erasure of a tape in one operation.

With either method of a-c erasure, it is essential that the first cycle or two be sufficient to saturate the magnetic material for complete erasure. Thereafter, the amplitude of the erasing field should decrease in intensity until the magnetic medium is at zero magnetization. When passing the tape or disc over the erase head while recording, it is necessary that the erase voltage variation (and resulting magnetic field) be reasonably symmetrical, or the tape will be left with some residual magnetization and the noise level increased. Many recorders have a noise-balance adjustment which either balances the output of the push-pull oscillator or neutralizes the effects of unbalance or leakage currents.

Usually a common high-frequency oscillator supplies the current for both erase and bias functions. Since the bias current is considerably less than the erase current, a portion of the erase current is coupled to the recording head. Some professional machines have metering provisions to adjust the proper erase and bias current. It is essential that the erase current be properly adjusted before adjusting bias, since later erase-current adjustments will affect the bias. Bias adjustments have no effect on the erase circuit.

Further details on magnetic recording theory can be obtained from some tape-

recorder instruction manuals and from reference books, such as "Elements of Magnetic Tape Recording" by N. M. Haynes.

COMPONENTS OF MAGNETIC RECORDER/REPRODUCERS

Transport Mechanism

The purpose of this unit is to move the magnetic material across the erase, record, and reproduce heads. In a reel-to-reel mechanism this involves winding the tape from one reel to the other, with provision for running at accelerated speeds in either direction to provide fast-forward and rewinding. When the tape is moved in the recording or playback modes, the speed must be very stable to prevent flutter and wow. The starting time should be very short to allow close cueing, and the tape speed should be very constant to allow close timing of the program material and the correct pitch. During all functions, the tape must be handled gently to prevent stretching or breaking.

Reel-to-reel Type

The best known design of a reel-to-reel mechanism, which accomplishes the above requirements, has three motors. A typical reel-to-reel machine is shown in Fig. 4-1.

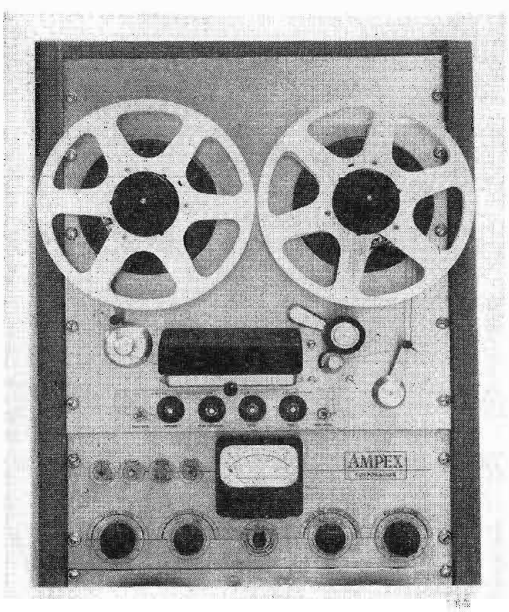

FIG. 4-1. Reel-to-reel tape transport. (*Courtesy of Ampex Corporation.*)

Two of the motors are used for supply and take-up reel control, which serves to keep constant tension on the tape during recording or playback. A third motor, usually of the hysteresis-synchronous type, is used to control the tape speed through the heads. Usually the tape passes between the motor shaft and a rubber pinch roller. To achieve fast starts, the motor should be running before the tape is started so the motor does not start under load. To start, a solenoid-actuated pinch roller moves the tape against the motor shaft, resulting in a very fast starting time and almost immediate stability.

For the fast-forward and rewind functions, power is removed from the pinch roller solenoid, allowing the tape speed to be controlled by the torque motors. Power can be varied between the two motors, by either a rheostat or switched resistors. The tape moves in the direction (and at a rate of speed) determined by the relative power division.

Cartridge Type

Another type of mechanism coming into general use in the broadcast field employs a continuous loop of tape.[1] A typical example is shown in Fig. 4-2. It is usable

FIG. 4-2. Cartridge type of tape transport. (*Courtesy of Collins Radio Company.*)

where a rewinding function is not required. The tape is contained in a special cartridge which allows the tape to be drawn from the center of the loop. This action causes the entire loop to turn and wind the used tape on the outer part of the loop. Since this does not require any provisions for take-up or rewind, the transport mechanism consists simply of the capstan motor and pinch roller.

One such machine on the market, which is known to have broadcast quality, has cartridges available that will play from 40 sec to 45 min. There are three basic sizes of cartridges containing from 25 to 1,700 ft of special lubricated tape. The tape speed is 7½ ips. The cueing is controlled by a tone burst which is recorded at the beginning of the recorded information. After the recorded information is played through, the machine is allowed to run through the remaining tape until the tone burst is played again. This tone stops the tape travel and leaves the cartridge cued up for the next time it is used.

Multiple-track Tape

A third type of mechanism recently introduced consists of a tape of about 13-in. width on which over 100 tracks can be recorded. This results in a mechanical transport similar to a piano roll player. This machine is shown in Fig. 4-3. The erase, record, and playback heads are manually moved across the width of the tape to select the proper track. The mechanism winds the length of tape from one roll to the other. The tape speed is approximately 5¼ ips, with a 90-sec recording requiring about 45 ft of tape. The particular model now on the market uses small windows (where the oxide is removed from the tape) together with small lamps and photoelectric cells to determine the beginning and end of the tape for automatic rewind

[1] Extensively used in Europe for musical-type station ID's.

and cueing functions. All tracks are cued up side by side, ready for instant selection. Other methods, such as automatic recording of control tones or silent sensing amplifiers, could also control the functions.

FIG. 4-3. Multiple-track tape transport. (*Courtesy of Gates Radio Company.*)

Magnetic-disc Type

The magnetic-disc recorder (as illustrated in Fig. 4-4) is quite a different machine but functions in a conventional manner. There is presently only one model on the market generally known to be suitable for broadcast use. The transport mechanism is identical with a standard phonograph turntable or changer unit. This uses a pregrooved disc, coated with standard oxide, the same physical size and shape as a 45-rpm disc. However, to get the necessary 70 sec recording time, the turntable revolves

FIG. 4-4. Magnetic-disc mechanism. (*Courtesy of RCA.*)

at 33⅓ rpm. The record-reproduce head is mounted in a conventional pickup arm and is very similar to a conventional tape-recording head.

When the disc is intended for use on an automatic changer, the cueing and changer trip functions are controlled by using a high-frequency control tone, which is recorded immediately before and after the audio signal. The unit described nses a 10-kc tone applied to the recording signal after the 10-kc audio components have been removed. They are generally removed by filtering earlier in the amplifier, by means of a bridged-T notch filter, to prevent false operation by the audio signal.

This same bridged-T circuit is used during playback to prevent the control tone from being fed to the program output connection. A separate amplifier, which is frequency selective, is nsed to amplify only the control tone and operate a plate circuit relay. When the disc is being cued, the changer stops quickly (upon detection of the 10-kc tone) at the beginning of the disc. When the tone is detected again, it operates the changer trip mechanism.

Erase and Record-reproduce Heads

Much of the performance of a magnetic recorder depends on the performance of the heads. Usually the erase head is the least critical, requiring only that it make good contact with the tape and that it pass the symmetrical waveshape of the erase voltage. It is almost always mounted separately from the record and reproduce heads and preceding them in the tape path. Some machines use one head for both recording and reproducing. Although this method is more economical, it does not allow direct "off-the-tape monitoring" while recording. Also, separate heads allow the gap spacing of each head to be optimum for the purpose.

The recording head is not so critical in this respect, but the reproducing head is very critical because the gap width controls the high-frequency response. The azimuth alignment of the heads is also critical. They should be aligned with a standard test tape to allow interchangeability of tapes on machines. Also, it is very important that the heads make good contact with the tape, or a considerable loss of high frequencies will be noticed. Therefore, a regular cleaning schedule should be conducted.

The gap in the reproduce head should be as small as possible so that it will intercept less than one wavelength of the signal on the tape (at the highest frequency to be reproduced). Of course, there is a practical limit to narrowing the gap, for both mechanical and signal-to-noise ratio reasons. The narrower the gap, the smaller the induced-voltage level. Therefore, a practical compromise must be reached.

At present the gap spacing of the heads can be reduced sufficiently that (with proper azimuth adjustment head contact and bias current) it is possible to secure response essentially flat to 15 kc at a tape speed of only 3¾ ips.

Amplifiers

The recording amplifier is used to raise the output of a microphone to the level necessary to drive the recording head. Since head gap width, tape velocity, and many other factors determine the frequency response, noise, and distortion of the record-reproduce process, it is advisable to include as much preemphasis as possible in the recording amplifier. The standard recording curves shown in Fig. 4-5 were derived from the tape-distortion characteristics. The tape, when recorded with these curves, will give approximately the same distortion at all frequencies involved in the playback process.

The recording amplifier usually contains the bias and erase oscillator, which drives the recording and erase heads. It is general practice to provide sufficient amplification in professional machines to record directly from a low-impedance microphone and bridge a balanced 600-ohm line with +8 VU of program level. Figure 4-6 is a block diagram of a professional recording amplifier.

The playback amplifier raises the signal (generated in the playback head) to a level suitable for feeding the console or other speech input equipment. This level

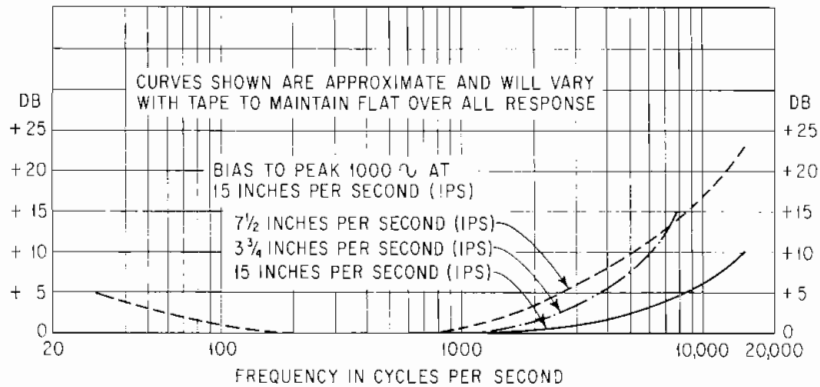

FIG. 4-5. Standard recording curve. (*Courtesy of Ampex Corporation.*)

ranges from −20 dbm to +8 VU. This amplifier also contains a deemphasis circuit to adjust for flat over-all frequency response. Figure 4-7 shows the standard playback curves. They are derived from the nonlinearities of the record-reproduce process as described above. In addition, there is a characteristic rise of approximately 6 db/octave in the playback process (until head losses and gap width overcome it at the high-frequency end) which accounts for the linear section in the playback curve. The total correction required to obtain a flat frequency response from the entire process can be determined by combining the recording and playback curves for the desired speed.

Other requirements in a good playback amplifier include a type of input tube which has an exceptionally low inherent noise level, a good grounding system, and filament bias and balance, or direct current on the filaments. Distortion is seldom a problem in a playback amplifier if normal precautions are taken.

In testing a playback amplifier, it is advisable to adjust the input level to obtain a constant output level for all frequencies. This prevents excessive overloading, which will never occur except on the test bench with a constant input. Figure 4-8 is the block diagram of a typical playback amplifier.

All tape recorder-reproducers have precision components that require periodic maintenance and adjustment. Brake-tension adjustments should be checked with

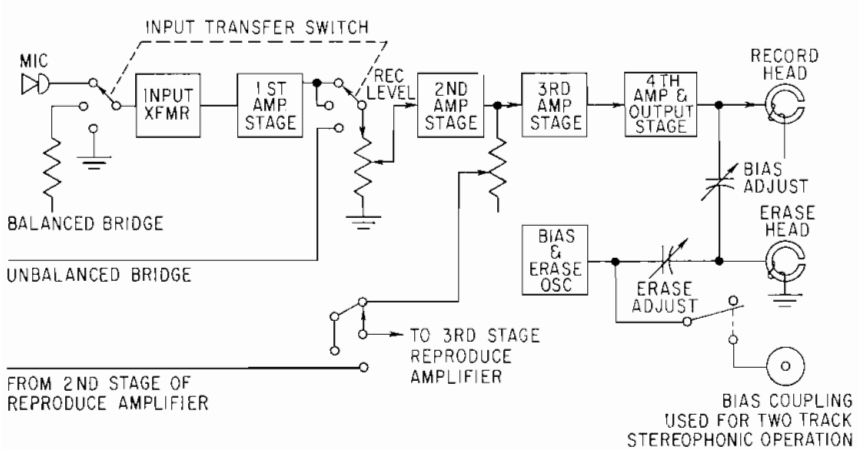

FIG. 4-6. Block diagram of recording amplifier. (*Courtesy of Ampex Corporation.*)

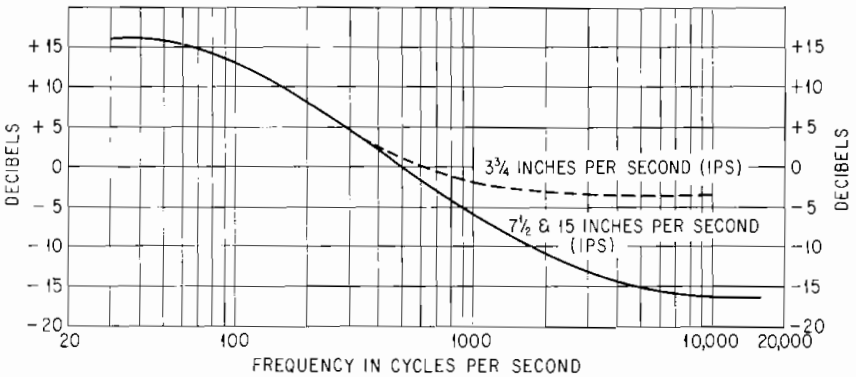

FIG. 4-7. Standard playback curve. (*Courtesy of Ampex Corporation.*)

the methods and equipment prescribed in the instruction manuals to maintain optimum performance. No attempt should be made to improve or change the basic design of a tape machine without approval from the manufacturer.

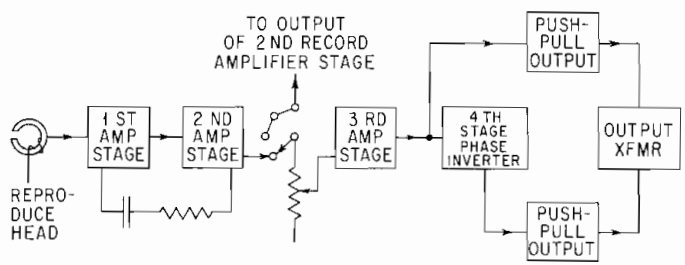

FIG. 4-8. Block diagram of playback amplifier. (*Courtesy of Ampex Corporation.*)

RECORDING-MEDIUM CHARACTERISTICS

Types of Tape

Two general types of recording tape are generally available. These are the acetate base and the polyester, or "mylar," base. The acetate base is a general-purpose tape for most recording purposes. However, the polyester base has many advantages for the broadcaster due to its more rugged nature.

Acetate-base tape uses 0.0015-in.-thick cellulose acetate. The breaking strength of this tape is on the order of 4 to 5½ lb for standard ¼-in. width. Normal recorder-tape tension is but a few ounces, so there is a reasonable safety factor to care for peaks of tension during machine starts and stops and for wide variations in strength caused by changing humidity and temperature. The coating on the base consists of a carefully controlled mixture of magnetic material and a binder of tough flexible combinations of synthetic resins. Since tape may be stored tightly wound on reels for long periods, there must be no tendency for one layer of tape to stick to the next. Also, the tape must remain flexible so it will conform to the heads and not impair high-frequency response. The coefficient of friction between the binder and metal heads or guides must be low so the tape will move smoothly without flutter or squeal. This antifriction quality is part of the formula and should not rub off on the heads or guides to excess, as this will foul the head gap or build up a deposit,

resulting in excessive wear. Regular cleaning is a must, to prevent even slight build-up of deposits.

Polyester-, or "mylar-", base tapes have the same characteristics in the oxide but are more stable (in the backing material) to temperature and humidity changes and somewhat stronger and more shock resistant. This tape is virtually free of dimensional changes (and distortion induced by these environmental changes) but does have a disadvantage in that a high shock or excessive abuse causes the tape to stretch permanently, causing a "wow."

This stronger base allows thinner tapes to be made, providing longer continuous programming. By using a base only 0.5 mil thick on a standard 10½ in. NAB reel and operating the machine at 3¾ ips, it is possible to record or play over 4 hr of programming without a single break. This is particularly useful for delayed programming of a sports event or opera. As this tape is very limp, excellent contact is achieved with the heads. This limpness causes the reel to wind unevenly occasionally, and it is helpful to obtain a special reel which has a narrow spacing between the flanges, on the order of 0.28 in. instead of the standard 0.345-in. spacing. It is possible to grind down existing flanges to make these special reels.

Print-through

If a tape is recorded and stored for a period of time, there is a phenomenon that sometime occurs called print-through. It occurs because a strongly magnetized tape is wound next to an unmagnetized portion and some of the magnetic effect transfers from one layer to another. Since the transfer is through a layer of acetate or polyester, the effect is quite small but often objectionable for high-quality broadcast work.

It has been found that the effect becomes serious as the recording level increases. Print-through will decrease about 2 db for a 1-db decrease in recording level. The effect increases with time of storage, higher temperatures, or exposure to stray magnetic fields. Most of the effect is in the mid-frequency range, with high- and low-frequency sounds virtually unnoticeable. Use of the thinner base tapes will slightly increase the effect.

If a tape is to be stored for some time, the following precautions will help in eliminating print-through. Program peaks should be held to a level not exceeding 0 VU on the recording meter. The storage temperature should be kept below 75°, and the reel placed in a steel can to protect against stray magnetic fields. To protect valuable recordings, it would be well to use a special tape (which is available) that has about 8-db lower print-through effect than standard tapes. Occasional playing or rewinding of the tape will redistribute the adjacent layers, thereby reducing the effect. Most machines wind the tape more tightly when rewinding than when playing. Therefore, it would be wise to store tapes before rewinding to take advantage of the slightly increased spacing between adjacent layers.

APPLICATIONS

The most common broadcast application is that of recording network or local programs for delayed broadcast. More recently, stations have started to prerecord commercials for audition to clients and on-the-air accuracy. Other interesting effects can be had by prerecording sound effects on a continuous basis, and (by means of the continuous-loop mechanism) the effect is available for any desired period of time. Reverberation, or "echo," effects are available on any machine which has separate record and playback functions and allows a delay proportional to the head spacing and tape speed of the machine.

A very flexible reverberation machine can be constructed using a continuous loop of tape, a variable-speed motor-drive capstan, and a number of heads. The loop of tape need be only 2 to 5 sec long. An erase head should be first in line followed by a recording head. Thereafter, a number of playback heads can be positioned on slides so they can be moved to various locations along the tape path to secure various degrees of time delay.

Precautions should be taken to be sure the azimuth alignment of the heads is not disturbed when they are moved. The outputs of each head can be connected to a playback amplifier where the required equalization and filters can be added to change the frequency response of each delayed portion of the audio. Outputs of the playback amplifiers are then combined and fed to the program output. If desired, a portion of this signal can be reinserted with the input to the original recording head for additional reverberation.

In operation, the faster the tape speed (and the closer the playback heads are to the recording head), the shorter the reverberation time. Many effects can be obtained by varying the gain controls on each playback amplifier.

Another use of the tape machine is to control automatic station equipment. With the use of a stereo tape recorder, one track is recorded with program announcements and the other track recorded simultaneously with control tones, which are used to perform automatic functions. When the playback is made, frequency-selective relays may cause the program audio to switch from the controlling machine to an automatic record changer or other tape playback machines at the conclusion of an announcement. Another tone will allow the tape machine to cue to the beginning of the next announcement and wait for a manual or automatic "command" to start playback again. Various tones can be used to trigger the start of several record changers or other similar automatic tape playback units.

Some automatic programming machines use subsonic and/or high-frequency control tones on the same track with program material. This may limit the flexibility of the system because not many of the tones can be used on a single track and retain good program quality. The useful frequency response of the tape falls within the audible range, and the tones used are generally at the lower and upper fringes of this band. Frequencies of 20 and 10,000 cycles are common in such systems. Their removal from the program material causes very little deterioration in program quality.

The multiple-track tape machine is ideally suited for short announcements such as station breaks, time announcements, sound effects, etc. It is also suitable for spot announcements and themes of much longer duration. Inserting subsonic or supersonic tones at the end of the announcement will allow automatic rewinding immediately or control of other programming devices.

The continuous-loop transport mechanism can be made to cue itself (for repeating a recorded announcement) automatically. When the recording is started, a tone is recorded momentarily on the second track. The machine is so connected that it will run until a playback head on this control track detects the tone, which immediately stops the machine (automatically cued to the original starting point). If the machine is manually stopped at the conclusion of the first recording, additional announcements can be made on the same loop, provided sufficient tape is on the loop. When in the playback function, the machine will sequentially recue to the start of the next announcement. An additional automatic function can be had by recording a different frequency of tone burst at the beginning of each announcement. By the use of frequency-selective relays, individual announcements can be automatically selected. A disadvantage to this type of unit is the absence of a fast-forward or rewind function. The complete tape length must be run at standard speed if it is desired to audition any particular announcement.

Similar but less flexible automatic control functions can be had with a metal-foil backing material applied to the reverse side of the tape. A pair of contacts ride on the tape and shut off the motor when the circuit is completed through the foil and motor-control relay.

A voice-operated relay can be used to control the cueing of the tapes. In this case, the machines run a predetermined time after the last audio signal. A disadvantage in this system is the wide tolerance in both the timing circuit and the make-up of the recorded tape. A better system uses a playback head a few inches ahead of the regular program playback head. This special head is connected to a voice-operated relay to "anticipate" the audio and stops the machine when cued a predetermined number of inches ahead of the next announcement.

CIRCUIT CONNECTIONS

Most professional tape recorders have microphone and bridging inputs. If used correctly, these cause very little trouble. However, on some machines, the bridging input is unbalanced (one side grounded). This invariably causes problems in the broadcast station. A balanced input can bridge or match either a balanced or unbalanced source (if there is no center-tapped ground on the input) with no difficulty. Thus, it would be best to modify machines that have unbalanced inputs and make them balanced.

Adding a Transformer

An interstage transformer would accomplish the job, it seems. However, it is difficult to find one that has good shielding and frequency response. Also, it is hard to find one that will tolerate the impedance mismatch that generally occurs without frequency discrimination.

A high-quality input transformer is quite easy to obtain. This can be connected as shown in Fig. 4-9. This circuit will give 31-db loss in the bridging pad (when

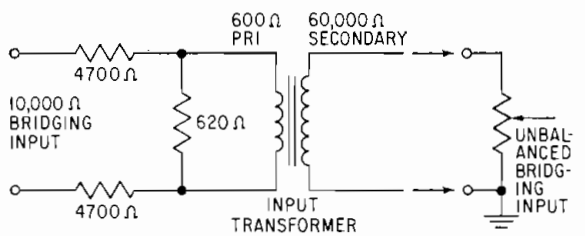

FIG. 4-9. Adding a bridging transformer.

bridging a 600-ohm terminated line), but the transformer will give 20-db voltage gain; thus, the net loss is only 11 db. This loss will seldom be a problem, since most bridging is performed on high-level lines.

Adding a Bridging Pad

Another method of installing a balanced bridge would be to connect a bridging pad to the microphone-input transformer. The microphone input is balanced on nearly all professional tape machines. For best results, a matching pad should fol-

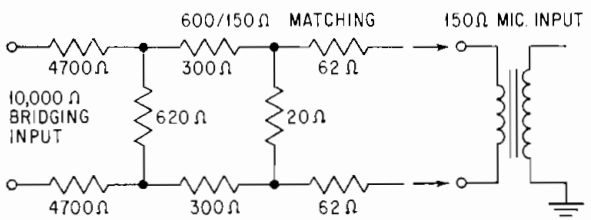

FIG. 4-10. Adding a bridging pad.

low the bridging pad. This splits the loss required and prevents frequency discrimination, which may occur in a single pad. Figure 4-10 shows a typical circuit. The 10,000/600-ohm bridging pad has 31-db loss, the 600/150-ohm matching pad has 30-db loss, which gives a total loss of 61 db. When bridging a 600-ohm terminated line with +8 VU level, the microphone input receives −53 dbm. This will give a good signal-to-noise ratio, yet prevent overloading of the input stages.

Converting High-impedance Recorder-Reproducers

Most professional high-impedance machines have a cathode-follower output which can be loaded with 10,000 to 20,000 ohms. Use a good-quality output transformer, with the 10,000- to 20,000-ohm primary connected to the output of the playback amplifier. The 150- to 600-ohm secondary will match into most speech input consoles.

The high-impedance input of these machines is generally in the 60,000- to 100,000-ohm range. Use a good-quality input transformer, with the 60,000- to 100,000-ohm secondary connected into the high-impedance microphone input of the recording amplifier. Connect the low-impedance microphone into the proper impedance on the primary winding of the input transformer.

RECORDING FROM SINGLE-CHANNEL CONSOLES

If the recording material is being fed through the program amplifier of the console, of course, this is no problem. The recorder may simply bridge it (as is the case, of either program amplifier, in a dual-channel console). Where it is desired to record material different from that being broadcast, it is best to connect the audition bus of the console into the microphone input of the recorder. The bus impedance of most commercial consoles is from 75 to 200 ohms and in the area of −45 to −55 dbm in level. Choose the microphone impedance closest to the bus impedance (as stated in the console instruction manual, or measure the audition bus with an ohmmeter). This method generally works very satisfactorily. If the level is higher than necessary, a series resistance, bridging pad, or bridging transformer can be used to decrease it.

If it is desired to switch the audition bus output into several tape recorders, some consoles have utility keys that can be used for this function. Of course, auxiliary keys can be installed in any convenient location that does not introduce noise into the console or the recorder.

Feeding the Console

Most professional tape-recorder playback amplifiers have an output level from −20 dbm to +8 VU. Generally, they are fed into an input channel on the console which does not contain a preamplifier. A level of −20 dbm is suitable for most consoles, because this is the approximate level out of the microphone preamplifiers. This allows the channel attenuators to set at the same position for both types of inputs.

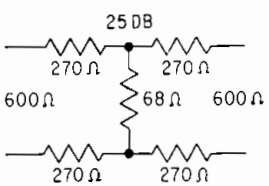

FIG. 4-11. 25-db 600/600-ohm "H" pad.

If the output level is +8 VU, it should be reduced to about −20 dbm level. This will prevent the necessity of using the channel attenuator in the section which is normally tapered to cutoff. The same condition is true for output levels of +4 VU. Since these levels are quite common, a 25-db "H" pad is shown in Fig. 4-11 that can be used to compensate these levels with optimum console input levels. It will give −21-dbm level from a +4 VU source and −17-dbm level from a +8 VU source. If the tape recorder is fed into a cueing amplifier, it is best to test the operation with these pads inserted on a trial basis before actually making a permanent installation. It may be necessary to modify the amount of loss to fit a specific application.

MAINTENANCE

Lubrication. At the end of 3 months or after 1,000 hr of operation, lubricate the capstan drive motor and capstan idler with a few drops of SAE 20 or manufacturer's

recommended lubricant. Most mechanisms require no further lubricant because the bearings are sealed.

Cleaning. The capstan, capstan idler wheel, head faces, and tape guides should be cleaned often (sometimes daily, with heavy use) with ethyl alcohol applied with a soft cloth or other recommended cleaning solution.

Demagnetize All Heads. At least once a month and after every maintenance operation, the heads should be demagnetized. This is required because the accumulated switching transients in daily operation and surges (due to removing tubes, etc.) will gradually magnetize the heads. Magnetized heads will partially erase the tape or disc when they are played and will increase the noise level. This should always be done before using standard test tapes to assure against partial erasure and incorrect readings.

Take-up and Holdback Tensions. These should be checked with a small scale while the machine is running in the normal forward mode. NAB hub size reels should produce 6 to 8 oz of tension; the smaller size should produce 3 to 4 oz.

Brake Tensions. These are adjusted with no power applied to the machine. With the scale pulling the reel in the direction of forward tape travel, the tension should be from 12 to 16 oz; in the opposite direction, it should be from 6 to 9 oz.

Capstan Idler Pressure. The pressure of this idler on the capstan shaft should be sufficient to cause positive drive to the tape, but not so great as to cause the motor to overload and drop out of sync. This is a great deal of latitude. One manufacturer recommends approximately 80 oz of pressure.

Playback Level Adjust. The gain control in the playback channel of the amplifier can be adjusted to give a predetermined level on the output of the playback amplifier from the standard level on the standard alignment tape. This is usually a low frequency to prevent variations resulting from equalization adjustments. Depending on the alignment tape used, the standard level will be full level or 10 dbm below normal level.

Erase Current. See paragraph under Theory of Magnetic Recording.

Bias Current. See paragraph under Theory of Magnetic Recording.

Signal-to-noise Measurements. Properly terminate the output of the playback amplifier, and connect a high impedance noise meter or sensitive VTVM across it. Using the standard playback level from the alignment tape as reference, measure noise below this reference with the tape stopped. If there is a filament balance or other noise balance (except that connected with the bias oscillator), adjust this for the lowest reading.

Replace the alignment tape with new or well-erased tape. Record a section with no signal input. Place a 0.02-μf capacitor across the noise meter input to remove the bias frequency. With a simultaneous record-playback machine, adjust the bias balance control for lowest noise (generally a popping or cracking noise). With a machine with a combination head, record and adjust, playback and observe until optimum results are obtained.

Azimuth Alignment of the Heads. Use a standard alignment tape to align the playback heads for maximum output at the specified alignment frequency to permit interchangeability of tapes and machines. Replace the alignment tape with a new or well-erased tape, and record the highest frequency specified for the speed you are using. On simultaneous record-playback machines, align the recording head for highest output from the playback amplifier. On combination-head machines, record and adjust, playback and observe until optimum results are obtained.

Playback Response. Terminate the output of the playback amplifier, and play back the response portion of the standard alignment tape. Connect the input of the noise meter or sensitive VTVM to the output of the amplifier. The level on the alignment tape is 10 to 20 db below the normal level. Adjust the playback equalizers for the optimum frequency response as specified in the instruction manual.

Record Response. After adjusting the playback response, use a blank tape and audio oscillator to record the frequency range expected. Record the level 10 to 20 db below normal level to prevent any possibility of overloading the tape. With a con-

stant recording input level, adjust the recording equalizing controls to obtain a flat frequency response from the playback amplifier.

Tension Scales. These are somewhat difficult to locate in some areas. They can be purchased from John Chatillon & Sons, 90 Cliff Street, New York City. The following scales are available: 0 to 8, 0 to 16, 0 to 64 (4 lb) and 0 to 80 oz (5 lb) The 0- to 16- and 0- to 80-oz scales are a suggested minimum.

Part 5

VIDEO-TAPE RECORDING

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BASIC PRINCIPLES

The Magnetic Medium

Magnetic recording tape, whether for audio, video, or other recording purposes, contains finely divided ferrous oxide particles deposited on a plastic backing. In the case of magnetic video recording with commercially available rotating-head equipment, the oxide coating must be extraordinarily resistant to abrasion at high temperatures and pressures, must be of a superficial smoothness much greater than that required for direct audio recordings, and must be substantially free from defects which would cause a momentary loss of continuity in magnetic characteristics or of contact with the magnetic heads. For video recording, the plastic backing must be capable of a minute amount of stretching, since stretching of the material is relied upon in the recording and reproducing process to assure equality of recorded track length, in a direction transverse to that of the tape motion, with rotating heads whose effective diameter will change slightly with wear.

The Recording Process

During the recording process, the magnetic medium is moved through the magnetic field which is created at the gap in the recording head, and the resulting flux pattern on the tape is a function of instantaneous magnitude and direction of the original signal *at the moment the tape leaves the head gap.* In so far as the response of the magnetic heads and of the magnetic tape can be made linear, *flux density on the tape is directly proportional to recording current.*

Reproduction

If the recorded tape is then moved past the gap of a reproduce head, which may be similar to or identical with the recording head, the magnetic flux from the tape will induce a voltage in the windings of the reproducing head. Assuming a constant rate of change of flux density in the moving tape, this voltage is proportional to the number of turns of wire in the head coil, the permeability of the core material, and

the efficiency of the magnetic structure at the reproducing frequency. Reproduction is an electrodynamic process, so induced voltage is proportional to the *rate of change* of magnetic flux in the head core. Thus, other effects being ignored, induced voltage will vary directly with relative head-to-tape velocity, directly with reproduced frequency, directly with flux density, and inversely with the wavelength of the recorded signal on the tape.

In typical commercial magnetic reproducing heads, the voltage induced, if the head-to-tape velocity remains constant, will be directly proportional to frequency up to a frequency whose wavelength, as it appears on the tape, *approaches* the effective width of the gap of the head. Above this the head efficiency declines, so voltage will decline, at first gradually, then more precipitously, until it reaches zero at that frequency whose wavelength on the tape equals the effective head-gap dimension.

The Limits of Magnetic Tape Recording

Disregarding the response of the associated amplifiers, the problems of maintaining constant tape velocity and adequate head-to-tape contact and of electrical losses in the head, there are certain inherent properties in the process which define the frequency limits which can be recorded and reproduced and the signal-to-noise ratio which can be obtained.

High-frequency Response

Useful high-frequency response is ultimately limited by the dimension of the head gap or by the resonant frequency of the head or both.

During recording, the tape coating assumes a permanent state of magnetization at the instant it leaves the head gap, so the gap width of the recording head is relatively uncritical. However, in reproducing, the magnetic flux emanating from the moving tape must induce a voltage differential across the reproducing head coil if the current is to flow in that coil. This voltage is induced only as the flux traverses the entire head core, forced into that path by the higher reluctance of the gap. The flux is proportional to the sum of positive and negative fields existing within the head gap at any given instant. Thus, when the recorded frequency is so high that its wavelength is equal to the gap width, the sum of positive and negative flux patterns in the gap at that instant is zero, as is the voltage induced in the head coil. This cancellation effect occurs, also, at multiples of the frequency represented, and for all practical purposes the head is useless above a frequency which is somewhat less than that corresponding to the wavelength of the first gap null.

At any given head-to-tape velocity, the uppermost reproducible frequency can be increased by decreasing the gap width. Limitations are reached when realistic manufacturing tolerances are exceeded or when head output falls to less than usable levels. Induced voltage decreases with head gap, because reduction in gap width constitutes a reduction in the reluctance of the magnetic path across the gap, which is, therefore, approaching a "short circuit" of the magnetic circuit.

The uppermost reproducible frequency can be further increased by increasing the head-to-tape velocity. This increases the wavelength of any given frequency as it appears on the tape.

The resonant frequency of the inductance of the head coil and the capacitance, either actual or distributed, of its circuit either must normally be outside the passband of the system, so that the drop in output after the point of resonance will not adversely affect the frequency response, or must be so placed at the extreme upper limit of frequency response that it provides a small extension of "flat" response. When good engineering design has reduced the circuit capacitance to an irreducible minimum, the only way to increase the resonant frequency is to reduce the inductance of the head coil by reducing the number of turns of wire on the core. This, in turn, reduces the head output over the entire frequency range and will particularly influence the usefulness of low-frequency output.

Low-frequency Response

The lowest frequency which can be reproduced in any tape system is ultimately determined by the lowest signal level which can be tolerated by the requirements of the system at low frequencies. As shown, the voltage developed across the coils of the reproducing head decreases with frequency until a level is reached which is insufficiently above the basic noise level of the system as a whole to be considered useful. Thus, the noise level in the associated electronic assemblies often will determine the low-frequency limit of the tape system. In general, the maximum bandwidth which can be effectively reproduced by any magnetic tape device is approximately 10 octaves.

Signal-to-noise Ratio

The requirements of the system for over-all signal-to-noise ratio usually determine the useful frequency limits of the system. As the signal-to-noise ratio requirement increases, the level requirement at each of the bandpass extremes increases. Thus, as the signal-to-noise ratio requirement increases, the bandpass decreases. The center of the bandpass will depend upon gap width and head-to-tape velocity.

RECORDING THE TELEVISION SIGNAL

The Problem Defined

The television signal contains energy in a bandpass from direct current to more than 4 Mc. To reproduce the 4-Mc signal, we can either decrease head gap or increase head-to-tape relative velocity. If an effective head gap of 0.25 mil (0.00025 in.) is assumed, the required head-to-tape relative velocity must be in excess of 2,000 ips, or more than 110 mph.

Reduction of the gap to an impractically narrow 0.025 mil (0.000025 in.) would reduce the necessary head-to-tape relative velocity to 200 ips. But if this velocity were to be obtained by simply moving the tape at that velocity past a stationary head, it would result either in a playing time too short for practical programming or in reels of cartwheel size. A reel of approximately 38 in. diameter, containing 60,000 ft of tape, would be required to provide a playing time of 1 hr at such a tape velocity.

Recovery of very low frequencies from high-velocity tape would also be impractical if dependence were placed upon direct recovery of long recorded wavelengths. Three seemingly conflicting requirements, therefore, face the designer of a television magnetic-tape system:

1. High relative head-to-tape velocity is needed to record and reproduce the high-frequency components of the video signal.
2. A means is needed to record and reproduce the lowest frequencies in the video signal.
3. Adequate playing time, using reels of reasonable size, is a requirement.

The Commercial "Video-tape" Recorder-Reproducer

Since 1956, magnetic video recorders have been in commercial service. These devices employ four video heads, mounted in quadrature on the periphery of a 2-in.-diameter drum, which rotates at 14,400 rpm. The heads trace a transverse path across slowly moving (15 ips) tape 2 in. in width. The tape is cupped around the head drum by a concave tape guide. The relative head-to-tape velocity is approximately 1,500 ips.

Each head describes an arc of approximately 120° while it is moving across the tape, so that before any one head loses contact with the tape, the succeeding head has made contact. During recording, all heads are fed in parallel. During reproduction, one head at a time is connected to the system through individual playback

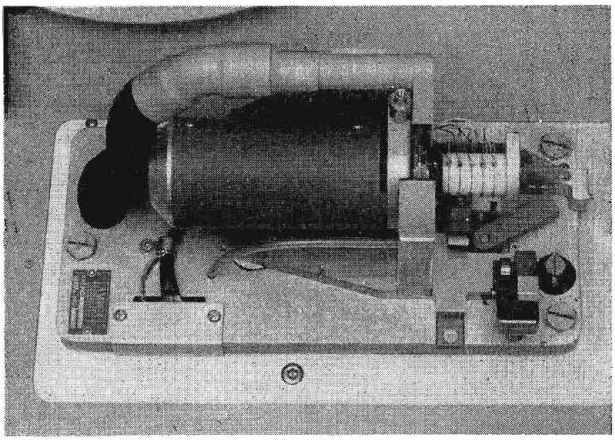
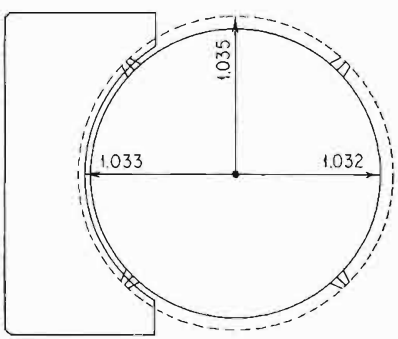


FIG. 5-1*a*. Video-head subassembly. The control track head is visible at the right of the vacuum guide.



PROFILE VIEW, DRUM & GUIDE

FIG. 5-1*b*. Profile view—drum and guide.

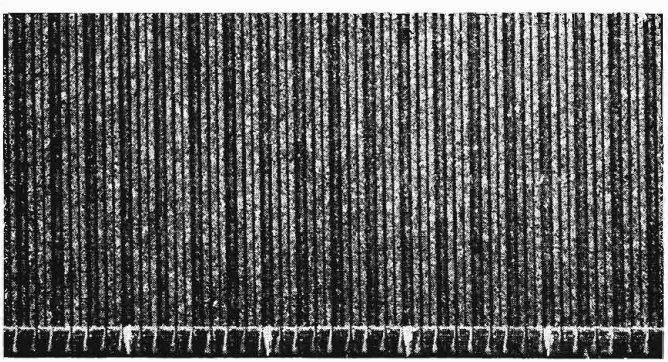


FIG. 5-1*c*. Lower section of recorded video tape after treatment with magnetic particles to render recording visible. Video tracks are 10 mils wide, 15⅔ mils center to center. The control track is at the bottom. Bright traces on the control track are editing pulses, occurring once each field, ¼ in. apart.

amplifiers, switching being accomplished during horizontal blanking intervals by automatic electronic means.

Since linear tape motion is at a velocity of 15 ips, head rotational rate is 14,400 rpm, or 240 rps, and since four tracks are traced transverse to the direction of linear tape motion during each revolution of the head drum, 960 tracks are laid down during each second of recording or reproduction along 15 in. of tape. The tracks

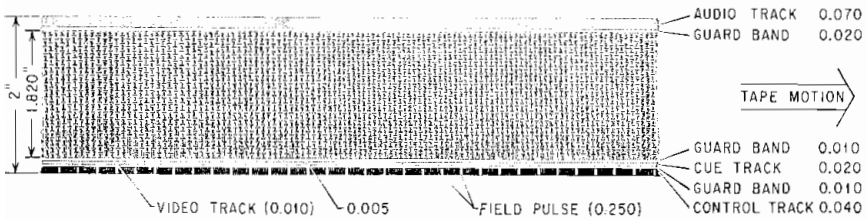


FIG. 5-1*d*. Currently used track dimensions for recorded TV tape.

are 10 mils (0.010 in.) in width, with a center-to-center spacing of 15⅔ mils. Each frame occupies ½ in. of tape; one field occupies ¼ in. More than 17 horizontal television lines are recorded on each transverse track. A certain amount of information is duplicated at the end of one track and the beginning of the next, since each head traverses approximately 120° of arc across the tape. During the overlapping period, the automatic switcher selects a horizontal blanking interval in which to accomplish the switching from one head to the next. Thus, either 16 or 17 horizontal television lines of video information are reproduced from each transverse track. The thickness of the tape specified for video recording (1-mil base, plus approximately 5-mil coating) is such that 4,800 ft can be wound on a reel 12⅝ in. in diameter, sufficient for 64 min recording or reproduction.

A Modulation System

Although the uppermost useful reproduced frequency in the system is of the order of 6 Mc, the lowest frequency which can be recovered with adequate signal level is now in the neighborhood of 3,000 cycles. Furthermore, practical apparatus for the purpose of causing the rotating heads to track precisely along the recorded tracks requires some tolerance for off-track reproduction. If the video signal were recorded directly or recorded by amplitude modulation, the video-signal level will vary approximately 10 per cent in the case of a tracking error of as little as 1 mil (0.001 in.). Noticeable and objectionable variations in contrast would result. Thus frequency modulation of a carrier within the passband of the recording system is employed. Since the amplitude of the recovered signal in an FM transmission does not depend primarily upon the amplitude of the RF signal, but instead upon dynamic frequency relations, the recording and reproduction of a frequency-modulated RF signal relieve considerably the necessity for extreme mechanical precision in the playback tracking of the recorded tape. This provides a "margin for error" in operation, maintenance, and manufacture. It is also comparatively easy to recover low-frequency information from an FM signal, so this problem is simultaneously solved.

The FM system is of unusual characteristics, since, with the configuration selected, all the useful information must be contained in the band below 6 Mc.

It has been classically assumed that the highest modulating frequency used in an FM transmission system will not exceed one-tenth of the carrier frequency and that deviation will be large compared with maximum modulating frequency. In the magnetic video recording system, a carrier frequency of 4.75 to 5.85 Mc is employed. Deviation is approximately ±500 kc. The highest useful modulating frequency is slightly over 4 Mc. The modulation index is, thus, approximately 0.125. For this

reason, if for no other, the signal-to-noise ratio is somewhat lower than that which is usually associated with FM systems, although experimentation has established that, quite aside from the undesirable contrast shifts which occur in an AM system, the signal-to-noise ratio of the FM system is equal or better. Typical obtainable ratios of peak-to-peak video to rms noise are in the range from 34 to 38 db.

It will be seen that in an FM signal which is deviated ± 500 kc from a center in the neighborhood of 5 Mc by modulation frequencies in the neighborhood of 4 Mc, through a system whose bandpass is sharply limited to approximately 6 mc, only the lower sidebands will be fully recoverable. The video magnetic recorder, therefore, operates as a "single-sideband FM" system.

The "sampling rate" of a carrier of this frequency, in conjunction with a modulating frequency of 4 Mc, is, of course, low. The highest frequencies are, therefore, distorted. The effects of high distortion in the high-frequency video bandpass are complex. However, the only detectable effect upon the picture is a small degree of aperiodic waviness in narrow vertical picture elements, which, as far as the eye is concerned, is integrated out by the frame rate. It is visible only in photographs of a single frame.

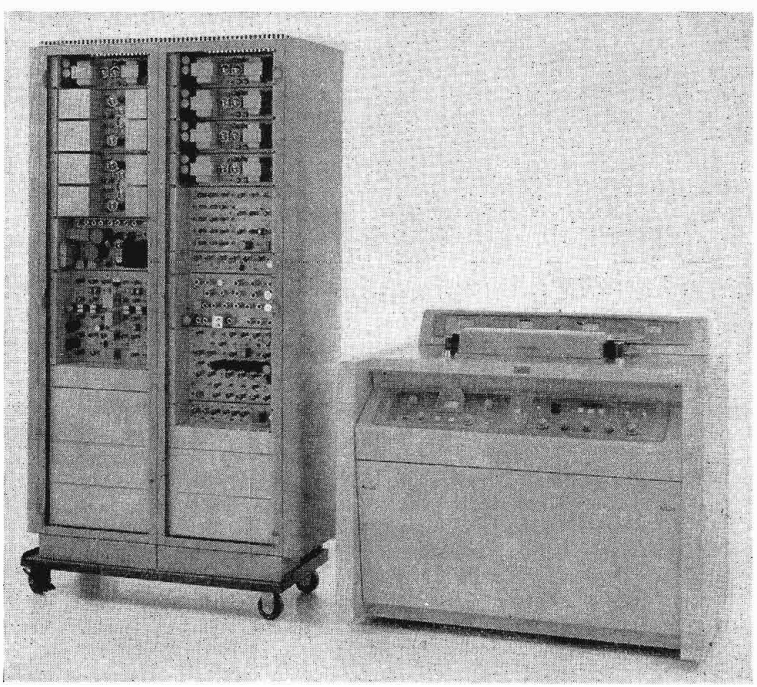


FIG. 5-2. Video-tape recorder complete.

THE "VIDEO-TAPE" RECORDER

General

The "video-tape" recorder may, for the sake of convenience, be divided into the video record-reproduce system, the control system, and the audio record-reproduce system.

The video record-reproduce system consists of all the elements of the recorder which receive, amplify, modulate, record, reproduce, switch, demodulate, and process

the composite video signal. The control system consists of the elements of the recorder which transport the tape and control its relation to the rotating heads, the elements which control the mode of operation (record audio and video, record audio only, reproduce, stop, fast-forward, and rewind) and the automatic switchings which accompany these selections.

Modulation

The incoming composite video signal is amplified through four video amplifier stages. Each of these four stages is overcompensated, giving 12 db more gain at 4 than at 0.5 Mc. This is compensation for an opposite characteristic inherent in

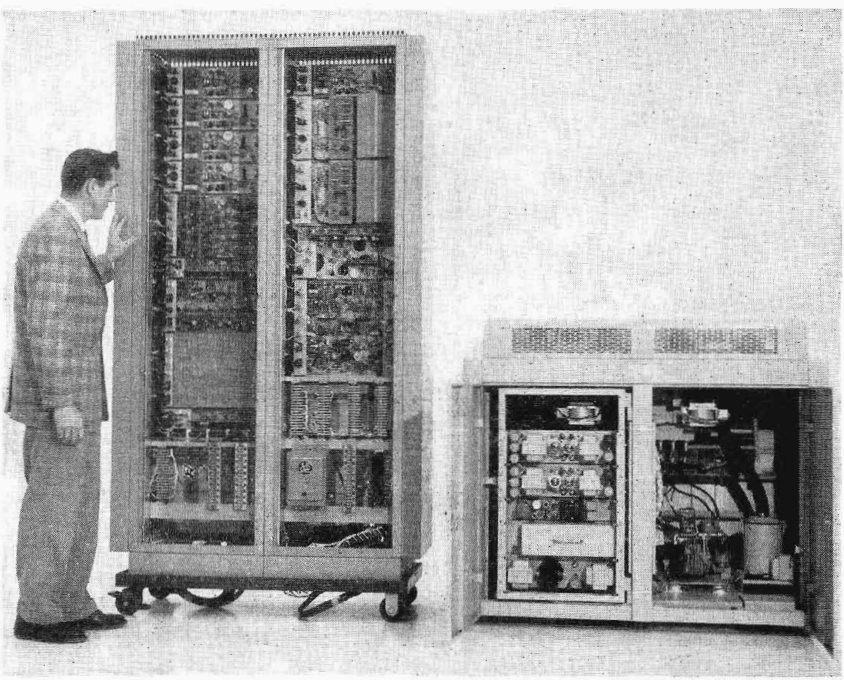


FIG. 5-3. Rear view of complete video-tape recorder.

the modulation process and the demodulator circuit. A video gain control is inserted at the output of the second video amplifier stage. The amplified signal is fed through a cathode follower and then, in the monochrome video recorder, to the grids of a multivibrator. The screen grids of these pentodes are *not* bypassed; the screen voltage, therefore, varies in unison with that of the plate.

The composite video which appears at the grids of the multivibrator is clamped at blanking level during the "back-porch" interval by clamping pulses. Direct coupling between the cathode follower and the multivibrator grids prevents the loss of the d-c component during the modulation process. The characteristics of the multivibrator are such that its natural frequency increases as grid voltage increases, so that the synchronizing pulses cause this frequency to *decrease* while signals in the white direction cause the frequency to *increase*. If the multivibrator is adjusted so that its unmodulated frequency is 5.25 Mc, a 15-volt peak-to-peak video signal at the grids of the multivibrator will cause the frequency to vary from 4.75 (sync tips) to 6.25 Mc (white base line). Since the input level control is in the modulating circuit only, it will not affect amplitude of the keying pulses.

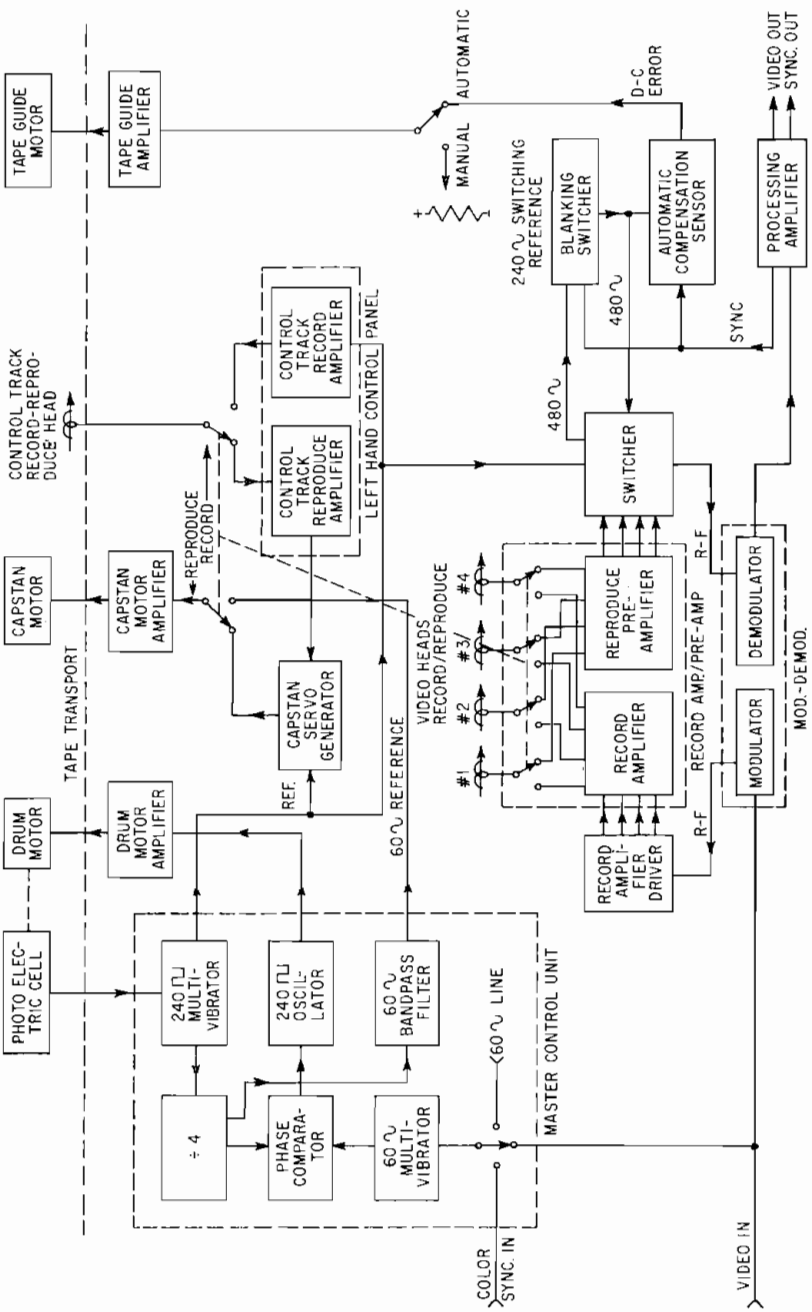


Fig. 5-4. Video-system block diagram.

The multivibrator output is fed through a transformer, providing balanced coupling, so that any simultaneous excursion of the multivibrator plates in the same direction, which might occur in the video signal fed through the tubes, will be canceled. Thus the base line of the FM signal will remain constant, and undesired phase modulation is prevented.

The final stage in the modulator strip is an amplifier whose output is connected to the record-amplifier driver.

The demodulator strip is mounted on the same chassis as the modulator.

Record-amplifier Driver

This chassis provides preliminary amplification of the FM signal from the modulator and supplies a low-impedance output to each of the four record power amplifiers.

This chassis is mounted in the console. Its adjustment points are accessible from the front of the console. The incoming FM signal feeds through a master record gain control and thence to an amplifier chain. The signal then passes through a cathode follower, which feeds in parallel four more cathode followers, providing four low-impedance-source signals, one for each high-power record amplifier. The gain of each of the four individual parallel legs is adjustable, so that variations in record-head sensitivity can be compensated. High-level FM is fed from each of these four sources to the record-amplifier chassis.

Record Amplifier, Etc.

One housing in the console contains four modulator plug-in units, each of which is a record amplifier and reproduce preamplifier, and a fifth plug-in chassis, a photoelectric-cell amplifier, which is associated with the control system.

High-level FM from each of the record-amplifier drivers is fed to one of the record power amplifiers in the record-amplifier–reproduce-preamplifier chassis. The high-power output of each tube is fed, individually through a slip-ring connector on the rotary head mechanism, to one individual recording head. Thus, while each rotating head is constantly fed a signal originating from a common source, the level of record current at each head may be different, depending upon the differing requirements for drive of each individual head. The objective attained here is that of obtaining successive tracks, each recorded at the same flux-density level.

During replay, the individual output of each head is first fed through an individual preamplifier strip. These preamplifiers consist of a pair of cascaded cascode-connected tubes followed by amplifiers. The output at each of the four preamplifiers is fed separately to the switcher chassis.

Switcher

The switcher unit sequentially switches the outputs of the four video heads during the reproduce mode so as to reconstruct a continuous signal from the discontinuously recorded tracks. When used with the retrace switcher, the unit provides automatic timing so that switching occurs only during horizontal retrace periods and does not appear in the reproduced picture.

Each of the four signals is amplified in the switcher chassis through two stages. These are conventional RF amplifier circuits, using shunt peaking in the plate circuits and small interstage time constants to limit the bandwidth to that of the FM signal. The amplified outputs are delivered, then, to the control grids of the gating tubes.

The multigrid gating tubes are so biased that the FM signal will appear at the output only if "trigger" voltages are supplied *both* to the screen and to the suppressor grids. These voltages occur in "get-ready," "go" sequence. The get-ready signal biases one of the two grids to the condition necessary for conduction, while the go

voltage biases the last of the grids necessary for conduction, completing the sufficient condition for conduction through the gating tube.

The get-ready signal is derived from the output of a photoelectric cell, which is located at the rotating-head structure. This cell views a disc which rotates with the head drum. The disc is half white and half black. The output of the photoelectric cell, thus, is an approximately square wave of 240-cps frequency. Its in-

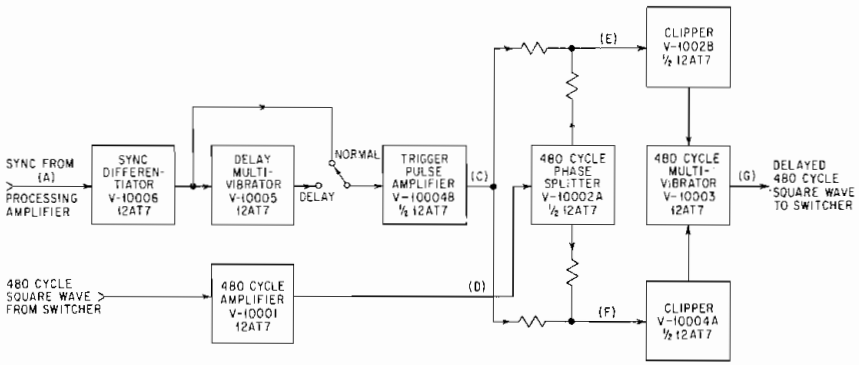


FIG. 5-5. Blanking switcher.

stantaneous phase at any moment is thus directly related to the position of the rotating-head drum. Four signals are derived from this 240-cps frequency, one of which is in phase, one lagging by 90°, one the inverse of the 90° lagging phase (thus, a 270° phase), and the last is the inverted 240-cps signal, constituting the 180° phase. The in-phase signal is fed to one of the two gating grids in one of the four gating tubes as the get-ready signal, the 90° phase component is fed to another of the four gating tubes, the 180° phase to another, and the 270° phase to the fourth. Thus, each of the four gates, in turn, receives a get-ready signal slightly before it

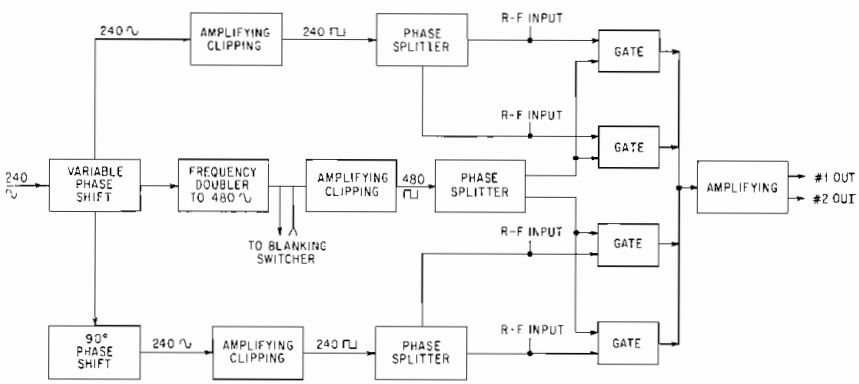


FIG. 5-6. Switcher.

is to begin conduction of RF and slightly before conduction of RF is to stop in the preceding gate.

The actual moment of switching is determined by a second grid in each gate, and this is touched off in less than 0.1 μsec by a square pulse derived from the television signal itself through the retrace switcher. This constitutes the go signal. This pulse halts conduction through one gate and begins conduction through the next during

the sixteenth or seventeenth horizontal retrace signal on each lateral recorded track on the tape. The parallel output of the four gating tubes is the reconstituted continuous FM signal. This is now amplified and fed in parallel to each of two amplifiers, one of which then feeds the demodulator at low impedance and the other feeds the built-in monitor oscilloscope.

Demodulator

The demodulator strip is located on the same chassis as the modulator. FM, received from the switcher, passes through five dual stages of limiting. As much as 50 db of limiting is employed. The objective is to remove all amplitude modulation and AM noise which may have been introduced during the record and reproduce processes. The signal is again amplified and fed through a cathode follower to the demodulator circut.

A delay-line demodulator is used. FM is fed in parallel to the grids of the two sections of a dual triode, but one of the two parallel legs is fed through a delay line whose time constant is equivalent to a 90° phase shift at the carrier frequency. The output of the delayed leg is mixed with the nondelayed RF at the plates of the mixing dual triode. One of the two mixed signals, thus, differs from the other in phase in proportion to the deviation from the carrier frequency. Thus, plate signal amplitude increases for frequencies below carrier frequency and decreases for frequencies above carrier frequency. An amplitude-modulated signal is therefore produced, although an FM component is still present. This signal is transferred through a cathode follower and then through a transformer for full-wave detection in a pair of diodes. Cancellation of RF is accomplished as fully as possible through a detector balance potentiometer.

The signal now passes through a three-stage amplifier. Selective inverse feedback is applied to these stages, to modify the frequency response. The signal next passes through a precise 4.5-Mc low-pass filter whose purpose is the elimination of the double frequencies developed in the full-wave rectifier diodes and most of the remaining RF in the region of the carrier frequency. A cathode-anode follower delivers a signal to the output of the chassis, from which it is cabled to the input of the processing amplifier.

Processing Amplifier

Distortion of the higher frequencies, due to the low sampling rate of the 5-Mc carrier, has deteriorated the synchronizing information in the composite video signal. Transients have been introduced during the retrace signal by the switcher. A certain amount of noise originates in brushes, tape dropouts, cross talk, unfiltered RF, and other sources. In the processing amplifier, the synchronizing information is stripped away and new synchronizing pulses are generated and recombined with the video information. Details of the amplifier were presented in an SMPTE paper in April, 1957, published in September, 1958.

The processing amplifier provides two video outputs, one of which is intended to constitute the main video output, the other to feed a picture monitor. A sync output is provided for convenience in locking an external sync generator to tape, and an additional sync output for the retrace switcher and for the automatic compensation senser. Adjustment of video level, blanking level, and sync level can be accomplished locally at the processing amplifier or, through suitable connections to the processing amplifier, at a remote location.

Control Systems

Three different systems comprise the control systems in the video-tape recorder.

1. The solenoid-operated push-button controls over the tape transport

2. The servo tracking system, which assures that the rotating heads, in playback, trace precisely the previously recorded transverse tracks

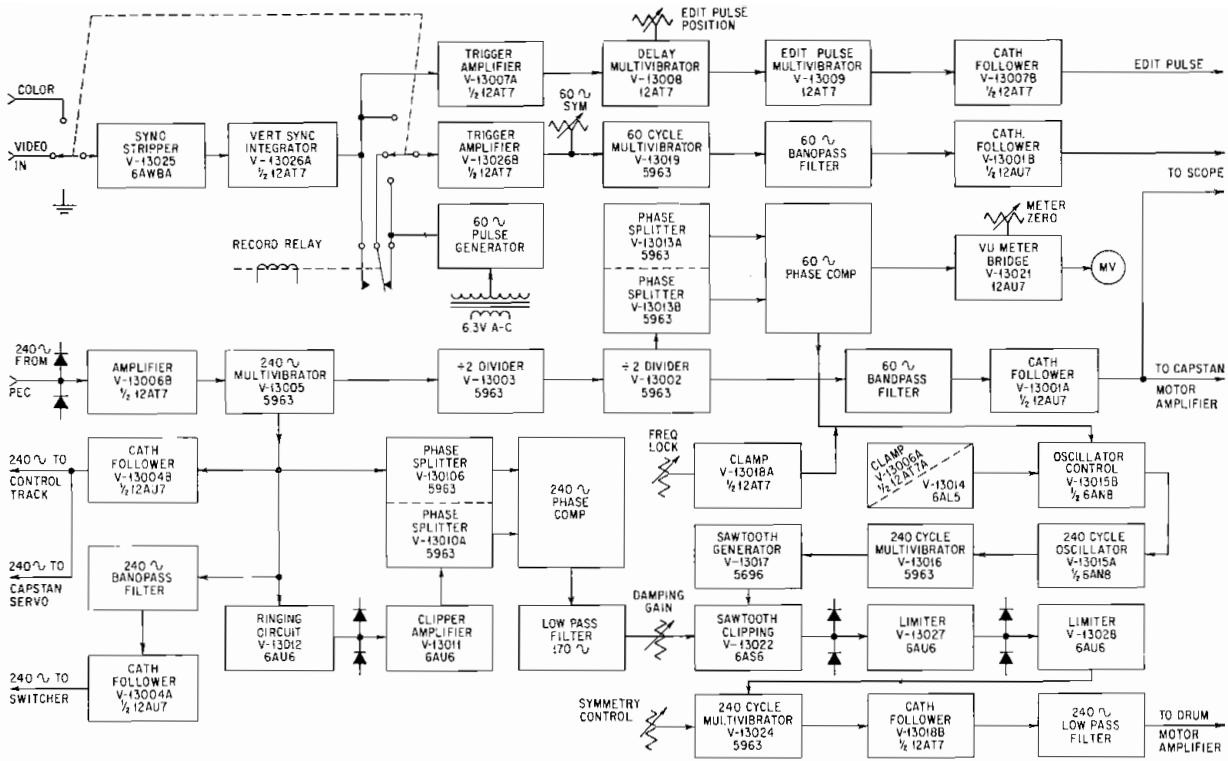


FIG. 5-7. Master control unit.

3. The tape guide servo, which controls the relation between the vacuum tape guide and the rotating head drum, automatically compensating for time-base displacements in the reproduced picture

Tape Transport Controls

Tape motion in the record and reproduce processes is controlled solely by the capstan, which pulls the tape from the supply reel, on the left, through the rotating video head assembly, past the control-track head, the audio-erase head, and the audio record-playback head and drives the tape toward the take-up reel on the right. Each reel hub is mounted on a torque motor. The supply torque motor opposes the motion imparted to the tape by the capstan, thus providing hold-back tension. The take-up motor supplies just sufficient torque to take up the tape as it is supplied by the capstan.

In fast-forward or rewind modes, the capstan idler is removed. The torque of the appropriate turntable motor is reduced by relay-connected resistors under the control of the corresponding push buttons, and tape is pulled from that turntable by the greater torque of the other turntable motor.

Tape Tracking Servo System

Tape speed during the reproducing mode must be controlled precisely to maintain accurate tracking of the video heads as they scan the recorded transverse tracks. The control process starts during the recording operation. During the record process,

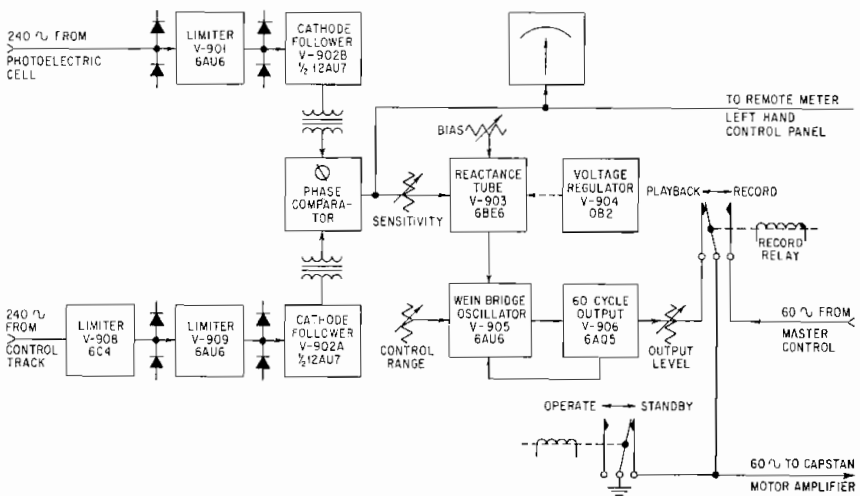


FIG. 5-8. Capstan servo generator.

the rotation of the head drum motor can be locked to any of three 60-cycle reference sources—the vertical sync pulses of the incoming video signal, an external source such as color sync, or the 60-cycle line. Selection of the reference source is made by adjusting a switch at the master control unit.

If the 60-cycle source is to be derived from a composite signal, the vertical rate is stripped from the video information and supplied as pulses to a multivibrator. Sixty-cycle line, if selected, is also applied at this point. Thus triggered, the multivibrator supplies a 240-cycle wave to the phase comparator in the master control unit. The output of the phase comparator is a correction signal, which affects the

frequency of a 240-cycle oscillator. The comparator measures the difference between the line-derived wave and a rotary-head-derived wave which is related in phase directly to the rotational position of the head drum. The output of the 240-cycle oscillator drives a power amplifier whose output, in three phases, provides the power to drive the head-drum motor. A disc on the head-drum shaft, painted half black and half white, is scanned by a photoelectric cell. Its output triggers a 240-cycle multivibrator; this 240-cycle signal then constitutes the second signal for the comparator. A servo loop is thus created whose function is to stabilize firmly the relation between head-drum rotation and vertical sync rate.

The 240-cycle signal, which has been derived from the head-drum photoelectric cell, is also amplified and recorded on a longitudinal track at the bottom of the 2-in. tape. The control-track record-reproduce head is located on the video head subassembly, very close to the rotating video heads. The signal recorded is a precise record of the continuous series of positions occupied by the head drum during the recording, and thus is the magnetic counterpart of film sprocket holes.

The 240-cycle drum-derived signal, after division to 60 cycles, feeds a power amplifier, during recording, which provides the power to drive the capstan motor. Thus, an electronic "gear chain" intimately connects the motion of the head drum to that of the capstan, so that tape motion is directly controlled by the rotating video head drum.

In the reproducing mode, the same choice of 60-cycle input can be made. Again, the head-drum motor operates within the servo loop described above. But the capstan is not, in reproduction, under the same direct control by the head-drum motor. Instead, the capstan motor amplifier is driven by an oscillator whose frequency is influenced by a phase comparator in the capstan servo generator. This phase comparator measures the difference between the 240-cycle head-drum-derived signal, at the time of reproduction, and the output of the control-track reproduce amplifier, thus modifying the instantaneous rotary position of the capstan, at any given time, in such a way that the *same relations* exist between *instantaneous head-drum position* and *tape motion* as existed at the time of the recording. In this way, the rotating video heads will precisely trace the recorded tracks. It is possible, during reproduction, for the rotating heads to be off track somewhat, although each tracing will be off track by the same degree. A manual control is, therefore, provided so that the automatic tracking can be brought precisely in line with the recorded tracks. Once so adjusted, precise tracking will be maintained for the duration of the replay.

In the video-tape recorder, the master control unit contains the vertical sync stripper, input multivibrator, phase comparator, 240-cycle oscillator, 240-cycle multivibrator, $^{240}/_{60}$ divider, and a 60-cycle bandpass filter whose function is to supply clean sine-wave signals to the capstan motor amplifier.

The capstan servo generator is a separate unit, which contains the phase comparator, used during reproduction to derive a correction signal from the 240-cps drum rate and the 240-cps control track and the comparator-influenced oscillator which supplies drive to the capstan motor amplifier in the reproduce mode.

Control-track record-reproduce amplifiers are contained in the left-hand control panel on the recorder console.

Tape-guide Servo Control

The video head drum contacts the tape inside a concentric groove in the vacuum guide on the video head assembly. Vacuum is applied to the back of the tape through the vacuum guide at a constant level. The relation of the guide groove to the rotating head drum is, during recording and reproducing, so intimate that the tape is minutely stretched in a direction lateral to its motion during the passage through the groove in the guide. The degree of stretch is determined not by the vacuum applied, which is constant, but by the space between guide and drum, which is variable. The length of the track being recorded or reproduced, and hence the precise time occupied by the tracing of a track, is thus minutely variable. When the reading rate is precisely equal to the rate at which the track was written, the reproduced picture will be free of hori-

zontal time-base aberrations. When the reproducing rate is different from the recording rate, vertical picture elements in each of the 16 bands in the picture will be diagonally offset, creating the "venetian blind" effect. Control, therefore, must be exercised over the precise position of the vacuum guide with respect to the head drum.

The position of the vacuum guide is determined by a small motor which is geared to the guide. Manual control for this motor is provided for test and maintenance procedures. In normal operation, control is exercised by the automatic compensation senser, whose output is amplified through the tape-guide amplifier, in the console, to control the tape-guide motor.

The automatic compensation senser provides an error signal when the tape guide is not correctly positioned. This error signal is fed to the tape-guide amplifier, which repositions the tape guide so as to remove the error signal. The error signal is de-

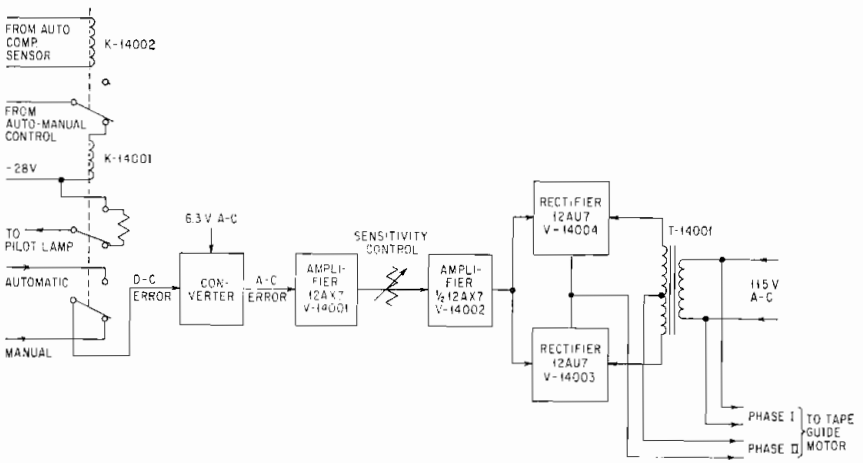


FIG. 5-9. Tape-guide amplifier.

rived from the reproduced video signal by sensing a time-displacement error caused by incorrect positioning of the tape guide. Sync pulses from the output of the processing amplifier are differentiated and clipped so as to produce positive pulses which correspond to the leading edge of the horizontal sync pulses. These positive pulses are fed as trigger pulses to a monostable multivibrator adjusted to provide a normal positive pulse of approximately 57.5 μsec. Since the horizontal sync pulses are spaced at 63.5-μsec intervals, approximately 6 μsec will elapse between the time that the multivibrator reverts to its stable condition and the occurrence of the next triggering pulse. As a consequence, a negative 6-μsec pulse is produced. Applied across an *RC* network, these become a series of sawtooth pulses, occurring at a rate corresponding to the horizontal sync pulses, whose peak amplitude is constant *as long as the time interval between the sync pulses is constant.*

But if the tape guide is not positioned correctly, a timing error is produced each time the heads are switched (every 16 horizontal lines). This would result in a corresponding change in the charge time of the *RC* network, resulting in an amplitude variation in the tip of the sawtooth wave.

The voltage at which the sawtooth wave is sampled can be selected so as to correspond, through the tape-guide amplifier and tape-guide motor connected, to correct tape-guide position. Once this value is set, negative or positive excursions from this selected voltage, since they represent time-base shifts, indicate negative or positive excursions from correct tape-guide position, and suitable correction signals may be generated and fed to the tape-guide servo motor. The sampling circuit uses as a reference the 480-cycle square wave which establishes the head switching time. This is drawn from the switcher unit.

Correct adjustment of the unit can best be made by playing a laboratory-standard recorded video tape on the machine, manually adjusting the head guide, zeroing in the automatic control to the then-existing manual control, and switching to "automatic" operation, after which the machine will both record and play back according to the standardized track length.

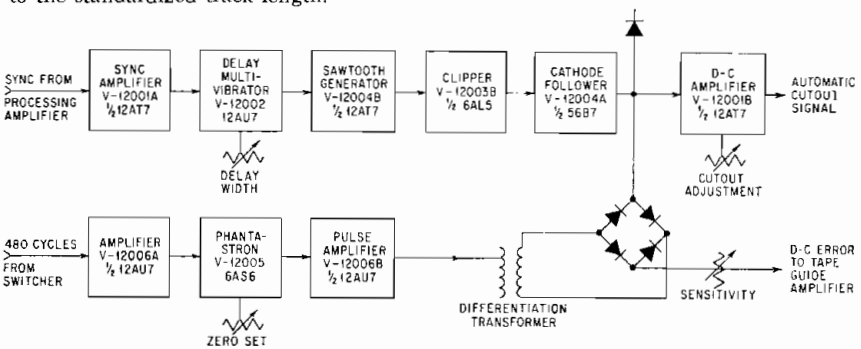


FIG. 5-10. Automatic compensation senser.

CUEING VIDEO TAPE

Since the video-tape recorder records the entire composite video signal, it follows that the output of the recorder is complete with sync. All switching operations which involve the output of the recorder, in playback, therefore must be planned with this in mind.

It is, of course, entirely feasible to lock a nearby synchronizing generator to the output of the video-tape recorder so that switching from tape to live or tape to film can be accomplished without any interruption or change in the synchronizing information. Switching *to* video tape, however, always involves switching the synchronizing source from that which preceded the change to the video-tape output.

Thus, the playback of the tape machine can be faded, wiped, or dissolved into the following picture if sync source for the following picture is local and has been locked to the playback of the tape recorder. The tape output can be split-screened with another picture if the sync information for the other-than-tape half of the split-screen image is locked to sync from tape. Such switchings cannot be accomplished, however, if the source of sync for the upcoming picture is remote or otherwise incapable of being locked to the sync from the tape.

It follows, then, that it will not always be possible to dissolve or wipe from any source sequentially *to* the tape playback. A local insert can be wiped or dissolved into a tape playback if sync for the insert is derived from a sync generator locked to the sync output of the running tape machine.

A "roll" *may* occur when switching from network, local-live, or local-film to tape for the same reason that a roll may occur when switching from network to local without locking the local generator to the incoming network sync.

The video playback does not begin instantly after the "play" button is depressed, but the interval between depression of the "play" button and the upcoming of stable picture is stable and predictable. About 5 sec is the period to which the machines are usually adjusted.

In order to provide precise cueing of switches from other sources to tape, audio methods are sometimes employed. With or without the recording of video, audible "beeps" at timed intervals may be recorded on the sound track down to the beginning of program. Usually, these beeps are automatically generated and consist of $\frac{1}{5}$-sec tones spaced 1 sec apart. At the moment of the beginning of the recorded program, audio is switched from the beep generator to the program source. Thus, it is possible manually to find the beginning of the program audio track by listening on the sound monitor of the recorder, then to back the tape manually through the desired number

of recorded beeps to a point 5, 10, 15, or any other desired number of seconds before the beginning of program. Because the tape motion begins approximately $\frac{1}{10}$ sec after the depression of the PLAY button, all beeps will be heard and a prearranged "count-down" signal is given to video control, indicating that the recorder is in operation and that the picture will be upcoming in the agreed-upon time.

Variations upon these methods are employed at various video-tape recording installations. In some cases, monoscope pattern, along with timed audio beeps, is recorded for exactly 1 min prior to beginning of any program. This gives visnal indication, upon replay, that the playback is of good quality and gives continuous audible indication of the time remaining before picture comes up from the tape playback. In still other cases, picture is recorded throughout the 1-min interval, changing every 5 sec, so as to give a visual as well as an audible "count-down."

Methods of cueing video tape are under consideration by the SMPTE VT Standards Committee in which NAB participates.

INTERCHANGEABILITY

When a tape playback is displayed on a picture tube, the picture is made up of 16 bands of 16 or 17 television lines each. Every band represents the output of one only of the four rotating heads. If each band is exactly like the others, then the bands are undetectable. A picture of, say, 35-db signal-to-noise ratio, with all bands having that value, is entirely acceptable. But if there is a *difference,* as there may be when head outputs are not equal, then banding becomes visible even if the worst band is *better* than, perhaps, 35 db. The human eye is a very efficient comparator, even though it's not efficient as an absolute-level measuring device.

It is possible to adjust the gain of the four individual preamplifiers so that the output from all bands is equal on any given tape. But that doesn't solve the problem entirely. The control system of the recorder is arranged so that when a recorder is playing back one of its own tapes, each head reads out exactly the saune tracks it recorded. Therefore the spacing of the 10-mil tracks on the tape can be fairly erratic. Likewise, the azimuth alignment of the head gaps may be a trifle off perfect perpendicularity, and it won't matter as long as the tracks are always reproduced by the head which recorded them. But if tapes are interchanged, very little looseness can be tolerated in the spacing of the tracks, or noise banding will appear owing to low output from those heads which are slightly off track. Any substantial deviation from a common azimuth alignment will be disastrous, since the highest frequencies will be the first to be lost, and the carrier frequency of the FM system is near the upper bandpass limit of the recorder.

The solution to these banding problems lays in establishing extremely tight tolerances on drum wobble and on head azimuth alignment. Fortunately, the picture itself gives a greatly magnified representation of any fault which may exist in the head structure, so the tolerances can be adjusted out, in production, without the invention of some new kind of supermicrometer.

Small differences in frequency response among the heads were not very important in monochrome-television recording. But with color, where minute variations in frequency response become large variations in color-carrier phase, individual equalizers are required for each individual head. This is not beyond possibility in commercial production. Head structures are not sufficiently refined that individual differences are small, and adjustable equalizers in the separate head amplifiers are adequate to the task.

Time-base Banding

Visible differences in the bands on the picture can also arise from time-base variations. These may be caused by "quadrature misalignment" or by differences between the tape-to-head relations in recording and the replay relations.

If a tape is recorded on a drum whose heads are spaced precisely 90° apart and then played on a drum whose heads are unevenly spaced, the picture contains displacements of vertical picture elements. Certain bands are wider than others. These represent

the output of heads which track more than their share of the time because of their greater angular separation from their successors.

This effect must be reduced to the point that misalignments are less than noticeable, if detectable at all. Although the Standards of Good Engineering Practice [1] suggests that such errors should not exceed 0.5 per cent of the line interval, or 0.3 μsec, so large an error is objectionable to viewers. Error actually *must* get down to about 0.1 μsec and in practice should be held to half this value. Since the heads operate at approximately 1,500 ips, 0.05 μsec of time corresponds to 38 μin. of tolerance; this is normally achieved in production heads, which are first aligned by machine methods to within ⅔ mil of correctness and then are brought within final precision, ±38/1,000 mil, by observation of the picture with adjustment and readjustment of tapered screws fitted into slots in the drum. These screws are wedges to increase or

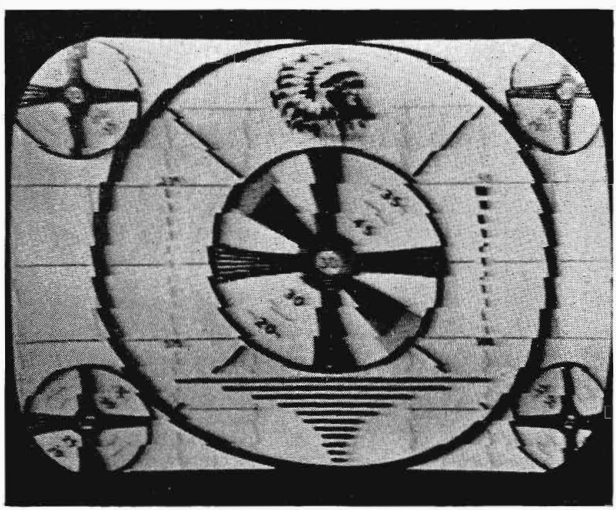


FIG. 5-11. Guide too close to head.

decrease the spacing between the four segments of the drum. The factory supplies precision-recorded tapes with which quadrature of any head can be checked against standard and, if necessary, adjusted in the field.

There are *several* ways in which the relation of the tape to the drum can vary. This relation is determined by the position of the vacuum guide with respect to the drum; by the effective diameter of the heads, which varies with wear; and by the vacuum applied.

In operation the vacuum is held constant, and an adjustment is provided for the lateral position of the guide. When the guide is moved close to the drum, the tape is stretched more in a direction transverse to its linear motion. Thus the tracks are lengthened slightly. If the guide is backed away slightly, the tape will be stretched less and the tracks will shorten. This makes it possible to tolerate the changes in the effective diameter of the drum which takes place as the heads wear down. But misalignment is possible at will.

If the guide is moved in playback so close in to the drum that the tracks are stretched longer than they were in the recording process, vertical picture elements will be slanted in each band, producing the "venetian blind" effect. This is readily remedied by backing off the guide, and in production models adjusted to maintain a standard track length, the process is automatic by means of a servo system which controls the position of the guide.

[1] See Part 3, FCC Rules and Regulations.

It is desirable, of course, that the contour of the female guide should be perfectly concentric with the axis of the drum. If it were not, the pressure on the tape at the part of the guide closest to the drum would be higher than that elsewhere, on each sweep of the heads, and wear on the tape would be uneven. But assuming this could be tolerated, small displacements of the guide upward or downward would not matter so long as the tape always were played back on a head assembly misaligned in the same manner. Picture defects appear only when a tape is played back on a machine whose vacuum guide is aligned differently from that on the recording machine.

If a recording has been made on a perfectly concentric drum and guide, then played back on an assembly whose guide is adjusted too high (see Fig. 5-12), the velocity of the head, with respect to the original track, is not constant throughout one

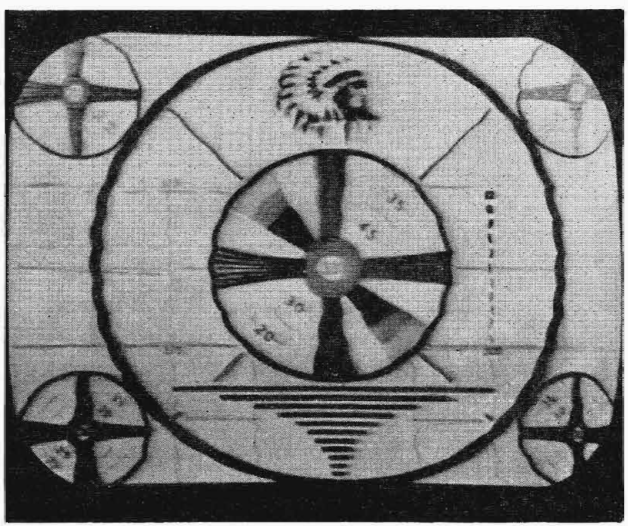


FIG. 5-12. Guide too high.

sweep across the tape. The tape is stretched *less* at the top and *more* at the bottom of the sweep.

The result of adjusting the vacuum guide too high is curvatures of vertical picture elements, or scalloping. Adjusting the guide too low will result in scallops rounded to the right. This effect can be prevented in interchanging tapes by adjusting all vacuum guides to a common height with respect to the drums. The position should be as nearly as possible concentric with the axis of the drum. The easiest way to accomplish this is to adjust all assemblies correctly at the factory and then to use standard tapes periodically in the field to check maintenance of the setting.

Larger dimensional errors are tolerable in vertical misalignment of the guide than in horizontal or quadrature misalignment. For example, if the vacuum guide is vertically displaced 1 mil in playback with respect to the position of the guide used in recording, the maximum scalloping excursion will be 0.3 μsec on the screen. Scalloping is not detectable at 0.1 μsec, so vertical positioning of the vacuum guide need be held only to a few tenths of a mil, plus or minus, to obtain satisfactory results. This is easier than obtaining the microinch tolerances which apply to quadrature, especially because the same magnification of the effect is obtained by using the picture as a micrometer.

All the factors which govern the interchangeability of tapes on VR-1000 monochrome recorders are, thus, under adequate control, and means exist through the use of standard tapes and available adjustments to keep these factors under control in commercial broadcast operations.

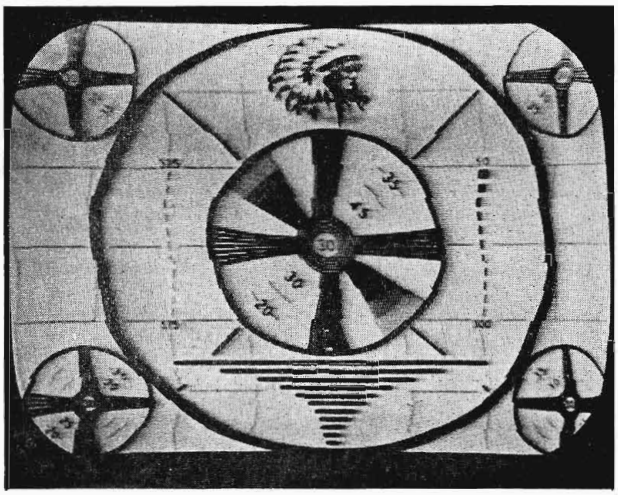


FIG. 5-13. Angular misalignment of heads.

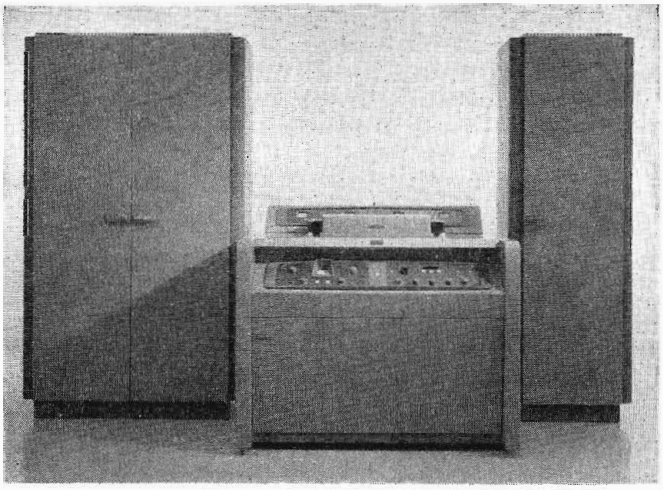


FIG. 5-14. Color TV tape recorder. Identical with its monochrome counterpart in every way, except for the addition of a rack of color electronics, the color TV tape recorder will handle either color or monochrome tapes.

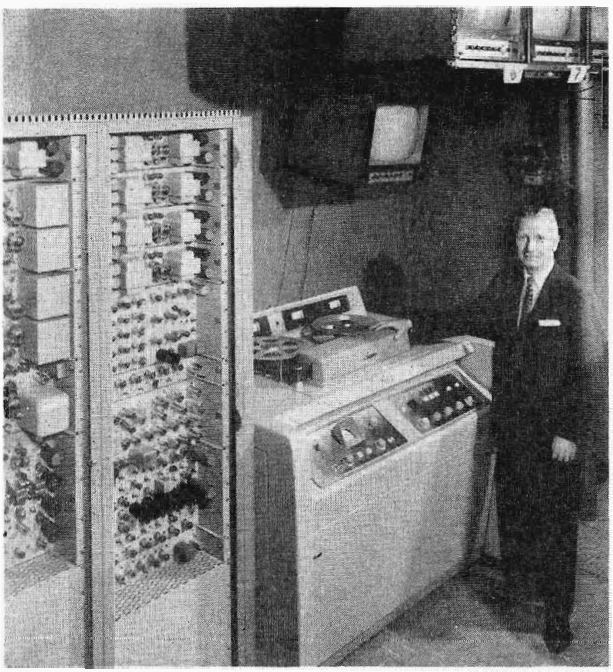


FIG. 5-15. Typical TV tape recorder installation (KGW-TV).

FIG. 5-16. Mobile TV tape system. The model shown here illustrates the manner in which one bus was outfitted as a mobile TV system, complete with tape recorder.

FIG. 5-17. A TV tape cruiser. Containing one video recorder, three cameras, centralized control facilities, and more than 10 kw of power-generating equipment, this air-conditioned cruiser covered more than 12,000 miles during the summer and fall of 1959, making recorded TV tapes "on the go" and on location.

THE FUTURE OF TV TAPE

Late developments, including equipment which intersynchronizes two TV tape machines in playback with a synchronizing generator, or with one another, and other new devices all make it clear that expansion is certain for the usage of TV tape in television broadcasting. The intersynchronizing device makes it possible to fade, wipe, lap-dissolve, or cut from tape-to-tape, tape-to-live, live-to-tape, tape-to-film, film-to-tape, tape-to-network, or network-to-tape. Thus, the TV tape recorder is now capable of producing all of the same effects which can be achieved in live TV, with the "hindsight" advantage possessed only by prerecording.

Syndicated TV tape programs are expanding in number and usage, and the entry of one or more of the large TV program producers, formerly exclusively users of film, into the syndicated tape market assures that programming on tape will not be confined to "target of opportunity" programs, produced by local stations only, but will expand to include name-star shows as well.

Commercials, prepared and distributed on tape, now make up a substantial portion of all national spots and network commercial inserts. Lower cost of production and live-quality reproduction account for this growth and will assure further expansion.

The growth of color will be stimulated by tape and will stimulate further use of tape. Since the recording medium is the same, whether the recording be in color or in monochrome, and since medium costs for color film are considerably higher than for either monochrome film or tape, the use of tape in prerecorded commercials, programs, and news events in color is sure to expand. While interchangeability of color tapes requires more exacting conformity to standard adjustments of the machines, it has been demonstrated to be commercially attainable and can be expected to become still easier.

Part 6

TV FILM HANDLING AND PROCESSING

NAB Engineering Department *

INTRODUCTION

General Information of Interest

Film plays a very important part in the program structure of the television station. When you consider that the "air time" of the average television station is between 30 and 40 per cent film, it then becomes apparent that as much sound planning and thinking is required in providing adequate facilities for handling this important program source as that of any other department in a television station.

In order to attain optimum television broadcast reproduction of 16-mm sound on film, the film prints should conform to the technical requirements of the television system.

Although many of these requirements do not differ from those necessary for good-quality theatrical prints, there are a number of requirements that are peculiar to television only.

Film prints intended for telecast should not exceed a density range of 1.5. Within this range, the significant highlights should not exceed a density of 0.4 and the shadow or dark areas should not have a greater density than 1.9. Although some slight overall shift of these densities can be made toward the toe of the print curve, the 1.5-density range between minimum and maximum scene densities must be maintained. It must also be remembered that in the toe portion of the curve, highlight density distortion increases as the base density is approached, and the characteristics of the print emulsion should be carefully appraised before any shift of important scene densities is made into this region.

Films primarily made for television use (*Life of Riley, The Loretta Young Show, Fireside Theater*, etc.) fulfill the density requirements for good telecast exhibition. However, film prints of motion pictures originally made for theatrical exhibition that have been reissued on 16-mm stock for television, in most cases, are printed on standard release positive to approximately the same density range as release prints intended for theatrical use. This density range is excessive for the television system and results in substantial losses in both shadow and highlight areas of the picture. Western feature films having simulated night scenes (made in daylight on infrared film with appropriate filters) printed on normal release positive stock are notable examples of prints with excessive density ranges.

Printing such prints "two printer lights lighter" than is customary for theatrical prints does little to make these prints acceptable for television use. While little can be done to make "soot and whitewash" infrared scenes acceptable for telecast, retiming of originals for printing on low-contrast release positive, together with proper process-

* Compiled from sources listed at the end of the chapter.

ing for this type of emulsion, will do much toward making most theatrical feature films conform more closely with television print density requirements.

However, having a film print with a satisfactory brightness or density range for the television system is not enough. All prints can, and all too frequently do, exhibit a variety of defects and imperfections that individually or collectively make the film print unsuitable for good television reproduction.

Vertical or horizontal unsteadiness of the print image will cause serious loss of definition when such a print is reproduced through the television system. For this reason it is essential to prevent image unsteadiness during the shooting and printing stages of the film and to exercise extreme care in the handling and use of these prints so that the film edges and perforations will not become worn or damaged.

Scratches, abrasions, and dirt, whether on the film surfaces or imprinted in the emulsion, cause a loss of picture definition and are generally distracting to the viewer. Such defects or imperfections appear as "noise" in the telecast picture. When similar picture defects occur during "live" local or network shows, it is indicated to the viewer that a "technical difficulty" exists. These technical difficulties that develop in the electronic system and impair the picture quality are infrequent, unforeseen occurrences, usually of short duration. Whenever they occur, the station is quick to declare the difficulty and apologize to the viewer for the poor picture quality. Since the quality of all film prints can be determined before telecast, the airing of defective or poor-quality film prints seems inexcusable and entirely inconsistent with good operational practice.

Cue marks and splices are similarly disturbing both to good picture quality and to the viewer. Although the use of visual cues has long been standardized for theatrical motion pictures, no such standardization seems possible for television, since film programming requirements differ at each station.

Accurate timing of film is easily accomplished. The use of the clock for getting "in" and "out" of films at indicated times rather than by the use of visual cues seems to make for a more satisfactory film operation.

When visual cues are used, operational hazards are increased by the number of cue marks present in the film. With the "timed method," the clock provides the operator with a positive reference check at all times and, of course, obviates the necessity of mutilating the film print with numerous sets of cue marks.

Splices, whenever necessary (and few should be necessary in any program film print), should be narrow, well made, and straight across the film.

A $\frac{1}{16}$- or 0.07-in. straight splice, carefully made, is entirely safe and satisfactory for projection use. Intermittent sprocket and continuous pull-down projectors pass these splices more easily than the heavier $\frac{1}{10}$-in. splice.

Because of the scanning ratio of the television system to the projected film image, diagonal splices should never be used.

Few splices should be necessary in any film. Half-hour syndicated program films with commercial spot films spliced in will usually necessitate 8 splices at most. (The splice at the head and tail leaders into and out of the film is not counted.) However, if such a film has more than 12 splices, including the splices for the commercial spot films, there is a good chance that the continuity of the sound track may be interrupted and that there will be evidence of other defects which will make the print unsuitable for good television reproduction.

Films with damaged sprocket perforations or films that have cuts, nicks, or tears in either side of the film are also unsatisfactory for telecast. Prints with "notched-out" sprocket perforations are unsafe for television projection regardless of how well the projectors will usually pass such film. There is the ever-present possibility of an edge of such a perforation getting caught or buckled in the feed or intermittent sprockets and causing a film stoppage.

Roughness of the guided edge is generally due to nicks, cuts, or tears and, however slight, defeats film steadiness in the gate. As noted earlier, any unsteadiness of the projected image will cause loss of definition in the telecast picture.

Sound quality of a film print is no less important than the picture quality. In

addition to having a constant sound level throughout the print, the sound track should have a good frequency range, have a good signal-to-noise ratio, be free of distortion, have the correct track for the picture, and be synchronized with the picture.

The frequency range of a good optical sound track should run from 60 to at least 6,000 cps with a signal-to-noise ratio at least 50 db down. Intermodulation distortion should not exceed 5 per cent.

It is not impossible for a film print to have the wrong sound track, and all too frequently prints with the correct track are found to be out of "sync" with the picture. Although prints having either of these defects should be detected at the laboratory, there is considerable evidence that these defects escape detection not only there but by the distributor and a number of exhibitors as well. For correct "lip sync," the sound track must be synchronized 26 frames ahead of the picture.

The sound-track area must be free of surface or imprinted scratches, abrasions, and dirt. Because 16-mm sound film has sprocket perforations on one side of the film only, pressure contacts are incorporated into most projector gates which contact the film between the picture and sound-track areas and also on the outer edge of the print. Often emulsion particles build up on these contacts, and the film becomes marked or scratched at these points. If these scratches or markings remain narrow and between the picture and sound-track areas, no harm is done. However, if they extend into the sound track, serious distortion and noise result.

Care and Cleanliness

Film is delicate and should receive careful attention at all times. Just as in an instantaneous recording, a certain degree of deterioration occurs each time the film is used. The exact amount depends entirely on the treatment it receives in projection, rewinding, previewing, handling, and shipping. To produce good pictures, cleanliness is a *must*. As it is projected and rewound (because of certain atmospheric conditions), a static charge will build up on the film and it actually becomes a magnet for the attraction of dust and dirt particles. Therefore, wherever film is handled in the station, it should be kept as clean and dust free as possible.

When negatives or prints become dirty or badly oiled, they should be properly cleaned before being placed in storage or in use. As mentioned previously, film should not be cleaned by passing it through a dry cloth because of the danger of scratching by dirt particles accumulated in the cloth. Cleaning can best be done by a motion-picture film laboratory, where suitable cleaning machines are available and proper techniques and precautions can be observed.

When prints must be cleaned by hand, the work may be done by rewinding the film slowly through a lint-free rayon plush or soft cotton cloth pad which has been moistened with film-cleaning fluid. The pad can be folded over the film and held in the left hand while the right hand is used to operate the rewind. The operation should be carried out slowly so that the cleaning liquid can evaporate from the film before it is wound into the roll. The pad surface must be changed frequently, since a dirty pad will redeposit oil and dirt and may abrade the film. Where large quantities of film are to be cleaned by machine, it is desirable to arrange to feed a length of cleaning pad slowly through the device so that as it becomes dirty, a clean area is automatically provided.

The cloth used for cleaning must be selected carefully. Best of all is a clean, short-nap rayon plush or velvet. Next best is a soft cotton canton flannel, knit fabric, or plush. Cotton batiste and nainsook are also used, although they do not absorb dirt so well or hold it away from the film. Baled rags should not be used, as these usually contain many harsh cloths that will scratch and abrade the film and may also contain a great deal of lint. It is false economy not to use new cloths specially selected for the job.

There are a variety of organic solvents or fluids which might be used for cleaning film. The requirements of a good film cleaner are rather exacting, however, and relatively few materials are fully satisfactory. These requirements include not only clean-

ing ability but such factors as freedom from toxicity and flammability, a suitable evaporation rate, effect on film base and equipment, cost, etc. Several solvents which have been used for cleaning motion-picture film are compared and described below.

Carbon Tetrachloride—Not Recommended

Carbon tetrachloride has been used a great deal in the past for cleaning motion-picture film but is not recommended because of its great toxicity. Carbon tetrachloride fumes are poisonous. Headache and nausea are a first warning, and *continuous exposure may be fatal.* Evaporation of only two teaspoonfuls of carbon tetrachloride into a small, unventilated film-inspection room is enough to raise the concentration of fumes beyond the safe level. Carbon tetrachloride is dangerous whenever the odor becomes strong enough to be obvious. If it is used for cleaning film, the ventilation must be good enough so that a person just entering the room where carbon tetrachloride is being used can barely smell the fumes. If the fumes become stronger, all windows should he opened, the cleaning stopped, and the room emptied until it has been thoroughly ventilated.

n-Heptane and Freon-113. A Mixture (1 to 1) Is Recommended

n-Heptane alone is highly flammable and should not be used, but if it is diluted with equal parts of Freon-113, a mixture is obtained which is considered safe to use. Its flammability is only moderate, and its toxicity is slight. Freon-113 alone is nonflammable and perfectly satisfactory for cleaning film but is rather expensive.

Inhibited Methyl Chloroform—Recommended

Methyl chloroform is much less toxic than carbon tetrachloride but is still "moderately" toxic and should be used with care. Fumes of methyl chloroform should not be breathed for any length of time. It should not be used without adequate venting or ventilation.

Methyl chloroform has no harmful effect on either black-and-white or color films when used as recommended for cleaning. However, contact of film with methyl chloroform for 15 min or more may cause an increase in curl, particularly with acetate propionate or acetate butyrate base. It is therefore important that the solvent evaporate completely before the film is wound up. This usually requires only a second or two. Methyl chloroform should not be spilled on Tenite plastic cores because of its softening action.

Methyl chloroform without inhibitor attacks aluminum, zinc, and their alloys with rather a vigorous chemical reaction. It is, therefore, necessary to use only inhibited methyl chloroform for cleaning film in case aluminum parts may be used in the equipment. Most commercial methyl chloroform customarily contains an inhibitor, but this should be definitely ascertained before using. Both Eastman Kodak methyl chloroform used in film cleaners and lubricants and Dow Chemical Company Chlorothene grade of methyl chloroform contain inhibitors which have been tested for inactivity toward film.

A word of caution is necessary in regard to cleaning lacquered film. Cleaning solvents may dissolve certain lacquers used on film and may result in streaking from incomplete removal of lacquer. Unless the lacquer properties are known, it is best to try the cleaning solvent on an end of the film first.

Removal of Fungus Growth

Water or water solutions should not be used for the removal of fungus growth from color or black-and-white films because, in the great majority of cases, fungus growth on the emulsion side causes a solubilizing of the gelatin. The use of water or water solutions will lead to disintegration of the image.

The film should be cleaned by wiping it with soft plush, cotton, or chamois skin

moistened with an approved film-cleaning liquid, as described in the previous section. Such a treatment will remove most of the surface growth. The idea is to rub off fungus growth, dirt, grease, etc., with a buffer wetted with any of the suggested fluids. The use of a fluid is suggested as a means of carrying off the dirt, washing out any debris that may be held in indentations, etc., and acting as a sort of lubricant to prevent excessive scratching that would result from the use of a dry buffer.

When the gelatin has become etched or distorted by the fungus growth, there is no satisfactory method of restoration. If films are lacquered, the etching effect caused by fungus will be greatly minimized. If the lacquer is damaged, it can be removed and fresh lacquer applied.

Space Considerations

Space requirements for handling film will vary with the station installation. However, there are two focal points in planning film facilities: (1) the projection room and (2) the area required for inspecting and previewing film. In the projection

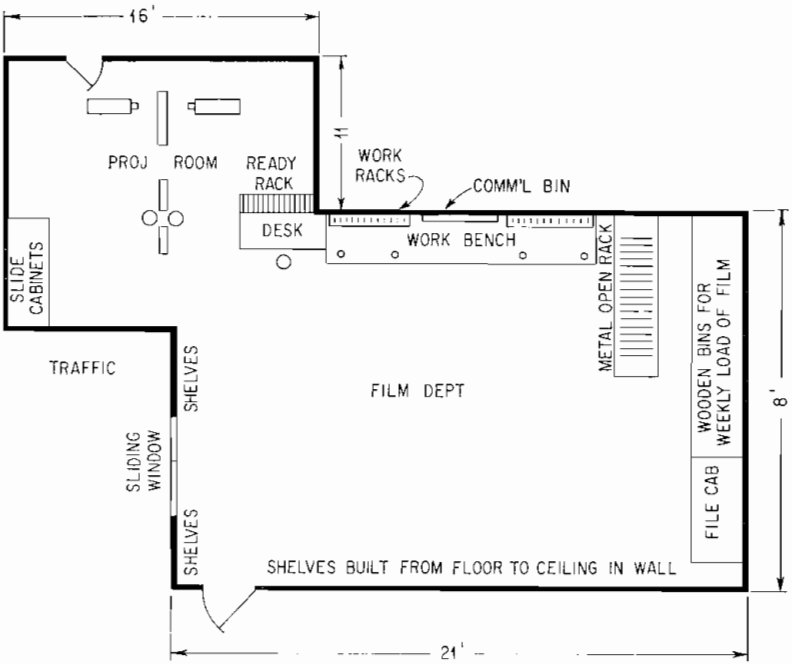


FIG. 6-1. KSBW-TV film and projection facilities.

room, adequate space should be provided for editing, splicing, rewinding, commercial insertion, and daily storage for shows that are to be aired. Just as in any other line of business, permanent storage is always a serious problem, and perhaps a good rule to follow is to double whatever your estimated space requirements might be. This really is not so foolish a statement as it might at first appear. Some film suppliers have initiated a procedure useful to themselves, but it may present a real problem to you. They will often advise you to hold film and ship upon receipt of their advice. However, it usually turns out that a considerable length of time has elapsed and you are left with the filing problem. So it is a good practice to return every foot of film that you do not own or do not intend to use in the very near future.

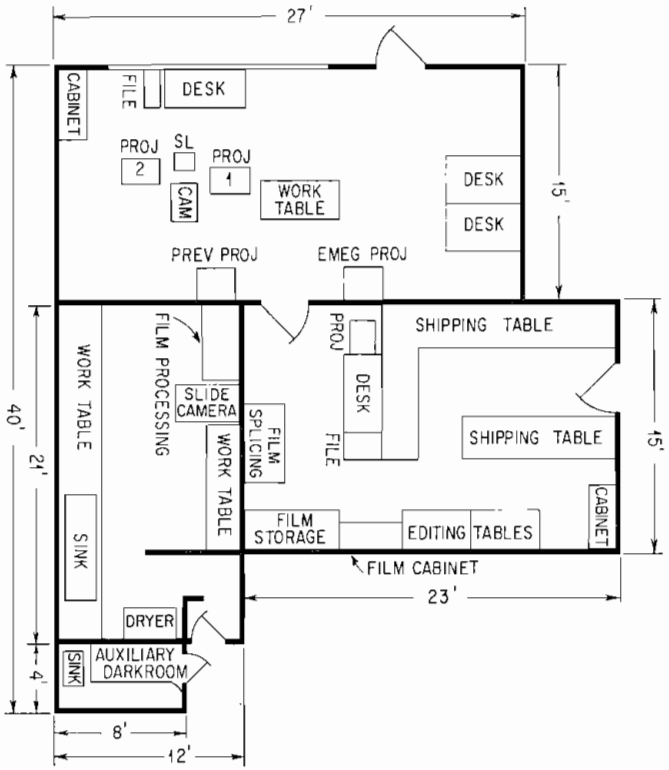


FIG. 6-2. WMT-TV Film Department and processing facilities.

Editing Area

An editing area should be situated best to accommodate last-minute, hurry-up changes so frequently encountered in the preparation of film for airing. The actual design of the editing table or bench will depend on local conditions and the particular likes and dislikes of the operating personnel. However, the following basic equipment will be needed:

One film splicer
One pair rewinds
One measuring machine
One small viewer
One editing table or bench
One 2- by 2-in. slide-file cabinet
One 3¼- by 4-in. slide-file cabinet
One open-face rack for storing large reels that will be aired during the day
One permanent-type storage cabinet
Twelve 2,000-ft flat steel reels
Twelve 1,600-ft flat steel reels
Twelve 400-ft flat steel reels
Fifty 100-ft flat steel reels
1,000-ft blank leader
One 14-in. steel rewind flange
One small screening projector
One 34- by 50-in. screen on tripod or wall mount

These are minimum requirements, and larger operations will call for larger quantities of the various items.

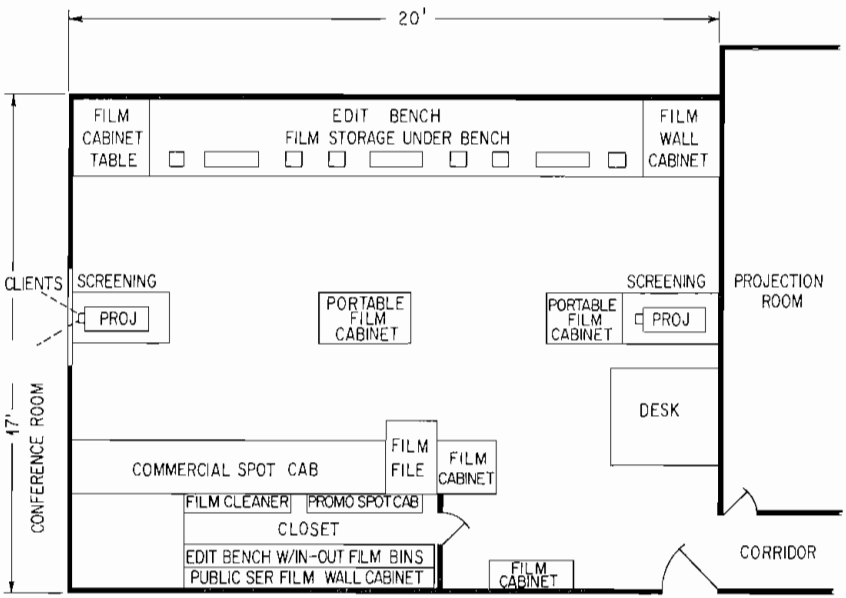


Fig. 6-3. WFMY-TV Film Department facilities.

Film-equipment Accessories

A word now about some of the film-equipment accessory items that are needed in the successful handling of film in a TV station.

Film Splicer. This instrument is used to splice film and should be considered as a precision instrument. A word of caution about film splicing! One faulty splice can cause a show, commercial, or presentation to be either a success or a "flop." Even though time is important in a television station, *there is no short cut to making a splice in film.* There are certain basic operations to be performed, in the proper order, and a definite amount of time is required to make a good splice. Faulty splices can usually be traced to dirty splices, incomplete removal of emulsion, wrong kind or old cement, improper adjustment of splicer, and insufficient drying time of the splice.

Scraping Tools. The usual instruments used in scraping off the emulsion of the film to be spliced are single-edge razor blades, emery board, and various types of commercial scrapers. Double-edge blades should never be used.

Film Cement. This is used in cementing the splice together after it has been prepared for splicing in the film splicer. It should be placed in a handy applicator bottle and when not in use kept tightly sealed. If the cement is allowed to become exposed to air for a period of time, its adhesive properties are destroyed and weak splices are sure to result.

Small Viewer. This is used for "quick" editing and is very handy for previewing short sequences, interchanging spots or scenes, and checking continuity of film strip or show.

Rewinds. Most TV projectors do not incorporate automatic rewinding mechanisms, so these, of course, are needed for rewinding film after it has been aired and for editing purposes.

Footage Counter. This is used for accurately measuring the time of a spot or any length of film. Previewing projectors are not normally equipped with sync motors, and accurate timing cannot be secured by projecting and timing with watch or clock. A 16-mm sound film is projected at a speed of 36 fpm, and by measuring the length

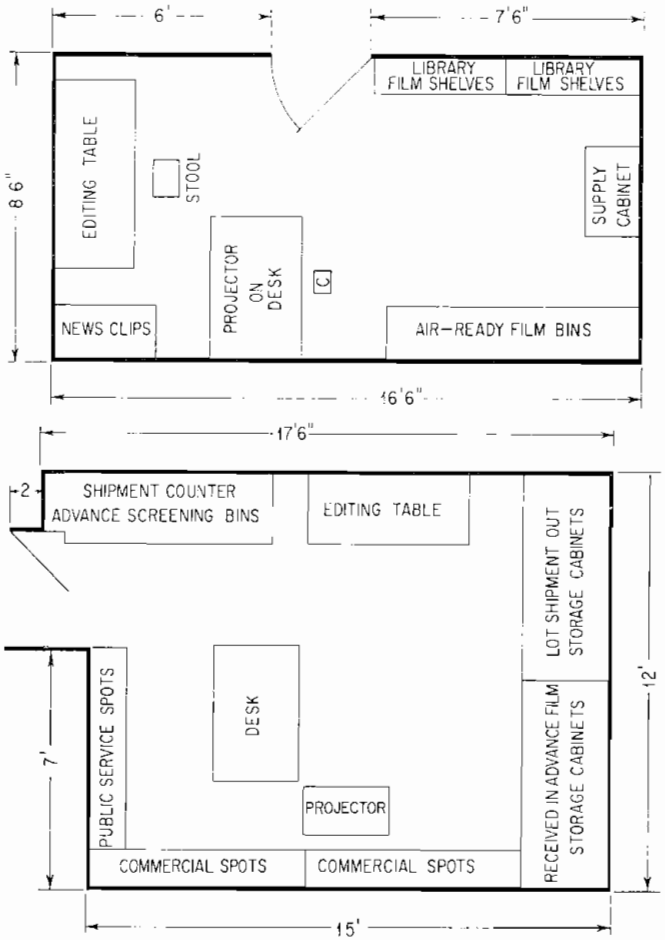


FIG. 6-4. WSPD-TV film editing room (above) and film shipping room. Facilities also include Film Department office and on-air projection room.

of the film on the footage counter, it is easy to determine the exact amount of time it will take to "air" the film.

Daily Storage Rack. Some form of rack must be provided in the projection room for the temporary storage of films to be "aired" daily. This rack should be able to accommodate at least a week's film supply. A very good method is to set up the file according to days of the week. This will enable the scheduling department to keep ahead of projection and save a frantic hunt at the last minute for a film that is to be aired immediately.

Slide-storage Cabinet. A filing cabinet to accommodate both 2 by 2 and 3¼ by 4¼ slides must be provided in the projection room for storing slides used every day or even occasionally.

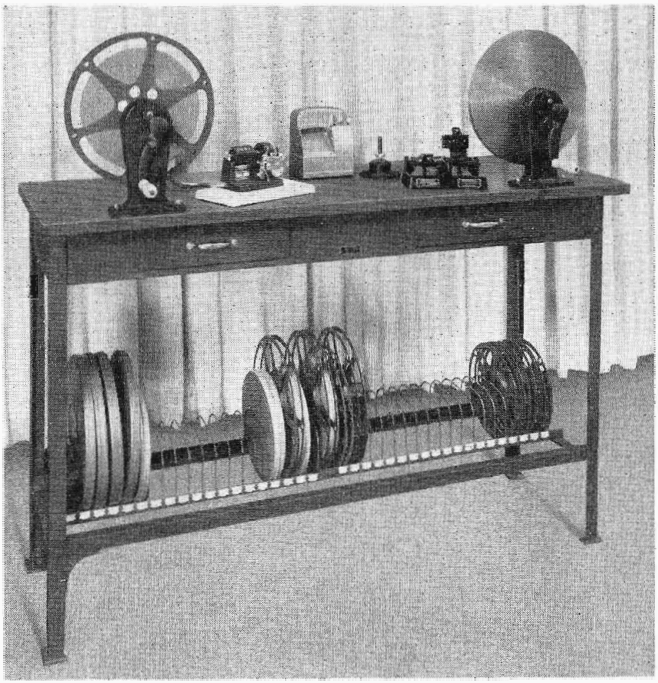
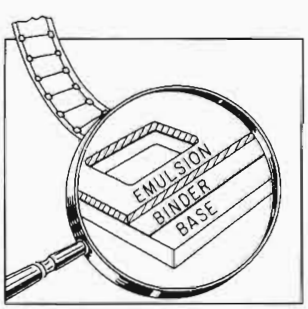
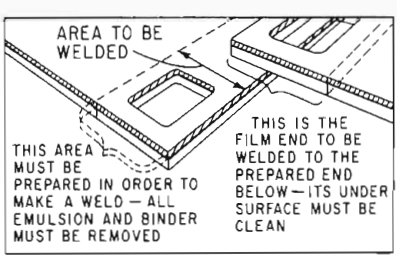


FIG. 6-5. View of a typical TV film-editing bench setup for television stations. Note that rewinds, splicer, viewer, and measuring machine are needed.



(LEFT) A MAGNIFIED AND SOMEWHAT EXAGGERATED DRAWING OF A SECTION OF MOTION-PICTURE FILM SHOWS THE PRINCIPAL LAYERS OF WHICH IT IS COMPOSED.
(LOWER LEFT) PREPARATORY TO SPLICING, THE EMULSION AND BINDER COATINGS SHOULD BE MOISTENED AND SCRAPED OFF. THE BASE SIDE OF THE UPPER PIECE OF FILM SHOULD BE WIPED WITH FILM CEMENT TO REMOVE ANY WAX OR OIL THAT MIGHT BE ON IT.
(LOWER RIGHT) A GOOD FILM SPLICE IS ACTUALLY A WELD. ONE SIDE OF THE FILM BASE IS DISSOLVED INTO THE BASE OF THE OTHER FILM.



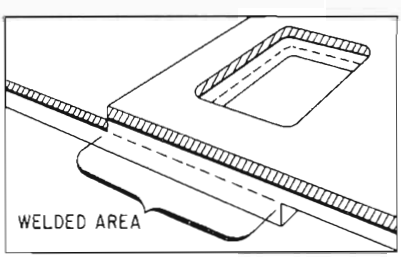


FIG. 6-6. A graphic illustration of the elements that go into a good splice. Reproduced, with permission, from the copyrighted Kodak publication "Industrial Motion Pictures."

"Screening" or Previewing

Volumes could probably be written on the subject of whether film should be previewed before it is aired. However, in pointing out some of the things that *have* happened and omitting many things that *could* happen, it will at least stimulate your thinking, and the decision rests with you as to whether film should be inspected or previewed before it is aired. Even today, stations receive film that is patched together with tape. You obviously are aware of what happens when you try to run a tape slice through a projector. It just won't work. Brand-new prints have been received with the sound track printed backward, wrong sound with wrong picture, picture printed backward, torn sprocket holes, commercials left in by the previous station, and many other difficulties too numerous to mention. In other words, you can't tell what the film is or its condition just by looking at it on the reel. It is suggested that some method of inspection or previewing be set up in your station. A complete previewing report form should be filled out for each film, listing all the necessary data that would be required by the Sales and Program Departments.

If space is provided for screening and previewing film, a small projector and screen will be necessary.

Scheduling Commercials

Just as in radio broadcasting, an accurate system must be used in scheduling spots. In TV the spots appear in the form of 10-sec, 20-sec, and 1-min lengths of film. If not furnished by the agency or supplier, leader must be spliced to these short lengths of film so they can be threaded in the projectors. Scheduling must provide all parties concerned with the proper information as to whether a spot is to be tacked on the head or tail of a certain show or run individually.

FILM MASTER CONTROL RECORD

Name of Series: _____ Received From: Ship To:

Day & Time of Telecast: _____ Contact: _____

How Normally Received? _____ Via _____ Delay Basis _____

	Incoming Way-Bill	Date Received	Show Name & Number if Film TVR Number if Kine	Telecast Date	Screen Initial	Time	Date Shipped	Out-Going Way-Bill	Remarks

Station _____

FIG. 6-7. One of the many types of film shipping and filing records developed by stations.

Receiving and Transshipping

A responsible party should be assigned these duties; they are important. An accurate receiving and transshipment record should be made on all film and should contain the following basic information: date, time received, source, type, postage paid or collect, disposition after airing, person receiving film, whether mounted on reel or core, shipping case, etc.

You will receive film from many sources. Most commercials will come from the advertising agencies or their suppliers directly to you. (In some cases, the client will furnish it.) Films will be in various quantities and physical size. Some of

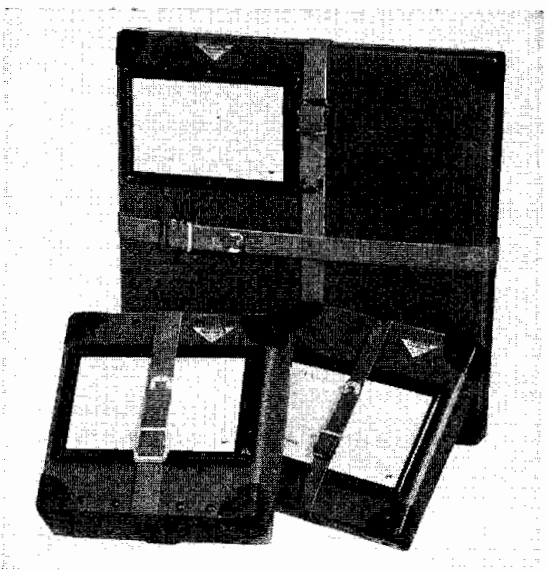


FIG. 6-8. Since films are expensive, a good sturdy shipping case is suggested.

them will be tied together, and it will be necessary for you to break these down, place them on small reels, catalogue them, and file for future reference. Others will come to you individually on plastic cores or sometimes on small 100-ft reels. A word about reels, especially the larger size, is appropriate. Inaugurate this rigid policy at the very beginning:

1. If you receive a film on a plastic core, ship it back on a plastic core after you are finished with it.
2. If you receive a film on a reel, ship it back on the same size reel after you are finished with it.

Reels are expensive! In other words, if you receive a film on a plastic core and ship it back on a professional reel, *you* lose. Over a period of a year, this can amount to a very sizable figure.

Under the present system of bicycling kinescopes, the following procedure is fairly well established by now. The network or originating station will film the show and release to various stations throughout the nation for a delayed play date. The network will advise each station where it should forward the film after it has "aired" the film and from what station it will receive its next film. So remember that you are just as dependent on a station for getting your show in good condition and on time as it is dependent on you for the same service. This is a responsible duty,

and conscientious personnel should be selected to supervise these duties. Many packaged shows and "kines" are open-ended, and space is allowed for insertion of local cutins or individual commercials. Needless to say, it is extremely important to see that the show leaves you in as good or better condition than you received it.

Mailing Charges

This brings us to the subject of express or mailing charges, which is an important item. For the film operation of an average station, the express charges for film directly chargeable to program expense will run between $5,000 and $7,000 per year. When you consider that kind of expense, the need for constant vigilance is apparent in selecting air express vs. regular express. Check and recheck your play dates, and whenever possible, ship and order all film to be shipped by regular express.

Slide-making and Film-processing Facilities

The local advertiser, along with many national accounts, cannot incorporate in their advertising budgets the price of having commercials made by a professional 16-mm producer. The average price of a 1-min, sound-on-film television spot made by a 16-mm producer is between $250 and $1,000 or more, depending on the type of spot desired. This means that the advertiser will turn to the television station operator for an economical answer. The station which can provide slide- and film-processing facilities will be in a better position to sell the air time. It is another instrument to help the Sales Department in providing a complete customer service and will help lower sales resistance. This is especially true with slides. Virtually every commercial or show will require very frequent changes in slides. Slides are inexpensive to make and if handled properly can provide the station operator with an additional source of revenue.

As mentioned previously, handling film in a television station is not difficult, but it does warrant serious preliminary planning in laying out the facilities.

Laboratory Practices on Films for Television [1]

These recommended laboratory practices on films for television are intended as a guide for both producers and laboratories engaged in production and processing of such films.

The recommendations contained herein are based on a committee survey of the literature and answers to a questionnaire sent to numerous people engaged in production, laboratory, and television operations.

Black and White

Photography and Lighting for Optimum Quality from Film. Any recommendations for laboratory practices on films for television should include certain recommendations for photography, lighting, and production. The laboratory can achieve the best results with the aid and cooperation of the people in these fields.

1. Negative (or reversal original) should be neither underexposed nor overexposed, as set forth in film manufacturers' recommendations. This is particularly important when the faces or essential shadow detail are unavoidably at extremes of the brightness range.

2. The use of close-ups and medium camera shots with only infrequent use of long shots is recommended. Wide-angle shots and long shots should be used only to establish perspective.

3. The ratio of key to fill lighting should be kept within the range of 1½ to 1 and 2½ to 1. The maximum brightness contrast in the scene, as read by reflectance meters, should preferably not be greater than 20 to 1 but in any case should not

[1] Taken from "Laboratory Practices on Films for Television" by The Association of Cinema Laboratories, Inc., Washington, D.C.

be greater than 30 to 1. Uniformity of fill lighting throughout the scene is advisable.

4. Night effects should be achieved by proper use of lighting and set arrangement, instead of requiring the printing down of day scenes for night effect, which is sometimes done for theatrical use.

5. Large areas of either white or black or any uniform density are not advisable.

6. Backgrounds for titles, trademarks and inserts should not utilize large expanses of uniform, unbroken density, especially if the background is either very light or dark.

7. Cutting back and forth between scenes where the background is alternately dark and light should be avoided. Alternate camera angles in a given sequence should have similar background brightness.

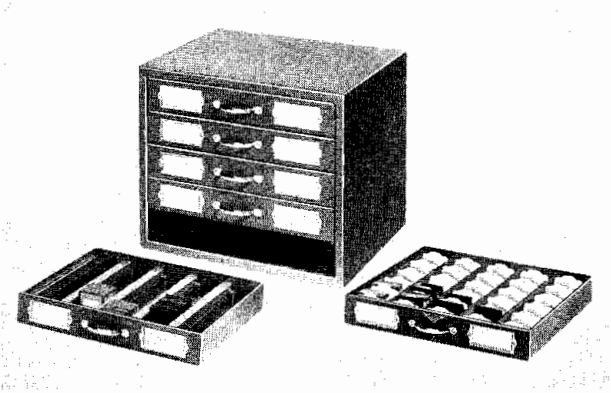


FIG. 6-9. The careful and orderly filing of slides in cabinets like the above is recommended.

8. Scenes should be composed and lighted so that there is always something in the scene lighter than the face or point of interest and, if possible, something darker than the face.

9. Camera apertures should cover sufficient frame area to be as large or larger than the television transmitted area. All important action should take place within the "safe-action area." All titles and other written material should be kept well within the "safe-title area." These areas are as follows:

	Transmitted area, in.	*Safe-action area, in.*	*Safe-title area, in.*
35 mm	0.792 wide by 0.594 high	0.712 wide by 0.478 high	0.621 wide by 0.466 high
16 mm	0.368 wide by 0.276 high	0.331 wide by 0.248 high	0.288 wide by 0.216 high

The recommended aperture size for the review room projector is 0.746 in. wide by 0.531 in. high, with rounded corners.

The safe-action area and safe-title area are those areas which will be seen on the majority of home TV receivers. Titles or important action should not extend into the corner areas, as these areas may be lost owing to the oval shape of some receiver masks.

Original Negatives. These should be developed to a normal Ib gamma of 0.65 to 0.70. The IIb gammas for a given Ib gamma will vary with film stocks and developers. Negatives should be free of excessive abrasion, dirt, drying streaks, and water spots within the laboratory control. Negatives should be developed with sufficient agitation so that directional effects are minimized.

Master Positives (Fine Grains). These should be developed to a normal print gamma of 1.4 (as read by the print-through method [2]) and should be printed so that the minimum highlight density is above 0.90. This density specification applies to all present emulsions. Introduction of new films now contemplated for this purpose could lower this value because of a lower toe break in the H & D curve.

Dnpe Negatives. These shonld be developed to a control gamma which will reproduce the contrast and gray scale of the original negative. On contact dupes, this is approximately a gamma of 0.65 as read by the print-through method. On optical dupes, this is approximately a gamma of 0.55. Negatives should be free of excessive abrasion, dirt, drying streaks, and water spots. Negatives should be developed with sufficient agitation so that directional effects are minimized.

Prints. Prints should be made on a positive stock and developed to a print contrast as required by the photographic contrast of the negative to be printed.

Where the negative is of consistently low image contrast, it can be printed and developed at the normal gamma of approximately 2.35 (gamma as measured by the print-through method). Where the contrast of the negative is of consistently high photographic contrast, it would benefit by being printed and developed to a lower print contrast, which may be as low as a gamma of 1.85 (gamma as measured by the print-through method). This contrast can be achieved by development of films such as Eastman fine-grain release positive film, type 5302, or Du Pont type 825 fine-grain release positive film to a lower than normal theatrical contrast or the use of low-contrast positive films such as Du Pont type 824 fine-grain low-contrast positive film or Eastman fine-grain duplicating positive film, type 5365, developed in a normal positive developer.

In the timing of prints, it is recognized that the printer lights for the numerous scenes comprising an edited film are selected from cinex tests or by visual evaluation of the negative. The resulting print intended for telecasting should appear somewhat higher in density in the highlight areas and somewhat lower in contrast than prints customarily intended for theater projection.

In prints thus timed with proper scene-to-scene balance, the majority of scenes should meet the following quantitative specifications:

Prints should be timed so that the face densities of normal middle-gray points of interest are a density of 0.75 ± 0.15. The minimum density of any area required to reproduce detail should be 0.40 or above. The maximum black of any area where detail is required should be 2.0 or below.

Prints should be timed so that the scene-to-scene balance of over-all density is as uniform as possible.

Prints should be free from any spots, streaks, or scratches not present in the negative.

Prints should be surface-treated with a lubricant or other protective treatment to ensure smooth projection and to minimize wear and scratches.

The conditions listed above apply with equal validity to prints made in 16 mm either by reduction printing or by contact printing from original or duplicate negatives.

Sound Negatives. These should be processed to negative gammas and densities to give minimum intermodulation distortion results on variable density and maximum cancellation on variable area when printed to the proper contrast for the picture in the television print. With 16-mm printing, variable-area sound negatives are recommended because of their inherent 5- to 6-db advantage in signal-to-noise ratio. Either 16- or 35/32-mm-width film negatives are acceptable for 16-mm sound printing.

Leaders. Leaders should be SMPTE television leaders with either a print of the sound negative or black-printed in the sound area starting at least 20 frames ahead of

[2] *Gammas as Measured by the Print-through Method.* This value of gamma has been specified because it takes into account variations in printing due to differences in color temperature and specularity of the printing light and difference in intensity level and the linear speed of printers. This is important because the effects of these factors are not the same for various types of print films.

The print-through gamma may be defined as that gamma value measured when the density of a gray scale is plotted on a horizontal axis, with the densities of the print from the gray scale being plotted on the vertical axis.

the first frame of picture in 35 mm and 26 frames ahead of the first frame of picture in 16 mm.

Color

Photography and Lighting for Optimum Quality from Color Film. Since there is no provision for contrast control in color-film negatives or prints available for use, more of the burden of producing acceptable color prints for TV falls on the photography and lighting. The lighting contrast should be kept to a level of 1.5 to 1 or 2 to 1, and unlit dark areas should be avoided. The exposure of the negative must be very carefully controlled in order to achieve maximum color saturation.

Most of the practices recommended for black-and-white photography are equally applicable here.

Negatives. Negatives should be processed as soon as possible after exposure. Developing should be done in accordance with the manufacturer's specifications.

Color Master Positives and/or Separation Master Positives. These should be exposed sufficiently to ensure a linear gray scale. Separation positives should be developed to the control gammas that will produce a balanced color internegative. Color master positives should be processed in accordance with the manufacturer's specifications.

Color Dupe Negatives and Internegatives. These should be made on the proper film stock for reproduction from Kodachrome, separation master positives, or color master positives. Exposure should be sufficient to ensure a good gray scale and give optimum color saturation. Developing should be done in accordance with the manufacturer's specifications.

Prints. Prints should be timed so that they are dark enough to give good color saturation but not dark enough to make shadows too dense. The equivalent gray density values should be about the same as those given for the best results in black and white.

A & B Printing. This is recommended for the making of dissolves and fades, in the manufacture of prints for TV from original negatives, or for the making of color master positives. This practice avoids the use of second-generation material intercut with the original material, which causes desaturation and mismatch of colors.

Black-and-white Prints. Black-and-white prints from color negatives should be made by first making a panchromatic master positive from the color negative, in accordance with the gamma and densities as set forth for a normal black-and-white master positive. A dupe negative is then made as with a normal master positive. The black-and-white prints are made from this dupe to television specifications as outlined previously.

All the other practices as outlined for black-and-white laboratory procedures apply also in color, 35 and 16 mm.

Fire Prevention [3]

Following an extended investigation, acetate-base film in the form of ribbon for motion pictures was listed by Underwriters' Laboratories, Inc., as slow burning, the fire hazard being classed as somewhat less than that of common newsprint paper in the same form and quantity. Motion-picture safety film having a cellulose acetate base is now being marketed for commercial and general use. It is claimed that this film has a greater projection life and is otherwise superior as compared with the older type of cellulose acetate film.

This type of film can be identified by the words "Safety Film" printed at frequent intervals along the edge. In case of doubt, acetate film can be distinguished from nitrate by a burning test, using only a small piece of film and burning it in a room where there is no film and no fire hazard. Nitrate film will burn fiercely; acetate film will burn quietly.

The ignition temperature of cellulose acetate is between 700 and 800°F, as compared with about 300°F, for cellulose nitrate. A temperature of about 500°F is re-

[3] Bulletin 283, National Board of Fire Underwriters, New York.

quired to produce the decomposition of cellulose acetate film. In the neighborhood of this temperature the evolution of fumes in material quantity occurs. These fumes are irritating and suffocating but not considered to be toxic under most conditions.

The decomposition of cellulose acetate film once started does not continue except under conditions where there is an external source of heat. On the contrary, in the case of cellulose nitrate film the decomposition continues when once started, even in the absence of external source of heat. This difference of decomposition is, therefore, of great importance from the fire and life hazard standpoint. Furthermore, great volumes of explosive and toxic gases are given off from decomposition of nitrate film, especially in a restricted supply of air, thus contributing to the life and fire hazard.

The rate of combustion of cellulose acetate film is relatively slow, and the amount of heat evolved is of a low order, being much less than that of paper or wood.

The most important safety factor with reference to cellulose acetate film is in its slow combustion, and any fire can be easily extinguished by the application of water or smothering, much in the same manner as fires in ordinary combustible materials.

The time will no doubt come when nearly all pictures will be on safety film, but there may be nitrate films in circulation for some time, and because of this, every precaution should be taken to avoid any relaxation in the regulations prescribed and methods imposed for the safe handling of flammable nitrate films. The safety factor supplied by the new acetate film can be taken advantage of by arranging its storage apart from any nitrate films. By this segregation, loss possibilities will definitely be reduced, and as nitrate inventories are progressively diminished, their isolated confinement will tend to control hazard possibilities further. In existing film exchanges, this segregation can be readily controlled by having separate film vaults for safety and nitrate films and marking their doors with the words "Safety Film" in *green* or "Nitrate Film" in *red*. Similar isolation of safety films from nitrate films can also be practiced using specially identified rooms for the safety film with such measures for protection against loss as may be desired. Small amounts of safety film can be appropriately stored in ordinary steel filing cases, but if the films are of high value, specially protected cabinets of the type designed for film storage should be given consideration.

In order to ensure the degree of safety now provided by the new film, it is suggested that all safety films be unmistakably identified by reel bands bearing in prominent letters the words, SAFETY FILM printed in bright green. All record cards and other control items that pertain to these films should also be printed in the same green color and bear as their main feature the words SAFETY FILM. In contrast, all flammable nitrate films should be equipped with reel bands printed in bright red with the words NITRATE FILM, with their record items correspondingly identified.

Film-handling personnel working under this plan for segregating the two types of film should take special care to prevent intermixture of the two types, and there should be exacting supervision of storage facilities to minimize all possible loss. By positive and intelligent management the safety factor provided by this new film base can immediately benefit all engaged in motion-picture-film activities. If such a plan for careful segregation is not followed, any place where both types of film are handled should follow for all film the safety precautions prescribed for nitrate film.

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Part 7

AUDIO AND VIDEO SPECIAL EFFECTS

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VISUAL EFFECTS

Electronic Switching Special Effects

In television video practice, the term "special effects," by accepted usage, is applied to techniques for creating visual effects which are beyond the capabilities of the normal complement of facilities found in the standard minimal studio. The purpose of such effects may be purely artistic or may be simply to aid the objective presentation of information. Electronic special effects can also be of economic advantage when they permit realistic simulation of pictorial material that would otherwise be prohibitively expensive.

The major category of electronic special effects is the use of electronic switching for simultaneous display of portions of two or more video signals by a pattern division of the raster. Other types of visual special effects are largely techniques for introducing distortions of the picture image, by either optical or electronic means.

Electronic Switching Techniques

Since the television picture is transmitted by a time-sequence scanning method, it is evident that appropriately timed instantaneous switching between two video signals can produce the visual effect of a geometric division of the raster area so that portions of each picture are displayed. Conventional electronic switching techniques readily permit the rate of switch required (on the order of 0.2 μsec). Methods of using this

technique are categorized by the source of the signal which determines the pattern of the display. In the most elementary application, the "wipe" keying waveforms are generated by pulse circuit techniques to create geometric patterns. It is also possible to obtain keying waveforms of any desired pattern by processing video signals from conventional camera equipment. The simplest form of this technique uses an independent camera trained on silhouette art work of the desired pattern, so that the resulting video signal closely resembles a pulse keying waveform and requires a min-

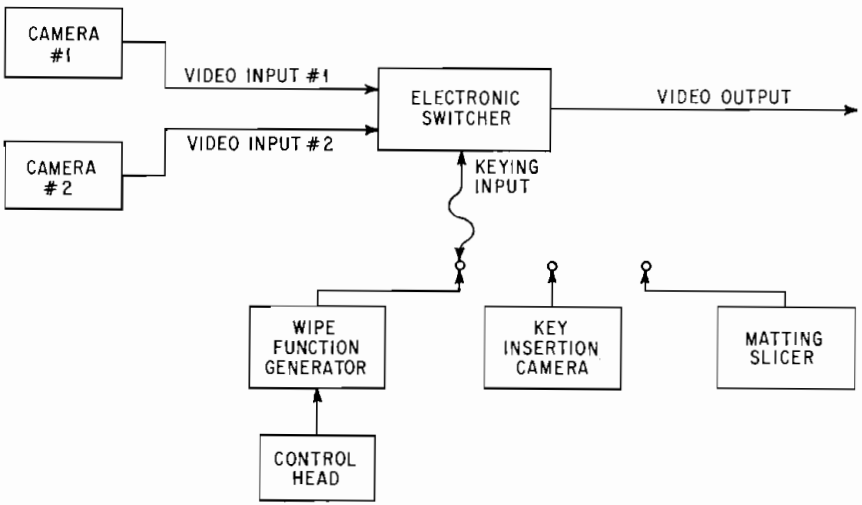

FIG. 7-1. Electronic switching special-effect system.

imum of processing. The most advanced application is "matting" (also called "montage"), where the keying signal is derived from one of the two video signals to be combined. This permits placing a subject visually into any background scene desired.

The arrangement of equipment components for these three forms of electronic switching effects is shown diagramatically in Fig. 7-1.

Electronic Switching

The circuit which is fundamental to any special-effects switching system is the electronic switching circuit itself. Functionally, this circuit takes three input signals, the two video signals and the keying pattern signal, and produces an output video signal which combines the two video signals in accordance with the area division established by the keying pattern signal. The keying pattern signal is assumed to be a two-valued function, or pulse signal. Switching circuits usually, however, include a clipper in the key-signal input channel to remove any noise or shading components that may be present. This permits the use of camera-generated signals developed from a silhouette art work without further prior processing.

The usual circuit arrangement (Fig. 7-2) employs a pair of gate tubes, such as the 6AS6, as the switching element. The keying signal, after clipping, is phase split so that it can be applied in opposite polarity to each of the two gate tubes. The gate-tube outputs are paralleled and fed to the output amplifier. Stability considerations usually require somewhat extensive auxiliary circuitry for clamping and blanking purposes. A chronic problem exists in the timing and shape of the opposed-polarity keying pulses, which should be precisely symmetrical to avoid a gap or overlap at the instant of switch. More advanced and complex circuitry has been applied to the solution of this problem, particularly for the matting application.

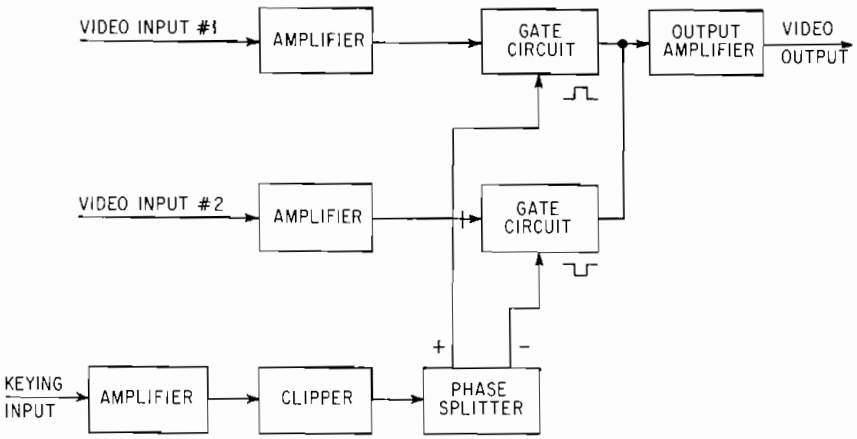

FIG. 7-2. Electronic switcher—typical circuit plan.

Wipe Function Generation

A wide variety of keying patterns can be electronically generated by conventional pulse circuit technique. Such signals are applied in two general ways (1) for a transition from one picture to another and (2) for a steady display of portions of two (or more) pictures.

The term "wipe," which originated as the description for the most elementary form of geometric transition (in which a dividing barrier sweeps across the raster with the new picture appearing behind it as it progresses), is commonly applied as a generic term to any system for electronically generating patterns of raster division. A "split-screen" is, of course, a stationary wipe. Some wipe effects actually involve more complex forms of motion, such as an iris action.

For the transition application, a variety of patterns are commonly employed, the simplest being the horizontal (Fig. 7-5) or vertical wipe. Diagonal wipes (Fig. 7-7) are also common. More complex wipes are possible with wedge and irregular shapes.

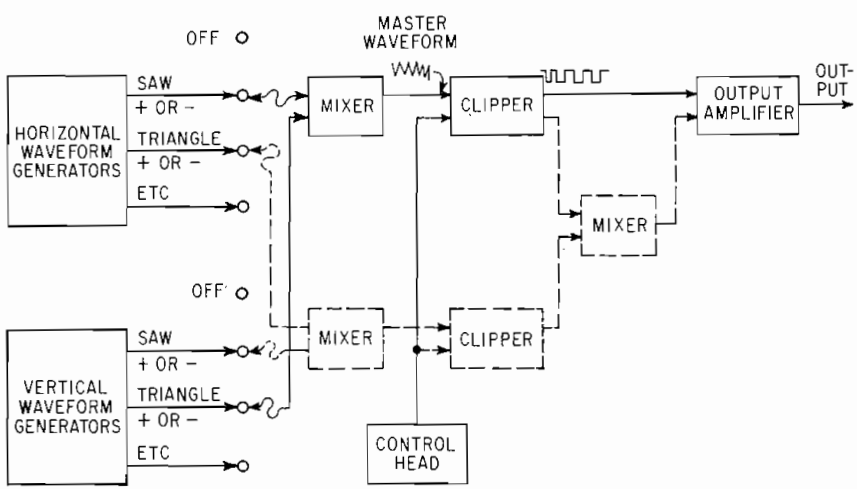

FIG. 7-3. Wipe function generator—typical circuit plan.

The box (Fig. 7-8) and the diamond are the most common shapes for the iris type of motion. A wide variety of more complex patterns can be electronically generated, including "venetian blind," "checkerboard," circular, star, triangle, etc.

Of the static patterns which are employed to display portions of two or more pictures simultaneously, the horizontal split screen (Fig. 7-5) is the simplest and is frequently used. Another popular pattern is the wedge (Fig. 7-6), in which a rectangular segment in one corner of the picture is keyed off, usually for insertion of the face of a commentator. A vertical split screen is sometimes employed to

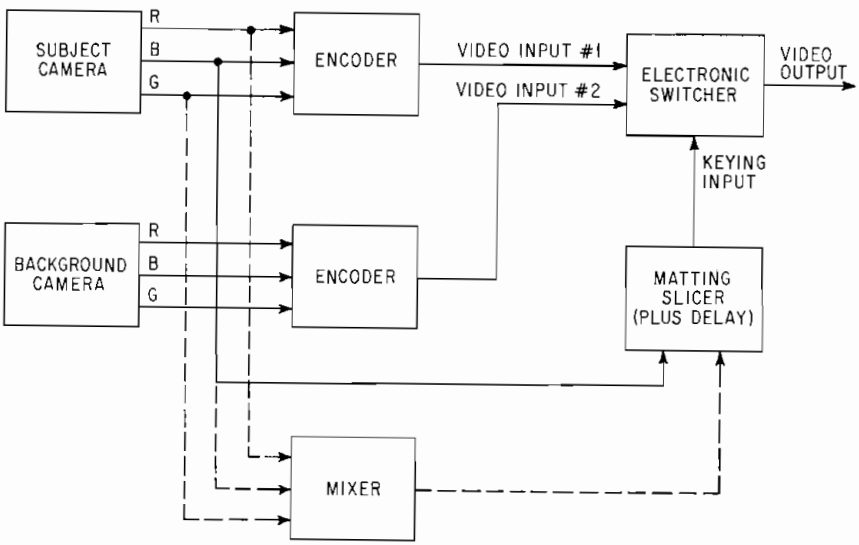

Fig. 7-4. Color matting system—block diagram.

insert written material in a strip at the bottom or top of the picture. On occasion, for planned news coverage, more than two signals have been combined, and as many as five pictures have been combined to display simultaneously the faces of news commentators from widely scattered locations. When pictures are so combined from different locations, it is, of course, necessary to phase-lock the sync generator at the combining location. When pictures from more than two points are combined, a chain hookup is needed so that each successive point can phase-lock its sync generator and insert its contribution to the final combination.

Circuitry for the generation of wipe keying signals usually employs certain principles that are common to all practical designs. A typical block diagram is shown in Fig. 7-3. In the typical system, vertical and horizontal waveforms are generated as elements for the synthesis of keying signals. The simplest patterns use horizontal and vertical sawtooth and triangle. For more complex patterns, multiple frequency and parabolic waveforms can be used as well. The wipe pattern is generated from a master waveform, which may be a combination of basic horizontal and vertical waveforms, by double clipping (or "slicing") to develop a pulse signal whose timing will depend upon the clipping level. The motion is thus imparted to the pattern for transition effects by manually changing the clipping level through the amplitude range of the entire master waveform. Some patterns require independent clipping of two waveforms with following mixing and clipping (in effect, logical mixing) of the two resultant pulse signals. Additional combinations of mixing circuits and basic signals make possible an extremely wide variety of patterns. In elaborate

systems, the major design problem becomes the switching arrangement for selection of a large number of circuit combinations.

FIG. 7-5. Horizontal wipe or split screen.

FIG. 7-6. Wedge insert.

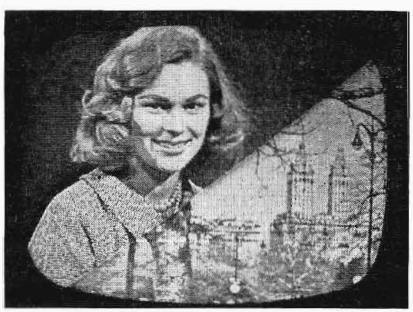

FIG. 7-7. Diagonal wipe.

FIG. 7-8. Box wipe.

FIGS. 7-5 to 7-8. Wipe and split-screen effects.

Keyed Insertion

Where an irregularly shaped pattern that cannot readily be generated electronically is desired as a split-screen or wipe pattern, it is necessary that the keying signal be produced by an image-scanning process. Conventional camera equipment can be used for this, either live or film. Flying-spot scanner equipment is particularly applicable to this application but has yet to be applied on a commercial scale.

The major application of keyed insertion has been for trick "split-screen" effects. There has been limited use for transitions, generally using a live camera with a zoom-type lens to produce the pattern motion. Film animation is another possible source for moving patterns, but its cost has seldom been considered justified.

Fixed keyed-insertion patterns are usually derived from live cameras with silhouette art work or with film cameras using projected slide or opaque material. In using a live camera with the usual type 5820 image orthicon, an important operating consideration is the lens exposure setting, since excess light produces electronic halation which can readily negate the usefulness of the camera chain output video signal for keying purposes.

Any camera signal requires double clipping to eliminate noise and shading components before use as a keying signal. The switching circuit will normally include sufficient clipping, but in some systems the key-insertion signal is fed through a portion of a wipe signal generator circuit to process it adequately.

The component pictures and results of a key insertion process are shown in Figs. 7-9 to 7-12. Figure 7-9 is the background camera, showing a map of the United States. Figure 7-10 is the key-insertion camera, a silhouette outline of the state of

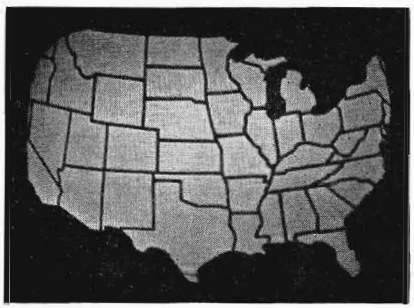

FIG. 7-9. Background camera picture.

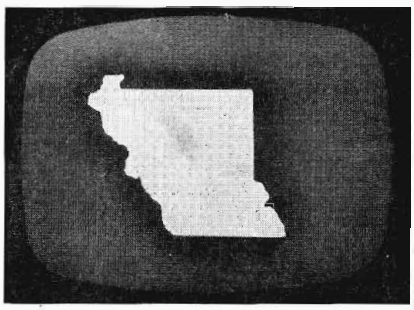

FIG. 7-10. Key-insertion camera picture.

FIG. 7-11. Subject camera picture.

FIG. 7-12. Final key inserted picture.

FIGS. 7-9 to 7-12. The key-insertion process.

Missouri. Figure 7-11 shows the picture from the subject camera. In the final product, the girl appears within the state outline in Fig. 7-12.

Matting

The object of the matting process is to insert a subject (usually human) into a background scene, sometimes for a trick effect but usually for the purpose of creating the illusion that the subject is actually in the scene. When skillfully applied, this process can offer an advantage of economically creating effects that would otherwise be prohibitively expensive.

To achieve matting, the subject is televised by a live camera against a flat backdrop of either black or white. If the video signal produced by the subject is completely differentiated in level from the backdrop, the camera signal can be properly clipped to produce the keying signal needed for matting. That is, if a black backdrop is used, all parts of the subject must be lighter than the backdrop; with a white backdrop, the subject must be entirely darker. The keying signal derived from clipping the subject signal is supplied to an electronic switch circuit, along with the subject signal itself and the desired background signal. This process places a more stringent demand on the electronic switching circuitry as regards the time of switch than does the wipe application, since a noticeable gap or overlap between subject and background is an artificial effect tending to destroy the desired illusion of continuity. Delay compensa-

tion usually enters into the system, since the keying signal "punches a hole" into the background into which the subject must fit with precision and will do so only if time concurrence is achieved between the two signal paths.

In actual practice, the achievement of successful matting faces such obstacles that great care must be exercised in its use, and as a result, it has not become a widespread or popular practice. The operating characteristics of the image orthicon are such that small dark areas of most subjects, even though not actually of less surface brightness than the backdrop, produce video signal voltages below that of any black background level that can be maintained. The white-background method has a tendency to distort the image of the subject by halation around its edges and also presents a lighting problem in the elimination of shadows on the backdrop. When the background must include the floor, the maintenance of a satisfactory reflectance on a surface that is walked upon is always a problem. The lighting must, in any case, always be set up with extreme care. When the setup is not sufficiently optimized, there is always danger of the appearance of "bleeding" resulting in the background scene appearing through an apparent hole in the subject—often an embarrassing mishap when it occurs. These factors have combined to make matting a highly specialized procedure, used only when the expense of a careful setup warrants it or for tricks or "gag" effects where mishaps can be tolerated.

Color Matting

Although it may appear paradoxical, matting can be achieved with greater facility in a color-television system than it can with monochrome. In the monochrome system, the signal-level separation between the subject and backdrop must be obtained from brightness, or luminance, information only. With color, an additional dimension of separation becomes available—chrominance. The result is that successful matting can be accomplished in a color system under much less stringent conditions than are required for monochrome. The usual practice is to use a backdrop of a bright primary color, sufficient to produce full "white" level in the corresponding channel of the system. The primary to be used is selected on the criterion that it be complementary to the predominant color of the subject. Since human subjects are most often used, blue is usually the optimum backdrop color. With mixing techniques, colors other than primaries, such as cyan, can also be used. An essential precaution is to avoid any use of colors approximating the backdrop color in the costume of the subject.

The matting-system layout in color differs from monochrome only in keying-signal source and processing, as shown in Fig. 7-4. The two video inputs to the electronic switcher are the encoded signals of the subject and background pictures. Instead of the subject signal itself as an input to the slicer, however, the desired primary component, before encoding, is used. This may be either an actual primary, such as the blue signal, or a matrixed combination.

Electronic-camera Distortions

Certain special effects for dramatic or trick purposes can be created by means of simple modifications to camera equipment or by the use of unorthodox operating techniques. The following are the most common and easily accomplished:

Scanning Reversal

Horizontal and vertical scanning are easily reversible by the installation of DPDT toggles switches directly in the yoke circuit. The effects made possible are the geometric inversion of the picture and horizontal reversing, which can be used for superimposition of mirror images.

Scanning Size Change

It is possible to produce sudden changes in picture size by a switch which changes scanning amplitude.

Polarity Reversal

Negative pictures can be produced by inverting the video signal, usually accomplished at the output of the camera video preamplifier. The simplest circuit technique is to change the output amplifier from plate-coupled to a cathode follower, or vice versa.

Ripple

The superimposition of an audio-frequency component on the camera horizontal scanning current causes a rippling motion in the picture which can be used dramatically to suggest dreams, fading of consciousness, etc. A frequency close to 60 cps or

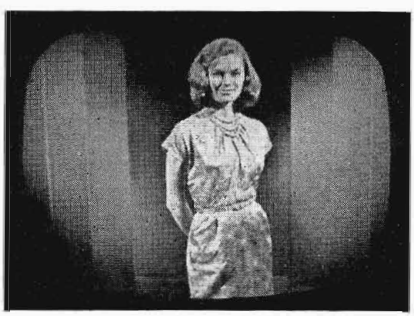

FIG. 7-13. Normal picture.

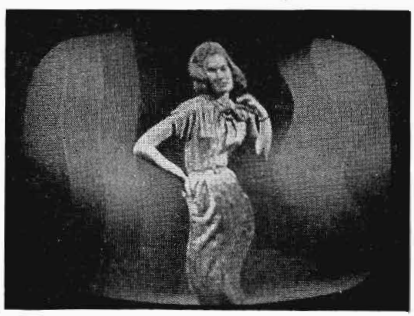

FIG. 7-14. Rippled picture.

FIGS. 7-13 to 7-14. The ripple effect.

its harmonics produces a suitable motion effect. The audio signal is normally injected onto the grid of the horizontal scanning output tube. The effect is illustrated in Figs. 7-13 and 7-14 showing normal and rippled pictures, respectively.

Unorthodox Operating Techniques

An easily produced picture distortion with an image orthicon is obtained by reducing beam current below the value necessary to discharge highlights. The effect is to wash out all highlights in the picture in a manner that can appear quite weird for a "dream" or "bleary-eyed" effect.

Video operators can use their ingenuity in a variety of ways to produce odd effects that a director may desire. Another example is the reduction of target voltage on an image orthicon, changing the gray scale so as to suggest a night scene. Deliberate display of the dynode structure by low exposure and high beam current is another possibility.

Optical Effects

Many very interesting effects can be achieved by attaching various optical devices to the camera. Images can be multiplied, rotated, inverted, flared, distorted, and arranged in a variety of different patterns. Among the devices used to perform these effects are several types of prisms, kaleidoscopes, filters, and etched lenses.

Multifaceted Prisms

One group of prisms is referred to as the "multifaceted" prisms because of the multiplicity of plane surfaces on the face of the optical element. These prisms are placed between the subject and camera lens and produce one subject image for each

plane surface on the face of the element and in a pattern corresponding to the arrangement of the surfaces. A diagram of a simple prism which produces three images is shown in Fig. 7-15. The center section *C* of this optical unit consists of an optical flat and passes reflected light rays from the subject S without deviation to the camera objective lens, which focuses it in the normal manner on the focal

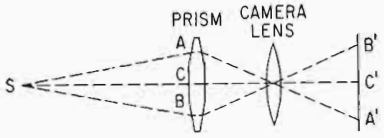

FIG. 7-15. Three-faceted prism.

FIG. 7-16. Multifaceted prism.

plan at *C'*. Rays from the subject S are bent by the wedge section at *A* at such an angle as to be received by the camera lens and focused on the focal plane at *A'*. In a similar manner, the subject is redirected by the wedge section at *B* to focus a third image on the focal plane at *B'*. Figure 7-16 shows a picture taken with a little more complex prism of this type with five wedges instead of two surrounding the central facet.

Dove Prism

Another useful prism is the Dove prism. This prism is placed in front of the camera objective lens in such a manner that its longitudinal axis coincides with the optical axis of the objective lens. Then rotating the Dove prism around its longitudinal axis will cause the image in the focal plane to rotate. Figure 7-17 shows

FIG. 7-17. Dove prism.

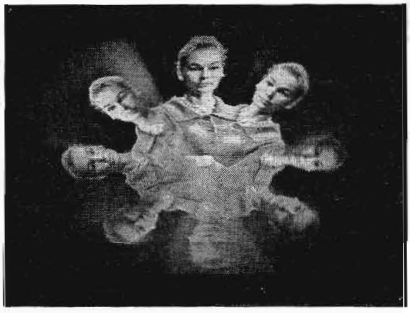

FIG. 7-18. Kaleidoscope.

this rotation in progress. It is interesting to note that for every degree that the Dove prism is rotated, the picture image rotates 2°. In this manner, turning the Dove prism through 90° will cause an upright picture to rotate through 180° and become upside down. Another 90° rotation of the Dove will complete the 360° rotation of the image and bring it back to its original upright position.

Kaleidoscope

One of the oldest optical effect devices is the kaleidoscope. By utilizing the basic arrangement of the two mirrors which form a V and shooting through it, studio scenes and performers can be picked up in all kinds of kaleidoscopic patterns. The number of images produced will depend upon the angle formed by the two mirrors and can be determined by dividing 360° by the angle. For example, if the angle is 60°, six images will be formed. Figure 7-18 shows a picture taken with a kaleidoscope whose mirrors formed a 45° angle. While smaller angles will produce more images, it should be noted that there will be a greater difference between the sharpness and contrast of the unreflected image at the top and the last generation of rereflected images or image at the bottom. Even though front-surfaced mirrors were employed in the kaleidoscope with which the illustration was taken, there is a marked difference between the top and bottom images.

Filters

Color and polarizing filters are also useful in the production of effects. In black-and-white television, radical changes in the gray scale of costumes, graphic arts, scenic elements, and make-up can be created by the use of color filters. The lines

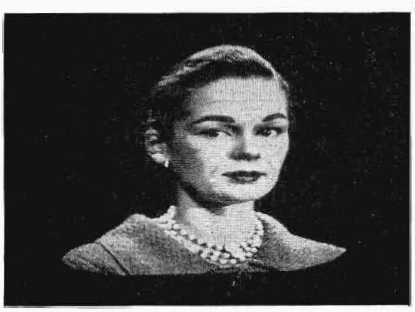

FIG. 7-19. Blue filter.

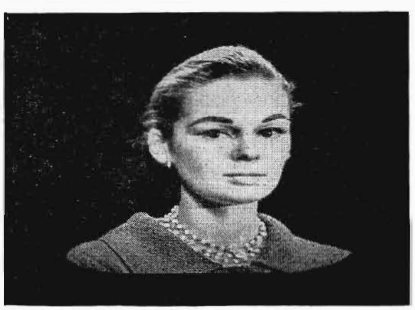

FIG. 7-20. Red filter.

in the face of the girl shown in Fig. 7-19 were applied with a red make-up pencil and a "blue" filter on the camera which took the picture made them appear very bold. Without any change in make-up, the blue filter was replaced with a "red" filter with the result as shown in Fig. 7-20. By adding one filter as the other is removed, in one continuous operation, actors can be made to appear to age or otherwise become transformed right on camera.

In color television, the filters quite obviously change hue and can be used only when there is some particular advantage in disturbing the color balance.

Polarizing filters also produce effects when used in conjunction with polarized light. Since most studio light is not polarized and much of what is, is of random polarity, it is usually necessary to employ polarizing filters on light sources to produce the effect. For example, two words on a sign might be lighted with polarized light of different polarities, one horizontally polarized and the other vertically polarized. Rotating a polarizing filter on the camera would then produce the effect of the words fading in and out alternately.

Etched Lenses

Another type of effect can be produced with etched lenses and fine-meshed screens. Ordinarily, great care is taken to avoid scratches on lenses, but in this particular case, lenses or optical flats are etched on purpose with some pattern such

as a series of concentric circles, dots, or crosshatching. The etching is fine enough not to cause much interference with picture quality except to deflect highlights in such a manner as to produce odd patterns of light flare. The picture shown in Fig. 7-21 illustrates the effect and was taken with a Hartley lens attachment.

Projected Backgrounds

For many years, scenic slides have been projected on the stage and in motion pictures to provide scenic backgrounds. The technique has been adopted by television and is commonly used to make fast background changes, provide backgrounds where photographic realism and authenticity are essential, and produce graphic or pictorial illustrations on news and special-events types of shows as well as commercials. In this latter group, the purpose is to "tie in" narrator and picture illustrations in one camera shot to permit the narrator to point to graphics or scenic features and provide a transitional shot between narrator and picture illustrations.

Rear and Front Projection

Although projected backgrounds are mostly rear projected, they are to a lesser extent projected from the front. When they are front projected, the projector is placed overhead and directed down on the front of the background screen at a

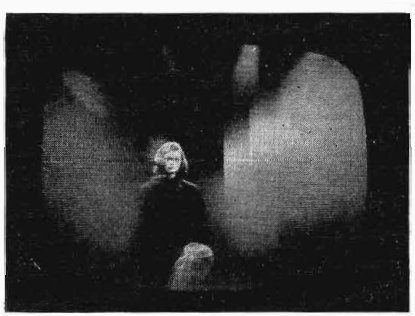

FIG. 7-21. Hartley lens.

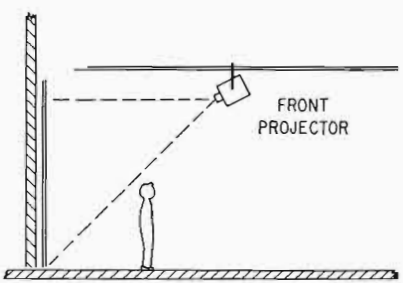

FIG. 7-22. Front projection setup.

steep angle. While this eliminates the need for space behind a screen, it results in some loss of playing area immediately in front of the screen where the actors cannot play without interfering with the beam of projection as illustrated in Fig. 7-22. In addition, some "keystoning" will result from the axis of projection forming less than a 90° angle with the plane of the screen, and this may require a compensating predistortion of slides or provision for an optical correction.

While rear projection must of necessity be used with translucent screens, front projection can and customarily is used with opaque screens. Because of the superior diffusive characteristics of opaque screens, the "hot-spot" problem normally associated with rear projection, in which the center is bright or the side toward the camera is off axis, is not experienced with front projection. Cameras can dolly from one side to the other without apparent change in the light distribution of the projected picture.

Projection Lenses

To present the camera with the most uniform distribution of screen illumination in the case of rear projection and the least amount of keystoning with front projection requires the use of projection lenses of long focal length. Unfortunately, these lenses create the longest paths of projection, and this consumes much space

behind the screen in the case of rear projection and much playing area in front of the screen with front projection. However desirable it may be to produce this technical quality, the long lenses seldom can be used in live television studios because of the ever-present problem of space. Fortunately, because of the operating characteristics of the camera picture tube (with highlights leveling off above the knee of the characteristic curve), unevenness of light from lenses of short focal length is not so much of a problem in television as in motion pictures and the quality is generally acceptable.

Light Sources

Both incandescent lamps and carbon arcs are used as sources of projection light, with the former preferred and most commonly used because of operating simplicity. Except for miniature screen applications, the minimum useful lamp for black-and-

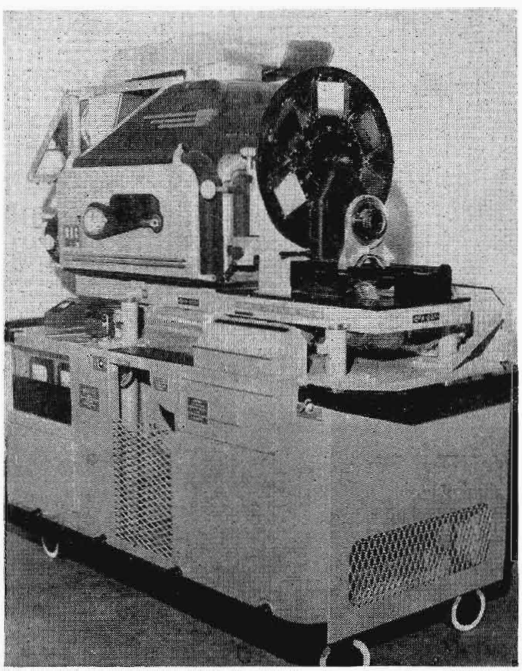

FIG. 7-23. Arc slide projector. (*Courtesy of NBC.*)

white television is the 2 kw. For color, requiring about three times as much light, the 2 kw is of little value and even the 5 kw has very limited usefulness.

For the very large black-and-white backgrounds, incandescent sources are inadequate and carbon arcs, such as the one shown in Fig. 7-23, must be used. As an example of the limits encountered, a fairly efficient projector employing a 5-kw lamp delivering 7,000 lumens on a 9- by 12-ft screen would produce approximately 70 ft-c on the projector side of the screen and, using a fairly typical translucent screen with good diffusion and a transmission factor of 50 per cent, about 35 ft-c on the front or opposite side. This latter measurement then represents the maximum illumination possible in the clear areas or brightest highlights in the slide. Assuming that the actors are lighted for black and white with a base lighting of 100 ft-c, faces with a reflectance of 35 per cent would be as bright as the brightest background-scene

highlights. Considering that a 9- by 12-ft background is not large, the capabilities of incandescent projectors becomes apparent. In actual practice, though, studio lighting levels are lowered somewhat and lens aperatures opened so that screens of 200 sq ft or more can be used satisfactorily.

Slide Sizes

Of the slide projection equipment, some projectors use 4- by 5-in. slides and some use the 3¼- by 4-in. slides. There is little difference in the size of the slide and also the performance of the equipment. Generally, larger slides are easier to cool, but the difference here is too small to be very significant. Equipment employing slides smaller than 3¼ by 4 in. is generally intended for the visual aid field and, except for use with the miniature screens, has little application for background projection.

Film Projectors

Both 16- and 35-mm film projectors are used for moving backgrounds. A typical 35-mm projector in its housing and with its companion operating booth is shown in Fig. 7-24. Because of the inadequacy of incandescent film-projection lamps for any-

FIG. 7-24. 35-mm rear projector. (*Courtesy of CBS.*)

thing other than very small screen applications, carbon arcs are used almost entirely. The amount of light which can be projected through a small 16-mm film frame without burning it is very limited. Something like 2,000 lumens is typical and satisfactory for small screen applications in black and white but of little value for color.

For color, arc sources are too blue and must be heavily filtered with something close to an Eastman Kodak 85-B Wratten filter, depending upon the color of the screen. If yellow flame carbons are used, less filtering is required and consequently less light is lost.

Some film moving-background projectors operate at standard sound speed, 24 frames per second, while others run at 30 frames per second. The 24-frame projectors use a two-three pull down, alternate frames being scanned for two and three

fields, respectively, and commonly have a 37½ per cent application time. While more expensive, sound tracks can be used, and the running time of film will not be altered.

Projectors that run at the 30-frame rate are generally less expensive because a standard movement is used with only the gearing and/or motor speed changed. The application time is 50 per cent for 90° shutters and longer for smaller shutters. Sound tracks cannot be used at this speed, and picture material, if shot at the 24-frame speed, will move somewhat faster.

Screen Materials

The performance of rear projection depends to a considerable degree upon the quality of the screen used. One of the desirable characteristics of a good screen is high light transmittance. A screen which transmits a small percentage of light wastes projection light which, as pointed out previously, is commonly in short supply. In addition to transmittance, a screen material must have good diffusive properties. For example, light passes freely through chicken wire and window glass but no diffusion takes place and consequently no image is formed. Diffusion should go beyond just forming an image but should be as complete and uniform as possible. Poor diffusion results in a severe bright area, or "hot spot," surrounding the point at which a straight line between camera and projector passes through the screen. As the camera arcs to one side, the hot spot follows and the opposite side of the screen gets quite dark. Figure 7-25 shows curves resulting from measurements of three commonly used screen materials. With the light source behind and perpendicular to the material tested, brightness measurements were made on the opposite side. As indicated, readings were taken at angular intervals between the perpendicular and plane of the screen, and since the material exhibited symmetrical characteristics, only one curve is shown. While material *A* showed high transmittance but poor diffusion, material *B* shows a good diffusive characteristic but rather low transmittance. Although material *B* would present the camera with even brightness over the screen area, the waste of projection light would be uneconomical and limit the size of the picture which could be produced. On the other hand, material *C* shows both a good diffusive characteristic and good light transmittance. Of the three materials, *C* is definitely superior.

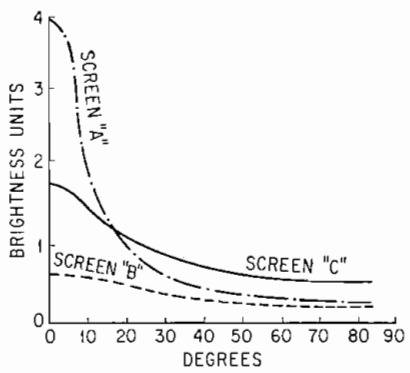

FIG. 7-25. Diffusion characteristics of screen materials.

Another consideration is the quality of reflectance. It is quite obvious that the reflectance must be diffuse, or nonspecular, to prevent the camera from picking up set lights, but in addition, it is desirable that the reflectance be kept low in order to maintain picture contrast. To reduce reflectance, it has been common practice in black and white to color-screen materials. While this reduces reflectance, it also reduces transmittance. Whether this is a good practice depends to a considerable extent upon the ultimate use. If the screen is used where spill light can be controlled, the problem of contrast has little significance and the undyed material with higher light transmittance is better. Where this control over spill light cannot be maintained, then the sacrifice of transmittance for lower reflectance may be a good one.

Beyond the optical requirements, the physical characteristics of the materials are of some consequence. It is customary to expect rear screens to be shifted around like studio scenery, and for this practice it is desirable that screens be made of lightweight, reasonably rugged materials. Some of the plastics, such as polyethylene and

polyvinyl chloride, have been found suitable. Another excellent material is latex. While this latter material has excellent optical properties, it is somewhat more fragile than the plastics. Just how durable the material must be is something that can best be decided after the actual application is known.

Lighting for Rear Projection

In addition to good equipment, the proper employment of studio lights is also essential to the successful use of rear projection. It is important that "key light" be kept off the screen. To do this it is necessary for the actor to play a distance at least

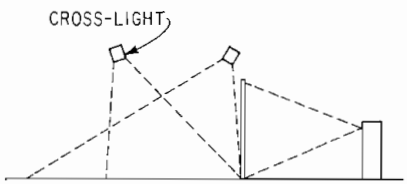

FIG. 7-26. Cross lights on rear projection set (elevation).

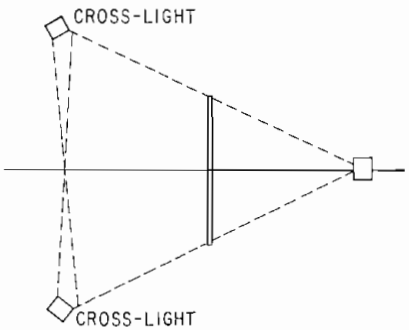

FIG. 7-27. Cross lights on rear projection set (plan).

equal to his height in front of the screen just as he would—or should—with other background scenery. Then it may be necessary to direct the key lights in from the side and employ them as cross lights as in Figs. 7-26 and 7-27. The esthetics of this may be questioned, but the end result seems good enough to justify the means. "Back lights" as indicated in Fig. 7-26 should be barn-doored to keep spill off the screen. And finally, the placement of the "fill light" is important. Fill light should be placed on a line which in plan is an extension of the axis of projection right through the screen into the playing area and in elevation as in Fig. 7-28. With the fill light

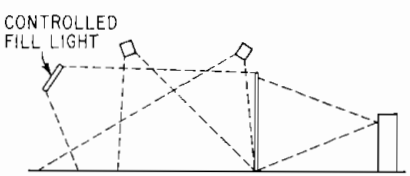

FIG. 7-28. Fill light on rear projection set.

set up in this manner, the camera will see a bright area on the screen corresponding to maximum reflectance of this light. By a fortunate coincidence, this bright area corresponds rather closely to the projection hot spot. Since the fill light has the effect of reducing contrast and since it reduces it most in the hot-spot area where contrast is highest, the proper setting of this light will greatly minimize the hot-spot effect. While this fill-light setup is not offered as a panacea for the hot-spot problem, it is suggested as a means of minimizing it.

Shooting Rear Projection

Good projection and screen equipment having been used and the set lighted properly, there still may be evidences of the hot spot which will prove troublesome unless the screen is shot properly. Referring to Fig. 7-29, the best way to shoot a scene from projector *A* is along the axis of projection with camera *A*. To camera *B*, the right side of the screen would appear bright and the left side dark. If it is

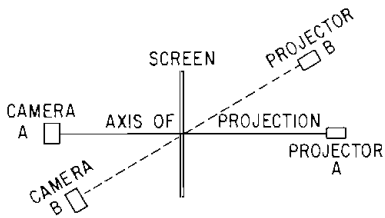

FIG. 7-29. Shooting on axis of projection (plan).

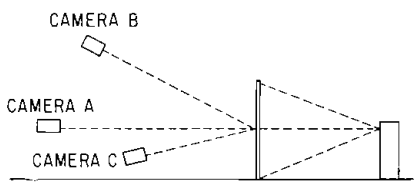

FIG. 7-30. Shooting on axis of projection (elevation).

known that the preponderance of shooting must be done with camera *B*, then projector *A* could be moved to the location of projector *B*. Focus would have to be split, and keystoning might have to be corrected. The same rule also applies to elevation. With the axis of projection parallel to the floor as shown in Fig. 7-30, the scene should be shot with camera *A* rather than camera *B* or *C*.

Slide and Film Processing

Another essential element in background projection is the slide or film. To what gamma these should be processed will depend to some extent upon the nature of the picture and how used. Generally, density results in loss of projection light and should be no greater than is required to reproduce the necessary picture detail and contrast. Density beyond the contrast range of the screen or the television system is to be avoided. Safe rules to follow are those currently set forth for good television film reproduction.[1]

AUDIO EFFECTS

Introduction

Sound effects in television are similar to sound effects in radio, but there are definite differences. For instance, in radio where there is *no* picture, the sound effects must create an image in the listener's mind. Actually the effects must be very real, and there can be no doubt left in the listener's mind as to what is happening. If the sound is obscure, then the dialogue carries the story to make sure everything is obvious for the listener. So the sound effects here must be quite realistic.

In TV the eyes take over for most things and the ears are not so conscious of the sound effects except those which are easily recognized. The important problem here is that the sound effect must synchronize with the picture exactly. Otherwise the out-of-sync action will be noticed. In radio any slight delay could be covered by the actor, but in TV this is difficult to do. The sound effect in TV does not have to be so creative, depending upon what is seen. However, quite often an effect is more complex and requires more study. It depends entirely upon the scene. It is sometimes even possible, if a scene is fast moving, that the effects may be completely submerged and music takes over. Then, only the highlight effects take over.

[1] K. B. Benson and J. R. Whittaker, Monochrome Television Film Standards, *J. SMPTE*, January, 1958.

There are four basic types of effects which must be considered for TV work.

First are the effects that are on mike or on camera. These effects one would expect to hear with a picture, as the picture would show the effect in action, for instance, a telephone bell ringing. The video picture would show the telephone bell or handset, and the audio would transmit the bell ringing—when the telephone is answered, the sound of the cradle being lifted would be heard. There are many other effects on mike or on camera which might have to be done by sound effects.

Second are the effects that are off camera. These effects are very much like radio effects and must be quite creative in themselves. They must paint a picture strictly by audio. For instance, perhaps a scene calls for the arrival of a person in a car. Let's assume that one of the actors might be looking out a window from inside a house. The viewer hears a car drive up—which is off camera, actually a sound effect. The actor would react to this effect, and the camera stays with this actor, never going outside. The car stops; the car door opens and closes; the car drives off. All this time the camera stays inside on the actor's face to get a reaction shot. The next things that are heard are footsteps and a knock on the door. So far everything that was heard was done by sound effects. When the actor opens the door, a second actor is standing in the doorway. The actor had been there all the time, but the audience got the story. It was all done with sound effects.

Third type of effects are those that are used for background or to set a scene. For instance, if a scene opens outdoors or on a street, one would expect to hear some traffic sounds—especially if it is a city street. It might be a side street, and a car might never drive past, yet as long as the camera is outside, the viewer would expect some sound. In a night scene outdoors in the country, night sounds like crickets would be heard. All these various effects help to set the scene.

The fourth type of sound effect in TV which is completely different from radio is the type where the sound man must create a sound track for a *silent* film. This is done mostly with news film, which is usually shot without track except for film which may have dialogue—and anything and everything may appear on film. It is up to the sound-effects man to get a viewing of this film and then put in these effects while the film is broadcast on the air, and this is one place where synchronization is very important. Usually there is never sufficient time to prerecord any sequence of effects before air time, so the sound-effects man needs equipment that is considerably flexible. In the following pages some of this equipment is described.

Sound-effects Console

Introduction

Radio and television production requires a wide variety of sound effects. Some of these effects are produced manually, some electrically and some from recordings of the actual sound. In order to reproduce and amplify these various effects, turntables, amplifiers, and associated equipment are necessary. A console (Fig. 7-31) to do just this for TV has been designed and constructed, and several have been in use for a number of years at CBS.

The Turntables

The console consists of three variable-speed turntables and four pickup arms. The variable speed is very desirable for sound-effects use. Most of the sound-effects records are cut at 78 rpm, but by being able to change record speed it is possible to get a variety of effects from the same disc. For instance, with a sound-effects record of a car running, the variable speed allows the sound-effects man to vary the speed during a chase scene or to even slow down and stop the car. Records played at 78 rpm can give other effects at slower speeds. For example, a waterfall record can be made to create an explosion at slow speeds.

FIG. 7-31. Sound-effects console. (*Courtesy of CBS.*)

The Pickups

The four pickups used are so designed and installed that any two arms will work on at least one table, so that all four arms can be used at once. This is valuable for cross fading and continuing the same effect for a long period of time such as a car running, a train-wheel click, etc. In addition, two different cuts of the same record can be played at the same time or quickly cross-faded. Another effect is to play a smaller record of one effect on top of a larger record, in effect, having a fourth turntable. Still another effect is to place two pickup arms in the same groove. By so doing an echo can be obtained, as one arm is one-quarter turn behind the other arm. The type of pickup used is a crystal with a replaceable steel needle. The reason for this is the necessity for fast cueing of sound effects. Originally a magnetic induction pickup was used, but the men were missing cues, so the crystal type was installed. It is not possible to play LP cuts with this type of arm. The fidelity is good enough for most sound-effects use with the exception of applause, which is difficult to reproduce authentically under any condition.

Amplifiers

Each pickup is equipped with its own preamplifier with a self-contained equalizer. The equalizer can raise or lower the treble end. This is useful for sound effects to be able to change response to suit arising conditions. It is possible with this setup to play voice cuts of records made overseas and make them more understandable than if they are played on so-called Hi-Fi reproducing equipment. These preamplifiers are fed to a mixing network along with two other inputs. The two other inputs can handle a microphone for acoustical or manual effects such as doors, telephones, bells, etc., or one of these other inputs can use an input coil instead of a preamplifier. Then it is possible to use additional high-level inputs such as other turntables, Foster electronic gun, tape devices, etc. The individual controls have a cueing position on the fader so that a cue can be found rapidly even though the console is feeding other effects on the air. This is very useful when last-minute changes have been made or a marked cue has been lost during an air show. As shown in the block diagram, Fig. 7-32, there is a booster amplifier between the mixing network and the master volume control.

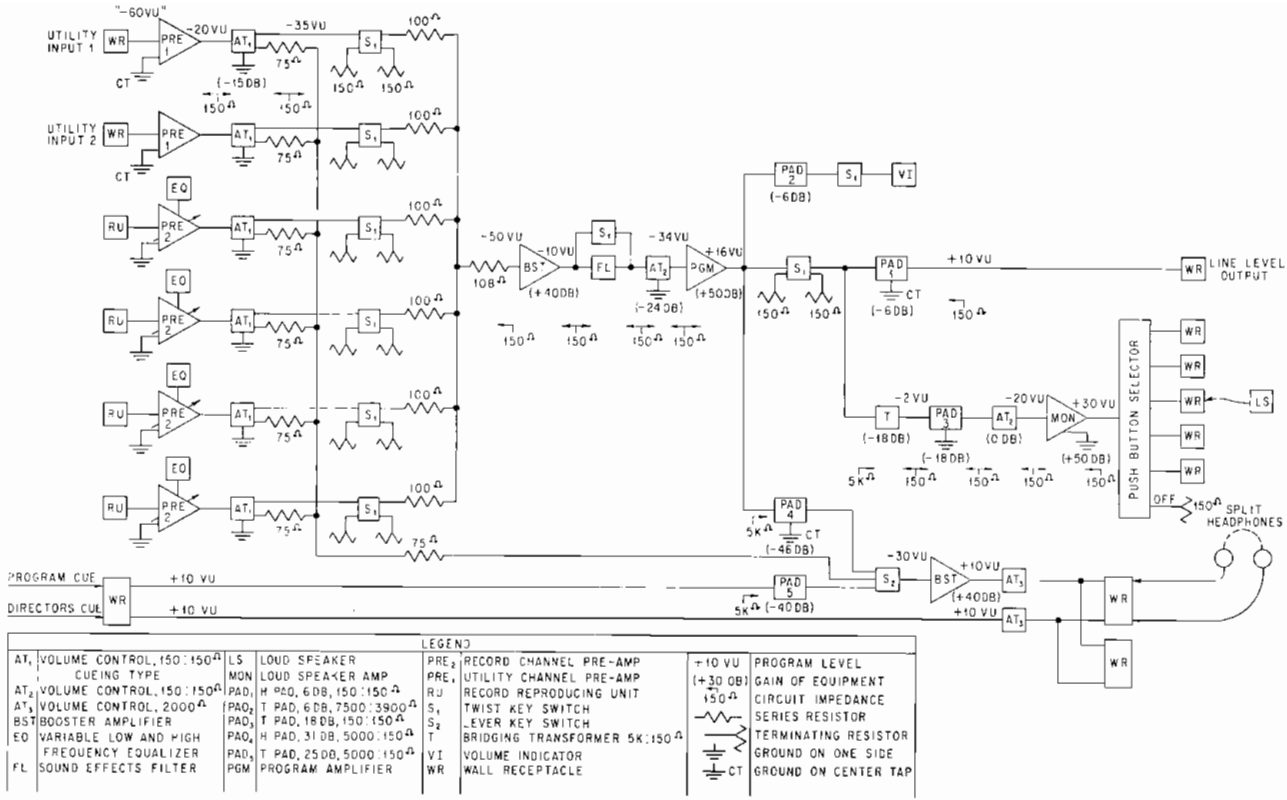

FIG. 7-32. Sound-effects console—block diagram.

Miscellaneous

A sound-effects filter of the low-pass–high-pass type is used for an over-all effect. This device has roll-off frequencies of off-100-250-500-1,000-2,000-3,000-4,000-5,000 on the high-pass and off-5,000-4,000-3,000-2,000-1,000-500-250-100 for low pass. Provision is made to feed a cue speaker for the actors over the particular set in which a scene is played. This is important so that the actors can hear the sound effect and react to it. It is possible to set up as many as six speakers in this way. An over-all volume control is used to prevent feedback between speakers and the sound-effects mike.

Conclusion

To show how a sound-effects man is actually set up to do a show using this turntable, see Fig. 7-33. First of all, the output of his console is fed on a line directly to the control-room audio console. He checks levels by using a tone record when

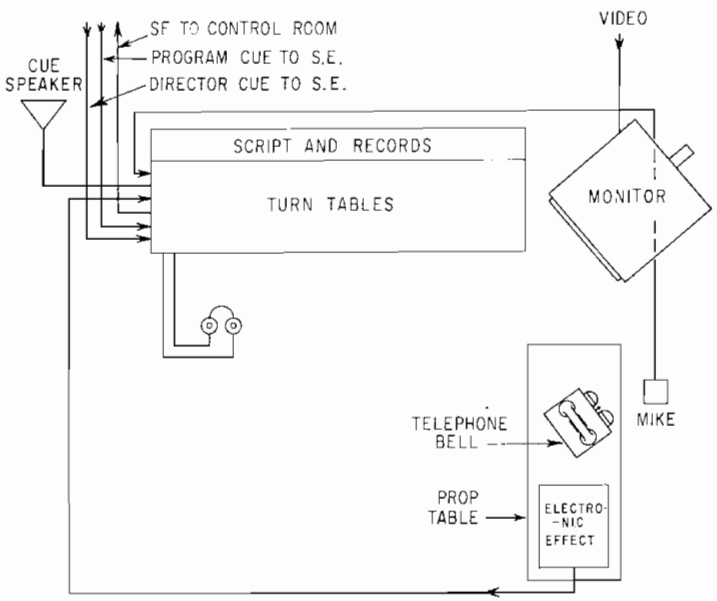

FIG. 7-33. Simplified circuit showing how a sound-effects console is connected to control room.

he checks in. Usually his fader in the control room is left open, and he is responsible to see that only those sounds that go to the control room are the correct sounds. The line that feeds the control room carries all his effects—recorded, acoustical, or electronic. In order to work this equipment remotely from the studio, the sound-effects man needs first of all to wear earphones so that in one ear he hears program cues which includes his own effects. In the other ear he can select either director's cue or boom cue, as he must anticipate every cue. He has to be ready for it when it appears on the screen and synchronize with the visual effect. At this point he could use several heads, one to watch the monitor, one to watch the script so as to prepare the up-coming effects, one to watch the VU meter, one to watch what he is doing at the moment he is making a particular effect. He must ride all his own gain including his own mike and he able physically to fade on and off manual effects. He must

make sure the level to his speaker is enough so the actors can hear the effect but not so high as to cause feedback to his own mike.

Original work on sound-effects consoles was started many years ago by Walter Pierson and more recently by Davidson Vorhes. Acknowledgments are also made to Howard A. Chinn, CBS chief audio video engineer, under whose direction this design was undertaken, to Price Fish and Bob Monroe, project engineers on the turntable console.

Electronic Gun

The Problem

A device to reproduce the sound of gunfire electronically has been a desire of sound-effects men for many years. There is now such a device that comes very close to doing just that. To achieve the dynamic range of an actual gun, the acoustic

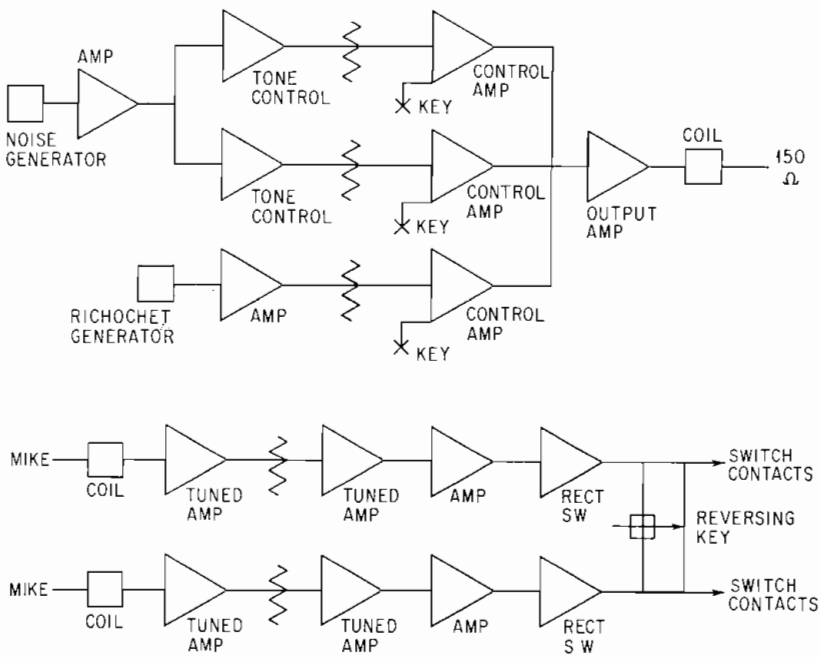

FIG. 7-34. Foster gun and Foster remote control—block diagram.

range is impractical, so the next best approach is necessary. That approach would be a sudden change from zero sound to maximum in as short a time as possible. The first approach was to key in some sort of a continuous sound having the continuous sound set at a maximum level. The next problem was to fade out this sound at an appropriate rate so as to simulate a gun firing. In dramatic shows in radio, live guns have been used for some time and can create a good effect. One problem has been the acoustic problem of damage to the microphone. As previously mentioned, an electronic device is impractical to get the same level. It is impossible actually to read the volume unit of a live gun, and usually the audio man just lets it ride. The peak is so high and short it is usually ignored with the thought that nothing can be done about it anyway. In TV there is an additional problem. If an

actor is handling a live gun on a set with an open boom mike, the gain of the circuit is so high that the audio man has very little if any control on the live gunshot, which will then reach the TV transmitter with enough level to actuate the limiter. As the limiter acts very rapidly, the louder the level reaching the limiter, the less sound that is actually transmitted because the limiter is pushing down as fast as the sound is pushing up. When the sound effect stops, the limiter requires a fraction of time to recover—sort of catches its breath—and, consequently, there is no sound at this point at all. So a gunshot that may sound great in the studios sounds terrible on the air, particularly at the local transmitter. Across a network it will not be too bad, as the various audio amplifiers will do a certain amount of compressing and prevent the rest of the transmitters from limiting along the network.

The Solution

Since the level of an electronic device *can* be controlled, the maximum is controlled which never reaches the level of a live gun. So to simulate a gun, the sound

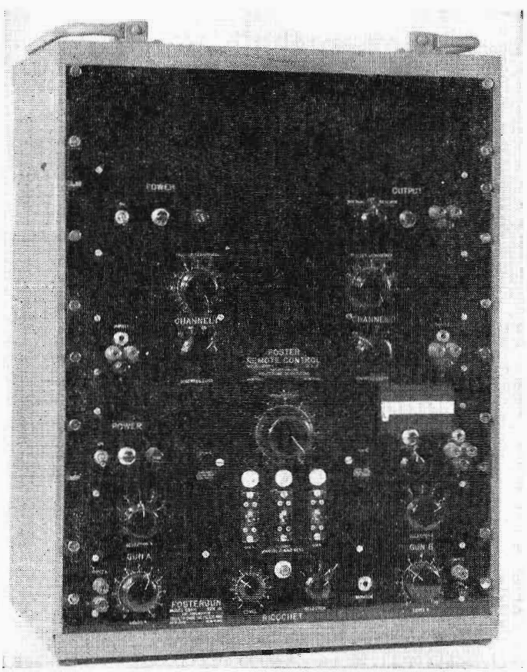

FIG. 7-35. Foster gun and Foster remote control. (*Courtesy of Teletronic Devices.*)

is extended instead of peaked. In other words, the gunshot is stretched out, which makes it sound big in the listeners' ears. This whole effect can be done simply with one tube acting as a noise generator and a second tube as a keyer. So to overcome this difficulty the electronic gun actually extends the length of the sound effect by adding to the original gunshot and putting a tail on it. The live gunshot can actually trigger the electronic gunshot but has to do so very rapidly; otherwise there is a double-shot effect. Another method is to not have any sound from the actor's gun, only smoke, and the sound-effects man fires the electronic gun manually. Here there is much more realism and levels are maintained. In TV it is best to work down from the loudest sound such as a gunshot to get a proper dynamic range between gun-

shots and dialogue. Usually there is considerable compression and equalization in film which is not done in live TV. Consequently, there is much better control in film, and the gunshots on film sound fine. Shown is a block diagram, Fig. 7-34, of a very elaborate electronic gun and Fig. 7-35 with two guns, double remote control, ricochet, etc.

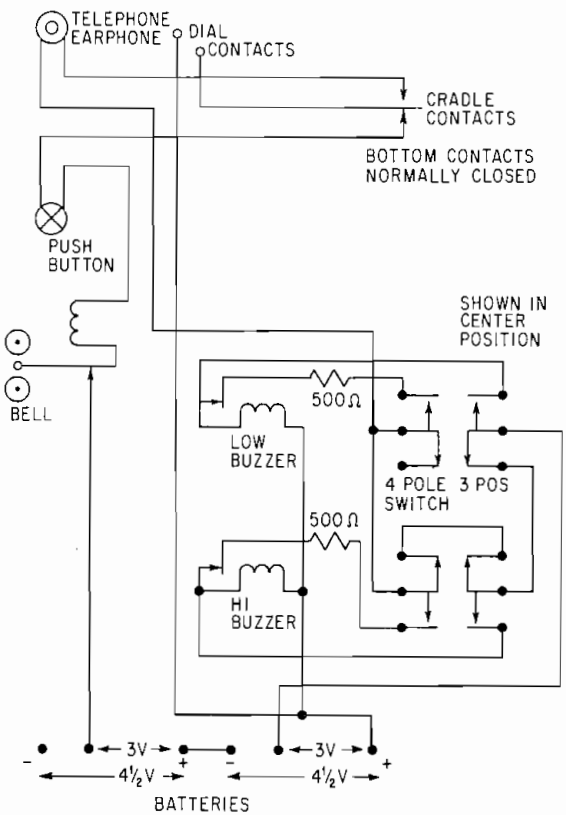

Fig. 7-36. Circuit of regular telephone with bell, dial tone, ringing effect, and self-contained batteries.

The Telephone

Telephones are widely used in TV dramas as well as in radio. In Figs. 7-36 and 7-37 we see a sound-effects telephone which has gained wide acceptance in the industry. This design accomplishes the following effects:

Telephone Bell Ringing. The bell sound that is used is a general type and can be used for a wide variety or types of telephones and will be acceptable. Operated by the sound-effects man this can also be rung on the set by remote control.

Telephone Ringing in the Line or at the Other End. Here there is no bell sound, but it is the sound the caller would hear in his earphone as the second party's telephone is being run by the telephone company. It is operated by the sound-effects man.

Various Types of Clicks. The clicks are used to indicate connecting parties together or a distant receiver being hung up. This sound would be heard by the caller who would be on camera. It is operated by the sound-effects man.

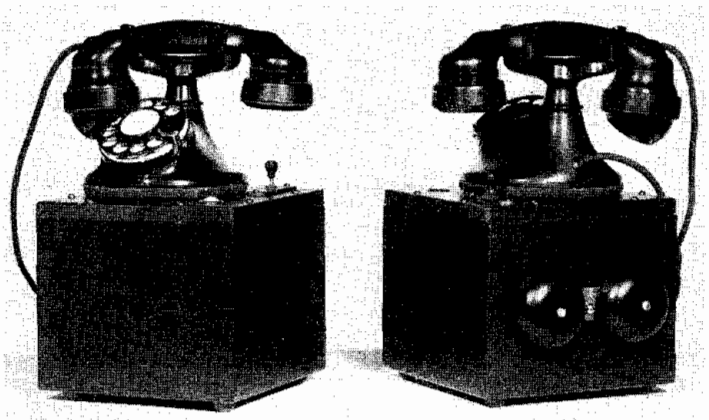

FIG. 7-37. Regular telephone with self-contained batteries, busy signal, dial tone, ringing effect and bell.

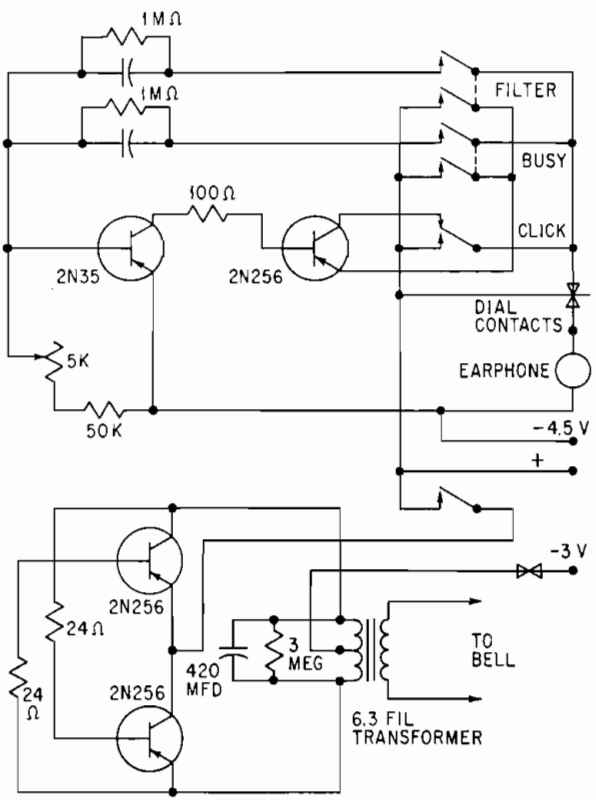

FIG. 7-38. Circuit of electronic telephone showing transistors.

Busy Signal as Heard by Caller. This is operated by the sound-effects man in any rhythm the director desires. Very close to the actual sound—good enough to give the effect.

Telephone Effects Using Transistors. In addition to the telephone device shown, CBS has recently developed in the sound-effects department a method of generating

FIG. 7-39. Electronic telephone using transistors.

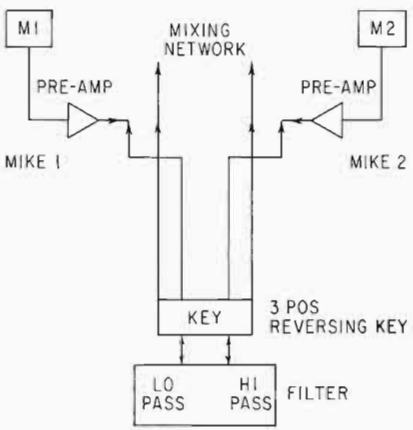

FIG. 7-40. Circuit showing hookup of two-way telephone filter effect.

and amplifying the necessary effects for telephone use with transistors. Circuit data are given in Fig. 7-38 shown when a battery supplies the power for the two-tone generator circuits, key click, and bell-ringer effect (Fig. 7-39). This is all contained in a modern handset with the handset mounted on the batteries. This particular type of bell set sounds very modern, so it can really be used only with a modern telephone prop. All the above effects are performed on the sound-effects microphone, and it is up to the sound-effects man to achieve the right perspective according to the picture. This is done not only by a change in volume as the picture gets tighter on the telephone ringing but also by bringing the instrument closer to the sound-effect microphone. Other telephone effects are achieved in a variety of ways.

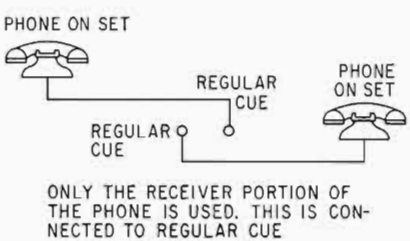

FIG. 7-41. Circuit showing hookup of practical telephones.

Telephone Filter. For instance, a so-called telephone filter uses a normal microphone which is fed through a sound-effects filter. The sound-effects filter is usually a low-pass–high-pass type which in essence then becomes a bandpass filter. This means that the low frequencies and extreme high frequencies that can be heard normally are cut off with the sound-effects filter, so the effect is that a person is talking over a telephone or the voice is "filtered." Quite often in TV as well as radio the actors switch places or reverse their "on" and "off" camera positions in which case the filter mike has to be reversed also by the audio man. This can be done with one filter unit and a reversing key that requires the output of the two mikes that are being used to be reversed. The reversal takes place at the output of their respective preamplifiers (see Fig. 7-40). Another possible method is that the filter is switched by the switcher on certain camera takes. This is a video interconnecting system with the audio filter. This would actually be set up for each program as needed. This method helps eliminate errors.

Practical Telephones. Another device that is needed in TV is a "practical" telephone for the actors talking on the telephone—both on and off camera. These telephones are made practical by actually (Fig. 7-41) connecting the receiver part of the telephone handset to a cable that can connect directly to program cue. So the actors then can hear themselves as well as all the program and the other end of their telephone conversation even though they may be quite a distance apart. Occasionally a switchboard can be used in a show which is not practical except for inserting the telephone plugs. In this case, the sound-effects man would have to supply all the necessary buzzers and bells that the switchboard sound might need. It usually is simpler to add the sound effects than it is to try to make the switchboard practical.

Bells, Buzzers, Chimes

A device that is widely used in TV is the sound of a doorbell or door buzzer and occasionally a chime. Once a particular bell or chime is selected for a set, this unit has to be always available whenever this particular set needs it. Door buzzers

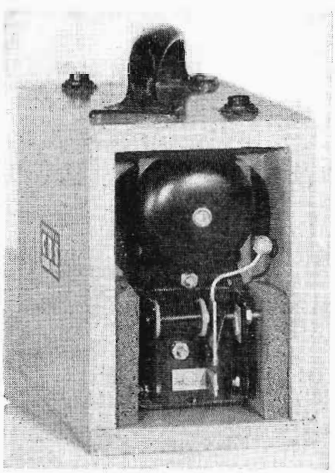

FIG. 7-42. Doorbell with self-contained batteries.

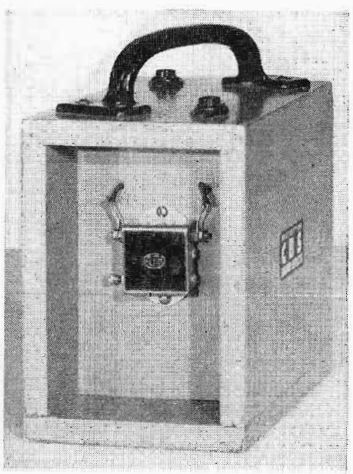

FIG. 7-43. Door buzzer with self-contained batteries.

are made up in such a way that a selection of various ones is available (see Figs. 7-42 and 7-43). The buzzers and bells are mounted on wooden boxes which also contain the operating batteries. They are shock-mounted on rubber also. Several types of chimes, door chimes especially, are always in demand. Figure 7-44 shows one type.

Reverberation

Definitions

There are various ways of producing "echo" and reverberation. These two terms are used synonomously, but actually they are different. Echo is a distinct delay that reproduces the original sound once or several times over. Reverberation is a continuation of the original sound with no separation between the original sound and the continuation. The term "echo chamber" is used almost universally when actually it is a reverberation chamber.

Acoustical

There were various acoustical designs of echo chambers that have been used for years in radio and are still used in TV. With the advent of the so-called Hi-Fi sound, echo and reverberation have been used and *misused* to give music a big sound. Realistic acoustics of a large auditorium are difficult to reproduce synthetically without actually using the auditorium. One approach acoustically is to use a large hard-surfaced enclosure and feed this enclosure with a loudspeaker (see Fig. 7-45). The sound from the loudspeaker bounces around in this room enclosure and is picked up by a microphone in the same area. The output from this microphone is then mixed with the original sound, and a big sound is achieved (Fig. 46). Many have been designed for this purpose; included here are the specification for these designs.

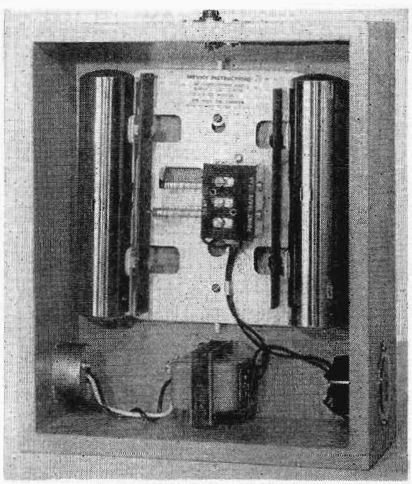

FIG. 7-44. Dual electric chime.

Engineering Department CBS Report E 578-M

The volume, shape, and acoustical characteristics of reverberation chambers are of prime importance as is the sound isolation afforded these units. Accordingly, as a minimum, the following precautions should be taken in their construction:

1. Reverberation Time. The reverberation time shall be as high as possible; i.e., rigid plaster walls finished with unpainted Keenes cement or equivalent shall be used.

2. Sound Isolation. Sound-isolating construction shall be employed for walls, ceilings, and floor to ensure a residual noise level of less than 30 db (ASA A weighting) under normal ambient-noise conditions.

3. Room Location. In order to alleviate the sound-isolation problem, reverberation chambers shall not be located close to potential sources of noise.

4. Room Volume. Room volume shall not be less than 2,000 cu ft and preferably larger.

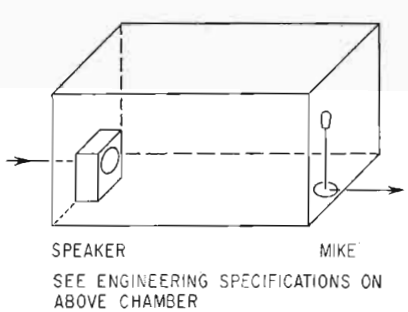

FIG. 7-45. Echo chamber—block diagram.

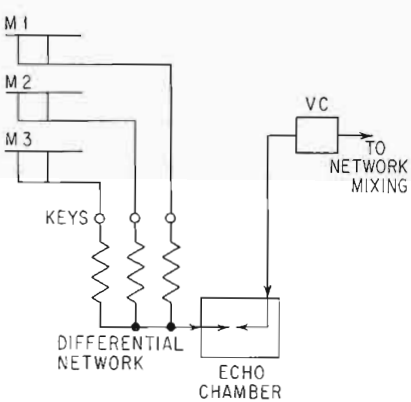

FIG. 7-46. Patching echo chamber—block diagram.

5. Room Dimensions. Rooms shall be roughly rectangular, but the ratio of any two dimensions shall not be a whole number or very close to a whole number (a ratio of length to width to height of 1.6 to 1.25 to 1.0 is generally found satisfactory).

6. Room Shape. No two walls shall be parallel to each other, nor shall the ceiling be parallel to the floor. Opposite surfaces shall be out of parallel by about 5° (approximately 1 in. in 1 ft). Preferably the walls and ceiling surfaces should consist of sections 4 to 8 ft wide and angled with respect to each other in accordance with the above.

Tape Echo

With the advent of three-headed tape recorders an electromechanical method of achieving echo was discovered. A very simple design of this type of echo is shown in Fig. 7-47. This machine, Centronix, has a record head which, when moved, can

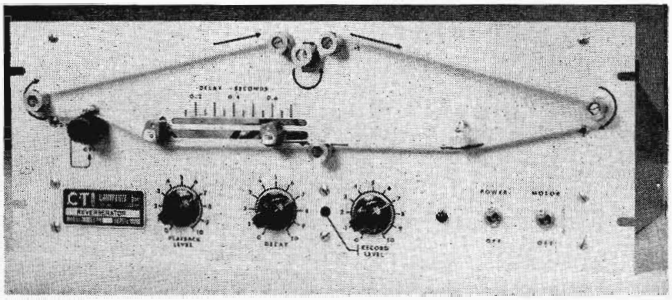

FIG. 7-47. Tape reverberation device. (*Courtesy of Centronix, Inc.*)

change the delay in echo. This makes it especially useful for various trick effects, etc. Most standard three-headed tape machines have all their heads fixed, so it is not possible to do too many tricks. Another design of tape echo which has found widespread use is the Audio Instrument machine. This design is very versatile in that a great variety of effects can be changed to get all sorts of reverberation and echo. This is shown in Fig. 7-48. The desired effect is a matter of end use.

Piano Echo

A piano can be used for an echo effect by simply holding down the loud pedal and speaking into the strings (Fig. 7-49). This works quite well for dramatic effects but, of course, is difficult to control, as reverberation is quite long. This method was used in radio for many years.

Mechanical Reverberation

A very simple method of reverberation is shown in Fig. 7-50, where a bronze sheet is driven from one end and reproduced from the other end. This principle is very old. The trick is to get the sheet vibrating with the sound, and of course, since it is mechanical, it will take time for the sound to die out, which is the reverberation.

Figure 7-51 shows a professional unit type EMT-140 reverberation unit by Electronic Applications. This unit is already finding widespread use by the industry. There are undoubtedly many other designs which might be included here.

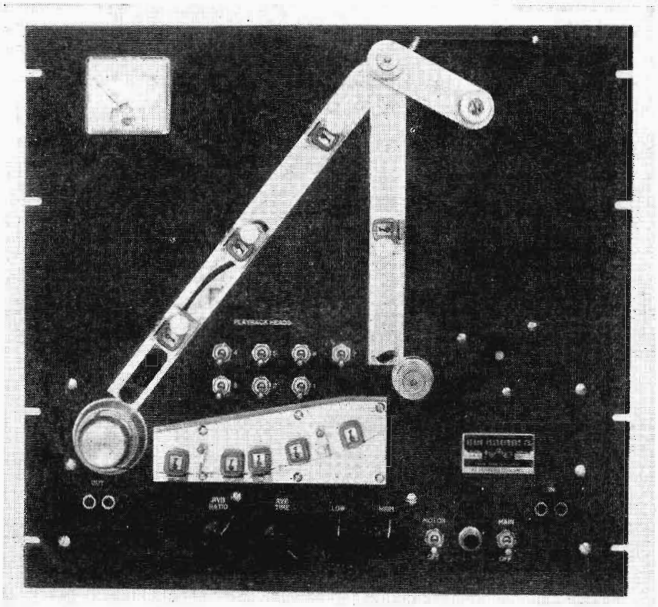

FIG. 7-48. Tape reverberation device. (*Courtesy of Audio Instruments.*)

FIG. 7-49. Piano for reverberation showing mike placement.

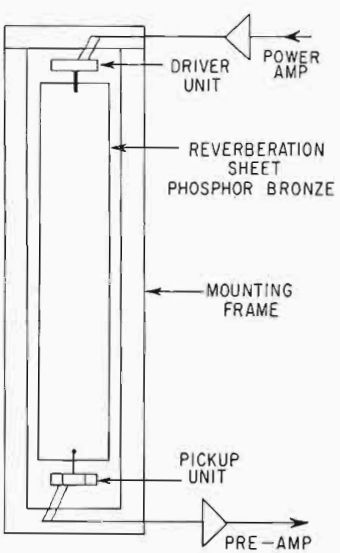

FIG. 7-50. Simple bronze-sheet reverberation.

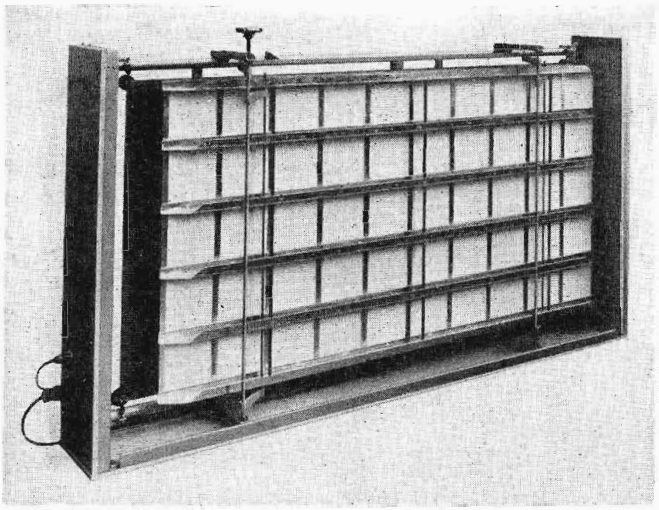

FIG. 7-51. Reverberation unit. (*Courtesy of Electronic Application, Inc.*)

Tape Devices

For many years there has been a definite need for an automatic tape loop device for sound-effects use that could be built with a number of multiple loops. The most difficult part of cueing sound-effects records is synchronizing these sounds with the picture. Once this is done, then repeating a cue while still trying to watch the monitor becomes a physical impossibility. Many suggestions have been made to use tape and record all the effects in the proper logical sequence. This is not too practical, however, as with a lot of effects, each one would still have to be cued as the previous effect finished. This would naturally require a lot of editing of tape, which would be expensive. In addition, as changes were made in the show from rehearsal to rehearsal, the sound-effects man would find himself thoroughly confused. He might find some effects deleted, timing changed, or some effects added. It is really more practical to have on tape only those things which have to be cued up very tightly to synchronize such as thunder, gunshot, explosion, automobile horn, etc. Continuous sounds such as traffic, rain, and water running can be cut in from a sound-effects record of a full cut of sound effects. Several tape machines of this type for quick cueing have been designed and built. One of the first was the so-called "laugh" machine, which had tape on the edge of 12-in. discs ¼-in. thick. These discs were under constant pressure to move but could not owing to a stop mechanism on the side of each disc. Upon pressing a key the disc was released and the tape traveled past a pickup head to give a reaction effect. This machine is fine for this audience-reaction type of work but would not be of much value in quick cues for sound effects. There was too much time between the start of the disc and the effect. In addition, changing tapes was difficult. A later model of this machine was designed with 16-mm tapes. This was not much better for sound effects but was all right for audience reaction. Since then several approaches have been tried and one model has been completed that works very well (see Figs. 7-52 and 7-53). Very short loops or loops up to 2 min can be used. The tape loop recues itself by going through its cycle and shutting itself off. The present machine has only three loops but is being changed to six loops. The only load the capstan must drive is the loop and a slight pressure to keep the loop taut as it passes the playback head. Cueing is very fast, with no wow or flutter of any sort. Transistorized preamplifiers are used throughout. Tapes can be changed quite rapidly. Using a tape machine to supply sound effects can be done with the turntables described. A block diagram (Fig. 7-54) shows how

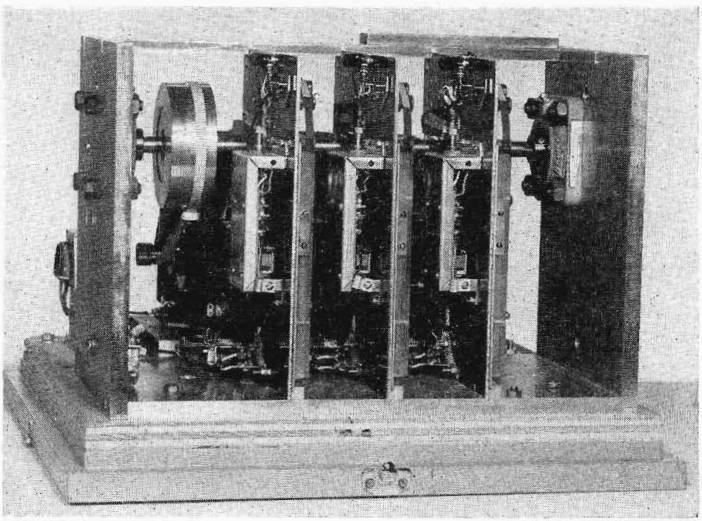

FIG. 7-52. Tape SFXer Binnie and Hartman design–front view.

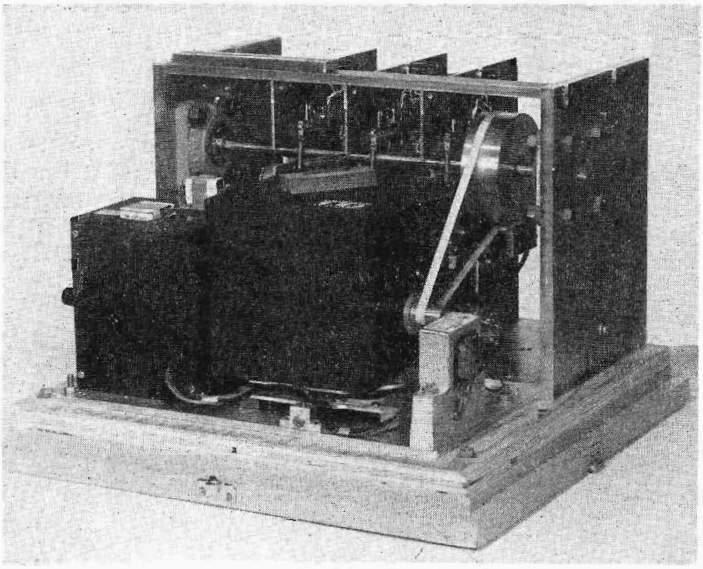

FIG. 7-53. Tape SFXer Binnie and Hartman design–back view.

this is possible. Once the effect is put on the tape and edited, splicing tape is used between effects so that progressively each tape is cued up. This will work if there is sufficient time to cue up between tapes, and of course, any timing changes during the playing of any particular tape will cause a loss of synchronization of that particular effect.

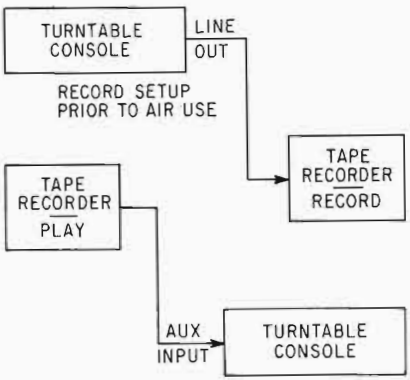

FIG. 7-54. Circuit showing output of console feeding tape recorder and also tape recorder feeding into console.

The output of the console can be fed to the record section of the tape recorder during rehearsal, so that sound-effects records can be dubbed to the tape to make up the necessary sequences. A very recent tape device in use today playing sound effects is the MacKenzie that is used at Disneyland and is a tape repeating device. This machine is shown in Fig. 7-55 and is excellent for sound-effects use. It has five magazines which are made up separately and can repeat individually. Cueing is very fast. This device should find many uses in sound effects as well as other fields.

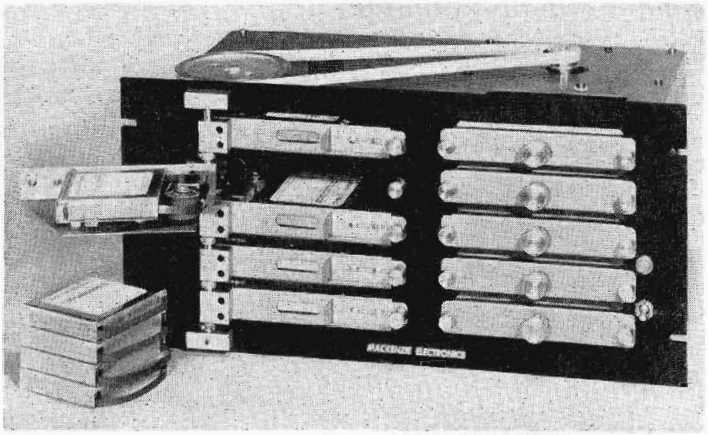

FIG. 7-55. Tape device. (*Courtesy of MacKenzie Electronics, Inc.*)

Other Electronic Effects

With the advent of LP records a more desirable type of portable record player was designed to be used by the sound-effects man. Inasmuch as sound-effects men are called on to play various types of music records as well as sound-effects records,

especialy for backgrounds, cafes, night clubs, etc., this particular design was a must. This table uses a good four-speed turntable and a properly balanced and weighted arm so that LP and EP's can be played with good quality. Although not so elaborate as expensive turntables usually found in control rooms, it still has found a wide use because of its portability. For cueing purposes it is equipped with a transistorized amplifier that feeds a small speaker encased in the turntable case. This is shown in Fig. 7-56.

The "Boing"

One type of electronic "boing" that is widely used is in effect a guitar string that is stretched over a magnetic pickup. The pitch is varied by a handle on one end. Figure 7-57 shows this device. Another type that is used is the ordinary Jew's-harp. This takes an artist to play it, however.

FIG. 7-56. Portable turntable for LP and EP as well as 78 rpm.

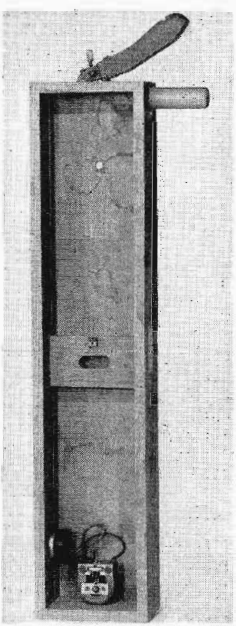

FIG. 7-57. Sound-effect "boing" showing steel string.

The Electronic Bat Crack

During the baseball season a good bat crack for sound effects is a necessity and something difficult to synchronize with a picture. But no more (see Fig. 7-58). This device uses a solenoid and tempo block operated by a foot switch. All the sound man must do is watch the monitor, and by stepping on the switch at the precise moment, he gets an effect of a bat crack. At the same time with his hands he operates his crowd-reaction records. It is not generally known, but most films of news events, except for actual speeches, are shot silent and the sound-effects man supplies all the effects. So during the baseball World Series rehash, he supplies all the effects on this news program.

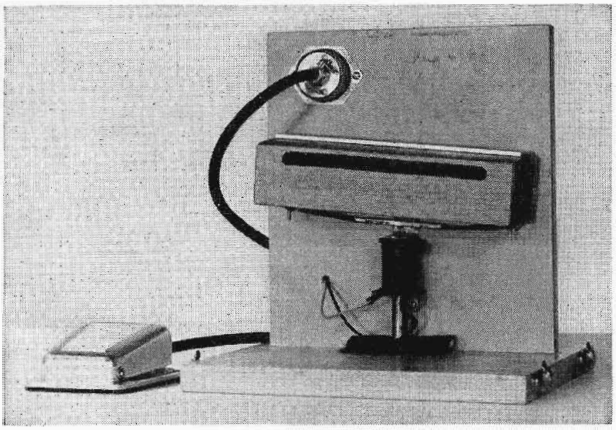

FIG. 7-58. Electric "bat crack" showing foot pedal.

Oscillators

Various types of oscillators are used in sound-effects work. Usually there is a demand for tones of all types. So everything from beat-frequency oscillators to single-tone self-operated types are called for. One type that found favor was the neon oscillator, shown in Fig. 7-59. This particular device was used mainly because

FIG. 7-59. Neon oscillator for sawtooth tone.

it would not change pitch over a program but would remain on pitch. This was important as it blended with organ music.

Electronic Chime

A recently developed device which is finding many uses is an electronic chime. This device, shown in Figs. 7-60 and 7-61 uses three separate tone generators and three separate keying tubes. Any type of tone can be used, although in this case the tones are generated in a triode oscillatory circuit and keyed in as needed. Normally each keying tube is cut off, and when triggered, maximum sound comes through

FIG. 7-60. Electronic chime—three-note.

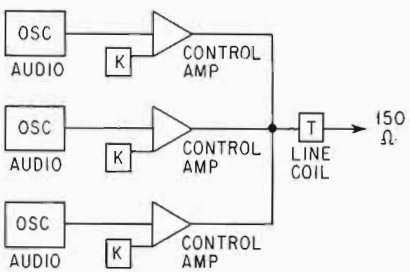

FIG. 7-61. Electronic chime—block diagram.

and fading is controlled by an *RC* circuit which can be almost any value to get the desired effect.

Manual Sound Effects

The Door

The sound-effects door that was designed for radio is also widely used in TV. Since this is a visual medium, the sound effects might look unnecessary. However, this is not the case. Quite often a door will open and close which will not be "on camera." Consequently the sound should be heard as indicated in the script. Otherwise, the story will not have continuity or meaning. Then quite often a door that is on camera or is visual may not sound like a door, or it may have the wrong latch on it or may be too far away from a mike to pick up the actual sound. In this case, once again the sound-effects door has to "fill in" the vacant sound. Occasionally a simple effect such as a knock on a door may cause a set to move or shake while on camera. Here once again the sound-effects man does the actual knocking, even though the actor may go through the motions. In Fig. 7-62, front, and Fig. 7-63, rear with screen, is shown a "door" that has been designed and constructed for radio and TV.

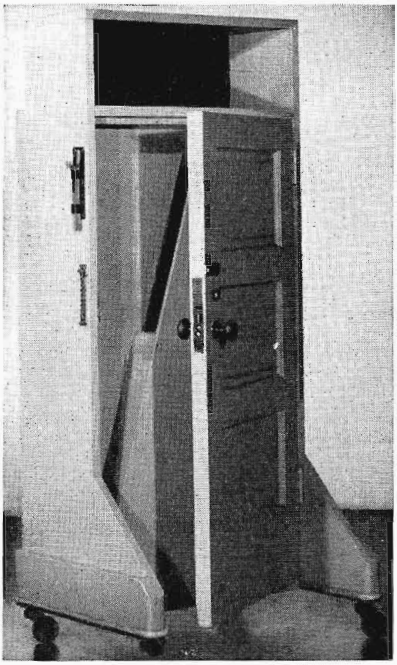

FIG. 7-62. Sound-effects door (front) showing door latch, chain, and acoustical chamber for resonance.

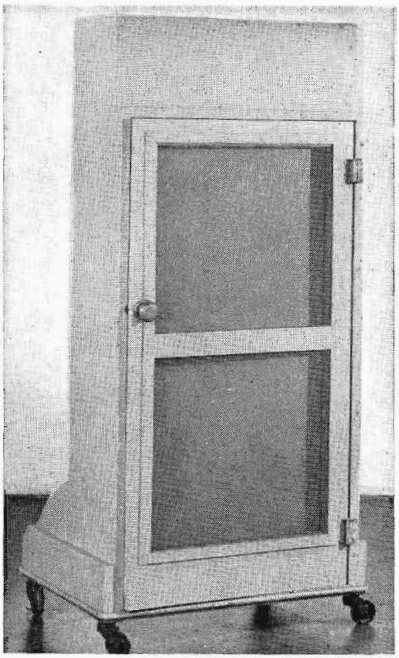

FIG. 7-63. Sound-effects door (rear) showing screen door.

The Sink

Another widely used device for sound effects is the sink. There is a sound-effects sink which is self-contained with a pump that provides running water from an actual faucet (Figs. 7-64 and 7-65). As can be seen in the exposed diagram (Fig. 7-66) this sink contains besides the sink a circulating pump, a reserve tank, a motor, and a vent and is connected with rubber hose to cut down noise. The motor must be running to provide running water. Consequently, used on the air this means it must be very quiet. The motor and pump assembly is cast heavy-duty and is shock-mounted on rubber mounts. The pump can run without having the faucet open, so that the pump has some pressure in the faucet before it is used. The reserve tank holds enough water so the sink can be filled if necessary. The vent allows this to happen without siphoning out the sink water. The entire cabinet is lined with sound-absorbing material 1 in. thick. The power switch is a mercury switch, so there will be no noise when it is switched on in a very quiet studio. This device is very useful in TV, since it is difficult to make sinks on camera practical.

Horses' Hooves

Coconut shells are used as much in TV as in radio depending on the script. Almost any effect which lends realism and can be controlled is actually much better done "live." Rubber plungers can also be used. Actually making a horse effect calls for good rhythm and coordination, and only a few people are gifted this way. When used with dirt or gravel as shown in Fig. 7-67, dirt should be wet down to avoid dust.

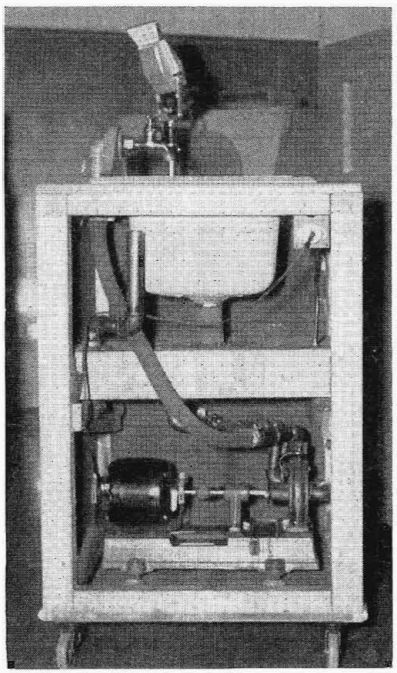

FIG. 7-64. Interior view of electric sink.

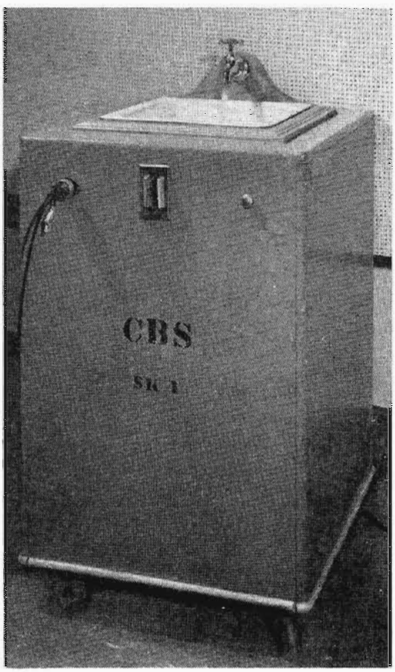

FIG. 7-65. Sound-effects sink showing running water.

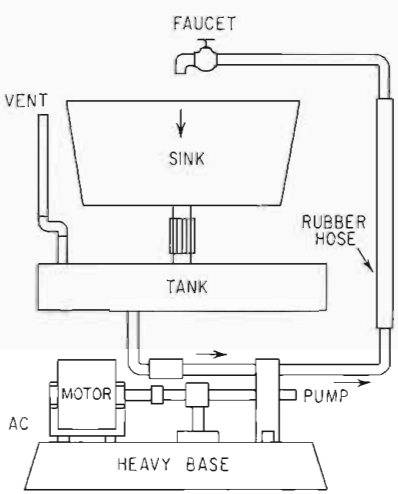

FIG. 7-66. Electric sink—block diagram.

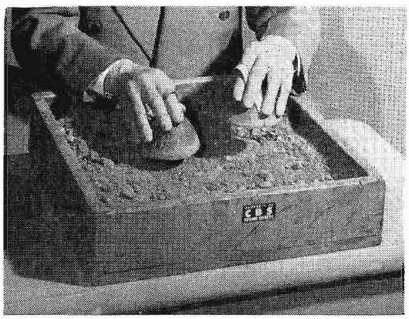

FIG. 7-67. Horses' hooves in dirt box—using coconut shells.

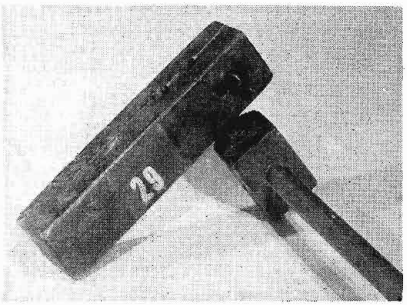

FIG. 7-68. Wood squeak for sound effects.

Door Squeak—Wooden

A wood squeak is caused by two dry pieces of wooden material rubbing together. A form of one type is shown in Fig. 7-68. Actually one end is in a dowel shape. This is moved in another piece of wood, preferably hardwood, and the squeak is adjusted by tightening down on the dowel. This must be adjusted to get a proper squeak. The whole assembly can then be put on a door with a temporary C clamp. This squeak can then be operated by a sound-effects man as in Fig. 7-69. This way the squeak does not have to follow any rigid pattern but can be different each time. One door for *Inner Sanctum* was actually built for just that show. So that no other show would use this door it was kept locked. When the show moved from one network to another, the door traveled with it.

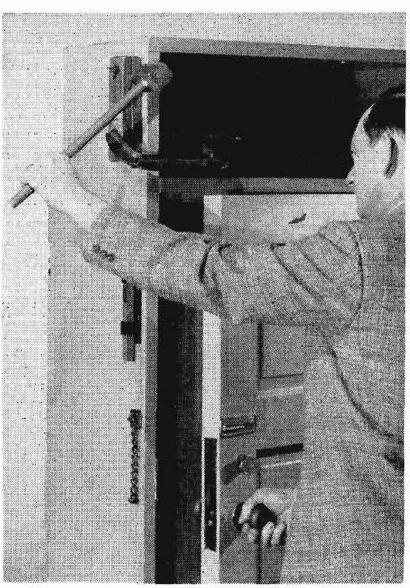

FIG. 7-69. Sound-effects door with wood squeak attached.

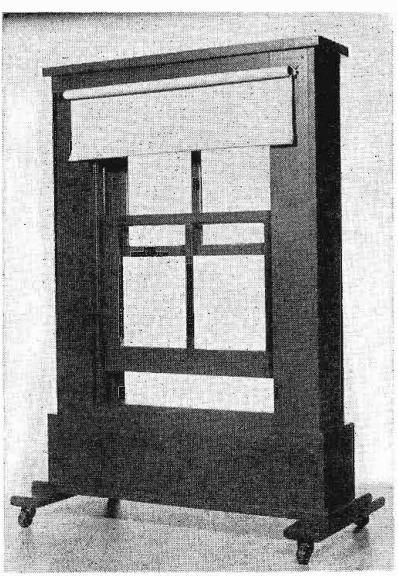

FIG. 7-70. Sound-effects window showing shade.

The Window

A device which is used quite frequently is the window. This is shown in Fig. 7-70. One window is hung with regular sash cord while the other uses chains to give a different effect. There is also a place for a window shade, as occasionally such an effect is needed.

Floor Boards

Most studios use concrete floors and tile. There is also a demand and need for wooden floor boards that are portable. A wooden floor board is used, of course, to

FIG. 7-71. Footsteps on a wooden floor board.

FIG. 7-72. Footsteps on a stone slab.

show actual movement or footsteps, especially when there is no dialogue present (see Fig. 7-71). Quite a few directors insist on footsteps, so all sound men carry an extra pair of shoes for sound effects with hard leather heels. Footsteps are not

FIG. 7-73. Footsteps on gravel (in bag).

used so much in TV as radio, however, as it is possible to see movement and any fast movement such as running can actually be picked up with the actor doing the effect.

In addition to wooden floor boards, sound-effects men are called on to simulate

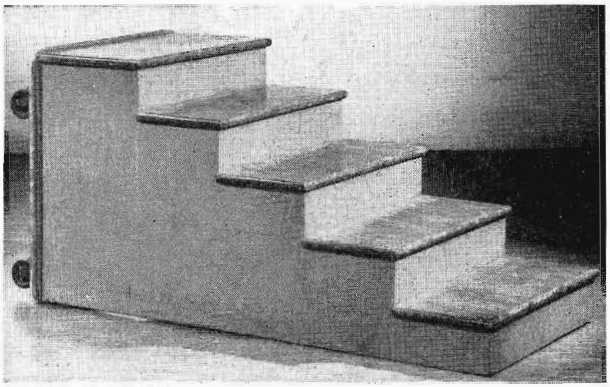

FIG. 7-74. Sound-effects stairs (portable).

walking on sidewalks. A marble slab about 12 by 24 in. can be used for this as shown in Fig. 7-72. Movement is expressed by walking in one spot up and down. Sound effects men are also called on to do footsteps on gravel, sand, snow, metal floors, brush—and you name it. Note in Fig. 7-73 steps on a gravel bag. The gravel is contained in a double canvas bag so that the sound will come out but not the gravel. This way there is no mess or spilled gravel on the studio floor. However, if the director insists, the bags can be opened easily and the gravel can be spread

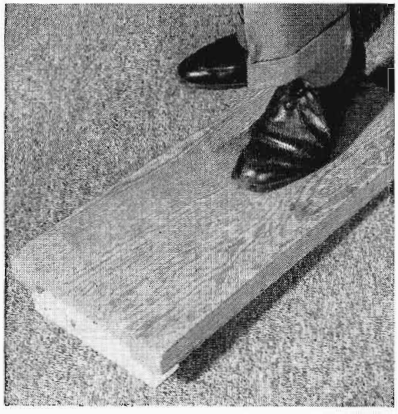

FIG. 7-75. Footsteps on a slanted board for stairs effect.

out on a canvas over a larger area. In a similar manner bags can also contain cornstarch to get an effect of walking on snow, or a small cardboard box of cornstarch well wrapped can give the same effect very close to the sound-effects microphone. The box is squeezed by hand. Occasionally an effect of walking in brush or through trees is called for, in which case broom straw is used. This can be done by hand or can actually be walked on if there is sufficient room.

Stairs

Wooden stairs are called for occasionally, and a set is shown in Fig. 7-74. If these are not available, there is a simulated effect which can be got from a floor board or a slanted board as shown in Fig. 7-75. Since the board is slanted, it is impossible to walk flat on it, so the foot slides onto it as in the case of stairs and the heel sound is not heard—only the sole of the foot.

Glass Crash

This shows a type of manual glass crash that actually breaks a piece of glass. Window glass is supplied in an 8 by 10 size, and when one or two sheets are placed in this frame, it can be broken by pushing down the lid of the machine (see Fig. 7-76).

FIG. 7-76. Glass-crush machine.

Prop Table

A very important item that is used on practically every show is a prop table. Prop tables have been designed in a number of ways. This table has a cork top so that it is quiet and durable. The height is a matter of practical mike placement on one side and the height of the sound man on the other. Besides holding props, this table can be used for such things as a body fall with elbows and arms landing on it.

Section 7

REMOTE-PICKUP FACILITIES

Part 1

A PRACTICAL 26-MC REMOTE-PICKUP BROADCAST SYSTEM

WILLIAM C. GROVE

Vice President and General Manager
Stations KFBC and KFBC-TV
Cheyenne, Wyo.

INTRODUCTION

General Information

The equipment described in this part consists basically of a one-way program shortwave system, operating in the 26-Mc band, groups D through J, Part 4.401 of the FCC Rules, paragraph 2. The transmitter is intended for mobile use, operating from a standard 6-volt car battery. The major units, except the dynamotor, are component parts of SCR 508 (SCR 528 and SCR 538 also contain the same components). These are the BC 604 transmitter and the BC 603 receiver. The transmitter costs $3, and the receiver costs $5.95. The incidental components, such as plugs and receptacles, are also mostly available as war surplus. Such items as the transformers for the receiver power supply, microphone sockets, and VU meter will probably be new materials. Spray painting of the components is recommended. Masking of the front panel and name plates will be found quite simple. Duco Feather Grey No. 246-54909 or equivalent is recommended. Circuit drawings and diagrams are furnished only for the changes and additions, it being assumed the user will procure a copy of War Department Technical Manual TM 11-600 which contains complete circuit and adjustment information of the equipment as originally furnished for the armed services. TM 11-600 does not cover the dynamotor PE 103. However, the circuit diagram of this unit, as well as changes, is included as Fig. 1-6.

There is one disadvantage to the 26-Mc band,[1] and that is potential diathermy interference. The equipment has one very handy feature to cope with this. The transmitter and receiver both are arranged from 10 preset channels, inasmuch as the original design covered the band from 20 to 27.9 Mc. Actually, it is customary to apply to the FCC for use of only a single group of frequencies, groups D, E, F, G, and H, consisting of three specific frequencies, and groups I and J, consisting of two frequencies. There are thus 19 specific frequencies available for this use in the range from 26.11 to 26.47 Mc. Most stations equip their transmitters with either two or three crystals, as the case may be, and preset their receiver push buttons correspondingly. If, during a transmission, diathermy interference occurs, a quick change to an alternate frequency usually eliminates the interference.

[1] As well as long-range interference during the "high" of the 11-year sunspot cycle.

Crystals

Crystals in mounting FT 241 are readily available on the surplus market and carry the channel number and carrier frequency. The crystal frequency is multiplied 54 times to generate the carrier frequency. Crystals are readily available to produce carrier frequencies just under several of those specified by the FCC for remote pickup service. They are as follows:

Channel No.	*Crystal frequency, kc*	*Carrier frequency, Mc*	*FCC channel, Mc*
61	483.333	26.1	26.11
62	485.185	26.2	26.21
63	487.037	26.3	26.31
64	488.889	26.4	26.41

These crystals are wire-mounted and silver-plated. They vibrate in such a mode that the frequency is determined for a given crystal and within limits by the large dimensions. Grinding one edge a very small amount will raise the frequency of the crystals listed above to fit the corresponding FCC channel exactly. It is also entirely feasible to grind somewhat more from the edge of the crystal, raising the frequency to one of the higher channels. The crystal mounting base is clamped in a vise, and the crystal itself held by its edges by means of a pair of long-nose pliers the prongs of which have been covered with thin rubber tubing, rubber tape, or masking tape. A few light strokes of very fine sandpaper will take off sufficient material to raise the frequency measurably. Results are better if the sandpaper is wet. It is necessary in this case to wash and dry the crystal each time it is tested as to frequency.

Transmitter

The frequency of 26 Mc lends itself to the use of a quarter-wave whip-type antenna suitable for mounting on a vehicle. The equipment described consists of a battery-operated transmitter and a 110-volt ac-operated receiver. The transmitter was originally designed as a plug-in unit, and this feature has been preserved. As used by the armed services, the standard installation was one transmitter and two receivers, plug-in mounted upon a sturdy shock-mounted base, known as the FT 237 mount. As modified, the mount is shortened and rewired.

The transmitter is frequency-modulated, using a novel modulator known as a Peterson coil. This is a small toroid, using a permalloy ribbon core. The coil, which bears the circuit designation L104 in the schematic, carries RF current at crystal frequency, which is approximately 450 kc, from the crystal amplifier stage V101. Also through the coil passes the audio-modulating frequency from the second audio stage V106. The current magnitudes are so arranged that, superimposed, they saturate the core of the modulator coil. Relatively large inductive kicks or spikes are caused by the saturation, and the phase relation of these inductive kicks produces the phase or frequency modulation. (See Fig. 1-9.) The sharp spikes thus caused also make it entirely practical to pick off the ninth harmonic and amplify it in the following stage. A doubler and a tripler follow, then a power amplifier, and thus, with a minimum number of tubes and consequently low total battery drain, a carrier frequency which is 54 times crystal frequency, is reached. The principal advantage of this system of modulation is that there are no heavy audio transformers. Modulation occurs at a low audio level, there being only two tubes used from microphone level to modulating level. There are only eight tubes used in the entire transmitter, six 6V6GT, one 6L6, one 807. These replace the original complement of seven type 1619 and one type 1626, which are a 2-volt direct-filament type, used for quick heating, making a complete push-to-talk operation feasible, with no idling current drawn from the battery as far as the transmitter is concerned. It was found that the

original tubes were unsuitable, since car generator and other noises came through into the audio, hence the change to heater-type tubes. A disadvantage of this type of modulator, and a very serious one, is the fact that the amount of phase shift, hence percentage of modulation, is proportional to audio frequency.

Receiver

While for the original purpose of voice communication it proved quite satisfactory, the lack of bass response is objectionable in many applications for broadcast station use. The over-all frequency response can be greatly improved by the addition of a simple circuit for base frequency reemphasis in the receiver. The network consists of the addition of two 0.01 condensers and one 12,000-ohm resistor and is illustrated in Fig. 1-1. A slight addition to the bass response in the audio circuits of the transmitter [2] will bring the over-all audio response, transmitter microphone terminals through receiver audio output, to within ±3 db from 75 to 15,000 cycles. The circuit accomplishes negative feedback in the receiver at frequencies above 500 cycles, and, owing to an unexpected assistance from a very poor audio system (poor from the standpoint of the broadcast engineer), there is a phase reversal or near reversal at the low end with the combination over all, and at 60 cycles there results actually a *gain* in the audio system from the addition of this negative feedback. The figure shows the basic audio system of the receiver, and the heavy lines indicate the additions.

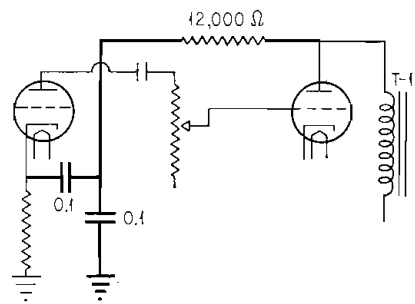

Fig. 1-1. Bass frequency reemphasis circuit to be added to receiver.

The volume control on the front of the receiver now becomes more of a tone control and should, under conditions for best audio response, be left full clockwise. Since it is now within a heavy feedback loop, rotation counterclockwise for the first approximately 200° of rotation serves only to drop the audio response at both the high and low ends of the range, mostly at the low end, and reduces audio volume very little. In extreme cases of noise, when too great a range of transmission is being tried and the received signal is filled with ignition and other noise, this can be of some use. However, over-all circuit noise out of the receiver will be at least 45 db down and sometimes 50 db down. This does not take into account atmospheric noise, which is mainly a matter of propagation path and receiving-antenna efficiency. Audio distortion will be less than 3 per cent over the range 75 to 7,500 cycles. It was discovered that a poor commutator in the dynamotor, especially in the low-voltage side, will at times contribute a surprising amount of low-frequency noise.

The receiver, the BC 603, will almost always be used at a fixed location, such as the main studio. When the receiving location is also the location of the broadcast transmitter, additional problems are frequently encountered. These are not insurmountable. The first thing to take into consideration is to select a group of frequencies that are not harmonically related to the broadcast frequency. This is examined before the remote-pickup CP is applied for. Next, watch out for harmonics at the IF frequency, which is 2.65 Mc. Stations on frequencies around 880 and 1,320 kc, might expect trouble from this score with the receiver located at the main transmitter. At KSID in Sidney, Neb., much difficulty was experienced when the receiver was located within 18 in. of the 250-watt broadcast transmitter. However, when it was moved to the basement, everything was fine. KSID operates on 1,340 kc the second harmonic being 2,680 kc. The IF must be broad in order to prevent am-

[2] For further information regarding this modification, see Fig. 1-10*a*, *b*, *c*.

plitude distortion of the frequency-modulated signal. The original dynamotor is replaced by a 110-volt rectifier which is built on the dynamotor base and plugs in just as the dynamotor did. No tube changes in the receiver are involved. The receiver is of moderate sensitivity and is reasonably stable if warmed up a half hour or so. It has an effective squelch, which will cause audio distortion and also some noise if left on during a program. A sensitive relay could easily be added so that a bell will ring upon a roving reporter calling in. For special applications, where it is desirable to work the receiver from a 6-volt source, a vibrator supply, constructed on the dynamotor base to preserve the plug-in feature, was found much quieter than the original dynamotor, and the dynamotor is available only in the 12- or 24-volt rating.

Where the propagation path from the desired remote-pickup point is too great for dependable operation, much use has been made in Cheyenne of locating the receiver at a remote point, its power being turnd on and off by remote control, simplexed over the telephone line used to carry the audio from the receiver to the studio. For special events such as fires or disasters in nearby towns, the central telephone office in that town is a logical place, particularly if it is a small town. Actually, a telephone office is a prolific source of local interference, but if the program is only a short distance away, as it would be in a small town, the noise is taken care of by the limiter. It is convenient to have special toll facilities quickly available. Holding a telephone instrument up to the loudspeaker of the receiver is another expedient that has been used in order to "get the show on," taking advantage of the beep-type service.

Microphone

As originally manufactured, the transmitter was designed to work from a carbon microphone or telephone-type microphone, or transmitter, as the telephone people call it. This feature has been preserved. All that is necessary is to plug in the carbon microphone, such as a T-17, which is available on the surplus market. The transmitter can be easily installed in other vehicles than an automobile, such as a train, an airplane, or a boat. Several installations in trains and airplanes have been made in Cheyenne. In a plane, the background noise level is so high that results are practically worthless and unintelligible with the usual dynamic-broadcast-type microphone such as RCA 88. However, with the carbon microphone, the signal comes through loud and clear, the noises being discriminated against by the restricted audio range of the carbon microphone and the fact that anybody just naturally talks much closer to this kind of microphone.

Remote Use

The FCC has assigned exclusively to the remote-pickup broadcast service the following 19 channels between 26.11 and 26.47 Mc: 26.11, 26.13, 26.15, 26.17, 26.19, 26.21, 26.23, 26.25, 26.27, 26.29, 26.31, 26.33, 26.35, 26.37, 26,39, 26.41, 26.43, 26.45, and 26.47 Mc. Further conditions of use are set forth in pages 1-18 and 1-19 of this handbook.

The equipment described has been in use for over 10 years, and hundreds of transmissions have been successfully relayed over KFBC. Many other stations have used identical equipment successfully. The range of reasonably quiet transmission is determined largely by the height and efficiency of the receiving antenna. Several stations report ranges of 10 to 25 miles. A good average figure is about 4 or 5 miles. In large metropolitan cities when working from locations surrounded by extremely tall steel buildings, particularly when the receiver is at some distance from the transmitter, deep fading effects may be experienced, and it is likely that in these locations somewhat better results might be experienced with equipment operating on the higher frequency bands. Little difficulty has been experienced in towns of less than 100,000 population from these effects.

FCC Authorization

Under Part 4, Subpart D, of the FCC Rules and Regulations the above and other frequencies are authorized for remote-pickup broadcast stations. The use of these frequencies is permissible regardless as to the availability of telephone lines. A license will be issued by FCC to an established broadcasting station, and renewals can be made concurrently with the application for renewal of the regular station license. Application for construction permit is made using FCC Form 313, which is a short form and requires only a minimum of information. Application for construction permit and license can be submitted simultaneously following instructions on FCC Form 313.

1. Type of station (remote pickup)
   Station with which proposed station is to be used (your call letters)
2. Frequency (one of those listed above)
   Power (40 watts)
   Type of emission (FM)
   Communication bandwidth, kc [2(8.5 + 0.005 per cent of carrier frequency in kilocycles)]
   Example: $2(8.5 + 0.00005 \times 26{,}410)$
   $= 2(8.5 + 1.3205)$
   $= 2(9.8205)$
   $= 19.641$ kc
3. Location of transmitter (vicinity of city in which standard station is located)
4. Antenna system (vehicle-mounted whip 114 in. high)
5. (Not required)
6. (Not required)
7. Transmitter manufacturer (various)
   Type No. (BC 604 modified)
   Maximum rated power output (40 watts)
   Oscillator, type of circuit (crystal)
   Oscillator frequency (carrier frequency divided by 54)
   Oscillator tube type (6V6 GT), make (various), number (one)
   Last radio stage:
   Tubes, make (various), type (807), number (one)
   Normal plate current (120 ma), plate voltage (500), modulation (not modulated)
8. Percentage of modulation or swing (8.5 kc)
   Frequency tolerance per cent (0.005 per cent)
   Means for maintaining frequency tolerance (temperature-controlled CT cut crystal)
   External means employed to ensure maintenance of assigned frequency within tolerance specified by FCC Rules (BC-221 frequency meter or crystal-controlled multivibrator, checked against WWV)

Rule 4.481 requires that a simple log be kept of each transmission. An operator holding a commercial license or permit is necessary at the remote-pickup transmitter.

CONVERSION

Materials Needed

Transmitter:

One BC 604 transmitter
Six 6V6GT tubes
One 6L6 tube
One 807 tube
One RCA K900849-501 microphone input transformer or equivalent
Three 0.001 300-volt mica condensers
One 10-$\mu\mu$f 300-volt mica condenser

One 2,200-ohm ½-watt carbon resistor
One 510-ohm ½-watt carbon resistor
One 16- to 20-μf 450-volt tubular electrolytic condenser
One 10- to 10-μf 25-volt tubnlar electrolytic condenser
One 40-μf 25-volt tubular electrolytic condenser insulated tie points
Two 75-ohm ½-watt wire-wound or carbon resistors
7-ft shielded, insulated, stranded, single-conductor hookup wire
5-ft insulated, stranded, single-conductor hookup wire
18-in. varnished-cambric tubing
20-ft lacing cord
One 3-ohm 2-watt wire-wound resistor
One crystal, in FT 241 mounting
One 100,000-ohm ½-watt carbon resistor

Receiver:
One BC 603 receiver
One ½-watt 2,500-ohm resistor
One small banana pin and socket
One miniature bayonet-base lamp socket
Two 20-μf 250-volt tubular electrolytic condensers
One 0.1-μf 300-volt paper condenser

BC 603 receiver power supply:
One base from dynamotor DM 34 or DM 36
One Stancor plate transformer P-6134 or equivalent
One Stancor filament transformer P-6010 or equivalent
Two 500-ohm 10-watt resistors, wire wound
One octal tube socket
One 110-volt power cord and convenience plug
One 5Y3GT tube
One 20-μf 250-volt condenser
One 75-μf 250-volt condenser

Transmitter mounting:
One transmitter mounting FT 237D
One socket SO-45
One Cannon receptacle, male P8-42
One SPST toggle switch

Dynamotor:
One PE 103 dynamotor
One 20-ohm ½-watt wire-wound resistor
One 16-μf electrolytic tubular condenser, 600 volts

Remote-control unit:
One box, removed from dynamotor BD 77c or similar, or plain steel box, 9 in. long by 5½ in. wide by 3 in. deep
One no-insertion loss, T wire wound or carbon 250-ohm volume control (1,800-ohm simple rheostat in shunt with microphone will work quite well)
Two miniature bayonet-base pilot-lamp mountings and 6-volt lamps
One VU meter, Weston model 301, type 23, 5,000-ohm resistance or equivalent
One open-circuit headphone jack (two in parallel if desired)
One hinged jack dust cover
One six contact banana plugs, male, receptacle, SO-45
Two microphone sockets, to match the mike plugs of the station
One DPST toggle switch
One DPDT toggle switch
One 5,000-ohm ¼-watt carbon resistor

Transmitting antenna:
One commercial police-type mobile antenna-mounting swivel, spring, and insulator
One mast section MS 49
One mast section MS 50
One mast section MS 51

Cables:

One dynamotor cable shielded, CD 501A, with male plug, P8-24 on one end, and female connector P8-23 on the other end, eight contact (seven contacts only used). This fits the socket P8-41 on the PE 103 dynamotor and connects the dynamotor to the transmitter mounting.

One 15-ft length cordage CO 213. This is a seven-conductor rubber-covered, shielded cable, with two of the conductors separately shielded within the over-all shield. CO 213 is a component part of SCR 508.

Two plugs PL 106. These are six-contact female cord connectors and are attached to the ends of CO 213 and the cord thus constructed is used to connect the remote-control box with the transmitter mounting, plugging into socket SO 45 on each end.

BC 604 Transmitter

Following is a step-by-step procedure for modifying the BC 604 transmitter. The essential modifications are as follows: Change the microphone input transformer to improve frequency response and reduce noise; change the direct-heated filament tubes to cathode type to adapt the filament supply to 6 volts and to reduce noise; change certain circuit elements to retain proper voltages on tube elements when plate supply is reduced to 500 volts; secure the bias of audio stages from cathode resistors instead of filament drop. Figures 1-2, 1-3, and 1-4 pertain to these notes, and the numbers circled in Figs. 1-2 and 1-3 refer to paragraphs 1 and 2 of these notes.

1. Unsolder heavy wires and the smaller wire from the contacts of dynamotor relay S102. Clip the leads to the coil of S102, at S102. Remove four screws holding relay S102, and remove the relay. Remove two screws holding condenser C162. Clip the strap connecting the + end of C162 to the tie point. Cut the wire connecting the – end of C162 to R133, at R133. Remove C162. Unsolder the heavy wire that connected relay S102 at #1 and #3, PG104, and discard. Splice the heavy wire that formerly connected #1, PG101 to the contact of S102 to the smaller wire that formerly connected to the same contact of S102, and slip a piece of spaghetti over the splice. This wire feeds the battery to the filaments. This operation removes the dynamotor relay and associated condenser, since they are no longer needed, but preserves the filament feed.

2. Mount a 16-μf 450-volt electrolytic lengthwise of the transmitter in the space formerly used in part by the dynamotor relay S102. Connect the positive end of this condenser to the hot terminal of C145 (or R147) with a wire about 6 in. long and the negative end to that end of R130 that is connected to #4, PG103 (–B), or using a longer wire run direct to #4, PG103, if preferred.

3. Install RCA mike transformer K900849-501 in the space formerly occupied by relay S101 and condenser C162.

4. Disconnect the WH lead that connects D126 (tank-other use) switch to #2 VS107 at #2 VS107, and ground D126 using the same WH wire, shortened, connecting at the solder lug close to D126. (This is necessitated by other changes in filament circuits.) Clip the wire at #2, VS107. Don't try to unsolder it here.

5. Change the lead connected to #2, VS101, from #7, VS106, to #2, VS106. Filament.

6. Ground #7, S106, to ground lug, not to #8, VS106, because #8, VS106, will be lifted from ground later. Filament.

7. Disconnect the lead connecting #2, VS106, from C139 at C139 end. Connect #2, VS106, to #2, VS105, using this wire that formerly connected to C139. Filament.

8. Disconnect the lead from #7, VS105, which runs to R127, and pull from the cable and discard. Also, discard R127, unsoldering the other lead to R127 at R127. Filament.

9. Ground #7, VS105.

10. Ground #7, VS101, using the wire that formerly connected #7, VS101, to R127.

11. Cut the strap connecting R113 to R140 and R141 at R140 and R141. Remove

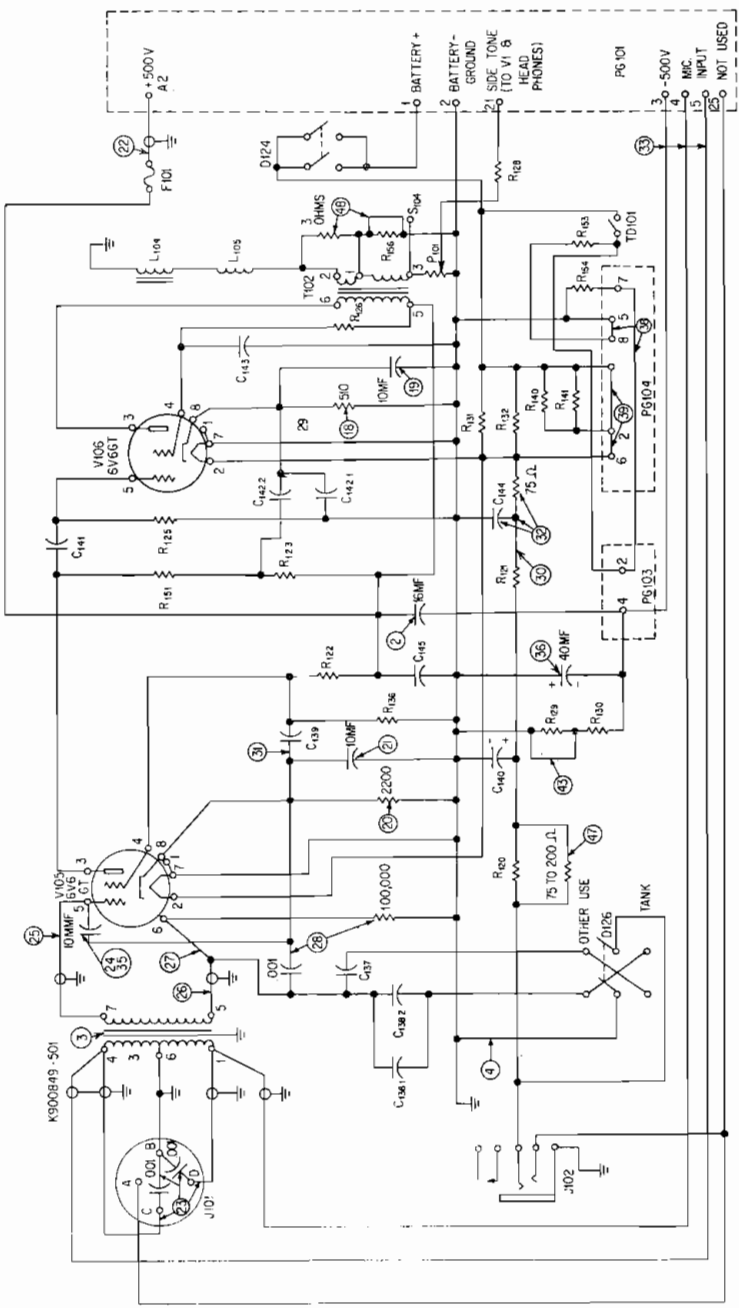

FIG. 1-2. BC-604 transmitter, audio circuits, converted. 31 indicates reference to paragraph 31, p. 7-12.

the screw holding R113 and disconnect R113 from #7, VS102, at R113, and use the wire formerly connected to R113 to connect #7, VS102, to R140 and R141 at the former junction with R113. Cut the yellow wire that connects to lamp ES101 from R113 and reconnect to R140 and R141 at the former junction of R140 and R141 with R113. (Cut the wire from R113. Don't try to unsolder.) This connection is made to the accessible end of R141. Discard R113. Filament.

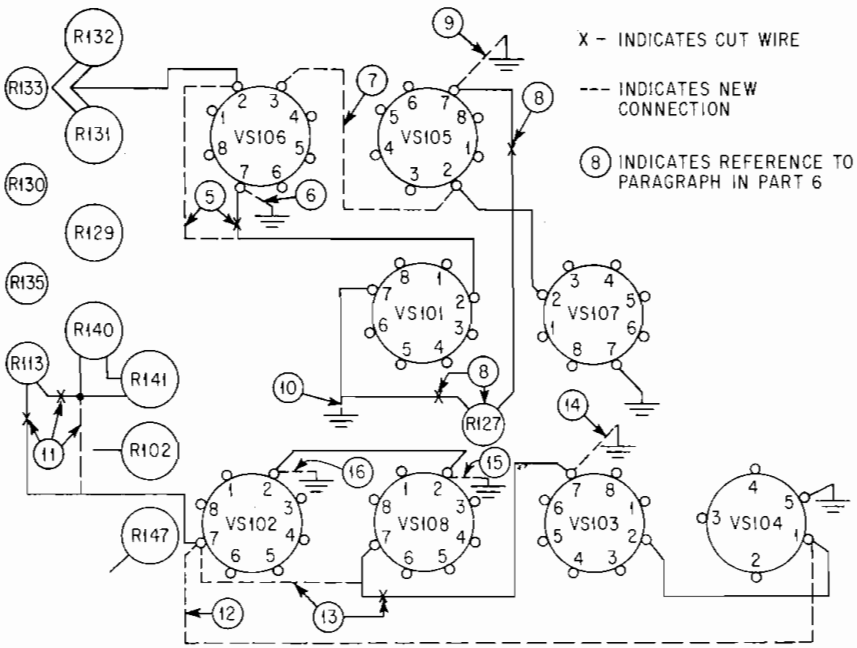

FIG. 1-3. BC-604 transmitter, filament circuit wiring diagram, showing changes made under BC-604 transmitter.

12. Connect #7, VS102, to #1, VS104, with a wire 13 in. long. Filament.
13. Change #7, VS108, from #7, VS103, to #7, VS102. Filament.
14. Ground #7, VS103. Filament.
15. Ground #2, VS108. Filament.
16. Ground #2, VS102. Filament.
17. Disconnect C110 from #2, VS102, and discard. There is no C110 in later units.
18. Install a 510-ohm ½-watt resistor between #8, VS106, and ground, removing ground from #8, VS106. Cathode-bias resistor.
19. Install 10-μf 25- or 50-volt electrolytic condenser between #8 and ground, VS106, + to #8 (cathode). Cathode bypass.
20. Install a 2,200-ohm ½-watt resistor between #8 and ground, VS105, removing ground from #8, VS105. Cathode-bias resistor.
21. Install a 10-μf 25- to 50-volt electrolytic condenser between #8 and ground, VS106, + to #8. Cathode bypass.
22. Disconnect the BL-YL wire connecting #8 on PG103 (+HV) to F161 at F161. Tape the end, and tuck it under the cable. Use the concentric line that connects C161 to #A2, PG101, for this +HV lead, making +B come through A2 on PG101 for using the external dynamotor. Disconnect C161 from the end of the coaxial transmission line. Cut the BL and GR wires from the center contact of S101.

Unsolder the bus wire connecting L111 to S101 at L111 and discard the bus. Unsolder the short coaxial cable that connects ANT terminal to S101 at S101. Remove the four mounting screws of S101. Clip the BLK wire and the BL-OR wire connecting to the coil of S101. Cut the BLK-RD and RD wires from S101. Remove relay S101. Mount an insulated tie point in the relay-mounting screw hole near the end of the coaxial cable connecting to A2, PG101. Solder the end of the coaxial cable to the tie point. Connect the tie point to F101 by means of an insulated stranded wire 19 in. long, taking this wire through hole A. Tie this wire to the cable at the top of the transmitter, also at the end, removing the plate at the right end of the transmitter to make the cable accessible. See paragraphs 43, 44, and 45 for disposition of the rest of the wires that formerly connected to S101.

23. Disconnect transformer T101 primary from terminals C and D of J101 at J101, and install condensers from C and D to ground (.001) and connect shielded wires from C and D to #4 and #1 of RCA mike transformer K900849-501. Ground shields at jack J102 (to solder lug installed under mounting screw) and ground shields at the transformer. Prepare and connect to transformer K900849-501 an additional shielded wire to each #1 and #4 and to #5 and #7 to be used later. Ground lug #6 of transformer K900849-501 to 6-32 screw adjacent, using a soldering lug and small 6-32 nut. Run the wire from this soldering lug to ground at C143. Slip spaghetti over ends of wires removed from C and D, J101.

24. Remove the lead connecting #5, VS105, to #5, T101, and discard the lead. If a small mica condenser is connected to #5, VS105, leave it connected to #5 but move the other end from #2, VS105 to #8, VS105.

25. Run the shielded lead from #7 transformer K900849-501 to #5, VS105. Ground the shield at both ends. Audio grid lead.

26. Connect the shielded wire from #5, transformer K900849-501 to #6, VS105 (used as tie point). Ground the shield at both ends.

27. Disconnect the wire that runs from the junction of C137 and C138 to #4, T101 at T101 end, and connect the junction of C137 and C138 to #6, VS105 (actually #5, transformer K900849-501). It may be advisable to replace the existing wire, which is solid, with a new wire about 3 in. long, which is stranded. Do not solder #6, VS105, until after the next step is completed.

28. Connect a ½-watt 100,000-ohm resistor from #6, VS105, to #1, VS105, and a 0.001 postage-stamp condenser from #6, VS105, to #8, VS106.

29. Disconnect BL-OR wire connecting C of C142.1 and C142.2 to C138 at C139 and move to #8, VS106 (it formerly went eventually to VS106, #2). Plate and grid isolation filters.

30. Disconnect R121 from C139.

31. Connect C139 (terminal formerly connected to R121) to #8, VS105. Screen grid bypass, V105.

32. Solder the ground lug of an insulated tie point to the terminal of C138 nearest PG101, and connect the end of R121 that formerly connected to C139 to the tie point. Connect a 75-ohm ½-watt resistor from #2, VS106, to the tie point. Remove the dust shield from the trimmer condensers and S104. Disconnect C144 from the radio-interphone relay S104, at S104, also at C144, and discard the wire. Connect a new wire 8 in. long from C144 to the tie point to which R121 is now connected, using hole E. Carbon-mike button current feed and filter.

33. It is necessary to remove four mounting screws holding PG101, also spacers. Be sure the spacers and grounding straps are restored after connections have been made. PG101 must be free to move. Connect #4, PG103, to #3, PG101 (−HV) with a wire 8 in. long. Connect #1, transformer K900849-501, to #4, PG101, using shielded wire and a ground shield at the transformer end. Connect #4, transformer K900849-501, to #5, PG101, using shielded wire and a ground shield at the transformer end. This operation disconnects the mike circuit of T101 and substitutes transformer K900849-501 for T101 and connects −HV of dynamotor to R130. Disconnect the present wires from #4, PG101, and #5, PG101, and slip spaghetti over the ends and tuck under the cable. Slip spaghetti over new wires to be connected to #3, #4, #5 of PG101, and slide it over the terminals after soldering.

34. Disconnect at the socket the shielded wire from #5, VS106, which goes to #2, S104, thus removing R148 from the circuit and raising the gain of the audio amplifier. Some sets do not have R148 and have no connection to Sec. 2, S104, and paragraph 34 can be disregarded in these cases. The purpose of R148 is to reduce the audio gain while transmitting, and, in any event, this gain-reduction circuit is not desired in this application. The easiest way may be to clip also the other shielded wire of this pair at #6, VS106 (used as tie point), also the ground of the

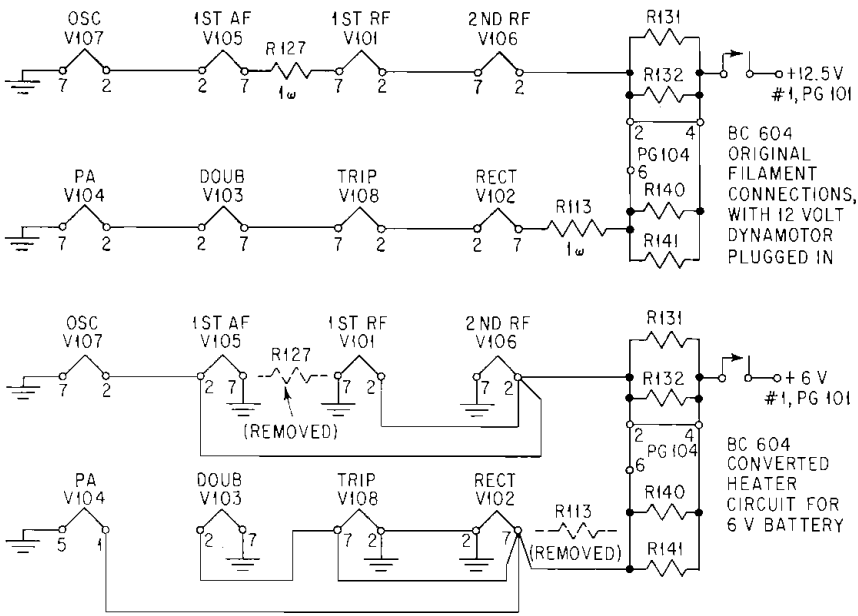

FIG. 1-4. BC-604 transmitter, original filament schematic and converted heater schematic.

shield, so spaghetti can be slipped over the end of the entire cable and the cable tucked away adjacent to the relay S103. R148 can also be disconnected from #6, VS106, also at its other end, and discarded.

35. Connect a 10-$\mu\mu$f condenser from #5, VS105, to #8, VS105, keeping leads not over $\frac{3}{8}$ in. long. Some transmitters already have such a condenser connected from #5, VS105 to #2, VS105. If so, this condenser has been reconnected in paragraph 24.

36. Lay a 40-μf 25- or 50-volt tubular electrolytic condenser in the space between the end of the transmitter and PG103 and PG104, and connect the positive end of the condenser to ground, using the ground lug at the corner of PG101, and the negative end to #4, PG103 (−B). Bias filter. If resistor R152 is in the way, disconnect it and remove it. This resistor serves as a load on the interphone output and is not needed. It is connected from #20, PG101, to ground. Cut the wire at #20, PG101, and at the ground lug. The screw can be retained to tie the condenser to.

37. Connect #4, VS104, to ground (#5, VS104), grounding cathode of V104, type 807.

38. Connect #2, PG103 to #7, PG104, and #5, PG104, to #8, PG104. Crystal heaters.

39. Connect #2 to #4 to #6, on PG104, shorting the 24-volt dropping resistors R131 and R132, and R140 and R141.

40. Disconnect R115 from C138 and from T101, and discard R115.

41. Cut the BR wire at D122 that connects to R135. Cover out the end with spaghetti, and tuck it under the cable. This makes it impossible to close the battery circuit through the coils of antenna relay S101 and receiver disabling relay S103, which are not used, thereby saving battery current.

42. Cut the RD-BR wire at the tie point (near R132 and to which tie point +C162 was formerly connected) which connects S104 to D124. This cuts the feed of the d-c filament battery to the coil of S104, radio-interphone relay, which is not used and which thereby saves a drain on the filament battery if the radio-interphone switch should be inadvertently thrown to "interphone."

43. Mount a soldering lug in the hole which formerly held S101, near L110, and ground the GR and BL wires which were removed from the contact of S101 to the lug, thus maintaining a continuous short to ground of R129. R129 was used to block all tubes quickly when the press-to-talk switch is pressed. This feature is not needed, since for this application the carrier is kept continuous.

44. Mount an insulated tie point with insulation suitable for RF near the end of the short RF coaxial cable that connects to ANT post, and solder the free end of this coaxial cable to the tie point. Connect the end of L111 formerly connected to S101 to the tie point by means of a piece of heavy tinned bus wire, taking care to form the bus so it will not short to ground.

45. Mount a three-point, vertical, insulated tie point strip in the remaining hole formerly used for mounting S101. To the lower tie point, connect BLK wire that formerly connected to coil S101. To the second point, connect BL-OR wire that formerly connected to the coil, S101. To the top point connect the RD and BLK-RD wires that are in series with the HV to V4. The antenna relay S101 is not used.

46. Remove the lamp E101, which is a 24-volt lamp, and replace with a 6- to 8- or a 12-volt lamp. The 24-volt lamp removed is used in the receiver.

47. Shunt R120 (200 ohms) with a 75-ohm ½-watt resistor. The carbon-mike current feed was designed to work from 12 volts and having added 75 ohms in series with R121 already in paragraph 32, it is now necessary to reduce the total resistance in the carbon button circuit so that the 6-volt source will cause sufficient button current to flow. However, if the particular carbon mike used does not give sufficient output, this 75-ohm resistor should be replaced with one of 200 ohms. If mike level is too high, substitute a 25-ohm resistor, which, while increasing the current flow, will act as a voice frequency load, reducing the signal level.

48. Clip the BL shielded wire from terminal #0 of L105, and clip the RD-BL shielded wire from #2, T102. Clip the ground wire of this shielded twisted pair, slip spaghetti over the bared end of the cable, and tuck it away in the space around the relay S103. Unsolder the bus wires from #1, L105, and temporarily remove L105. Short R156 by connecting #1, T102, to ground with a short bare tinned wire. Connect an insulated stranded wire 3 in. long to #2, T102, skin and tin the other end of the wire. Connect a 3-ohm 2-watt wire-wound resistor between #2, T102, and ground. Restore L105 to its original mounting. Connect #0, L105, to #2, T102, by means of wire already connected to #2, T102. Reconnect bare bus wires to #1, L105.

49. Rearrange screen grid dropping resistors R114 and R116, for V104, from series to parallel. Clip the strap at #2, VS104 (screen grid), and solder the clipped end to the adjacent terminal of R114, thus connecting R114 and R116 in parallel. By means of an insulated wire 4 in. long, connect the original junction of R114 and R116 to #2, VS104.

50. Install tubes in the transmitter as follows:

V101	6V6GT	V104	807
V102	6V6GT	V106	6L6
V103	6V6GT		
V105	6V6GT		
V107	6V6GT		
V108	6V6GT		

Transmitter Mounting

Mounting FT 237D is a component of SCR 508, SCR 528, and SCR 538. FT 237D is designed to accommodate one BC 604 transmitter and two BC 603 receivers. The mounting is cut by means of a hack saw, so as to accommodate only a transmitter BC 604. It is necessary to dismount the right-hand shock mount from the discarded part and remount the shock mount under the right-hand end of the receiver. All existing wiring of the FT 237D is discarded. Socket S045 and receptacle P8-42 are mounted on the left end of FT 238D, as is the SPST toggle switch. J 403 is retained. The mounting is wired in accordance with the diagram in Fig. 1-5. The mounting provides a plug-in shock mounting for the transmitter. No tools are needed to remove the transmitter for test or storage.

PE 103 Dynamotor

Most cars use a grounded negative battery. The PE 103 dynamotor is originally designed for use with a positive battery ground. The BC 604 transmitter is designed for a negative battery ground. (The electrolytic condensers of the carbon-mike circuit dictate a negative battery ground.) The changes of the PE 103 dynamotor consist mainly of the following: Reverse the input polarity (this amounts to reversing the polarity of the high-voltage brushes and interchanging the + and − signs at the ends of battery cables). Raise the operating current value of the HV overload breaker. Bring the negative high voltage out through terminal #2 of the output connector, thus isolating the high-voltage output from the d-c input circuit. A high-voltage filter condenser is also added. Following is a step-by-step procedure to accomplish these modifications. The following paragraphs refer to Fig. 1-6.

If it is desired to use the equipment with a positive ground, replace the carbon-mike filter condensers in the transmitter with insulated tubular type, reversing the polarity of the connections. For positive battery ground, the only changes that will be needed in the original PE 103 are the addition of the HV condenser, raising the operating point of the two breakers, bringing out the negative high voltage through #2, 3K1, shorting 3R2.

1. Remove HV and bell (long brush cover, opposite end from battery cables). Loosen four knurled screws in the top plate, and remove the dynamotor from the base.

2. Remove the terminal bolt from the old −HV brush. Isolate the two heavy wires formerly connected to the old −HV brush, but connect them together by means of the screw and nut just removed. Slip a piece of sleeving over the junction of the tape. Clear the heavy strip connected to the old −HV brush by bending it toward the outside.

3. Reconnect the green wire to the old −HV brush by means of a new bolt and nut, but clip the green wire at the lug and at the condenser. Solder a new insulated wire 8 in. long to the lug just bolted to the old −HV brush, and connect the other end of the wire to the condenser that is connected to the old +HV brush (by means of the green wire) and RF choke.

4. Clip the green wire at the condenser and RF choke to which the old +HV brush was formerly connected; also clip the same wire at the old +HV brush. By means of an insulated wire 8 in. long, connect the old +HV brush to the condenser which formerly connected to the old −HV brush.

5. Disconnect three wires from breaker 3E3 and three wires from breaker 3E5. Remove two screws at the front of breaker 3E5 and one screw from the rear of breaker 3E5 and remove the breaker. Disassemble breaker 3E5, divide the coil into two approximately equal parts, and reconnect the two halves in parallel, with the current flowing around the core in the same direction in each half.

6. Before replacing 3E5 run an insulated wire 14 in. long through the hole in the base. Connect one end of the wire to the old +HV brush and the other end to the tie point that connects to condenser 3C8 and #2, 3K1. Clip the wire at the tie

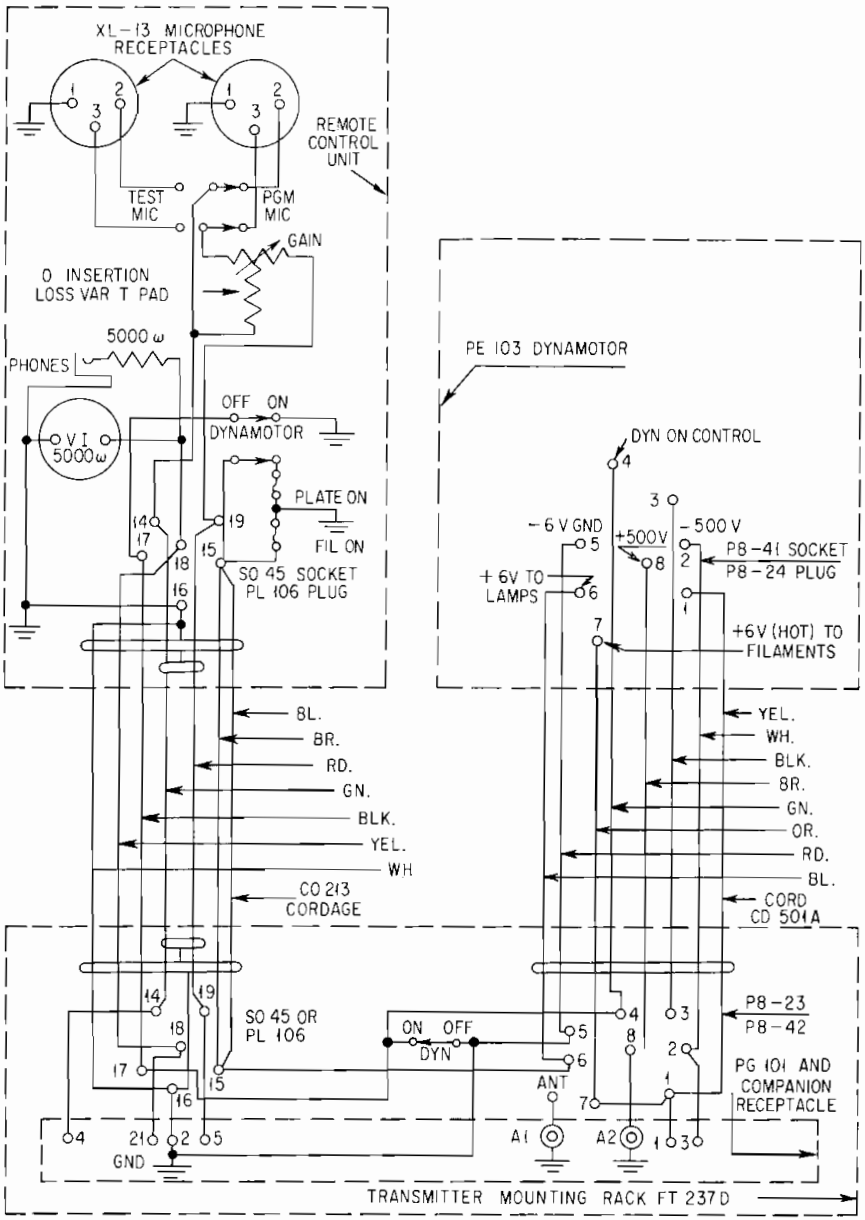

FIG. 1-5. FT 237-D mounting, schematic as modified. Remote-control schematic and connections for interconnecting cords, plugs, and sockets.

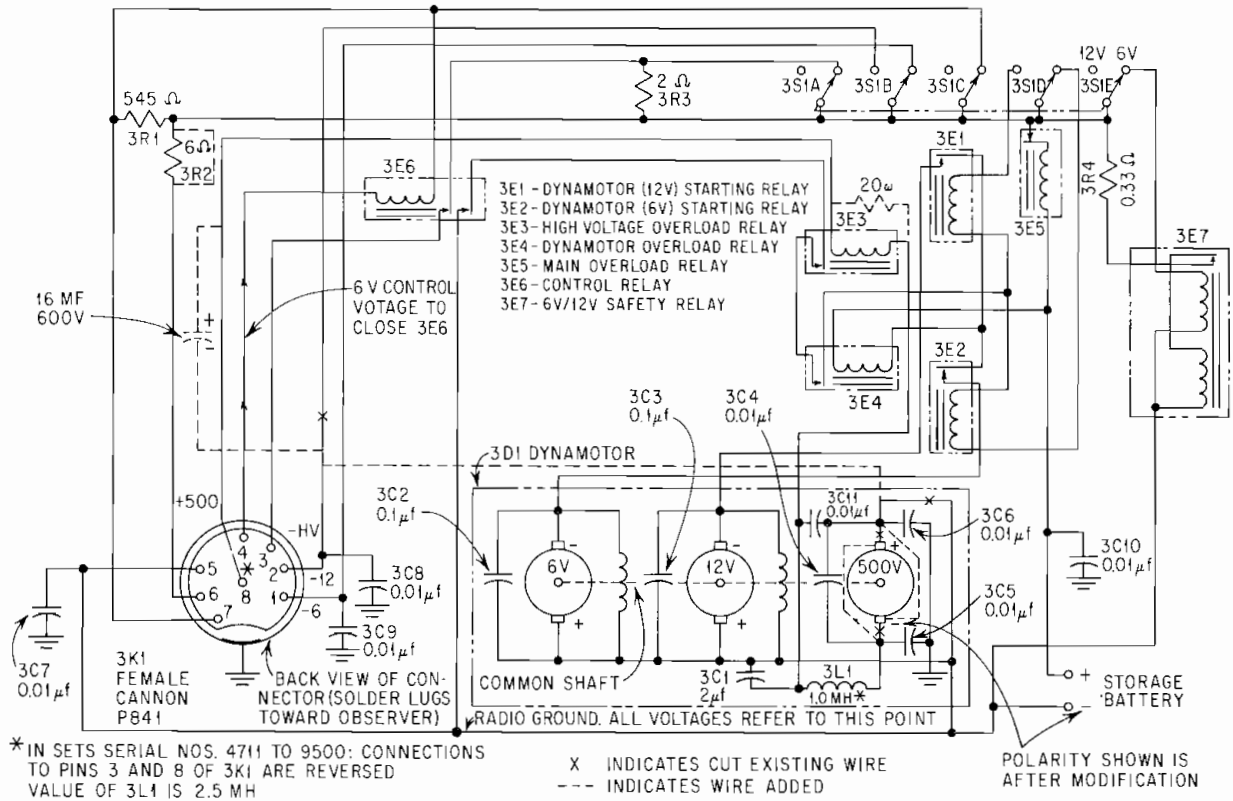

FIG. 1-6. PE-103 dynamotor schematic, showing modifications.

point that connects the tie point to 3S1B, and slip the sleeving over the end of the wire. Connect the other end of the wire to the old +HV brush. This becomes the new −HV brush, and the −500 volts is thus isolated from the 6-volt circuit and is brought out separately through #2, 3K1.

7. Restore breaker 3E5 to the original mounting position. Restore three wires to 3E3 and three wires to 3E5.

8. Connect a 10-ohm 2-watt wire-wound resistor between the two coil terminals of breaker 3E3. These are the terminals to which are connected two black wires leading from inside the breaker. This raises the tripping point of the HV overload from the original 0.220 to about 0.400 amp.

9. Drill a small hole through the bakelite strip mounting the insulated tie point which is connected to 3C8 and to #2, 3K1. Connect an insulated wire 5 in. long to a 16-μf 600-volt tubular electrolytic condenser at the − end. Lay the condenser parallel to breaker 3E3 in the space between 3E3 and the metal bracket supporting the old +6-volt terminal, with the − end of the condenser nearest the panel. Tie the condenser in place with lacing cord. Connect the + end of the condenser to the terminal of 3E3 farthest away from the panel of the dynamotor, the terminal which connects to +500 volts, #8, 3K1.

10. Short resistor 3R2 (6-ohm) which connects to #6, 3K1, by means of a heavy wire.

11. Restore the dynamotor to its case. Restore the HV end bell.

12. Change the − tag to the battery cable now bearing the + tag, and move the + tag to the cable now bearing the − tag.

BC 603 Receiver

Following is a step-by-step procedure for modifying the BC 603 receiver. The modification of the receiver proper consists mainly of adding plate-supply filter condensers, reducing the audio level through the first audio stage, connecting the receiver ON switch into the 110-volt a-c supply to the rectifier, and adding a pilot lamp.

1. Remove the front guard by removing four screws in the corner. Remove the dust cover by releasing the shakeproof screw in the rear.

2. Remove the front panel by removing six 6-32 screws, including that holding the EMERGENCY LOCK if the receiver has this feature, and two 8-32 screws, one above and one below the push buttons. The front panel is plug-in, and by working back and forth the plug at the bottom should readily disengage.

3. BC 604-DM only. [The 604-DM has four contacts on D5 (is a make-one-break-one switch), whereas D5 on BC 604-D is a simple open-and-close switch. BC 604-DM has no R22, R32, R33.] Mount two 4,700-ohm ½-watt resistors in parallel between the two tie points at the end of the bakelite terminal strip, removing the wire connected between these two points. This puts the new 2,350-ohm resistance in series with T1, the output transformer, and D2. Clip at both ends and remove from the cable the wire connecting the center terminal of P1 to D5. This wire is connected through #12, PG-3, then through #7, PG-1, and to the receiver disabling relay of the transmitter. Receiver disabling is not used in this application, and since this wiring is in the grid circuit of the first audio amplifier and is unshielded, it is best disconnected.

4. BC 604-D only connects a ½-watt 2,500-ohm resistor in parallel with R22, R32, R33.

5. Remove the spare fuse mounting.

6. Mount a bayonet miniature lamp socket in the hole formerly used by the spare fuse. It will probably be necessary to enlarge the hole slightly by reaming or filing.

7. Connect a small banana pin socket to the center terminal of the lamp mounting. Such a socket can be obtained by disassembling a plug and socket such as is used in the 247N command sets. Take care that the center pin of the lamp mounting is left free to move, and slip a piece of spaghetti or rubber tubing over the banana socket for insulation.

8. Solder the shell terminal of the lamp socket to the frame of the mounting, grounding one side of the lamp.

9. Replace the front panel on the receiver. Replace the front guard.

10. Place the soldering lug under the 6-32 screw at the lower left-hand corner of the front panel, strip and tin the ends of an insulated wire 3 in. long, solder one end of the wire to the soldering lug, and insert the other end in the G binding post, thus grounding one side of the antenna input at the front panel, in addition to the ground at PG-1.

11. Connect by means of an insulated wire 19 in. long, #8, PG-2, to #1, J-3. If #8, PG-2, is strapped to #11, PG-2, remove the strap. Run a wire along the main cable, and tie to same with a lacing cord. This places REC ON switch, D1 also fuse F1, in series with the 110-volt a-c supply to the rectifier cord.

12. Lift the cable from the fear of the receiver and place the 20-μf 250-volt electrolytic tubular condenser in the corner under PG-2, vertically, and connect the + end to #13, PG-2, and the − end to the − terminal of C25 (lower terminal) or optionally to #7, PG-2. Plate supply filter.

13. Mount a 20-μf 250-volt tubular electrolytic condenser in the space over condenser C20, and connect the − end to the − end of C25 and the + end to the + end of C25. Tie the condenser in place with a lacing cord. Plate supply filter.

14. Connect a 0.1-μf condenser from #1, LCU4 (which is connected to #15, J3), to ground at the lug to which L1 is grounded.

15. Skin and tin the ends of a piece of insulated wire 13 in. long; connect a banana plug, the mate to the banana jack of paragraph 7, to one end of the wire; and connect the other end of the wire to #2, VS4. This connects the hot 12-volt filament to the pilot lamp. Slip a piece of spaghetti or rubber tubing over the banana pin to insulate same. Tie this wire with a lacing cord to the conduit carrying the antenna wires.

16. Remove the 250,000-ohm resistor, R10, which connects #4, V7, to C11 and remove the megohm resistor, R11, which connects between the junction of C11, C13, C26 and #2, V9. Return these resistors to the circuit with their positions interchanged. In other words, change R10 from the original value of 250,000 ohms to 1 megohm and change R11 from the original value of 1 megohm to 250,000 ohms. This reduces the audio level at the grid of the first audio stage to prevent overloading.

17. Cut a piece of sheet metal of such size to cover the plug on the back of the receiver, drill two holes in the cover and two matching holes in the receiver at the ends of the plug, and by means of self-tapping 6-32 screws, mount the cover. This is to protect the live contacts on the plug which now bear 110 volts a-c.

18. Install the negative feedback circuit as outlined by heavy lines in Fig. 1-1.

Power Supply for Receiver

Since the receiver in most cases will be located at a place such as the studios or the main transmitter location, where 110-volt 60-cycle a-c power supply is available, it is modified to operate from such a power source rather than from a d-c source. The receiver requires 12 volts filament supply. If the components are carefully chosen, they can be mounted on the base of the originally furnished dynamotor DM 34 or DM 36. The socket for the rectifier tube is mounted flush with the dynamotor base. Two 500-ohm 10-watt resistors plus a 20- and 75-μf condenser are used as a filtering network and a voltage-dropping device to drop the voltage from that provided by most stock transformers that will fit the base. The base suggested will plug into the receiver, thus making a convenient arrangement. The receiver requires 200 volts at about 60 ma. Figure 1-7 indicates suitable wiring of such a rectifier and strapping of the multiconnector socket on the base to connect the front-panel ON-OFF switch into the primary and to connect the separate filament strings in parallel.

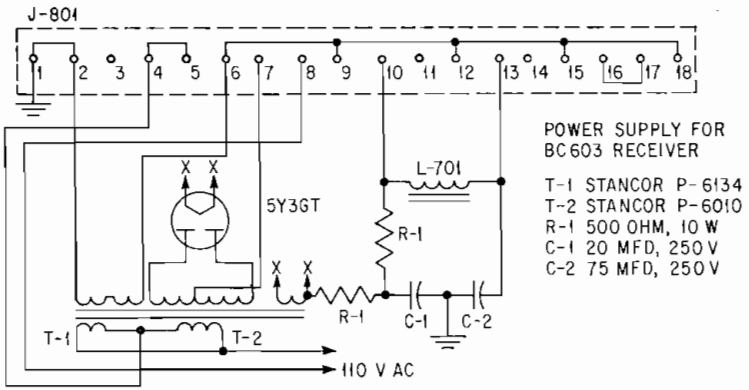

FIG. 1-7. BC-603 receiver, 110-volt a-c supply.

INSTALLATION

Receiver

Results as regarding distance covered without objectionable noise will depend largely on the height and efficiency of the receiving antenna. A ground-plane quarter-wave antenna or coaxial half-wave antenna located on top of the main transmitting tower will probably be the best, provided the main transmitter is not too far removed from the area in which most of the relayed programs will originate. Next best is a similar antenna on top of a tall building in the center of the area in which programs will originate. Good results can be had over shorter distances with an antenna located in an open and quiet location on a 40-ft telephone pole. The receiving antenna is matched to a concentric transmission line such as RG 8U, and the line connected to the receiver. The squelch control of the receiver should be OFF during program reception. The audio output is taken from the receiver at the phone jack. VOLUME is adjusted for +4 VU into 500 ohms. One side of output is grounded. The receiver should be peaked at carrier frequency by means of the RF trimmers. It is vital that the antenna trimmer be so peaked.

Transmitter

If a pleasure car is used, the transmitter is installed in the luggage compartment on the left side. The mounting is screwed to the floor by means of heavy sheet-metal screws or bolted down. It must be carefully grounded to the chassis of the car.

Transmitting Antenna

The transmitting antenna is mounted on the left side of the body of the car at the rear, keeping the antenna lead as short as possible. Use three mast sections, a total of 114 in. A commercial police-type antenna mounting and insulator, which includes a spring to protect in case of driving under an obstacle, should be selected.

Dynamotor

Mount the dynamotor permanently in the rear luggage compartment next to the transmitter on the right side of the car. Clamp the low-voltage lead to the frame of the car. Cut a hole 1¼ in. in diameter through the floor. Pass the + low-voltage lead through the hole and forward to the car battery. Clamp the lead directly to

the hot terminal of the battery, splicing with similar cable if necessary. Clamp by means of pipe straps and tie snugly to the underside of the floor of the car to prevent chafing and shorting. By means of cable CD 501A connect the dynamotor to the transmitter mounting.

Remote Control

The function of the remote control is to provide a convenient means of controlling the audio level and indicating when the filament is on, also of switching the plate supply dynamotor on and off. By frequent use of the DYN ON switch, much battery current is saved during test transmissions and cueing transmissions. Means is also provided for switching in a test microphone in place of the regular program mike. The remote control is usually placed on the seat beside the driver of the car. When not in use, it is removed from the connecting cord and put in an out-of-the-way place.

If more than one mike at a time is needed, a regular four-channel remote amplifier is connected in place of the pro-mike by means of suitable level-reducing pads and isolation coils. Since the volume indicator is fed from the ouput of the audio amplifier at about zero level through the same cable that the low-level microphone is fed to the audio amplifier, it is absolutely necessary that the two microphone conductors be separately shielded, preferably within the over-all shield of the cable. Such a cable is CORDAGE 213, a component of SCR 508. Figure 1-5 is a circuit diagram of the internal wiring of the remote control, also the manner in which the remote control is connected to the transmitter through the transmitter mounting and to the dynamotor. The lettering of the remote control shown in the photograph is engraved. An excellent job of lettering can be done with decals.

OPERATION

Leave the filament switch of the transmitter on. Leave the high-voltage and main overload switches of the dynamotor on. Turn the filaments on by means of turning on the filament overload of the dynamotor (the switch nearest to the hinge of the door covering the overload control). If left on continuously, this switch causes a small drain of about 15 ma on the battery. Allowing the normal time for the filaments to warm, turn the DYNAMOTOR switch of the remote control to ON position. This applies high voltage to the transmitter and places the carrier on the air. Microphones of an output level as great as that of the RCA 88 type must be used. Those of a low output level such as the RCA 44 type will not fully modulate the transmitter. Such microphones can be used, however, using a regular remote amplifier, the output of which is fed through the microphone terminal of the remote control or directly into the transmitter through the MAGNETIC MIC socket. Once properly tuned up, the transmitter and transmitting antenna circuits will need little readjustment. These circuits will keep their adjustment even though the car is driven over hundreds of miles of rough roads. The equipment has been used for many years without any readjustment of any kind. Since the equipment draws approximately 32 amp from the 6-volt battery, it is well to run the car engine if transmissions are longer than 15 min.

For transmission from airplanes, where the acoustic noise level is high, provision in the modification instructions is made for use of a carbon microphone. In such conditions, the carbon microphone will give better over-all results than a high-quality broadcast-type microphone. The close-talking variety such as T-17 is most suited. The carbon microphone is plugged into the CARB MIC jack. The volume control on the remote control is turned off during use of the carbon microphone. No variable volume control for the carbon microphone is provided. However, the TANK OTHER USE switch is a high-low carbon-microphone volume control. The gain for a given carbon microphone can be adjusted by the shunting resistor R120 within the transmitter. The volume will be indicated on the VU meter. It should be anticipated that the announcer will use a high voice level under high noise conditions.

Transmitter Notes

Since the type 1619 tubes have been replaced in the RF line-up with type 6V6GT, and since the 6V6GT has a different internal capacitance between the elements from the 1619, the trimmer condensers across the tuning coils will have to be changed to compensate. While this effect is very substantial, nevertheless, the condensers do not need to be rotated more than about 15° in order to bring the circuits into resonance. Some will be increased; some decreased. The tune-up procedure is to set the meter switch at position #3, rectifier grid current, and rotate the main tuning shaft until a reading of 20 or 21 or maximum on the meter is had. Then set the meter switch to position #4, doubler grid current, and adjust C153 and C157 for maximum meter indication. Next, set the meter switch to #1, tripler grid current, and adjust C114 and C116 for maximum meter deflection. Next, set the meter switch to #5, power-amplifier grid current, and adjust C120 for maximum deflection on the meter. Great care must be used to see that the ninth harmonic of the crystal frequency is selected in the plate circuit of the rectifier tube and not some other harmonic. One method, before modifying, is to connect the transmitter by means of using dynamotor DM-35 and a 12-volt source and a dummy antenna A162, and rotate the main tuning shaft with a tuning lock loosened until maximum output into the dummy antenna is had, all in accordance with instructions contained in the technical manual.

With the use of an absorption-type wavemeter, the proper harmonic can easily be selected, and with such an instrument at hand, it should be not necessary to tune up the transmitter initially before making the modifications. There is the advantage, however, since surplus and not new equipment is being used, that if there may be any defect in the transmitter, it can more easily be located and remedied if the transmitter is tested before modifications are undertaken.

Typical meter indications, after conversion outlined herein, are:

Meter position	*Circuit metered*	*Meter reading*
2	RF amplifier grid	19
3	Rectifier grid	21
4	Doubler grid	20
1	Tripler grid	23
5	Power-amplifier grid	20
6	Total B-supply current	60

The only value that is critical is the rectifier grid current, meter position #3. The only requirement in the other grids is that sufficient grid excitation be had in each stage to drive the stage following and to secure stability of operation.

The SIDETONE control adjusts the voltage fed to the VU meter. With a meter as specified, the proper setting of this control will be about 15° less than maximum clockwise position. Apply 1,000 cycles of audio frequency to the microphone input, at such level as to cause 11.5 volts to appear at terminal 21 of PG 101 of the BC 604 transmitter, with the VU meter and headphones of the remote control disconnected, measured with a vacuum-tube voltmeter, with the SIDETONE at maximum clockwise. This will produce a frequency swing of about 5 kc. Modulation peaks will achieve the level limit of 8.5-kc swing. Connect the VU meter, insert high-impedance headphones, and adjust the SIDETONE control to indicate +4 on the VU meter.

If the transmitter is adjusted so that a reading of other than 20 or 21 with meter selector on position 3 in obtained, the carrier swing (modulation percentage) and distortion will not be optimum. This reading can be controlled by changing the screen grid voltage of the first RF amplifier, V101, by changing the value of R103.

The antenna-current meter reads not only the antenna current but the capacitance current of the small section of concentric line in the antenna circuit.

Frequently, large-scale readings of antenna current can be had with the antenna entirely disconnected. Two antenna mast sections will produce a higher antenna current reading than three, but three will give considerably more radiation than two.

There is provision for operation on 10 different frequencies, changed by means of pressing a single push button. For this application, the trimmers should be peaked at the single frequency, disregarding tracking over the whole band. Follow the tuning instructions of Technical Manual TM 11-600 in every other respect.

The modifications make inoperative the RECEIVER-TUNE and RADIO-INTERPHONE switches. Tune the output stage and antenna coupling circuits for maximum antenna current, with three masts connected.

Difficulties Which May Be Encountered

Of the hundreds of installations that have been made, the most frequent causes of difficulty that have been encountered are discussed below:

1. *Connection and matching of transmitter to antenna.* There is about 18 in. of low-impedance coaxial cable *internally* in the transmitter. If the output is taken from the antenna terminal on the front of the transmitter, this cable is still shunted

RESISTOR AND CONDENSER, FROM PHANTOM ANTENNA, A-62.
THERMOCOUPLE, METER, AND CASE, FROM ANT. RELAY, BC-442.
COIL, 8-10 TURNS, 1/2" DIA. HEAVY WIRE.

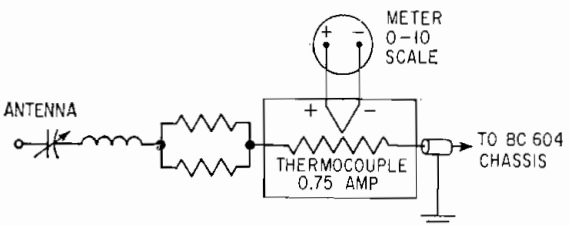

FIG. 1-8. Antenna output-tuning indicator.

across the antenna output. If the antenna output current is taken, as it will generally be if a plug-in mounting is used, through the coaxial connector at the end of the transmitter, then this internal coaxial cable is in series with the antenna. It has been found that only an open wire, not to exceed 18 in. in length, can be used to connect from the cannon plug to the base of the whip. A coaxial cable *can* be used—preferably RG 8U—for the connection to the whip, but this coaxial cable *must* be exactly one or more half waves long electrically.[3] When installed in a standard pullman car, a coaxial cable of three half waves in length was used. When an odd length of coaxial cable is used for this connection, the output tuning elements of the transmitter apparently cannot achieve resonance and a match. An antenna-current meter is provided, but it is coupled to the antenna circuit in a rather unusual way, and when everything is right, it makes a very reliable antenna resonant indicator. It should be noted that under extreme conditions of nonresonance or mismatch, a large showing can still be obtained from this meter, with practically no radiation.

2. *Receiver installation.* Generally speaking, results will be governed very largely by the efficiency of the receiving antenna. The higher the receiving antenna, the better the results, assuming, of course, that there is an impedance match. The receiver apparently presents a fairly good match to RG-8U cable. A ground plane quarter-wave antenna, omnidirectional, matched to RG-8U cable, the antenna being mounted about 45 ft above in the clear, will give good results. Actually satisfactory

[3] Obviously, a matching network could be provided to feed any length of coaxial line with a low VSWR, but this assumes no additional circuits.

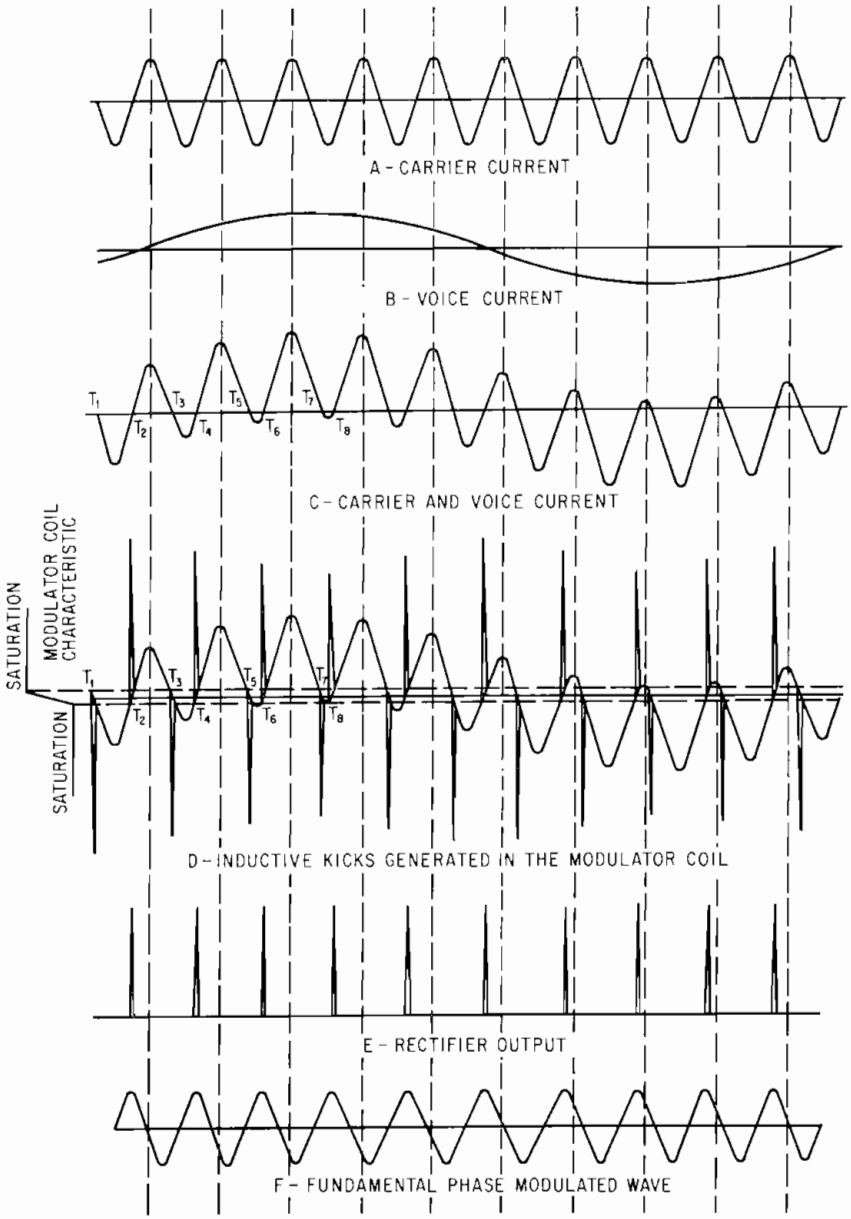

FIG. 1-9. Radio transmitter BC-604, method of modulation.

reception has been had over a distance of 2 or 3 miles with a 15-ft piece of wire hung out of a second-story hotel window, provided the input of the receiver is carefully tuned.

3. *Receiver antenna tuning.* On the left side of the receiver is the antenna trimmer, C1.1 on the schematic diagram. This adjustment has the same effect that most antenna trimmers do, and its purpose is to bring the first tuned circuit in the receiver to resonance, regardless of the nature of the impedance that is connected across the antenna input terminals. Thus, for each particular antenna, there will probably be a certain best adjustment of this trimmer. It need not be adjusted when different channels are selected within the allocated 26-Mc band for this service, but it should be checked from time to time to make up for any change in the antenna or if the first tube is changed. This adjustment is best made with no transmitter carrier on, tuning for maximum noise, with the main tuning set to between 26 and 27 Mc. A good technique can be developed for this adjustment by using the "sensitivity" control in connection with the "squelch feeling" for the antenna trimmer adjustment that causes the noise to just operate the squelch, with the "sensitivity" the farthest counterclockwise that will still cause the squelch to operate as the trimmer is rocked.

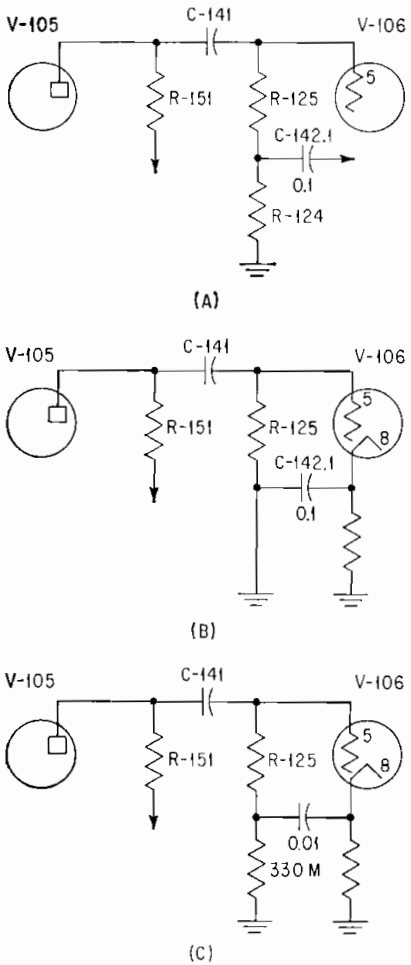

FIG. 1-10. (*A*) Partial diagram of BC-604 transmitter audio circuit as it appears in original diagram in Technical Manual TM 11-600. (*B*) Partial diagram of BC-604 transmitter audio circuit as it appears in Fig. 1-2. (*C*) Partial diagram of BC-604 transmitter audio circuit including modification which should be made to increase frequency response. (This modification is not included in Fig. 1-2.)

Cueing

A logical question which arises at this point relates to cueing. The reader may ask, "Why isn't two-way cueing utilized?" The answer is that there is a better way to do the "talk-back" job. The initial requirements are for a high quality, dependable, noise-free remote-pickup circuit which is mobile and easily portable.

The transmitting equipment described draws about 32 amp from the 6-volt battery. A new fully charged standard equipment car battery, with no other load on it, will operate this transmitter for over an hour. With the car engine running, it will operate for considerably longer. As other loads are added, first a receiver, then lights, perhaps a heater, etc., the margin grows narrower. As a matter of fact, for complete freedom of worry from this source, many stations install the Leece-Neville alternator-rectifier type of generator in their mobile unit. This will put out up to 100 amp continuously, with engine barely above idling speed. A condenser

and coil filter are usually necessary to suppress ripple. The 32 amp is about the feasible limit, and this transmitter uses about 40 watts input to the plate of the final stage. Input to the last tube of, say, 250 [4] watts or more would surely indicate some kind of gasoline generator, with all its cumbersome complications. Next, a mobile transmitting antenna is indicated. This means that to get any efficiency, the antenna should be about a quarter wave long. At 26 Mc, the car body, with its large capacity to ground, serves as a pretty good substitute for a ground, and a quarter-wave whip is of a very convenient size. Thus, a good transmitting efficiency is achieved. And so we find that for *mobile* use, this power range and this frequency are naturals. Now examine the requirements for the circuit in the reverse direction,

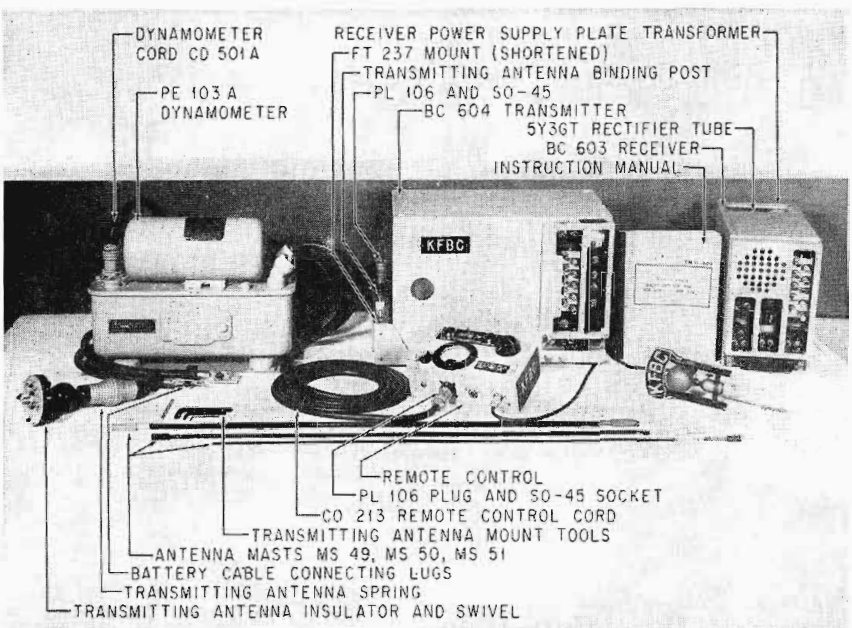

FIG. 1-11. View of the various components of the system.

or the "talk-back." To begin with, the location of the talk-back transmitter, in the general case, will be fixed, and, in addition, it will mostly be at the same location as the main broadcast transmitter, which means that a near-perfect transmitting ground is available. There is nearly always a tall structure (the main transmitting tower) close at hand. Furthermore, the transmitter can and surely will be operated on an a-c source, not a car battery. Thus, there is no rigid limitation on the number of watts available from the primary power source. And, probably the most important difference in the requirements between the talk-back and the mobile pickup equipment is the fact that the talk-back needs only to transmit intelligence. Finally, and very compelling, is the question of the receiver for the talk-back, which is, of course, located in the vehicle which carries the pickup transmitter. This vehicle will inevitably have a standard broadcast receiver as part of its original equipment. Group B of the FCC assignment specifies 1,606 kc, in addition to other frequencies. Many standard BC car receivers will tune to 1,606 as they come from the factory. Those that do not can be made to do so with a very slight adjustment of the oscil-

[4] Not recommended for a single 807 tube.

lator trimmer, with no serious impairment to their operation across the broadcast band. Thus, the receiver part of the talk-back circuit is already provided in a most satisfactory manner. The talk-back transmitting antenna, using the regular ground, and a wire supported to prevent any detuning of the main radiator will prove highly efficient. Experiment has shown that this is quite feasible, using about one-third to one-half the available height, if the tower is located away from the building. In any event, a good ground is available. Since voice-only transmission is required, any of the many war-surplus communication transmitters are adequate from this standpoint. A good example is the BC 191, which is available on the surplus market at approximately $29.90 complete with tuning unit TU 5. This is rated at 100 watts input to the last stage. It will have to be modified to crystal control. This is a very simple modification. The present oscillator is changed to an RF amplifier, and

FIG. 1-12. View of the remote-control unit.

a 6L6 tri-tet crystal oscillator is constructed on a separate chassis and fed by coaxial cable to the BC 191. In addition, a 1,000-volt 350-ma power supply will be needed. Parts for this will cost no more than the transmitter. A push-to-talk relay is built into the transmitter, and a small d-c rectifier will be needed for this. Thus, for less than about $100 worth of materials, plus our labor, we are in business with a talk-back that will surely communicate out as far as the remote pickup will transmit in. It will immediately be apparent that the first station in any community to apply for group B assignment for its talk-back is the lucky one. Actually, however, it is fairly simple to make a converter so that almost any of the lower authorized frequencies in groups A, B, or C, will serve very nicely. The BC 375 transmitter is more readily located on the war-surplus market and will do about as well as the BC 191 but will require somewhat more extensive changes to operate from alternating current instead of the intended 28 volts direct current.

NOTE: Equipment discussed in this part can be obtained from the following sources:

R. W. Electronics, 2430 S. Michigan Ave., Chicago 16, Ill.
Fair Radio Sales Co., 132 S. Main St., Lima, Ohio.
Columbia Electronics, 2251 W. Washington Blvd., Los Angeles 18, Calif.
C & H Sales Co., 2176 E. Colorado St., Pasadena 8, Calif.
Texas Crystals, 8538 W. Grand Ave., River Grove, Ill.
G & G Radio Supply Co., 51 Vesey St., New York 7, N.Y.
Edison Electronic Company, 1902 N. Third St., Temple, Tex.

Part 2

A PRACTICAL 160-MC REMOTE-PICKUP BROADCAST SYSTEM

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CONVERSION OF THE MOTOROLA FMTRU 30 EQUIPMENT FOR USE IN THE 160-MC REMOTE-PICKUP BAND

Introduction

The equipment described in this part consists basically of the Motorola FMTRU 30 which is designed to operate in the 152- to 162-Mc band with an output power of 30 watts. This is a crystal-controlled unit and maintains its operating frequency within a tolerance of 0.0025 per cent (minus 20 to plus 60°C). The unit is frequency modulated utilizing an angular balanced modulator with a required 20-kc deviation for 100 per cent modulation. It is primarily intended for 6-volt operation but with slight modifications can be adapted for 12-volt systems. After modification the frequency response will be found to be substantially flat from 50 to 5,000 cycles with extremely low distortion and noise. Dependable transmission in excess of 25 miles can be expected from such a unit, depending, of course, on the height of the receiving antenna and the local terrain and noise level. *Before conversion is attempted, a complete original instruction manual should be obtained from the manufacturer.*

Frequency Allocation

The FCC has allocated nine remote-pickup channels between the frequencies of 152.87 to 153.35 Mc. These are shared with the Industrial Service, and in fact, the Industrial Service has priority of use. It should be pointed out here that band loading by the Industrial Service will increase because of the recent channel-splitting decision of the FCC, with consequently less opportunity for broadcast shared use of this band. Since Industrial interference posed such a problem in the 152.87- to 153.35-Mc

band, no attempt was made to convert this unit for these frequencies but to utilize a band which had fewer disadvantages to the remote-pickup service.

The frequency of 166.25 Mc was decided upon even though the Commission has imposed certain limitations upon its use. This frequency under present rules may not be utilized within the area bounded on the West by the Mississippi River, on the North by the parallel of latitude 37°30′ N and on the East and South by that arc of the circle with a center at Springfield, Ill., and radius equal to the airline distance between Springfield, Ill., and Montgomery, Ala., subtended between the foregoing West and North boundary and also within a 150-mile radius of New York. Another limitation to the use of this frequency is that no interference shall be caused to government radio stations. To date, operation of this equipment has produced no known interference complants.

It should be pointed out that the Commission in its Notice of Proposed Rule Making, Docket 11959,[1] proposed to delete this frequency and substitute in lieu thereof six exclusive remote-pickup channels each 30 kc wide between 161.646 and 161.825 Mc. These will be exclusive to the broadcast inlustry, and, *if they are allocated,* this equipment could be easily converted to this band.

Where the propagation path from the desired remote-pickup point is too great for dependable operation, the receiver can be used at a remote point, and its power turned on and off by remote control merely by simplexing the telephone line used to carry the audio from the receiver to the studio. For special events such as fires or disasters in nearby towns, the central telephone office in that town is a logical place to tie into the telephone facilities, particularly if it is a small town.

Conditions of Use

Remote-pickup broadcast stations will not be granted exclusive frequency assignments, and the same frequency or frequencies may be assigned to other licensees in the same area.

Applicants may request information about the existing remote-pickup assignments in a particular area and apply for unassigned frequencies to the extent permitted by the FCC rules. The Commission is unable to supply information regarding existing assignments to the industrial radio stations in the band shared by remote-pickup stations with the service.

Where a frequency is shared by two or more remote-pickup stations and simultaneous operation is contemplated, the transmission of actual program material has first priority, the transmission of cues and orders including preparatory communications has second priority, and the use of the remote-pickup station for other authorized communication has the lowest priority.

For detailed conditions of use see pages 1-18 and 1-19 of this handbook.

Licensing

Under Part 4, Subpart D, of the FCC rules and regulations, the above and other frequencies are authorized for remote-pickup broadcast stations. *The use of these frequencies is permissible regardless of the availability of telephone lines.* A license will be issued by FCC to an established broadcasting station and renewals may be made concurrently with the application for renewal of the regular station license. Application for construction permit is made using FCC Form 313 which is a short form and requires only a minimum of information (see below). *Application for construction permit and license may be submitted simultaneously,* following instructions on FCC Form 313.

1. Type of station (remote pickup)
   Station with which proposed station is to be used (your call letters)
2. Frequency (166.25 Mc)
   Power (30 watts)
   Type of emission (60 F3)

[1] NAB testimony in this docket requested 10 channels.

Communication bandwidth, kc (60 kc)
3. Location of transmitter (vicinity of city in which standard station is located)
4. Antenna system (vehicle mounted)
7. Transmitter manufacturer (Motorola)
Type No. (FMTRU-30)
Maximum rated power output (30 watts)
Oscillator, type of circuit (crystal)
Oscillator frequency
Oscillator tube type (7C7), make (various), number (one)
Last radio stage:
Tubes, make (various), type (2E26), number (two)
Normal plate current (260 ma), plate voltage (420), modulation (angular balanced)
8. Percentage of modulation or swing (±20 kc)
Frequency tolerance per cent: 0.005 per cent from −30° to +80°C., or 0.0025 per cent from −20° to +60°C.
Means of maintaining frequency tolerance (quartz crystal)
External means employed to ensure maintenance of assigned frequency within tolerance specified by FCC rules (BC-221 frequency meter or crystal-controlled multivibrator, checked against WWV)

Section 4.481 requires that a simple log be kept of each transmission. An operator holding a commercial license or permit is necessary at the remote-pickup transmitter.

Base-station Antenna Location

We constructed a ground plan antenna as shown in Fig. 2-2 and first tried mounting the antenna on a TV mast on top of our studio building. The antenna was about 40 ft

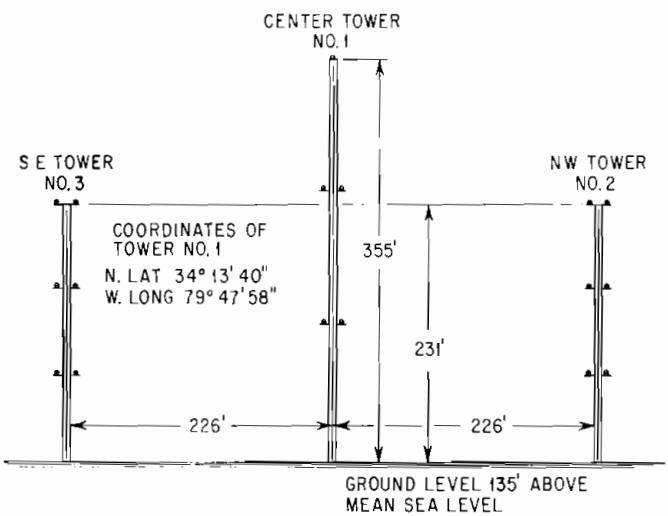


Fig. 2-1. Existing WJMX antenna system.

above the ground. This location proved to be unsatisfactory because of a very low signal-to-noise ratio.

Next, with proper authority from the FCC, the base-station antenna was mounted on top of our AM broadcast station antenna. This put the antenna 231 ft above the ground and proved to be well out of the ignition-noise area.

RG 11 U coaxial cable was used from the antenna to the base of the tower. At

that point the coaxial cable was formed into a coil, and a fixed condenser placed across the coil (outer conductor of the coaxial cable). The coil was then tuned to the station frequency by "cut-and-try" adjustment of the coil tap.

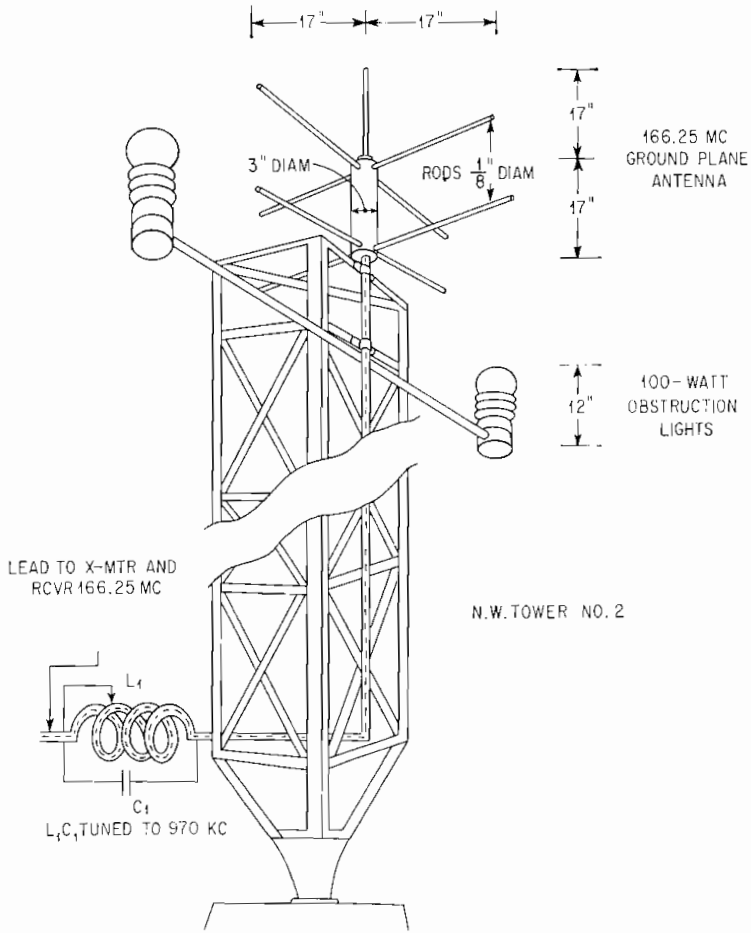


FIG. 2-2. Proposed method of mounting 166.25-Mc antenna to NW tower 2.

In some cases the FCC requires that a "skeleton" proof of performance be made in order to assure the Commission that the installation of the remote-pickup antenna has not adversely affected the operation of the AM antenna system. It is suggested that due caution be applied in such installations, particularly when a tower of a directional-antenna system is involved.

Conversion

The material needed for the conversion of the basic transmitter and receiver is as follows:

One Motorola-type FMT-1 crystal, frequency 3463.542 kc
One Motorola crystal, type D-14 (9,879.4 kc)

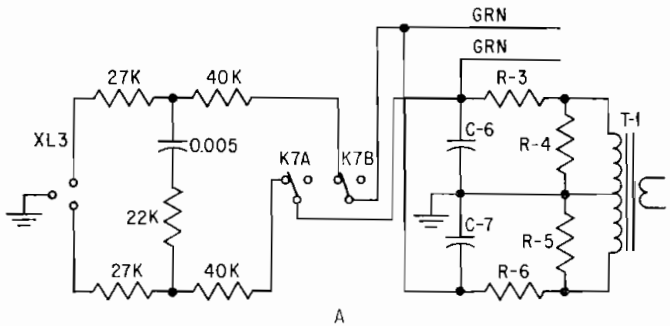


FIG. 2-3*a*. Mobile-transmitter audio and control modifications—frequency-compensation network.

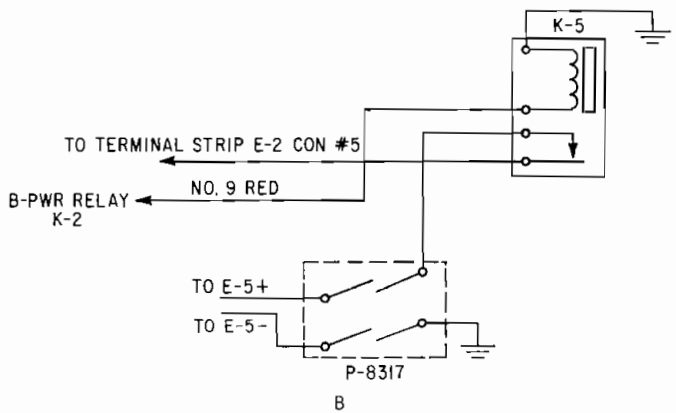


FIG. 2-3*b*. Mobile-transmitter audio and control modifications—dynamotor relay K-5 is included in some units.

One 3 PDT, 6-volt relay
One Cannon XL-3 connector
Two phono jacks
Two 27,000-ohm resistors
Two 40,000-ohm resistors
One 0.005-μf condenser
One 22,000-ohm resistor
One four-prong plug
One 100,000-ohm resistor, 1 watt
One 240,000-ohm resistor, ½ watt
One 0.001-μf, 600-volt condenser
One 0.05-μf, 600-volt condenser

The above list does not include the additional material required for the construction of the power supplies for 110-volt operation of either the receiver or transmitter, nor does it include the necessary parts for the construction of the frequency-compensating line amplifier.

Transmitter Conversion (RF)

1. Refer to the transmitter schematic in the construction manual and Fig. 2-3*a*, *b*, and *c* contained herein.
2. Replace the existing crystal with Motorola type FMT-1. Frequency 3,463.542 kc.
3. Tap down *one turn* on coil T5UA (plate side).
4. Shorten the PA plate line by moving C55 and C56 up on the lines as far as the wire will permit (approximately 1½ in.).
5. The transmitter is now ready for alignment.

Receiver Conversion (RF)

1. Refer to Fig. 2-4.
2. Install a new Motorola crystal, type D-14 (9,879.4 kc).
3. Disconnect C89, C91, and C93.
4. It may be necessary to remove one or more plates from C2 in order to tune the receiver to the antenna. In our case, one rotor plate was removed.
5. The receiver is ready for alignment.

At this point, the transmitter and receiver could be used for news and speech pickups; however, frequency response, distortion, and noise leave much to be desired. Considerable improvement in the response and distortion was noted by using the new transistorized mobile microphones in place of carbon mikes.

We proceeded to improve the over-all characteristics of the system to enable us to broadcast musical programs.

Inasmuch as the mobile receiver and base-station transmitter are not in the broadcast-air circuit, no audio modifications in these units was deemed necessary.

Mobile-transmitter Audio and Control Modifications

In the angular balanced modulator used, the deviation increases as the audio frequency increases. The maximum permissible frequency swing at low audio frequencies is limited by the allowable distortion. We found the maximum frequency deviation to be limited at high audio frequencies by the receiver bandwidth. For complete analysis, we used a frequency deviation meter, signal generator, and distortion analyzer. We found T1 to be unsatisfactory; therefore, a remote amplifier was used to feed the modulator grids through a compensation network. Furthermore, it was decided that on most remotes where music was to be transmitted, commercial power would be available, and in order to conserve battery power and to eliminate dynamotor noise, an a-c power supply would be used. We also decided to let the filaments operate from the battery, since d-c power was necessary for the control of relays. In order to do this and retain battery operation when desired, an additional 3PDT, 6-volt coil relay was added and wiring changes were made as shown in Fig. 2-3*a*, *b*, and *c*.

1. Install a Cannon XL-3 connector in the right side of the chassis.
2. Install relay K-7 (3PDT) under the chassis behind P2 and J3.
3. Install a phono jack on the front panel between P2 and J3 for the external carrier switch.
4. Connect one side of the coil of K7 to 4 on E2.
5. Connect the other side of the coil of K7 to 3 on J4.
6. The frequency-compensation network as shown in Fig. 2-3*a* is now connected between XL-3 and two of the normally closed contacts of K7 (K7A and K7B).
7. The movable contacts of K7A and K7B are connected at the grids (pin 4) of V2 and V3.
8. The normally closed contact of K7C was connected to the phono jack.
9. Disconnect the K2 and K3 coil leads at pin 3 of J4 and reconnect to the movable arm of K7C.
10. Connect the normally open contact of K7C to 3 of J4.

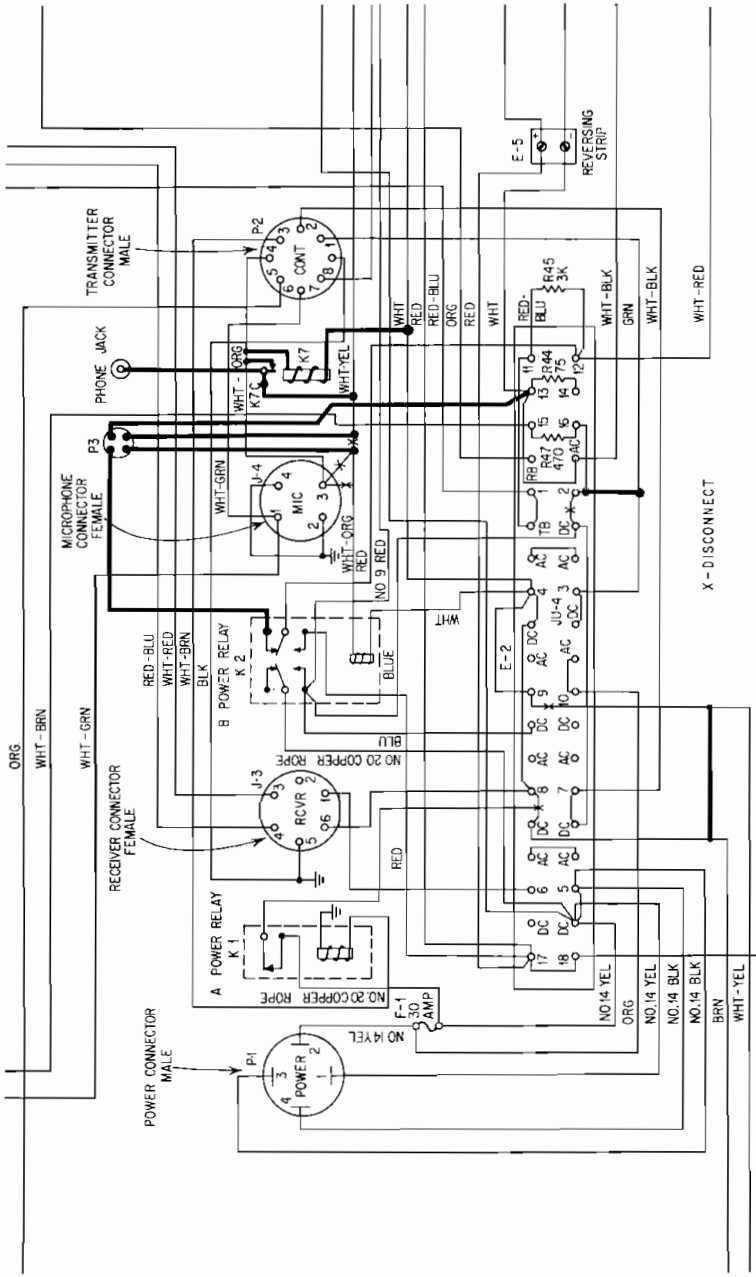


FIG. 2-3c. Mobile-transmitter audio and control modifications—external carrier switch and power connection.

11. B+ from the a-c power supply was connected to the normally closed B+ contact on K2.

12. B− from the a-c power supply was connected to 13 on E2.

The above connections were made through a four-conductor, four-prong plug (P3). The other two conductors were connected in series with K2 coil between K2 and K7C. These leads were connected to a pair of normally closed contacts of a relay in the a-c supply, which were opened by presence of d-c plate voltage from this supply. This allowed the dynamotor to operate automatically upon failure of d-c plate voltage from the a-c supply.

A standard power supply, delivering 420 volts at 280 ma with a low-current d-c normally closed SPST relay operated on B+ was constructed. B− is above ground.

The output of the remote amplifier was padded to give ±15-kc deviation of the transmitter when the VU meter indicated normal level.

Base-station Receiver Conversion

Because of distortion and poor frequency response in the receiver output stage, we used the output of the first audio stage to drive the frequency-compensation amplifier.

The following changes were made in the receiver (see Fig. 2-4):

1. Add a 100,000-ohm 1-watt resistor in parallel with R55.

2. Connect a 240,000-ohm resistor, ½ watt in series with a 0.001-μf 600-volt condenser to ground from pin 4, V15.

3. Connect a 0.05-μf 600-volt condenser to pin 3, V15. Bring out the other side of the condenser to a phono jack, which can be mounted on the front panel, next to the metering jack.

4. Disconnect C83.

The audio output of the receiver was taken from the phono jack and fed through a shielded cable to the frequency-compensation amplifier, indicated in Fig. 2-6.

The circuits of this amplifier were developed more or less by a cut-and-try method to produce the over-all response characteristics as indicated in Fig. 2-5. This response of the frequency-compensation amplifier was necessary because of the limited low-frequency response of the transmitter.

The vibrator supply in the receiver was removed, and a supply was constructed to deliver 180 volts at 100 ma and 6.3 volts alternating current at 3 amp and connected to J4.

Base-station Transmitter Conversion

The following changes were made to the base station transmitter to enable the use of an a-c supply:

1. Remove the dynamotor. It was necessary to separate the filament wiring from the relay coil wiring before applying 6 volts a-c.

2. Remove direct current to 8 jumper on E2.

3. Remove direct current to 2 jumper on E2.

4. Connect 2 to 3 on E2.

5. Break the filament line on 9 of E2 and connect to direct current formerly jumpered to 8. Six volts a-c connects to this point (see Fig. 2-3*c*).

6. Six volts d-c connects to the transmitter on P1.

7. HV (plus direct current) and (minus direct current) connects to the transmitter on E5.

8. One side of 6 volts a-c and 6 volts d-c connects to ground.

The base-station-transmitter a-c supply is conventional except for the necessary d-c mike and relay supply, which is approximately 1 amp at 6 volts d-c. Plate supply for full power requires 420 volts at 280 ma and filaments require 6 volts a-c at 4.5 amp.

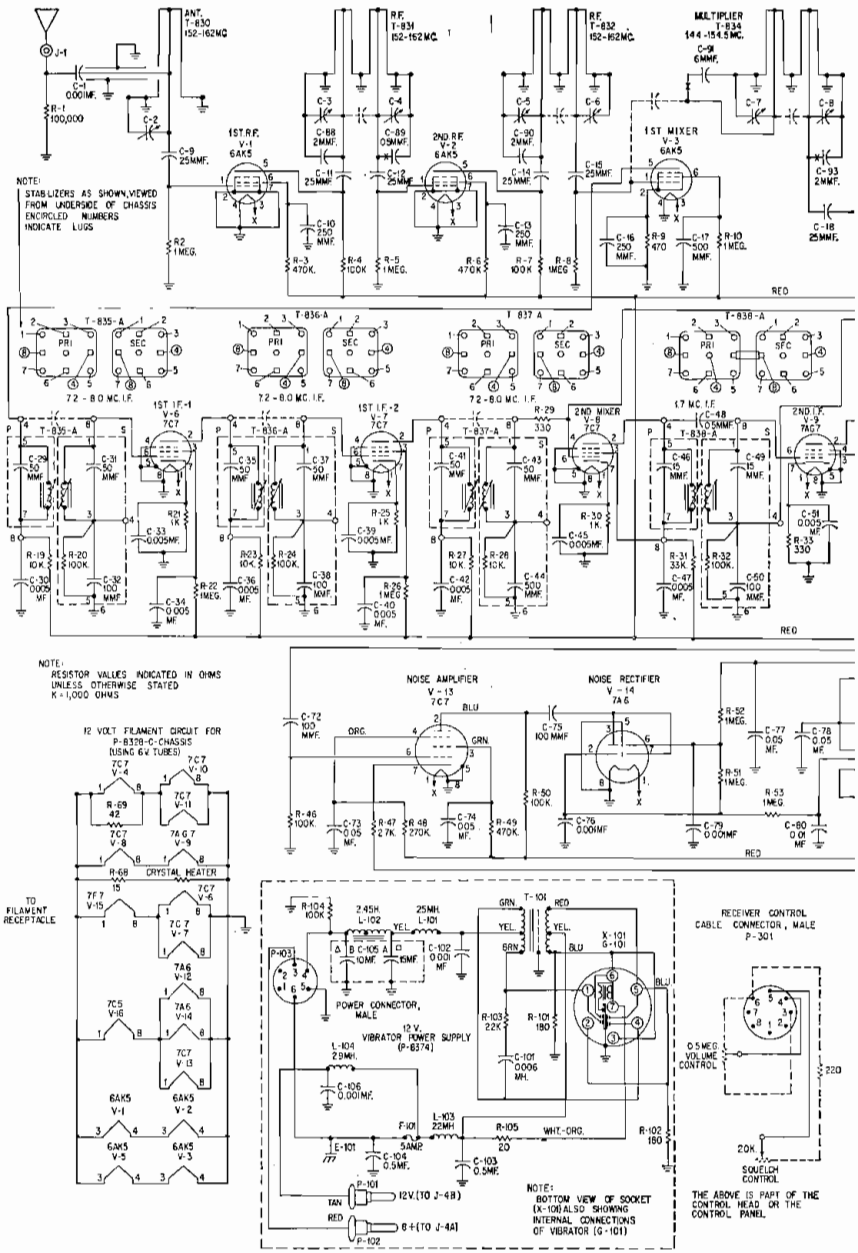
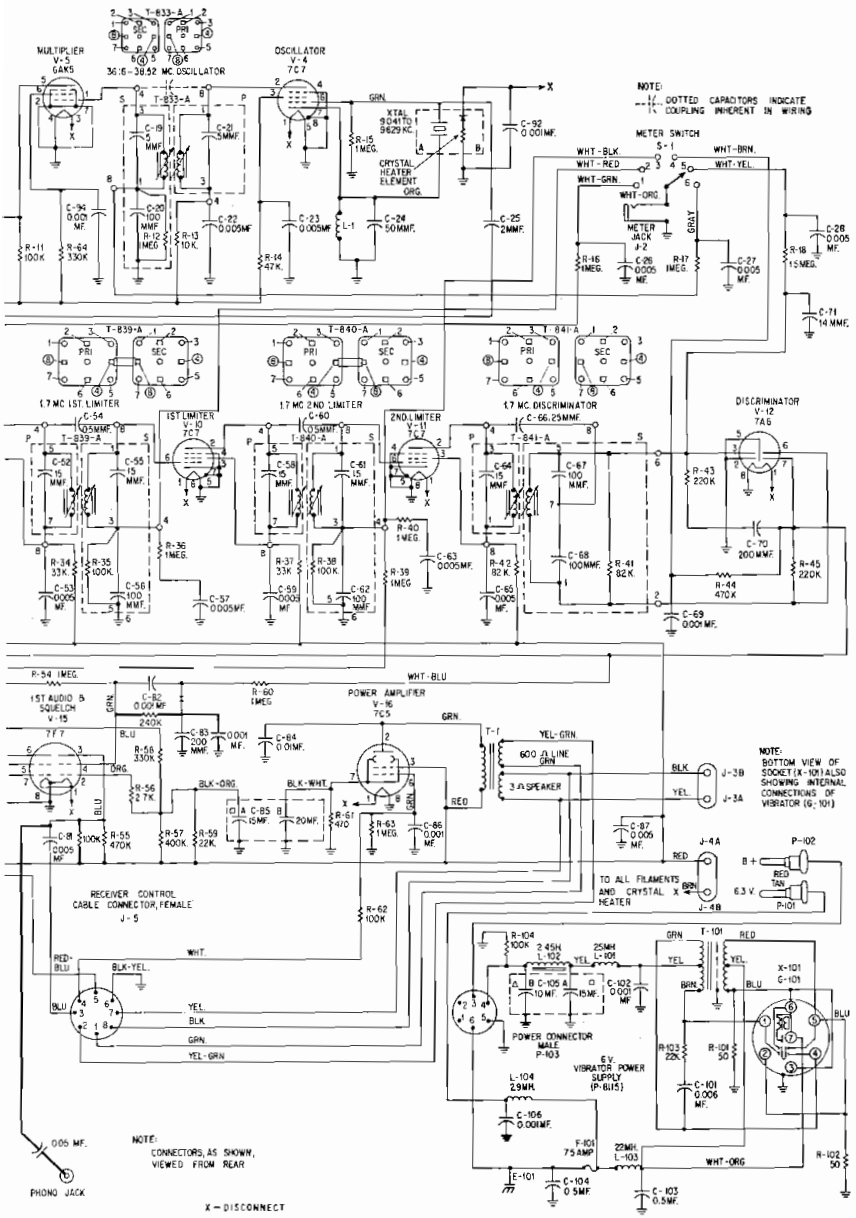


FIG. 2-4. Schematic diagram of Motorola receivers PA-8333-A and PA-8341-A. Heavy



lines indicate circuit modifications. *X* indicates removal from the circuit.

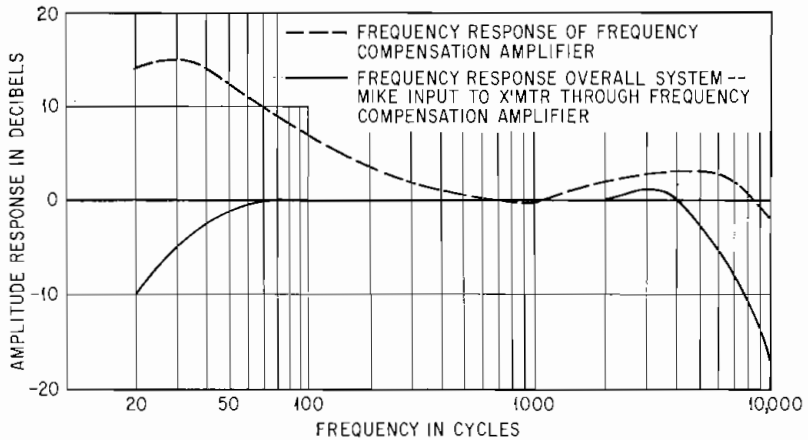


Fig. 2-5. Frequency-response curve.

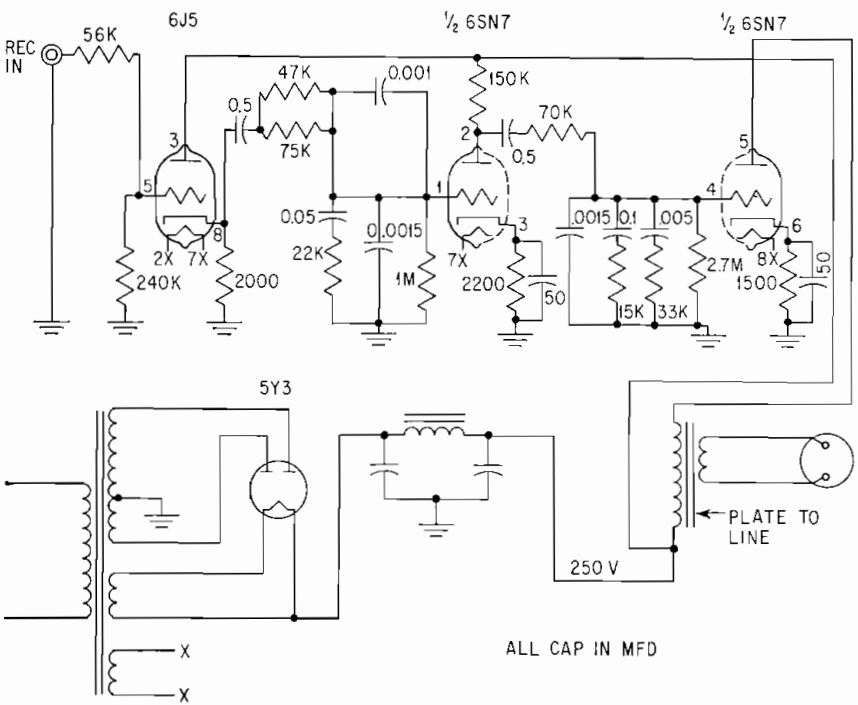
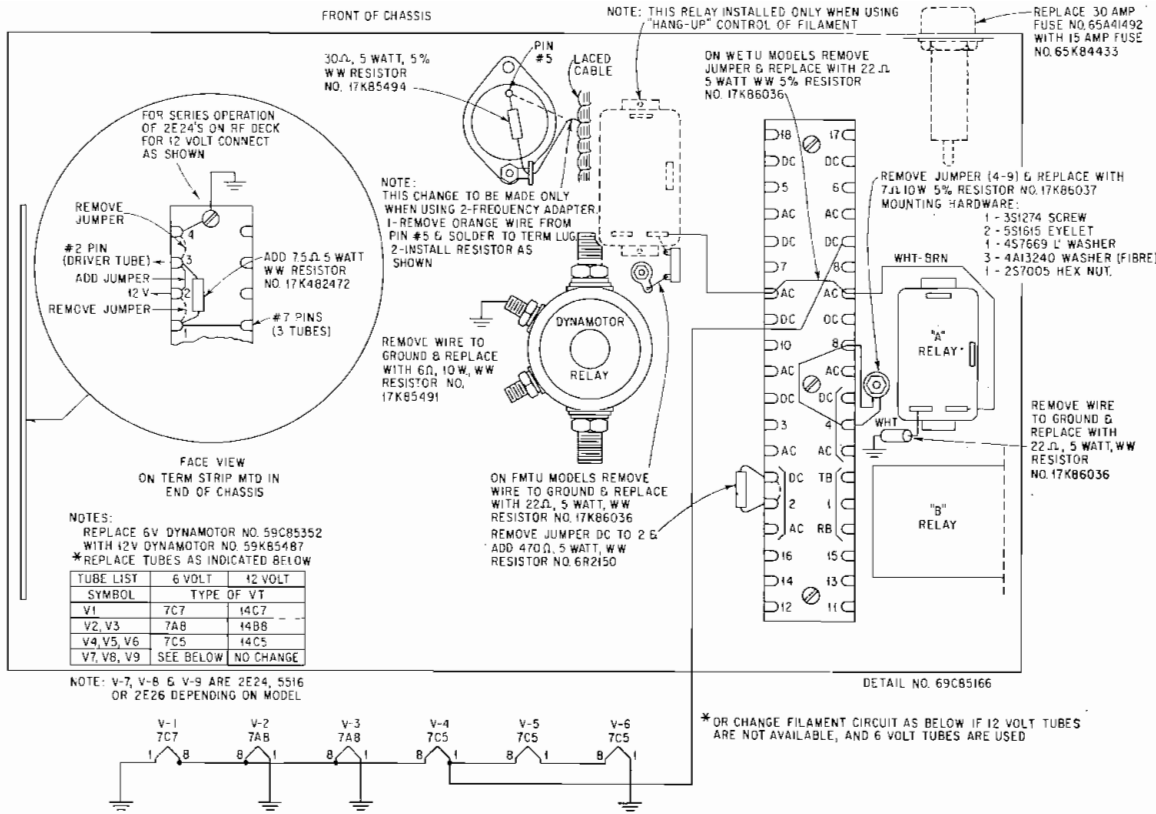
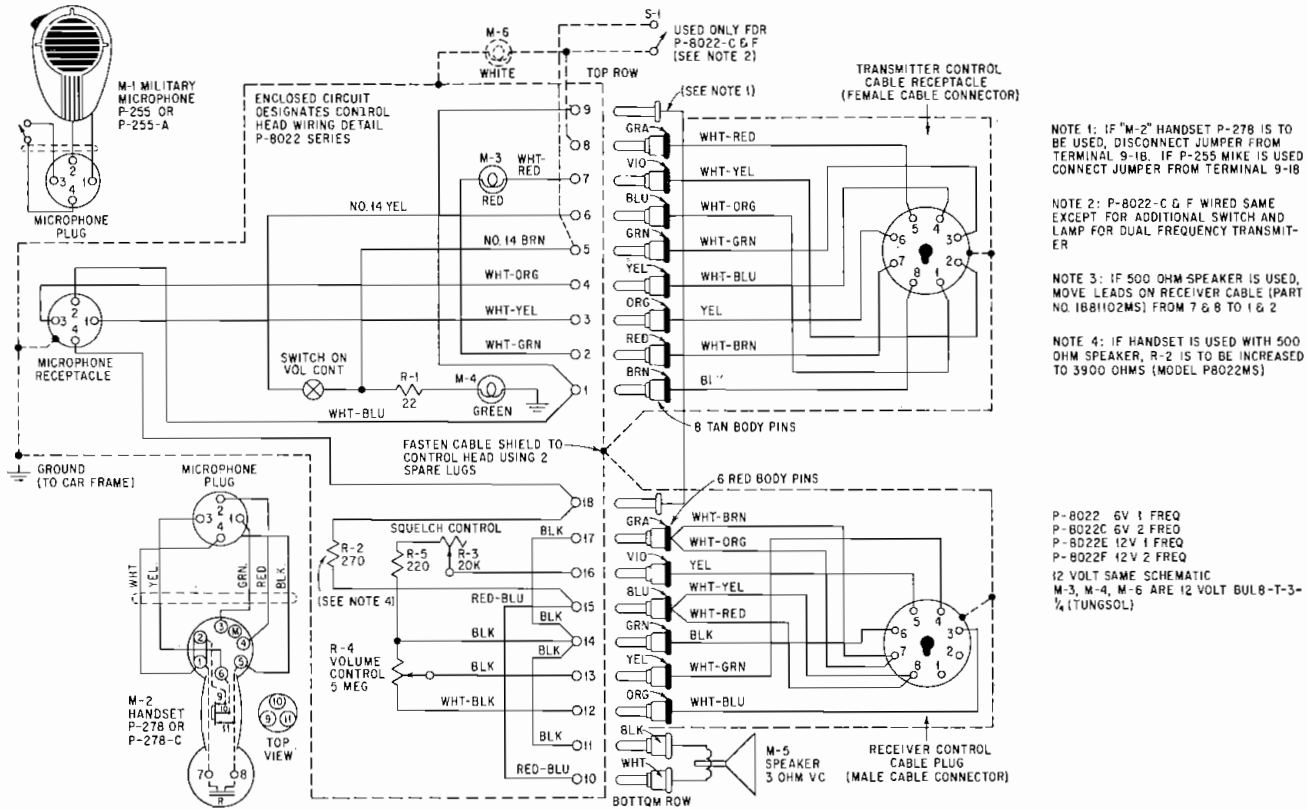


Fig. 2-6. Frequency-compensation line amplifier.



TUBE LIST	6 VOLT	12 VOLT
SYMBOL	TYPE OF VT	
V1	7C7	14C7
V2, V3	7A8	14B8
V4, V5, V6	7C5	14C5
V7, V8, V9	SEE BELOW	NO CHANGE

FIG. 2-7. 6- to 12-volt conversion detail for Motorola 152- to 162-Mc mobile transmitter.



NOTE 1: IF "M-2" HANDSET P-278 IS TO BE USED, DISCONNECT JUMPER FROM TERMINAL 9-18. IF P-255 MIKE IS USED CONNECT JUMPER FROM TERMINAL 9-18

NOTE 2: P-8022-C & F WIRED SAME EXCEPT FOR ADDITIONAL SWITCH AND LAMP FOR DUAL FREQUENCY TRANSMITTER

NOTE 3: IF 500 OHM SPEAKER IS USED, MOVE LEADS ON RECEIVER CABLE (PART NO. 188102MS) FROM 7 & 8 TO 1 & 2

NOTE 4: IF HANDSET IS USED WITH 500 OHM SPEAKER, R-2 IS TO BE INCREASED TO 3900 OHMS (MODEL P8022MS)

P-8022 6V 1 FREQ
P-8022C 6V 2 FREQ
P-8022E 12V 1 FREQ
P-8022F 12V 2 FREQ

12 VOLT SAME SCHEMATIC
M-3, M-4, M-6 ARE 12 VOLT BULB T-3-¼ (TUNGSOL)

FIG. 2-8. Schematic diagram of control head.

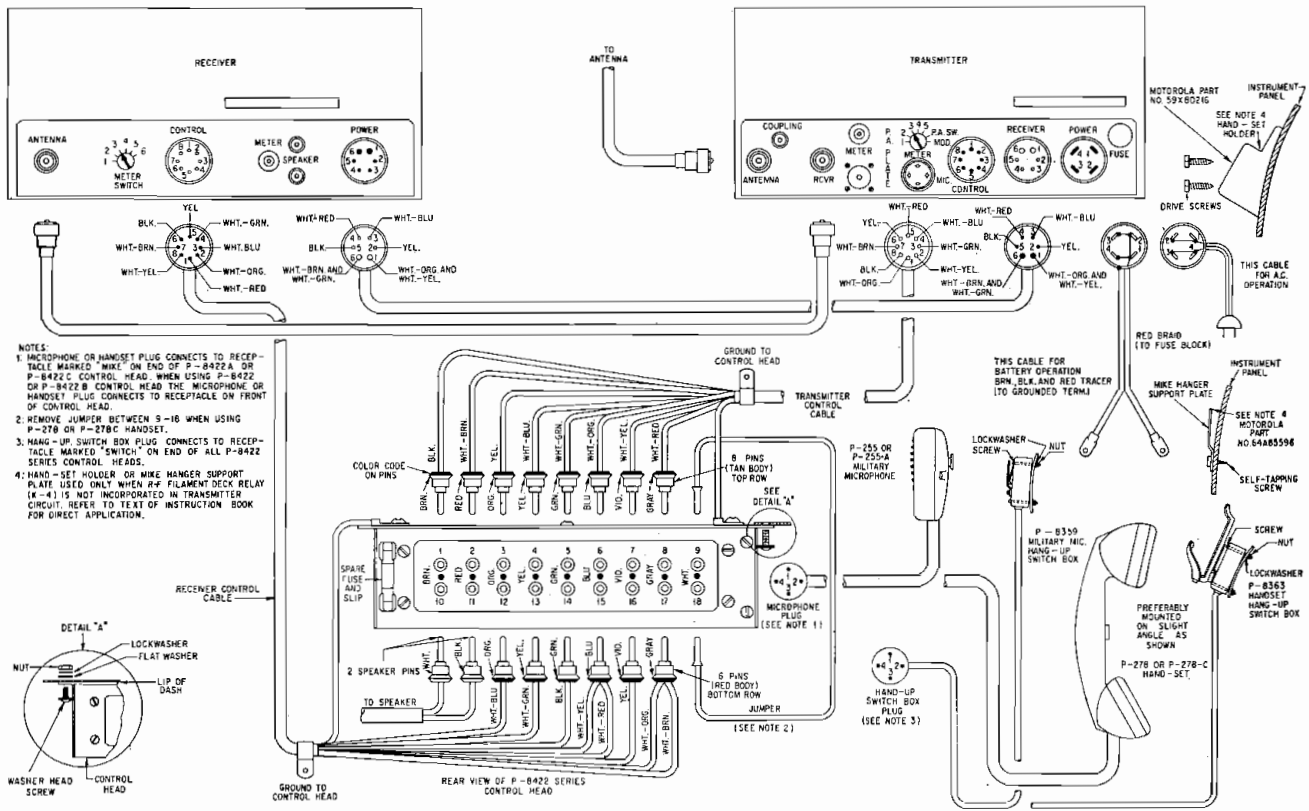


FIG. 2-9. Intercabling diagram, Motorola 72- to 76- and 152- to 162-Mc mobile and survey transmitter-receiver.

Conclusion

For remote control of the base station, we extended the carbon-mike/control cable. We also extended the receiver metering jack (normally switched to position 2) to provide an indication of signal strength.

The frequency-compensation amplifier was located adjacent to the receiver, and its output fed to a remote input on the console.

Figures 2-7 to 2-9 are included to aid in stalling, servicing, and 12-volt conversion of the equipment. Incidentally, 12-volt military surplus dynamotors were used for our mobile 12-volt system.

The equipment has proved to be very satisfactory and dependable, from the standpoint of both maintenance and quality. Under "low-noise" conditions, the quality is better than local telephone lines and, of course, far more versatile and economical. Over-all coverage with mobile units has been solid to 20 miles; however, signal-to-noise ratio has shown improvement by moving as little as 6 in. at some downtown locations. Fringe-area operation largely depends on terrain and antenna heights.

REMOTE-PICKUP BROADCAST COVERAGE TESTS ON 152.93 MC [2]

Introduction

From the following data it will be evident that FM mobile relay broadcasting in the 152- to 162-Mc band will be of considerable value to the broadcaster who may encounter extreme and adverse conditions with respect to terrain in the operation of a remote-pickup broadcast service. It will be logical to conclude that where terrain conditions are more favorable, results exceeding those mentioned in this report can be expected.

Purpose of the Test

The accelerated wartime development of transmitters and receivers for use on frequencies between 100 and 200 Mc resulted in production of equipment suitable for broadcast use on channels in the 152- to 162-Mc band. The Facilities Section of the General Engineering Department of ABC, therefore, undertook to investigate the usefulness of the 152- to 162-Mc band for mobile relay broadcasting by determining the maximum useful range of transmissions from a mobile unit to a receiving point 900 ft above sea level in Manhattan. The results showed that this band would provide excellent coverage within line-of-sight distance.

Equipment

Transmitter

A transmitter powered from the 6-volt car battery was used in the mobile unit. It is designed for communication type of service and has the following specifications:

Assigned frequency, Mc	152.93
Output power, watts	15
Frequency stability, %	±0.005
Method of modulation	Phase
Frequency deviation for 100% modulation, kc	±20
Audio response	±1 db from 500–3,000 cps
Duty	Intermittent

[2] From tests conducted by the General Engineering Department of the American Broadcasting Company, 4th edition, "NAB Engineering Handbook."

Receiver

A receiver powered from 115 volts 60 cps was used. It was installed on the roof at 30 Rockefeller Plaza, New York City. This unit is designed for communication type of service and has the following specifications:

Sensitivity	1 μv for 20-db noise suppression
Selectivity	6 db down at ±20 kc, 85 db down at ±120 kc
Audio response	±2.5 db from 350–5,000 cps
Duty	Continuous

Signal-strength readings were made at the receiver by measuring the current in the first limiter grid circuit. The use of this method of measurement results in a scale of values which gives a good spread from no signal level to limiter saturation level. The receiver sensitivity was calibrated by feeding a measured signal in microvolts, as obtained from a signal generator, to the antenna terminals of the receiver. The current in the first limiter grid was measured as this input signal was varied from 0.2 to 60 μv. The curve of Fig. 2-10 was plotted from the above test. With this curve it is a simple matter to convert all the readings taken in this test to microvolts of signal at the input of the receiver.

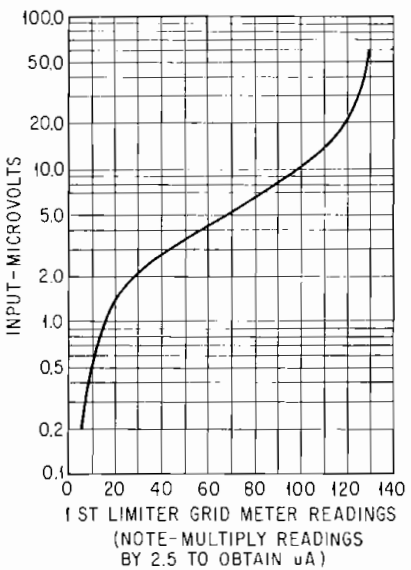


FIG. 2-10. Sensitivity curve of receiver.

Antennas

Transmitting. The transmitting antenna is a one-quarter-wave flexible whip mounted above the top of the car. The metal roof acted as the ground screen below the antenna. Ten feet of type RG-58/U coaxial transmission line having a nominal characteristic impedance of 53.5 ohms was used to connect the transmitter to the antenna.

Receiving. A five-element Yagi-type antenna was used for reception. It consists of a half-wave radiator and four parasitically excited elements—one reflector and three directors. A 300-ohm "ribbon"-type transmission line was used, delta-matched to the antenna. This line was connected to the 50-ohm input of the receiver through a one-quarter-wave matching section near the receiver. The antenna was installed in the clear, approximately 900 ft above sea level, at 30 Rockefeller Plaza, New York City. Since this antenna is directional, it was arranged so that it could be rotated. Vertical polarization was used at all times except during the cross-polarization test described later.

The antenna was directed toward the mobile transmitter during all these tests, although no attempt was made to rotate it for best results on each transmission. This practice was followed, as published data on multielement antenna arrays indicated that signals at the receiver should be essentially constant as long as the mobile unit was within ±15° of the heading of the array.

Receiving-antenna Pattern. In order to check the actual variation in received signal for the 15° maximum error of antenna heading held throughout the field tests, the pattern of the receiving antenna was determined. This was done by using it at the mobile unit for the transmitting antenna. During this test the mobile unit was located in a flat open field to reduce to a practical minimum any reflections of the

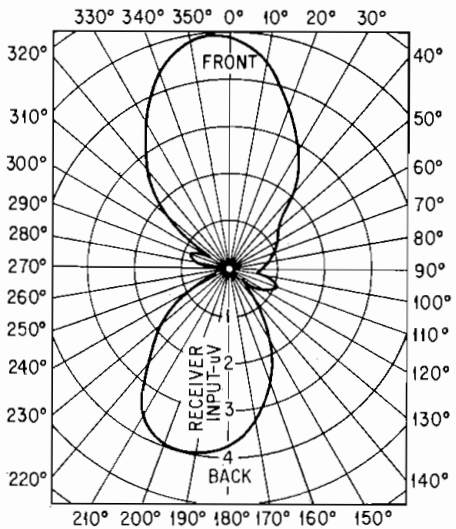


FIG. 2-11. Five-element Yagi-antenna radiation pattern—vertical polarization.

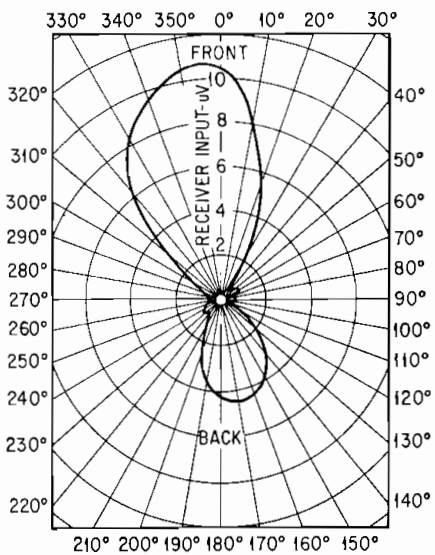


FIG. 2-12. Five-element Yagi-antenna radiation pattern—horizontal polarization.

signal. The receiver was located about ½ mile away with a clear line of sight path from it to the transmitter. A 4-in. length of wire was used for the receiving antenna in order that the received signal remain below the saturation level of the limiter at all times.

Using both horizontal and vertical polarization, the directional antenna was rotated in 10° steps and readings were taken of the receiver meter for each of these points. The results converted to microvolts input to the receiver were plotted as shown in Figs. 2-11 and 2-12.

From these curves we find that an antenna heading 15° off the actual transmitter location resulted in a decrease of signal strength at the receiver of approximately 10 per cent. For purposes of these tests, this 10 per cent variation was ignored in computing the signal levels at the receiver for the various locations of the mobile transmitter.

Results

Transmission from Car to Roof

Routes for the mobile transmitter were selected to give check points out to the limits of coverage in all directions from the receiving point. Transmissions were made from the mobile unit to the fixed receiver from hundreds of points along these routes, ranging from the immediate vicinity around the receiving point out as far as 42 miles from the receiver. In each case, a signal-strength reading was recorded at the receiver to be used in the final tabulation of results. Unfortunately, the requirement that the transmitter be operated on an intermittent duty cycle prevented the making of continuous recordings, but enough spot readings were obtained to give a close approximation of such a recording.

The results obtained were plotted on a map of the New York metropolitan area (Fig. 2-13), making the following information readily available:

1. Location of transmission point
2. Distance from transmission point to receiver location
3. Signal strength in microvolts input to the receiver from each transmission point
4. Relative usability of received signal

The received signals obtained from various points throughout the borough of Manhattan were of great interest in view of the difficulty experienced with numerous dead spots when operating on the 30- to 40-Mc channel. A very thorough coverage was therefore made of this area and included many transmissions from both avenues and cross streets from the Battery to the Henry Hudson Bridge. It was found that good signals were obtained from every point tried in this entire area with the exception of a short section of Front Street in the vicinity of Whitehall Street at the Battery. Here the signal level dropped to a nonusable value, but moving the car a short distance brought the signal level back to a usable value. The Wall Street region has in the past been particularly "dead" for 30- to 40-Mc transmission. Accordingly, a large number of tests were made from this district. These were made on Wall, Pine, Cedar, and other streets close by, along their entire traverse from the Hudson to the East River. Again good, usable signal levels were obtained with some instances of very quick signal dips. These, however, were of such short durations that it was found impossible to stop the car at any point which would produce a nonusable signal. Spot checks were made from many points in upper Manhattan, all of which gave good usable signals. It can therefore be assumed that, with the exception previously noted, complete coverage of the borough of Manhattan can be counted on.

It will be noted that practically all the transmission points in Manhattan fall within a 5-mile circle. Following the completion of runs in other directions, a general pattern of results based on distance became apparent. For example, inside a 5-mile circle, all transmissions except those previously noted and those from a small area near North Bergen, N.J., were received with good signal strength. The few points of nonusable signal within the 10-mile circle were caused by shielding from large buildings or hills close to the transmitter and directly in the transmission path. Beyond the 10-mile circle, results became somewhat erratic and were completely de-

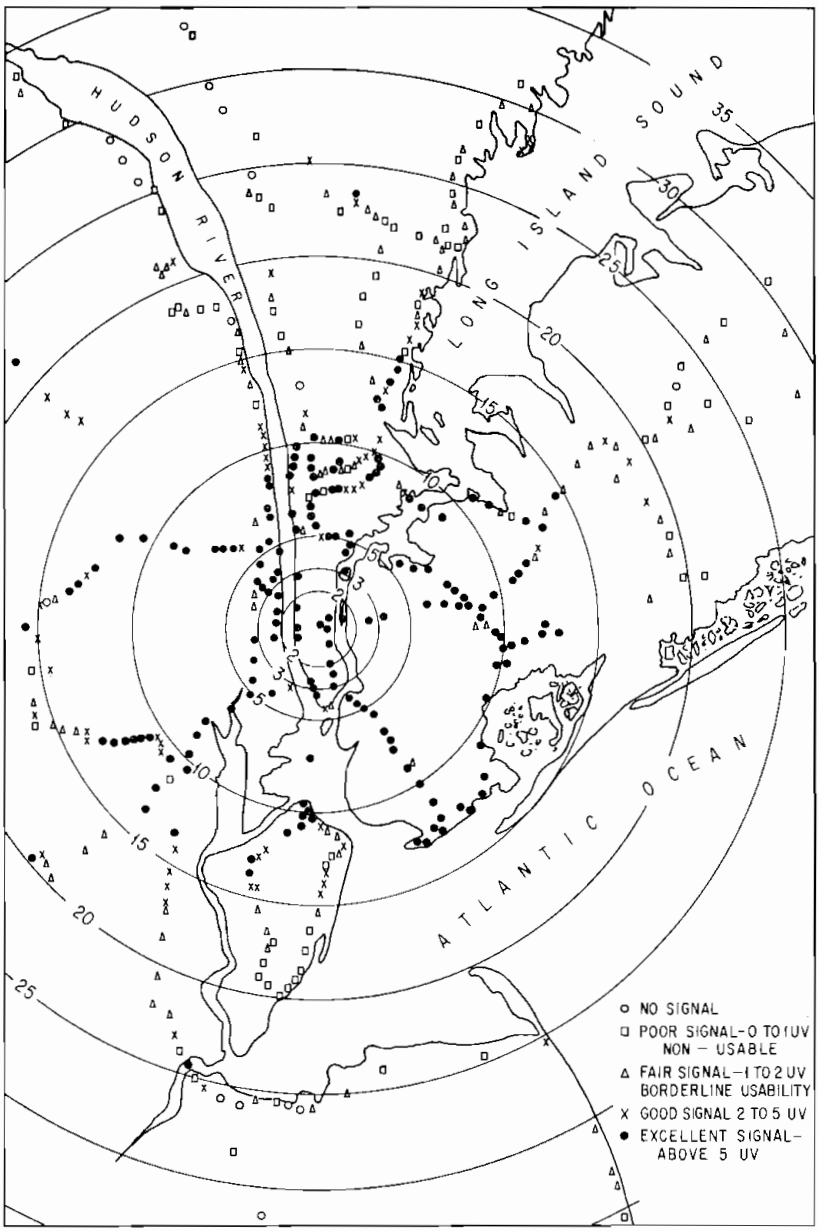


FIG. 2-13. Relay broadcast field test.

pendent on the terrain. Figure 2-13 shows the results obtained on all transmissions from the mobile unit to the fixed receiver.

Comparison of Antennas and Polarization

Changes in Transmitting Antennas

All the tests described so far were made using a quarter-wave whip antenna above the car and a five-element Yagi antenna on the building roof. Both of these antennas were vertically polarized. In order to determine the effects of some changes in antenna types and polarization, the following tests were made: The mobile unit was parked on top of Bear Mountain. This point is 42 miles from our receiving point, and there is a clear line-of-sight path between them. The receiving antenna was set for vertical polarization and carefully lined up for maximum signal from the transmitter. Transmissions were then made from the mobile unit using:

1. Quarter-wave vertical whip
2. Half-wave dipole
3. Half-wave folded dipole

The last two were operated both vertically and horizontally polarized at a height of 9 ft above ground. Signal-strength readings at the receiver were made for each of these transmissions. The receiving antenna was then changed to horizontal polarization, and the same series of tests repeated. Table 2-1 shows the signal strength ex-

Table 2-1. Signal Strength at Receiver Input in Microvolts

Transmitting antenna		Receiving antenna 5-element Yagi			
		Polarization			
Type	Polarization	Vertical		Horizontal	
		μv	Db	μv	Db
Quarter wave whip	Vertical	10.8	0	6	−5.1
Half-wave dipole	Vertical	14	+2.28	2.9	−11.41
	Horizontal	6	−5.1	20	+5.39
Half-wave folded dipole	Vertical	16.5	+3.69	14	+2.28
	Horizontal	9.5	−1.14	26	+7.6

pressed in microvolts at the receiver input for each of these combinations. This table also shows the signal change in decibels for these antenna tests using the combination of the vertical quarter-wave whip antenna at the mobile transmitter and the vertically polarized Yagi antenna at the receiver as the 0-db reference level.

An additional mobile-antenna test was made from Staten Island. At a point on Hylan Boulevard 21 miles from the receiving point the received signal in New York was too far down in the noise to be useful. Two parasitic elements, a director and a reflector, were mounted around the quarter-wave vertical whip on the car top. Spacing between elements was one-quarter of a wavelength. An increase of 3.06 db was recorded at the receiver as a result of this change.

Change in Receiving Antenna

The five-element Yagi antenna was used for reception in all the tests so far. To check the gain of this antenna against a standard half-wave dipole, a series of transmissions were made from the mobile unit to the fixed receiver over a ronte extending from the Queensboro Bridge to the vicinity of Hicksville, Long Island, and return.

The Yagi antenna was used at the receiving point for the run out and the half-wave dipole for the return trip. While it is true that a single comparison would give a gain figure, it is of interest to check the actual results over varying terrain conditions and distance between the transmitter and receiver.

Signal-strength recordings were therefore made at the receiver for a representative group of transmitter locations using the same points on each run so that the difference in results could be attributed to the change in receiving antennas. The following readings were taken:

Table 2-2

Distance from receiver, miles	*Input to receiver, μv*	
	Half-wave dipole	*Yagi*
13	3.6	7.5
13.5	10	6
16	1	2.1
19	1	2.5
21	1.8	3.6
22	0.7	1.8

From this table we can calculate that the average gain for the Yagi antenna over the standard half-wave dipole is approximately 6 db. In one case the half-wave dipole showed a higher signal level than the Yagi antenna, which can probably be attributed to effects of signal reflection due to the terrain.

Summary and Conclusions

The principal purpose in making the survey described above was to establish the utility of the 152- to 162-Mc band for short-range relay broadcasting. In addition, it was important to learn the maximum usable range of the specific equipment on hand. The test shows that with a 15-watt FM transmitter feeding a quarter-wave vertical whip mounted 6 ft above ground atop the mobile unit and with a directional receiving antenna having gain of at least 6 db mounted 900 ft above sea level in Manhattan, the following coverage around the receiving point can be expected:

1. Complete coverage within a radius of 5 miles
2. 95 per cent coverage within a radius of 10 miles
3. 85 per cent coverage within a radius of 15 miles
4. Some coverage within a radius of 30 miles, depending on the location of the mobile unit with respect to surrounding terrain

Previous experience with mobile operations using 30- to 40-Mc AM equipment has shown that coverage was very unreliable within the New York metropolitan area. Dead spots were numerous, and any attempt to follow a parade resulted in noisy reception at the pickup point from many spots throughout the parade route. Similar results would be expected in the 26-Mc band.

Part 3

REMOTE-PICKUP BROADCAST OPERATION ON 450 MC

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The use of the 450- and 455-Mc bands for remote-pickup broadcast station operation is becoming popular owing to the excellent propagation conditions. It has been found that for communications between a mobile unit and a base station the reliability of the circuit is virtually 100 per cent. There are practically no dead spots even in the "canyons" of New York, where line-of-sight conditions are far from a reality.

The fact that UHF transmission of television has many "dead spots" whereas UHF

FIG. 3-1. American Broadcasting Company television emergency mobile unit.

frequencies for remote-pickup services provide solid coverage can be explained by the fact that the ear is not so sensitive to the effects of phase delay in aural transmission as is the eye to its effect in television transmission. The fill-in in the canyons of a city come about by reflections from several objects all adding substantially but not exactly in phase. The slight time differentials are not objectionable to the ear, whereas a picture under the same conditions would be full of ghosts. Another reason for the better coverage is that the communications receivers used with their narrow

FIG. 3-2. 450-Mc unit as viewed from the video-audio operating position.

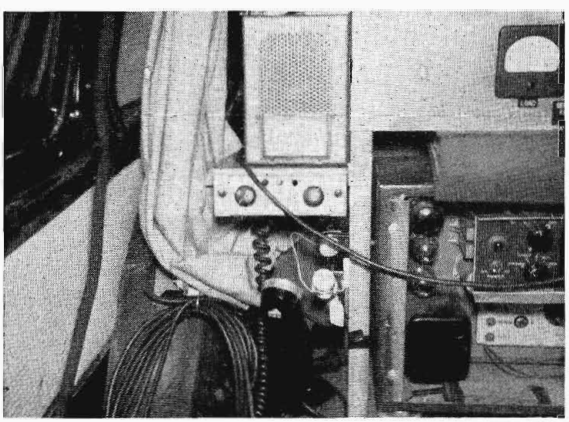

FIG. 3-3. Remote-control and speaker panel as viewed from the video-audio operating position.

bandwidth have a sensitivity of about 1 μv, which is considerably better than most UHF television receivers.

The American Broadcasting Company has been operating 15-watt units in its television emergency mobile unit (Fig. 3-1). One of these operates on 450 Mc, and one on 455 Mc.

Thus, it is possible to have continuous program circuit and cue circuit from transmitter-receiver units mounted in the same mobile unit. Because of problems of selectivity of the receiving circuits, it has been found impossible to operate two-way circuits within the 1-Mc bandwidth of the 450- or the 455-Mc bands. For this reason, NAB has filed comments in connection with the FCC Proposed Rule Making (Doc. 11959, 11997) to retain two bands separated by about 5 Mc in the 450-Mc portion of the spectrum. The folded-dipole antenna for one of these units can be seen mounted on the right rear fender of the station wagon. The antenna for the other transmitter is

located on the left rear fender. The fixed stations are located on the eighty-fifth floor of the Empire State Building, and uninterrupted communications have been experienced over a radius of 20 to 30 miles. Figure 3-2 shows one of these units as viewed from the video-audio operating position. Figure 3-3 shows the remote-control and speaker panel as viewed from the same position. Figure 3-4 shows the second unit as viewed through the rear window of the mobile unit.

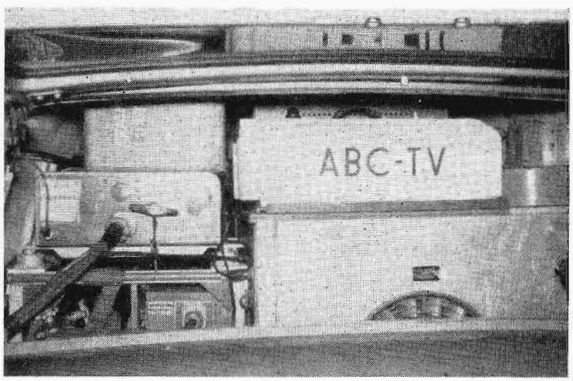

FIG. 3-4. Second unit as viewed through the rear window of the mobile unit.

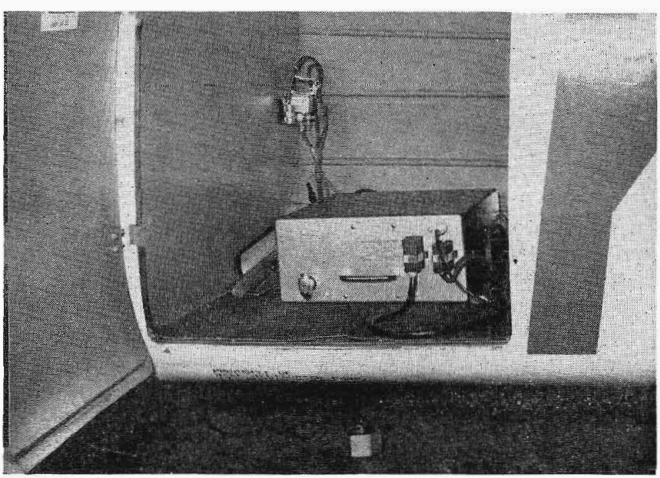

FIG. 3-5. 450-Mc transmitter-receiver mounted in the baggage compartment.

The American Broadcasting Company's radio station KABC in Los Angeles has been using 450-Mc remote-pickup broadcast equipment to broadcast traffic conditions on the Los Angeles Freeways from the vantage point of a helicopter. This equipment has been successfully used over a radius of 20 to 30 miles. The advantages of using a helicopter to report traffic conditions are obvious. The crew of the helicopter consists of a pilot and an announcer. Figure 3-5 shows the 450-Mc transmitter-receiver mounted in the baggage compartment. The antenna is a one-fourth-wavelength whip and extends down from the fuselage of the ship as shown in Figure 3-6.

Figure 3-7 is an over-all view of the helicopter. On the bulkhead back of the seat can be seen two transistor receivers, one of which is tuned to KABC and the other to

the police frequency. As the electrical equipment for the helicopter was 24 volts, a separate 12-volt battery and generator was installed for the 450-Mc equipment. During the shakedown of the 450-Mc equipment a 3-watt 26-Mc handy-talkie was carried in the helicopter. The 26-Mc antenna can be seen in Figure 3-7 extending downward from the front of the passenger compartment. While the 26-Mc equipment worked

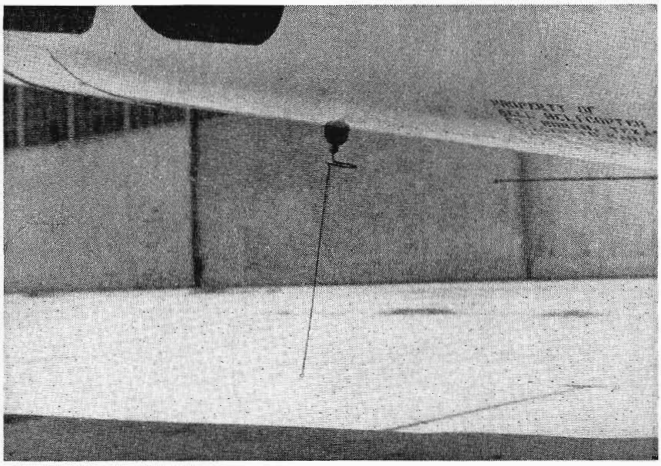

FIG. 3-6. One-quarter-wave whip antenna.

FIG. 3-7. Over-all view of helicopter showing 26 Mc antenna.

quite satisfactorily, its range was limited to about 2 miles. In addition to the remote-pickup equipment, the helicopter carries its own aircraft electronic equipment.

The American Broadcasting Company has a 30-watt remote-pickup station which was designed for operation on 150 Mc but was converted for operation on 450 Mc by adding a tripler stage ahead of the final amplifier. This equipment is kept available for use where it is necessary to have greater range than is possible with the 15-watt units.

The 15-watt 450-Mc remote-pickup stations are used for all types of broadcasts involving mobile units, such as disasters, fires, parades, presidential inaugurations, etc. The 15-watt units come in very handy in lining up microwave dishes, particularly on long or difficult paths. Several 0.1-watt Mc handy-talkie units are available for short-range pickups such as golf matches, political conventions, etc.

Four hundred and fifty-megacycle remote-pickup equipment is quite useful for radio backup of wire lines in CONELRAD cluster operation. The use of remote-pickup equipment for this type of operation has been recommended by the Federal Communications Commission. Figure 3-8 shows a simple one-way radio backup circuit for CONELRAD operation. The key station requires a 450-Mc transmitter and a 455-Mc receiver (or vice versa), and the other cluster stations require a receiver for reception of the transmissions of the key station. More complex circuits can be used to provide duplex channels, control by the alternate key station, etc. A radio backup circuit is shown from the circuit defense headquarters to the key station. Also, in some areas it may be desirable to have radio backup between adjacent CONELRAD clusters.

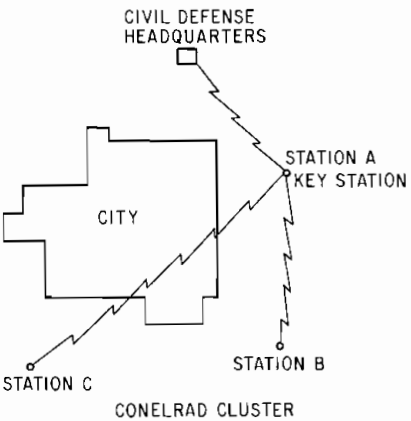

FIG. 3-8. Simple one-way radio backup circuit for CONELRAD operation.

It has been noted that more and more remote-pickup stations are being licensed for operation on 450 Mc, which is indicative of the general usefulness of this frequency.

Part 4

RADIO ON WHEELS

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With ever-changing programming formulas in radio, the station engineer's ingenuity is constantly being called upon to develop equipment to do simply and effectively disc-jockey remotes, which have become a feature of many radio stations.

The problem of today's remote has become far more complex than the old dance-band remote or the Saturday morning amateur hour from the local department store.

Portability is the prime requisite for today's remote. While station policy varies from station to station and method of operation in some stations calls for technical personnel to assist the disc jockey, other stations operate with nontechnical personnel only.

The author will endeavor to outline problems and solutions experienced by him in doing many disc-jockey remotes.

Radio is being put on wheels by many leading broadcasters. Equipment is mounted in either a permanent or semipermanent manner in the vehicle of the station's choice.

CHOICE OF VEHICLE

The choice of a vehicle for a studio on wheels is probably the most difficult decision to make when starting to put a studio on wheels. The size of the vehicle, of course, determines the amount of space available for equipment.

Experience has proved that there are many additional uses to be made of the studio on wheels in addition to just on-the-air use.

EQUIPMENT

In planning equipment for the studio on wheels, of course, the size of the vehicle determines the amount and size of such equipment.

Briefly the following is an outline of what the author found necessary for the studio on wheels. Details will follow:

1. Small console
2. Two three-speed turntables
3. Tape recorder
4. Public-address system

5. AM-FM tuner
6. 110-volt a-c generator (optional)
7. Power-distribution panel (optional)
8. Mobile radio system—FM (optional)

The Console. The determination as to what type of console the studio on wheels should contain, of course, depends upon the budget allowed for equipment. We endeavored to make the operation as simple as possible when arriving on location, and since space was available on the vehicle to allow for a small console, a commercially available four-channel console was installed. Small consoles are available from most commercial manufacturers which contain the necessary preamplifiers, line amplifiers,

FIG. 4-1. Turntables and console mounted in vehicle.

and monitoring amplifiers. In smaller installations the console monitoring can be substituted for the public-address system. While this method reduces initial installation cost, it is not recommended because of the limited amount of gain available.

Combining the turntables and the console on one desk simplifies installation in the vehicle and permits use of such equipment indoors should the need arise (Fig. 4-1).

In our operation all turntables are equipped with a cueing-type mixer. We have continued this method in the field because of the simplicity of operation.

While most commercial consoles provide a cueing position in the monitoring system, we chose to add a small additional amplifier to the console-turntable unit for cueing purposes. This does necessitate small wiring modifications to the console. These circuits are available on the audio terminal block. While this does mean a small additional expense, the convenience is well worthwhile (Fig. 4-2).

The console output is permanently wired to feed either land-line or radio relay facilities. In addition, outputs are available for taping on location plus a feed to the public-address system.

Bridging outputs are used to feed the public-address system and tape recorder. The bridging circuits can be transformers or balanced bridging pads or bridging controls. Care must be exercised since most high-level input circuits to public-address

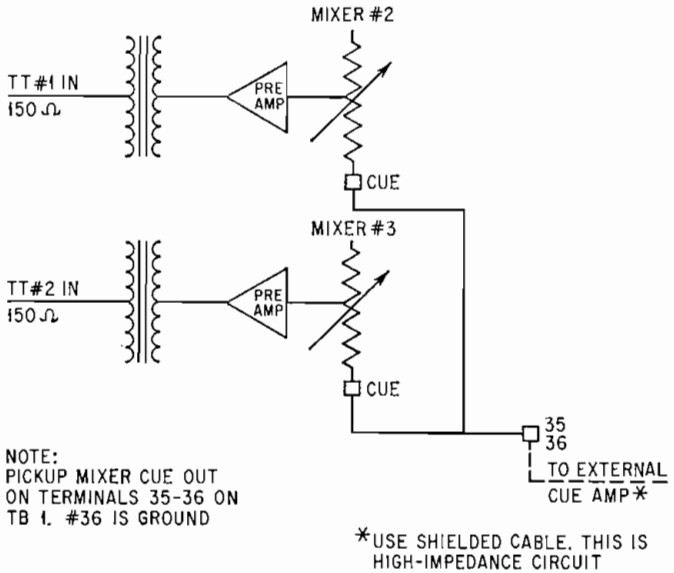

FIG. 4-2. Turntable cueing modification BC-5A console.

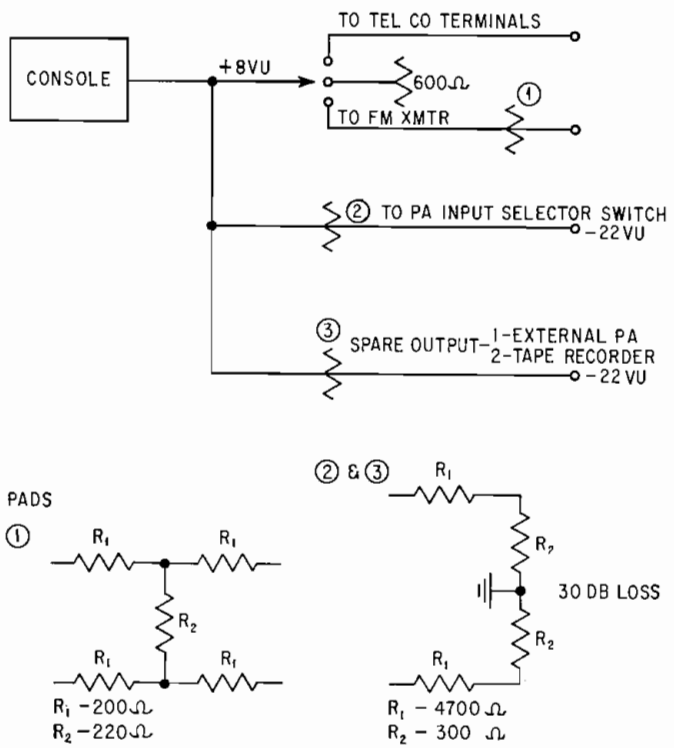

FIG. 4-3. Block diagram, console output.

systems and tape recorders are unbalanced circuits and telephone lines are balanced circuits. It is recommended that a 1-to-1 isolation coil be used on the public-address-system input to isolate balanced circuits from any unbalanced circuits that might be used (Fig. 4-6).

The station engineer can, of course, modify an existing remote amplifier to accomplish the same results. If cueing mixers are substituted for existing microphone mixers, the microphone preamplifiers can be used as turntable preamplifiers. Many remote amplifiers use high-level mixing. An existing microphone preamplifier can thus be used as a turntable preamplifier (Fig. 4-4).

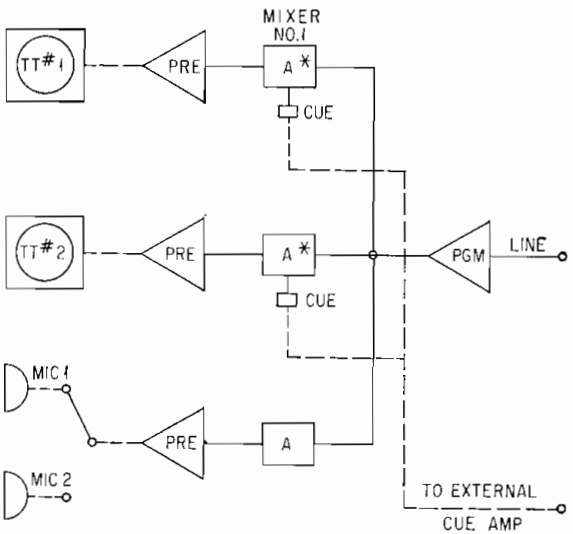

Fig. 4-4. Modified BN-2A amplifier.

If the amplifier uses low-level mixing, the problem becomes more complex. Modifying remote amplifiers that use low-level mixing is not recommended.

The Turntables. The choice of turntables probably is the easiest problem to solve. Available today are many models to fit almost any budget. The use of a record-changer-type turntable is not recommended, but it could under certain conditions give satisfactory service.

The biggest problem to be encountered while operating turntables in the field, particularly in a vehicle, is the need for some leveling device so that tone arms will track properly when using microgroove records on location.

Permanent installation of at least two small indicating levels on the turntable-console unit will aid operating personnel in setting up.

Experience has proved the need for some sort of device to level the turntable-console unit under varying conditions. The installation of four small leveling jacks on each corner of the unit will solve this problem under the most severe conditions encountered in the field (Fig. 4-5).

Since some record-compensating filter will probably be used, the type with low-impedance output will work very satisfactorily with microphone preamplifiers. Output of these filters on a tone record is −50 VU, which provides a satisfactory level for the microphone preamplifier.

The Tape Recorder. Here again any of the popular available models work satisfactorily.

If the station engineer chooses to install a tape recorder, the recorder should be one of the more popular units commonly used for portable use. The broadcaster will

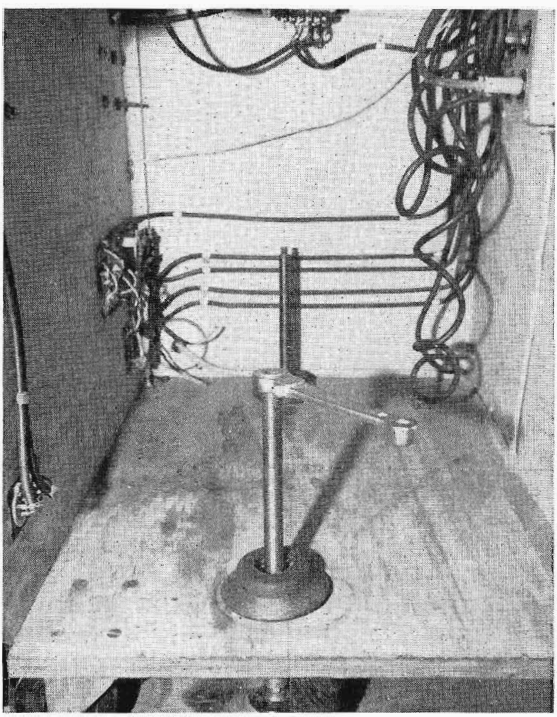

FIG. 4-5. Leveling device for turntable-console unit.

find many additional uses for the studio on wheels. Therefore the tape unit might be used to play back prerecorded tapes made on a studio unit.

Likewise the broadcaster might record a disc-jockey show in the field and play back on a studio unit.

The Public-address System. Any unit of the station engineer's choice will prove satisfactory. Any amplifier with approximately 25 watts undistorted output is sufficient.

When the public-address system is used in conjunction with an on-the-air show, because of feedback problems, any larger amplifier is not deemed necessary (Fig. 4-6).

AM-FM Tuner. The AM-FM tuner helps the broadcaster reduce overhead costs when doing disc-jockey shows from the field. The use of the tuner provides an excellent feed for the public-address system.

Any portions of the disc-jockey show that originate from the studios of the station are available to the audience at the pickup point.

If the station has FM facilities, the use of FM is more satisfactory than AM.

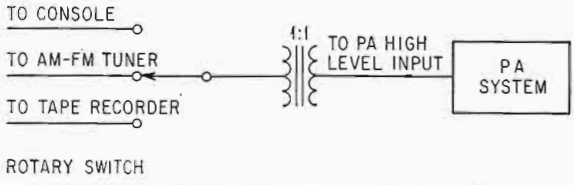

FIG. 4-6. Public-address-input selector switch.

FIG. 4-7. Interior of vehicle, note rack-mounted equipment.

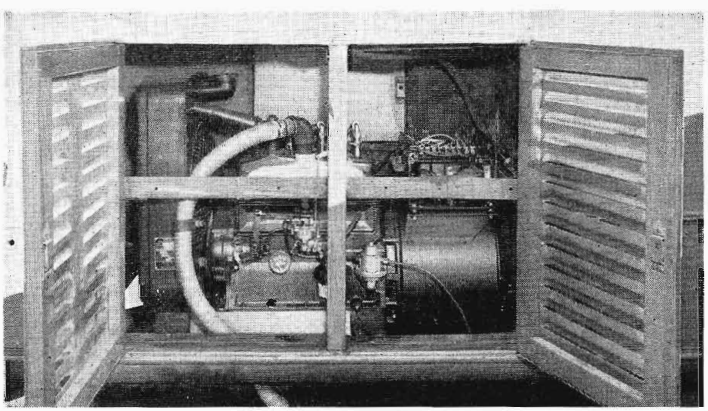

FIG. 4-8. 110-volt a-c motor generator.

A permanently mounted simple FM dipole antenna is recommended to be used with an FM tuner. Line cord FM antennas might prove unsatisfactory under some conditions.

It is recommended that all the units, the tape recorder, the AM-FM tuner, the public-address system, be rack-mounted (Fig. 4-7).

OPTIONAL ITEMS

The 110-volt a-c Generator. The installation of a 110-volt a-c generator in a vehicle in the author's opinion is a "must." The noise developed by such a generator does not prove to be a handicap for promotional activities when the vehicle is in motion (Fig. 4-8). Such a generator also is available in case of failure of commercial power while on semipermanent location.

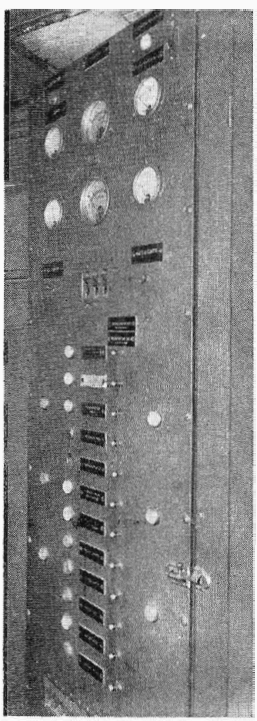

FIG. 4-9*a*. Power-distribution panel.

The size of such a generator depends, of course, on the load developed by the equipment and display lighting attached to the studio on wheels. Most available commercial generators guarantee 1 per cent frequency accuracy when the generator is operated within load limits. This is particularly important for proper operation of tape recorders or turntables when the generator is used as the power source. In planning a generator installation, manufacturers caution about oversizing such a generator. If the load is not sufficient, the engine driving the generator does not work hard enough. This could raise the maintenance costs of such a unit.

Should the station engineer choose to install a 110-volt a-c generator in the vehicle, care should be taken to allow for sufficient ventilation of the generator unit, since most generators can be equipped with safety cutoffs should the water temperature become excessively high. If the available space is small, supplemental forced air should be installed to guard against excessive heat building up. A fixed-position 110-volt a-c fan will work satisfactorily to force out any excessive heat.

Since the generator is a gasoline-driven device, provision should be made to obtain gasoline from the main tank of the vehicle. This permits the personnel to use the gasoline gauge of the vehicle as a guide for sufficient fuel at all times. A separate supplemental tank can be used, but generally there is no gauge for judging the amount of fuel in the supplemental tank.

Normal winter and summer protection for the cooling system must be observed, just as with the vehicle engine.

Power-distribution Panel. While the installation of a power-distribution panel will undoubtedly raise the initial cost of installation, the safety factor, particularly for generator protection plus protection of off-air time, should make the cost and effort worthwhile (Fig. 4-9*a* and *b*).

Mobile-radio System. While the above-mentioned facilities provide the broadcaster with all the necessary means for doing disc-jockey remotes by using land-line facilities, some broadcasters may desire to add mobile radio so that land lines are not always necessary.

Since the disc-jockey remote runs upward of 1 hr of air time, an a-c-powered transmitting unit must be used. The problem becomes more complex when using mobile radio.

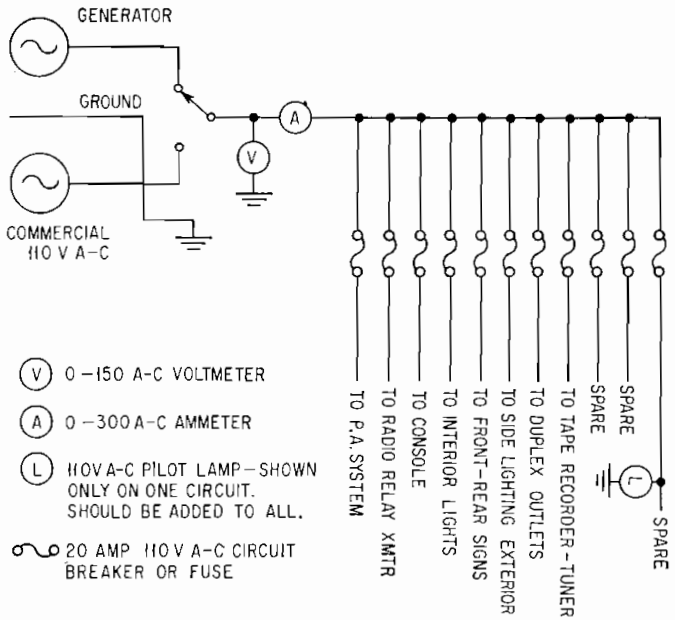

FIG. 4-9*b*. Schematic of power-distribution panel.

Because the broadcaster does not have exclusive use of the 152.87- to 153.35-Mc band, licenses for transmitting equipment in this band are issued on a nonexclusive basis only. Industrial services have priority of use for frequencies in this band.[1] This could prove to be a serious problem if the broadcaster is located in a large metropolitan area where many industries use mobile radio.

[1] See Frequencies for Use in the Broadcast Service, Sec. 1.

Part 5

TELEVISION REMOTE PROGRAM ORIGINATIONS

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Unanimity of thought does not prevail among television stations regarding the best equipment or procedures to follow in the origination of television remote programs. Consequently, the following discussion of equipment and methods employed by WTOP-TV in Washington, D.C., is not intended as a standard for the industry but only as a guide for stations unfamiliar with the problems involved.

A discussion of "television remotes" or "nemo" programs can be divided into two general categories: (1) equipment and facilities required and (2) operation of a typical remote, including problems normally encountered.

EQUIPMENT AND FACILITIES

Mobile Unit

General Requirements

The basic function of a television mobile unit is to provide a transportable control room for remote program originations. The obvious answer to this requirement is a motor vehicle with a specially built body. For monochrome remote programs, this vehicle is usually a 1½-ton truck chassis with a custom-built body (Fig. 5-1). The engine should be capable of transporting the fully loaded vehicle at reasonable highway speeds. Minimum size is an important consideration since narrow alleys, sharp turns, and low overhead clearances are often encountered. Weight distribution of the fully loaded mobile unit must be such that no instability results when driving over rough roads. The roof of the mobile unit should be capable of supporting the weight of two cameras, two cameramen, a microwave transmitter, and operator (Fig. 5-2). Tie points to anchor the tripods securely to the roof must also be provided (Fig. 5-3). Access to the roof can be made by a ladder or built-in steps (Fig. 5-4).

Control-room Requirements

Opposed to the requirements of minimum size of the mobile unit for ease of handling are the requirements for maximum interior space to accommodate the control-room personnel, operating equipment, and storage of technical equipment. The first consideration that determines interior size is the maximum number of

FIG. 5-1. RCA type TJ-53A mobile unit (foreground) designed for three-camera monochrome operation. This particular mobile unit was modified by WTOP-TV to accommodate four cameras. An older RCA model TJ-50A mobile unit is also shown.

FIG. 5-2. The television mobile unit should provide a sturdy roof platform capable of supporting cameras, microwave transmitter, and operators.

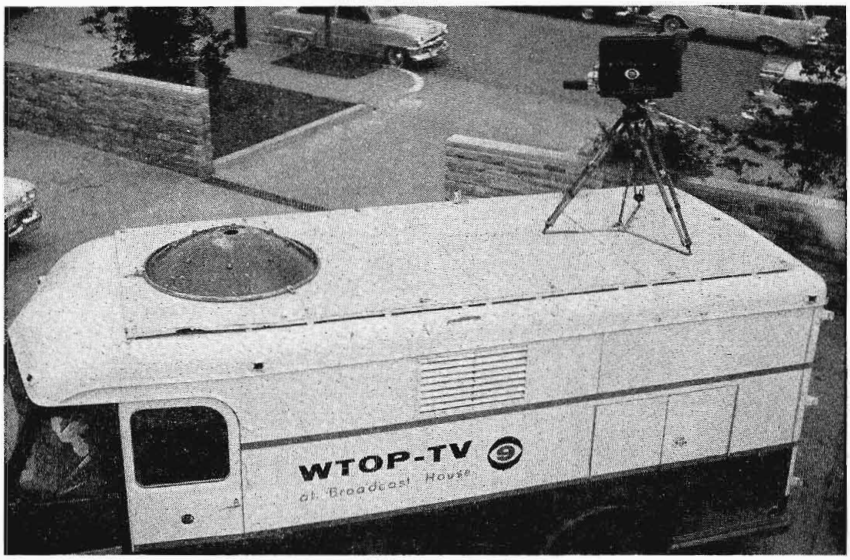

FIG. 5-3. Microwave reflector storage is shown on the left. On the right a camera is secured to the mobile-unit roof by use of a metal T and a chain from the tripod to a hook welded to metal roof.

FIG. 5-4. Access to roof of mobile unit is by means of built-in steps on rear door. Detachable mast is used to support off-the-air receiver antenna as well as camera and microphone cables when required to bridge sidewalks.

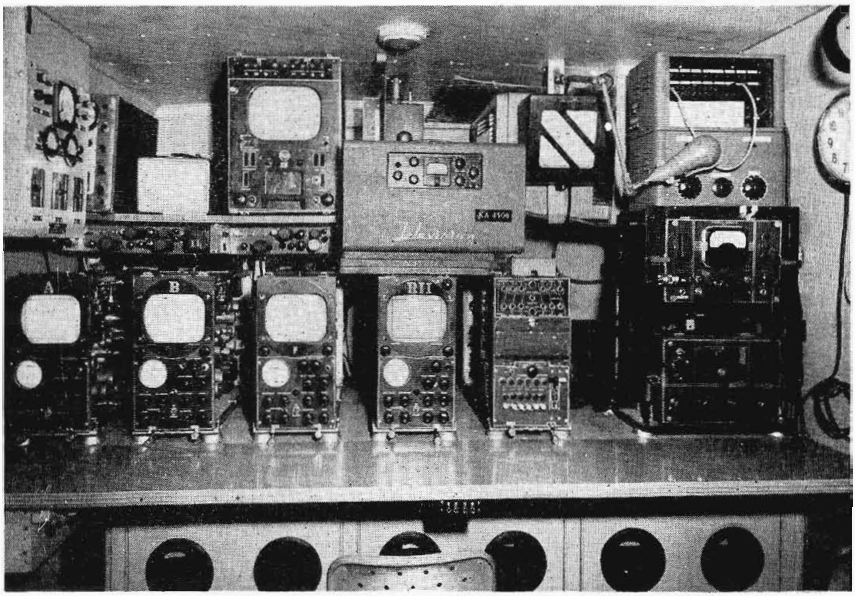

FIG. 5-5. Interior view of mobile-unit control room. Four camera control units, video switcher, and audio mixer are mounted directly to top of control desk. Above these units from left to right are a-c voltage control panel, oscilloscope, 8-in. off-air receiver, master monitor, microwave transmitter control, air conditioner (rear), cue speaker (front), audio patch panel (above), audio bridging and matching unit (under patch panel), and clock. Ventilated enclosure for power supplies and sync generator are visible beneath desk.

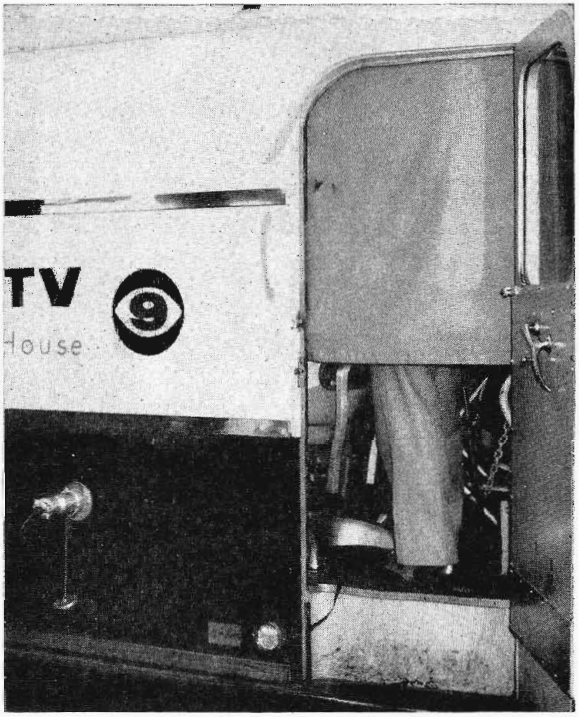

FIG. 5-6. Removable curtains darken the control room during a remote for better visibility of the television picture monitors.

cameras to be accommodated. In the past, two cameras were considered adequate. Three or four cameras are now used on most TV remotes. Occasionally five or more cameras are required, but in this case it is usually necessary to use an enclosure near the program area for a control room, using the mobile unit primarily for transporting the equipment.

A mobile unit providing four-camera operation seems to be a good compromise between size and program requirements. Control-room space should therefore be

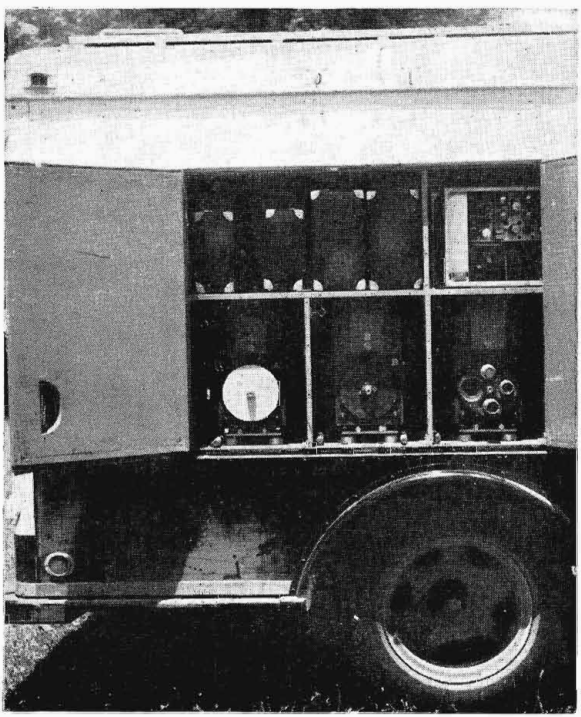

FIG. 5-7. Cameras are transported on shock-mounted bases to prevent damage to camera components. Suitcases contain extra lenses, headphones, etc. A spare sync generator is visible at upper right.

provided for the four-camera control units, a video switcher, an audio mixer amplifier, a microwave relay transmitter control, and three technical operators (Fig. 5-5). In addition to the above space for the technical crew and control equipment, space must also be provided for a director and producer. Both should be able to see the video monitors. The director's position should be near the video switcher and audioman for giving instructions during the program. Provisions must also be made to darken the control-room area for viewing the television monitors (Fig. 5-6).

Storage Requirements

Since it is desirable that the TV mobile unit transport all necessary technical equipment used with a four-camera remote, as well as a microwave relay transmitter, considerable storage space should be provided. Camera control units, power supplies, video switcher, master monitor, video distribution amplifiers, sync generators, microwave transmitter control, and audio amplifiers can be transported in place on

shock-mounted bases. Cameras, view finders, and microwave transmitter should be stored on shock-mounted bases also (Fig. 5-7).

Storage space is needed then for camera cable (Fig. 5-8); tripods (Fig. 5-9); microwave "dishes" microphones, and cable (Fig. 5-10); lenses; spare tubes; test equipment; etc.

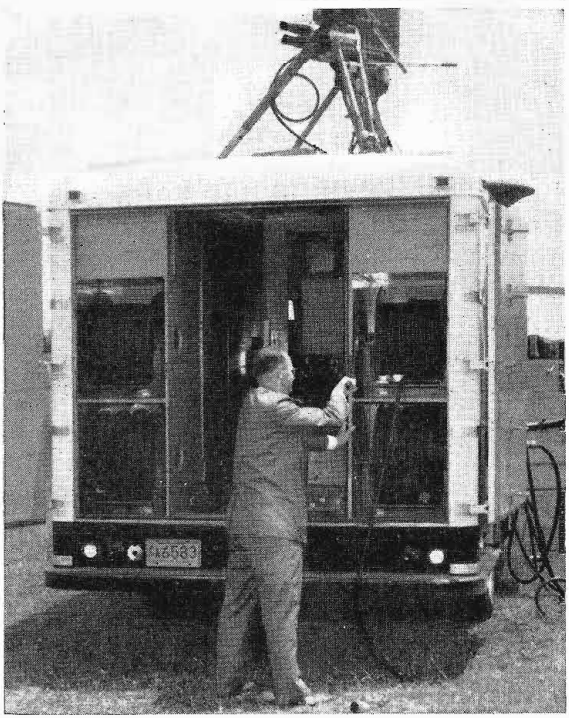

FIG. 5-8. Camera-cable storage.

Electric-power Considerations

A commercial source of a-c electric power at the remote site is normally used to operate the television equipment. Means must therefore be provided in the mobile unit to distribute this power to the various pieces of equipment. Initially, a power-connecting cable of ample capacity is needed to feed from the source to the mobile unit. Since the available power source may be 110 volts a-c, 220 volts a-c single-phase with or without a neutral, 120 to 208 volts a-c three-phase four-wire, or possibly, three-phase with no neutral (Fig. 5-12-1), it is evident that the number of conductors in the power cable could be two, three, or four. If an isolation transformer is used in the mobile unit, the simplest arrangement is to use a two-wire rubber-covered power cable with large enough conductors and connectors to handle at least 70 amp of current (Fig. 5-11). If the isolation transformer can be switched to handle 110 or 220 volts a-c at the primary winding (Fig. 5-12-2), the two-conductor power cable can be connected across either a 110- or 220-volt a-c single-phase power source or across 208 volts a-c of a three-phase source. A connection across two phases of a three-phase source will unbalance the feed power, but this does not ordinarily cause much concern if the source of power is more than adequate. *A very important safety consideration must be mentioned at this point and is required*

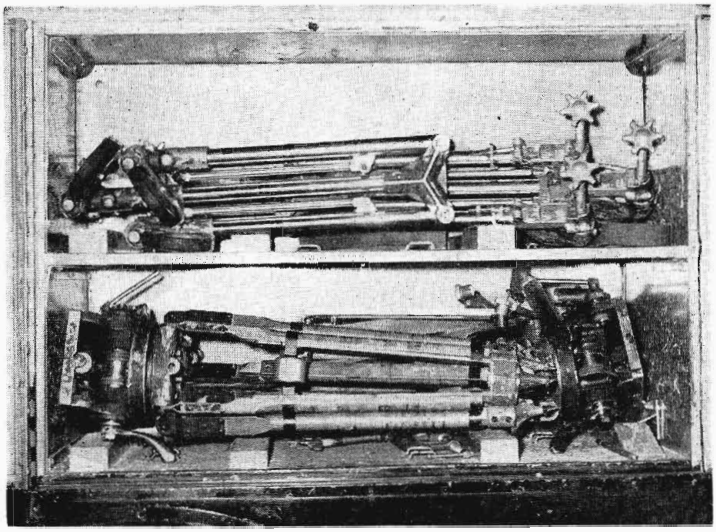

FIG. 5-9. Tripod and dolly storage compartments are accessible from the outer side of mobile unit.

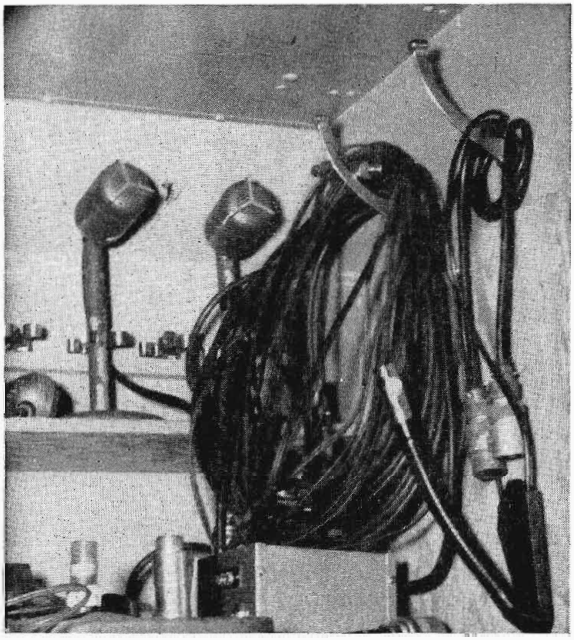

FIG. 5-10. Microphone and cable storage compartment is located over camera cable reels.

FIG. 5-11. 70-amp two-conductor rubber-covered power cable and connector are shown at right. Audio-video patch panel (left) provides rapid and convenient connection between mobile unit and cameras, microphones, telephone lines, microwave, etc.

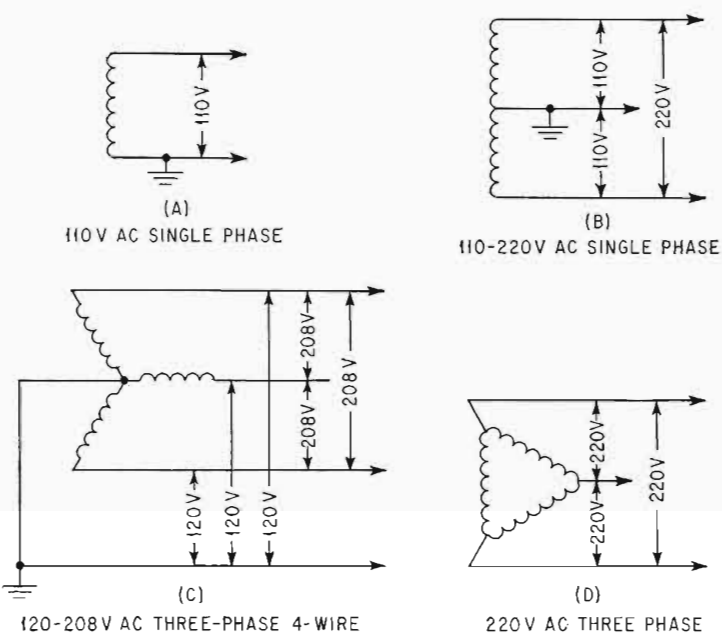

FIG. 5-12-1. Four possible arrangements of commercial power sources from which electric power can be taken to operate mobile unit equipment. The 120- to 220-volt switch and isolation transformer shown in Fig. 5-12-2 permits two conductor power cable to be connected to any of the four power arrangements shown. In (*A*), the switch would be thrown to the 110-volt position. In (*B*), (*C*), or (*D*) the switch would be thrown to the 220-volt position. Since a neutral wire is not used in the last three cases, electrical codes and safety precaution require that the mobile unit be connected separately to a good electrical ground.

by most electrical codes. A heavy-duty ground wire must be connected between the mobile unit and ground. The ground must be a metal stake driven into the earth, an underground water pipe, or a connection to the ground circuit of the electrical power source. If this precaution is not observed, a shock hazard will exist when stepping from the mobile unit to the ground if any piece of equipmeut develops a partial or direct short in its electrical wiring.

The isolation transformer in the mobile unit should be of sufficient capacity to

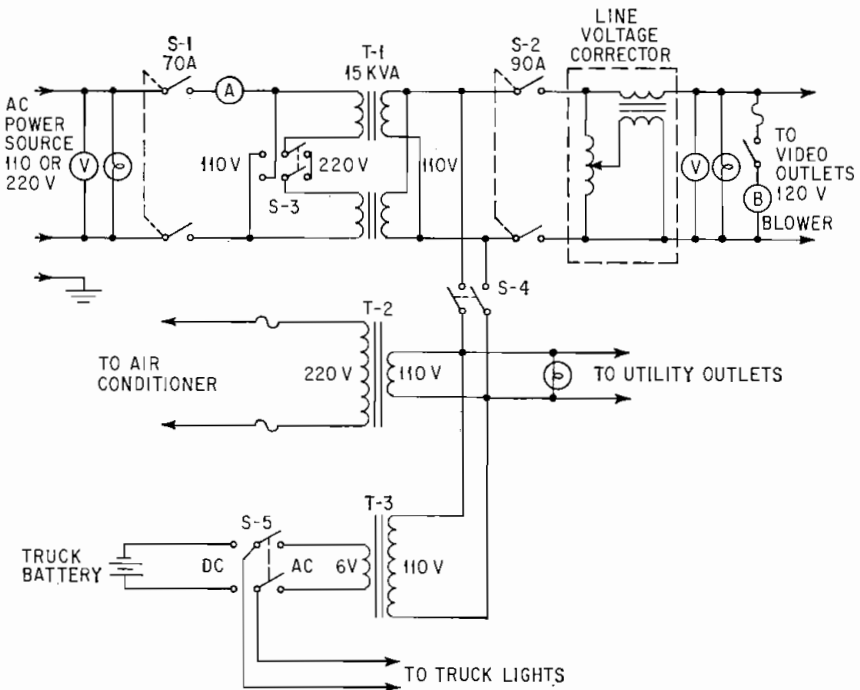

FIG. 5-12-2. Mobile-unit isolation transformer (*T*-1). Switch *S*-3 permits operation from either 110- or 220-volt source. Voltage to video outlets is regulated to 120 volts.

handle the total electrical load used by the television equipment. A rating of 15 kva seems adequate. The secondary winding should, of course, be 120 volts to provide correct voltage to the various pieces of equipment. The transformer should be protected with a 70-amp circuit breaker, and means should be provided to regulate the secondary voltage automatically or manually. If manual operation is provided, the control should be located in the mobile-unit control room convenient to a technical operator of the television equipment. A primary winding or input voltmeter and ammeter are desirable, as well as a secondary wiuding or output voltmeter.

For the rare occasions when commercial electric power is not available, a stable, well-regulated, portable 60-cycle gasoline generator having a minimum capacity of 10 kw is a very desirable addition to the TV remote equipment. This generator can be trailer-mounted and drawn by the TV mobile unit or a station wagon. (Fig. 5-13*a* and *b*).

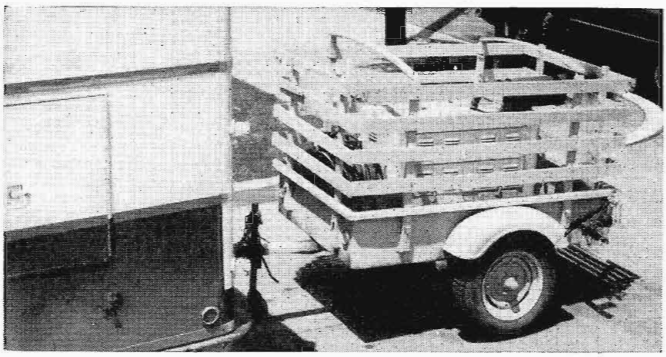

FIG. 5-13*a*. A trailer-mounted gasoline generator (6 kva) attached to mobile unit. Two cameras only can be accommodated by this particular generator.

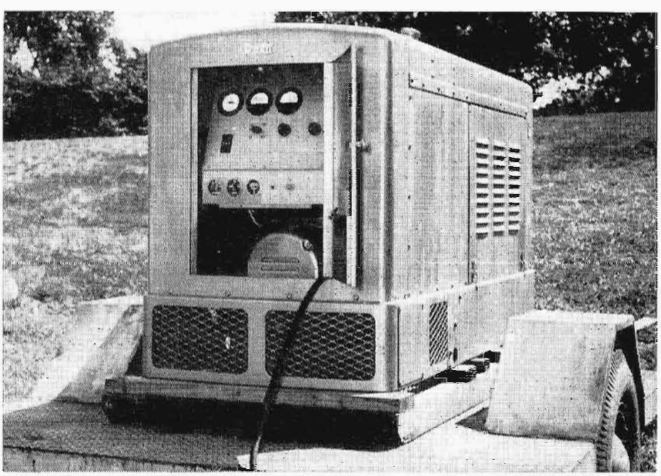

FIG. 5-13*b*. A larger gasoline motor-generator (35 kva) was used to supply power for four cameras on a *Jimmy Dean* water ski show on the Potomac River. Commercial power was not available.

Audio-video Connections

A time-saving feature of the mobile unit is a patch panel convenient to the outside of the control room on which all connections can be made to camera cables, video coaxial cables, incoming and outgoing telephone lines, microphone cables, etc. From the patch panel, all cables are connected semipermanently to the proper equipment in the mobile-unit control room.

Auxiliary Equipment

Heat generated by the various pieces of equipment and operating personnel in the control room added to the heat and humidity of a hot summer's day readily points up the need for air conditioning of the mobile-unit control room. Part of this heat can be exhausted separately from enclosures housing power supplies and sync generators, but the camera control units, audio amplifier, switcher, line and air monitors, microwave transmitter control, etc., normally must be exposed to the

control-room air and soon add excessive heat. An air conditioner having a minimum cooling capacity of 1½ tons is required for the size control room described above. A 1½-ton unit generally requires 220 volts a-c for operation. This voltage can most conveniently come from the 120-volt secondary of the main isolation transformer using an additional 120- to 220-volt step-up transformer to feed the air conditioner. An air conditioner of 1½-ton capacity will put a load of approximately 3 kva on the transformers.

In order that control-room lights can be operated from the mobile-unit d-c battery before connecting to a commercial power source and to operate from a-c power

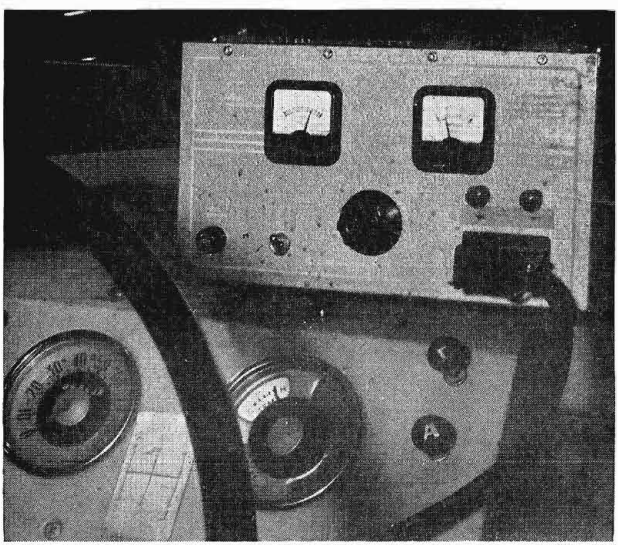

FIG. 5-14. Portable battery charger permits continuous use of battery-operated communication transmitter.

during a remote program, a 120- to 6.3-volt a-c transformer is needed. A switch to select the appropriate source should be provided.

A built-in battery charger is very desirable, since normal usage of the mobile unit does not always keep the battery fully charged. The battery charger can be used when the mobile unit is on standby status or during a remote program (Fig. 5-14).

Experience has shown the need for an "off-the-air" TV receiver mounted in the mobile unit control room. An outside antenna is usually required. This can be supported by a detachable mast on the outside of the mobile unit. The mast can also serve to support camera cables, microphone cables, etc., if required to run above sidewalks from the mobile unit.

Microwave Equipment

Whether a television station chooses to do its own microwave relaying or to engage the services of the local telephone company, the same problems exist and similar equipment is used. Microwave equipment generally used by the broadcaster operates within a 25-Mc channel in the 7,000-Mc band. The telephone companies have channels allocated to them in this band [1] as well as in the 4,000-Mc band. Channels are also available to the broadcaster in the 2,000- and 13,000-Mc bands. The high-frequency transmitter has relatively low power (1/10 or 1 watt) and relies on the

[1] Three channels in the 7,000-Mc band.

power gain of its parabolic reflectors to relay the signal from the remote site to the receiver location at the studios. A microwave receiver tuned to the transmitter frequency receives the transmitter signal over a line-of-sight path (Fig. 5-15). A parabolic reflector is also used with the microwave receiver to increase the antenna

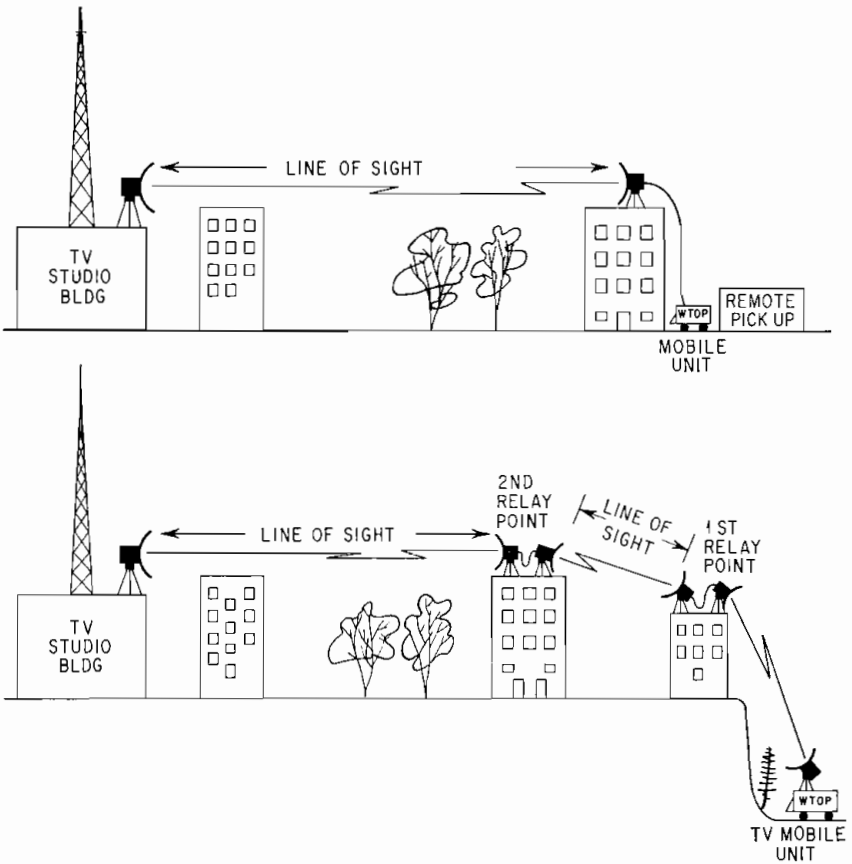

FIG. 5-15. Line of sight must ordinarily exist between microwave transmitter and microwave receiver. Obstructions between remote site and studio building may require use of multiple-hop microwave equipment.

gain. A 4-ft parabolic reflector increases the antenna gain by approximately 5,000. When a 4-ft reflector is used at 7,000 Mc, the resulting microwave beam is very narrow—approximately 5° between the half-power points (Fig. 5-16). Therefore, it is obvious that both the transmitting and receiving reflectors must be accurately and securely aligned in order that the signal not be lost during a program. If there are trees with leaves in the path of the microwave signal, it may not be possible to transmit the signal to the receiver because the leaves create high attenuation of the signal. With the more recent 1-watt 7,000-Mc transmitters, it is sometimes possible to get enough signal through trees, but for extended distances this is not probable. An advantage of the lower frequency (2,000 or 4,000 Mc) equipment seems to be that its signal will usually pass through some trees without serious attenuation. It is

generally required, however, that a good line-of-sight path between microwave transmitter and receiver be chosen on all microwave bands. No intervening buildings or structures can normally be tolerated. It may be necessary to use two or more sets of microwave equipment in a "double hop" or "triple hop" in cases where the pickup site is low or obscured from the receiving point by trees, buildings, etc. A pair of binoculars is invaluable for determining the best locations for microwave equipment. In some cases it is advisable to employ a crane in order to elevate the microwave transmitter sufficiently to clear trees near the remote site (Fig. 5-17*a*). For other uses of a crane on TV remotes see Figs. 5-17*b* and *c* and 5-18*a*.

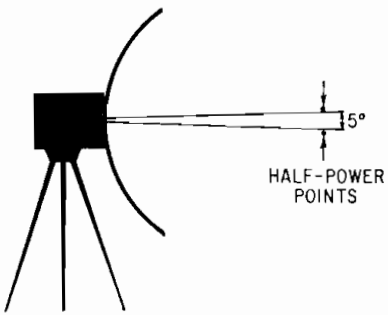

FIG. 5-16. Illustration of narrow beam of microwave equipment (using 4-ft reflector at 7,000 Mc).

When telephone lines are available from the remote site to the studios, they are ordinarily used for the audio signal. It is very desirable, however, to have microwave equipment with provisions for multiplexing both the visual and aural signals. When insufficient time prevents installation of telephone lines, the importance of this feature is apparent.

By using 4-ft parabolic reflectors, 7,000-Mc microwave equipment can be used over line-of-sight distance to approximately 30 miles.[2] Six-foot reflectors will extend this range somewhat but are cumbersome to handle and difficult to keep aligned because of the narrow beamwidth of approximately 2½° and the excessive wind loading. Twelve- or twenty-four-inch reflectors can be used up to several miles separation between transmitter and receiver. These smaller reflectors are useful especially with a transmitter installed on a moving mobile unit or other vehicle, since the accuracy of panning is less stringent owing to the wider beamwidth (Fig. 5-18*a* to *f*).

Radio Communications Equipment

If time does not permit the installation of adequate telephone communications facilities between the remote site and a station's master control room, it is desirable to be able to use radio communication. A radio telephone installed in the mobile unit or accompanying vehicle may suffice in many such cases (Fig. 5-19). This equipment is somewhat limited in that the telephone company radio channel may be in use by another customer when needed urgently to communicate between the remote and master control.

The FCC has allocated FM communication channels in the 26-Mc band which can be used by broadcasters to expedite remote-program setups. The use of transceivers in aligning microwave transmitter and receiver "dishes" is particularly valuable. All such radio communication transmitting equipment must, of course, be licensed and operated in conformance with FCC Rules.

A typical arrangement of radio communication equipment as used by WTOP consists of a 50-watt transmitter-receiver operated from the master control room of the station (Fig. 5-20*a* and *b*) and a battery-operated 35-watt transmitter-receiver installed in the mobile unit (Fig. 5-21). These transmitters are tuned to the same frequency. Two "walkie-talkie" transceivers tuned to the same frequency as the master control and mobile unit are used to align microwave—one at the remote microwave transmitter and one at the microwave receiver (Fig. 5-22). In many cases, the walkie-talkie transceivers can be used directly to align the microwave. However, if the distance is too great, it may be necessary to relay alignment informa-

[2] Distances over 100 miles have been used.

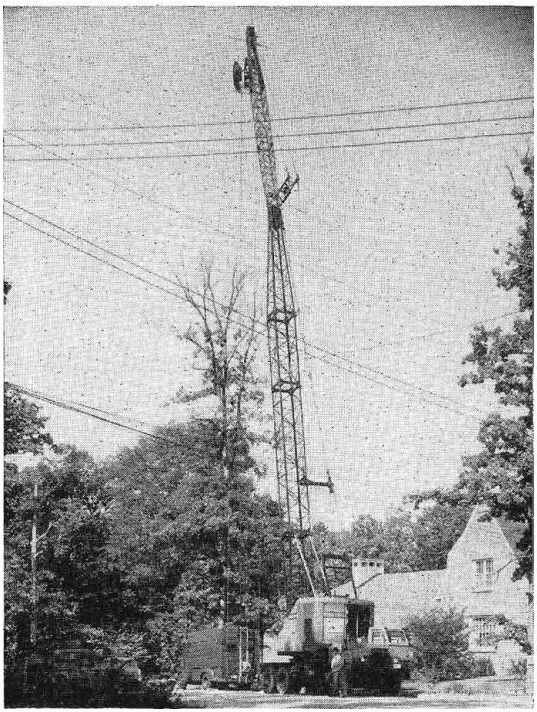

FIG. 5-17*a*. A crane was employed by the local telephone company to elevate microwave transmitter sufficiently to clear nearby trees for Edward R. Murrow's *Person-to-Person* remote from Secretary of Agriculture Benson's residence in Washington, D.C. A crane can also be useful as a camera platform (see Figs. 5-17*b* and *c* and 5-18*a*).

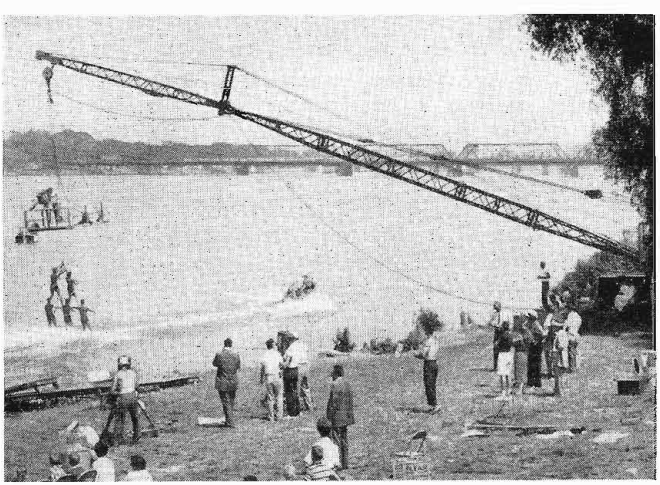

FIG. 5-17*b*. A crane was used for an overwater camera platform on *Jimmy Dean Water Show* (Potomac River, Washington, D.C.).

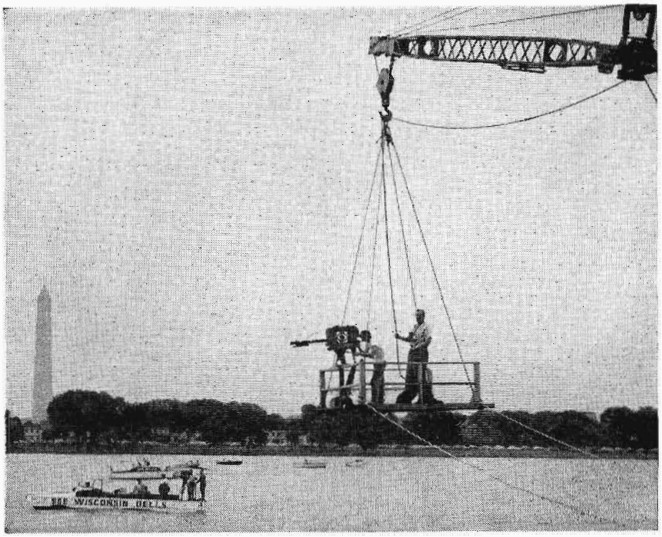

FIG. 5-17*c*. A crane-supported camera above Potomac River in operation with a field Zoomar lens. Left foreground shows camera-equipped amphibious "Duck." Washington Monument appears in background.

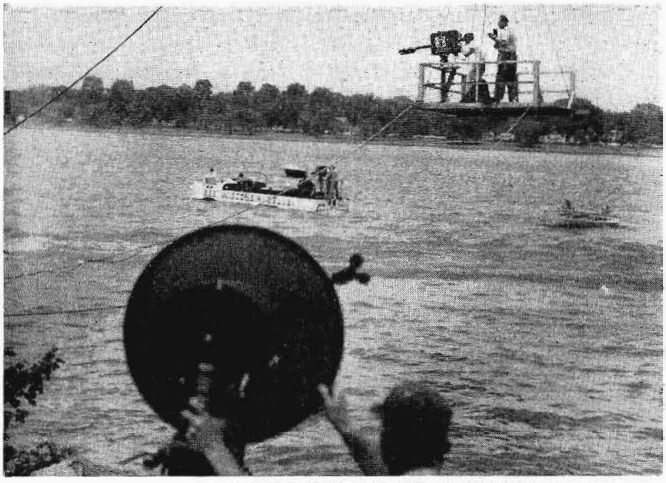

FIG. 5-18*a*. 2-ft microwave reflectors are used on the receiver (above foreground) and on the microwave transmitter in the "Duck" because of the broader microwave beamwidths as compared with the more common 4-ft reflectors. Note aiming sight attached to rim of reflector.

FIG. 5-18*b*. Close-up view of gasoline motor-generator (left), camera control unit, microwave transmitter, and camera installed in amphibious "Duck" for *Jimmy Dean Water Show*. Note 2-ft reflector used on microwave transmitter.

FIG. 5-18*c*. The gasoline motor-generator used to power camera and microwave transmitter must be well regulated at 60 cps to ensure steady pictures.

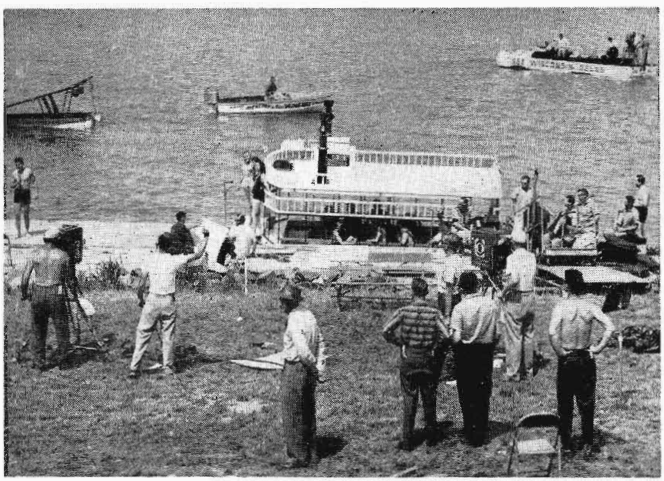

FIG. 5-18*d*. *Jimmy Dean Water Show* in progress. The camera-equipped amphibious "Duck" provided close-up pictures of water stunts.

FIG. 5-18*e*. This Packard convertible was used during the inaugural parade in January, 1953, to relay continuous close-up pictures of President Eisenhower to a microwave receiving point on the roof of the U.S. Capitol. Not visible is the 3-hp gasoline motor-generator installed in the trunk. Accurate panning of microwave reflectors is required to prevent loss of picture signals.

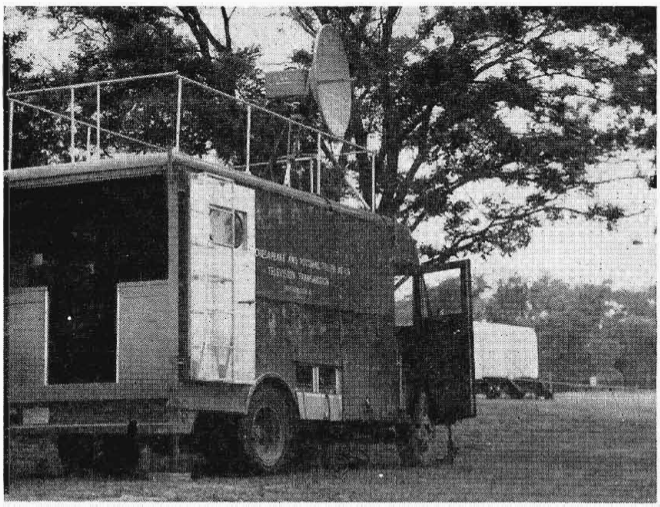

FIG. 5-18*f*. Local telephone company microwave operating on 6125.5 Mc. Note jacks under mobile unit to stabilize microwave beam. The microwave transmitter and tripod are securely anchored to roof. A gasoline motor-generator was used to supply electrical power.

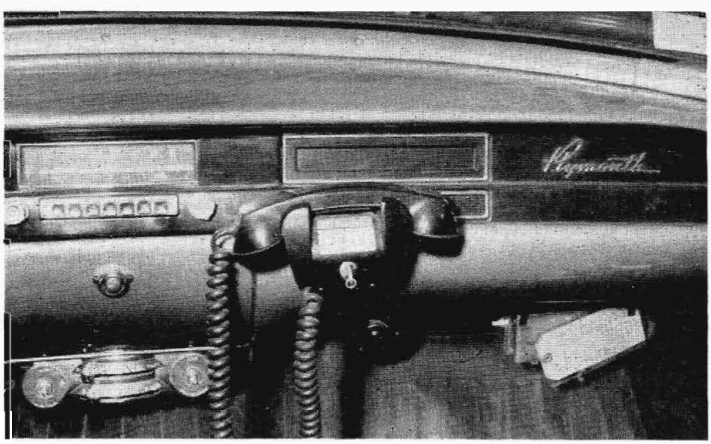

FIG. 5-19. Radio telephone installed in WTOP station wagon.

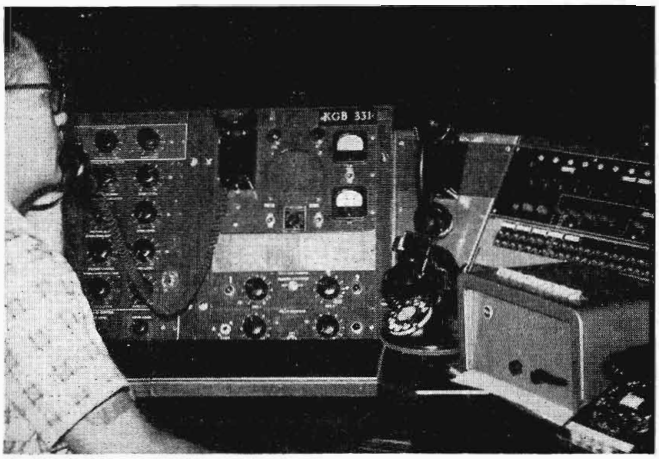

FIG. 5-20*a*. The control equipment for the 50-watt 26-Mc radio communications transmitter-receiver is operated from TV master control desk. This equipment is used for communications with the TV mobile unit.

FIG. 5-20*b*. 50-watt 26-Mc FM transmitter-receiver operated from WTOP-TV master control.

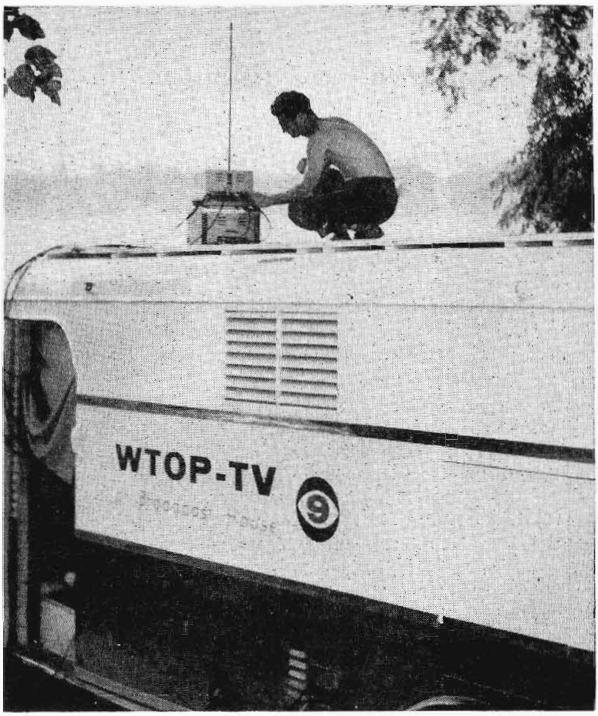

FIG. 5-21. 35-watt 26-Mc FM transmitter-receiver temporarily installed on mobile-unit roof for communicating with boats during *Jimmy Dean Water Thrill Show* on Potomac River. "Walkie-talkies" transceivers (see Fig. 5-22) were used in a boat towing Dean on water skiis as well as in the amphibious "Duck" (see Fig. 5-18*c*). Contact with WTOP-TV master control was also possible (see Figs. 5-20*a* and *b*).

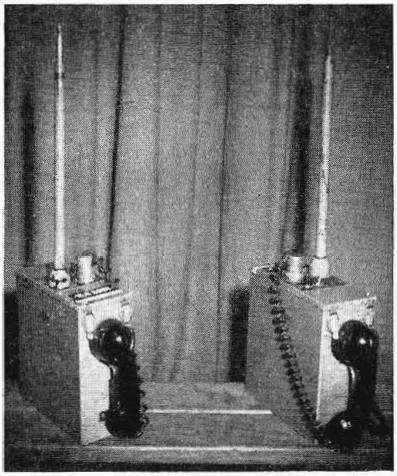

FIG. 5-22. "Walkie-talkie" FM 26-Mc transceivers operate on same frequency as mobile unit and TV master control room communications transmitters-receivers. Alignment of microwave transmitter and receiver reflectors is simplified by use of these units.

tion via the more powerful mobile unit or master control transmitters. Following the microwave alignment, the larger powered eqnipments are used to relay program timing and cue information, etc.

Video Equipment

1. Portable field camera equipment is used on remote pickups. The cameras, view finders, camera controls, power supplies, sync generators, video switcher, and monitors are normally equipped with carrying handles for convenient handling. Rain covers shonld be provided for cameras. Camera cables of lengths from 25 to 200 ft are carried on reels in the mobile unit. Cables longer than 200 ft are too heavy for convenient handling.

2. Lenses ranging in focal length from 35 mm to 100 in. have been used on remotes by WTOP. Each camera should have a "normal" complement of lenses: a 50, 90, and 135 mm and an 8-in. Other lenses frequently used are 35 mm and 10, 13, 15, 17, 20, and 25 in. Zoom lenses which operate from approximately 2½ to 7, 2½ to 15, and 3 to 22 in. are also frequently used. Forty-inch lenses are available for television cameras but not often required. A 100-in. lens owned by the Army was used on one program, primarily as a "gimmick."

3. Stndio-type tripods are nsed on remotes. Portable tripod dollies arc nsed almost exclusively, since the heavier pedestal dollies are cumbersome to handle. The portable dollies should be capable of negotiating a 30-in. doorway, and large wheels (about 6-in.) are desirable where cameras are required to be dollied over rugs or rough floors.

A tripod T is required when a dolly is not used. These T's can be either of metal with sockets for the tripod legs or of wood in which the sharp leg fixture can be embedded (see Fig. 5-2). T's prevent the older models of wooden tripods from collapsing accidentally and protect floors, etc., from being marred. It is a good practice to anchor the tripod to a T or platform to prevent cameras from falling if a leg is inadvertently kicked by the cameraman.

Audio Equipment

Amplifiers

A portable remote audio amplifier having four microphone inpnts will usually be adequate for most remote programs. The microphone inputs should be balanced and low impedance to prevent stray electrical pickup. It is desirable that the remote amplifier be powered with batteries with a change-over switch to operate from alternating current. Another feature which wonld be helpful but is rarely found in a remote amplifier is a multiple line feed by which two or more program lines can be fed simultaneously. It would also be advantageous if one of the line outpnts incorporated a switchable pad to reduce one output to microphone level so that another station at the remote site desiring a low-level feed could be accommodated or, alternatively, to feed an additional remote amplifier in cascade where more than four microphones are required. The amplifier should, of course, incorporate a VU meter and a master gain control.

Microphones

Low-impedance microphones having low wind noise are used for remote pickups. Some types of microphones which would be satisfactory for studio use produce excessive wind noise when used in only moderate winds because of their physical structure. These types must be avoided in outdoor pickups.

Radio microphones are sometimes used on remote programs such as Edward R. Murrow's *Person-to-Person* show when considerable movement of the participants is involved and where it is required that microphones uot show in the televised pictnres.

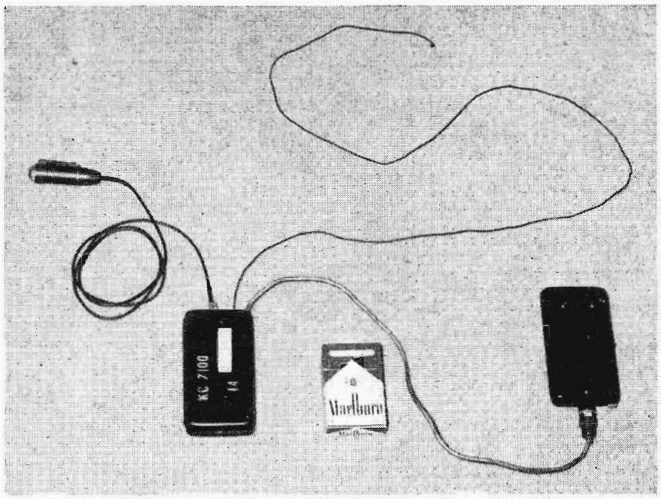

FIG. 5-23. Budelman radio microphone worn by participants in Edward R. Murrow's *Person-to-Person* television shows. Microphone is shown at upper left, 26-Mc transmitter at lower left, antenna wire (top), and battery pack at right.

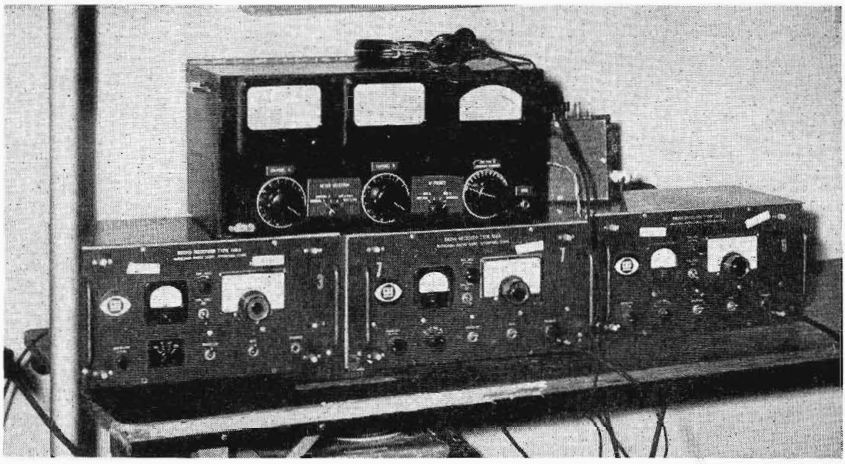

FIG. 5-24. Three Budelman radio microphone receivers are shown side by side on table. A diversity mixing amplifier is on top. The primary participant's radio microphone signal is picked up by two receivers on left, and the receiver outputs are then fed to the diversity amplifier above. This procedure minimizes fading caused by movement of participant. The remaining receiver is tuned to a separate radio microphone channel used by secondary participant.

These radio microphones are actually miniature battery-operated transmitting equipments. The microphone, transmitter, antenna wire, and battery are worn by the participant concealed beneath clothing (Fig. 5-23). The equipment used on *Person-to-Person* operates on approximately 27 Mc, and each radio microphone must operate on a separate frequency. The transmitting equipment must be licensed and operated under FCC Rules. The participants need not be licensed, however, as long as a licensed operator is responsible for the operation of the equipment. Because of the low power output from the radio microphones, there is no danger from burns or shock hazard. The usable range varies up to about a quarter of a mile depending on transmission conditions. When radio microphones are used inside a building constructed of metal materials, multipath reflections will occur and cause erratic operation of the equipment. It is sometimes necessary to run considerable receiving antenna wire to various rooms to ensure proper operation of this equipment. Two radio microphones and three receivers are normally used on *Person-to-Person* programs (Fig. 5-24).

Microphone cable used on remotes preferably should be three-conductor, shielded, flexible, insulated, and lightweight. Rubber-covered wire is heavier and generally less satisfactory than some plastic-covered varieties.

Lighting Equipment

Two general types of lighting equipment are used in television studios—fluorescent and incandescent. Fluorescent lighting is meeting with less favor because of its limited

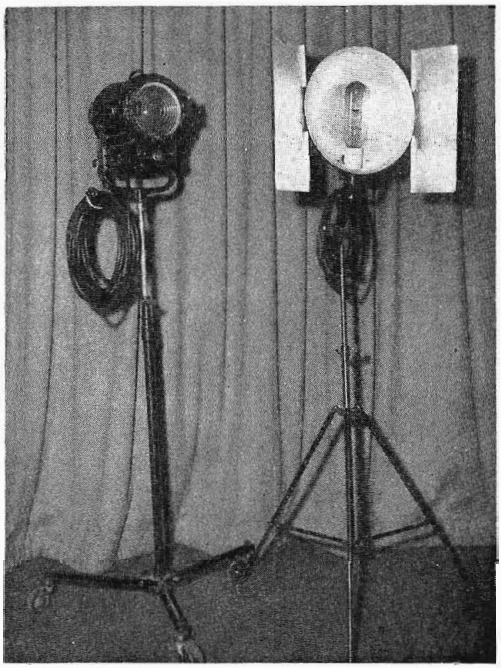

FIG. 5-25. Focused narrow-beam Fresnel spotlight type (left) and broadbeam "scoop" with "barn doors" on right.

"throw" of light and the large and cumbersome fixtures involved, and in some cases it causes flicker in the TV pictures. Incandescent lighting is used almost exclusively on remote pickups.

Incandescent-lighting equipment is available in two general types—focused narrow-

beam types for high-intensity light over a small area and the broad-beam types for wider area illumination (Fig. 5-25). Adjustable-height stands with roller caster bases are available for both types of fixtures and are almost always required on a remote.

The narrow-beam spotlight types are usually equipped with a Fresnel lens in front of the lamp and a reflector behind the lamp with provision to vary the lamp-to-reflector distance, thereby broadening or narrowing the light beam as desired. The usual sizes of spotlights used on remotes are 500, 750, 1,000, 2,000, 3,000, and occasionally, 5,000 watts. The larger sizes are needed to illuminate auditoriums or other

FIG. 5-26. Vertical "polecat" consists of telescoping spring-loaded aluminum tubing. "Clip-on" lights are shown attached to polecat.

large areas, while the 500- to 750-watt sizes are usually adequate for close lighting up to about 25 ft.

The broad-beam-type lights usually consist of a 750- to 1,500-watt inside-frosted lamp in a 15- to 18-in. parabolic reflector. These lamp fixtures may also be rectangular in shape. In general, this type of light is used for broad illumination and "fill" lighting.

Another type of fixture which is used where a number of small areas must be lit is the "clip-on" light. This consists of a regular house-lighting socket secured to a rubber-covered spring clamp that can be attached to a board, chair, pipe, etc. (Fig. 5-26). Reflector flood or reflector spot lamps are generally used with the clip-on fixtures in sizes up to 300 watts. A convenient mounting in rooms of ceiling heights of about 8 ft is the "polecat" (Fig. 5-26). This is a telescoping tubing about 1 in. in diameter and is used vertically between floor and ceiling. These can also be used horizontally between walls (Fig. 5-27). The telescoping section is spring-loaded, which holds the unit firmly in place. Of course, padded ends are used to prevent marring the floor or ceiling. The clip-on fixtures then clamp at the desired height.

Cables for lighting fixtures should be rubber-covered, should be capable of carrying the required current (about 43 amp in a 5-kw lamp), and should incorporate an equipment-grounding wire to run from the fixture to the common ground point to reduce shock hazard. A lighting-distribution panel incorporating fuse or circuit-breaker protection for each circuit with ample capacity is a must for remotes (Fig.

FIG. 5-27. Horizontally mounted polecat showing two "clip-on" light fixtures with barn doors for preventing direct light from falling into camera lenses.

5-28). For reliable operation and to meet electrical code requirements, the distribution system must be carefully planned and constructed. Since most stations use different methods of lighting and types of connections, this panel is usually custom-built.

OPERATION OF A TYPICAL REMOTE

Preparing for a television remote program, as contrasted with a studio program, involves a multitude of technical problems. Assuming that the program department has informed the engineering department of the general requirements for a remote pickup such as place, date, time, and number of cameras required, the following sequence of steps is taken by the engineering department to prepare for the event:

1. Ascertain that sufficient engineering personnel will be available.
2. If cameras are taken from the studios, determine which cameras will come from which studio and when they can be freed for the remote.
3. An on-the-spot survey of the proposed remote program site is then undertaken with the following people (together if possible):
   a. The producer and director of the remote program.
   b. The engineering department representatives (usually the engineer in charge and the technical supervisor assigned to the show).

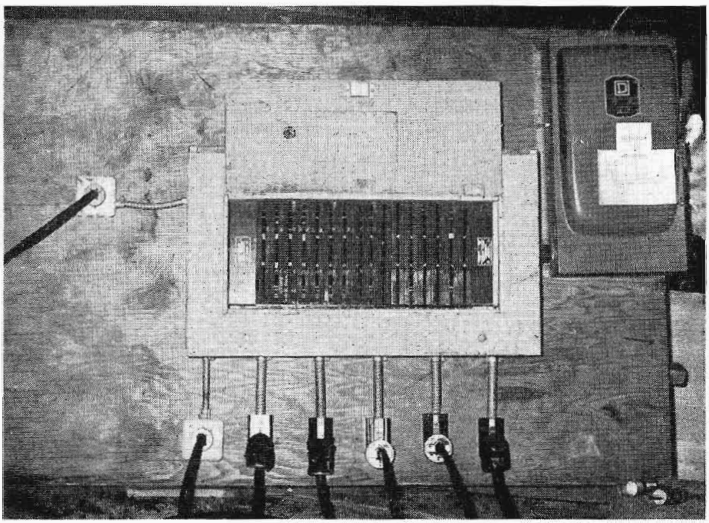

FIG. 5-28. Lighting- and power-distribution panel used on remotes where a large quantity of electric power is needed. The circuit breaker panel is fed by a 200-amp disconnect switch which can be wired for single-phase or three-phase four-wire power. Ordinarily a special temporary service is provided by local power company direct to power panel.

FIG. 5-29. A "Public Space" permit was required for this *Person-to-Person* remote because the sidewalk was needed for camera and Fearless dolly operation. The mobile unit occupied public space for approximately 12 hr and also required permit. Electric power was fed to distribution panel (see Figs. 5-30 and 5-31) from manhole in sidewalk.

c. A master electrician of an electrical contracting firm who is authorized to take out necessary electrical permits who will provide adequate wiring facilities from the maiu power source to the television mobile unit and supply a licensed electrician for standby during the remote program if considered necessary.

d. A representative of the local telephone company concerned with video microwave relay (if the station does not choose to use its own microwave equipment and personnel).

e. A representative of the local power company if sufficient power is not immediately available at the site.

f. Anyone concerned at the remote program site such as owner or manager of the premises, chief engineer of the building, etc., depending on the place and nature of the proposed remote pickup.

4. If it is determined from the survey that the mobile unit will occupy public space, it will usually be necessary for the engineer in charge to make application at the local license bureau for permission to park the mobile unit and give details of the program such as sidewalks or alleys to be blocked off, time and duratiou of vehicle on public space, etc. This step usually involves the local police in that special "No Parking" signs may have to be posted for the general public, traffic rerouting, etc. (Fig. 5-29).

5. If the proposed remote is inside a building, plans for needed lighting should be made during the technical survey. This phase can present problems other than technical when newsreel cameramen or other television stations having a different technical union are involved in a pickup of the same program. The problem is normally resolved in the Washington, D.C., area by using the facilities of a stage lighting company satisfactory to all parties and the cost of the lighting is shared by the television and newsreel companies.

6. Following the technical survey, the uecessary audio and video circuits are ordered from the local telephone company if the program is to be fed to the master control of the station. Iu the event that the program is to be fed directly to the network instead of the master control of the station doing the pickup, it will then be necessary to contact the person iu the network traffic department, since a local station cannot order facilities directly to the network. The usual order for an average remote television pickup will consist of:

a. A video transmit circuit.

b. An equalized 5-kc audio transmit circuit.

c. A nonequalized audio receiving circuit (used for cueing).

d. Two nonpublished business telephones in the mobile unit (one for program and one for engineering).

e. Additional private-line facilities if required.

7. The next step is to determine the "time iu" for the technical crew. Based on the complexity of the particular remote program and whether or not rehearsal is required, the crew assignment may be from 2 to 10 hrs ahead of air time. At this point the show is theoretically "on the road," but invariably changes affecting some phase of the program will arise, at which time it is necessary to contact the person or persons involved in the program changes.

8. A complete list of technical equipment to be used for the remote program should be made by the technical supervisor, and immediate steps taken to accumulate and check out the equipment (Fig. 5-30). The mobile unit should be kept in good mechanical condition at all times. Some of the items to bear in mind are:

a. Condition of the mobile-unit battery.

b. Gasoline and oil levels.

c. Condition of tires, lights, cooling system, and brakes.

These items seem unimportant but any one can delay starting on a remote. If time permits, the complete camera setup should be checked out before leaving for a remote, including a close observation of the sync generator pulses. A spare sync generator is always desirable.

9. Before the technical crew departs for a remote, provisions should be made to see that they are able to get a lunch period if the remote is of extended duration. This item is quite important because of the extra physical exertion involved in this type of

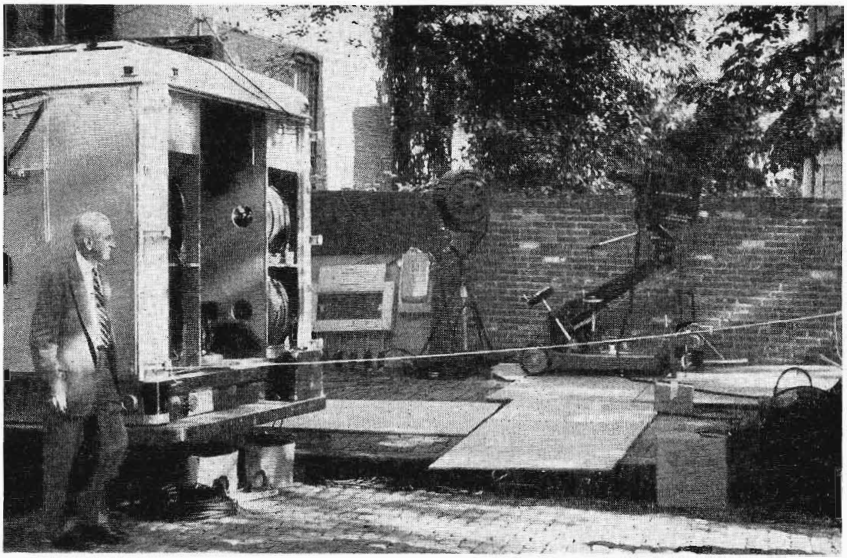

FIG. 5-30. The equipment used on a television remote can be quite extensive. On this remote, 18 sheets of 4- by 8-ft plywood were used to provide a smooth surface for Fearless camera dolly operation. Since the show was aired at 10:30 P.M., considerable lighting equipment was needed to illuminate sidewalk area and garden beyond wall.

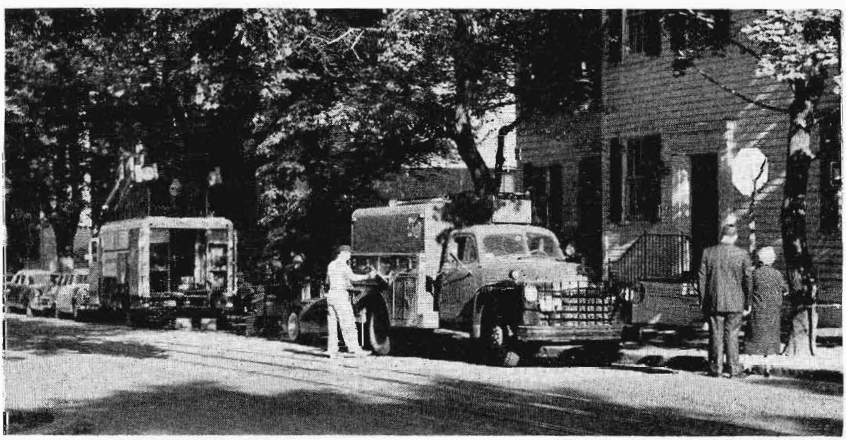

FIG. 5-31. *Person-to-Person* television remotes usually require more electric power than is available in the homes visited. Consequently, a special temporary electric service is needed. A power-company crew is providing this service at a Georgetown, Washington, D.C., residence.

television program. Also, on many remotes in Washington, D.C., it is necessary to get security clearance for technical crew members. This is required on all remotes involving the President of the United States.

If a thorough surveying and planning job has been made, the remote pickup should proceed with only minor technical problems. When the technical crew arrives on the site with the television mobile unit (and station wagon for extra transportation), the first item of business is to park the mobile unit at the predetermined spot. The telephone representative should be on hand to point out the location of previously ordered audio and telephone lines and the coaxial video cable for picture transmission. The supervisor will direct camera and platform placement (at predetermined spots), camera cable routing, and microphone placement and cable routing. The electrician should have an adequate power source available for the mobile unit (Fig. 5-31). This should be the predetermined single-phase 110 or 220 volts a-c or three-phase 208 to 220 volts a-c, depending on the particular requirements (Fig. 5-12). The capacity should be at least 25 per cent above the maximum anticipated load to provide a margin of safety. Lighting fixtures and cables are placed in position by the technical crew, and then all equipment is turned on and checked out.

If required, video monitor and communication cables are run to the announcer and floor director positions from the mobile unit. A multitude of minor changes are usually made in camera, light, and microphone placements that almost invariably become necessary.

Prior to air time a check is made with the station to synchronize the mobile-unit clock. If time permits, the audio and video signals are sent to the master control of the station to set levels and check on pulse widths, picture and sound quality, etc. Immediately prior to air time, the remote director establishes communication with the control studio director and exchanges last-minute bits of program information. Then the show is ready to begin on cue.

Section 8

MEASUREMENTS, TECHNIQUES, AND SPECIAL APPLICATIONS

Part 1

THE TRANSISTOR—A NEW FRIEND FOR THE BROADCASTER *

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INTRODUCTION

Broadcast engineers who make no attempt to become acquainted with transistors will very rapidly find themselves unable to participate in some of the liveliest technical conversations in the industry. The transistor, scarcely more than ten years old, has been refined and developed to the point where it is a fast-rising contender for many of the circuit functions required in broadcast equipment, both audio and video. It is not such a miraculous device that it will make tube-type equipment obsolete overnight, but it offers enough advantages that we can confidently predict a steady trend toward transistorization in all categories of broadcast equipment. Reputable manufacturers and wise broadcasters will be careful to see, however, that transistorized equipment fully measures up to broadcast requirements before it is offered for sale or pressed into service. The novelty value which helps to sell transistorized consumer products is useless to the broadcaster, who must demand reliability in all equipment involved in the handling of his highly perishable product—broadcast time.

The purpose of this part is to introduce the broadcast engineer to the transistor in such a way as to initiate a lasting friendship between the two. The material is intended, of course, only for those broadcast engineers who have not yet had the opportunity to become acquainted with transistors through education or actual experience with them. The authors feel qualified to make an appropriate introduction, because we have had the privilege of getting to know both broadcasters and transistors through our professional activities extending over several years. We appreciate that broadcasters are not professional physicists, so we shall avoid the conventional approach

* This material was delivered by Mr. Wentworth at the 13th NAB Broadcast Engineering Conference, Chicago, Ill., March, 1959, as a technical paper.

which attempts to describe transistor behavior in terms of "holes," electron flow, energy levels, and other aspects of semiconductor theory. We shall assume that transistor designers have done their job well, so the transistor can be introduced to the broadcaster as just another basic component, like the resistor, capacitor, inductor, or diode, that can be called upon to do specific jobs in electronic circuits. We shall present a brief summary of the "personality traits" of transistors and a description of their typical behavior. We shall explain how they can be put to work in a few typical circuits and shall conclude with a few observations on handling precautions that will help to keep transistors and broadcasters on friendly terms with each other.

ADVANTAGES

The major advantages of transistors in comparison with hot-cathode tubes have been so widely publicized that only a brief summary is required here. The small size of transistors, coupled with their very low power-input requirements, makes possible substantial reductions in the size and weight of electronic equipment. These advantages will be appreciated by broadcasters not only for portable field equipment but also in cases where new facilities must be added to broadcast plants without increasing the floor space in control rooms. The reduced heat dissipation not only will add to operator comfort in crowded locations and reduce the power bill for technical equipment but will also increase the life expectancy of nearly all circuit components (which always age less rapidly at reduced temperatures). The transistor itself enjoys a much longer life expectancy than its vacuum-tube cousin, provided it does not meet an untimely death from overexposure to unfavorable conditions. There is considerable evidence that many transistor types have a life expectancy of the order of 70,000 hr (about 8 years) of continuous service if used under conservative conditions. This long life contributes, of course, to greater reliability in transistorized equipment. The absence of heated cathodes reduces substantially the warm-up time required for transistorized circuitry. Still another trait that is winning friends for the transistor is its versatility. It can be constructed in a variety of forms, many of which will do jobs that could never be done reasonably with tubes. Two transistors can be made as "mirror images" of each other for use in balanced or symmetrical circuits, for example, and it is even possible to make a transistor which behaves exactly the same whether it is hooked up "backward" or "forward."

PRESENT LIMITATIONS

These obviously friendly remarks about transistors should not lull the reader into the false assumption that transistors are paragons of virtue. They have their faults and limitations, and broadcasters would do well to become acquainted with these less favorable attributes of transistors right from the beginning so as to make proper allowances for them. Fortunately, many of the limitations of transistors are not of major concern to equipment *users*, provided the equipment *designers* understood them and took them into account.

At the present state of the art, transistors are definitely limited in either frequency response or power-handling capability. Types have been developed which handle substantial amounts of *power* for such applications as series regulators in power supplies, but these types are generally useful only for frequencies below a few thousand cycles per second. At the other end of the scale, types can be obtained which operate up to hundreds of megacycles, but their power-handling capabilities must be measured in milliwatts or microwatts. This problem is a basic one, resulting from the fact that the transistor action actually occurs in a tiny active region within a pellet of semiconducting material. Because of the submicroscopic spacing between the "elements" of a transistor, its input and output capacitances tend to be quite high unless the active area is kept very small. When the active elements of a transistor are made large enough to handle appreciable amounts of power and are thermally coupled to heat-dissipating structures, the capacitances become so great that operation at high frequencies becomes impossible.

A transistor may be regarded superficially as a sophisticated type of nonlinear impedance, implying that it does not follow Ohm's law when voltages or currents are applied to its terminals. It should not be surprising, therefore, that inherent nonlinearity must be counted as one of its limitations in many circuit configurations. An ingenious circuit designer can get around this problem in a variety of ways, but nonlinearity prevents the use in high-quality broadcast equipment of many simple circuits that look like obvious approaches to the transistor novice.

The relatively low impedance characteristics of most transistors may be either good or bad, depending upon the application. Broadcast engineers who have been "brought up" on tube circuits will probably find it difficult to break away from the habit of ignoring input impedances. A tube normally has an input impedance of several megohms, which can safely be ignored when shunted across the load impedance of the preceding stage. A transistor, however, has an input impedance that may vary from a very few ohms up to perhaps 100,000 ohms, depending upon the transistor type and the circuit configuration. In almost all cases, the transistor draws significant current from the preceding stage, so its input impedance must be taken into account when analyzing or designing circuits.

Two transistor traits of great significance to broadcasters are temperature sensitivity and rapid response to conditions of overstress. Transistor performance characteristics definitely vary with temperature, although a competent circuit designer should be able to provide stable performance over a reasonable operating range. There is a temperature threshold, however, above which transistors cannot be operated without suffering irreversible damage. For most germanium transistors, this critical temperature is about 85°C at the active region. When due allowance is made for normal temperature rises within the transistor cases and within confined equipment spaces, we find that about 55°C (131°F) is about the practical upper limit of ambient temperature for transistorized equipment using germanium devices. Silicon transistors will operate at substantially higher temperatures but are considerably more expensive and are limited in some other performance characteristics. Until the temperature problem is overcome, broadcasters would do well to mount transistorized equipment in relatively cool locations.

The transistor cannot compete with its cousin the tube when it comes to tolerating occasional abuse "beyond the call of duty." While a tube is quite vulnerable with respect to its mechanical structure, it is surprisingly tolerant with respect to severe overrating conditions aplied to its internal elements on a momentary or accidental basis. An accidental short of a grid circuit to +B may cause a tube to glow red very quickly, but it can be restored to its normal condition if the overstress is not continued too long. Not so with the transistor. If it is pushed well beyond its ratings in any respect even momentarily, it just quits in less time than a human hand could possibly take corrective action. Usually there is no flash, no red glow, no puff of smoke, not even a little "pop"—the transistor just dies, in silent protest against the intolerable conditions imposed upon it. Broadcasters need not fear transistors for this reason but should use appropriate caution when poking around in "hot" transistor circuits.

THE TRANSISTOR AS A RELATIVE OF THE DIODE

The transistor is a very close relative of the familiar semiconductor or "crystal" diode. A diode is formed at the junction between two electrically dissimilar materials when they have the property of conducting freely in one direction but not the other. In most practical diodes, the basic material is usually highly refined germanium, but minute quantities of impurities are added to control its electrical properties. Germanium which has been "doped" properly to serve as the anode of diode junction is called "*p*-type" germanium, and germanium doped to function properly as a cathode is called "*n*-type" (*p* and *n* stand for ***positive*** and ***negative***, respectively). When the *p* side of a junction diode is connected to the positive terminal of a battery, the diode conducts freely and behaves like a relatively low impedance (commonly about 50 ohms). When the battery is connected in the reverse direction, however, the current flow is impeded, and the device appears to have an impedance of the order of 100,000 ohms or more.

A junction transistor consists, in essence, of two diode junctions in series, with the same very thin piece of *n*-type material shared by both diode junctions. The three elements of the transistor are connected to separate leads and are labeled *emitter, base,* and *collector,* as shown. In a few transistor types of symmetrical design, the emitter and collector have identical properties and can be freely interchanged, but in most transistors the collector junction has a larger area than the emitter junction, leading to differences in electrical characteristics.

In the majority of practical transistor circuits, the emitter junction is biased in the forward direction (i.e., in the direction of easy current flow) while the collector junction is biased in the reverse direction. If the transistor really behaved like two independent diodes in series, the operating currents would appear as shown in Fig. 1-4. The current through the reverse-biased collector would be very small compared with the emitter current, and the base current would be almost equal to the emitter current. Actually, the situation is almost the reverse (see Fig. 1-5). The forward-biased emitter draws current freely from its bias supply, but instead of flowing down through the base, the great majority of this current flows straight through to the collector (where its flow is aided by the added "push" of the collector supply battery). In a typical transistor, only about 2 per cent of the emitter current will appear in the base lead. This apparently strange behavior is the very key to transistor action. As noted earlier, it is vitally important that the emitter and collector junctions are very close to each other (on a microscopic scale) and that they share the same base material. While a complete description of the action which takes place in a transistor is beyond the scope of this material, the matter can be covered superficially by the statement that the current-flowing activity in the emitter junction so alters the characteristic of the immediately adjacent collector junction that it is able to pass the emitter current rather freely. Of great significance is the fact that a deliberate change in either the emitter current or the base current will cause the same *percentage* change in the collector current. Considerable gain is made possible by the fact that a change in the relatively small base current can control the much larger collector current.

The foregoing figures indicate that a transistor, in its simplest form, may be thought of as a "sandwich" of *n*-type "meat" and *p*-type "bread." When constructed in this manner, it is called a *p-n-p* transistor. However, perfectly good transistors can be constructed by reversing the "bread" and the "meat," as shown in Fig. 1-6.

This arrangement is known as an *n-p-n* transistor. The major difference between the two types lies in the fact that the various voltages applied to a *p-n-p* transistor must be reversed for an *n-p-n* transistor.

In schematic diagrams, *n-p-n* and *p-n-p* transistors are identified by the contrasting symbols shown in Fig. 1-7. In both cases, the element symbolized by the arrowhead is the emitter, and the direction of the arrowhead indicates the direction of easy current flow.

THE TRANSISTOR AS A RELATIVE OF THE VACUUM TUBE

The transistor, being an amplifying device, bears a resemblance to the vacuum tube in that the three "elements" of a transistor correspond (approximately) to the three elements of a vacuum tube. Equivalent functions are performed, for example, by the vacuum-tube cathode and the transistor emitter. The same may be said for the base and the grid and the collector and the plate, respectively. These equivalences can be used to produce the equivalent symbols shown in Fig. 1-8.

One should not infer, however, that these equivalences are anything but approximate. For example, consider the difference between a grid and a base. A grid, in normal negative-biased operation, draws no current. The total cathode current flows in the plate circuit as indicated in Fig. 1-9. It was stated above, however, that the emitter current in a transistor divides between the collector and the base, so that the base has an appreciable current flowing in it as shown in Fig. 1-10. Since the current that flows (for a given voltage) is an indication of the impedance of a circuit, the fact that the base draws current while a grid does not leads to the conclusion that the impedance seen looking into a base would be very much smaller

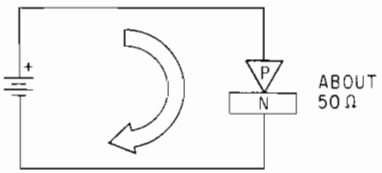

FIG. 1-1. Simple conducting diode circuit with p and n appropriately connected to a battery.

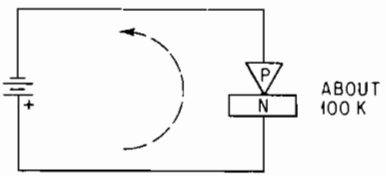

FIG. 1-2. Reverse connected transistor exhibiting high impedance to the current flow.

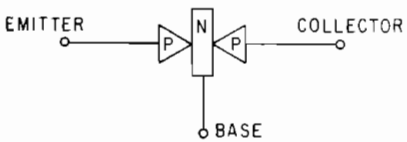

FIG. 1-3. A junction transistor.

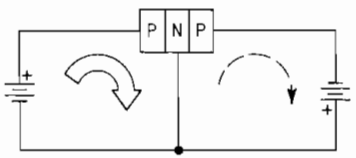

FIG. 1-4

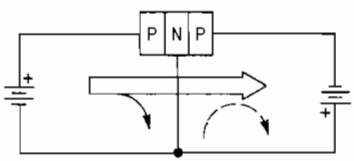

FIG. 1-5

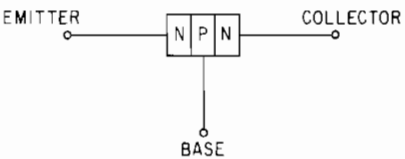

FIG. 1-6

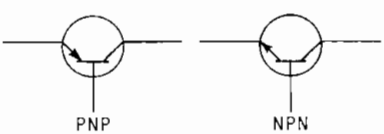

FIG. 1-7

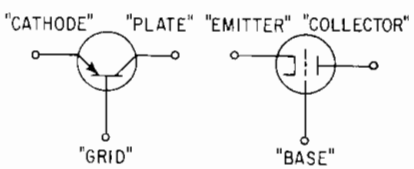

FIG. 1-8. Equivalent symbols for transistor and three-element vacuum tube.

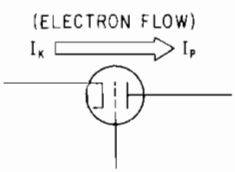

FIG. 1-9. Electron flow in vacuum tube.

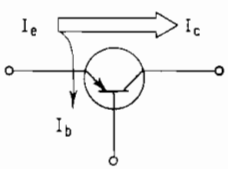

FIG. 1-10

than the impedance seen looking into a grid. The conclusion is correct: a typical vacuum tube, it is well known, has a grid impedance of several megohms, while a typical transistor may have a base impedance of less than 2,000 ohms.

Definitions of Alpha (α) and Beta (β)

Two transistor parameters that have an importance in transistor circuits comparable to the importance of transconductance (g_m) and amplification factor (μ) in tube circuits are those designated *alpha* and *beta*.

Alpha is the ratio of the collector current to the emitter current and is typically of the order of 0.98 for small transistors at low frequencies. Alpha is always less than unity and indicates the current-gain capabilities of the transistor when operated as a common-base amplifier. (The common-base circuit configuration will be described presently.)

Beta is the ratio of the collector current to the base current and is related to alpha by the expression, $\beta = \alpha/(1 - \alpha)$. For a typical small transistor with $\alpha = 0.98$, $\beta = 0.98/0.02$, or 49. Beta indicates, in a general way, the current-gain capabilities of a transistor in the common-emitter configuration to be described presently.

Unless indicated otherwise, α and β describe the behavior of a transistor for small signal-current swings at low frequency around the no-signal operating point; values for α and β determined by d-c measurements alone may differ somewhat from the a-c or signal values. Both α and β tend to decrease with frequency. The alpha and beta cutoff frequencies commonly listed in transistor specification sheets represent the frequencies at which α and β, respectively, decrease to 70.7 per cent of their low-frequency values. In general, β decreases much more rapidly with frequency than does α.

The Three Basic Circuit Configurations

As in the case of tubes, transistors can be used in a wide variety of circuits, designed to function as amplifiers, oscillators, clippers, modulators, regulators, dividers, and other specialized devices. There are, however, three basic circuit configurations which are encountered very frequently and which should be mastered by the transistor

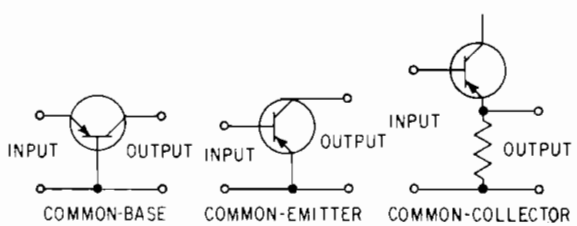

FIG. 1-11

novice as a prerequisite for understanding the more complex configurations. Within the limited scope of this part, we can examine the three basic configurations only in the relatively simple forms in which they are found in straightforward amplifier service.

The three basic circuit configurations are usually designated common-base, common-emitter, and common-collector and are symbolized in simplified form in Fig. 1-11. These three basic configurations are superficially equivalent to the vacuum-tube configurations commonly known as grounded-grid, ground-cathode, and cathode-follower, respectively.

Transistors are similar to tubes in that certain power-supply voltages (or currents) must be applied to establish reasonable operating conditions before the devices can handle signal voltages or currents in a useful fashion. As noted earlier, the great

majority of practical transistor circuits involves a *forward* bias (in the direction of easy current flow) in the emitter junction and a *reverse* bias in the collector junction. The voltages required for transistor circuits are relatively low compared with those employed for tubes. In many transistorized devices, the highest voltage encountered is only about 20 volts. The fact that transistors require no special supplies or wiring for heaters is a definite advantage which helps to keep transistor circuits simple and compact.

Instead of describing each basic circuit configuration in detail before going on to the next, we shall discuss in parallel the major aspects of all three types, so that their differences will be more readily apparent. We shall begin by considering typical input and output impedances. Then we shall continue by describing practical bias arrangements and conclude this section of the part by examining typical behavior for a-c signals. For the sake of simplicity, we shall consider only *p-n-p* transistors and shall confine our attention to low-frequency behavior. For the practical illustrations, we shall assume the use of a single transistor type with reasonably typical values of α, β, input impedance, and outpnt impedance. We shall also assume that the same α and β values hold for both d-c and a-c conditions.

Typical Input and Output Impedance

The broadcaster who is only mildly interested in the principles of semiconductor physics which account for transistor behavior will often find it helpful to think of transistors in terms of the equivalent impedances represented by the input and output circuits, just as he has found it helpful to think of diodes as equivalent to either very low or relatively high resistances, depending upon whether the diode is forward-

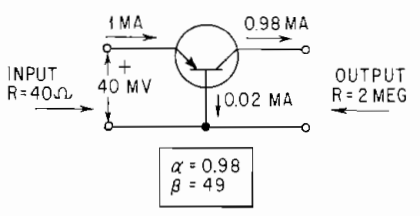

FIG. 1-12

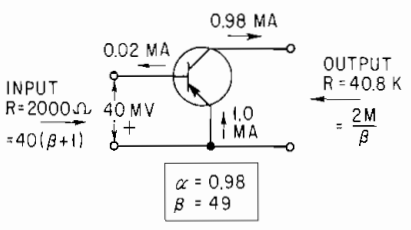

FIG. 1-13

biased or reverse-biased. For the present discussion, we shall assume that practical bias arrangements have been provided to keep the emitter junction in a freely conducting condition and the collector junction in a reverse-biased condition.

Typical input and output impedances are easiest to visualize in the case of common-base circuits, where the forward-biased emitter appears as the equivalent of about 40 ohms (in a typical case) and the reverse-biased collector appears as about 2 megohms as shown in Fig. 1-12. The voltages and currents shown represent small *changes* superimposed on the steady-state bias conditions. The very high output impedance implies that the operating currents are quite independent of the collector voltage. Even a wide change in collector voltage would cause very little change in the collector current. A voltage change of only 40 mv on the emitter, however, would cause a 1-ma change in the emitter current, leading in turn to current changes of 0.98 and 0.02 ma in the collector and base, respectively.

If the very same transistor is operated in a common-emitter circuit, however, the input and output impedances are substantially altered, as shown in Fig. 1-13.

In this case, as before, a 40-mv change in the base-to-emitter voltage results in current changes of 1.0, 0.98, and 0.02 ma in the emitter, collector, and base, respectively, but the resistance looking into the base is $E/I = 40/0.02 = 2{,}000$ ohms. Note that this is exactly $(\beta + 1)$ times greater than the resistance looking into the emitter, by virtue of the fact that the emitter current is $(\beta + 1)$ times greater than the base

current. The output impedance is reduced by a factor of β relative to the output impedance of the same transistor in a common-base configuration. This reduction occurs by virtue of the fact that the very small reverse-bias current that flows as a result of the collector supply voltage (normally negligible when superimposed on the much larger current flowing into the collector as a result of the forward bias in the emitter-to-base junction) is also drawn through the emitter-to-base junction, resulting in its amplification by a factor of β. Hence, a given voltage change on the collector of a common-emitter stage will cause a collector current change β times as great as in the case of a common-base circuit.

When the same transistor is used in a common-collector circuit (often called an *emitter follower* because of its similarity to the cathode follower), the input and output impedances are both significantly influenced by the value of the load resistor. Let us consider the case where the load resistor has the reasonably typical value of 2,000 ohms (see Fig. 1-14). The collector, in this case, must be connected to a

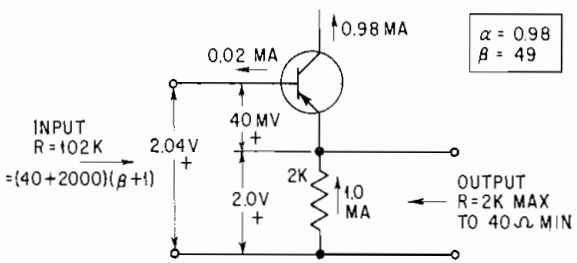

FIG. 1-14

source of suitable supply voltage but does not directly influence the circuit behavior. As in the two previous cases, it still requires a 40-mv change in the base-to-emitter voltage to cause current changes of 1.0, 0.98, and 0.02 ma in the emitter, collector, and base, respectively. Because of the inherent feedback resulting from the presence of emitter resistor, however, the *input* voltage must be changed by 2.04 volts to realize a 40-mv change in the base-to-emitter voltage. By Ohm's law, the input resistance is $E/I = 2{,}040/0.02 = 102{,}000$ ohms. Note that this is $(\beta + 1)$ times greater than the sum of the load resistance and common-base emitter resistance of the transistor itself. If the external resistance in the base circuit is very high, the output impedance of the emitter follower is nominally equivalent to the load resistance. If, however, the base is driven from a very low-impedance source, the IK load resistance is shunted, as far as the output is concerned, by the emitter-to-base resistance of the transistor itself, and thus the output impedance may fall to slightly less than 40 ohms.

Practical Bias Arrangements

Let us now consider the problem of providing practical biasing arrangements to achieve reasonable d-c operating conditions. For the sake of consistency in our practical illustrations, let us assume that we are to handle fluctuating *emitter* currents on the order of 1 ma peak-to-peak. To achieve reasonable linearity, we must arrange conditions so that the direct emitter current at the zero-signal operating point is of the order of 2 ma. We must also see that the collector always remains at least a few volts negative relative to the base to assure a proper reverse-bias condition. Let us assume that we have stabilized sources at +20 and −20 volts available. (These are reasonably typical values for transistorized circuits.)

The simplest bias arrangements for common-base circuits are quite straightforward, consisting of the collector load resistor plus an emitter bias resistor as shown in Fig. 1-15. Since the emitter input resistance of only 40 ohms is negligible in series with the 10K bias resistor, the emitter bias current is determined by dividing the bias

supply voltage (20) by the resistance (10K), giving 2 ma. If the transistor has a d-c α of 0.98, the collector current is 1.96 ma and the collector voltage is equal to the supply voltage (−20) less the drop across the load resistor (9.8 volts), giving −10.2 volts. The actual value of the load resistor is normally determined more by considerations of gain or bandwidth than by bias considerations.

Unfortunately, the simplest type of bias arrangement for the common-emitter configuration is a very poor one for practical amplifier circuits, but it is worth reviewing as an illustration of several aspects of transistor behavior. This simple, though impractical, bias arrangement requires only two resistors and a single voltage source as shown in Fig. 1-16. Since the 2,000-ohm imput resistance looking into the base of the transistor is negligible in series with the 500K bias resistor, the nominal bias current is determined by dividing the supply voltage (−20 volts) by the bias resistance (500K), giving 0.04 ma in the direction indicated. The collector current is β times as great, or 1.96 ma, and the collector voltage is determined by subtracting the drop across the load resistor from the supply voltage.

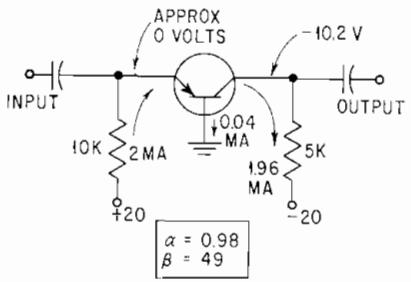

FIG. 1-15

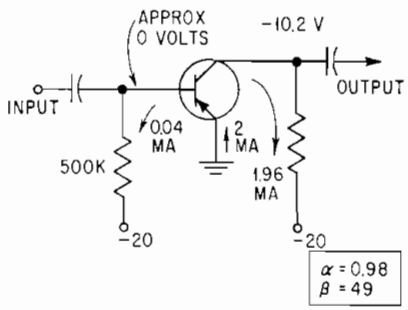

FIG. 1-16

The two major deficiencies of this simple but impractical bias arrangement are: (1) It is unduly sensitive to variations in the β of the transistor, and (2) its operating point tends to vary excessively with temperature. When the α of a transistor falls from 0.98 to 0.97 (causing only a slight variation in the performance characteristics of a common-base circuit), the β falls from $\frac{98}{2} = 49$ to $\frac{97}{3} = 32.3$, a change of almost 35 per cent! This change would seriously affect both the d-c operating point and the a-c gain of the simple common-emitter circuit in Fig. 1-16. The temperature sensitivity of the circuit results from the fact that substantially all the reverse-bias current (i.e., the current that flows through the collector diode even when the emitter is open) must pass through the emitter-to-base junction, where it becomes subject to the current-amplifying action of the transistor. This current varies exponentially with temperature and may become large enough to cause a significant shift in the d-c operating point.

The usual approach to the stabilization of a common-emitter circuit to avoid these problems involves (1) lowering the external impedance of the base circuit and (2) raising the external impedance (at least for direct current) in the emitter circuit. It is interesting to note that these actions make the circuit behave more nearly like the common-base circuit described earlier, which is a very stable circuit. A practical arrangement is shown in Fig. 1-17. Because of the 2,000-ohm emitter resistance, the d-c resistance looking into the base of the transistor is 102,000 ohms, just as in the case of Fig. 1-14. This high resistance is negligible when shunted across 2,000 ohms, so the current in the voltage divider in the base circuit is nominally equivalent to the supply voltage (−20) divided by the total resistance (10K), or 2 ma. The voltage on the base is therefore approximately −4 volts. Because the voltage drop across the forward-biased emitter-to-base junction is negligible, the voltage at the emitter must also be about −4 volts, implying that 2 ma must be flowing through the 2K emitter

resistor. If the α and β of the transistor are 0.98 and 49, respectively, the collector and base currents must be 1.96 and 0.04 ma, respectively. The collector voltage is determined by subtracting the drop across the load resistor from the supply voltage.

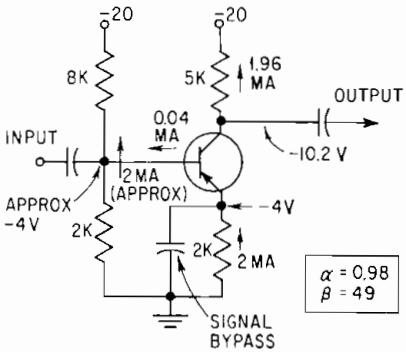

FIG. 1-17

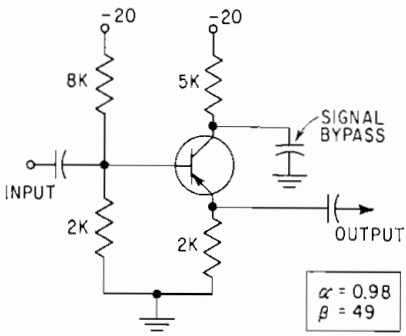

FIG. 1-18

For a rigorous analysis, the small 0.04-ma base current should be taken into account in the determination of the actual voltage on the base, but since it is only 2 per cent of the nominal current in the bias network, it can safely be ignored for a practical, approximate analysis.

This practical version of a common-emitter circuit provides less current gain than its simpler counterpart and also has a lower input impedance because of the shunting effect of the bias network in the base circuit. These handicaps are outweighed, however, by the greatly reduced temperature sensitivity and decreased dependence on β. Reasonable current gains can still be achieved (as will be shown later) provided the emitter resistor is bypassed to avoid the inverse feedback that would otherwise result.

A practical version of a common-collector circuit (or emitter follower) can be obtained by nsing exactly the same circuit constants shown in Fig. 1-17, except that the bypass capacitor should be moved to the collector circuit and the output taken from the emitter (see Fig. 1-18). If the same transistor type is used, the d-c operating conditions are exactly the same as in the preceding example and the analysis need not be repeated. The only function of the bypassed resistor in the collector circuit is to reduce the collector dissipation by decreasing the effective supply voltage. In many practical circuits, the collector resistance and its associated bypass capacitor would not be needed. Because a reasonable degree of stabilization is provided by the load resistor in the emitter circuit, the impedance of the bias network in the base circuit could safely be increased in many practical applications where a higher input impedance is required, but this action would tend to make the circuit increasingly sensitive to temperature.

LOW-FREQUENCY PERFORMANCE OF TYPICAL PRACTICAL CIRCUITS

In considering the performance of a practical transistor circuit for low-frequency a-c signals, it is necessary to take into account the source impedance of the preceding stage, because the input impedances of transistor circuits are generally so low that their loading effects on the preceding stages cannot be ignored (as in the case of tubes). Keeping this factor in mind, let us examine the low-frequency performance characteristics of the practical circuits previously described.

The *current gain* of a common-base amplifier is always less than unity, because some of the input signal current is always lost in the base, but the voltage gain may be quite appreciable if the load resistance is much larger than the input resistance of the circuit, as in Fig. 1-19. This figure illustrates the basic performance characteristics

of common-base amplifiers, which can be summarized as follows: (1) low input impedance, nominally equal to the input impedance of the transistor alone; (2) relatively high output impedance, nominally equal to the load resistance; (3) no polarity inversion; (4) current gain only slightly less than unity; and (5) the possibility of considerable voltage gain, approximately equal to the ratio of the output impedance to the input impedance. It is interesting to note, however, that it does no good to cascade two or more common-base amplifiers if voltage gain is the objective—the voltage gain in each stage is effectively canceled by the loading effect of the following stage unless an impedance-matching transformer is used.

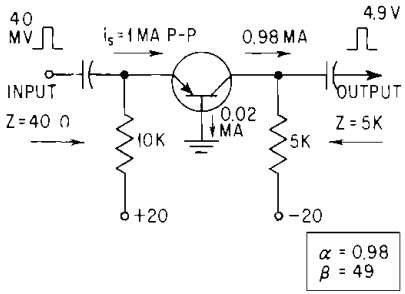

FIG. 1-19

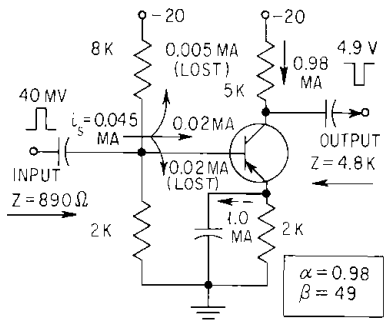

FIG. 1-20

The performance characteristics of a practical common-emitter circuit are illustrated in Fig. 1-20. In summary form, the key features of this circuit are (1) a current gain of about 22, which is less than the β of the transistor primarily because of the loading effect of the base bias network; (2) a voltage gain of about 122, assuming that the output is not loaded down appreciably by the following stage; (3) a reversal in the polarity of the signal; (4) an input impedance appreciably higher than that of a common-base amplifier but considerably lower than the 2,000-ohm input impedance of the transistor alone because of the loading effect of the base bias network; (5) an output impedance that is slightly less than value of the load resistor because of the shunting effect of the output impedance of the transistor itself. The shunting impedance is somewhat higher than the 40,000 ohms indicated in Fig. 1-13, because not all the reverse-bias current that is involved in the determination of the output impedance of the transistor is drawn through the emitter-to-base junction in this practical circuit—some of it is drawn directly from the base bias network. The output impedance of the transistor alone turns out to be the order of 200,000 ohms in this case, which is intermediate between the 2 megohms expected of a common-base circuit and the 40 kilohms expected of a common-emitter circuit with very high impedance in the base lead. It should be noted that the analysis performed here is only approximate, based on several simplifying assumptions, but the characteristics indicated should hold within about 5 per cent.

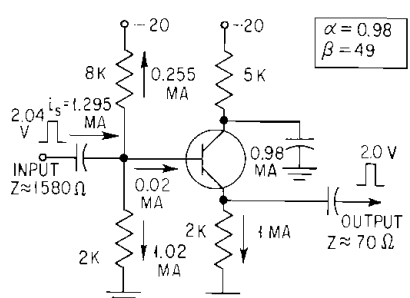

FIG. 1-21

The common-emitter configuration finds wide applications where either current gain or voltage gain is required. In general, it provides more gain than the common-base configuration, but its frequency response for a given transistor type is more severely limited.

As shown in Fig. 1-21, the common-collector circuit behaves very much like a conventional cathode follower. The important characteristics of this circuit are (1) a voltage gain only slightly less than unity, (2) a current gain slightly less than unity (This is not necessarily typical of emitter followers, but results from the use of relatively low bias resistors. Note that the current gain of the transistor itself is +1, a value which could be approached in the complete circuit by the use of very high bias resistors, at some sacrifice in temperature stability), (3) no polarity inversion, (4) a moderately high input impedance, and (5) a relatively low output impedance, consisting of the output impedance of the transistor shunted by the load resistor. The impedance characteristics of this circuit could be changed substantially by altering the bias network. For example, if the two resistors in the base circuit were increased 10 times to 80K and 20K, the input impedance would become about 13,800 ohms, the output impedance would go up to about 305 ohms, and the current gain would go up appreciably.

HANDLING HINTS AND PRECAUTIONS

We hope that we have succeeded thus far in introducing the transistor as a potential friend and ally of the broadcaster. As in the case of any good friend, the transistor has a right to be treated with a reasonable degree of consideration and respect. The rules of etiquette when dealing with transistors are really quite simple and should not interfere with the smooth working of the broadcaster-transistor team.

The most important rule to remember is that the transistor is a tiny little fellow with little capacity to absorb heat. He does his best work when kept cool and commits suicide in protest when his junction temperature is raised above a safe limit. He appreciates the delicate touch of a pencil-type soldering iron, applied only sparingly to his leads. A big 200-watt bruiser can make him very unhappy, even if it is only held near his case. It's a good idea to use a transformer-type soldering iron, because many 110-volt types pass enough leakage current through their tips to damage a small transistor.

There are many potential hazards in the servicing of electronic equipment that can cause a transistor to fail, usually from a momentary thermal overstress. In the case of equipment employing socket-mounted transistors, it is important to remember that, unlike tubes, transistors can easily be inserted in their sockets the wrong way, possibly resulting in the application of excessive voltages. A few minutes spent in gaining familiarity with transistor basing arrangements and socket connections will pay big dividends in avoiding frustrating accidents. It is wise to adopt the general rule that power should always be removed before inserting or removing a transistor from its socket. A brand-new transistor may lay down its life in vain if it is expected to absorb a charging surge for a capacitor or if its bias is suddenly altered by the removal of a circuit mate in an adjacent socket. If the broadcaster finds it absolutely necessary to poke around in a "hot" transistor circuit, he would do well to use well-insulated test prods and miniature test leads. As noted earlier, a transistor gives no visible or audible warning when it has become the victim of an accidental short circuit—it just doesn't feel like working any more.

One of the attractive features of transistors is the ease with which they can be tested, at least superficially, with an ordinary ohmmeter. It is important, however, that only the $R \times 10$ or higher scale be used. The $R \times 1$ scale on most ohmmeters can deliver enough power through the test leads to destroy a small transistor. Resistance measurements between emitter-base and collector-base pairs should both show a very low resistance in one direction and a relatively high resistance in the other; that is, the test should indicate that there is an active diode between either of these pairs. The direction of easy current flow (low resistance) depends upon whether the transistor is of the *p-n-p* or *n-p-n* type. Resistance measurements between the emitter and collector leads should always indicate a high resistance in both directions. If a transistor passes all these ohmmeter tests, chances are very good that it is an operable unit.

The authors hope that those broadcasters who have first become acquainted with transistors through this part will enjoy a long and happy association with them.

Further information can be obtained from An Introduction to Junction Transistors by R. N. Hurst, appearing in the October, 1958, issue of *Broadcast News*. We wish to acknowledge the generous and constructive assistance of Mr. Arch C. Luther, Jr., in the preparation of this material.

Part 2

SUBSIDIARY MULTIPLEX SERVICE FOR FM BROADCAST STATIONS

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FM MULTIPLEXING †

A unique form of broadcasting is now in use that enables the FM broadcaster to enhance his income. By a process known as multiplexing, additional program channels are transmitted on the same carrier that serves the general public. By specific authorization of the Commission, these "closed-circuit" channels can be used for such purposes as transmitting background music or commercials to stores. The purpose of this portion of the part is to describe the technical processes and equipment required to make possible this method of broadcasting.

General System

In order to multiplex, a high-pitch or supersonic tone is transmitted along with the regular program heard by the public. In other words, a high-pitch tone far beyond the range of the human ear is generated and sent into the transmitter. The pitch, or frequency, of this tone will be between 20,000 and 75,000 cps as compared with the regular main-channel audio that lies between 50 and 15,000 cps. This supersonic tone, in turn, is "modulated" with the desired audio and at the receiving end is filtered from the main-channel audio and in turn "detected." Thus, special receivers will hear the information transmitted on the so-called "subcarrier" and the general public will be unaware of its existence.

The high-pitch tone called the subcarrier is in turn modulated with program information by a frequency-modulation method. We now have an FM-on-FM system where a frequency-modulated supersonic tone is in turn frequency-modulating the signal transmitted by the station along with the regular program material heard on the regular FM receiver.

* No longer employed in this capacity.
† By Dwight Harkins.

Since AM broadcast transmitters and bandwidth allocated would not permit the transmission of these supersonic tones, multiplexing is available to broadcasters in the FM band from 88 to 108 Mc.[1] Each station is allocated sufficient bandwidth to permit transmission of the complex signals generated without causing interference.

At the present development of the art, two supersonic tones or subcarriers are being transmitted in addition to the regular audio below 15 kc. This allows a single transmitter to broadcast three separate programs at the same time. The Federal Communications Commission will grant authorization for a Subsidiary Communication Authorization permitting the FM broadcaster to use these multiplex channels for such purposes as storecasting, functional music, and similar closed-circuit uses where the listener must subscribe to the service. The function of the station as a broadcast service to the public is not changed.

Although FM is well known to be capable of broadcasting audio frequencies up to 15,000 cps with low distortion and noise, the system must now faithfully transmit and receive up to 75,000 cps in order to permit successful multiplexing.

In both the transmitting system and at the receiver certain techniques must be used to prevent intermodulation taking place. The first type of intermodulation or cross modulation is that caused by the regular program audio modulating the transmitter in the range of 30 to 15,000 cps. This undesired intermodulation shows up as cross talk of the main-channel program breaking through into the subcarriers. This occurs both in the transmitting end and at the receiver.

The second type of intermodulation is that caused by noise pulses. The FM method of transmission has been long considered noise- and static-free through the use of limiters in the receiver. For normal FM broadcast reception this has been adequate. When a noise pulse actually phase-modulates the supersonic subcarrier, however, this noise cannot be removed by amplitude limiting or any other known method of reception technique. If the multiplex channels are to be received as well as the main channel, all parts of the system must be designed to prevent intermodulation or phase modulation by noise pulses. When this has been accomplished, reception of the subcarriers can be realized throughout the same coverage area served by the regular FM broadcast service.

Figure 2-1 shows a block diagram of the transmitting and receiving process. The equipment needs for an over-all system consist of an exciter, a subcarrier generator, a station multiplex monitor, and the receiver. Each of these will be described in detail. Before the individual sections of the over-all multiplex system are described, the problem of cross talk, intermodulation, or cross modulation that is common to all parts of the system will first be discussed.

Causes of Cross Talk

To understand better the cross-talk problem and its cure, an examination of basic FM theory must be made. As the transmitted carrier is modulated, the energy is divided up into additional carriers known as sidebands. In comparing FM with AM, it can be shown that the AM carrier develops an upper and lower sideband of energy directly related to the audio frequency being transmitted. The total power being transmitted varies directly with the modulation and is not constant. One hundred per cent modulation in the case of AM is considered that point where the audio wave has caused the AM carrier to go to zero instantaneously on one half the cycle and to twice carrier amplitude on the other half of the audio cycle. Modulation beyond the 100 per cent point causes severe distortion, since the carrier voltage is doubled on the upward swing of AM and the radiated power is the square of this or four times. The energy of the additional power radiated by the AM transmitter is to be found in the sidebands generated from the audio introduced into the modulation system. With a sine-wave audio signal modulating an AM transmitter 100 per cent, the average power output will be found to be 1½ times that of the unmodulated carrier.

The pair of sidebands above and below center carrier in the AM case are found to be 180° out of phase with each other.

[1] 88 to 92 Mc allocated to educational stations.

In the FM case, radically different conditions exist. *First,* as the audio modulates the carrier by causing it to shift in frequency, the total power radiated is unchanged. *Second,* the carrier power is divided into many sidebands above and below unmodulated carrier in frequency. *Third,* the energy in the sidebands represents a portion of the center carrier power. *Four,* the individual upper and lower sidebands created are 90° out of phase with each other. *Five,* under certain conditions the total carrier power is divided up among the sidebands and the carrier is absent. *Six,* the position and amplitudes of the sidebands is a direct relation between modulation frequency and amount of carrier shift in frequency. This is known as the modulation

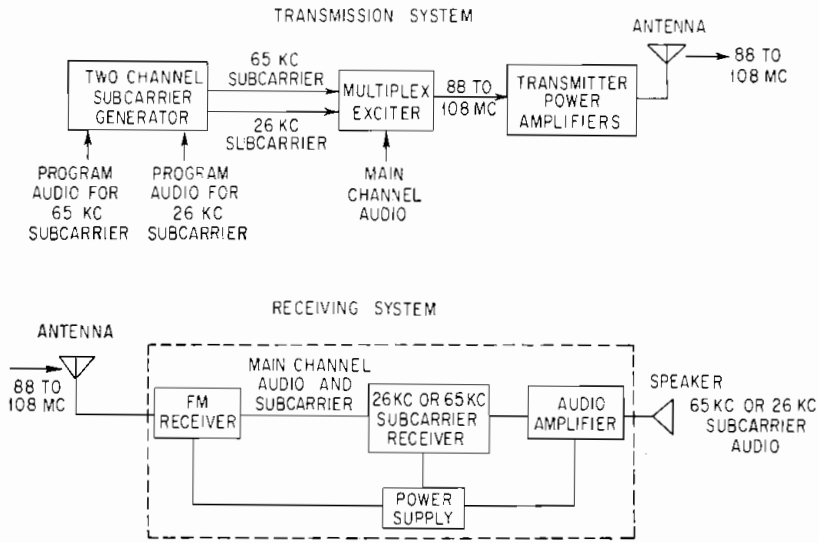

FIG. 2-1. Block diagram of transmitting and receiving process.

index and is determined by dividing the amount of carrier deviation by the modulating frequency. *Seven,* the point of 100 per cent modulation is established in the FM system by system standards rather than limitation of the process. For example, 75-kc deviation is considered 100 per cent for the FM broadcast band, while 25-kc deviation is considered 100 per cent for the TV aural transmission. FM microwave units will deviate several megacycles with ease.

It is seen at this point that the FM signal is much more complex than the AM wave. For example, a 1,000-cycle tone modulating the FM rig 100 per cent would produce several hundred sidebands above and several hundred below the center carrier. The streugth of each sideband can be computed mathematically and easily tuned in and measured individually with the proper equipment. Those sidebands that fall more than 75 kc above and below center carrier are usually considered insignificant for undistorted reception of the audio signals between 30 and 15,000 cps in the case of the FM broadcast transmitter.

Since we are now dealing with a complex signal occupying quite a bit of space above and below carrier, we must reckon with the bandwidth of the system in order to allow all the desired components to reach the point of detection.

For example, in the AM case, a bandwidth in the system of 10 kc would accommodate the upper and lower sidebands from a 5,000-cps audio signal modulating the transmitter 100 per cent. In the FM case, a bandwidth of 150 kc would be called for to accommodate the upper and lower sidebands created by the same modulation. Even with a bandwidth of 150 kc there would be a small percentage of the generated sidebands that did not get through.

The term "bandwidth" is used to describe the ability of a tuned circuit, transformer, antenna, or any device used in the transmitting and receiving system to pass a certain "band" of frequencies instead of just one single frequency. For example, a circuit that permits equal passage of frequencies from 1,000 to 1,100 kc and rejects all others would be said to have a bandwidth of 100 kc. For many years, the FM receivers sold to the public have been built with IF bandwidths of 200 to 300 kc to ensure high-fidelity reception of the FM signal. Prior to multiplexing, the highest audio frequency desired to be passed was 15,000 cps. Prior to multiplexing, the measuring stick for successful FM broadcasting consisted of low harmonic distortion, low residual noise, and flat frequency response in the audio range. Measurements of intermodulatiou distortion were never taken or required by the Commission. As a matter of fact, the intermodulation distortion between low and high audio frequencies was low enough that it was not considered a factor of performance. The intermodulation between a tone of 1,000 cps and one of 25,000 cps, however, was a horse of another color and was found to be on the order of 5 to 10 per cent at the receiver. This was especially discouraging to multiplexing, as the intermodulation showed up in the supersonic tone as a phase-modulated component of the lower audio tone.

The causes of cross talk can be generalized by referring to the basic FM theory outlined. It was pointed out that the FM signal consisted of many sidebands which are found to be 90° out of phase when any pair above and below the carrier center is compared. It can uow be stated that any part of the transmitting or receiving system that either restricts the passage of the sidebands or alters the phase relationship of the sidebands will cause cross talk. The observed result in either case is the same. With either narrow bandwidth or phase distortion the FM carrier develops an amplitude-modulation component. Its amplitude varies with modulation. The existence of a combination AM and FM signal is easily ascertained with relatively simple measuriug equipment. The limiting action of Class C stages of the transmitter coupled with the receiver limiter tend to "whitewash" the apparent AM component, but even though limited out, a remaining phase intermodulation makes multiplexing unsuccessful.

This last statement is best understood by recalling the early days of AM broadcasting when it was found that frequency modulation was an unwanted byproduct of amplitude modulation. It is to be remembered that one of the original methods of obtaining phase modulation consisted of first creating an amplitude-modulated wave, then clipping out the AM components or balancing them out and proceeding to use the residual phase shifts produced as the basis for multiplying into an FM signal.

If the audio modulating the FM transmitter produces an AM component anywhere in the system from start to finish, the result is cross talk into the subcarriers. With this basic fact established, the individual components of the system will be described with pointers showing how the pitfalls of multiplexing are avoided.

The Exciter

All existing FM transmitters have one function in common. All of them produce the modulation at a relatively low frequency and then by means of multipliers arrive at the transmitting frequency in the 88- to 108-Mc region. By process of multiplication, the amount of deviation is increased directly by the factor of these stages. In the transmitters using reactance-tube modulators the multiplication is on the order of 11 to 16 times, while in the transmitters using phase modulation, or "indirect FM," the multiplication is from 400 to 1,000 times in various units.

Early in the experiments toward multiplexing, it was discovered that the simple process of introducing the supersonic subcarrier along with the regular audio was impractical owing to the bandwidth restrictions of the lower frequency multiplier stages. It was found that a secondary modulation stage higher in the multiplication stages would be best for subcarrier injection and that a low-distortion and low-noise-modulation system must be used for the main channel.

Meeting all requirements for the main chaunel was the system known as the Serrasoid, developed by J. R. Day (*Electronics*, October, 1948). The Serrasoid has proved

itself to be reliable, with extremely low distortion and noise along with excellent linearity of frequency response. It also enables direct crystal control of the center frequency of the station. As incorporated in the multiplex exciter, the output of the Serrasoid is multiplied 972 times to make possible the necessary deviation of plus or minus 75 kc at the output frequency.

Figure 2-2 illustrates the schematic of the Serrasoid section. *V*1 is a crystal oscillator functioning in the 100-kc range and chosen so that its frequency multiplied by 972 arrives at the assigned frequency of the station in the FM band. The oscillations of the crystal are converted into positive pulses by *V*2. These pulses are applied to *V*3, both halves of which make up a nonoscillatory sawtooth generator and bootstrap cathode follower, timed to allow a linear sawtooth wave to be developed upon the application of each input pulse.

The linear sawtooth waves thus generated at a recurring rate of approximately 100 kc are applied to the grid of *V*4, and the cathode resistor adjusted to a point where the grid bias created by plate current is such that conduction occurs when the sawtooth applied is about 50 per cent of its way up. Upon conduction, the balance of the sawtooth wave is clipped, and at the very instant the tube conducts, a negative pulse is observed on its plate. This is the most important event of the process, for it is by this means that the linear sawtooth can be utilized to produce a phase-modulated or frequency-modulated transmission.

If the cathode bias resistor on the left half of *V*4 is varied, it is easily shown on an oscilloscope that the negative pulse formed on the plate at time of tube conduction will vary its position either sooner or later in reference to the starting of the sawtooth. In other words, a conduction point lower or higher on the slope of the sawtooth causes the plate pulse to be formed in time position either sooner or later. If, instead of varying the conduction point by adjustment of the cathode potentiometer, an audio voltage was applied at this point, the plate pulses would be positioned by the audio voltage superimposed upon the cathode. At this time a system of pulse-position modulation has been developed or, to put it another way, the plate pulses are phase-modulated by the audio voltage determining the instantaneous conduction point of the tube.

The amount of phase shift possible with this circuit is on the order of plus or minus 150°. In actual application, only 90° of plus or minus 1½ radians is used as the basis for producing 100 per cent modulation at the output frequency after being multiplied 972 times. Since all systems of phase modulation deviate 6 db/octave more as the audio frequency is increased, it is apparent that the greatest excursions of the sawtooth clipping will occur at 50 cycles and that the familiar "predistortion" network must be applied to the audio signal in order to realize flat response required for frequency modulation. In addition to this, preemphasis must be inserted to allow the final product to meet the Commission's Standards for FM stations.

The two audio tubes and associated circuits not only provide a distortion- and noise-free audio signal for the cathode of the sawtooth modulator tube but also include the corrections in the response curve that are necessary.

Figure 2-3 shows waveforms resulting in the pulse-forming and modulation process just described. The phase-modulated negative pulses are inverted to positive-going pulses by the other triode section of *V*4. These positive pulses are applied to the grid of the first of a string of multipliers. In the first plate load, the resonant circuit converts the pulse into a frequency-modulated sine wave. After a series of multipliers being doublers and triplers a total factor of 972 yields a carrier in the FM band with a deviation capability considerably in excess of plus or minus 75 kc.

Probably the only deficiency of this system of modulation is that the fundamental crystal frequency is so low that it produces a component in the early multiplier stages that rides through to the final of the transmitter. For example, a station operating on 97.2 Mc would have a master crystal of 100 kc. This 100-kc component appears at the 300-kc stage and thereafter just as an unwanted subcarrier. In order to attenuate this unwanted 100-kc component better than 70 db, the arrangement of Fig. 2-4 was used at the first multiplier stages.

Referring to Fig. 2-4, *L*1 through *L*6 are tuned to 300 kc and then stagger-tuned

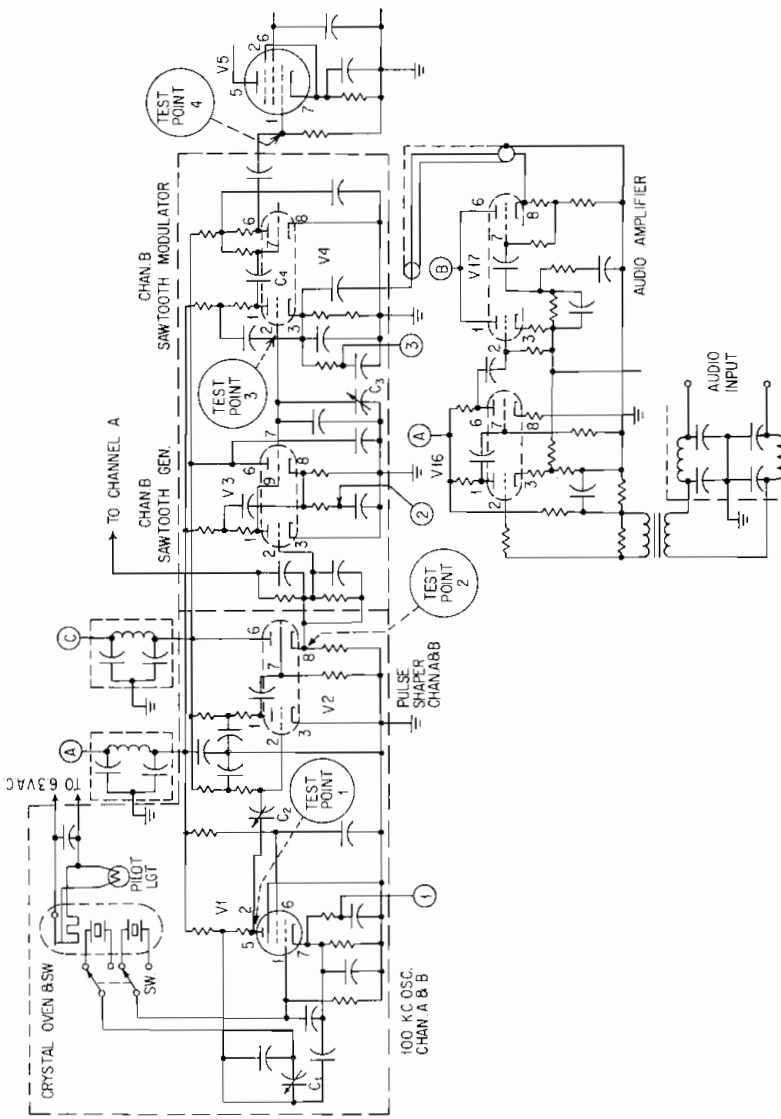

FIG. 2-2. Schematic diagram of Serrasoid modulator.

to produce a 30-kc bandpass. This is necessary in order to allow 15,000-cps audio modulation properly and at the same time to give better than a 70-db rejection of the 100-kc crystal component. This filter network further rejects unwanted noise and hiss products in the regions above 15 kc. If only an excellent FM transmitter were desired, we could let our development stop at this point. However, certain additional precautions must be taken in the multiplication process to make possible multi-

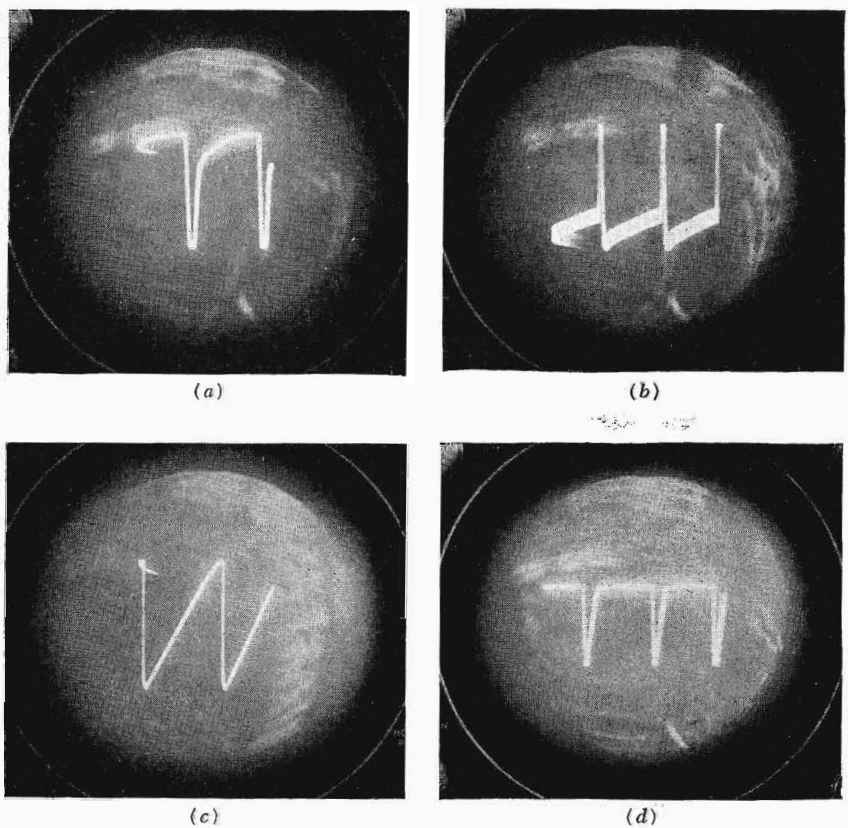

FIG. 2-3. Waveforms resulting from pulse-forming and modulation process. (*a*) At plate of *V*1. (*b*) At pin 2 of *V*3. (*c*) At test point 3 with full bias. (*d*) At test point 3 with cathode bias set for normal operation.

plexing. The circuits normally used for multipliers in FM transmitters have been found to have insufficient bandwidth as well as phase distortions whenever the carrier was modulated. A remedy was found in the use of interstage filters as shown in Fig. 2-5.

It will be seen in Fig. 2-5, that *L*1 and *L*3 make up the parallel-resonant circuit of the plate and grid and are coupled together at a low-impedance point by the series-tuned circuit. The circuit is tuned to have a passband of at least 500 kc.

As outlined earlier, phase distortion produces an AM component which, in turn, causes cross talk. When a signal passes through a stage such as the one under discussion, the circuit is to be measured not only in respect to amplitude vs. frequency but also by phase shift as the frequency changes. In any network or filter, the phase

shift is zero at a certain frequency, usually the center frequency of the filter. As the frequency goes above or below center, the phase shift changes but not always in exact ratio to the change in frequency. If, for example, the change in phase as the frequency is shifted higher is at a different rate from the change in phase as the frequency is lowered, we then have a nonlinear phase shift. In this case we want the positive phase shift to occur the same distance away from center frequency as the

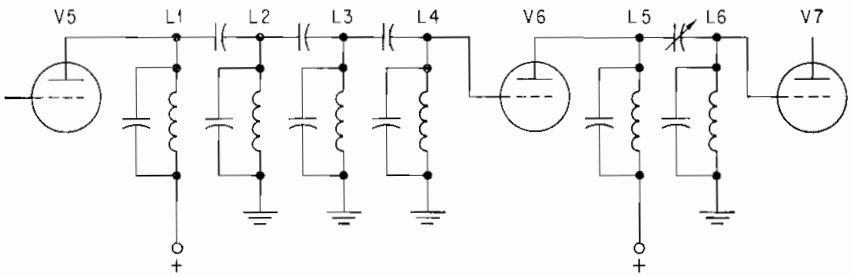

FIG. 2-4. 300-kc attenuation circuits in first-multiplier stages.

negative phase shift occurs on the other side of center frequency. A regularly tuned circuit has a relatively narrow range of linear phase shift.

The phase shift must be linear throughout the range of frequencies occupied by the many sidebands generated by the FM signal. When properly adjusted, no AM component can be detected resulting from the signal going through this multiplier stage. This form of interstage coupling is used in all the multipliers operating below 20 Mc. Above that frequency the desired linearity is obtained with overcoupled coils.

Thus far we have dealt only with obtaining the main-channel modulation and ensuring that it is treated correctly as it is being multiplied to operating frequency. At the 10-Mc level we are now going to add an additional phase modulator and inject the supersonic audio tones known as subcarriers. We desire a device that will phase-shift the carrier already on hand at this frequency and yet not cause any amplitude variation from either the supersonic tones to be added or the audio-modulation components already present from the earlier Serrasoid modulations. Such a device was found with the simple circuit of Fig. 2-6.

In this circuit, variation of the transconductance G_m of the tube has no effect on the magnitude of the output voltage. It will cause the phase of this voltage to vary over a total range of 180° as the transconductance varies from zero to infinity. The device does not have very good linearity because the relationship between the phase shift with change in transconductance and in turn in relation to the modulating voltage is not correlated. By "juggling" the balance of the three nonlinearities, it is easily possible to obtain a relationship between phase shift and the modulation voltages of the subcarriers that is linear over the limited range required. Because of the high frequency of the subcarriers relative to the audio frequencies the amount of phase shift required is in the order of only a few degrees. This tube offers no amplification to the carrier as it passes through to the next multiplier stage. Application of lower audio frequencies below 15,000 cps does not result in enough phase shift to be measured at the transmitter output.

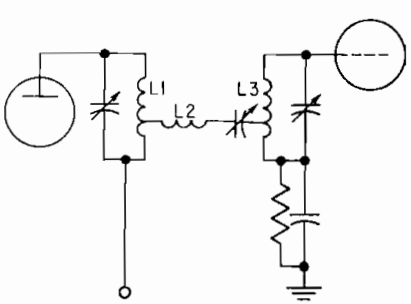

FIG. 2-5. Diagram of interstage filter.

If two subcarriers are injected, they are allowed to deviate the main channel 15 per cent each in accordance with the Commission's regulations.

After the subcarriers are injected, the signal goes through additional doublers and triplers until it reaches output carrier frequency. The exciter then delivers a signal of approximately 15 watts power at carrier frequency.

At this time, over-all measurements should be made, and if all circuits are functioning correctly, the main-channel proof-of-performance figures will be considerably better than the Commission's requirements and the subcarrier will have cross talk lower than 50 db below a reference obtained by 10-kc deviation at the same time that any audio frequency is modulating the main channel 100 per cent (75 kc).

The exciter can now be used to drive the power stage of the station's existing transmitter and the signal then radiated from the antenna. It is at this point that some unusual variations in results have been obtained in experience gained from over

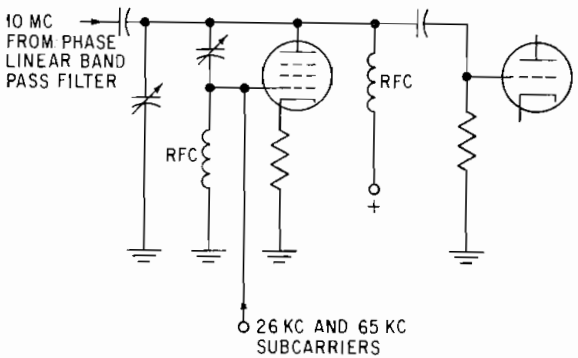

FIG. 2-6. Schematic of circuit to produce carrier phase shift with no amplitude variations.

50 installations around the country. In order to tune the equipment properly, a multiplex station monitor was developed. This device is a linear demodulator, making possible the detection of the entire signal and the further demodulation of the subcarrier. Direct measurements of cross talk are made possible, and transmitter tuning is done to find minimum cross talk. If necessary, the monitor can be coupled into the main transmitter at any point in order to isolate the stage in which the cross talk may be produced. In the transmitters which have been modified thus far, the most critical stages have been tetrodes and their neutralization adjustments. Coupling between stages has also been found critical.

By far the most troublesome part of the transmitting equipment has proved to be the antenna system. If, for any reason, the VSWR is appreciably more than unity, a condition is created making it impossible to get the same signal generated by the exciter on the air. In some cases, the antenna has caused as much as 20-db reduction in the cross-talk readings, making for a subcarrier that is not usable.

Under ideal conditions all the energies contained in the upper sideband maintain an exact phase relationship with the lower sidebands. If the transmitter is loaded into an incorrectly tuned or terminated antenna system, a reactive load exists which offers a different reaction to the upper sidebands from that to the lower, and as a result of phase shifts, the correct relationship between sidebands no longer exists as before. The first obvious result is the development of an AM component in the FM signal. This normally does not degrade the regular FM service but, in connection with multiplexing, causes serious intermodulation of the subcarrier (or cross talk).

Since it is the purpose of this part to outline the processes, it is well that the station engineer who contemplates multiplexing be made aware of the importance of all aspects, especially the transmitter antenna.

In the power stages of the FM station the following items have been found to cause degrading effects:

1. Improper coupling between stages
2. Improper neutralization
3. Regeneration of any type (such as between stages)
4. Old tubes
5. Improperly adjusted harmonic filters
6. Defective transmission lines
7. Improperly tuned antennas
8. Improperly terminated transmission lines

Although the bandwidth linearity problems imposed by multiplex transmission are not so stringent as for television, the same problems exist. If a transmitter and antenna were designed to equal that of a TV system, the problems just discussed would probably be nonexistent.

Bandwidth Occupied

During the development of FM multiplexing, the Commission requested a study of the spectrum occupied by the FM signal. The question arose as to whether or not the addition of subcarriers caused any spurious radiation outside the bandwidth

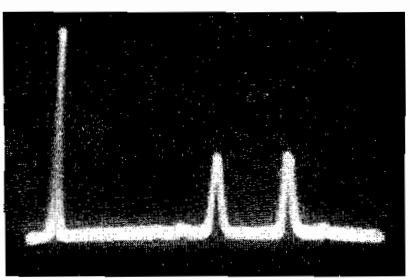

Fig. 2-7. Panoramic presentation of main carrier relative to the first sidebands above 26 and 65 kc.

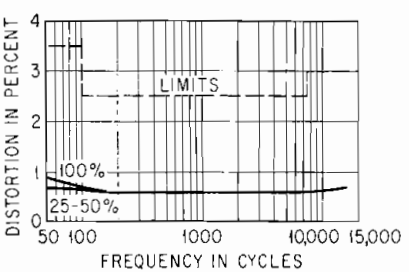

Fig. 2-8. Distortion measurements on main carrier at WMBR-FM.

allocated. For purposes of these tests, a panoramic receiver was used together with a frequency meter and a sensitive communication receiver. With a 15,000-cps signal modulating the main carrier 55 per cent together with a subcarrier of 26 and 65 kc modulated 15 per cent each, a measurement of the intensity of each sideband was made. Results of this test as well as with many other modulating frequencies on the main channel proved that multiplexing did not create any undesired effects outside the bandwidth allocated for the station.

Figure 2-7 shows the panoramic presentation of the main channel in relation to the first sidebands above 26 and 65 kc. Since the modulation index of the supersonic subcarrier frequencies is so low, only the first pair of sidebands is significant and the second pair is better than 60 db down. No deterioration of the main-channel performance has ever been encountered due to multiplexing. Typical of main-channel results is the chart of Fig. 2-8 from an installation at WMBR, Jacksonville, Fla.

Subcarrier Generator

In addition to the multiplex exciter just described, an additional unit must be used which actually generates the modulated supersonic subcarriers. The subcarrier generator consists of a Serrasoid modulator operating at 100 kc whose output goes through a string of multipliers until it deviates at least plus and minus 10 kc which

occurs at about 19.2 Mc. This FM signal at 19.2 Mc is then beat against a fixed crystal oscillating at 19.265 Mc to produce a 65-kc beat note. This beat note is amplified and filtered to become the actual subcarrier injected into the exciter. In the two-channel generator, the use of a second Serrasoid together with a multiplication chain of different frequencies is used to produce a beat note of 26 kc. The generator unit also includes a demodulation unit that acts as a frequency monitor and modulation monitor of the subcarrier.

Receiver

Assuming that all elements of the transmitting system are operating correctly, a receiver must be used that does not distort the correctly generated signal. Unfortunately, the same circuits that are used to provide maximum gain and noise reduc-

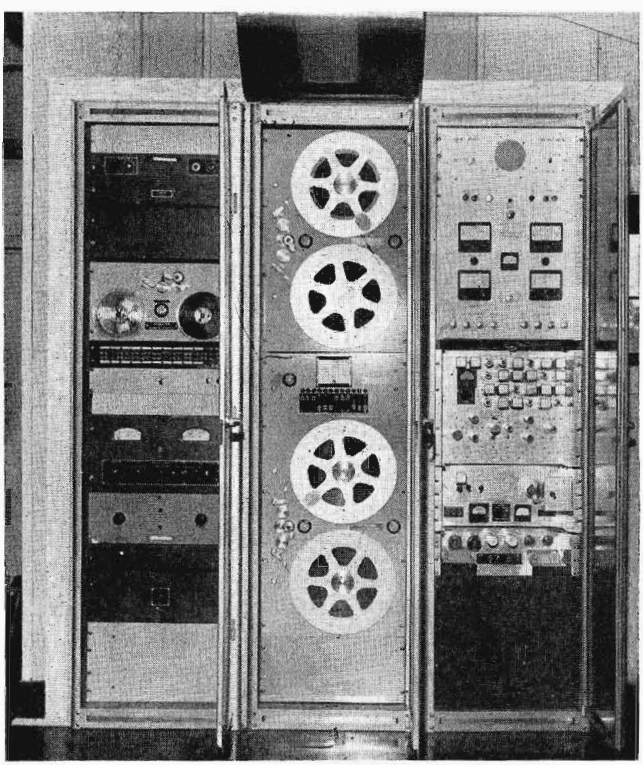

FIG. 2-9. Multiplex installation at WMBR, Jacksonville, Fla. Multiplex monitor, two-channel generator, and exciter are at the right. One subcarrier is programmed with music only, while the other channel is used for transmitting commercials and music to a group of chain-store supermarkets.

tion are also guilty of manufacturing conditions that cause intermodulation or cross talk. In the ideal receiver, a signal would be demodulated that accurately reproduces the modulation imposed at the transmitter.

The multiplex receiver consists first of a main-channel section comprising a crystal-controlled oscillator used to form the IF, which is, in turn, amplified and detected.

At the main-channel detector, the supersonic subcarrier is filtered out, amplified,

limited, and then detected. The "count-down" detector has proved most popular for the last function.

If the receiving antenna is incorrectly oriented or its transmission line mismatched, a condition of cross talk can be easily produced.

Under actual operating conditions in over 50 cities, it has been proved that commercial multiplex operation is possible at any location where main-channel reception is enjoyed. Some stations have subscribers at locations more than 100 miles from the transmitter. Techniques similar to fringe-area TV reception are employed in the reception of the fringe-area multiplex signal with signal boosters and high-gain antennas being used. From the standpoint of service requirements it has been proved that if the installation of the receiver is made correctly, no more service calls are required than for a normal FM receiver.

Development of the multiplex receiver has been the last portion of the step-by-step perfection of multiplexing. During the first few years multiplexing was used by broadcasters, there was not available a linear station multiplex monitor and it was common practice to use a multiplex receiver to seek best transmitter adjustment. This led to misleading conclusions, since it was possible to adjust certain receiver nonlinearities to counterbalance transmitter faults. When the transmitter and receiver nonlinearities were carefully balanced against each other, some remarkable results were obtained. Unfortunately, if a hundred receivers were so aligned by stagger tuning and then a minor adjustment made at the transmitter, all receivers would have to be readjusted for a new point of correct operation.

Along with the development of a phase-linear receiver it was found that correct operation resulted when all circuits at both the transmitter and the receiver were tuned to resonance. All circuits in the phase-linear receiver are tuned only for correct maximum reception of the main channel. Transmitter adjustments are likewise made the same way, with a daily check with the station monitor.

Achievement of the low-intermodulation characteristics of the receiver follow the same principles as in the transmitter and exciter, except when applied to the IF strip and detector itself.

System Requirements

From the installations made throughout the country it has been ascertained that a commercially usable system must have a signal-to-noise ratio on the subcarrier approaching 40 db. This is qualified to mean that a ratio of 40 db exists between the modulation peaks normally received on the subcarrier and the measured residual noise with no modulation. The residual noise then measured is that caused either by main-channel modulations or by other noise generated in the system. If the transmitter and station antenna permit a 50-db signal, this allows a 10-db margin of safety in the receiver. For actual measurement purposes, the main channel is modulated 100 per cent with 1,000 cycles.

The art of broadcast multiplexing has been commercially applied for a relatively short time. Most of the improvements have come from actually field testing at the same time commercial use was being made of the system. A vote of thanks is due the many station engineers who have spent countless nights of testing, obtaining the peculiar behavior patterns of equipment observed during multiplex operation.

The following is a partial list of the stations at which tests have been conducted: WBBQ, KQXR, KHFM, WCRB, WCPO, WSAI, WHK, KDMC, KDFW, WXFM, KBMS, KWJB, WGCM, KAIM, WMBR, WJDX, WKZO, KCMO, KCMK, KMLA, KGLA, KRKD, KSEL, KCMS, KWFM, WLOL, WMCF, KTYL, WAHR, WWMT, WMC, WBFM, KABC, WHLD, WPEN, WWSW, KGMS, KSL, KITE, KDFC, KCCT, WPIC, KCFM, KTKT, WWDC, WMAL, and WTOP-FM.

PRACTICAL ASPECTS OF MULTIPLEXING *

Introduction

The Rural Radio Network started operations as an FM-only relay operation in June, 1948. The system is shown in Fig. 2-10 with the approximate coverage of each station. Affiliated with the network are six other FM and 21 AM stations.

FIG. 2-10. Rural Radio Network, operated by Northeast Radio Corp.

Basic equipment for each station in the network is a General Electric 250-watt exciter, 1,000-watt power amplifier, and an RCA four-bay pylon antenna. Gasoline-motor-driven auxiliary power plants automatically take over when commercial power fails.

Multiplexing was included in the original plans for the network. The first actual use of multiplex was made in 1948 when a constant-amplitude variable-frequency facsimile system was developed. In 1950, we again operated multiplex facsimile, this time relaying from New York City to Ithaca by FM relay through four stations. The same year, we operated radio photo on an experimental basis between Ithaca and Buffalo with a successful series of tests through three stations. Although both were reliable and quality was good, they were not commercially feasible at that time.

* By Donald E. Udey.

Transmitting

The economic aspects of relaying over a five-station FM network already in existence on a relay basis becomes quite apparent when one considers the equipment necessary. Only one complete set of FM multiplex equipment is needed at the point of origin, WRRA. This equipment consists of subchannel generators, the main-channel Serrasoid modulator, and a phase modulator to inject the multiplex signal on the main carrier.

At each relay station, the only equipment necessary is a relay receiver to pick up the subchannel, a phase modulator to reinsert the subchannel on the carrier, and the Serrasoid modulator for the main-channel frequency. Thus, it is unnecessary to have subchannel generators at each of the remote stations. This amounts to a substantial saving on initial purchase, as well as cutting down maintenance and having less equipment to cause trouble.

There are several advantages to this type of operation, the most important probably being that the quality of the subchannel does not deteriorate so much as if the subcarrier program were returned to audio and remodulated on the subcarrier at each station. Preliminary tests have shown no appreciable increase in cross talk with each relay point. The cross talk originates mainly in the transmitter originating the subchannel and in the receivers involved. Relay stations which do not have subchannel generators do not appear to increase cross talk. As an example, we measured 52 db down on cross talk at WRRA and the same measurement at WRRI after the program had gone through WRRE, a total distance of 88 miles. Particular attention must be paid to relay receivers to see that they operate with minimum noise and distortion, as well as minimum cross talk.

We are serving a large territory with comparatively low-powered transmitters. Our signal gets into areas which are far beyond range of telephone-line facilities because of line charges. Many small businesses which cannot afford wire service or on-premise installation of music equipment can be served. Chain-store organizations that would not be interested in a strictly local service are prospective customers because of network operation.

As may be expected, some difficulties were encountered in installation of the multiplex relaying system. These difficulties are of two types: first, interference caused by others; second, interference caused by our own operation.

Some interference was encountered at WRRL from a Canadian television station. This station did not interfere on main channel but did interfere on subchannel. Additional filtering was required to relieve this situation. At WRRD, we encountered interference from a local FM station. This interference was quite serious and required two coaxial high-Q bandpass filters to eliminate it. These were custom-made filters constructed from 1⅝-in. coaxial transmission line. Here again, interference was on our subchannel only, and not on main channel. Commercially available notch-type filters were tried but with only a slight improvement in eliminating unwanted interference.

Remote Control

Several years ago our manual operation was converted to a radio-operated remote-control system, designed and constructed by our own engineering department. WRRA was chosen as the control point because of its central location. The first subchannel was put at 67 kc to get as far away from this remote-control operation as possible. The remote control uses frequencies of 19 through 29 kc with 1,000-cycle separation and a single frequency at 45 kc for control of the four remote stations. Obviously lower frequency subchannels would directly interfere with these control tones. It was found that by keeping control-tone levels low, we were able to operate the 67-kc subchannel without any interference in either direction.

To understand better what is involved with the remote control system, it is briefly described as follows:

Remote-control functions fall into two distinct categories:

1. Those associated with the audio input requirements of the remote-controlled

transmitter, including receiver selection and station breaks, hereafter called "receiver switching"

2. Those associated with the control of the remote station: adjustments, tower-light checking, auxiliary power-plant start and stop, etc., hereafter called "telemetering." These functions must be independent of each other, either being carried on without interfering with the other.

Receiver Switching. A telephone dial controls the pulsing of tones for transmission on the controlling transmitter (WRRA). A series of one to nine pulses of 19 kc operates stepping relays at each of the four controlled stations. These relays step to the same position and control the audio input of the remote transmitters. This permits control of network feed from any remote station or any affiliate that can be picked up on a receiver at the nearest controlled station. Position 10 on the control dial activates a continuous-loop tape playback at each station giving the station break. A 20-kc pulse controlled by a push-button switch resets all stepper relays to the ZERO or OFF position. As an additional insurance against noise or static stepping the relays at remote stations, a pulse of 29 kc is sent just ahead of the 19-kc pulses. The 29-kc pulse opens a "gate" circuit, holding for 5 sec. Only during that time can the 19-kc pulses operate the equipment. Thus, it takes a combination of first the 29-kc "gate" pulse and then 19-kc pulses to operate the stepper relays.

Telemetering. Station control, adjustment, etc., as described in 2 above is performed by a separate frequency for each station. Considering only one remote station, WRRE, Bristol Center, for example, pulses of 22 kc are used to operate stepper relays giving a total of 19 positions at the remote transmitter. Each position is wired to perform a certain function and/or metering.

Reversible motors control five adjustments. They are a-c input to exciter and final, plate tuning of final, antenna loading, and audio input. Clockwise rotation is controlled by a continuous 26-kc frequency, while counterclockwise rotation is controlled by 27 kc. These two frequencies are controlled at WRRA by a key switch. Transmitter on-off-overload reset is also controlled by first dialing into the proper stepper position and then pulsing 27 kc. Reset for the telemetering steppers is 25 kc and is common to all stations.

Return information from each remote station is by 45 kc. Since only one station can be metered at a time, a selector switch at WRRA picks a meter calibrated for the desired remote station. This same switch picks the proper control frequency for that station. Dialing any metering position from 1 to 19 sends out pulses on the chosen frequency, and only the remote station adjusted for that frequency will respond.

At the remote station, the telemetering stepper moves into the dialed position. A sampling voltage from the desired circuit is used to bias a linear amplifier operating at 45 kc. Changing this bias changes the output of the 45-kc signal. The main FM transmitter is modulated with this 45 kc, and receiving equipment at WRRA detects this on a meter calibrated for that station. This meter uses an expanded scale, and it is actually possible to read it more accurately than the meters on the remote transmitter.

Metering of the remote station can be done while mechanical adjustment is made on associated controls. Thus, the final amplifier plate current can be "dipped" while watching the meter reading. Position 1 is meter calibration, used to compare and adjust the remote-station indicating meter at the control point with a constant-voltage source at the remote station. This assures accuracy of readings on each station.

Control frequencies and their functions are as follows:

19 kc, receiver switching
20 kc, receiver switching reset
21 kc, telemetering control WRRL
22 kc, telemetering control WRRE
23 kc, telemetering control WRRD
24 kc, telemetering control WRRC
25 kc, telemetering control reset
26 kc, telemetering control clockwise rotation
27 kc, telemetering control counterclockwise rotation
29 kc, receiver switching "gate"
45 kc, telemetering return from all stations.

Table 2-1. Telemetering and Control Functions Performed

Function	*Meter reading*	*Controls*
Calibrate	Yes	
Exciter a-c volts in	Yes	Raise-lower
Final a-c volts in	Yes	Raise-lower
Auxiliary power plant	Yes	Start-stop
Final plate current	Yes	Raise-lower
Antenna loading	Yes	Raise-lower
Audio input		Raise-lower
RF output	Yes	
Tower lights:		
Beacon	Yes	
Side	Yes	
Building temp.	Yes	
Transmitter on		On
Transmitter overload reset		Reset
Transmitter off		Off
CONELRAD alarm		Start

A block diagram of the functions of station WRRE is shown in Fig. 2-11. This station relays control frequencies on to WRRL and relays telemetering from WRRL back to WRRA, the control point.

Monitoring. A General Electric BM1A-FM station monitor is operated at WRRA for each remote-control station. Since these monitors were intended to be driven with RF directly from the transmitter, it was necessary to build up the signal from receivers through IF amplifiers. A "flip-flop" aural monitor is employed to monitor two stations constantly. By selector switch any two stations can be picked, but under normal circumstances we monitor WRRL and WRRC, the end stations of the network.

These station monitors, in addition to furnishing the aural signal, also provide readings of modulation percentage and frequency deviation, as required by the FCC.

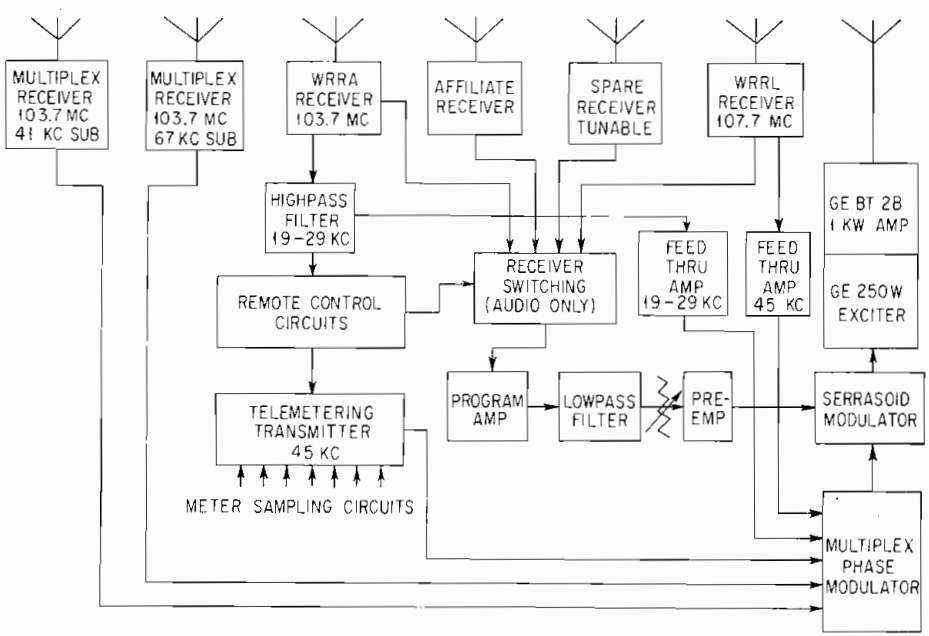

Fig. 2-11. Block diagram of station WRRE, Bristol Center, N.Y.

In addition, each remote station has an identical station monitor for use by the maintenance personnel.

Special "feed-through" amplifiers are used at WRRE and WRRD for passing control tones (19 to 29 kc) on to the end stations and for passing the 45-kc tone back from the end stations to WRRA. These amplifiers have filter circuits to attenuate the unwanted program material.

"Fail-safe" operation is provided by the relay receivers at each remote station. Unless the carrier of the control station is detected, the remote station will not go on the air. If carrier of the control station goes off, all remote stations follow suit.

CONELRAD requirements are met by a motor-driven switching device at each controlled station which removes and restores carrier, after which the tone and announcement are originated at the control station.

It should be noted that the remote-control system for main-channel operation does not affect the subchannel. Program feed on subchannel is always from WRRA regardless of where feed on main channel originates.

Second Subchannel. When we experimented with a 41-kc subchannel in addition to the 67 kc, we knew we would have interference between 41- and the 45-kc telemetering frequency. This proved to be the case, and for experimental purposes only we interlocked the telemetering in such a manner that any use of our telemetering circuitry would remove the 41 kc from the transmitter during the period of usage. Permanent installation of the 41-kc subchannel will require movement of the 45-kc telemetering frequency to 52 kc, where it will cause no interference and will not be interfered with.

The two subchannels operated very well simultaneously with no apparent interference between them. It was discovered, as was expected, that the second harmonic of the 20- and 21-kc control tones did get into the 41-kc subchannel. It would appear that the most logical solution to this problem is the establishment of a third rather low-quality subchannel in the lower range of possibly 22 or 23 kc to handle our remote-control system. This could offer many advantages and improvement to the remote-control system. We anticipate use of this subchannel for possibly one leased service in addition to our own remote control.

Receiving

Ignition noise from automobiles seems to be the one drawback in the multiplexing field today. The signal from the transmitter needs to be strong, but it requires more than a strong signal in some places to eliminate the ignition interference. Tests were made in locations 25 miles from a transmitter where we had a very strong signal and found much ignition noise, whereas a weak signal 55 miles from the same transmitter was clean. Development of some type of inexpensive filter is needed to improve this situation. Several commercial boosters were tried. They do a great deal to bring the strength of the signal up but seem to do nothing to eliminate interference, even though peaked on the operating frequency.

Receiving antennas are one of the most important parts of the system. Multielement Yagis have given the most satisfactory results. The best cure for ignition noise seems to be a high antenna with as much gain as possible, very carefully located. Sometimes moving a few feet one way or the other will make a noisy signal usable. Where noise comes from a definite area, such as a street below, vertically stacked antennas with a null in the horizontal plane should help. An excellent noise generator for such work is a car with the motor running, the hood raised, and a clip lead on one ignition wire.

Much remains to be done in the receiver field to improve the ignition noise situation. Receiver design in the past year has improved noise rejection considerably. A more carefully designed antenna, cut to frequency, that is within reasonable price range is needed.[2]

[2] See preceding discussion by Mr. Harkins.

Automatic Operation

Since this network is set up as a four-station remote-controlled unattended operation, it was necessary that the multiplex relay fit into this picture. For this reason, every attempt was made to keep the operation automatic. The tape equipment originating background-music programming at our control station features two tape playback machines for music, a third playback machine for spot announcements, and a 12-position program selector which sequentially selects any desired programming arrangement from these three tape machines.

To remove the subcarrier subchannel from the air during pauses between musical selections, a silent sensing relay device was built which removed the subcarrier after a pause of about 3 sec. This automatically mutes all multiplex receivers and prohibits cross talk being heard by customers during the silent periods when it would be most prevalent.

An alarm system has been incorporated operating from a multiplex receiver at the control point which rings a bell if programming is removed from the subchannel for a period exceeding 1 min. Thus, if for any reason the operator on duty is not monitoring the subchannel, he becomes aware in a very short time that the program has ceased on the subchannel. Failure of the originating or transmitting equipment of the subchannel also operates the alarm.

Installation of the Serrasoid-type modulators throughout the network has improved the station performance through reduction of distortion, since these units are capable of better performance than the original equipment. These units use mostly receiver-type tubes, which are readily available, and the operating cost is reduced. The old General Electric exciter equipment is available for immediate usage by turning on the power supply and changing one coaxial connector.

Riding gain at the control point is especially critical, since overmodulation on the main channel will cause splatter or cross talk in the subchannel. A General Electric Unilevel amplifier is used on the subchannel to keep the levels constant, and a Langevin Progar on the main channel. The additional limiting in the subchannel receivers from a strong signal holds levels at remote stations constant.

Summary

By moving our background-music service from main channel to subchannel we are able to perform a much better public-service function than formerly. We are at greater freedom to pick what we program on the main channel than we were when we had commitments to broadcast only background-type music during certain portions of the day. We are now able to go to high-fidelity programming, including considerable classical music which was prohibited before except after the hours of background-music service. We feel that our new operation has greater public acceptance than the background-type music, although we had many favorable comments on that programming.

There are many future possibilities for multiplex, contingent upon approval of the FCC. Some of these are news distribution by facsimile, teletype, and teletypesetting; photo relaying; printed information for business use by facsimile; music for transit groups; weather programming; stock-broker ticker tape slow-scan television; special program relay such as baseball games; closed-circuit sports events; electronic computer feed; and stereo sound.

Multiplexing will be a real source of revenue to the FM operator. It is here; it is successful. We can look forward to greater simplicity of equipment and higher standards of operation with the development of the art.

Part 3

A COMPATIBLE SINGLE-SIDEBAND SYSTEM FOR STANDARD BROADCAST STATIONS

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COMPATIBLE SINGLE SIDEBAND *

Introduction

This section describes a new technique which has been developed to convert standard AM broadcast transmitters to single-sideband operation. Conversion is achieved by use of an adapter which can be installed with existing transmitters, and the signal can be received on conventional AM receivers.

The system, known as "compatible single sideband," or CSSB, is quite similar to standard AM transmission, except that the spectrum energy is concentrated on one side of the carrier. Because of this basic difference, the following advantages over normal AM are obtained:

1. An effective 2-to-1 power gain for a given signal fidelity
2. A reduction in adjacent and cochannel interference
3. A reduction in certain types of selective fading distortion
4. A potential improvement in audio fidelity which, besides improving reception of musical programs, improved intelligibility of speech, thus increasing service range
5. A reduction in television-receiver radiation interference

The compatible single-sideband system has been used continuously since the summer of 1956 at the *Voice of America*'s megawatt station in Munich, Germany. Domestic tests with experimental CSSB equipment were made and completed in New York on 50-kw radio stations WMGM and WABC. Production models have been installed at KDKA,[1] the Westingbouse station in Pittsburgh; WSM in Nashville; and KBIG at Catalina Island in California.

* By Leonard R. Kahn.

[1] See reference 6.

Early Proposals

Application of single-sideband techniques with AM broadcasting has previously been considered impractical, since its adoption would involve modifications of home receivers. However, a number of years ago the British Post Office prepared a United Kingdom proposal to use a full-carrier single-sideband system for high-frequency broadcasting. British engineers argued that full-carrier single-sideband signals could be received on conventional AM receivers. However, they confined their proposal to short-wave broadcasting because full-carrier single-sideband waves possess some rather serious limitations. Furthermore, general use would have necessitated the replacement or extensive modification of existing transmitters.

The limitations pointed out in the British study were referred to a full-carrier single-sideband wave modulated by a single tone under peak modulation conditions. It was shown that the envelope wave shape is not sinusoidal and that more than 23 per cent harmonic distortion is present.

It was also noted in the mathematical analysis that the fundamental term has a peak envelope of 67 per cent, relative to the d-c term. Therefore, maximum effective modulation of a full-carrier single-sideband wave is only 67 per cent. This means that a transmitter that can be rated at 1 kw, on either AM or compatible, can be rated at only 444 watts on the full-carrier system. Although distortion can be minimized by reducing sideband level, the effective modulation will become greatly attenuated. When distortion is reduced to 10 per cent, for example, the effective modulation is only 38 per cent. This results in a reduction of over 5.3 db in effective power.

Two proposals [2] have been made for reducing the distortion effect at the lower frequencies by transmitting double sideband for low audio frequencies and single sideband for higher frequencies. However, these systems require more spectrum and are more critical to selective fading than pure single-sideband systems. They also require the replacement of most existing transmitters. Compatible single sideband, however, does not suffer from any of the above limitations.

Compatible Single-sideband System

Before describing the new adapter system, an examination of the structure of a single-sideband wave, as shown in Fig. 3-1, should be of interest.

Figure 3-1*a* shows a plot of the frequency spectrum (voltage vs. frequency) of a single-sideband wave with the carrier and upper sideband equal in amplitude. The upper sideband represents a single sine-wave audio frequency of 600 cycles. The carrier and upper sidebands, shown as two displaced vertical lines, represent two radio frequencies of equal amplitudes.

Figure 3-1*b* is the phasor representation of the single-sideband wave shown in Fig. 3-1*a*. It will be seen that sideband phasor f_s (sideband) revolves past the carrier frequency reference f_r ($C \times r$) at a velocity equal to the tone frequency of the signal. The resultant of the two frequency components varies in both amplitude and angular velocity. *Therefore, single-sideband waves contain both amplitude- and phase-modulation components.*

Figure 3-1*c* represents the amplitude-modulation envelope of the single-sideband wave (a plot of voltage vs. time) shown in Fig. 3-1*b*. It should be noted that this envelope is identical with the wave shape derived from a full-wave resistance-loaded rectifier when fed a sine wave.

As previously explained, single-sideband waves possess both amplitude- and phase-modulation components. If these components are first isolated and then amplified independently, they can later be combined in such a way as to produce a conventional single-sideband wave.

The CSSB system transmits a full-carrier single-sideband wave produced by the single-sideband generator. The output of the generator is passed through a limiter wherein the phase-modulation component of the wave is isolated. The phase-mod-

[2] See references 4 and 5.

ulated wave is then amplified by Class C amplifiers or, for that matter, any other class of amplifier and finally feeds a modulated stage.

The single-sideband generator also feeds a product demodulator, wherein the sideband of the full-carrier SSB wave is electronically multiplied by the carrier. The

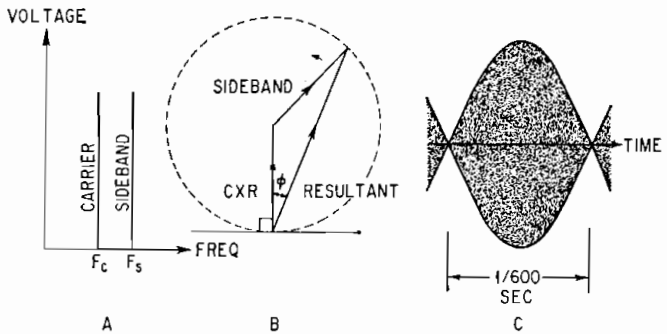

FIG. 3-1. (*A*) Spectrum diagram of single-sideband wave. (*B*) Revolving vector representation of single-sideband wave. (*C*) Envelope waveform of single-sideband wave.

resulting wave possesses spectrum components that are identical with those fed to the input of the single-sideband generator. This wave is amplified and used to modulate the phase-modulation component in the modulated amplifier stage.

If the modulation process is linear, the output envelope wave will be theoretically free of all harmonic distortion, and in practice, figures of less than 1 per cent have been regularly measured. Therefore, demodulation can be achieved in a conven-

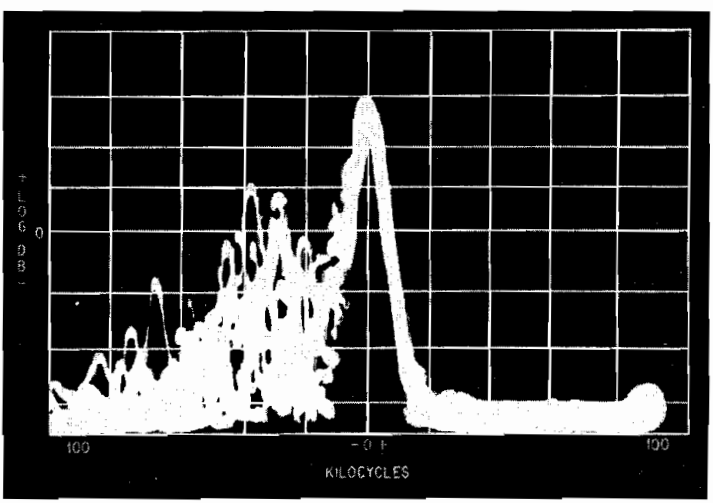

FIG. 3-2. Actual photograph of a major New York network station's 50-kw (200-kw PEP) CSSB wave viewed on a Panoramic Panalyzer. Undesired sideband measures better than 25 db below the desired sideband, including third-order intermodulation products.

tional diode detector with theoretical zero distortion at 100 per cent modulation. This means, of course, that unmodified AM receivers can be employed.

Analysis and measurements show that the undesired sideband of this wave is approximately 30 db below the desired sideband. Even though the compatible single-

sideband wave looks exactly like an AM wave on an oscilloscope, the energy of the wave is actually concentrated in only one sideband. Figure 3-2 is a photograph of a 50-kw (200-kw PEP) CSSB wave viewed on a high-resolution Panoramic panalyzer,

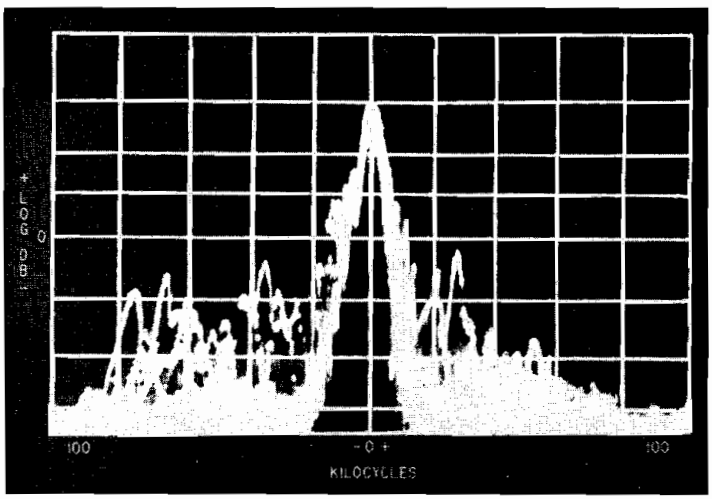

FIG. 3-3. Wave from same transmitter after switching back to conventional double-sideband AM transmission.

showing the asymmetrical concentration of energy. Figure 3-3 shows the waveform from the same transmitter after switching back to conventional AM double-sideband transmission.

Advantages

The advantages of the compatible single-sideband system are as follows:

Reduction of Interference. Since compatible single-sideband systems concentrate energy in only one sideband, CSSB transmissions reduce adjacent- and co-channel interference.

Adjacent-channel Interference. In the case of adjacent-channel interference, the use of the compatible single-sideband system can increase the spacing of adjacent sidebands on one side of the carrier by two times the highest andio frequency transmitted. Thus, the increased effective sideband spacing greatly reduces adjacent-channel interference.

This form of interference comprises three main types: sideband monkey chatter, undesired cross talk, and carrier heterodynes. In the United States, the 10-kc separation between carriers tends to reduce carrier heterodyne interference because of limitations in receiver IF bandwidth and audio fidelity, as well as the aural limitations of the listener. The cross-talk effect is reduced by AM masking, and except for extremely large, undesired signal levels, it is relatively unimportant. Thus, the main source of adjacent-channel interference is sideband monkey chatter wherein the desired carrier beats with the undesired sideband components. If CSSB techniques are correctly applied, the frequency of the monkey chatter can be sufficiently removed from the desired carrier (10 kc) to be relatively unimportant.

Co-channel Interference. If co-channel stations are equipped for CSSB operation, the listener can, by tuning to the desired upper or lower sideband of one station, effectively reduce interference from the other station. The optimum tuning point appears to be 1.5 to 2 kc on the desired sideband side of the carrier, and conventional

home receivers offer a co-channel signal-to-interference gain of 5 to 8 db. Moreover, if a listener in a particularly poor region were to purchase a special high-selectivity receiver, approximately 30-db signal-to-co-channel interference gain can be obtained.

In addition, CSSB reduces beat-note distortion, which in AM systems is caused by the "phase beating" of interferring carriers. Reduction in beat-note distortion is discussed in the paragraph devoted to the Reduction of Selective Fading Distortion.

Radiation Interference of Television Receivers. A relatively new type of interference which has assumed very important proportions in the past few years is caused by television-receiver radiation. Poor shielding in many home television sets allows strong horizontal-sweep frequency harmonics to be radiated. They have created considerable interference, not only in the broadcast band, but in the short-wave communications spectrum as well. This problem has, in effect, placed some 68 superpower stations on the air. In view of the extremely crowded conditions of the broadcast band, it appears quite unlikely that there is sufficient room for them, especially when each station effectively covers the entire nation day and night. These signals are spaced 15.75 kc apart throughout the broadcast band. When CSSB is employed, however, the upper or lower sideband, whichever is the farthest removed from the nearest interference frequency, can be selected for transmission. This permits the listener to tune away from the interference and greatly attenuate the interfering beat note.

In order to determine the severity of this problem, a number of questionnaires were recently (1958) mailed to 1,500 individuals selected at random from various New York metropolitan- and suburban-area telephone directories. Out of this total, more than 50 per cent of the 400 replies received stated that TV interference was objectionable to AM broadcast reception. It has been subsequently noted that this interference is possibly even more prevalent in rural sections, where lower interference ratios of AM signal to TV are normally encountered.

Reduction of Selective Fading Distortion. Another advantage of compatible single-sideband operation is the reduction of certain forms of selective fading distortion. In AM reception it can be shown that one of the main causes of fading distortion results from an incorrect relative phasing between the carrier and the sidebands. This condition can be demonstrated by eliminating the carrier from an amplitude-modulated wave and then reinserting it at different phase relationships. When the carrier differs by 90° from its correct phase, the signal will be completely distorted when demodulated in an AM detector. The distortion produced will be independent of the percentage of modulation.

However, when one of the sidebands is suppressed or greatly attenuated, as is the case with CSSB, the relative phase between the carrier and the remaining sideband will be less critical. Therefore, CSSB is less sensitive to this form of distortion.

It should be pointed out that the relative insensitivity of CSSB to phase deviation is another reason for the reduction afforded in co-channel interference. When the undesired AM signal has a carrier frequency approximately equal to that of the desired carrier frequency, the combined carriers will be phase-modulated at low-frequency beat-note rate. This wave will then go in and out of proper phase and produce a form of beating distortion. The compatible single-sideband system reduces this problem because this system is less sensitive to phase discrepancies.

Improved Fidelity and Signal-to-Noise Ratio. Compatible single-sideband waves occupy only one-half of the normal AM spectrum. Therefore, the bandwidth of IF and RF amplifiers used in normal receiver design can be halved. Since the fidelity of most receivers is restricted by the IF amplifiers employed, CSSB offers a means for appreciably improving the effective fidelity of these sets.

Stating it another way, an improvement of 3 db in signal-to-noise ratio will be noted for a given fidelity because receiver bandwidth can be halved. Receivers can also be made somewhat cheaper because more gain can be obtained in narrow-band IF amplifiers than in those of wideband design. It will also be easier to obtain improved selectivity with attendant reduction in co- and adjacent-channel interference.

In field tests, CSSB signal-to-noise gain has measured 3 to 4 db; however, the increase in intelligibility under noise conditions appears to represent a somewhat greater

effective increase in signal-to-noise gain. The reason for this is due to a phenomenon in hearing called audio masking, which is somewhat similar to capture effect in frequency-modulation transmission. Thus, when two tones are heard, the stronger tone will bend to mask the weaker tone. In speech the first components to be lost in noise are the high-frequency low-amplitude portions of the voice wave.

Thus, when the noise is slightly greater than the weak high-frequency speech components, the latter actually becomes further reduced in amplitude because of the masking effect. Therefore, significant improvements in fidelity and intelligibility are available with inexpensive receivers through the use of CSSB because higher frequency sounds are heard. Components of the order of 3 kc can be raised in such receivers by a factor of 10 to 15 db.

Because of this improvement, CSSB has been recently proposed for use on the AM channel of an AM-FM stereophonic broadcast system. The advantage accrued is that CSSB will provide audio fidelity on the AM channel approaching [3] that of the FM channel, thereby improving stereophonic broadcast quality.

Installation Procedure

Compatible single-sideband adapters have been used with a number of different types of transmitters including high-level, low-level, and Doherty systems.

Phase-modulated Carrier-frequency Output. There are two outputs from a compatible single-sideband adapter that must be connected to the transmitter. The first contains a phase-modulated wave centered at the carrier frequency. This wave must be connected to the associated transmitter at a low-level point in the circuit. In a typical installation using a Gates 10-kw transmitter, a separate switch position was provided to permit the operator to switch from the two normal crystals to a third position fed by the compatible sideband adapter. Other installations have bypassed the crystal oscillator in order to feed the following amplifier stage. Two to three watts of phase-modulated energy is supplied at a 72-ohm impedance. This is sufficient to drive many low-powered amplifiers, and an increase in drive voltage can be achieved by using the tap-tuned circuit provided. For instance, by tapping a coil or condenser in a parallel-tuned circuit, a gain factor of approximately 10 can be achieved to provide over 100 volts. Of course, the impedance which is seen by the tuned circuit cannot be too great. An amount in the order of 70,000 ohms, however, is satisfactory. When such circuits are used, care should also be taken with the magnitude of the Q's employed. If the Q is too high, the bandwidth of the circuit will be greatly restricted, causing distortion of the phase-modulated wave. An RF bandwidth of at least 30 kc should be provided throughout the AM transmitter, and this is normally quite simple to achieve over the entire broadcast band.

If low-level stages are used with high-Q circuits, it may be necessary to increase loading so as to reduce the Q and thereby increase the bandwidth. It is also quite necessary to make certain that the transmitter is well neutralized, because regenerative characteristics in the transmitter can distort the phase-modulated wave. Such problems as parasitic oscillations, regeneration, and other difficulties which would affect the phase-modulation component must also be carefully eliminated if optimum sideband rejection is to be achieved.

Audio-frequency Output. The second output from the compatible single-sideband adapter is an audio feed which is connected to the input of the aduio system of the transmitter. Once the equipment is set up and the undesired sideband output is minimized, it is extremely important to maintain the polarity of the audio wave being fed from the compatible single-sideband adapter to the transmitter. Therefore, permanent wiring or polarized connectors should be used. It should be noted that the *input* polarity of the wave being fed to the single-sideband equipment is not important. The output audio level from the compatihle single-sideband system is +10 dbm across a 600-ohm line. It may be balanced or unbalanced, as desired.

Test and Adjustment. There is a third connection that must be made from the

[3] Modulation frequency will depend on the adjacent-channel limitations.

transmitter to the adapter. This is the RF sample which is obtained from the output of the transmitter. It is the same feed that is normally used for measuring distortion in AM transmissions, and it is connected to the 72-ohm input of the compatible single-sideband test unit. The RF sample is used to measure and monitor the characteristics of the single-sideband wave.

From the above description, it is evident that the phase- and amplitude-modulation components must reach the modulated stage simultaneously if optimum sideband rejection is to be achieved. Therefore, a phase time-delay network is incorporated

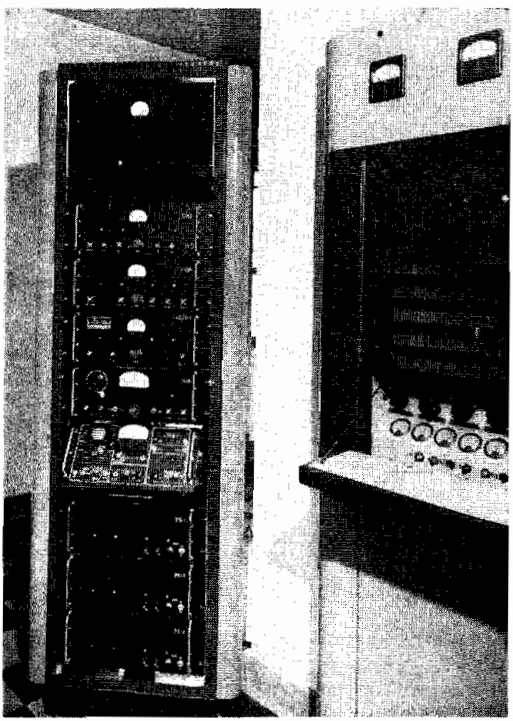

FIG. 3-4. KDKA, Pittsburgh, Pa. showing CSSB equipment.

in the CSSB adapter. Normally, the amplitude-modulation path is slower than the phase-modulation branch because the bandwidth of the modulator is narrower than half the phase-modulation bandwidth. Thus, it is usually necessary to delay the phase modulation in the CSSB adapter by inserting the time-delay network in the PM branch. If it is determined, however, that the modulator time delay is insufficient, causing the phase modulation to arrive ahead of the amplitude-modulation component, the time-delay network can then be inserted in the AM branch. There is a simple method for determining where the time-delay network must be inserted. In order to observe the timing of the phase whip, it is possible to drop the level to the limiters so that when the single-sideband wave goes through zero, an observable pip is produced and thus the timing can be examined.

A test oscilloscope is provided for checking the wave shape of the transmitter as well as other wave shapes in the single-sideband equipment. Measurement of the undesired to the desired sideband ratio is quite simple. It is made by throwing a panel switch to the desired sideband position, adjusting the VI meter for a calibration reading, throwing the switch to the undesired sideband position, and reading

the amount of sideband rejection directly in decibels. A multifrequency audio oscillator is also provided in the test unit. It can be operated by throwing a TEST-OPERATE panel switch to the TEST position. Care must be taken to throw the TEST-OPERATE switch to the OPERATE position before resumption of programming. It should be pointed out that a fairly good indication of desired to undesired sideband radiation can be achieved during program operation by observing the peak readings of the meter while throwing the test unit switch from the desired to undesired sideband positions.

Examination of the simplified block diagram of the compatible single-sideband [4] adapter shows that there are, in effect, two modulations taking place in the system. The first takes place in the single-sideband generator, and the second in the AM transmitter. It is very important that the sideband level at the output of the single-sideband generator does not exceed the carrier level. This condition is not noticeable on a normal AM detector, but it negates the spectrum economy of the system and causes interference similar to double-sideband transmission if allowed to continue. Therefore, care must be taken with the levels fed to the CSSB unit. Otherwise, overmodulation effects similar to those in normal double-sideband AM can be produced in the associated transmitter.

It should be noted that once the CSSB adapter is properly, adjusted, a certain percentage of modulation will be achieved for a given input to the sideband adapter. Thus, audio-level gain in the associated transmitter should not be readjusted without checking desired to undesired sideband measurements.

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EXPERIENCE WITH CSSB AT KDKA [*]

The application of the Kahn compatible single-sideband adapter to standard broadcast transmitters was described by Kahn in a paper presented at WESCON in the fall of 1957. Field experiences at WABC, New York; WSM, Nashville; and KDKA, Pittsburgh, all standard broadcast stations, were discussed at the 1958 Engineering Conference of NAB.

G. A. Olive [5] of RCA, Princeton Laboratories, and John P. Costas,[6] General Electric Co., Syracuse, N.Y., have made mathematical analyses of their understanding of the Kahn CSSB adapter.

This paper gives some additional information on the details of its design and operation. It also discusses results of measurements at the transmitter on the radio-frequency spectra radiated and some explanation of the effect of CSSB on typical

[4] See next portion of this part.

[*] By Ralph N. Harmon.

[5] 12th Annual NAB Engineering Conference Paper, April, 1958.

[6] IRE, July, 1958.

receivers with respect to adjacent channel interference, selective fading distortion, and receiver fidelity.

Design, Operation, and Analysis

The Kahn compatible single-sideband adapter should be renamed (a full-carrier compatible single-sideband adapter, i.e., FCC-SSB [7]). When it is used with a standard-band broadcast transmitter, it modifies the spectral output of the transmitter so that under modulation, essentially all the energy is radiated at carrier frequency and on one side of the carrier, either above or below, as desired. Moreover, the

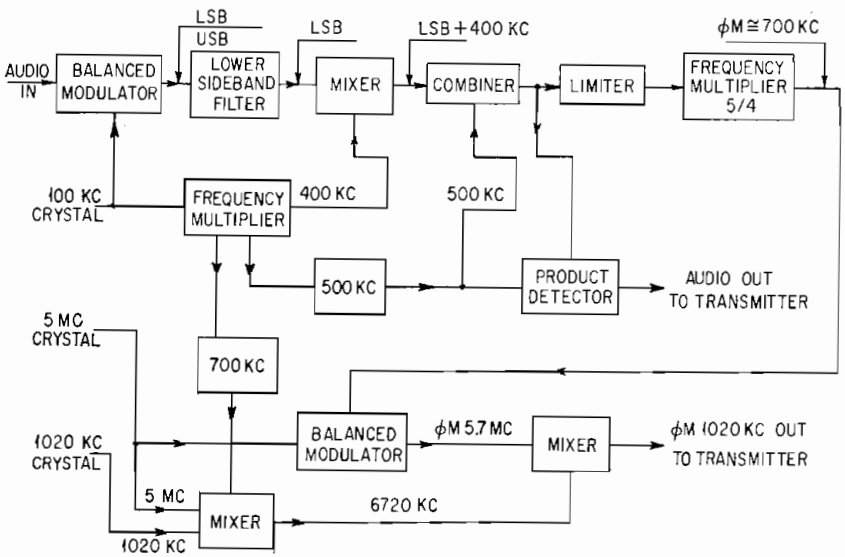


FIG. 3-5. Block diagram of CSSB system.

envelope of the radio-frequency output of the transmitter, when under modulation, is an exact facsimile of the input audio program and, therefore, is receivable on standard receivers without distortion.

Figure 3-5 shows a simplified block diagram of the Kahn adapter. Note that it requires one audio input and has two outputs, one a delayed audio output similar to the audio input, the other a phase-modulated carrier at the assigned carrier frequency of the station. For KDKA this is 1,020 kc. The phase-modulated output of the adapter is connected to the first radio-frequency stage in the transmitter following the crystal oscillator which is not used. The audio output of the adapter is fed to the normal audio input of the transmitter.

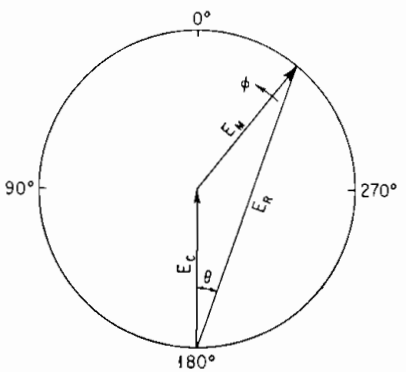
It should be noted that the adapter has three crystals, one at 100 kc, another at 5 Mc, and the third at 1,020 kc. Starting at the top left of the figure, it is noted that audio aud 100 kc are fed into the balanced modulator. The output of this modulator is an upper and lower sideband centered around 100 kc.

The next block contains a crystal filter which passes the lower sideband and rejects the upper. The output of the filter is then heterodyned up in frequency by the fourth harmonic of the 100-kc crystal. The signal at this point is a single-sideband one centered just below 500 kc. The carrier signal, the fifth harmonic of the 100-kc crystal, is then combined with the 500-kc single-sideband signal to make the com-

[7] Probably some other terminology should be adopted which would not suggest approval by the Federal Communications Commission (FCC) in the abbreviation.

bined signal a *full-carrier single-sideband signal.* The 500-kc carrier injection is made equal to the amplitude of the single-sideband signal at the 100 per cent modulation level.

This signal is connected to a four-stage limiter which removes all amplitude variations, leaving phase changes only. These phase changes are multiplied by a factor of 5/4 using a frequency multiplier of 7, $7 \times 500 = 3{,}500$ kc, and a divider of 5, $3{,}500/5 = 700$ kc, so that the phase-modulated frequency becomes 700 kc with an increase in phase modulation over the original amount it had at 500 kc. This phase-modulated signal is then raised to the station carrier frequency of 1,020 kc by three steps of processing. First, the seventh harmonic of the 100-kc crystal, the output of the 5-Mc crystal, and the 1,020-kc crystal are combined in a mixer whose output is the sum of these three frequencies, namely, 6,720 kc; second, the 700-kc phase-modulated frequency is fed to a balanced modulator along with the output of the 5-Mc crystal oscillator. The output of the balanced modulator is a phase-modulated wave at 5.7 Mc. Third, the 6,720-kc and the 5.7-Mc phase-modulated waves are mixed, and the output is the difference frequency of 1,020 kc, having the original phase modulation contained on the phase-modulated 700-kc wave. This is fed to the transmitter in place of the regular crystal output at 1,020 kc. The only difference in this 1,020 kc is that when audio is fed to the adapter, the 1,020-kc output of the adapter contains phase modulation.



$E_C = E_1 \sin WT$
$E_M = E_2 \sin (W + 2\pi M)T$
$\frac{E_2}{E_1} = X$

FIG. 3-6. Output of full-carrier SSB adapter before signal is amplitude-limited and when modulated by a single audio frequency.

The second path the 500-kc full-carrier single-sideband signal follows is to a product detector which also has fed into it the fifth harmonic of the 100-kc crystal, resulting in an audio output of the same wave shape as the original input. The only difference is the delay it suffers in going through the modulators and filters of the adapter. This audio is then fed to the audio input of the transmitter after certain minor delay and response equalization adjustments have been made to compensate for the transmitter audio response and delay characteristics. This is necessary in order to maintain envelope coincidence of the phase-modulated wave and the audio as seen at the modulated amplifier of the transmitter.

Figure 3-6 [8] shows the output of the full-carrier single-sideband part of the adapter before the signal is amplitude-limited and when modulated by a single audio frequency. Since the two vectors $E_c = E_1 \sin WT$, the carrier frequency, and $E_m = E_2 \sin (W + 2\pi M)T$, the side frequency due to modulating frequency M, differ in frequency by the audio-modulating frequency and rotate with respect to each other at the audio-modulating rate M, this rotation will give a resultant vector E_r whose amplitude will vary with the depth of modulation; i.e., $E_1/E_2 = X$-depth of modulation.

The envelope of E_c for different modulating levels is

$$E_c = \sqrt{1 + X^2 + 2X \cos 2\pi MT}$$

and is shown on Fig. 3-7 for various depths of modulation. It will be noted that at large modulation levels the envelope departs radically from a sine wave. Figure 3-8

[8] M. S. Corrington, Frequency-modulation Distortion, *RCA Rev.*, December, 1946.

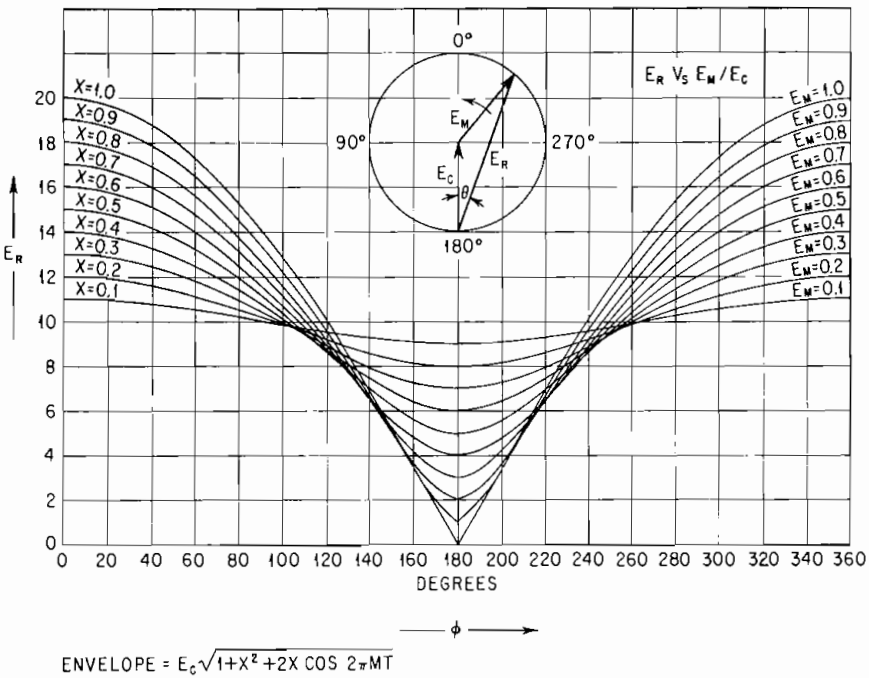


FIG. 3-7. E_c envelope for various modulating levels.

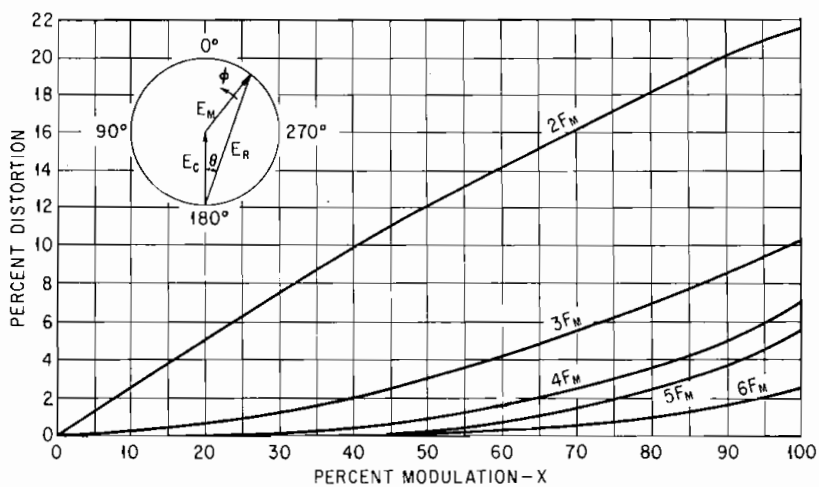


FIG. 3-8. Harmonic distortion with high modulation levels.

shows the various harmonics in this distorted wave. It is clear from these figures that detection of the envelope of E_m and E_c, i.e., E_r for various ratios of E_m and E_c between zero and unity, by an envelope- or diode-type detector will result in large distortion. More will be said about this later.

The phase shift θ of the resultant wave E_r for various depths of modulation is given by

$$\theta = \tan^{-1} \frac{X \sin 2\pi MT}{1 + X \cos 2\pi MT}$$

and is shown in Fig. 3-9 for different values of X, i.e., depths of modulation.

Note that θ = zero at the positive peak of the modulation cycle, i.e., $\phi = 0°$, and also at the most negative point, $\phi = 180°$. However, at the most negative point θ is changing most rapidly and at X equals 1 (Mod. = 1), θ changes from -90 to $+90°$ instantaneously. Also, $d\theta/dt = K$, except at 100 per cent negative modulation; i.e., θ is a sawtooth wave with infinite slope at 100 per cent negative modulation. Note that the phase scale for θ at the left of the figure is for the output of the adapter after phase multiplication of 5¼, and at the right side the scale is for the phase shift at the input to the limiter in the adapter.

The instantaneous change of frequency, or $d\theta/dt$, over the modulating cycle is of considerable interest because it will determine the phase shift of the transmitted carrier and, therefore, the phase-modulated sideband spectra.

$$\frac{d\theta}{dt} = \frac{d}{dt}\left(\frac{\tan^{-1} X \sin 2\pi MT}{1 + X \cos 2\pi MT}\right) = fd$$

$$fd = \frac{M}{\dfrac{\cos 2\pi MT + 1/X}{\cos 2\pi MT + X} + 1}$$

fd vs. X, i.e., depths of modulation, is shown in Fig. 3-10, which shows that at 100 per cent modulation the frequency deviation from carrier frequency is constant and equal to half the modulating frequency M for all points of the audio cycle except at the instant the audio cycle passes through the 100 per cent negative modulation point, where the frequency deviation or instantaneous change of frequency is infinite. From a practical viewpoint the frequency-multiplier-divider chain of the Kahn adapter will not follow such a rapid change of frequency, so the 100 per cent modulated point, as far as phase shift is concerned, must be avoided. Even if the Kahn adapter could follow such a rapid phase shift, the standard-band broadcast transmitter would not.

Such a situation is avoided by simply not phase-modulating the adapter above 85 to 90 per cent, which, as shown in Fig. 3-10, holds the instantaneous frequency within reasonable limits. Note that there is considerable disymmetry in the deviation frequency over the modulating cycle.

Since the phase-shift sidebands are a function of the rate of change of phase, and they, in turn, are amplitude-modulated by the audio modulation in the modulated amplifier of the transmitter, there is the necessity for the proper amount of phase shift for each modulation depth as it relates to the audio modulation if sidebands are to be eliminated from one side of the carrier and the resultant radio-frequency envelope is to be an undistorted replica of the original audio.

It should be noted, however, that the Kahn adapter has considerable latitude in the control of the generation of both the phase-shift and, therefore, phase-modulated sidebands and the depth of audio modulation. By using varying depths of modulation as applied to the full-carrier single-sideband portion of the adapter and by applying a phase stretcher device (5¼), it has been demonstrated and measured at KDKA that the adapter does permit undistorted reception by envelope detectors in standard broadcast receivers of a full-carrier single-sideband radio-frequency spectra.

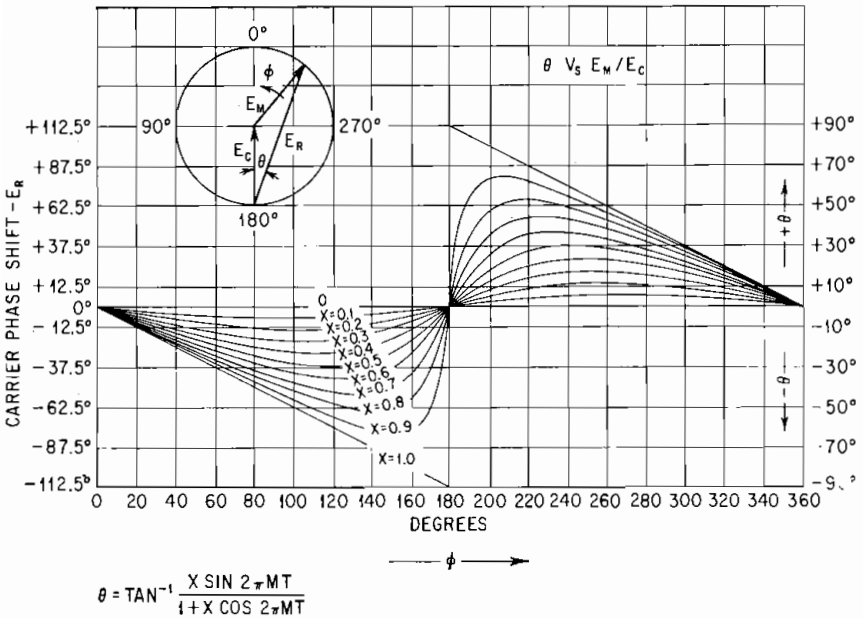


FIG. 3-9. Phase shift with varying modulation depths.

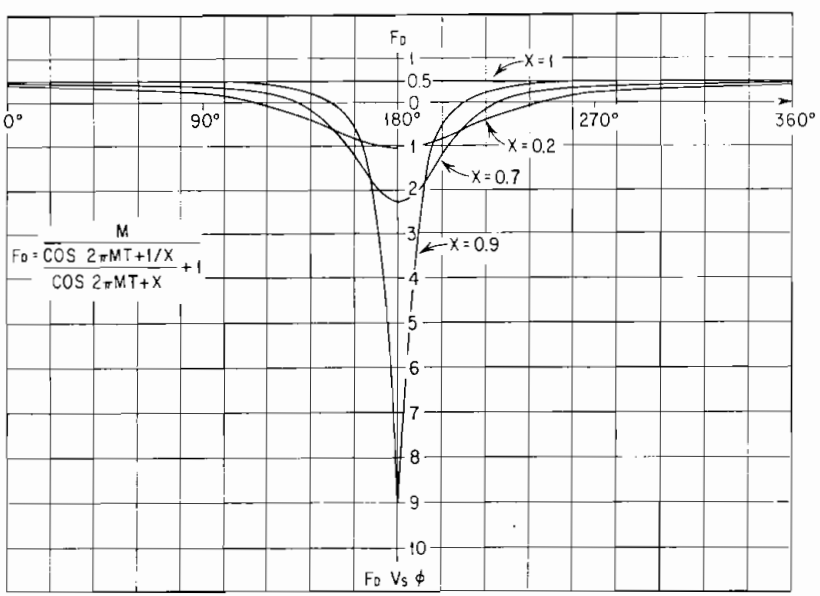


FIG. 3-10. F_d vs. ϕ; note constant frequency deviation from carrier frequency at 100 per cent modulation.

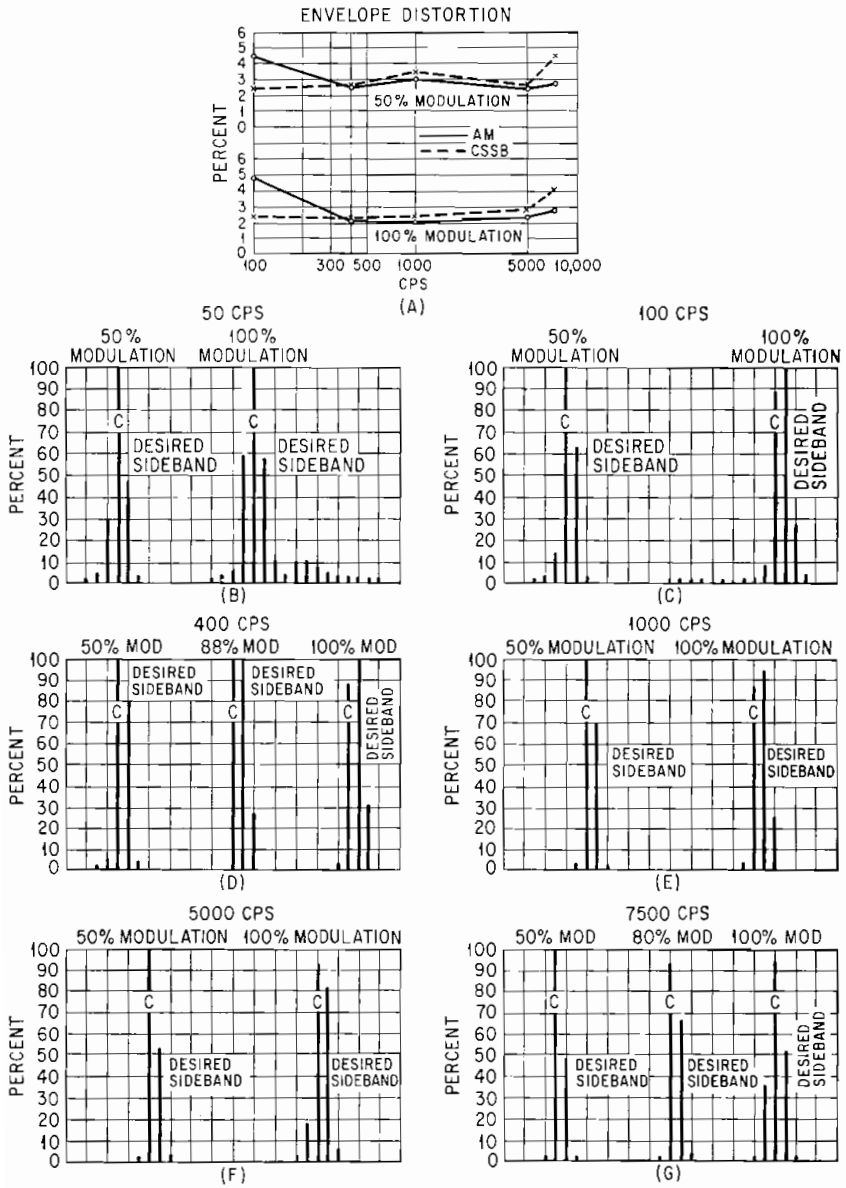


FIG. 3-11. (*A*) Envelope distortion with double and single sideband for modulation percentages of 50 per cent and 100 per cent. (*B*)–(*G*) Sideband distribution for various modulation frequencies and percentages.

Transmitter Measurements

Measurements of the performance of KDKA's transmitter when the adapter was used were considered of prime importance, since the results of field measurements and reception tests would be controlled by the radiated output of the transmitter.

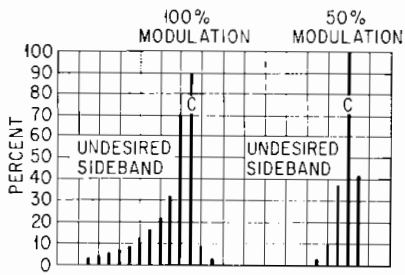


FIG. 3-12. Transmitter sidebands with phase modulation only for 50 and 100 per cent modulation.

Measurements of the frequency response and distortion at all levels of modulation and all frequencies between 50 and 8,000 cycles were made. The transmitter performance was very much the same with CSSB and with normal DSB.

Figure 3-11*A* shows envelope distortion at 50 and 100 per cent modulation for DSB and CSSB types of modulation.

The small difference in envelope distortion with CSSB vs. DSB is easily explained if it is understood that the transmitter is amplitude-modulated with the normal audio and in the normal manner. (KDKA's transmitter is high-level plate-modulated.) Thus, if the input and output radio-frequency circuits of the modulated amplifier are sufficiently broadband, the amplitude modulation of this amplifier when it is also phase-modulated will cause no distortion of the output radio-frequency envelope. The *phase shift merely redistributes the radio-frequency spectra of the output amplitude-modulated envelope.* With little or no phase shift the spectra will be essentially symmetrical, i.e., double sideband. As phase modulation is increased,

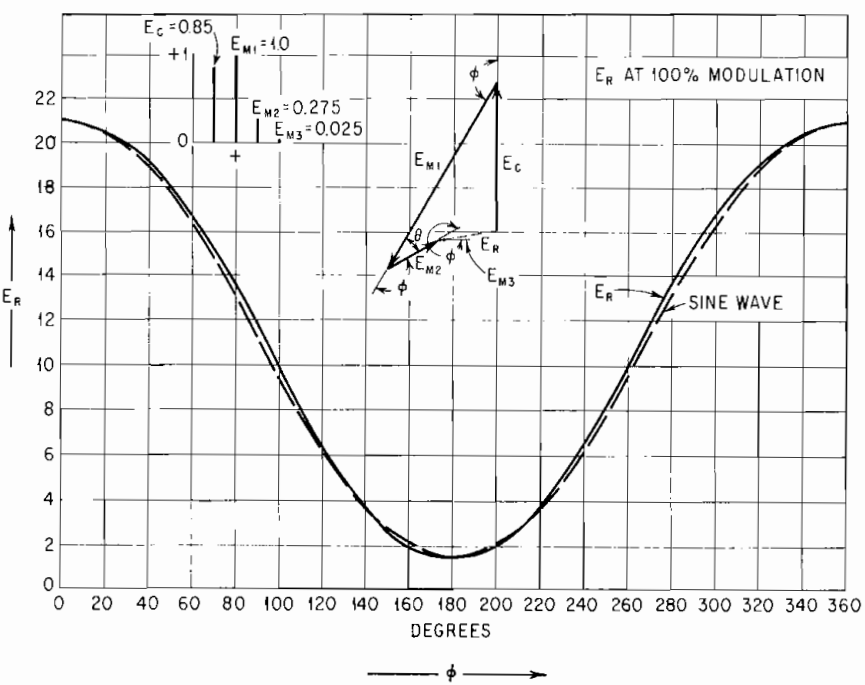


FIG. 3-13

there will be a value of phase shift for each depth of amplitude modulation where output spectra of the radio-frequency-modulated amplifier will be essentially full-carrier single sideband.

Figure 3-12 shows the sidebands in the transmitter output with phase modulation only, for 50 and 100 per cent phase modulation (i.e., zero-amplitude modulation). Note the asymmetry of these sidebands and the number of them, particularly at 100 per cent modulation. When these sidebands are amplitude-modulated, the resultant is a full-carrier single-sideband output as shown in Fig. 3-11*B* to *G* for various frequencies and depths of modulation.

Note that at amplitude-modulation levels above 50 per cent a *second-order* sideband on the desired side is developed which at amplitude-modulation levels approaching 100 per cent is approximately *25 to 30 per cent of the amplitude of the full carrier, which at this point is reduced to about 85 per cent of its zero-modulation amplitude.* Note, also, that the first-order desired sideband is greater than the carrier at this point and is usually equal to the carrier amplitude at zero modulation.

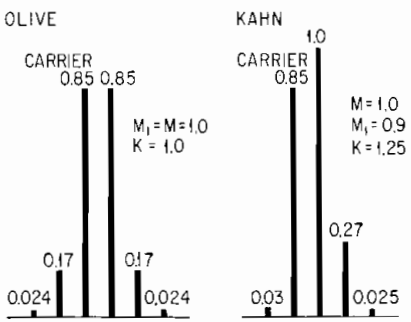


FIG. 3-14

It will be recalled from Figs. 3-7 and 3-8 that it is impossible to have a distortion-free envelope with only two frequency components for each modulating frequency (i.e., carrier and one side frequency), particularly at high levels of modulation.

Since measurements show little envelope distortion, it is clear there is a need for more than one order of side frequency for each modulation frequency. Figure 3-13 shows an example of the components needed at 100 per cent amplitude modulation with all the components on one side of the carrier. Note that the carrier is 0.85, the first-order desired side frequency 1.0, the second-order desired side frequency 0.27, and the third-order desired frequency 0.025. This envelope has less distortion than the nonlinearity of the transmitter, so normally the third-order desired component will be masked by transmitter nonlinearity. It should be noted that the radiated spectra agree quite well with this requirement, particularly at mid audio band.

Figure 3-14 is of interest in that it shows the sideband spectra predicted by the C. A. Olive compilations based on a slightly different arrangement of phase shift vs. amplitude modulation from that used in the Kahn adapter and *measured spectra on the transmitter output when the adapter is used at KDKA.* It should be noted that *both spectra have very little envelope distortion.*

Received-signal Observations

Field tests of signals from transmitters using the Kahn adapter have been the subject of considerable controversy, probably partly due to the fact that it is at best a subjective matter and, perhaps not less important, the results are highly dependent on the characteristics of the receivers used and how they are tuned.

Some understanding of the probable characteristics of the output signals can be obtained by referring to Figs. 3-15 to 3-17, which are typical receiver-selectivity curves. It will be noted for the narrowest band receiver that the response will be down about 6 db, 2 kc off resonance and for the widest band receiver only about 1 db down.

It is clear that these three receivers will show different results between double and single sideband.

The wideband receiver will very likely not be able to discern any difference between DSB and CSSB. On the other hand, the narrow-band receiver will certainly

show a difference, particularly if it is tuned, as is normally proper on CSSB, off resonance between 1 and 2 kc. Generally, such tuning will make the CSSB signal sound more treble and, if the transmitter isn't modulating heavily on either double or CSSB, make it sound louder.

The reason it will sound louder on CSSB is that off-resonance tuning tends to enhance the amplitude of the side frequencies and attenuate the carrier, giving the

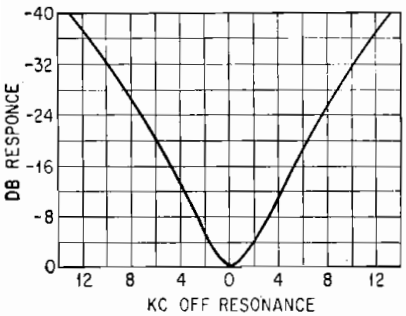


FIG. 3-15

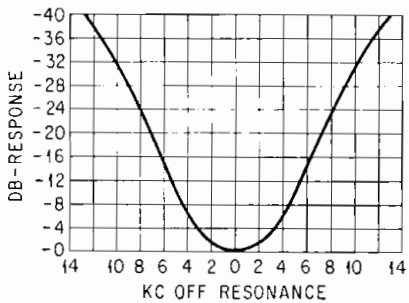


FIG. 3-16

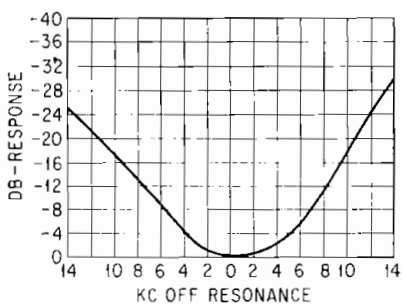


FIG. 3-17

FIGS. 3-15, 3-16, and 3-17. Typical receiver-selectivity curves.

effect of increasing the depth of modulation. However, if the transmitter is deeply modulated, it will be found impractical to tune off resonance, but very slightly, owing to the overmodulation distortion effect arising from such tuning.

It must be remembered that the CSSB wave *is very sensitive to envelope distortion* if the several components (carrier and first- and second-order side frequencies) are disturbed in their amplitude relationship; it is clear, especially at high modulation levels, why off-resonance tuning will create large amounts of distortion.

For example, taking the narrow-band receiver and tuning it off resonance by 2 kc would attenuate the carrier with respect to a 2-kc side frequency by 6 db. Now, assume that the transmitter was modulated approximately 50 per cent by a single 2-kc sine wave. The CSSB spectra would be radiated with the carrier at unity, the first-order side frequency at approximately 0.6 with little evidence of any second-order desired side frequency.

The narrow-band receiver, however, would amplify and attenuate these two frequencies 6 db differently. The carrier would end up around 0.5, and the 2-kc side frequency 0.6. Such a relationship would have about 20 per cent envelope distortion and would require a second-order side frequency of about 20 to 25 per cent to reduce the distortion to tolerable values.

The above discussion leads immediately into results of reception tests to determine CSSB ability to reduce selective fading distortion. It is well known that *suppressed-carrier single-sideband* transmissions as received by an exalted-carrier-type receiver have a very considerable immunity to selective fading distortion. This is, of course, because of the ability to reinsert a large carrier component at the receiver so that the envelope detector sees a wave which has very small side-frequency components, i.e.,

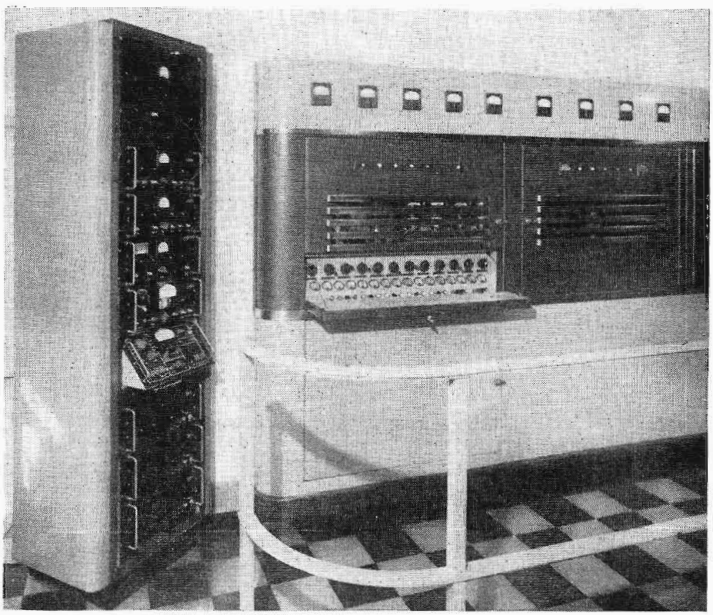


FIG. 3-18. CSSB equipment installed at KDKA, Pittsburgh, Pa.

low modulation, and is therefore not affected by phase or amplitude changes of the side frequencies in so far as distortion is concerned.

This, of course, is not the case for double-sideband transmission, where a change of phase between the carrier and the side frequencies will create large amounts of distortion. In *full-carrier single-sideband* system it would appear that if low depths of modulation could be tolerated, some approach to the immunity of the suppressed-carrier single-sideband system to selective fading distortion could be obtained. (This would also be the case for all levels of modulation on CSSB if an exalted-carrier-type receiver were used.) However, low per cent modulation cannot be tolerated, so any improvement along this line cannot be relied on. On the contrary, with the normally high levels of modulation which will cause the carrier and the first-order desired side frequencies to be approaching each other in amplitude as well as the presence of a second- or even third-order desired side frequency, at least three of the four need to retain *their original amplitude ratios* and phase relations among the three desired side frequencies. Also, if the receiver is narrow banded and tuned off resonance, the distortion due to unequal amplitude fading of the various carrier and side frequencies will be unfavorably affected, as such tuning tends to attenuate the carrier and thus further remove the transmission from immunity from amplitude and phase changes.

Conclusion

In spite of the above facts, not a single complaint of bad reception of any type has been received from KDKA's transmissions on CSSB for a period of over 5 months.

Various measurements on different receivers indicate that, with normal care, any receiver which is acceptable for double-sideband transmissions will be satisfactory for CSSB. Some narrow-band receivers will need to be tuned slightly off resonance for best reception. Broadband receivers give little indication of change of tuning from DSB to CSSB.

In strong signal areas with broadband receivers there is difficulty in choosing between DSB and CSSB.

On CSSB narrow-band receivers show, if tuned off resonance, some gain in treble response and in some cases, particularly if the transmitter is not modulated heavily, a louder signal.

Results in noisy low-signal-level areas favor the CSSB signal, especially if a narrow-band receiver is used and the transmission is predominantly voice.

Results of field tests on selective fading distortion will have to be evaluated on a statistical basis, as the difference is apparently only slightly in favor of CSSB. This is yet to be done, even though a considerable amount of tape recording has been made alternating the transmission between CSSB and double sideband, either under control of the field receiving location or at timed intervals of short periods such as a change from CSSB to DSB every 3 min.

The chief gain to KDKA of using CSSB is the reduction of adjacent-channel interference between KDKA on 1,020 kc and WBZ in Boston on 1,030 kc. The removal of KDKA's upper side frequencies has relieved interference to WBZ's reception, and the ability of receivers tuned to KDKA to tune slightly off resonance away from WBZ and toward the radiated lower sideband of KDKA has also given KDKA some additional immunity from WBZ.

In our experience with the Kahn adapter at KDKA it has been reliable, stable, and simple to operate.

Part 4.

UHF TELEVISION TRANSLATORS

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INTRODUCTION

General Considerations

Translator rebroadcasting of television signals has become a proved method of extending service to remote or shielded areas. By this method television has been brought to many communities too small or areas too sparsely populated to support even a single channel of regular television broadcasting. Communities with this type of service are as small as a few hundred people, while larger population groups have as many as five channels operating. Figure 4-1 is a typical translator site.

Translator rebroadcasting retransmits the signal on an assigned channel which can be received by anyone. This service must, therefore, be supported by indirect means such as public subscription or an appropriation by a local governmental unit or by a private group which operates it as a public service. A number of regular TV broadcast stations operate translators as a means of filling in their coverage.

The term "translator" might equally well be applied to any device which changes a signal from one channel to another for any purpose. However, in practice it has come to mean a device which receives an incoming signal off the air and rebroadcasts it on another channel. Any required channel can be received. However, the conversion must result in an output which is on the channel assigned for transmitting, normally one of the UHF channels from 70 to 83.

While several methods of processing the input signal into an output on a new channel could be used, the simplicity and reliability of the heterodyne-repeater method have resulted in its universal selection. Heterodyne repeating takes advantage of the same principle of mixing as used in superheterodyne receivers. However, in this application the sum of two signals rather than the difference is selected to produce an output in the desired part of the UHF band. When an output is produced in a frequency band where licensing is available, similar equipment can be successfully used for many other types of services, such as point-to-point television relays, and for broadcasting, rebroadcasting, or relaying other types of intelligence, such as telemetry carriers. Other types of modulation, such as single-sideband and various types of pulse modulation, can be transmitted. However, in this article, except as otherwise mentioned, the term "translator" will apply to television rebroadcast apparatus with an output in the UHF band on one of the channels assigned for translator service.

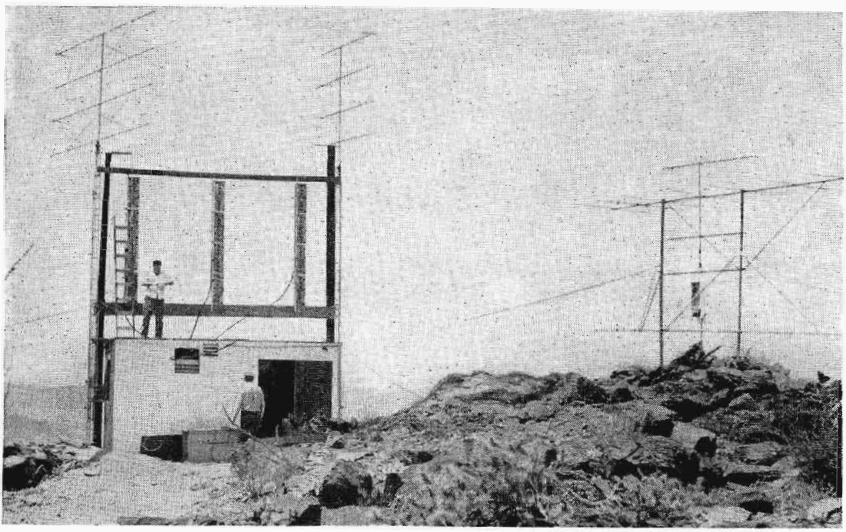


FIG. 4-1. Typical translator installation. Three channels are rebroadcast to Blythe, Calif., in the Palo Verde Valley. The area covered is 50 miles wide by 35 miles deep. The received signals from Phoenix, Ariz., are translated as follows: Channel 3 (KTVK) to Channel 71, Channel 10 (KOOL-TV) to Channel 75, and Channel 12 (KVAR) to Channel 79. (*Courtesy of Industrial Television, Los Angeles, Calif.*)

Elements of a Translator Installation

The three distinct elements found in any translator system are:

1. The signal reception system to deliver an adequate input signal. This signal must contain a minimum of noise and extraneous pickup. Its magnitude must be sufficiently above the input noise of the translator channel amplifier to allow a noise-free picture.
2. A properly designed translator which will reproduce the signal without compression, with adequate and preferably adjustable sound carrier, without cross modulation, and without spurious outputs.
3. A transmitting-antenna system which will make maximum use of the available power output at the end of the transmitter transmission line and deliver this power to the proper area. Directional antennas are almost invariably utilized to deliver the signal to the center of population. The antenna array must have a low VSWR to prevent reflections which would be radiated as "ghosts."

SIGNAL-RECEPTION SYSTEM

Basic Requirements

The signal-reception system for a translator installation is faced with the same basic problems as any other installation of a TV broadcast receiving antenna in a fringe area. The system must deliver a signal of sufficient strength to the translator and discriminate against any interfering signals or noise as completely as possible.

Noise Considerations

The noise of a VHF signal received off the air depends upon noise contributions from two sources. These are noise which is received by the antenna along with the signal and the extraneous noise introduced by the electronic circuits in the translator.

At the low end of the VHF band, the electronic circuits are relatively quiet and the noise received by the antenna relatively high, so the latter is usually the limiting factor. Conversely, at the high end of the VHF band the received noise is significantly less and the electronic circuits are appreciably noisier. Thus, at the top end of the VHF band the limitation is usually found to be the inevitable noise of the translator input circuit.

The noise received by the antenna is specified in terms of a fictitious "equivalent temperature." This is the temperature of an ideal resistance which would have the same available noise output voltage as does the antenna from the noise it receives. Thus, antenna temperatures greater than 290°K correspond to more noise than available from an ideal resistance at room temperature, while antenna temperatures less than 290°K represent correspondingly less noise. The effective antenna temperature will vary with the frequency of the received signal in the VHF region and with the direction to which it is pointed and will be influenced by any local sources of man-made noise, particularly at the low end of the band. Typical equivalent temperatures of a receiving antenna range from 4600°K (12 db noisier than a resistor) at Channel 2 to 180°K (2 db less noisy than a resistor) at Channel 13. The inevitable noise contributed by the electronic circuitry is usually specified in terms of the "noise figure" of the equipment. A rigorous definition of the concept of "noise figure" as a measure of the noise added to a signal by an amplifier must be left to other sources.*

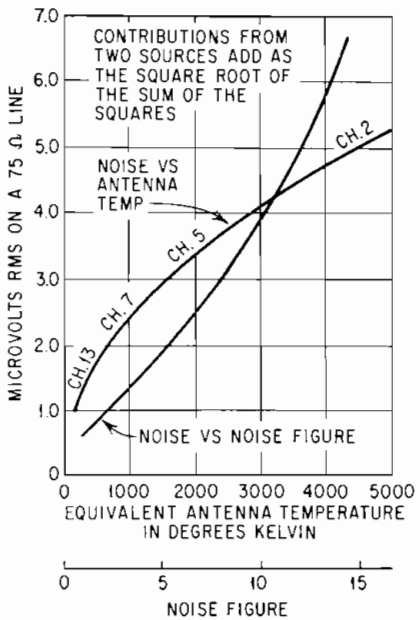


FIG. 4-2. RMS noise voltage contributed by an antenna vs. its equivalent temperature and by a receiver vs. its noise figure. The sum of the noise voltages from these two unrelated (noncoherent) sources is the square root of the sum of the squares of the two voltages. It covers most of the noise added to the signal in a translator installation.

As a practical guide to the installation of translators Fig. 4-2 provides typical values of noise voltage on a 75-ohm line (6-Mc bandwidth) for a range of antenna temperatures and amplifier noise figures.†

A good low-noise preamplifier will have a noise figure of 3 to 4 db on the low VHF channels and about 1 db more on the high channels. Ordinary channel amplifiers exhibit noise figures of 6 to 15 db, again with the better performance on the low channels. The recommended signal strength in microvolts at the output of the transmission line from the antenna is a signal 40 db greater than the rms combination antenna noise and extraneous amplifier noise.

The normal signal strength must be sufficiently above the minimum value to provide a margin for the inevitable fading of fringe-area signals. The depth and duration of fades vary with each location and must be determined as a matter of experience at a particular receiving site. A desirable fade margin would be 20 db above the bare minimum indicated for a 40-db signal-to-noise ratio. In most instances, fades deep enough to produce a noisy picture would then be very infrequent and of short dura-

* Superscript numbers refer to references at end of this part. See Refs. 1 and 2.

† For transmission-line impedances other than 75 ohms, multiply the rms noise voltage by $\sqrt{Z/75}$. More general curves are given in Ref. 1.

tion. In addition, the signal must be of sufficient strength to produce good AGC action in the translator itself.

Amplification at the Antenna

Best results will be obtained if the first amplification of the signal takes place as close to the antenna terminals as possible. The improvement gained in return for the effort of mounting an amplifier in a weatherproof housing at the antenna location can make the difference between a successful and unsuccessful installation in those instances where the signal is marginal. The longer the transmission line between the antenna and the translator, the more important it is that some VHF amplification be provided between the antenna and the transmission line.

Translators are normally constructed with two self-powered VHF channel amplifiers. When dealing with medium to fairly weak signals one of these channel amplifiers can be removed from its normal position in the translator and located at the antenna terminals. For very weak signals best results will be obtained through the use of a separate low-noise channel amplifier. The additional gain of such an amplifier will ensure more than adequate signal at the translator for proper operation of the AGC circuits. Furthermore, such an amplifier designed and tested to have a low noise figure will contribute significantly less noise to the signal than an ordinary channel amplifier.

Preamplification before the transmission line improves the signal-to-noise ratio in three ways. First, even for a long transmission line the preamplifier will more than make up for the cable loss, so the signal at the input to the first channel amplifier in the translator will be well above the internal noise. Second, the attenuation losses in the transmission line are the equivalent of resistance in the circuit, which in turn contributes noise. A preamplifier added to this transmission line raises the signal level well above the noise generated in the cable. Third, with a higher signal level in the transmission line and at the input to the translator, the possibility of picking up extraneous signals at the input of the translator or in the transmission line is minimized. This is particularly important in installations where the translator is located physically close to other transmitters such as the fixed stations associated with mobile systems. In such an installation the receiving antenna may be located some distance from the other transmitter units and their antennas and possibly shielded from them, even though the translator itself shares the same building. Preamplification raises the level of the desired signal before it enters the area where pickup is possible. Thus circuits which could pick up extraneous signals when operated at a low level are, in fact, operated at high level. In cases of extreme interference from other transmitters, power lines, or gasoline-driven generators, double-shielded cable has been found helpful in eliminating pickup.

Receiving Antennas

In order for a translator to transmit a picture of maximum quality, it is necessary that the signal at its terminals be as free from degradation of any sort as possible. In any area local practice with respect to receiving antennas for fringe-area signals is a good starting point. These antennas will have been designed to cope with local conditions, environmental and otherwise. A combination of the best features of local practice and the refinements outlined below should be combined in selecting the receiving-antenna elements. Figure 4-3 is a receiving-antenna installation.

An advantage can be obtained by having the receiving antenna cut for the particular channel of the incoming signal.

High-gain receiving antennas will deliver more signal voltage, which is helpful when the amplifier noise is the limiting factor. When received noise ("antenna temperature") is the limitation, however, a high-gain antenna will not produce an improvement unless a major part of the noise is from a discrete location in a direction well away from the direction of the received signal.

When signals on two or more channels are desired for running multiple translator

installations, separate receiving antennas to feed each translator have proved to be most desirable. Not only do broadband antennas represent a compromise on each of the channels on which they are used, but the angle, both vertical and horizontal, from which the signal arrives may be different for the various channels. Even for signals from a common geographical location, the compromise between extraneous pickup and

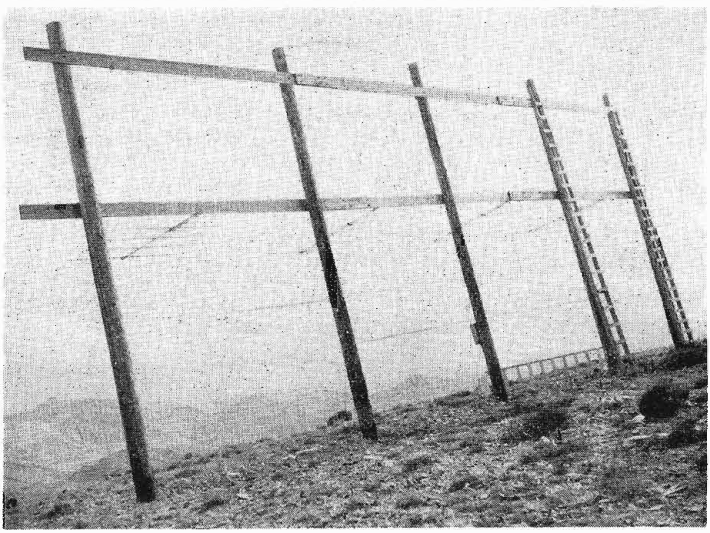


FIG. 4-3. A receiving-antenna installation for Channel 2 located on Serro Gordo Mountain 150 miles northeast of Los Angeles, Calif. Although it is below the "line of sight" from the transmitter, the measured signal strength from the array is 1 mv. Chicken wire stretched across the poles screens the antennas from signals from the rear. Note the preamplifier in a weatherproof box on the center pole. The translator shares a building with two fixed 250-watt VHF mobile-system transmitters, so the cable from the antenna was buried in conduit to minimize pickup. (*Courtesy of Industrial Television, Los Angeles, Calif.*)

the desired signal may be different for each channel. For instance, one received channel may be free from co-channel or on-channel interference from unwanted stations while another channel subject to these interferences may require unusual antenna orientation to minimize them.

TRANSLATORS

Fundamental Block Diagram

A translator must convert a low-level VHF signal to a high-level UHF signal. Ideally it must accomplish this conversion without altering the signal in any way except for changing the frequency of the carriers. Practically it must not degrade the signal in any way in an amount which will be detectable on a good-quality receiver. It is highly desirable that any degradation be held well below the limits of detection so that translators can be run in cascade. In addition, a translator, to comply with the licensing rules, must contain auxiliary circuits for periodic automatic identificaton and for remote control on a fail-safe basis. Before type approval is issued by the Federal Communications Commission for a translator, it must demonstrate the aforementioned features, including the ability to reproduce a picture without degradation, and it must have all spurious emissions radiated either from the antenna with the desired signal or directly from the equipment, reduced to acceptable levels.

A block diagram of a translator meeting these requirements is shown in Fig. 4-4. The VHF preamplifier raises the received signal to a convenient level in the neighborhood of 1 volt. It also exercises the automatic-gain-control function. This signal is combined with a UHF crystal-controlled signal in a vacuum-tube-type mixer. The final ontput channel is the sum of the injection frequency and the input-channel frequencies. The sum signal passes through three stages of linear amplification and a power monitor before being fed to the antenna transmission line.

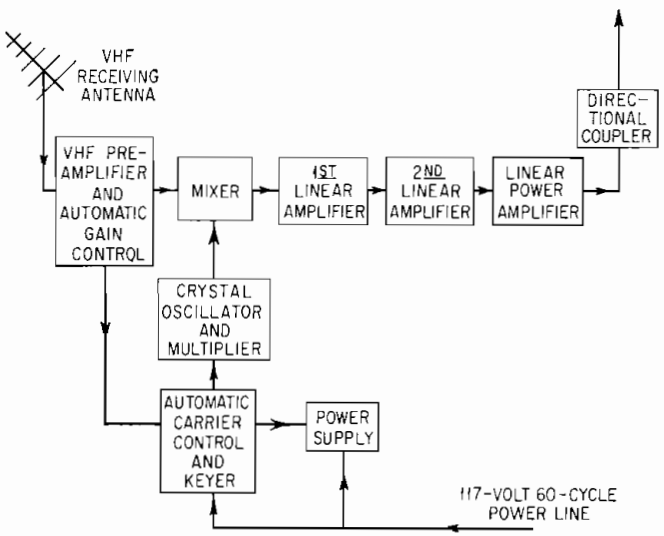


Fig. 4-4. Block diagram of a 10-watt translator.

The automatic-carrier-control and keyer unit controls the plate power of all circuits after the VHF channel amplifiers. It activates these stages only if three conditions are satisfied. These are as follows: A proper VHF signal must be present, a pair of remote-control terminals are closed, and the high-voltage interlocks and the air-flow switches indicate proper operation. In addition, it contains a 30-min timer and the code wheel which periodically identifies the translator station in Internatioual Morse Code.

VHF Amplifier

The VHF channel amplifier must provide the mixer with a constant-value signal even in the presence of fading of the input signal. It must have the power capability to drive the mixer. The VHF amplifier contributes to the over-all bandpass characteristic of the translator, rejecting signals outside the desired channel. By various higher-order mixing combinations, even weak off-channel signals might produce an output in the desired UHF channel, and strong undesired signals which overload the mixer would be quite certain to cause interference.*

Typical system requirements call for the VHF amplifier to deliver 1-volt peak sync, plus sound, to the mixer and to do this with as little as 1-mv normal input signal. This requires 60-db gain. Two typical channel amplifiers connected in cascade which have been used for this purpose have a maximum total gain of 80 db and an AGC

* For instance, if it were not rejected by the VHF amplifier, a frequency which is one-half of some frequency within the desired input channel conld, through second-harmonic generation as well as heterodyning in the mixer, produce a signal in the desired UHF passband.

range of approximately 20 db. If the gain of this combination of amplifiers is reduced 5 db, 15 db of AGC will be left to cover fades and 5 db will be left to take care of any unexpected increases in signal strength without overloading the amplifier. Such a combination will reduce fades of 15 db to a 1.0-db variation in output power. One thousand microvolts (1 mv) has beeu chosen as the minimum rated input for the normal signal because such a sigual can be expected to carry with it occasional fades of 15 db. If the rating were carried to lower input signals, not only would there be insufficient gain in the channel amplifiers but especially during fades the signal would become low enough so that the input noisc of the first channel amplifier would be excessive. When traulators are required to be operated on a signal smaller than 1,000 mv, an exterual preamplifier should be included to overcome both the gain and input noise limitations.

Mixers

The function of the mixer is to produce new frequencies at the output channel through the combination of the input-channel frequencies and an injection frequency. The required heterodyne action is the result of a characteristic of nonlinear devices, the outputs of which contain uew components which are the sum and difference of the two inputs. In this application, both the visual and aural signals are heterodyned simultaneously to the new band, using the sum of the VHF input and the injection frequency. A typical conversion is shown in Fig. 4-5. If a higher injection frequency were used such that the difference signal instead of the sum fell in the desired band, the visual and aural carriers in the final signal would be inverted and improper operation would result.

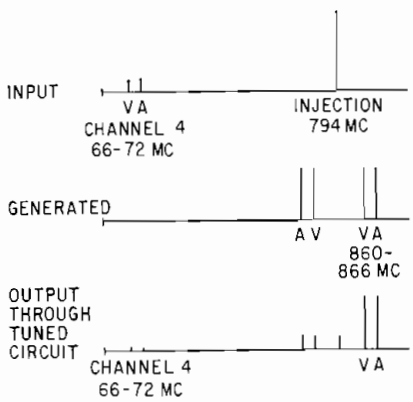
A perfectly linear stage will produce no mixing. In such a stage the only components in the output will be those found in the input. When the output-vs.-input curve departs from linear, it is said to have higher-order terms. The output is in part proportional to the input and in part proportional to the square of the input, the cube of the input, etc. The term which represents an output proportional to the square of the input is the term which produces the desired mixing. Higher-order terms representing outputs proportional to the cube or the fourth power, etc., of the input produce spurious signals such as a combination of the second harmonic of the input signal plus the injection frequency, etc. An ideal mixer would be a device in which the output varied strictly as the square of the input. Even in this case, however, with two carriers as one input being mixed with an injection frequency, spurious outputs will result.*

The nonlinear device produces a 4.5-Mc beat between the two carriers. Spurious signals will also be found 4.5 Mc above and below the two carriers and with decreasing maguitudes at 9 and 13½ Mc, etc. above and below. The spurious products 4.5 Mc above and below the two desired carriers are the most troublesome because they are relatively large components and are close to the passband of the tuned circuits in the UHF stages. Other spurious products, such as a second harmonic of the injection frequency, for instance, will differ enough in frequency from the desired signals so that they will be rejected quite completely by the succeeding tuued circuits. In addition to being difficult to eliminate in the tuned circuits, the componeuts 4.5 Mc above and below the carrier are annoying because they can be tuned in on a receiver by error or conceivably interfere with another desired signal on a nearby channel.

Aside from the generation of spurious products, the linearity of mixing is important in retaining the quality of the picture information, the sync and blanking pulse heights, etc. The desired output sideband will exhibit very satisfactory amplitude linearity as long as the injection signal is much greater than the input-signal frequency. If the

* A diode mixer can be treated as a device in which the current is a nonlinear function of the applied voltage. A triode or pentode mixer can also be treated this way or by considering the variation of gm with grid voltage. See L. B. Arguimbau, "Vacuum Tube Circuits and Transistors," pp. 431 ff. and 291 ff., John Wiley & Sons, Inc., New York, 1956, for details of the two methods. The conclusions stated above follow if the signal is composed of two separate frequencies representing the visual and aural carriers; i.e., $Q(t) = Q_v \sin(\omega_v t + \phi_v) + Q_a \sin(\omega_a t + \phi_a)$, and the injection signal is a third frequency $P(t) = P \sin(\omega_p t + \phi_p)$.

signal amplitude is raised in level to obtain more output, a point will be reached where the nonlinearity of the tube becomes so violent that the higher-order terms, now large in magnitude, contribute serious distortion within the desired output passband. This usually first shows up as moderate sync compression and excessive spurious signals 4.5 Mc above and below the carriers. As the effect becomes more severe, intermodulation products show up as interference in the picture. The video signal will, through this intermodulation, amplitude-modulate the aural carrier to the point where it is difficult or impossible to remove the "sync buzz" in the aural channel of receivers. The same problems arise when the input signal is of proper amplitude but the injection voltage falls sufficiently below normal to result in an unfavorable ratio of the two signals.



	VISUAL	AURAL
CHANNEL 4	67.25	71.75
INJECTION	794.00	794.00
CHANNEL 79	861.25	865.75

FIG. 4-5. Frequency spectrum associated with a typical VHF-to-UHF conversion. The visual and aural carriers have the proper frequency relationship only in the upper sideband. The output circuit which is tuned to the desired sideband partially rejects the other potential outputs.

The most appropriate type of mixer for heterodyning to the higher UHF channels is a grounded-grid triode. The triode mixer allows operation at a considerably higher level than a crystal mixer and has more than unity conversion gain. The amount of amplification needed at UHF is thus reduced. The grounded-grid circuit produces valuable isolation between the plate circuit of the mixer and the input circuits. In such a stage both the VHF signal and the injection frequency source must be introduced on the cathode. Since these frequencies are quite different, it is possible to isolate each of them through a circuit which blocks the other. Thus, the injection-frequency source will not load the cathode circuit at the VHF frequency and vice versa. This is illustrated in Fig. 4-6. The plate circuit of the mixer stage must be tuned to the sum of the VHF input signal and the injection frequency. The necessity for achieving the full 6-Mc bandwidth occupied by the television signal is usually a limiting factor in the design of the plate circuit. It is desirable to have the plate of the mixer working into a double-tuned circuit critically coupled or slightly overcoupled in order to produce a flat top or slightly double humped curve. Optimum amplitude and phase characteristics will then be obtained. These circuits should be designed with a minimum of capacitance for optimum bandwidth. In practice, this means working with the irreducible minimum of stray capacitance present in the physical construction of the circuit. Physically the double-tuned circuit is located partly at the plate of the mixer tube and partly at the input of the succeeding stage, with the coupling supplied by the interconnection coaxial cable.

It is possible through the use of tubes with large power-handling capabilities to build mixers with large outputs. Such an arrangement, however, is not used for several reasons. A very high power injection source would be required for such a large mixer, and the unwanted products and straight-through signals at the output of the mixer would be comparable in size to the desired output of the apparatus. Several stages of filtering would be required to isolate the desired signal from the other products so that the spurious signals fed to the antenna would be reduced to an acceptable level. Furthermore, the generation of the spurious products at a high level would necessitate extreme precautions to prevent them from being radiated directly from the translator itself as cabinet radiation. If mixing is accomplished at a lower level, the

succeeding stages of tuned amplification act as filters in themselves, the spurious products are generated at a much lower level, and the cabinet radiation of the injection signal and spurious products is much less of a problem. Typical mixers for

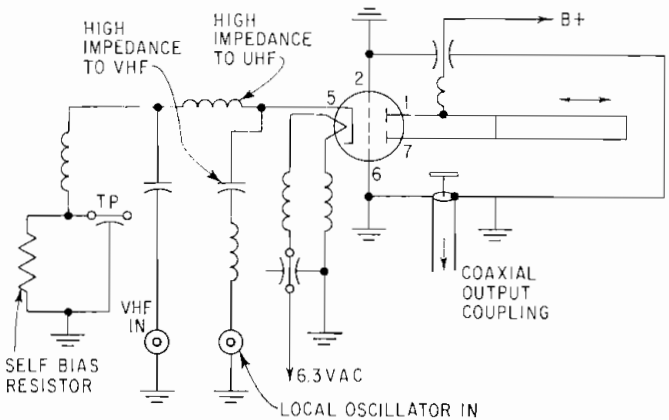


FIG. 4-6. Mixer circuit for heterodyning signals from VHF to UHF. The input circuits are lumped constants, while the output circuit is a half-wave open-circuited transmission line.

this application will generate desired signals of 10 to 100 mw. Above this, diminishing returns are obtained for the extra efforts involved.

Linear Amplifiers

In a practical translator several stages of linear amplification at the final output frequency are required. Because of the linearity requirement Class C stages cannot be used. However, Class B stages are used, especially at higher power levels, where efficiency becomes important as a limit on the maximum output available from a given tube. Intermediate stages are frequently run Class A to obtain maximum gain. At the usual translator frequencies the grounded-grid configuration is most practical as a means of preventing regeneration or oscillation. Self-bias is usually desirable as a means of stabilizing the d-c operating point of the tube, although this prevents complete Class B operation and results in fairly heavily biased AB operation instead. Figures 4-7 and 4-8*a* and *b*, show a schematic and photographs of a typical cavity stage capable of 10 watts output with 10-db gain and 6-Mc flat-top bandwidth. The input circuit of this stage consists of a transmission line terminated with an adjustable short circuit. In addition, the input connection to the transmission line is adjustable so that the signal can be fed into the transmission-line tuned circuit at a point which has an impedance of 50 ohms. Such an arrangement eliminates any loss from impedance mismatching of the input circuit and permits interconnection between cavities without critical dependence upon the length of a cable. The tuned-plate circuit of a driving stage and the input tuned circuit of a driven stage plus interconnecting cable are electrically equivalent to a lumped-constant double-tuned circuit. Since the input to an amplifier stage is inevitably quite lossy at these frequencies, the characteristics of the combination will be those of a double-tuned circuit in which the Q of the secondary is much less than the Q of the primary. A proper bandpass curve is achieved by adjusting the output coupling from the driving plate circuit. The plate circuit is also a concentric transmission line tuned with an adjustable shorting plunger. A short-circuited transmission line of less than one-quarter wavelength appears induc-

tive at the open end.* The short is therefore positioned at a point less than one-quarter wavelength from the tube where the line resonates with the inevitable capacitance of the tube and mounting. It is also possible to use a line slightly less than three-quarters or five-quarters, etc., wavelengths long if the one-quarter wave position

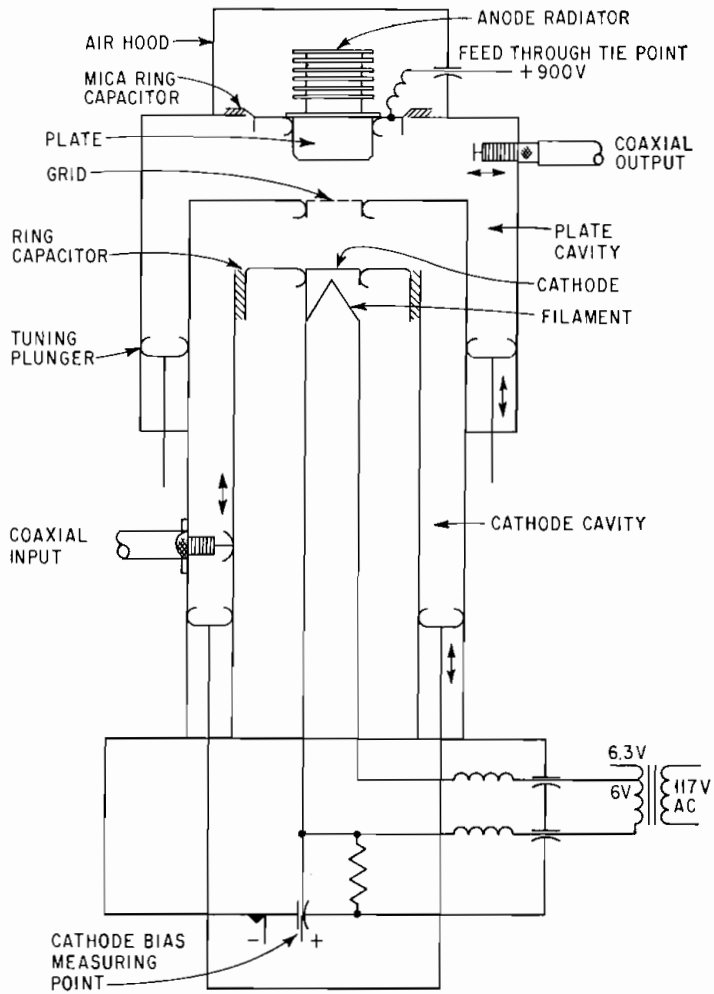
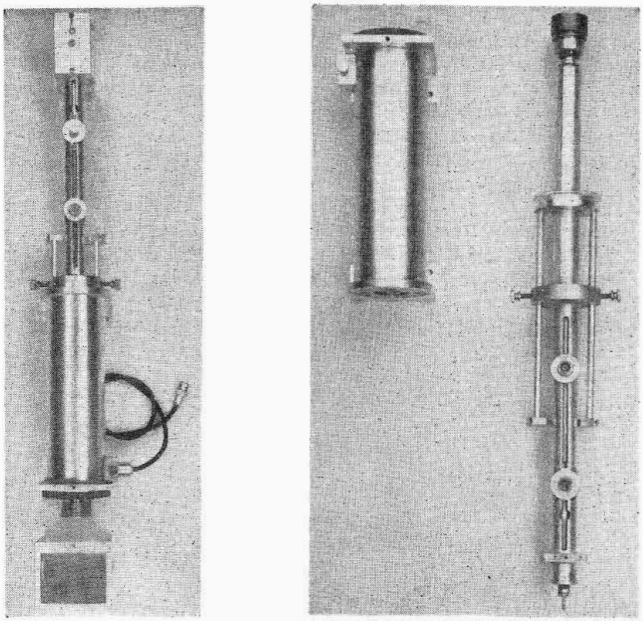


FIG. 4-7. Schematic diagram of a UHF amplifier cavity for the 2C39 family of tubes.

is so close to the tube as to be mechanically impractical. Such higher mode operation, however, results in a poorer gain-bandwidth product and is to be avoided if possible.†

* "NAB Engineering Handbook," 4th ed., pp. 5–1–03 to 5–1–05, National Association of Broadcasters, Washington, D.C., 1949. See also Ref. 1, pp. 567, 577.

† For a complete discussion of coaxial cavity amplifiers see Staff of the Harvard Radio Research Laboratory, "Very High Frequency Techniques," vol. I, chap. 15, McGraw-Hill Book Company, Inc., New York, 1947.



(*a*) (*b*)

FIG. 4-8. (*a*) Photograph of a UHF amplifier cavity with the air-flow hood lifted to show the 2C39 tube in place. (*b*) The same cavity partially disassembled to show the plate circuit inner conductor and shorting plunger. The grid ring of the 2C39 tube is inserted into a ring of flexible fingers at the top of the inner conductor. The tuning range is 450 to 900 Mc. (*Courtesy of Adler Electronics, Inc.*)

Injection Sources

To complement the mixer, an injection signal must be provided. The signal source whose frequency is the difference between the input and output frequencies must supply sufficient power for linear mixing with about 0.005 per cent frequency stability under all possible conditions of temperature and voltage. Higher accuracy is required if translators are to be run in tandem (tolerances will add). Crystal-oscillator tolerances of 0.001 per cent are readily achievable without temperature stabilization and are considered desirable.

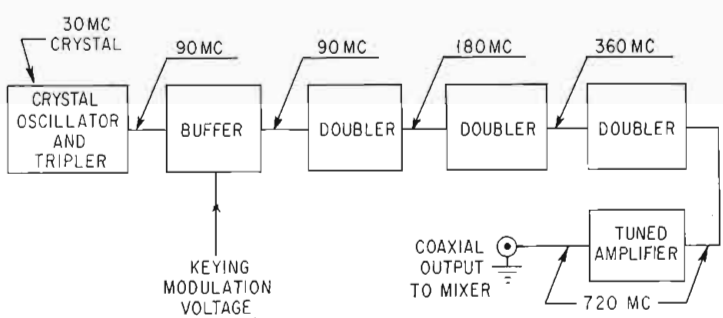


FIG. 4-9. Block diagram of an oscillator-multiplier chain. The output frequency is 24 times the crystal frequency.

In converting from one VHF channel to another relatively low frequency injection signals are required. These are supplied by a crystal oscillator followed by a doubler or tripler stage if required. For conversion to UHF a much higher frequency is required. Multiplication to twenty-four times the crystal frequency is typical. The block diagram of such a multiplier is shown in Fig. 4-9, and the frequencies involved in each possible conversion are listed in Table 4-1.

Certain precautions are necessary in the design of such a high-multiplication injection source. Each stage must be carefully arranged to preclude self-oscillation. Furthermore, each multiplier stage must be carefully isolated to prevent any improper signal components from feeding through. For instance, heater and plate power-supply leads must be electrically isolated with chokes and capacitors to prevent low-frequency components from traveling along these leads and appearing at the output of the multiplier chain. Such frequency components would lead to spurious responses in the mixer which in turn might show up in the output channel.

The careful bypassing of the leads mentioned above as well as the use of a housing which militates against RF leakage will both contribute to the reduction of extraneous radiated signals (cabinet radiation) to acceptable levels.

Control Circuitry

Auxiliary circuits must be included to perform functions required by the FCC rules for translators and by good engineering practice. These circuits through their control of the plate power to the stages succeeding the VHF channel amplifiers prevent

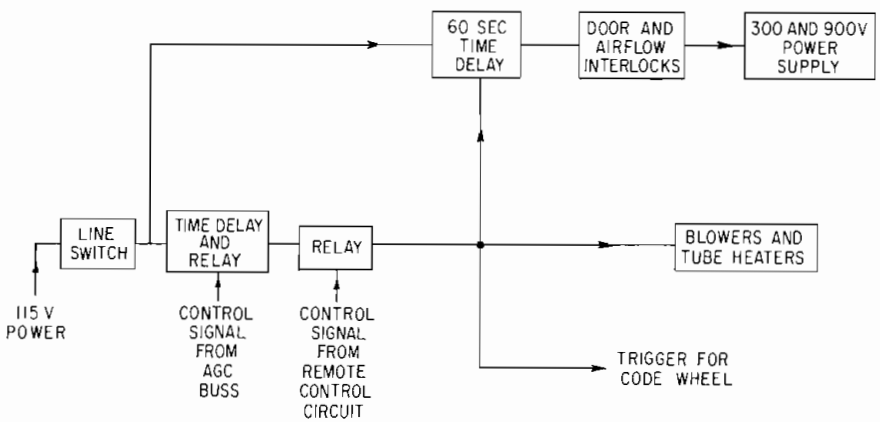
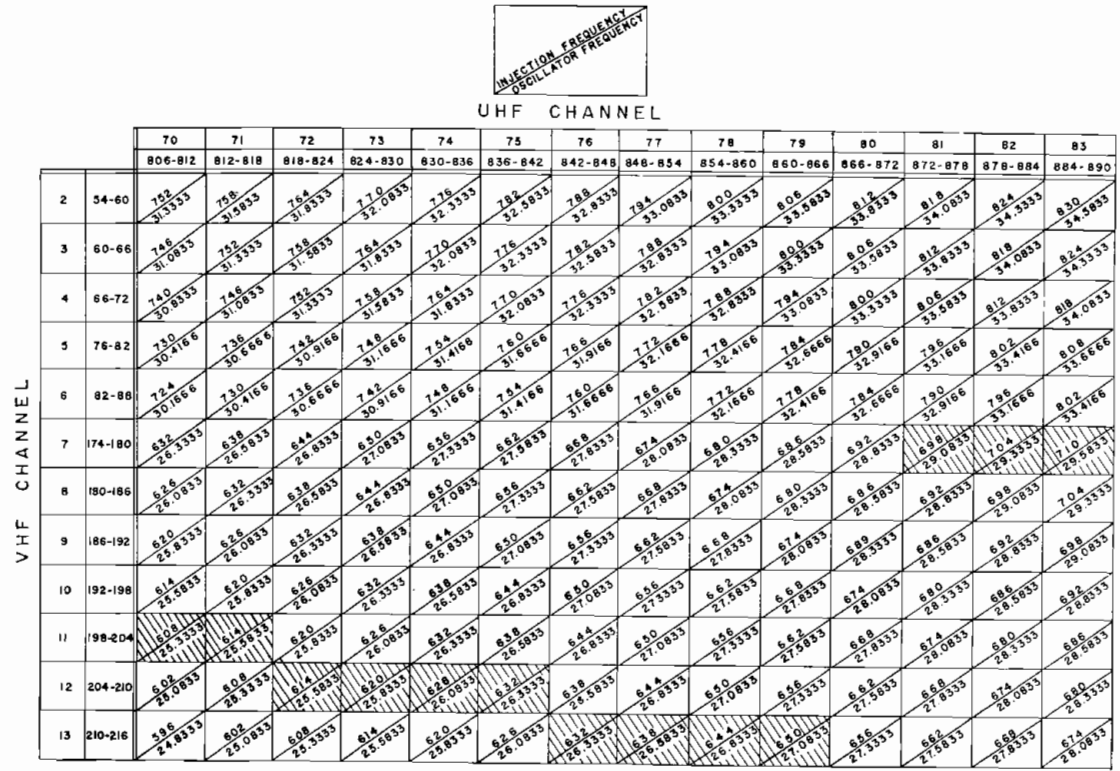


FIG. 4-10. Block diagram of the control circuitry in a translator.

operatiou of these sections of the translator unless the originating station is on the air. The high-voltage circuits are interlocked against the opening of that part of the apparatus that gives access to them and against loss of air flow at the forced-air-cooled UHF amplifier tubes. In addition, a code wheel and keying circuit are included for transmitting identification of the translator at appropriate intervals. Figure 4-10 is a block diagram of the control circuitry.

The first of the circuits in the control chain is the one which is activated when the desired input channel is present in sufficient strength for proper operation. In the absence of such a signal the translator is held inoperative to prevent the translation of spurious signals. The channel amplifiers would not have their gain reduced at all by AGC action. Thus, even a signal which is somewhat off the input channel might go through the translator with sufficient strength to produce a significant spurious output. This spurious output would fall outside the assigned channel of

Table 4-1. UST-10 TV Translator-Transmitter



VHF CHANNEL		UHF CHANNEL 70 (806-812)	71 (812-818)	72 (818-824)	73 (824-830)	74 (830-836)	75 (836-842)	76 (842-848)	77 (848-854)	78 (854-860)	79 (860-866)	80 (866-872)	81 (872-878)	82 (878-884)	83 (884-890)
2	54-60	752 / 31.3333	758 / 31.5833	764 / 31.8333	770 / 32.0833	776 / 32.3333	782 / 32.5833	788 / 32.8333	794 / 33.0833	800 / 33.3333	806 / 33.5833	812 / 33.8333	818 / 34.0833	824 / 34.3333	830 / 34.5833
3	60-66	746 / 31.0833	752 / 31.3333	758 / 31.5833	764 / 31.8333	770 / 32.0833	776 / 32.3333	782 / 32.5833	788 / 32.8333	794 / 33.0833	800 / 33.3333	806 / 33.5833	812 / 33.8333	818 / 34.0833	824 / 34.3333
4	66-72	740 / 30.8333	746 / 31.0833	752 / 31.3333	758 / 31.5833	764 / 31.8333	770 / 32.0833	776 / 32.3333	782 / 32.5833	788 / 32.8333	794 / 33.0833	800 / 33.3333	806 / 33.5833	812 / 33.8333	818 / 34.0833
5	76-82	730 / 30.4166	736 / 30.6666	742 / 30.9166	748 / 31.1666	754 / 31.4166	760 / 31.6666	766 / 31.9166	772 / 32.1666	778 / 32.4166	784 / 32.6666	790 / 32.9166	796 / 33.1666	802 / 33.4166	808 / 33.6666
6	82-88	724 / 30.1666	730 / 30.4166	736 / 30.6666	742 / 30.9166	748 / 31.1666	754 / 31.4166	760 / 31.6666	766 / 31.9166	772 / 32.1666	778 / 32.4166	784 / 32.6666	790 / 32.9166	796 / 33.1666	802 / 33.4166
7	174-180	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333	686 / 28.5833	692 / 28.8333	698 / 29.0833	704 / 29.3333	710 / 29.5833
8	180-186	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333	686 / 28.5833	692 / 28.8333	698 / 29.0833	704 / 29.3333
9	186-192	620 / 25.8333	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333	686 / 28.5833	692 / 28.8333	698 / 29.0833
10	192-198	614 / 25.5833	620 / 25.8333	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333	686 / 28.5833	692 / 28.8333
11	198-204	608 / 25.3333	614 / 25.5833	620 / 25.8333	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333	686 / 28.5833
12	204-210	602 / 25.0833	608 / 25.3333	614 / 25.5833	620 / 25.8333	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833	680 / 28.3333
13	210-216	596 / 24.8333	602 / 25.0833	608 / 25.3333	614 / 25.5833	620 / 25.8333	626 / 26.0833	632 / 26.3333	638 / 26.5833	644 / 26.8333	650 / 27.0833	656 / 27.3333	662 / 27.5833	668 / 27.8333	674 / 28.0833

the translator with the attendant possibility of causing interference to other signals. Similarly, co-channel signals arriving as the result of unusual propagation conditions would not pass through the translator unless they reached and maintained a signal strength comparable to the usual input signal. Translation of a co-channel signal would be undesirable because of its lack of reliability as well as its constituting operation not in accordance with the translator license, which is valid only for the specified originating station.

The action of the control circuit is developed from the AGC voltage generated in the channel amplifiers. An initial control circuit is activated when the AGC voltage rises to within the normal operating range. Since an improper signal might reach this value on a transient basis, a 1-min time delay is imposed upon the operation of the control circuit to prevent the translator from being turned on by such a transient signal.

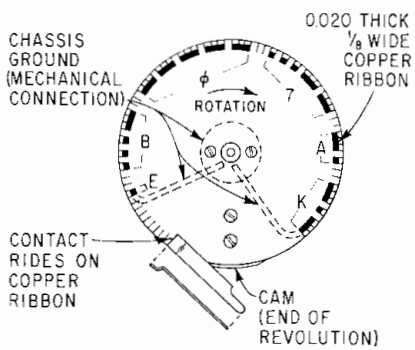


FIG. 4-11. Code wheel for automatic translator identification. The copper ribbon which forms the code characters is continuous, running on the underside of the wheel where no contact is required, and is connected to ground at the hub.

One of the requirements for translator operation imposed by the FCC rules is that the output of the translator be monitored periodically by an operator who, in the event he detects improper operation, will either correct the operation or shut down the translator until the correction can be made. An important adjunct to the operation of all translators where no operator is present is a fail-safe remote-control circuit. This makes it possible to control the translator from a convenient location, even though the translator is at a remote site. A circuit in the translator is brought out to a pair of terminals which must be closed through a rectifier for the circuit to operate. A wire line of virtually any length can then be used to connect the translator to the remote-control point. Only if the line is closed through a rectifier at the control point will the circuit operate. If the wire line is inadvertently broken or short-circuited so an a-c voltage is returned to a circuit sensitive only to direct current, the operation of the translator will be interrupted by an inoperative link in the control chain.

Interlocking is provided for the protection of personnel against high voltage and for the protection of the air-cooled UHF amplifier tubes against the failure of the air supply. The high-voltage interlocking is a conventional interlock switch on the door which gives access to high-voltage circuits. Air-flow interlocking is accomplished by a sensitive switch controlled by a vane in the air stream. When both of these interlock circuits are in proper operating condition, the third step in the control circuit is closed.

When the conditions imposed by the circuits of the three preceding sections are satisfied, power can be supplied to the oscillator-multiplier chain, the mixer, and the UHF amplifiers. In accordance with good engineering practice a time delay is included in the high-voltage circuit so that high voltage is not supplied to these circuits until they are ready to draw current.

The remaining control requirement is fulfilled by the code wheel and keying circuit which identify the translator station in International Morse Code when the station first comes on and at the hour and half hour as operation continues. The keying is most conveniently accomplished by 100 per cent audio tone modulating one of the stages of the oscillator-multiplier chain. This shows up on a home receiver as a series of horizontal bars corresponding to the audio frequency but are of brief duration to avoid annoyance to the viewer.

Since translators run unattended, means must be provided for generating the call-

letter codes. A convenient method of accomplishing this is with metallic inserts in an insulated wheel. Contact between a pickup arm and the conducting inserts activates the audio modulation of the oscillator-multiplier chain, and one revolution of the code wheel identifies the translator station. Figure 4-11 is an illustration of such a code wheel.

An auxiliary requirement imposed upon some translator stations by the originating station is a means of controlling the translator with a signal included in the transmission of originating station. A typical means of accomplishing this control is through the inclusion of a supersonic tone such as 20 kc on the aural channel when translator operation is to be permitted. To accomplish this control function circuits are included to demodulate a sample of the frequency-modulated aural carrier. Circuits responsive to a 20-kc signal as low as 10 to 20 db below normal modulation govern an added step in the control chain of the translator.

100-watt Amplifier

When power outputs as high as 100 watts are required, the combination of a 10-watt translator and a 10-db amplifier with a 100-watt capability can be used. The 100-watt amplifier is packaged as a separate unit for a variety of reasons. Among them is the fact that it is larger in physical size and in cost than the entire 10-watt translator. Since the 100-watt amplifier almost doubles the equipment cost of a translator installation, it is frequently added when experience with a given 10-watt installation shows the desirability of increasing the power to bring better coverage to larger areas. In addition, the two-unit construction provides flexibility in carrying equipment over poor roads and installing it in what is sometimes a very small available space. Furthermore, as the power handled becomes greater, the type of construction changes significantly, so that many features are found in a 100-watt amplifier which are not necessary in a 10-watt unit. Figure 4-12 is a photograph of a 100-watt amplifier.

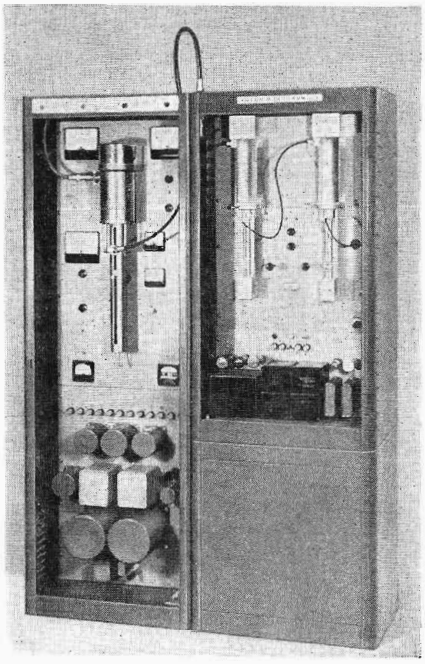


FIG. 4-12. 100-watt amplifier shown connected to the 10-watt translator which drives it. Front doors of both units are removed. The amplifier has a tuning range of Channels 14 to 83.

The cavity for such an amplifier is similar in construction to those described in connection with the 10-watt unit but is designed for a tube of higher power-handling capability and may be designed for a tetrode as shown in Fig. 4-13. In particular the cathode-grid circuit tuning and matching features are the same as for the 10-watt cavity, so that the tuning and matching procedures of such a cavity are the same as previously described.

The ability to adjust the coupling to the last plate circuit of the 10-watt translator and the 100-watt amplifier cathode circuit makes it easy to integrate the two units into an over-all system from an RF point of view and to maintain this integration when tubes are changed in either the driving or final circuit. To complete the integration the power-supply circuits in the 100-watt final amplifier are controlled by the 10-watt translator; thus the 100-watt

amplifier functions in every respect as a logical extension of the 10-watt translator with its power supply coming on at the same time power is supplied the UHF stages in the translator.

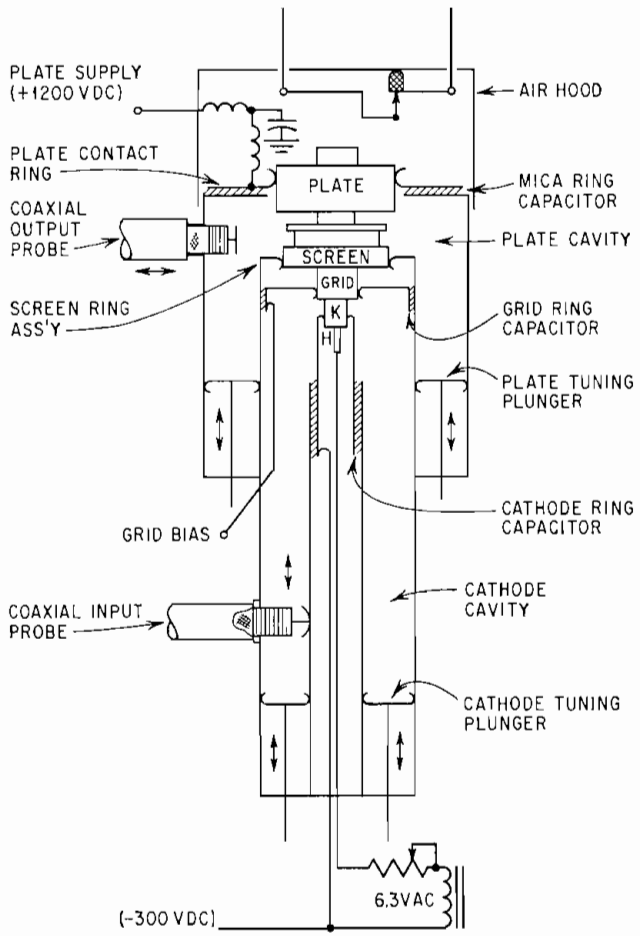


FIG. 4-13. 100-watt UHF amplifier cavity for a tetrode. Position of the input probe is adjustable for impedance matching to the input cable. The output probe is adjusted for proper loading of the plate circuit.

Among the additional refinements appropriate to the higher power operation are an overcurrent relay which shuts off the plate supply voltage if the cathode current becomes excessive, a screen-voltage interlock required for tetrodes which prevents the application of the screen voltage unless the plate voltage is applied, and extensive built-in metering of all supply voltages as well as power-output monitoring.

UHF Input Translators

Translators for operation from a UHF input signal differ only from the previously described VHF input translator by the inclusion of a UHF-to-VHF converter. Con-

version to VHF is preferred to straight UHF-to-UHF conversion for a number of reasons. Foremost of these is the relative ease with which the signal can be amplified at VHF frequencies. The approximately 80-db gain achieved at VHF in a regular translator would require a great many stages and/or expensive specialized UHF tubes. Furthermore, many UHF-to-UHF translators require a change of only a few channels and the separation between the input and the output frequencies will be only a few per cent of the output frequency. In this case, the tuned circuits after the mixer will not reduce the input frequency component sufficiently unless special precautions are taken.*

The UHF-to-VHF converter is comprised of three elements: a preselector to pass only the desired signal, a mixer to heterodyne the signal to a VHF channel, and an injection source.†

Conversion should be to a low VHF channel to take advantage of amplifier noise figures, which are lower than at the high VHF channels.

The preselector must eliminate any interfering signals would could produce a signal at the VHF output. The most important of these is the image frequency at twice the VHF frequency below the desired input. Signals which could beat with a harmonic of the mixer would also be troublesome. The preselector will also serve to prevent the injection frequency from being radiated by the receiving antenna. The preselector must be low loss not only to preserve the available signal but to prevent the introduction of noise from the equivalent resistance corresponding to any circuit loss. It should have the bandpass characteristic of a double-tuned circuit critically or slightly overcoupled. The most suitable circuit elements are resonant transmission-line sections, either coaxial or flat-plate type, with proper coupling between the sections.

The mixer consists of a crystal diode in a holder which provides an impedance match between the signal input and the crystal diode, allows the injection signal to be applied to the crystal, and provides an output through a low-pass filter which bypasses the UHF frequencies.‡

The injection source should be crystal controlled, since any frequency error in this conversion will cause a corresponding error in the final frequency. The injection frequency must be below the incoming signal in frequency to prevent inversion of the carriers.¶

The requirements of the injection source are similar to the injection sources previously described for use in VHF-to-UHF translators except possibly for power-output requirements. The requirements here will vary with the cable loss used between the injection source and the mixer, with 10 mw usually required at the mixer.

The preselector and mixer should be located at the antenna to prevent the consequences of signal loss in a long cable. The injection source can be located remotely

* A typical translator might have 30-db gain in and after the mixer for frequencies in the desired output frequency range and −40 db for a signal a few channels off. Thus the input signal would be amplified 60 to 80 db before the mixer and −40 db after or +20 to +40 db net. This could result in ghosts from a signal feed back from the transmitting to receiving antenna with a delay corresponding to the distance between the antennas. In extreme cases where the isolation between the antennas is less than the net gain, oscillation would result.

The same problem exists in VHF-to-VHF translators where the difference between the input and output frequencies is only a few channels.

† New techniques for the use of solid-state diodes as low-noise amplifiers are developing rapidly. At the time of writing, they promise a significant improvement in noise figure over mixing without RF amplification. As the development of these devices continues, they should come to be practical for field installations. At UHF frequencies antenna temperatures are much lower than at VHF. Thus an improvement in the noise figure of the receiving circuit produces a very significant reduction in the value of the minimum usable signal.

‡ For a brief description of this type of mixer see F. E. Terman, "Electronic and Radio Engineering," 4th ed., p. 579, McGraw-Hill Book Company, Inc., New York, 1955. A more detailed discussion can be found in Staff of the Harvard Radio Research Laboratory, *op. cit.*, vol. II, chap. 29.

¶ This is the opposite of regular television receiver practice where the oscillator is above the incoming signals and the carriers are inverted by the conversion to the IF frequency.

provided sufficient signal is available at the end of the cable which brings the signal to the mixer.*

It is usually desirable also to locate the first VHF amplifier or preamplifier at the antenna.†

Table 4-2. Attenuation of Various Cables at Translator Frequencies in Decibels per 100 Ft

		UHF	
Cable	*Impedance*	*800 Mc*	*900 Mc*
RG 8A/U	50	7.0	7.5
RG 14A/U	50	5.0	5.5
RG 17A/U	50	2.9	3.2
RG 58C/U	50	19	21
⅞ in.*	50	1.4	1.5
1⅝ in.*	50	0.80	0.85
3⅛ in.*		0.32	0.34
RG 11A/U	75	7.8	8.2
RG 59A/U	75	13	14
300 tubular hollow	300	4.0	4.3

	VHF	
	50 Mc	*200 Mc*
RG 11A/U	1.5	3.3
RG 59A/U	2.5	5.5

* Semiflexible.

Translators in Tandem

Operation of a translator on the signal rebroadcast by another translator has been found entirely practical in a number of installations. Up to four translators in series have been utilized in areas where the original signal may be reliably received only at the first translator. In such operation all translators after the first are necessarily of the UHF-to-UHF type described in the previous section.

In tandem operation any degradation of the signal in each translator will result in poorer performance as the signal progresses through the chain. This type of operation therefore makes more critical demands upon a translator than normal operation. While a translator operated at rated output will not degrade either the video or aural information, it will generally introduce a few per cent of sync compression. This effect is not large enough to be of concern in a single translation, but the cumulative effect may become objectionable. It is then necessary to run each translator at a somewhat reduced power output to minimize the compression at each step. A reduction in power output of 3 db would not normally decrease the coverage of the individual translators appreciably but will reduce the compression to an immeasurable level.

Standard translators singly and in tandem are utilized in many countries for point-to-point relaying by substituting highly directional transmitting and receiving antennas for the area-coverage antennas normally used for rebroadcasting. In the United States this technique is used but with the output frequency raised to one of the bands such as 1,990 to 2,110 Mc, where channel assignments are available for the purpose of relaying.

Internal Interferences

In practice, not all input-output channel combinations can be used. All frequencies associated with a desired conversion must be carefully examined for spurious signals which fall within or close to either the input or output channel.

* See Table 4-2 for attenuations of commonly used cables.

† The considerations are much the same as when the signal comes from a VHF antenna. See the discussion under Amplification at the Antenna.

The input channel in particular is sensitive to even very low level signals. Thus, if any stage in the oscillator-multiplier chain operates on a frequency, at or near the input channel, it can be expected to produce interference. Table 4-1 shows the interferences which arise from a typical injection source. Sometimes this source of interference can be eliminated by changing the order of multiplication. For instauce, if the second harmonic of the crystal oscillator falls in the input channel, the oscillator-multiplier chain could be changed to a tripler followed by a doubler instead of vice versa. While it is not usually feasible to change the multiplication factor between the crystal frequency and the iujection freqnency in a standard oscillator-multiplier unit, this avenue of approach is open if the design of a special oscillator multiplier is justified.

The other aspect of the problem concerns the generation of spnrious products in the mixer which would fall in or near the output channel. Such a problem would arise if the second harmonics of the input carriers fall at or near the ontput chanuel as it would in converting from Channel 6 (aural carrier 87.75 Mc, second harmonic 175.50 Mc) to Channel 7 (174 to 180 Mc). This type of problem is less apt to occur when the output channel is widely separated from the input, as it is in VHF-to-UHF translators.

When two or more translators are to be installed in close proximity, it is necessary to examine the frequencies generated within each translator for possible interference with the input channels of the other units.

AREA-COVERAGE PROBLEMS

Line-of-sight Requirements

Up to this point the techniques and equipment necessary to produce a high-qnality 10- or 100-watt translated signal have been described in detail. This has been done to provide the system designer with the fullest possible understanding of those elements of his system even though he will be working with fairly standardized receiving-antenna techniques and type-approved translating equipment. Providing proper coverage will, on the other hand, be an original problem for each installation, since the terrain and population distribution will be different in each case. It is fortunate, considering the relatively low power available from either a 10- or 100-watt translator, that directional antennas can be used to concentrate energy in the populated areas and that at translator frequencies even highly directional arrays do not require large physical size. Conversely, since there is even less propagation beyond obstacles than at VHF, the transmitting-antenna site must be chosen to provide a clear line of sight to all population areas to be served.*

In this connection, it must be remembered that optical clearance is not sufficient; at least first Fresnel-zone clearance over any obstruction is required. At any point where a potential obstruction exists along the path between transmitting and receiving antennas, the required clearance (first Fresnel-zone radius in feet) can be calculated from †

$$R = 81\sqrt{\frac{D_1 D_2}{D_1 + D_2}}$$

where D_1 = distance from transmitting antenna to potential obstruction, miles
D_2 = distance from same point to receiving antenna, miles

This shows that the required clearance increases ont to the halfway point between the transmitter and the receiver and decreases beyond that point to zero at the re-

* Required clearance for 850 Mc. For other frequencies multiply by $\sqrt{850/f}$.

† Refraction in the atmosphere bends the waves. Profiles of the terrain used to determine clearance are usually plotted as though the earth radius were 4/3 times its actual value.

ceiving antenna. A more complete discussion of the importance of first Fresnel-zone clearance in line-of-sight propagation can be found in any of several books.*

Transmitting Antennas

The dipole is the simplest practical antenna which could be used for an installation. It could be used where a figure-eight type of pattern in the horizontal plane would be appropriate. However, such an antenna is a very inefficient device in terms of concentrating energy in areas where it will be used. Inasmuch as it radiates energy equally well in all directions in a vertical plane, as much energy is radiated straight up or down as is radiated toward the horizon. Dipoles are therefore normally used as components in an array or with reflecting elements to produce vertical and horizontal directivity. Figure 4-14 shows an antenna with four dipoles fed in phase and stacked vertically with a half-wavelength separation. This combination produces no net radiation above and below the antenna and, with the back plate acting as a reflector, radiates approximately 9 db more energy in the forward horizontal direction than an isotropic radiator.† The lack of net energy in the vertical direction can be predicted by considering the phase of the radiated waves from each of the four dipoles. An electromagnetic field is propagated from each of the four dipoles in the same phase. Because the separation is one-half wavelength, however, the energy from the second dipole will pass the first dipole out of phase. Similarly, energy going in the vertical direction as waves from the fourth antenna will be out of phase with waves from the third antenna. Thus, at a distance many wavelengths from the antenna, where the minor differences in the distances traveled have no effect on the relative signal strengths but do result in the waves arriving out of phase, no net energy will be observed. Conversely, in the forward direction at a point many wavelengths from the antenna, the vertical separation among the elements will cease to have any effect upon the radiation arriving from each of the four dipoles and the waves will add directly in phase. At intermediate angles, such as 45°, the waves from the two pairs of dipoles arrive with a phase-angle difference determined by the different path lengths as shown in Fig. 4-15. Figure 4-16 shows the vertical directivity pattern of such an array of four dipoles fed in phase. The pattern of an array of any complexity can be calculated in similar fashion by considering each dipole as a point source of electromagnetic waves and by establishing the relative phase corresponding to the number of fractional wavelengths traveled from the various point sources.‡ Figure 4-17 is such a plot.

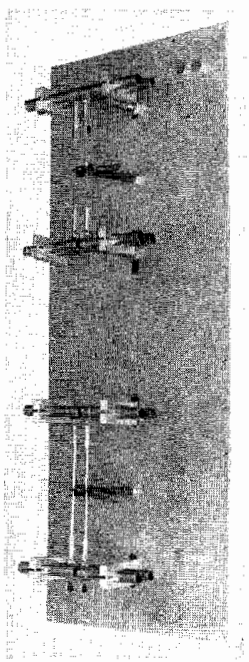


FIG. 4-14. Basic transmitting antenna with fiberglass cover removed. It is used singly and as a building block for arrays. (*Courtesy of Adler Electronics Inc.*)

* For a brief description see Ref. 1 at the end of this part. A more complete discussion is included in Section 4 of this handbook.

† An isotropic antenna is a fictitious point source which radiates equally in all directions. It is frequently used as a reference to which other antennas are compared. A dipole in its maximum direction has 2.15-db gain over an isotropic radiator.

‡ If an array is made up of groups of dipoles with the pattern of each group known, each group can then be considered a point-source radiator at the center of the group and with the same pattern as the group. Note that the patterns cannot be superimposed directly but the contributions at each angle must be added as vectors with relative angles corresponding to the phases of the various contributing signals; i.e., if one signal travels $\lambda/4$ farther than another, it will lag 90° in phase; if $\lambda/2$, then 180° lag, etc.

Frequently exact patterns are not so important as knowledge of the gain to be expected in the direction of maximum intensity. In this case a useful rule of thumb is as follows: Doubling the number of dipoles in an array increases the signal level in the maximum direction by 3 db. If these dipoles are stacked at half-wave intervals vertically, this increase is gained as the result of a narrower vertical pattern. If they are stacked horizontally, the gain is the result of narrowing the horizontal pattern.

The antenna illustrated in Fig. 4-14 has a forward gain of 9 db over an isotropic antenna. Two such units stacked vertically exhibit 12-db gain. Two more such antenna units comprising a vertical stack of eight dipoles can be placed alongside the first combination to produce an additional 3 db in the maximum direction for a total of 15-db gain over an isotropic radiator.

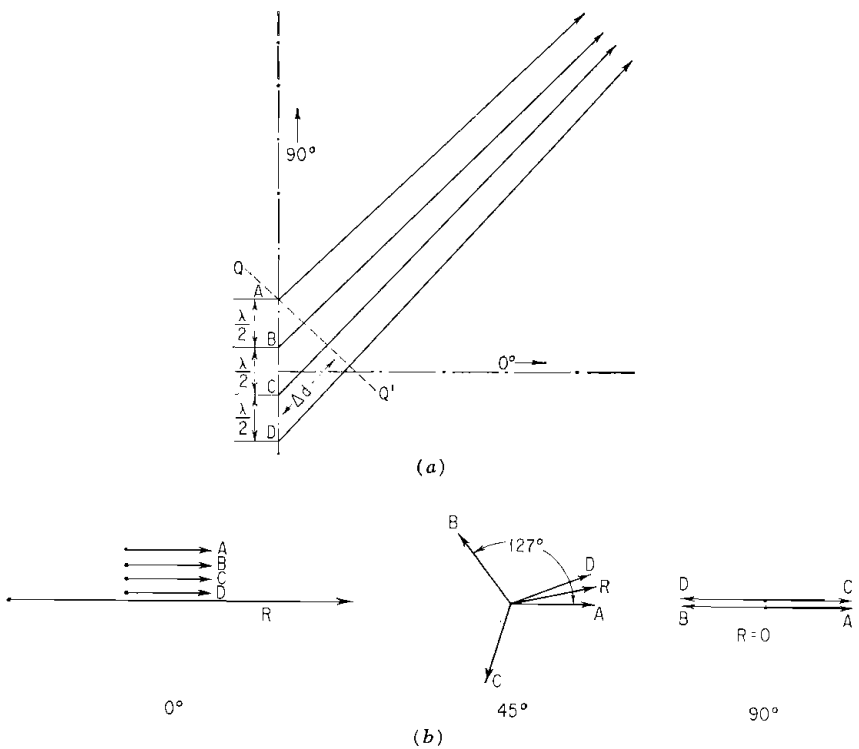


FIG. 4-15. (*a*) Four half-wave dipoles fed in phase. Distances Δd from points *B*, *C*, and *D* to line *QQ'* are the extra path lengths traveled by the waves from the respective antennas. The phase delays generated by these distances are

$$\Delta\phi = (\Delta d/\lambda) \times 360°$$

(*b*) Phase diagram of the contributions from each of the four dipoles. At 0° all are in phase. At 90° they are out of phase in pairs. At 45°:

$$\Delta d_B = (\lambda/2) \sin 45° = 0.707\lambda/2$$
$$\Delta\phi_B = (0.707\lambda/2\lambda)360° = 127°$$
$$\Delta\phi_C = 2\Delta\phi_B = 254°$$
$$\Delta\phi_D = 3\Delta\phi_B = 381°$$

The resultant *R* is the magnitude and phase of the sum of the four contributions. It does not refer to the direction of travel, which is radially outward from the array.

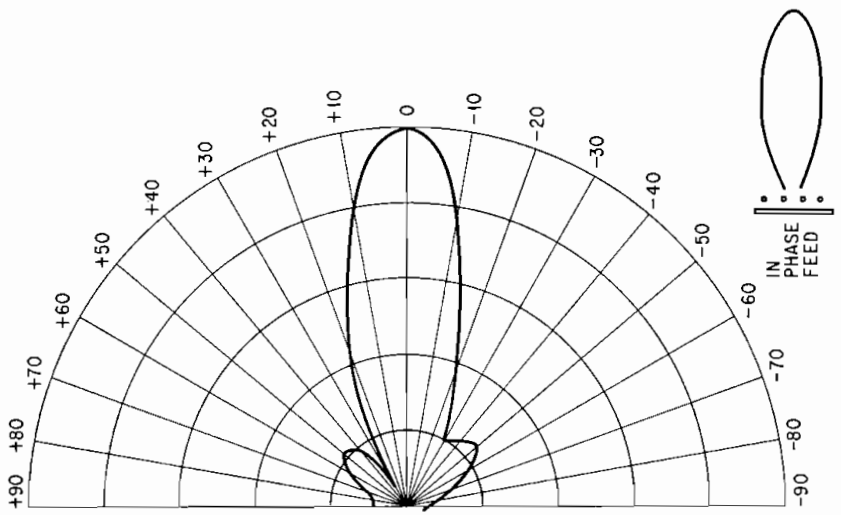


FIG. 4-16. Vertical pattern of four dipoles in front of a reflector and fed in phase (from measured data).

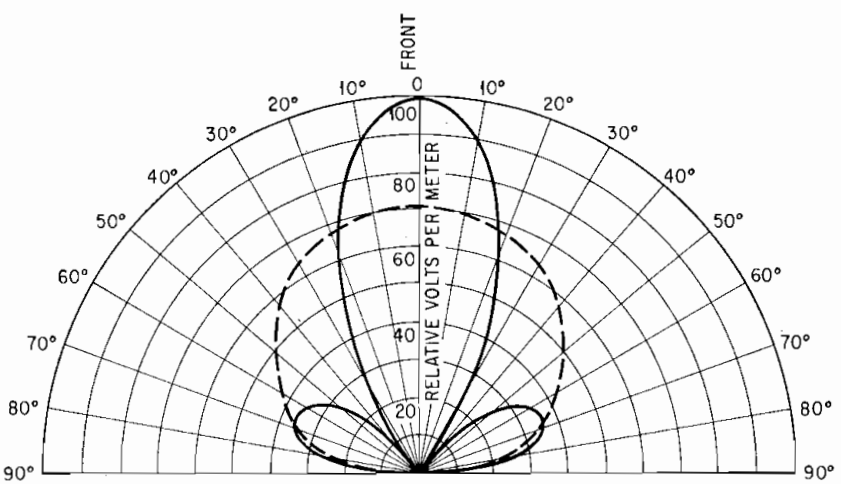


FIG. 4-17. Horizontal pattern of two of the antennas of Fig. 4-14 placed side by side (from calculations as described in text. Dashed line—Pattern of a single antenna; Solid line—Pattern of combination).

When arrays are built up of standard antennas as building blocks, it is most convenient to make the interconnections with coaxial cable of the same impedance as the main transmission line, usually 50 ohms. To maintain this impedance match, impedance transformers must be used where two sections are fed in parallel from a common line. While a number of matching techniques are known, the T transformer with tapered sections is favored for its compactness and the ease with which it can be made weatherproof. An array built up using such transformers is shown in Fig. 4-18.

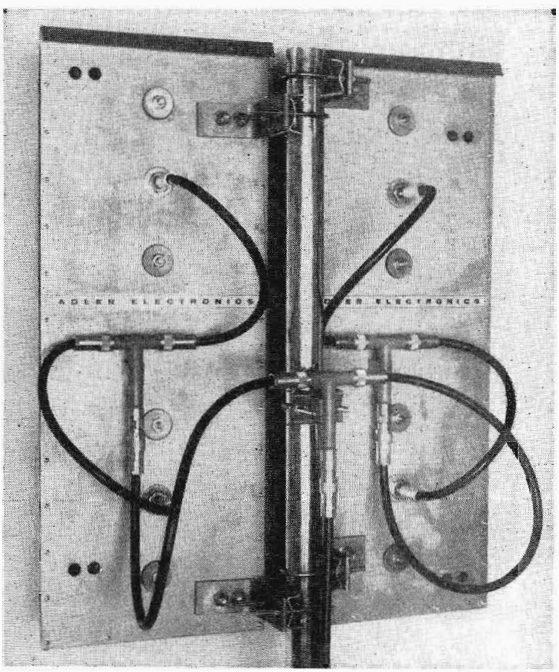


FIG. 4-18. Impedance matching with T transformers. The two halves of an antenna, each of which has a 50-ohm impedance, are joined with a T transformer, providing a 50-ohm impedance for the combination. Two 50-ohm antennas are joined through another T transformer. (*Courtesy of Adler Electronics Inc.*)

While the previously described antenna unit can be used in combinations to solve a great many coverage problems when extreme directivity is required, they become unwieldy and uneconomical compared with other types. Translators installed, for instance, at one end of a long, narrow valley can profitably use a parabolic-reflector-type antenna to concentrate the energy in a very narrow beam. At 800 to 900 Mc such an antenna has a forward gain of more than 20 db for a 6-ft reflector. Such an antenna would provide a given signal strength out to a distance approximately twice as great as an array of 16 dipoles connected as described above. Such an antenna would be suitable for use only when the population is concentrated within a narrow angle from the translator, since the coverage is about 15 to 20° wide.

Coverage Calculations

The desirability of establishing coverage over a wide angle must be balanced against the required forward gain which the antenna must have to reach the maximum distance to be covered. Coverage calculations can be conveniently made with the aid of Fig.

4-19, which shows propagation losses between isotropic antennas for various distances. Other losses between the transmitter and the receiver terminals include the transmission line from transmitter to transmitting antenna and the lead-in at the receiver. Losses for typical transmission line and receiving lead-in are shown in Table 4-2. The gains of the transmitting and receiving antennas, however, reduce the loss, so that the power available at the receiver will be greater by the amount of these two gains. Table 4-3 shows a typical calculation. Field experience has shown that a signal of

Table 4-3. Typical Path-attenuation Calculation

[Conditions chosen for this example are coverage required out to 15 miles, transmitting on Channel 71 (812 to 818 Mc)]

	10 *watt* *	100 *watt*
Transmitter power	+10 dbw	+20 dbw
Antenna transmission-line loss, 50 ft RG17 at 800 Mc	−1.5 db	−1.5 db
Antenna gain (two of units illustrated in Fig. 4-14)	+12 db	+12 db
Path loss (from Fig. 4-19)	−118 db	−118 db
Receiving-antenna gain (typical corner reflector)	+10 db	+10 db
Receiving transmission-line loss (50 ft 300 ohms tubular)	−2.0	−2.0
	−89.5 dbw	−79.5 dbw

* Adequate signal will be available from the 10-watt translator over the horizontal arc between the 6-db (50 per cent voltage) points of the antenna horizontal pattern.

300 mv on a 300-ohm lead-in is a minimum safe signal for a first-class picture with a typical receiver. This is a power level of 3×10^{-10} watt, or approximately 95 db below 1 watt (−95 dbw). When coverage patterns are set up, every effort should be made to supply this signal as a minimum to the populated area.

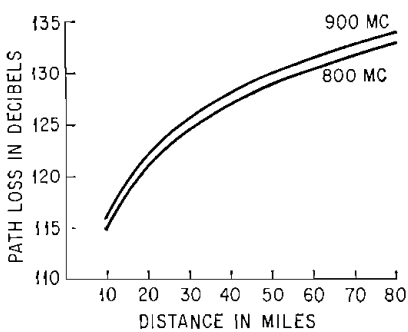


FIG. 4-19. Free-space path loss between isotropic antennas at translator frequencies. The loss between actual antennas is reduced by the gain of each of the antennas.

Sites

The selection of a site is a problem with a great many aspects, no one of which can be compromised beyond a certain point without adversely affecting the ultimate performance. They are listed in order of the firmness of the requirement. The first two are absolute requirements; the others become less stringent but may result in a more complex or costly installation or a less convenient one for maintenance.

1. Path clearance for transmitting the signal to the area to be covered. Only the transmitting antenna need be so situated. A tower to raise the transmitting antenna is sometimes the only solution.

2. Adequate VHF signal for a snow-free picture. While a large array will derive an adequate signal from relatively weak field strengths, the terrain must be suitable for erecting a large array which may spread over linear distances of hundreds of feet. In other instances, particularly where the terrain is relatively flat, there is not enough signal near the ground to get out of the noise with any conceivable array and a tower to elevate the receiving antenna is required. The structure(s) used must hold the antenna(s) rigidly and properly oriented through any combination of environmental conditions such as icing and windstorm which may be encountered.

3. Accessibility at any time with conventional vehicles. If this requirement cannot

be fulfilled, special vehicles capable of traveling over snow must be available when needed or the possibility of extended periods of inoperation must be faced. A site shared with an essential service such as public-safety radio transmitters will usually be accessible a high percentage of the time.

4. Power availability. The availability of commercial power will reduce the complexity and enhance the reliability of the installation. Adequate capacity should exist to permit the use of at least 1,000 watts of test equipment in addition to the translator requirements. Further capacity to permit some heating at least during maintenance periods will be found highly desirable if no other source of heat is available.

5. Adequate shelter. The shelter should protect the translator from the outside environment as fully as possible in two respects. The maximum temperature should be held as low as possible through the use of a fan and thermostat. The expected periods of operation between failures will be significantly increased as the maximum ambient temperature is reduced. Protection against low temperature is not normally a problem, and any drift in the tuned circuits as the ambient changes from summer range to winter range will be corrected by the regular periodic checks of the tuning. The other major problem is dust. Even though the air passed through a translator is filtered at the entrance to the equipment, it is highly desirable to draw air into the shelter through a filter in locations which might be described as even moderately dusty.

INSTALLATION AND MAINTENANCE

Site Layout

The first phase preceding the actual installation of a translator should be careful planning of the site layout. The principal task will be to design an optimum arrangement which will permit the shortest transmission lines, especially from the translator to the transmitting antenna. The shelter should be so located that vehicles can be driven close to it if possible. The receiving antenna can be located somewhat more remotely.

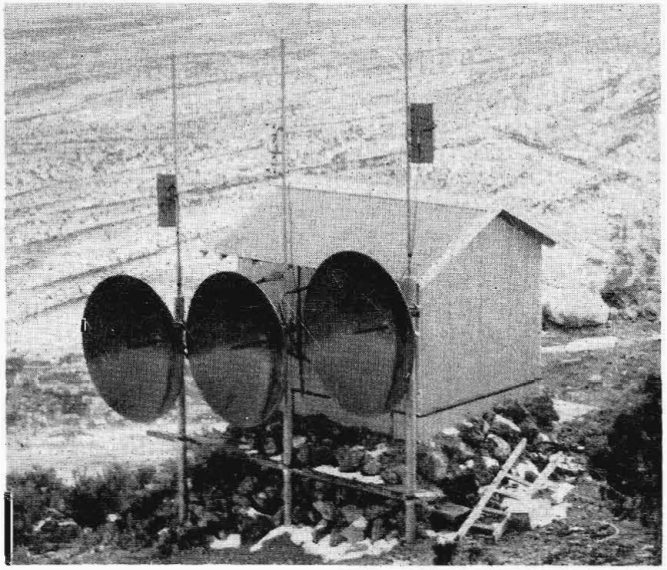


FIG. 4-20. Site of a three-channel installation. The parabolic antennas in the foreground receive UHF signals from three other translators. The three transmitting antennas are raised sufficiently for line-of-sight clearance to McGill, Nev., in the background. (*Courtesy of Industrial Television, Los Angeles, Calif.*)

In particnlar, it shonld be as widely separated from existing power lines as possible, especially when low-channel signals are being received. New power lines shonld approach the shelter from a direction away from the receiving antenna. A compact site is shown in Fig. 4-20.

Installation Details

An installation will be reduced to the least possible effort by advanced planning of all details. A sketch showing all system components, all mounting arrangements down to the individual nuts and bolts, all interconnecting cables and connectors and power wiring fixtures is valuable. It may save a long trip back to town.

The mounting arrangements of the receiving antenna must be determined from the manufacturer's literature. Unless included with the antenna, a means for converting from a balanced circuit to an unbalanced transmission line must be provided at the antenna. Transmission line (usually 75 ohm) and connectors (weatherproof) will be reqnired between the receiving antenna and the translator.

A pedestal or low table is frequently provided for a 10-watt translator to bring it to a convenient height. Power outlets for the translator and for the associated test equipment must be provided near by. Storage facilities for spare tubes and components are desirable.

More cable and connectors will be required for the transmitting transmission line. If air-dielectric or semiflexible cable is used, adapters to small connectors will be needed. It is also desirable to provide a short length of more flexible cable such as RG 8A/U between the heavy cable and the translator and at the antenna. The cable should be supported securely at frequent intervals throughout its entire length outside the shelter. A pump for pressuring air-dielectric cable is desirable.

Mounting provisions for the transmitting antenna will depend upon the type used. The antenna illustrated in Fig. 4-14 mounts with U bolts on a pole up to 1½ in. OD. Parabolic antenuas mount on a 4-in. pipe.

Test Equipment for Installation and Maintenance

Some specific test equipment may be recommended by the translator manufacturer as being particularly well adapted to a specific task. However, the following list is basic and represents the minimum requirements for testing and alignment of translators:

1. Service oscilloscope. To be used for viewing sweep patterns and video waveforms. It should have a vertical amplifier bandpass of 4.5 Mc minimum.
2. 50- and 75-ohm crystal detector. Sierra Electronics model 148A or equal. (Extra 50-ohm disc resistors should be ordered. These can be altered to provide a 75-ohm resistive termination, making the same instrument useful for both 50 and 75 ohms.)
3. RF dummy load, 50 ohms, with a power rating exceeding the output of the translator (10 or 100 watts).
4. Commercial UHF television receivers, one at the transmitter location and another at the remote-control location, both for monitoring.
5. VHF sweep generator RCA model WR 69A * or Kay Electric Company, model RF-P sweeping oscillator.†
6. Multimeter, 100-μa range normally required.

* Earlier models of the WR-59 series will be satisfactory except on the lowest channels, where it is sometimes difficult to obtain adequate sweep width for this application. For either type, assemble the 75-ohm output adapter described in the instruction book. These sweep generators require external markers to delineate the passband. Normally, the carriers from the originating station can be used for this purpose by coupling the receiving antenna lightly to the input circuit.

† Marker pulses for the oscilloscope display are generated within this instrument. No marker signals pass through the system nnder test. This permits a more certain interpretation of the sweep pattern.

Table 4-4. Check List for a Translator Installation

I. Transmitting channel available	
A. Consistent with allocations requirements	See Sec. 4.702(A) and (C) of Federal Communications Commission Rules
B. Does not interfere with other translators	See Sec. 4.702(B) and (D) and 4.703(A) of Federal Communications Commission Rules
II. Site selection	
A. Received signal	Signal-reception System. Signal path to receiving antenna should be clear of foliage
1. Adequate strength	
2. Freedom from extraneous noise	
3. Freedom from interfering signals	Amplification at the Antenna. Tabulate all frequencies generated in nearby equipment. Pay especial attention to strong signals, their harmonics, and beats between them which fall in or near the input channel. Traps in the antenna line are sometimes effective in removing off-channel interferences. Include other translators in tabulation (see Internal Interferences)
B. Transmitting coverage	Line-of-sight Requirements. Count foliage as opaque
1. Line of sight to area to be covered and Fresnel-zone clearance	
2. Coverage feasible	Coverage Calculations. Gain requirements and horizontal pattern required for coverage must be within practical limits of transmitting antennas
C. Terrain at site suitable	
1. Building	Flat area required
2. Receiving and transmitting antenna poles and towers	Bases for towers and/or holes for poles may be required
3. Guy wires	Must be able to dig holes to pour concrete anchors or fasten to rock formations
4. Ground connection	Means must be found to establish a ground connection for shielding and lightning protection
D. Authorization to use site	Such authorization in writing becomes part of construction-permit application
E. Access roads	Access by vehicles essential. Much operating and some test time will be after dark, when foot travel back to the end of the road is hazardous. If road must be built, examine terrain for feasibility
F. Power lines	Considerable expense will be saved by locating at or near existing power lines of adequate capacity.* If reliability of power lines is doubtful, an auxiliary engine-driven generator should be installed for standby
III. Organizational requirements	
A. Incorporation or association documents or other agreements	Information from these documents forms a part of the application for a construction permit, which will not be granted unless the information is in proper form

* 2,000 va for a single 10-watt translator plus 900 va for each additional translator and each 100-watt amplifier is required. Long lines to remote points frequently are subject to wide voltage fluctuations. A constant-voltage transformer for each translator is recommended.

Table 4-4. (*Continued*)

B. Engineering personnel 1. Installation supervisor	Training by a translator manufacturer or experience with television transmitters desirable. Statement of qualification required on construction-permit application
2. Licensed operator	First- or second-class radio-telephone operator's license required of person making or supervising repairs and adjustments
C. Funds for construction and operation	Balance sheet indicating ability to purchase equipment and finance operation for one year from funds on hand or pledged required with construction-permit application
D. Remote-control point	Must be so located that the licensed operator can easily observe the transmission at the required intervals
E. Permission from originating station	Statement from originating station must be included with the construction-permit application
F. Application for Authority to Construct or Make Changes in a Television Broadcast Translator Station, FCC Form 346	File original and two copies including statement described in *E* above. Obtain required topographical maps in advance
IV. Construction	
A. Power lines	Check power company regarding construction standards. Bring power in first so it can be used for other construction
B. Housing for equipment	Should be erected early to provide storage space and shelter while rest of installation is constructed. Cinder-block, wood, or prefabricated-metal buildings adapted to local conditions have all been used. Provide access holes through building for signal cables
C. Erect receiving-antenna structures and elements	Make field-intensity measurements so any additional receiving equipment can be obtained while rest of construction proceeds (see Testing and Alignment)
D. Erect transmitting structure and elements	Include means for reaching transmitting antenna for maintenance
V. Installation	
A. Assemble main and auxiliary equipment and supplies at site	Installations are normally made with the aid of a representative of the translator manufacturer. If this service is not used, follow the planning suggestions under Installation Details
B. Site the translator within the building	Location should permit shortest possible transmitting cable. Enough room should be available to permit easy opening of the front and rear doors and to permit test equipment to be assembled for use near the translator
C. Follow Testing and Alignment procedure	Testing and Alignment. Tune the translator with a dummy load. Equipment as outlined under Test Equipment for Installation and Maintenance will be required. Operating spares should be on hand
D. Notify the Federal Communications Commission and the engineer in charge of the radio district of intention to conduct on-the-air tests	On-the-air tests can be conducted after this notification
E. Set up station log	See Sec. 4.781 of Federal Communications Commission Rules for log requirements

Table 4-4. (*Continued*)

F. Conduct tests of entire system	Measure bandpass and power-output capabilities of the translator driving the antenna. Establish that a satisfactory signal is reaching the entire area to be covered. Visual aiming of the transmitting antenna is unreliable. Some reorientation may be found desirable when the coverage is sampled. Two-way radio communications equipment such as citizens band transceivers have been found helpful in this phase
G. File Application for Television Broadcast Translator Station, FCC Form 347	Original and two copies required. Station should first be in satisfactory operating condition. Two days after notification of the FCC and the engineer in charge of the radio district interim programming may begin and be continued until action is taken on the license

Testing and Alignment

The receiving antenna should first be tested by observing the signal on the best quality receiver which can be made available at the site. If possible, the actual values of the two carriers should be measured with a field-strength meter.*

The values observed over a period of time should be recorded for future reference to permit the system to be checked for deterioration at a later date.

A visual-to-aural carrier ratio of 2 to 1 in power (1.41 to 1 in voltage) should be maintained. If the received signal has carrier strengths much different from this ratio, the recommendations of the translator manufacturer should be followed in making compensating adjustments or in adding additional devices to adjust the ratio.

When the translator is placed in operation the initial check and alignment instructions of the manufacturer should be followed. This will entail installing any components or subassemblies removed for shipping, checking key operating voltages, and tuning the translator in accordance with a specific procedure.

The transmitting antenna and associated transmission line can be partially checked by observing the sweep, the detected waveform, and the forward and reverse power produced by the translator when connected to a dummy load and when connected to the antenna system. If the reverse power increases appreciably when the antenna is the load, all cables and connectors should be carefully checked. If the problem persists, the trouble can be localized by substituting the dummy load for the antenna at the far end of the transmission line. If the antenna is reflecting power but has no visible defect, the manufacturer should be consulted.

When the antenna is radiating full power, the only remaining untested quantity is the antenna gain and pattern. Since antenna measurements are difficult without special facilities, the best field check will be the presence of adequate signal strength throughout the coverage area.

Experience has shown that the transmission of program material should be held to a minimum until permanent operations can be sustained. Any periods of temporary programming will serve to increase the impatience of the viewers for regular service.

* Model 704B VHF field-strength meter manufactured by Jerrold Electronics Corporation is frequently used for this purpose. If a field-strength meter is not available, relative values can be obtained from the developed AGC voltage in a receiver or channel amplifier. Absolute values can be obtained by substitution if a signal generator with a calibrated output is available. Some ambiguity will result from the use of a continuous instead of pulse-modulated carrier if the AGC is derived from a peak detector.

Maintenance

A maintenance schedule designed to prevent failures before they happen will pay dividends in satisfactory service and eliminating unscheduled trips to the site to rectify failures. Lubrication and cleaning of various parts of the translator will be required as outlined by the manufacturer. In addition, a log of operating voltages at all power supplies and test points will indicate trends toward tube and component failure.

Mechanical inspection of all external equipment for deterioration and tightening of mountings and connectors on a regular schedule is desirable.

REFERENCES

1. "Reference Data for Radio Engineers," 4th ed., pp. 768–770, International Telephone and Telegraph Co., New York, 1956.
2. D. G. Fink (ed.): "Television Engineering Handbook," pp. 16–8 to 16–15, McGraw-Hill Book Company, Inc., New York, 1957. A discussion of the design considerations of low-noise circuits follows in Secs. 16.303 to 16.305.

Part 5

REMOTE CONTROL OF BROADCAST STATIONS

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Burbank, Calif.

INTRODUCTION

One of the modern operating techniques associated with broadcast stations in recent years is the remote control of transmitters. In 1953, the Federal Communications Commission authorized nondirectional stations up to and including 10 kw to apply for such operation. At the present time there are over 1,500 broadcast transmitters authorized to be operated in this manner.

As a result of considerable data filed with the FCC by the National Association of Broadcasters in 1956, the FCC, in September, 1957, amended the rules in Part 3 to permit the remote control of *all* radio transmitters, AM and FM, with certain conditions. At the present time a limited number of stations have applied for remote-control permission under the amended rules, but the indications are that an increasing number of stations are becoming aware of the potentials of this type of operation. Various provisions of the rules appear to preclude an economical operation, considering the equipment costs, etc., but in the near future it is believed that the largest barriers will be removed.

It is the purpose of this part to outline the necessary conditions for remote control that must be supplied the FCC in the application Form 301-A and supporting exhibits and the reasons therefore.

Nondirectional AM and FM, 10-kw Maximum Transmitter Power

The remote-control application for stations in this category is relatively simple, assuming that the equipment system is satisfactory. The application should be filed on FCC Form 301-A, which consists of three pages. Note that for this category of stations, only items 1 through 5 on page 1 and all of page 3 need be completed. The remaining items on this form apply to either *directional stations* or *stations with a transmitter power in excess of* 10 *kw or both.* The information required is not complicated and can, in most cases, be completed by the station chief engineer. The chief engineer should, of course, be familiar with the pertinent provisions of the Commission's rules on remote control.[1] Installation of the equipment may be done by station personnel or by the manufacturer, and no certification is required that the equipment has been made in a prescribed manner except that it must comply with the general safety and fire underwriters' code. Reference to Fig. 5-1 (Form 301-A)

[1] See Section 1 of this handbook.

FCC Form 301-A
November, 1957

Form Approved
Budget Bureau No. 62-R145.3

File No.

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION

REQUEST FOR MODIFICATION
BROADCAST STATION AUTHORIZATION
(REMOTE CONTROL)

1. Name of licensee or permittee

2. Mailing address

Street .....

City .....

State .....

INSTRUCTIONS

A. This form is to be used only by licensees or permittees of Standard, FM and Non-commercial Educational FM Broadcast Stations.

B. Use separate form for each station.

C. Prepare this form in triplicate, swear to one copy, and forward all copies to the Federal Communications Commission, Washington 25, D. C.

D. Number exhibits serially in the space provided in the body of the form and list each exhibit in the space provided on page 3.

E. This application must be executed by applicant, if an individual; by a partner of applicant, if a partnership; by an officer of applicant, if a corporation or association; or by attorney of applicant only under conditions shown in Section 1.303, Practice and Procedure, in which event satisfactory evidence of disability of applicant or his absence from the Continental United States and authority of attorney to act must be submitted with application.

F. Before filling out this application, the applicant should familiarize himself with the provisions of Part 3 of the Commission's Rules and Regulations dealing with remote control.

G. BE SURE ALL NECESSARY INFORMATION IS FURNISHED AND ALL PARAGRAPHS ARE FULLY ANSWERED. IF ANY PORTIONS OF THE APPLICATION ARE NOT APPLICABLE, SPECIFICALLY SO STATE. DEFECTIVE OR INCOMPLETE APPLICATIONS MAY BE RETURNED WITHOUT CONSIDERATION.

3. Identification of existing station:

Call letters	File No.

Station location

City .....

State .....

Authorized facilities

FREQUENCY	POWER IN KILOWATTS		NON-DIRECTIONAL ANTENNA:
	NIGHT	DAY	DAY ☐ NIGHT ☐

DIRECTIONAL ANTENNA:

DAY ONLY (DA-D) ☐

NIGHT ONLY (DA-N) ☐

SAME CONSTANTS AND POWER DAY AND NIGHT (DA-1) ☐

DIFFERENT CONSTANTS OR POWER DAY AND NIGHT (DA-2) ☐

4. Request is hereby made for authority checked in the boxes.

☐ Establish a remote control point located as follows: (this is point from which transmitter is controlled)

STREET ADDRESS (OR OTHER IDENTIFICATION)

City .....

State .....

☐ Delete remote control point located as follows:

STREET ADDRESS (OR OTHER IDENTIFICATION)

City .....

State .....

5. Main Studio Location (if different than that on present authorization)

Street ..... City ..... State .....

6. Submit as Exhibit No. ____ a statement describing the stability of the directional antenna system during the one year period preceding this application. This statement shall include, but shall not be limited to, such information as the nature and degree of any adjustment required, the maintenance procedures followed and the adequacy of the present monitoring system to indicate changes in the operation of the array.

FIG. 5-1. FCC Form 301-A, application for remote-control authorization.

FCC Form 301-A Page 2

7. Antenna resistance measurement

Attach as Exhibit No. the following:

a. Qualifications of engineers taking measurements

b. Schematic diagram showing clearly all components of coupling circuits, point of resistance measurement, location of antenna ammeter, connections to and characteristics of all tower lighting isolation circuits, static drains, and any other fixtures, lines, etc., connected to or supported by the antenna, including other antennas and associated circuits.

c. Full description of method used to make measurements.

d. Manufacturer's name of each calibrated instrument used and manufacturer's rated accuracy.

e. Date, accuracy, and by whom each instrument was last calibrated.

f. Table of complete data taken and date taken.

g. The graph drawn of 10 to 12 readings in a band 50 to 60 kilocycles wide with the operating frequency near the center.

8. Operating constants based on data in paragraph 7: (If directional system, give current at point of resistance measurement.)

RF common point or antenna current without modulation for night power in amperes	RF common point or antenna current without modulation for day power in amperes
Actual measured antenna or common point resistance (in ohms) at operating frequency Night _____ Day _____	Actual measured antenna or common point reactance (in ohms) at operating frequency Night _____ Day _____

Currents, and phases for directional operation

TOWER	PHASE READING IN DEGREES		ANTENNA BASE CURRENT		REMOTE INDICATION OF ANTENNA CURRENT	
	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY

9. Submit as Exhibit No. the weekly readings of field intensity at each monitoring point specified in the station license for the one year period preceding this application. (Monthly readings will be acceptable where such readings are authorized.)

10. Submit as Exhibit No. the values, for each pattern, of antenna base currents, common point current, phase monitor sample currents or remote base currents, and phase relations, for the thirty day period preceding this application. The values shall be those obtained from readings taken at approximately the same time.

11. Submit as Exhibit No. a partial proof of performance consisting of at least 9 or 10 measurements taken at a distance of from 2 to 10 miles from the antenna on each radial measured in connection with the last complete adjustment of the directional antenna system. These measurements shall be analyzed in accordance with Section 3.186.

12. If application is for remote control of a transmitter with power in excess of 10 kilowatts, submit as Exhibit No. An analysis of the transmitter operating logs, and maintenance logs and records for the 12 month period immediately prior to the application.

13. If the station is a standard broadcast station and is authorized to operate with directional antenna and/or with power in excess of 10 kilowatts, submit as Exhibit No. a description of the equipment which will be installed so that the station can be satisfactorily operated on a CONELRAD frequency from the remote control position.

14. Applicant certifies that remote control operation will be in accordance with the Commission's Rules and Standards.

15. REMARKS:

FIG. 5-1. (*Continued on next page*)

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The applicant hereby waives any claim to the use of any particular frequency or of the ether as against the regulatory power of the United States because of the previous use of the same, whether by license or otherwise, and requests an authorization in accordance with this application. (See Section 304 of the Communications Act of 1934.)

The applicant represents that this application is not filed for the purpose of impeding, obstructing, or delaying determination on any other application with which it may be in conflict.

All the statements made in the application and attached exhibits are considered material representations, and all the exhibits are a material part hereof and are incorporated herein as if set out in full in the application.

The applicant, or the undersigned on the applicant's behalf, states that he has endeavored to supply full and correct information as to all matters which are relevant to this application and that he has done so as to all matters within his own knowledge.

Dated this ..... day of ....., 19.....

.....
(Name of applicant)

By .....

.....
Title

Subscribed and sworn to

before me this ..... day of ....., 19.....

.....
Notary Public

(SEAL)

(Notary public's seal must be affixed where the law of jurisdiction requires, otherwise state that law does not require seal.)

My commission expires .....

If applicant is represented by legal counsel, state name and post office address:

EXHIBITS furnished as required by this form:

EXHIBIT NO.	SECTION AND PARA. NO. OF FORM	NAME OF OFFICER OR EMPLOYEE (1) BY WHOM OR (2) UNDER WHOSE DIRECTION EXHIBIT WAS PREPARED (SHOW WHICH)	OFFICIAL TITLE

I certify that I am the Technical Director, Chief Engineer or Consulting Engineer of the radio station for which this application is submitted and that I have examined the foregoing statement of technical information and that it is true to the best of my knowledge and belief. (This signature may be omitted provided the engineer's original signed report of the data from which the information contained herein has been obtained is attached hereto.)

.....
Technical Director, Chief Engineer or Consulting Engineer

F.C.C. - WASHINGTON, D. C.

FIG. 5-1. (*Continued*)

will reveal the general nature and simplicity of the information required in the application.

Nondirectional AM and FM, Transmitter Power Greater than 10 Kw

Except for one item of information, the required information for this category of stations in applying for remote control authorization is the same as in the preceding paragraph for the lower power. This item concerns the reliability of the transmitter. This additional information consists of an analysis of the transmitter operating logs, maintenance logs, and records for the 12-month period immediately prior to the application. This analysis is to include the following items:

1. The number of outages, their cause and duration together with what corrective measures were taken to remedy the malfunction and to prevent such a recurrence
2. The nature and consistency of past maintenance performed and a statement of the maintenance practice and policy to be followed after remote-control authorization

From the above it would be natural to assume that a transmitter would have to be in operation for a period of at least a year prior to submitting the application. This is not necessarily the case. The Commission realizes that no broadcaster would be willing to jeopardize his own operation and public-service responsibility by remotely controlling an unproved transmitter. In the case of a new transmitter, undoubtedly it will have been designed and constructed with remote control as a provision of operation. Most new transmitters have remote-control provisions built in. If the transmitter has been in operation less than 12 months and the operating data attest to its reliability, then the application may reasonably be submitted with a request for waiver of the full 12-month period.

Directional Stations of Any Power [2]

In addition to the normal requirements for remote control, the FCC has included certain items that must be monitored. These relate to the directional antenna and its stability. In the Commission's decision they are stated as follows:

On the basis of the comments filed and our experience with the problems of directional antenna systems, we have determined that the basic information necessary to establish the stability and proper adjustment of a directional antenna system, and hence, the information which we will require as part of an application to operate a directional antenna by remote control is as follows:

(*a*) A statement describing the stability of the system for the preceding one year period. This statement shall include, but shall not be limited to, such information as the nature and degree of adjustment required, the maintenance procedures followed and the adequacy of the present monitoring system to indicate changes in the operation of the array.

(*b*) Weekly readings of field intensity at each monitoring point specified in the station license for the preceding 1 year period (moothly readings will be acceptable for those stations which are presently authorized to measure monitoring points field intensities on a monthly basis).

(*c*) Readings once each day of antenna base currents (for each pattern) and readings taken at approximately the same time of common point current, phase monitor loop sample currents or remote base currents, and phase indications for the preceding 30 days.

(*d*) A redetermination of the comunon point impedance of the directional antenna system.

(*e*) A partial proof-performance consisting of at least 9 or 10 measurements taken at a distance of from 2 to 10 miles from the antenna on each radial measured in connection with the last complete adjustment of the directional antenna system, properly analysed in accordance with Section 3.186.

[2] For transmitters over 10 kw, the same reliability factors for the transmitter apply as for nondirectional stations.

CONELRAD Requirements

On the subject of CONELRAD, the Commission indicated that

. . . we believe that we are justified in conditioning an authorization for remote control of a station operating with a directional antenna and/or a power in excess of 10 Kw. upon the installation of equipment that would permit the changeover from the licensed operation to CONELRAD operation to be made from the remote control point. . . .

Applications for remote control involving either a directional array or a transmitter with power output in excess of 10 kw must be accompanied by a description of the equipment which will make it possible for the station frequency to be switched from the regular frequency to either 640 or 1,240 kc by remote control. The station is not required to take part in the CONELRAD program, but it is required to be able to switch to either 640 or 1,240 kc, whichever is assigned, by remote control. A station may also employ an auxiliary transmitter at the remote-control point and operate it on 640 or 1,240 kc.[3]

The equipment to perform switching to 640 or 1,240 kc need not be installed prior to the filing of the application for remote control. The switching to the CONELRAD frequency is normally accomplished with one control operation, throwing relays to change frequency, switching necessary inductances or capacitances to retune the transmitter, any antenna switching or tuning necessary, as well as audio switching if required and provision for automatic operation from cluster control.

The ruling requires a station to be able to transmit at least one-half of its regularly licensed power on the CONELRAD frequency but in no case more than 5,000 watts.[3] As an example, a 1,000-watt station would be required to transmit at least 500 watts on the CONELRAD frequency,[4] a 5,000-watt station would be required to transmit 2,500 watts,[4] but a 50,000-watt station would be required to transmit only 5,000 watts on the CONELRAD frequency. If a station operates a lower power at night, it is necessary to transmit only one-half of the nighttime power on the CONELRAD frequency. If such an interpretation of the ruling were to require a station to transmit a higher power on the CONELRAD frequency than would be necessary for practical operation in a particular CONELRAD cluster, this ruling may be waived. A letter from the CONELRAD authority stating that the lower power is sufficient power for practical operation in this CONELRAD cluster should be made part of the application.

Operator Requirements

In regard to operator requirements, the Commission has covered these in Sec. 3.93 of Part 3 of their Rules which appear in Sec. 1 of this Handbook and are not repeated here.

General Considerations

There has been some confusion regarding the acceptable methods of making RF pickup at the respective towers for a remote indication of base currents at the control point. It is acceptable, of course, to install a RF pickup coil at the base of each tower, rectify and filter the RF for conversion to direct current, and feed it back to the transmitter house for connection into the remote-control system. If such a procedure is not inconvenient, this probably would be the most acceptable method. However, the FCC has indicated to NAB that use of the sampling loops is also satisfactory provided the loop currents are accurately calibrated with the respective tower base currents. The coaxial lines from the sampling loops which feed the phase monitor can be *disconnected* from the latter and connected to a rectifying and filtering unit, which can then be used in conjunction with the remote-control system for remotely reading the tower base currents. Details are provided later in this part.

[3] See Subpart G, Part 3, of the FCC Rules concerning permissible power.
[4] Unless otherwise certified by the FCC CONELRAD supervisor.

One of the most unpalatable provisions of the remote-control rules for directional stations is the requirement for sending a man to the transmitter within 2 hr of a change in pattern or within 2 hr of the beginning of the broadcast day for stations operating with a single pattern. This man is required to read and log at the transmitter location once each day for each pattern (as explained above) common-point current, base currents, phase-monitor loop sample currents, or remote base currents and phase indications. It is understood that the reason for these measurements hinges on the lack of a suitable remotely operated phase monitor. It would appear logical that if such a phase monitor can be purchased and installed and its accuracy established to the satisfaction of the Commission, a station might obtain a waiver of this provision. It is known that such a phase monitor is in the process of development at the time of writing and perhaps may be available by publication date.

A D-C REMOTE-CONTROL SYSTEM

Remote control of a transmitter is normally accomplished over two telephone circuits. It is also possible to control a transmitter remotely over a radio circuit with the metering information being fed back on a radio circuit. The operation is similar to a d-c operation except that the control is accomplished with the use of audio or radio frequencies. The information is fed back to the remote-control point by radio, converted back to a meter reading, and calibrated against the original meter reading at the transmitter.[5]

Telephone-line tariffs may play an important part in establishing the fixed recurring cost of remote controlling a transmitter. Generally, remote-control lines are quite short and the cost very reasonable. In the case of longer runs, however, a broadcaster should take care to see he has ordered his telephone circuits properly and that he is getting the advantage of the proper tariff. In one city where the cost of a program loop between the studio and a transmitter was well over $100 and an order wire cost was well over $50, remote-control circuits were available at a cost of only $25 each. The gap is not always so great. When telephone lines are ordered for a "d-c" remote-control system, order "signal circuits," sometimes referred to as telemetering control (TC) circuits and classed as 0- to 15-cycle lines. They must be metallic circuits and cannot be phantoms or simplexes. On long lines, the telephone company may have more than one way of figuring a circuit. As an example, one radio station found that its telemetering control lines would cost $45 per month on a straight mileage basis, but when the circuit was broken down to a combination intercity and intracity rate, the cost was only $25 per month. Many radio stations remotely control the transmitter over 50 or more telephone-line miles.

Once one is familiar with the rules governing remote control, a decision must be made as to the type of equipment to be used to control the transmitter remotely. Excellent commercial equipment is made by several manufacturers and is available in a wide price range. Composite equipment may be constructed. In either event, this part will describe how to make a remote-control installation.

Most systems employ two metallic telephone circuits and, generally speaking, will meter over one of the telephone lines while performing controlling functions over the other. Smaller systems generally work against ground, whereas larger systems will employ voltage differential and/or polarity switching to effect several operations over a single pair. Voltages and currents to be remotely metered are converted to a low voltage, varying from about ½ (full scale) to about 5 volts (full scale), depending on the system employed. Metering can be accomplished on an arbitrary scale using correlation charts for each meter reading, or direct scales duplicating transmitter meter scales can be employed. Metering accuracy must be maintained within 2 per cent.

The FCC requires that remote-control equipment allow an operator to turn the transmitter on and off and to raise and lower the output of a transmitter. A "fail-safe" circuit must be incorporated to ensure that the transmitter will be automatically

[5] See Part 2 of this section for additional details.

shut down in the event of any trouble which would prevent the operator from controlling the transmitter.

Communication is essential between the transmitter and the remote-control point to allow calibration of the meters. This may be a regular city telephone, a separate

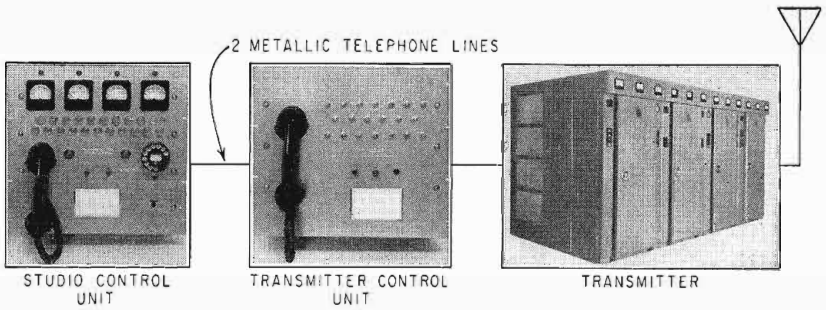


FIG. 5-2. Block diagram of basic remote-control installation.

order wire, a telephone built into the remote-control system, or if the program line is available, it can be used when the station is off the air, although the latter may prove awkward.

An off-air monitor is highly desirable. It can be equipped with an alarm which will sound in the event of loss of carrier or loss of program and will help to hold lost air time to a minimum.

A CONELRAD receiver will be required at the remote-control point of a station regardless of whether or not a direct CONELRAD line is installed at the remote point.

A standby transmitter is considered a good investment by many stations installing remote control. If an operator from a remote-control point can switch to a standby

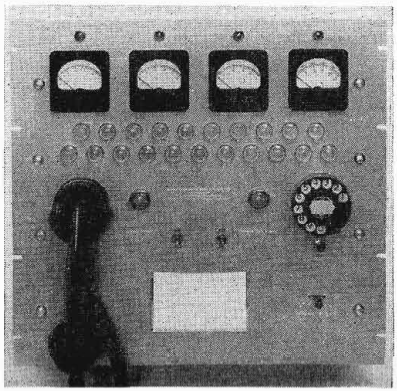


FIG. 5-3. Studio remote-control unit.

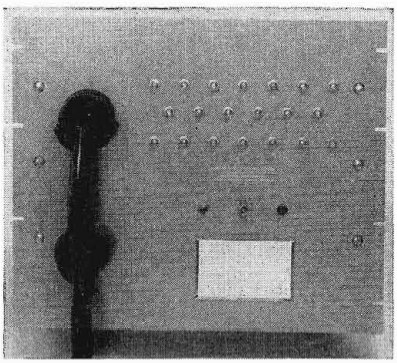


FIG. 5-4. Transmitter remote-control unit.

transmitter in event of the failure of a main transmitter, lengthy outages may be eliminated.

Fire has not been a serious factor. It is possible on any remote-control system to read room temperature or any other temperature remotely, and of course, fire-alarm equipment as well as burglar-alarm equipment can be employed at a transmitter to reduce the possibility of these hazards. In actual practice, fire-extinguishing equipment or fire-alarm circuitry is rarely employed.

When *remote-control* equipment is initially installed, it is wise to operate the transmitter by remote control from the remote point with the transmitter still manned. In this way, an excellent opportunity is afforded to be certain that everything is in perfect working order before actually remotely controlling the transmitter unattended.

Remote-control equipment described here in detail is the Schafer Remote-Control-System Model 400-R. Any system could be connected in a similar manner whether

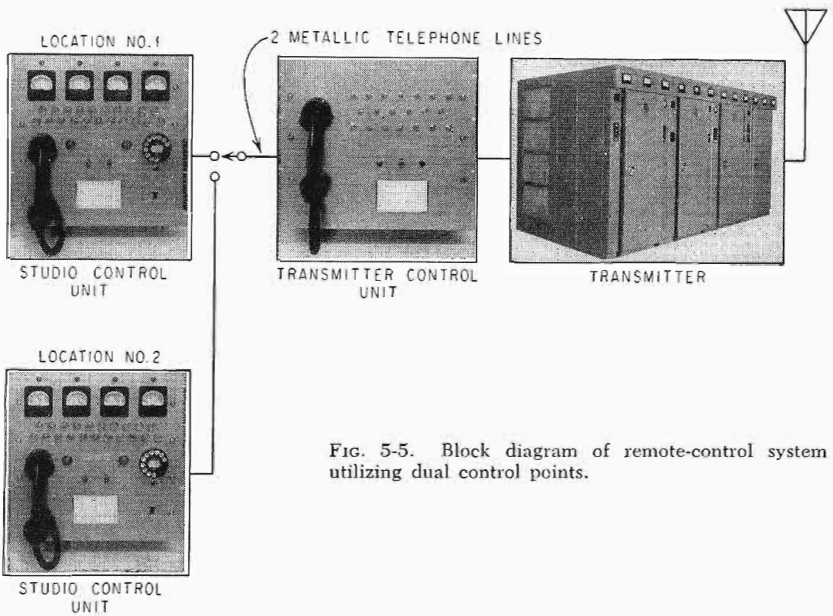


FIG. 5-5. Block diagram of remote-control system utilizing dual control points.

the system be a composite or commercial system. This system is a d-c system, utilizing two pairs of telephone lines between the transmitter and the remote-control point. It utilizes a 26-position stepper, making possible the connection of 26 metering circuits and 52 control circuits.

The basic remote-control installation includes a "studio control unit" and a "transmitter control unit" as shown in Fig. 5-2 (block diagram) and Figs. 5-3 and 5-4. Note the inclusion of the telephone for communication between the transmitter and remote point when making calibrations.

A system which allows remote control from two control points is outlined in Fig. 5-5.

THE REMOTE-CONTROL SYSTEM

The system described herein will operate on any two metallic circuits, each of which has a loop resistance of 10,000 ohms or less. A simplified diagram of the system is shown in Fig. 5-6.

Description of the Operation of the Remote-control System

The metering information is fed from the transmitter to the remote-control point on telephone line 1 except when line 1 is being used for dialing. A holding voltage is fed to the phantom circuit (balanced between the two lines). This is the "fail-safe" circuit. It holds the transmitter power relay closed. When the voltage is tripled, the "phantom" relay is closed.

The voltage is tripled at any time operation of the dial system is taking place, switching telephone line 1 from a metering line to a dialing line. A positive or negative voltage is fed to line 2 to operate the "increase" or the "decrease" relay. These relays will operate through the stepper and will control whatever circuit is dialed up. They can be employed to turn a circuit on or off or to raise or lower a circuit. When a circuit is dialed up, it can be metered continuously and controlled simultaneously. At any time the push button on the transmitter can be depressed, and 60 volts 60 cycles will be fed back to the studio, ringing the bell in the studio control unit. One

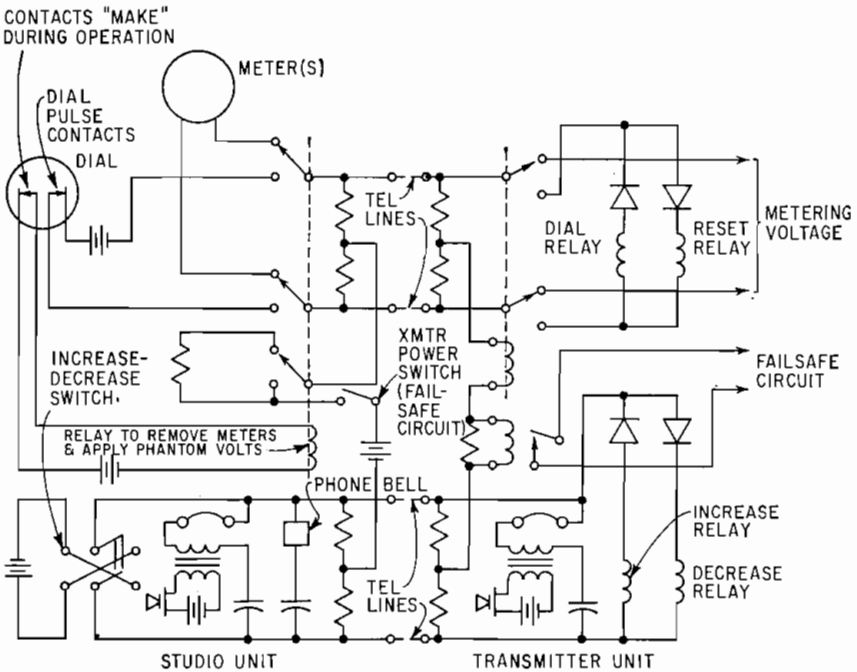


FIG. 5-6. Simplified schematic of typical remote-control system utilizing two metallic circuits.

of the control circuits can be used to ring a bell at the transmitter, thereby providing two-way ringing. At each end a telephone is connected in such a way to feed audio to line 2. In this way the telephone can be used for communication during metering and during controlling.

Because the fail-safe circuit is on a phantom between the two lines, it is possible to retain on-off control of the transmitter even if one side of either or both telephone lines should open.

Figure 5-7 is a diagram of the studio control unit.

Figure 5-8 is a diagram of the transmitter control unit. This is the equipment which takes the voltage and current from the transmitter shunts and enables their transmission over the telephone lines to the remote point.

Figures 5-7 and 5-8 include the complete studio control unit and transmitter control unit. When connected at points 1*A*, 1*B*, 2*A*, and 2*B*, the units will operate together, providing remote control and remote metering for up to 26 circuits. In the commercial model of this system, 20 metering circuits are connected to internal meters. Auxiliary meters can be connected to any of these circuits. Circuits 21, 22, 23, and 24 are brought out to external meters for frequency modulation or any other external

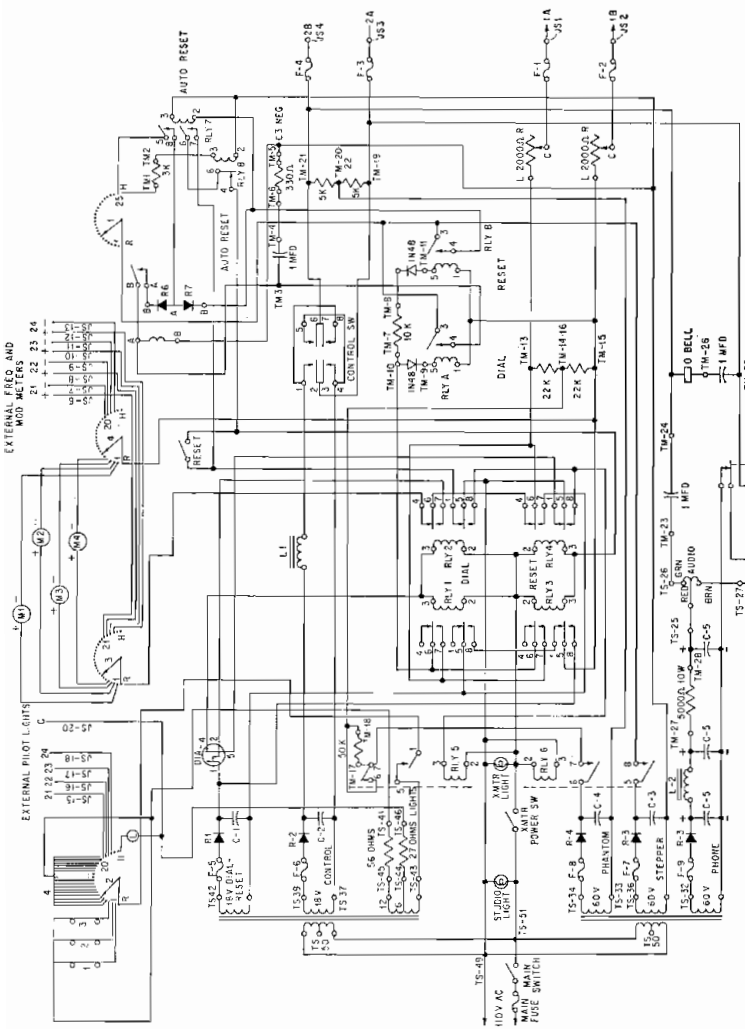


FIG. 5-7. Schematic diagram of studio control unit.

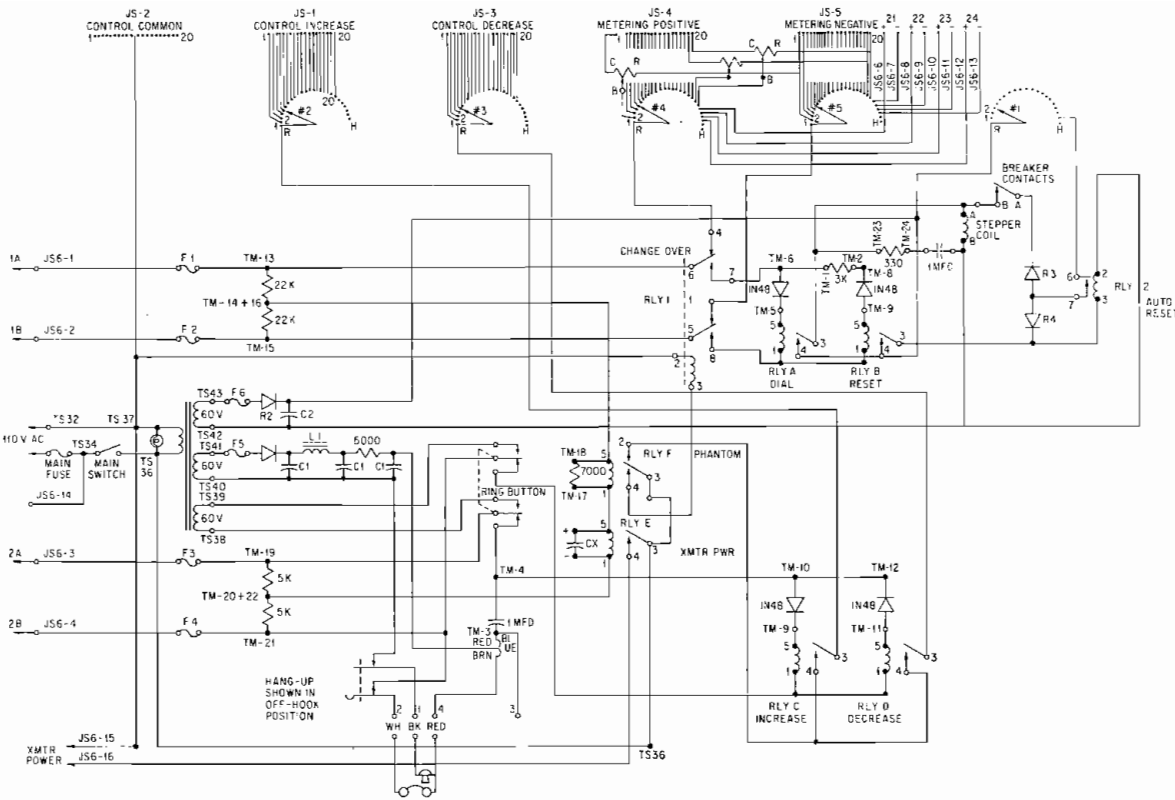


FIG. 5-8. Schematic diagram of transmitter control unit.

meter application. One or more of these external circuits can be used as a spare audio circuit. In the following pages, typical connections of metering circuits as well as control circuits are discussed in detail.

Frequency and Modulation Remote Metering

All current-model frequency and modulation monitors provide external connections for remote meters. Some earlier monitors do not provide external connections, but it is possible to meter frequency or modulation remotely from virtually any frequency or modulation monitor. The remote meter may be a meter duplicating the meter on the monitor or one slightly more sensitive to allow for calibration. Modulation monitor meters range from 0 to 400 d-c to 0 to 600 d-c μa. Most AM frequency monitor meters are 100-0-100 d-c μa. FM frequency monitors employ more sensitive movements.

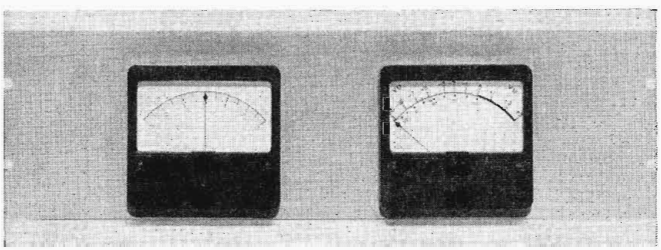


FIG. 5-9. Typical panel mounting of modulation and frequency meters for remote reading.

The remote frequency and modulation monitor meters for AM include typical scales and can be mounted in panels as shown in Fig. 5-9.

The remote frequency and modulation monitor meters for FM can be mounted similarly in a panel. The frequency-deviation meter scale should be 3-0-3 kc or 3,000-0-3,000 cycles.

If the remote meters are more sensitive than the meters in the monitor, the calibration panel such as shown in Fig. 5-10 can be used. A panel such as this has the

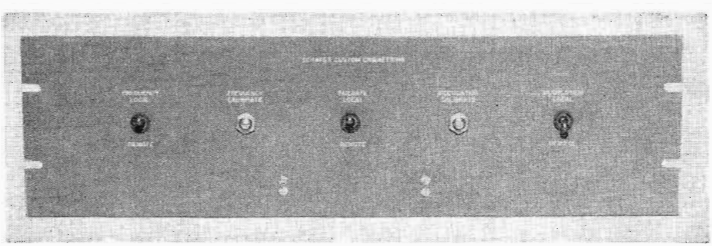


FIG. 5-10. Calibration panel for frequency and modulation monitor.

advantage of providing local and remote switching for these metering circuits as well as for the fail-safe circuit. Because the remote meters are actually in series with the meters in the monitor itself, it is necessary to short out the external meters or replace the external connections with a resistor equal to the line resistance of the telephone line so that local monitoring at the transmitter can be accomplished without error at times when the meter is not dialed up in the remote-control system. Figure 5-11 is a circuit diagram of the connections to the panel shown in Fig. 5-10.

It is possible to meter modulation remotely from any modulation monitor known. Remotely indicating frequency is sometimes slightly more complicated than merely adding a meter. As an example, in the case of the Gates frequency monitor MO-2890

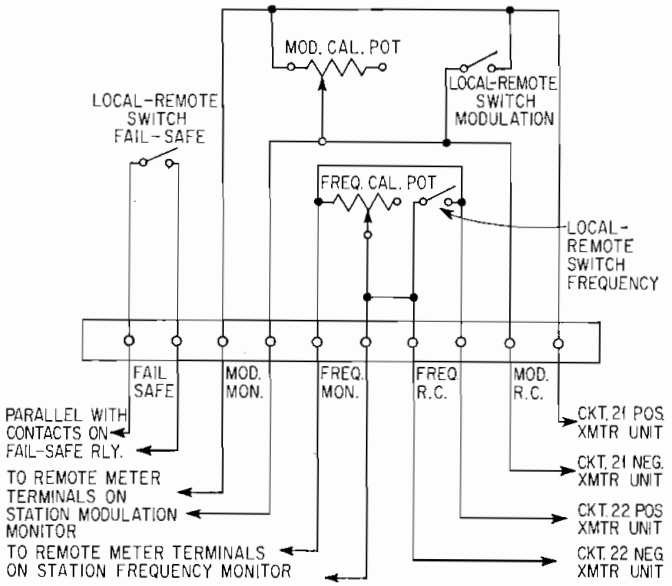


FIG. 5-11. Circuit diagram of the connections to the calibration panel for frequency and modulation monitor.

or the Doolittle frequency meter, it is necessary to use a special remote panel. In these monitors a difference frequency provides a tone which is measured by a reactance device and associated meter. For this reason, it is necessary to take this tone, feed it into the remote-control system over the telephone line, amplify it at the remote-control point, and feed it into a similar reactance device and meter.

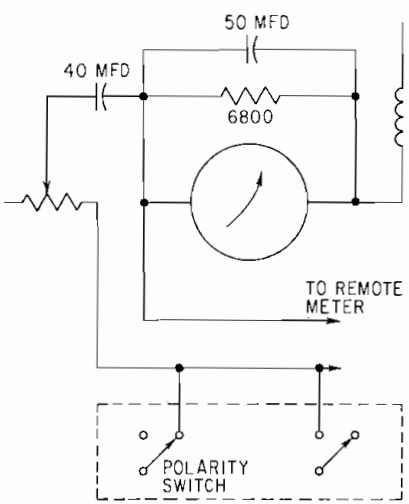


FIG. 5-12. Schematic diagram of remote metering connections to the Hewlett-Packard frequency monitor.

The Hewlett-Packard frequency monitor employs a very sensitive frequency-deviation meter in a bridge-type circuit. In order not to upset the circuit and to get accurate indication of frequency deviation remotely, the circuit in Fig. 5-12 was developed by the engineering department of McClatchy Broadcasting Co.

In the case of the Western Electric 1A or 1C AM frequency monitor, the frequency-deviation meter has a 1-ma movement. Therefore, either a more sensitive meter can be used and calibrated accordingly, or the 1-ma movement can be used. A relay must replace the switch which is to be pushed to provide the remote frequency reading. The second push button on the monitor is actually a capacitor which determines whether the deflection is a difference high or low and is not necessary if the monitor is normally adjusted to indicate, say, 5 cycles high at zero frequency and calculations are made from this reference, making the directional differences obvious.

In the case of any frequency monitor, it is desirable to have a normal reading at some point other than exact zero to be certain that a reading is actually being observed. A zero-center meter will always rest at zero, and should a trouble develop in which no current would be present, no variation could be taken to mean zero deviation. While most stations utilize remote meters, thereby leaving the frequency and modulation monitor at the transmitter, it is also possible to employ a RF amplifier which can be used to drive a frequency and modulation monitor at the remote-control point. The advantage of this is that a constant indication of the frequency and modulation is available at the remote-control point. The disadvantage is that unless duplicate sets of monitors are employed, no frequency or modulation readings are available at the transmitter, which is especially unhandy during maintenance or test periods.

If the Doolittle frequency monitor is operated at a remote-control point, especially a studio location, special care must be taken because the Doolittle frequency monitor transmits the signal approximately 1,000 cycles from the station carrier frequency and the signal is strong enough to produce a "beep note" in any nearby receivers, especially in a nearby air monitor.

Metering Circuits

It is necessary to develop a small d-c voltage proportional to each voltage or current to be metered remotely. In the system herein described, approximately 3 volts will be developed for full-scale deflection of each circuit. In the commercial systems available, the voltage necessary to give proper deflections to the meters will vary from ½ to 5 volts, depending upon the system employed.

Antenna Current

In some cases, the station will have a remote antenna current meter at the transmitter location. If this is a diode meter, the voltage feeding this meter can be used to feed the remote-control system. If the voltage is insufficient to provide the necessary 3 volts, the voltage can be raised by increasing the coupling or by changing the circuit. Care must be taken that adequate calibration is provided to calibrate the "local" remote antenna meter as well as to have adeqnate voltage to feed the remote-control system. If direct current is not readily available, it can be developed by the use of a pickup loop and diode unit as pictured and described in Fig. 5-13. Figure 5-14 is a photograph of the RF pickup coil and rectifying-metering unit.

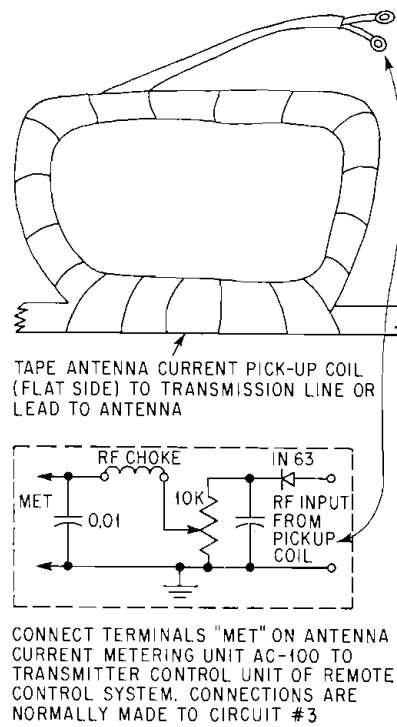


FIG. 5-13. Connections to antenna-current pickup coil for rectifying and filtering RF.

The pickup loop and diode unit described above can be connected to indicate common-point current or base current of any tower by taping it to the appropriate feed line. It should be connected ahead of the regular base-current meter so that the latter will be the final indication of current in the circuit. Likewise in the case of common-point current, the pickup loop should be taped to a point ahead of the regnlar common-point-current meter for the same reason.

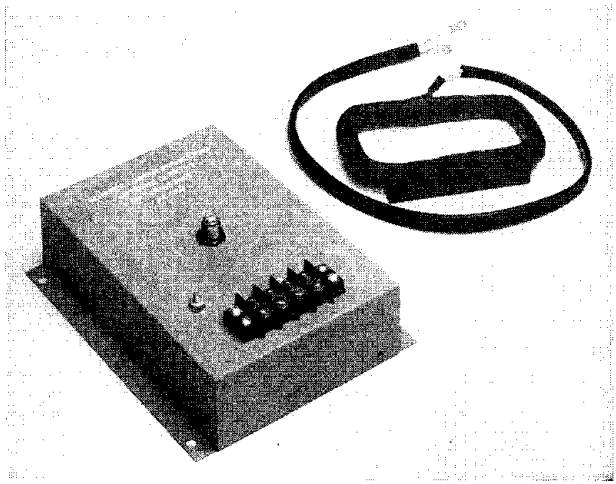


FIG. 5-14

Remote Base Currents in the Directional System

These may present a problem in that many stations employ loop-current meters and do not have remote-base-current meters. In order to provide remote-base-current meters, it may be necessary to run a pair of wires to each tower. Unless this is desirable for some other reason, it is now considered acceptable to use the RF from the pickup loop which feeds the phase monitor to develop direct current for remote reading. *The rule will not permit a diode to be connected directly across the coaxial line, but a switch may be installed to switch the coaxial line from the input of the phase monitor to the diode unit, or a relay may be connected to perform this switching function.* An alternative method would be to construct a chassis with the sufficient number of diode units, and the coaxial lines could be plugged either into the phase monitor or into this chassis. This chassis, in that case, would provide direct current to the remote-control system. Figure 5-15 is a schematic diagram of such a switching unit.

Plate Voltage Metering

This is relatively simple, especially in transmitters which employ a plate voltmeter with 1-ma movement. If the resistor between a plate voltmeter and high voltage is on the order of 1 megohm per 1,000 volts measured, the meter is a 1-ma movement. Virtually all Collins, General Electric, and Gates transmitters employ basic 1-ma plate voltmeter movements, and some meters supplied in RCA, Western Electric, and other transmitters are 1-ma movements. Some RCA, Western Electric, and other transmitter plate voltmeters are 5-ma movements.

In the case of a 1-ma movement, the metering resistor as shown in Fig. 5-16 can be incorporated to develop the remote metering voltage. It will not upset the plate voltage metering in the transmitter.

Plate Voltage Metering Unit PV-10. If your present plate voltmeter has a 1-ma movement and is connected between ground and an external meter multiplier, remove the connection between your present plate voltmeter and ground, and connect the PV-10 between the present plate voltmeter and ground. Connect the terminals from the PV-10 (in addition to connections just described) to the proper metering circuit on the Schafer Remote-Control System. Connection is usually made to metering cir-

cuit 1. Observe polarity. Before actual connection is made, the voltage can be checked on a voltmeter across a 10,000-ohm load. If the present voltmeter does not fit the circuit described in the beginning of this paragraph, an external plate voltage metering multiplier will be required.

Care must be taken that the lower end of the plate voltmeter circuit returns to or very close to ground potential. In a case of some RCA 250-watt transmitters, a plate rheostat is employed between B-minus and ground, thereby raising the potential at the low end of the plate voltage metering circuit to as much as 200 or 300 volts above ground. This voltage will cause trouble when placed on a telephone line as it would normally be connected. This difficulty can be overcome in several ways. The taps on the transformer can be changed so that the plate rheostat will be operating near the low-resistance side thus keeping the voltage drop across the rheostat below 50 or 60 volts.

A simple method of correcting this difficulty is to provide a remotely controlled plate rheostat in the high-voltage lead. As long as the manual rheostat is not adjusted after the plate voltmeter is calibrated, this will be perfectly satisfactory.

In this case, or in the case of any transmitter not employing a 1-ma plate voltmeter, the circuit shown in Fig. 5-17 can be employed. Instructions for connecting the unit are as follows:

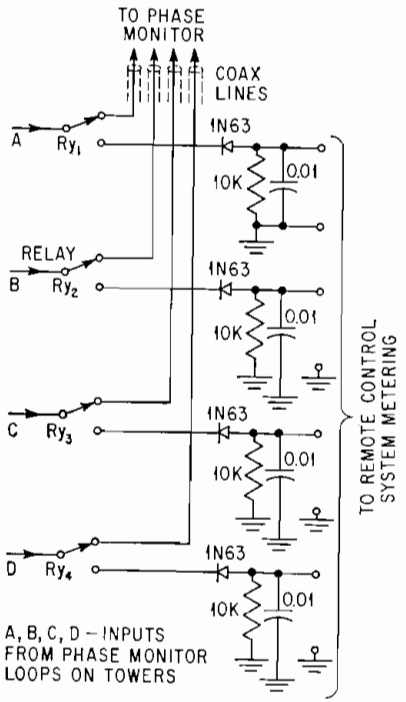


FIG. 5-15. Switching center connection of coax from loops on towers to remote-control system.

Plate Voltage Metering Multiplier (PVMM). Connect one end of the PVMM to the high-voltage source to be remotely measured. Connect the other end of the PVMM to the PV-10 plate voltage metering unit. Connect the remaining end of the PV-10 to the negative end of the high-voltage power supply to be measured. Connect the PV-10 (in addition to the connections already made) to the metering circuit on

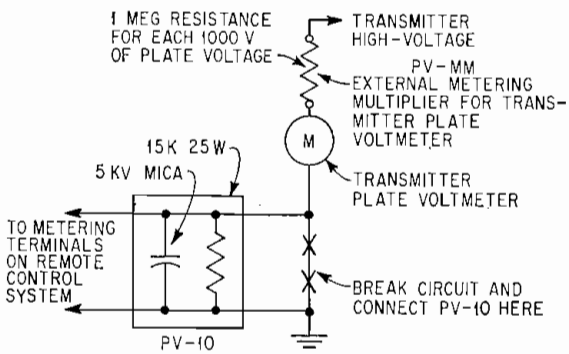


FIG. 5-16. Instructions for connecting metering voltage units supplied with Schafer remote-control system.

the Schafer Remote-Control System. Observe polarity. Metering circuit 1 is generally used for the plate voltage. If other high-voltage sources are to be measured, connection is made in a similar manner to the metering circuit on which reading is desired.

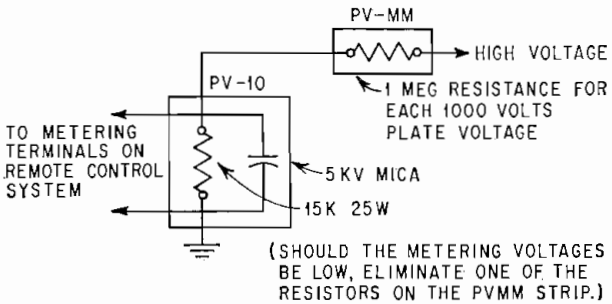


FIG. 5-17. Plate voltage metering multiplier (PVMM).

Plate current metering remotely is accomplished by inserting a fairly low value resistor in series with the plate return, actually indicating cathode current. The circuit normally employed is shown in Fig. 5-18. In making connections to this unit select a point in the circuit of your transmitter which can be broken, through which will flow the total cathode current of the stage to be metered. This point will usually be found at the center tap of the filament transformer of the stage on which plate current is to be measured, or where the cathode circuit returns to ground. At this point break

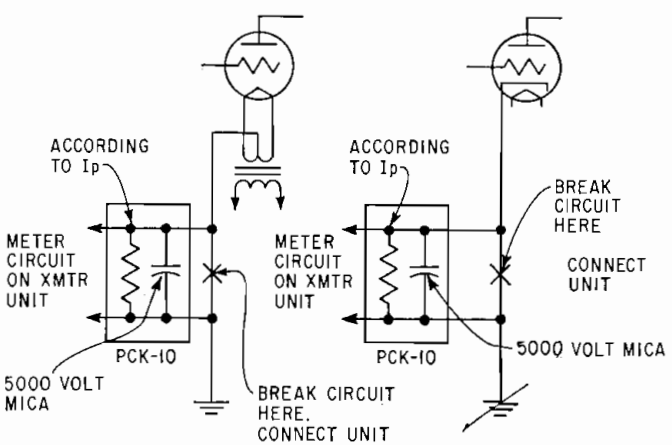


FIG. 5-18. Diagram of plate current metering unit (PCK-10).

the circuit, and insert the PCK-10 metering unit. Observe polarity, and be certain this point has no high-voltage reference to ground.

If the total plate current is 300 ma, a 10-ohm resistor is used on PCK-10.
If the total plate current is 500 ma, a 5-ohm resistor is used on PCK-10.
If the total plate current is 1 amp, a 3-ohm resistor is used on PCK-10.
If the total plate current is 2 amp, a 2-ohm resistor is used on PCK-10.
If the total plate current is 5 amp, a 1-ohm resistor is used on PCK-10.
If the total plate current is 10 amp, a 1-ohm resistor is used on PCK-10.
A photograph of Unit PCK-10 is shown in Fig. 5-19.

Plate current metering in some Collins transmitters does not require the above resistor to be inserted. Some Collins transmitters have a resistor in the circuit to provide audio output of the transmitter, and the voltage drop across this resistor is just about right for remote metering. In some other transmitters, the voltage drop across the coil of an overload relay may be just right to develop the proper voltage.

Plate current metering with d-c filaments may be impossible at a low-voltage potential. Where it has been found impractical, the Commission has waived the requirement, although thus far this situation has been limited to older transmitters used as standby or CONELRAD transmitters.

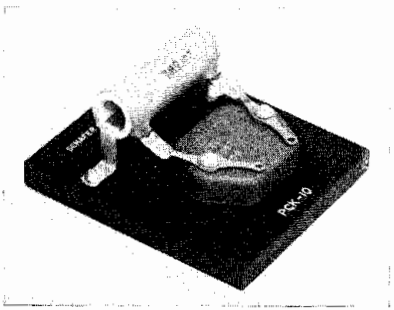


FIG. 5-19

Filament Voltage Metering

In the case of a-c filaments as found in most transmitters, this is a matter of selecting the filament source to be metered and reducing it to a few volts d-c. If the circuit shown in Fig. 5-20 is used, the filament voltage is merely rectified and filtered, and the voltage reduction is accomplished by the calibrating potentiometer in the remote-control system. Connect the terminals marked FIL to the filament voltage to be measured. The unit is designed for any a-c voltage to 15 volts. Connect the terminals marked MET to the metering circuit on the remote-control system. Observe polarity. Metering circuit 4 is usually used for this purpose.

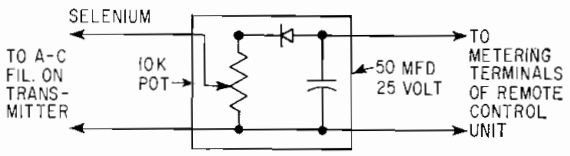


FIG. 5-20. Filament voltage metering unit.

Filament voltage metering in the case of d-c filaments requires only a simple voltage-divider circuit to drop the voltage to the metering voltage required. In most cases, the calibration potentiometer on the remote-control system will act as voltage divider and the filament voltage can be fed directly to the remote-control system.

Filament voltage metering is often most easily accomplished by actually measuring the line voltage (usually 230 volts) feeding the input of the filament transformers. In this case, the connection is the same as described below for line voltage metering except that the 115, 230, or 440 volts is taken from the input of the filament transformer circuit.

Line Voltage Metering

This is accomplished by reducing the line voltage of 440, 230, or 115 volts to a low voltage, then rectifying and filtering the low voltage. Line voltage metering can be done on a single phase or all three phases of more than one source as required. Circuitry for a single phase is shown in Fig. 5-21.

Tower-light Current Metering

This is accomplished by converting the current feeding one or more tower-light circuits to a small d-c voltage. The circuit in Fig. 5-22 shows the manner in which

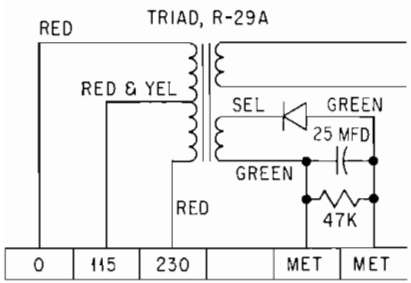


FIG. 5-21. Line voltage metering unit.

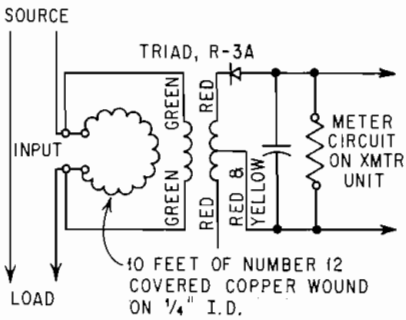


FIG. 5-22. Tower-light current metering unit.

the small resistance capable of handling high current is developed by using No. 12 wire. The small voltage drop across this resistance is fed into a transformer, stepped up by the transformer, then rectified and filtered. The output is direct current, proportional to the tower-light load. It is possible to tell how many side lights are burning and how many beacons are flashing by variations in this direct current. Usually one unit is used for each flasher. Connections to the TC-25 unit should be as follows: Connect the terminals marked AC in series with the line feeding alternating current to the tower lights. Connect the terminals marked MET to the metering circuit on the Schafer Remote-Control System. Adjust the potentiometer on the unit so the calibrating pot on the remote-control system itself (for that particular circuit) is operating in the top half of its range. The output voltage from the metering unit in this case will be approximately 5 volts when the tower light load is approximately 1,550 watts. If the tower-light load is not enough to develop the 3 volts required for remote metering, the voltage can be increased by connecting the unused RED transformer wire to the point where the RED and YELLOW wire is now connected.

Voltage metering circuits of any kind can be incorporated into remote-control systems by following the basic theory. Reduce the voltage to a few volts by using a voltage divider. The voltage divider should be designed to draw about 1 ma. Remember that the 10,000-ohm load across the metering circuit of the remote-control system will be present across the metering load at all times.

Current metering circuits of any kind can be incorporated into a remote-control system by following the familiar theory that it is necessary merely to convert to a small voltage. The remote-control system will have little or no effect on the circuitry because the 10,000 ohms will be quite high as compared with the few ohms required to develop the voltage required in most circuits.

Miscellaneous metering is practical with most remote-control systems because sufficient extra metering circuits are available so that anything which can be converted to direct current can be metered, such as room temperature, wind velocity and direction, and almost anything else imaginable.

Remote Controlling of Circuits

This is a matter of installing relays and motors to do what is normally performed manually. *Anything electrical which can be done manually can be done remotely.* Anything controlled by a switch can be controlled by a relay. Anything controlled by a knob can be controlled by a motor. Automatic controls are often desirable. Some stations have employed locks on the remote-control systems so that only specified personnel can control any circuits, or in some cases, locks are provided so that only certain personnel can control certain circuits in a remote-control system.

Remote control of any circuit locally controlled by a switch can be accomplished by

the use of a latching relay as shown in the circuit of Fig. 5-23 and the photograph in Fig. 5-24. Instructions for use are as follows: A circuit now controlled by a switch must be remotely controlled with a latching relay. A latching relay is a relay with two coils. When one coil is momentarily energized, a pair of contacts are closed. When the other coil is momentarily energized, the pair of contacts open. For this

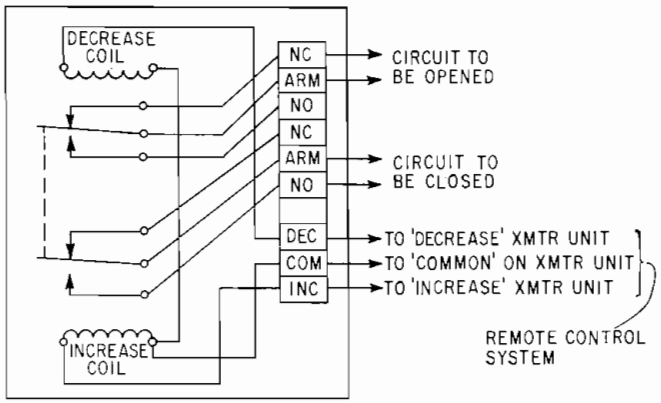


FIG. 5-23. Latching relay circuit diagram.

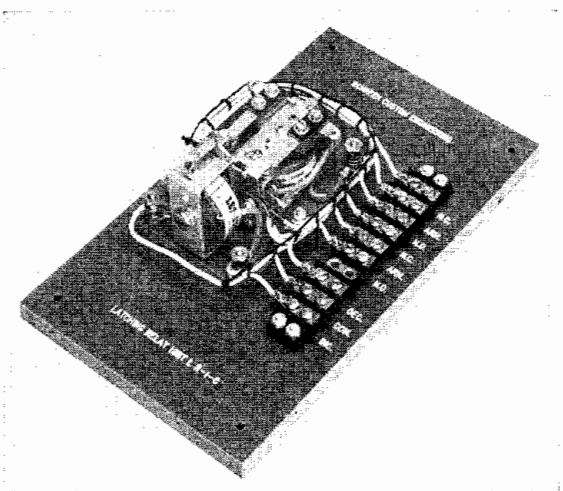


FIG. 5-24

reason, one coil can be connected to a control "increase" circuit, and the other connected to a control "decrease" circuit, and in this way remote control of a circuit locally controlled by a switch is a simple matter. Two push buttons are provided so local control of the latching relay can be connected as shown in Fig. 5-23. If a circuit is normally controlled with a manual circuit breaker, and if the protection the circuit breaker provides is important to the safe operation of the transmitter, a remotely controlled primary circuit breaker should be used for remote control of this circuit.

Remote control of any circuit locally controlled by push buttons can be accomplished

by the use of momentary relays as shown in Fig. 5-25. This relay unit, MR-2-C, shown in Fig. 5-26, consists of two momentary relays the coils and contacts of which are connected to a terminal strip, all mounted on sturdy black spauldite. An MR-2-C is used for two-way on-off circuits, such as filament voltage on-off, plate voltage on-off, etc. The MR-2-C is used to control a circuit remotely which is locally controlled by

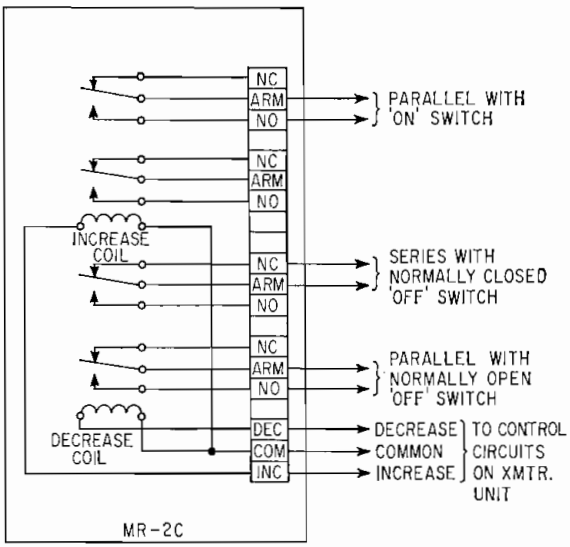


FIG. 5-25. Momentary relay circuit diagram.

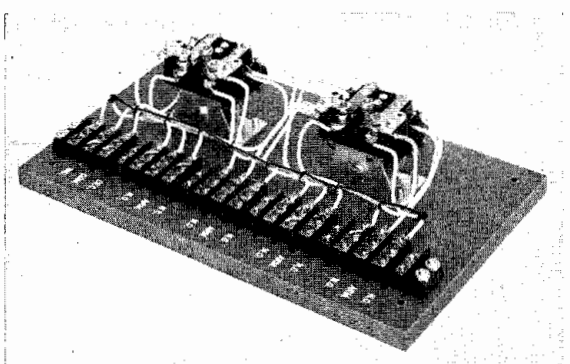


FIG. 5-26

push buttons. The relays are connected to perform the same function as the push buttons now perform. Care must be taken to connect the unit accordingly. While most ON buttons momentarily "make" a circuit, some OFF buttons break a circuit or simultaneously make and break a circuit. Obviously the relay should be wired in series with normally closed circuits and in parallel with normally open circuits.

Remote control of a circuit locally controlled by a motor is possible by merely remote-controlling the push buttons which now control the motor with a circuit similar to that shown in Fig. 5-25.

Remote control of an operation locally controlled by a knob can be achieved by connecting a motor to the shaft and remotely controlling the motor. Provision should, of course, be made for locally controlling the motor as shown in Fig. 5-27. Figure 5-28 is a photograph of such a motor control unit.

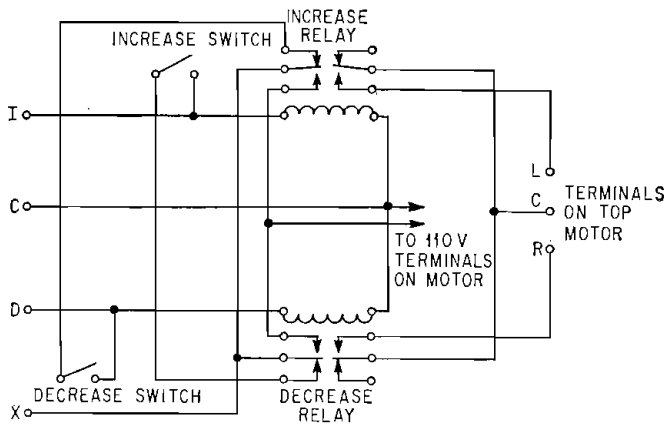


FIG. 5-27. Motor control unit.

Remote control of a circuit locally controlled by a circuit breaker requires a decision as to the importance of the circuit breaker and the experience with the breaker. If the breaker never drops out, it may be safe to connect a latching relay in series with it and retain the protection of the breaker while remotely controlling the latching relay and thereby the circuit. If the circuit breaker has a tendency to drop out, it may be desirable to connect a latching relay in parallel with the breaker, thereby eliminating the breaker from the circuit and, of course, eliminating the protection it affords. In any event it may be considered very desirable to include a secondary overload relay which can be reset by remote control as shown in Fig. 5-29.

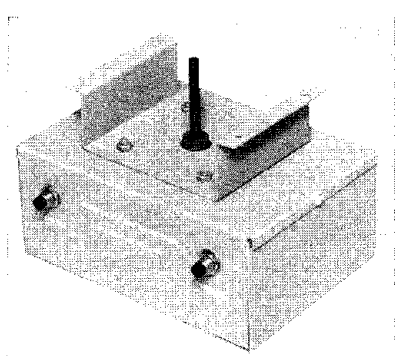


FIG. 5-28

Laying Out the Pattern for Connection of a Remote-control System

A remote-control installation may be as simple as to provide for the turning on and off of a transmitter and the reading of plate voltage, plate current, antenna current or may be complicated and involve several transmitters and more than one remote-control system. First, determine what you want metered and controlled. Then plan a logical layout for these metering and control circuits, bearing in mind that only one circuit can be controlled while a given circuit is being metered, although circuits can be cross-connected to provide for one circuit to be controlled on one or more metering circuits, or vice versa. Once you plan what circuits to meter and control, lay them out in a logical pattern. The following is a typical pattern for a basic installation:

Dial circuit	*Metering circuit*	*Control circuit*
1	Plate voltage	Plate voltage on-off
2	Plate current	
3	Antenna current	Power output—raise-lower
4	Filament voltage	Filaments on-off
5–20	Miscellaneous	
21	Frequency deviation	
22	Percentage of modulation	

The circuit for such a pattern is shown in Figs. 5-30 and 5-31 for both metering and control.

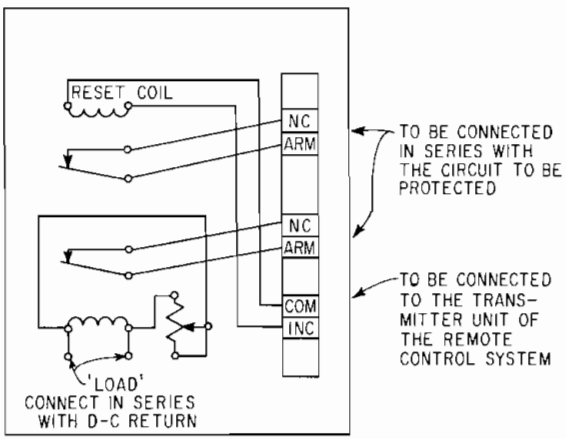


FIG. 5-29. Secondary overload relay unit.

CONCLUSION

Remote control of broadcast transmitters is an acceptable modern technique for operation of these stations. Concurrent with the application of remote control is the requirement for a stable transmitter. For directional stations, this requirement includes the stability of the array as well. There is no technical reason why remote control of television transmitters could not also be performed satisfactorily assuming that the preceding requirements are satisfied. Associated with remote-control systems are automatic logging and control of broadcast transmission parameters which are covered in Part 6 of this section. Application of both techniques to broadcast transmitters, both radio and television, will be a long stride forward in the modernization of our broadcast operating program.

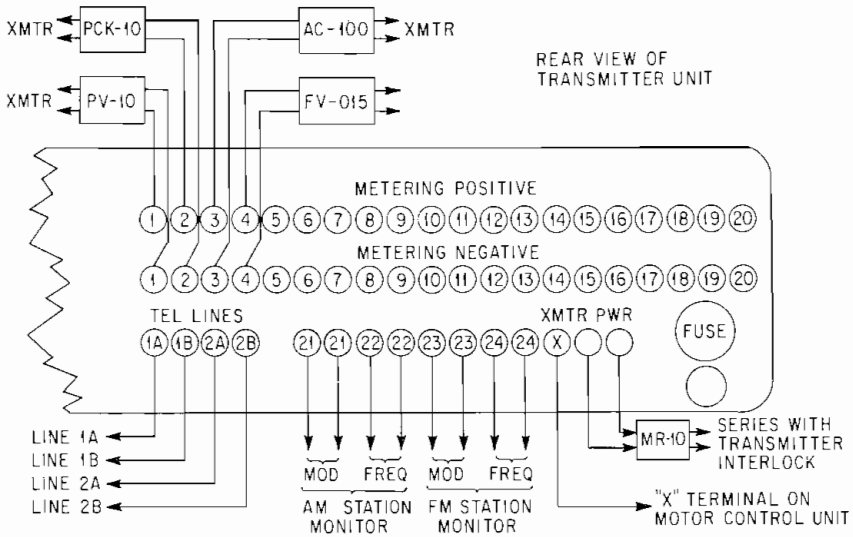


FIG. 5-30. Typical metering connections in a simple installation.

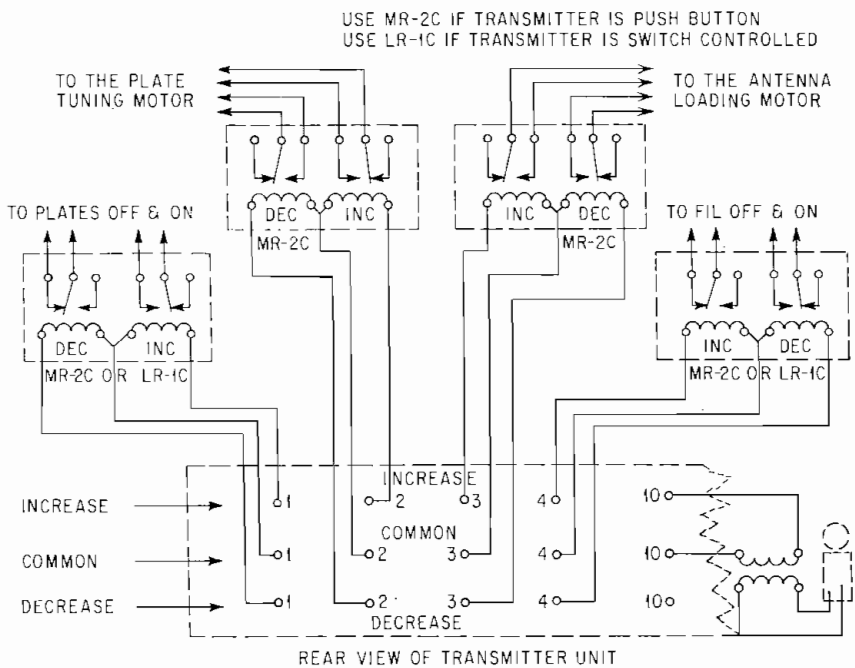


FIG. 5-31. Typical control connections on a simple installation.

Part 6

AUTOMATIC LOGGING AND CONTROL OF BROADCAST TRANSMISSION PARAMETERS

NAB Engineering Department

INTRODUCTION

For many years the Federal Communications Commission, in Part 3 of their Rules, has required broadcast stations to keep a transmitter log of specified circuit values. These meter readings have been made by the transmitter operator and written in a log sheet for a record of the performance of the transmitter. The existing rules of the FCC still require such a manually kept transmitter log. NAB intends to file a request with the FCC (July, 1960) to permit keeping the transmitter log for both radio and television stations by mechanical-electrical means.

Countless other nonregulated industries have applied automatic devices for years in recording information necessary to their operations. There is no valid reason why such techniques should not also be incorporated in the operating equipment of broadcast stations. The application of these techniques to broadcast transmitters must be in such a manner that the fundamental requirements of the regulating body (the FCC) are satisfied. Basically, the FCC is responsible for and validly concerned with four fundamentals: the operating frequency, the audio and video characteristics of the equipment used for transmitting including the degree of modulation, the performance of the antenna system in terms of the license specifications, and the power output or radiated power. These basic parameters are all related to the orderly operation of a broadcasting system in the United States, taking into account the effect of such operation on other countries in the North American region. If these fundamentals are satisfactorily controlled, it would appear that the governing body for broadcasting would have no valid objection to agreeing that the licensee should conduct his technical operations in a manner that satisfies both his own operating requirements and the public responsibility incumbent on each licensee of a broadcast station. Such techniques and even a vast simplication of automatic logging have been used for some time by government-owned and -operated broadcasting stations in other countries. The 150-kw medium-wave station at Daventry, England, operated by the British Broadcasting Corporation has only two operating controls, a START and STOP button. All other monitoring functions are performed by an off-the-air instrument which measures performance of the transmitting equipment. A necessary factor to be taken into account in such operation is maintenance of the equipment.

Although some engineers will argue with the premise, it has been demonstrated that in the vast majority of stations, transmitting equipment will operate unattended with no more outages than when an engineer is present during the operating period. There is even considerable evidence that the equipment performs better under such

circumstances. Such statements are not made without regard to some basic criteria which often are lost sight of in relation to modern operating techniques:

1. A stable, completely reliable transmitter that will operate day in and day out with no "babying" or coaxing, designed and built for unattended operation and having provisions incorporated in it to ensure its continued electronic health throughout its normal life

2. An antenna system which meets the terms of the license not only when installed but during continued operation in order to provide both service to the intended area and a prescribed minimum of interference to other stations

Undoubtedly a large percentage of stations installed in recent years have transmitters which meet the first criterion. There are many stations, however, with old transmitters which do not measure up. These transmitters, in all fairness, are still doing a creditable job with engineers in attendance, but in some instances, they should not be expected to operate unattended. Some of the low-serial-number transmitters in the 50-kw category have been operating 25 years and holding up well but with the requirement for operating techniques as old as the transmitters.

Antenna systems fall into two categories, omnidirectional and directional with varying degrees of complexity. In both cases, we are finding that as in all things, age and deterioration are taking their toll. Towers themselves can usually be made to last indefinitely if good maintenance and inspection procedures are carried out. Ground systems are somewhat like the internal organs of man—you may know something is wrong but sometimes surgery is necessary to locate and correct the trouble.

LOGGING PHILOSOPHY

Logging parameters which are of fundamental concern of the FCC and those which a licensee may wish to record in the interest of his own technical operation can be discussed together.

Frequency

For standard broadcast stations, it has been demonstrated beyond any doubt that the average frequency stability today is ±3 cps of the assigned frequency.[1] This is well within the permitted tolerance of ±20 cps. The existence of such stable oscillators in the transmitters raises the question whether a frequency monitor should be required or the entire responsibility of maintaining frequency should be on the licensee without the requirement in the Rules of the FCC for specific equipment. It certainly is no difficult task for an engineer to make use of the standard frequency transmissions of WWV or WWVH [2] to calibrate a secondary frequency standard and multivibrator and determine to the cycle the frequency of a standard broadcast transmitter at any time. Such transmissions are radiated on frequencies which should make reception at any location in the United States and possessions relatively easy. Although, at the present time, the FCC Rules require logging of the frequency deviation, it seems reasonable that sometime in the future this responsibility may be placed on the licensee without specific instructions as to how the frequency shall be maintained.[3]

FM and television broadcast stations are not yet in the same situation with regard to frequency tolerance. Insufficient evidence is on file at NAB to enable similar conclusions for these stations. It is true that as the frequency increases, the stability under normal operating conditions is not so easy to maintain, even within a larger

[1] The average of frequency deviation obtained from 1,700 standard broadcast stations in the United States.

[2] See Section 1 of this handbook.

[3] NAB has filed a petition and substantiating data with the FCC requesting amendment of the rules to permit logging the frequency monitor at the beginning and end of the broadcast day and for 24-hr stations once in each 12-hr period. No action has been taken by the Commission.

percentage of tolerance. There are signs, however, that even for these stations, frequency-tolerance compliance may in the near future become somewhat equivalent to that for standard broadcast stations. Obviously, such compliance could be maintained now with additional equipment with more rigid accuracy specifications.

Characteristics of Audio and Video Equipment

The FCC has established standards applicable to broadcast equipment, and these are contained in Part 3 of their Rules. Any system of high performance, such as broadcasting, must have such criteria. Compliance with these standards is ensured by means of the proof-of-performance measurements which must be made and kept on file at the station. These requirements are not a part of the daily operating log but are important in maintaining the reputation for "broadcast quality" which has accrued to the industry.

Antenna System

The Rules of the Commission require logging of certain parameters of the antenna depending upon whether it is directional or nondirectional. These are set forth in Part 3 of the Rules. While there may be variations in the necessary readings to ensure that an antenna is performing in accordance with the terms of the license, the FCC believes that those now required are the proper ones. There is no difficulty in adapting automatic logging equipment to take care of these values. This will be made clear later in this part.

Power Output

Power is a basic factor in any radio allocation system. Together with the antenna characteristics, it determines the degree of service and also the interference potential (with due regard to propagation and noise considerations). Early in the development of broadcasting, maintenance of power level was not so simply accomplished as today with our modern methods of voltage regulation, including those associated with the primary power source. While relatively simple to maintain, it is a fundamental factor to be considered by the FCC and can easily be included in the logged readings.

AUTOMATIC LOGGING EQUIPMENT

The ideal operating situation would be to start and stop a transmitter and leave the rest of the considerations to electronic compensating and regulating devices. There is no technical barrier to such a system at the present time. Economics would enter the picture, although the additional cost would be small. In anticipation of the probable desires of the licensee and consideriug the existing and probable requirements of the FCC for the future operation of broadcast stations (AM, FM, TV), the NAB initiated discussions with manufacturers which have resulted in the production of equipment to perform the transmitter logging and control functions. Single-circuit simple recording voltmeter types of equipment have been used by broadcasters for years, and the FCC does permit their use in transmitters, but *not in lieu* of the manually kept transmitter log.

One type of automatic logging and control system has been developed by the Brown Instrument Division, Minueapolis-Honeywell Regulator Company. This equipment is used to log automatically in sequence, on a 12-in.-wide strip chart, various parameters. Each parameter is identified by a printed number on the chart, and the point by the number registers the position of the chart scale to give the measured value. Time lines on the chart give the time of measurement, because the chart is driven by a synchronous motor.

This equipment is designed to operate in conjunction with any of the standard remote-control systems and utilizes for logging purposes one of the two normally required pairs of lines (i.e., the metering line). During logging operations, the

metering line is connected to the logging equipment. Should a remote dial-up operation be desired using the remote-control equipment, the logging equipment is disconnected by means of a switch and the normal functions performed. The logging equipment *should be located at the remote-control point*, which in most instances is the studio location.

The Minneapolis-Honeywell automatic logger consists of two units, a logger transmitter and a logger receiver. All circuits to be recorded by this equipment must be either d-c voltage or direct current. RF can, of course, be rectified, filtered, and converted to an equivalent d-c voltage or direct current with one side at ground potential. Consequently, any and all circuit values pertaining to the transmitter of an AM, FM, and TV station or the requirements of the FCC such as the frequency-monitor reading can be logged and, if desired, controlled with appropriate apparatus deriving its exciting signal from this equipment. The accuracy of this equipment is 0.25 per cent, which is well within the FCC tolerance for remote indicating devices (2 per cent).

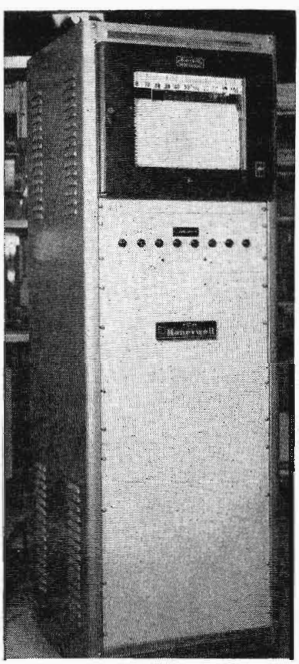


FIG. 6-1. Recording instrument and alarm light panel.

Reference to Fig. 6-2 will indicate the general system and its capabilities in a broad sense. All the required log functions of a radio and television transmitter can be handled by the equipment. The signal through the logger transmitter (see Fig. 6-3) starts from the input circuits *A*, *B*, *C*, *D*, *E*, *F* through the input selector switches S_1 to the measuring and control circuit M_1 then to the telemeter T_1 for transmission over a telephone line K_1 to the logger receiver. One input parameter signal is transmitted every 30 sec. At the end of each 15-parameter sequence there is a 30-sec interval of time before the next 15-point squence starts, during which time the synchronizing pulse-generating circuit in the telemeter transmits a pulse to signal the receiver when the next sequence of 15 input parameter signals will start.

The input parameter signal from the telephone line (K_1) to the logger receiver is fed directly to the signal measuring M_1, recording R_1, and alarm circuit A_1 (see Fig. 6-3). The synchronizing pulse from the telephone line to the logger receiver is fed directly to the print wheel and alarm-timing switch motor-control circuit. The print-wheel motor-control circuit in the logger receiver stops the print-wheel motor after each sequence of 15 parameters, and the synchronizing pulse from the logger transmitter starts the print-wheel motor again. The logger-transmitter input-selector switch is driven by a synchronous motor in the receiver. Since these motors are geared to drive the transmitter input-selector switch and the recorder print wheel at the same rate, the receiver print wheel and the transmitter input-selector switch will remain synchronized through each 15-point sequence.

Logger-transmitter Input Circuits

On the right of the Fig. 6-3 diagram there are six types of input circuits from *A* through *F*.

Type *A* input circuits will accept voltages from a tower-lighting transducer (see Fig. 6-11). The light-circuit transducer converts the navigational tower-light-circuit alternating currents to d-c voltages. The transducer response time to input current changes is slow enough to provide a steady output voltage even when the tower lights are flashed on and off at the rate of forty times per minute with approximately

equal on and off times. The output voltage from a light-circuit transducer is fed to the input of a circuit of type A (Fig. 6-3). From the input of a circuit of type A the signal passes through a radio-frequency filter to a voltage-divider circuit with two adjustments. The first voltage-divider adjustment provides a means of calibrating

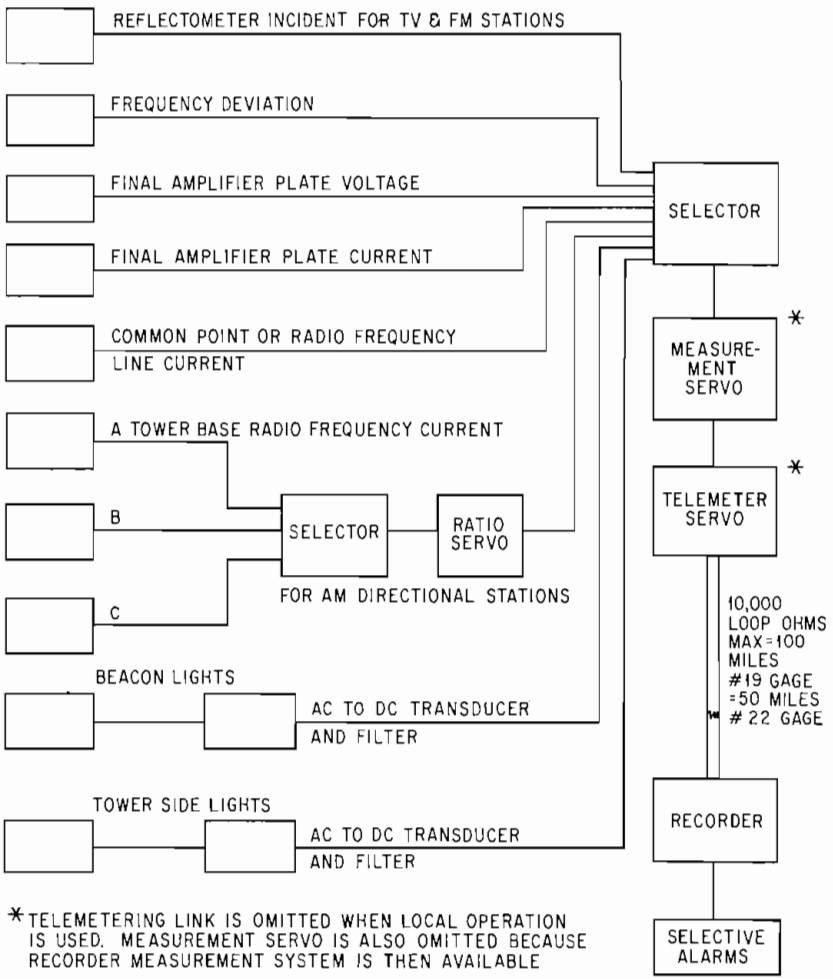


FIG. 6-2. Block diagram of Minneapolis-Honeywell automatic logging and control system.

the divider output voltage to a fixed full-scale value when tower light bulbs are replaced without disturbing the operation of the logging system. This is done by adjusting the voltage at one point in the divider circuit to equal a fixed reference voltage as detected by a reference voltage and galvanometer circuit. This means that the recorder will always indicate approximately the same point on the scale for all lights on, even though the total current drawn by the new lamps is not exactly the same as that drawn by the lamps they replaced. The second adjustment permits the operator to choose a point in the upper 20 per cent of the scale of the receiver recorder for indicating the "all lights on" condition that will not be in line with other

points needing more exact scale readings. A maximum of 10 type *A* circuits can be obtained.

Type *B* input circuits (Fig. 6-3) receive d-c voltages such as might come from

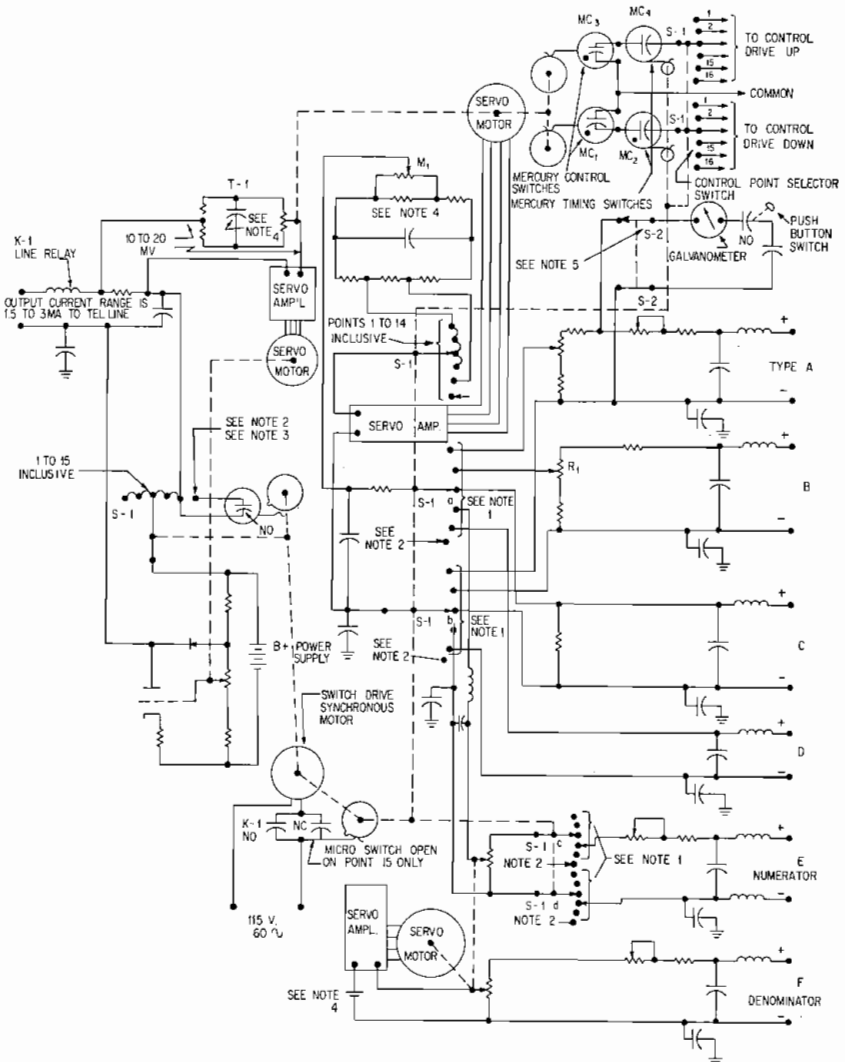


FIG. 6-3. Automatic logger-transmitter circuits.

the radio-transmitter final amplifier plate current, plate voltage, and common-point RF current circuits. At the input of the type *B* circuit these voltages are fed through a radio-frequency filter to an adjustable voltage divider R_1. The circuit can be equipped with dividers to accept 0 to 1, 0 to 5, 0 to 8, or 0 to 10 volts d-c with a ± 10 per cent span adjustment. The input resistance for a type *B* circuit is 40,000 ohms/volt. A maximum of 15 type *B* circuits can be obtained.

Type *C* input circuits receive direct currents from the radio-station equipment (such as frequency deviation monitors). This current signal is fed through an RF filter to a 10-mv d-c shunt. It can be designed for any current between 0 to 25 μa to 0 to 10 ma with no provision for span adjustment. A maximum of 15 type *C* circuits can be provided.

Type *D* circuits will accept 0 to 10 mv from any d-c source. As may be noted, only RF filtering is provided. The span of the measuring circuit of the transmitting equipment is 0 to 10 mv. If all measurements from a transmitter are brought out at

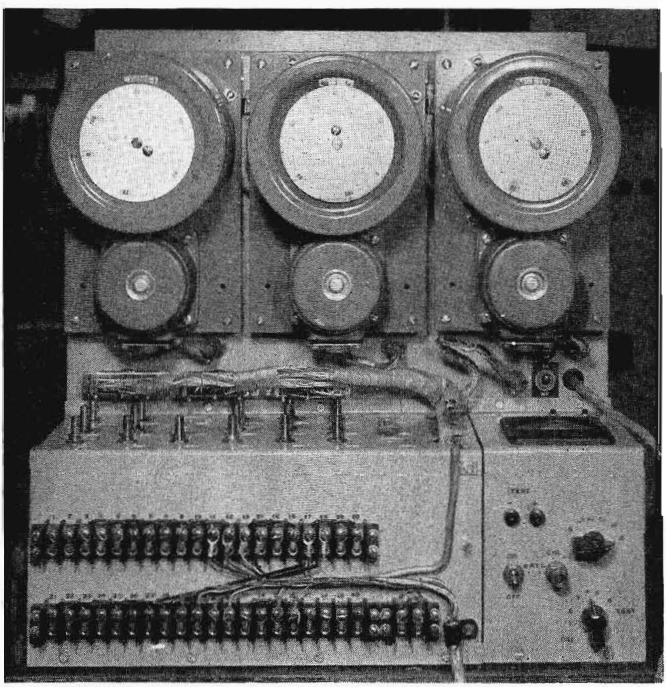


FIG. 6-4. Back of transmitter showing ratio, measuring, and telemetering servos and input terminals.

a 0- to 10-mv value, no adjustment would be required in the input circuits of the transmitting unit. A maximum of 15 type *D* circuits is available.

Type *E* and *F* input circuits form the numerator and denominator of a ratio circuit. These circuits provide RF filters, voltage dropping resistors, and span adjustments for d-c voltage inputs to the d-c voltage ratio computer. The maximum full-scale voltage to these circuits should not exceed 10 volts, and the minimum denominator voltage should not be less than one-tenth of the maximum denominator voltage. The type *F* denominator circuit places a maximum current drain on the voltage being ratioed of 115 μa, and the type *E* numerator circuit places a maximum current drain on the voltage being ratioed of 45 μa or less, depending upon the full-scale ratio desired. The circuits can be provided for any full-scale ratio span between ½ to 10.

If suitable circuits are provided for converting the tower RF currents to proportional DC voltage signals *the ratio computer can be used to indicate the tower RF current ratios.*

The maximum number of total input circuits (circuit type *A* + type *B* + type *C* + type *D* + type *E* and *F*) permissible is 15.

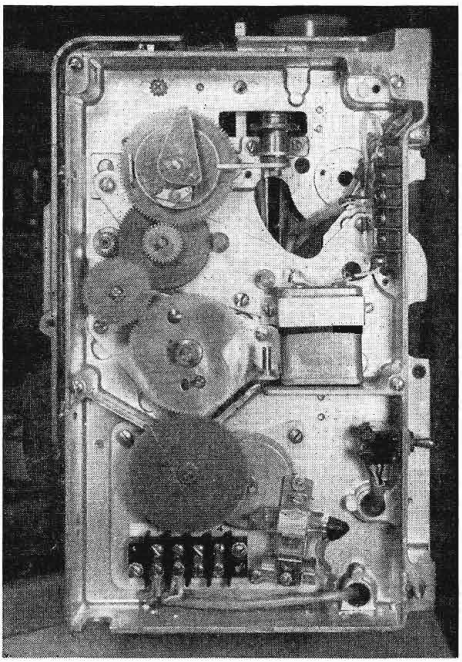


FIG. 6-5. Side view of transmitter showing sequencing gears.

Logger-transmitter Ratio-computer Circuit

The two ratio-computer input circuits are electrically isolated from each other. The slidewire position of the denominator circuit servo varies inversely with the denominator input voltage. The numerator-circuit slidewire is mechanically ganged with the denominator slidewire and, therefore, multiplies the inverse of the denominator voltage by the numerator voltage to produce an output millivoltage which is proportional to the ratio of the numerator and denominator voltages.

Logger-transmitter Signal-measuring and Control Circuit

The 0- to 10-mv signals from the type *A*, *B*, *C*, *D* input circuits in Fig. 6-3 and the ratio computer are coupled to the signal-measuring circuit by the input selector switches on a time-sequence basis. The measuring circuit is a potentiometer-type servo null-balance-measuring circuit which produces a servo slidewire position proportional to the input signal. A transmitting slidewire is ganged to the measuring slidewire to transmit the signal to the telemeter circuit. Also ganged to the measuring slidewire are two control mercury switches MC_1 MC_2 MC_3 MC_4 one of which closes if the signal is below a desired value and the other closes when the signal is above a desired value. The signal-level zone where neither switch closes is adjustable. These control switches are wired in a circuit with selector switches ganged to the input selector switches and with timing switches such that the appropriate control drive motor is selected and then connected to the control switches to be driven up or down scale after the signal being measured has been recorded and just before the next signal is connected. About 10 sec is allowed for control action on each point. Since parameters to be controlled do not normally drift in the 8-min intervals between control actions, the 10-sec control time (using slow-moving control

driving motors) should be sufficient to bring a parameter back to its desired value should an extraordinary change occur.

The logger transmitter has a maximum capacity of two control set points. For this reason all input circuit spans for input parameters that are to be equipped

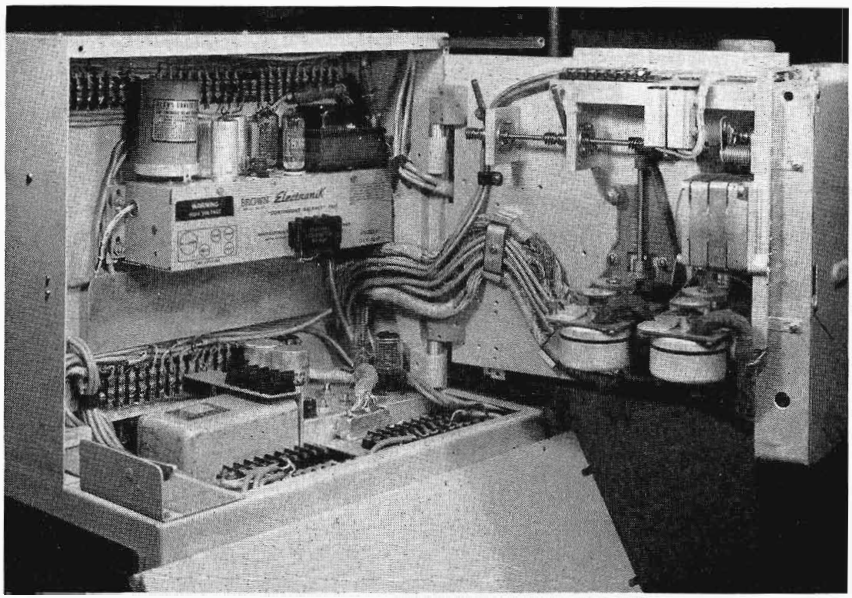


FIG. 6-6. Transmitter showing input selector switches on back of amplifier panel. Note space left for automatic-control selector switches.

with automatic control by the transmitter must be chosen so that the desired operating point of the measuring circuit servo will be at one of the two positions chosen for the set points.

Logger-transmitter Telemeter Circuit

The telemeter consists of a regulated voltage source whose output voltage is made to vary with a servo slidewire position. This voltage is connected across the telephone line, and a precision resistor is inserted in series with the telephone line so that all the telephone-line current must pass through the resistor. The telemeter servo amplifier compares the voltage across this precision resistor to the voltage from the d-c measuring circuit transmitting potentiometer slidewire circuit and drives the telemeter output voltage until the signals are equal. In this way the telephone-line current is made to be linearly proportional to the d-c measuring servo position and thus proportional to the input parameter signal. The function of the synchronizing pulse-generating circuit in the telemeter is covered in the next part of this description.

Transmitter Selector Switch and Print Wheel Synchronizing

The synchronizing circuit is shown partly on the logger-transmitter drawing (Fig. 6-3) and partly on the logger-receiver drawing (Fig. 6-10).

When the telephone-line loop is closed, the logger-transmitter switch drive synchronous motor runs continuously. This is because the K_1 telephone-line relay will

always be in the actuated condition owing to the telephone-line current except during the interval of time that the synchronizing pulse is being transmitted. This pulse is transmitted only during part of the interval of time that the switch S_1 is on position 16. The microswitch which parallels the K_1 contact can be open only during the time that S_1 is on position 15, and therefore the switch-drive motor is always energized.

When the telephone-line loop is closed, the logger-receiver motor will run continuously on all its S_1 switch positions except point 16, because its K_1 telephone-line relay will be in the actuated position (except during the interval of time that the synchronizing pulse is being transmitted). When the receiver switch S_1 is driven

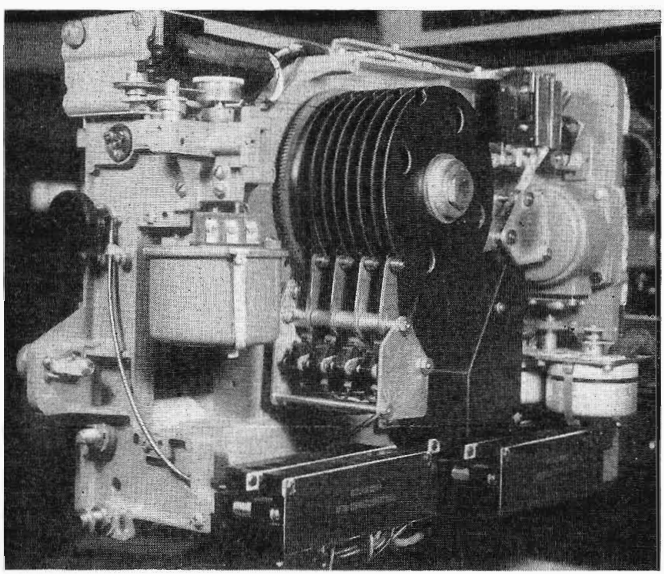


FIG. 6-7. Receiver chassis swung out showing selective alarm adjustable cam switches.

to point 16, the synchronous motor, which drives this switch and the print wheel, will stop in about 3 sec when the arc suppression switch opens, since the motor circuit through point 16 and the K_1 relay contact will be open at the relay contact. S_1 in the logger receiver requires 30 sec of motor-drive time for all points except point 16, where only 6 sec of motor-drive time is required. The S_1 switch in the logger transmitter requires 30 sec of synchronous-motor-drive time for all points. About 15 sec before the logger transmitter is switched from point 16 to point 1, the synchronizing timing switch in the transmitter opens the telephone line (this timing switch is open for about a 6-sec interval), which allows the K_1 relay in the logger receiver to release and start the print wheel synchronous motor in the receiver. The receiver then drives to point 1 in about 3 sec, and 12 sec later the logger transmitter will switch to point 1. During the next 15 sec the logger transmitter will drive the point 1 parameter to its proper value by means of the control switches (if it differed from the control set point) and switch to point 2. During the next 15 sec the receiver would balance to the point 2 value and print point 2, etc., through the 15-point sequence.

If the logger receiver and recorder are disconnected from the telephone line (as, for example, when the telephone line is to be temporarily used for remote-control metering), both the logger-receiver print wheel and transmitter selector switch

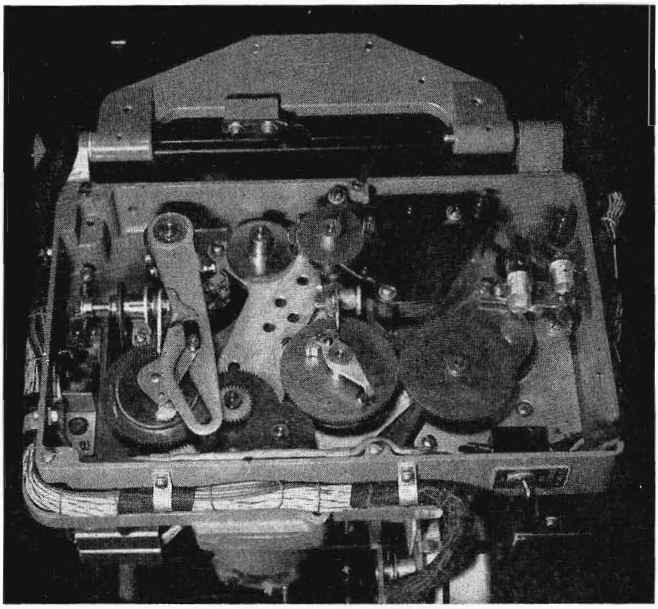


FIG. 6-8. Side of receiver chassis showing printing mechanism and synchronizing gears.

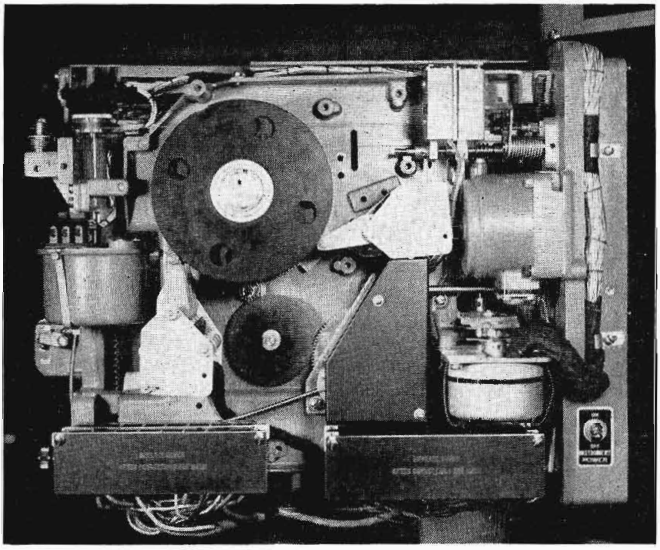
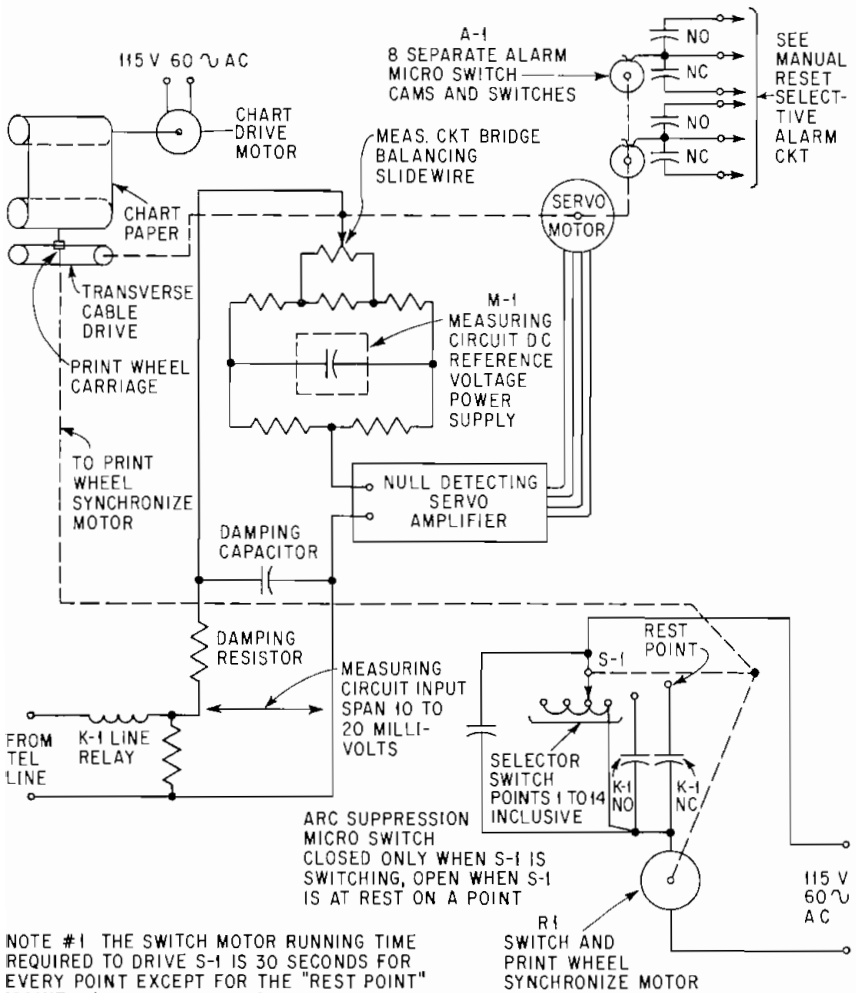


FIG. 6-9. Receiver chassis, full rear view.



NOTE #1 THE SWITCH MOTOR RUNNING TIME REQUIRED TO DRIVE S-1 IS 30 SECONDS FOR EVERY POINT EXCEPT FOR THE "REST POINT" (POINT 16). FOR POINT 16 ONLY 6 SECONDS OF MOTOR RUNNING TIME IS REQUIRED TO DRIVE S-1 TO THE NEXT POINT

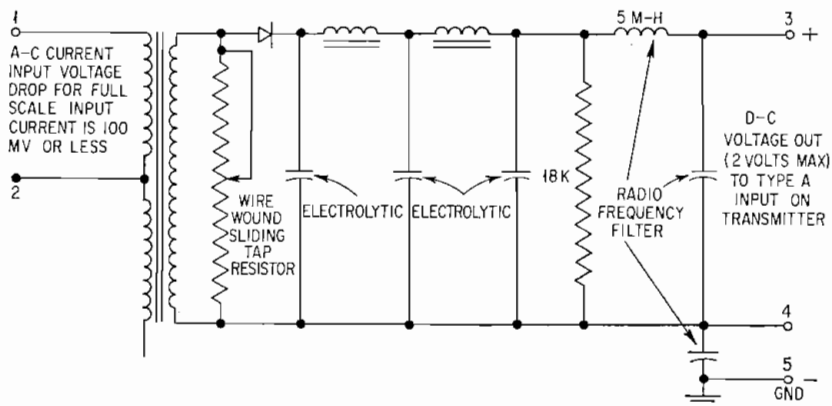
NOTE #2. PRINT WHEEL IS IN SYNCHRONISM WITH S-1 BECAUSE THEY ARE MECHANICALLY GEARED TOGETHER. THE PRINT WHEEL PRINTS NUMBERS 1 TO 15 ON A CHART TO IDENTIFY WHICH INPUT PARAMETER IS BEING LOGGED

Fig. 6-10. Automatic logger-receiver circuits.

synchronous-drive motor will stop just as they reach point 15 because the K_1 relay in both units will be deenergized. Therefore, no control, alarm, or recording will occur until the telephone line is again connected. When the telephone line is reconnected, the K_1 relays will close simultaneously, starting both units out in synchronism on point 15 and continue the logging operation as before for a closed telephone-line loop.

Logger-receiver Measuring Circuit

The logger-receiver measuring circuit (see Fig. 6-10) is of the potentiometer null-balance type. A servo motor driven by the null-detector amplifier drives the potentiometer slidewire to a position such that the millivoltage of the measuring circuit equals the millivoltage of the input signal. The telephone line signal direct current is fed through a precision resistor at the input to the potentiometer measuring circuit,



NOTES:

1. INPUT CURRENT TO BE IN THE RANGE FROM 2 TO 10 AMPERES.
2. FOR INPUT CURRENT RANGES IN EXCESS OF 10 AMPERES USE STANDARD 100 M-V A-C CURRENT METER SHUNT ACROSS INPUT TERMINALS 1 AND 2. THE CURRENT RATING FOR THE SHUNT TO EQUAL THE DIFFERENCE BETWEEN DESIRED INPUT CURRENT AND 10 AMPERES, FOR EXAMPLE: FOR 15 AMP. INPUT USE 5 AMP. A-C METER SHUNT DESIGNED FOR USE WITH A 100 M-V METER MOVEMENT.

FIG. 6-11. Schematic for tower-light alternating current to d-c voltage transducer.

creating the signal millivoltage which is measured. The receiver measuring circuit servo drives the print-wheel carriage to the proper position on the chart to make a permanent chart record of the signal value.

The chart is continuously driven by a synchronous motor at the rate of 8 in./hr, thus providing the chart record time base. At the rate of 8 in./hr each chart will record 7½ days.

The measuring circuit servo also drives the eight alarm-set-point cams to actuate the alarm microswitches if the signal level is above (or below) the predetermined alarm set points (circuit tolerance).

Logger-receiver Alarm Circuit

The logger-receiver alarm circuit, which is actuated by microswitches of the recorder signal-measuring servo, is as shown by Fig. 6-12.

If each parameter is not within its alarm set points at the time it is recorded, the

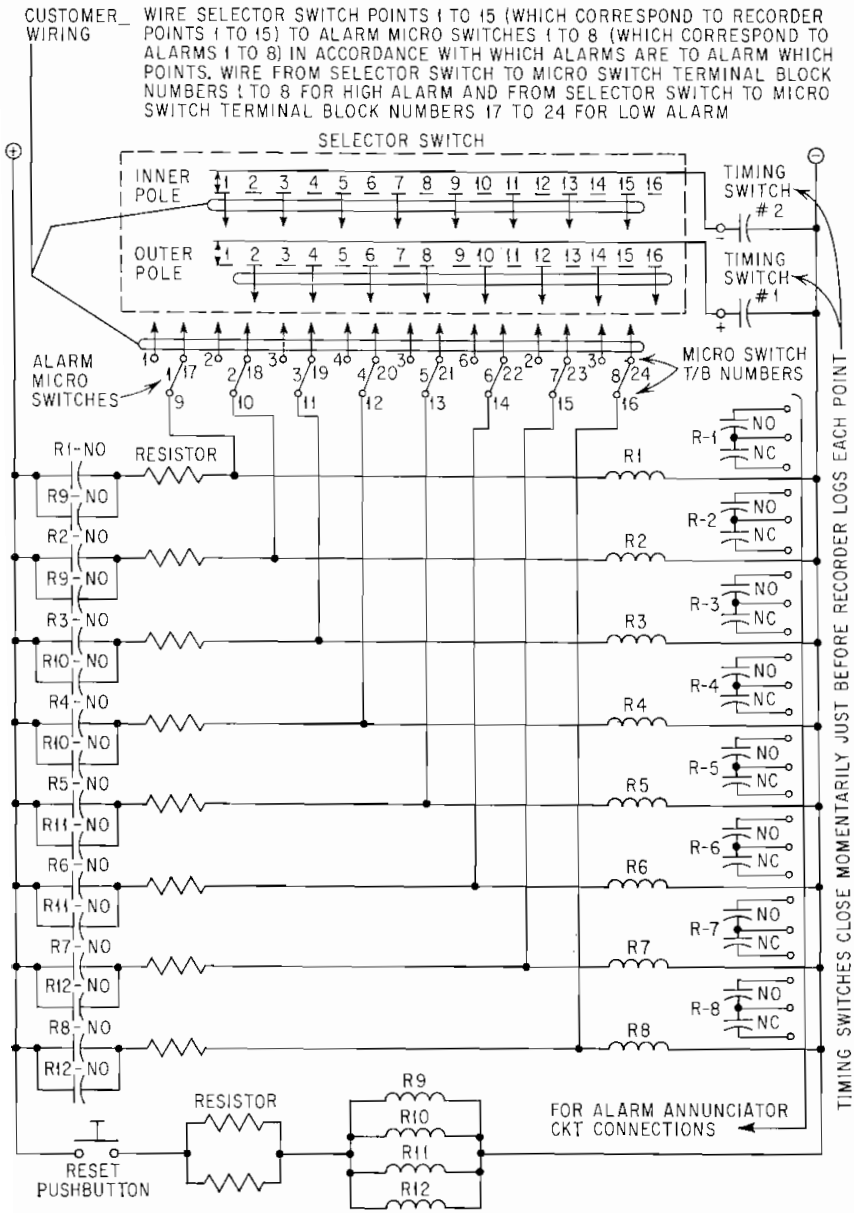


Fig. 6-12. Alarm schematic.

associated alarm relay will momentarily be short-circuited, causing it to drop and lock out.

Reset is accomplished by a manual reset push button, and reset relays and all alarms are reset simultaneously.

Since the alarm-circuit timing switches are closed only during the interval of time that a parameter is actually being recorded, no alarms will occur except when a parameter is out of limits during that interval of time.

Local Operation

Systems can be supplied for a consolidated station as well as for remote transmitters.

CONCLUSION

There are, of course, other types of equipment that can be used to record the varions parameters of a broadcast transmitting plant. The ordinary single-circuit strip chart recorder which has been used extensively in recording field strength can be adapted to this use. However, when more than a few circuits are to be recorded, the use of such equipment could become both expensive and cumbersome and would not have the advantage of having been designed for the job. Although it is known that other manufacturers are developing equipment which will be comparable to that described herein, the Minneapolis-Honeywell automatic equipment is the only type known to be on the market as a complete recording-control system for broadcast stations. It has been installed at WTOP, Washington, D.C., where it records all the FCC requirements of the transmitter log for their 50-kw AM, FM, and television transmitters, and at KFI, Los Angeles, Calif., in conjunction with their 50-kw AM main transmitter and auxiliary.

As a final note, it should be pointed out that as this is being written, *the FCC has not yet changed their rules to permit this equipment to be used in lieu of a manually kept transmitter log.* On this basis, it would be the decision of the stations to utilize it in conjunction with the presently required log. There is no doubt that such a recorded log would provide a most accurate indication of the "electronic health" of the equipment with which it can be used. Maintenance of equipment components could be immensely facilitated with such a recorded indication of performance, and undoubtedly the utilization of manpower could be made more efficient. There is no valid reason why such recording and control equipment should not be incorporated in broadcast transmitter operation in lieu of the presently required manually kept transmitter log.

Part 7

CONELRAD

(*CON*trol of *EL*ectromagnetic *RAD*iation)

NAB Engineering Department

BACKGROUND

Before the decision was made to adopt the "pseudo-synchronous-sequential" mode of operation for the CONELRAD system of emergency broadcasting,* a great many possible combinations and procedures were investigated. The utilization of straight synchronous operation of transmitters within a particular city seemed to hold promise of meeting the main criteria of intelligible coverage of the metropolitan area and adequate navigational deception. In investigating the possibilities of common-frequency operation, it was recognized that fairly high sky-wave field limitations would prevail in addition to whatever distortion or "mush" zones were produced.

A fairly substantial amount of information was available on common-frequency operation, most of which was concerned with actual operation of either two standard broadcast stations or one station and its associated booster. For a regular broadcast service, experience had shown that the carrier frequency difference should be less than 1.0 and, preferably, 0.5 cps in order to obtain the full potential benefits of synchronous operation. Study of the resulting distortion produced when the signals from two stations approach the same order of magnitude for varying degrees of modulation and audio phase differences indicated that a ratio of carrier field strengths of 6 db (2 to 1) would not result in objectionable interference even for relatively large audio delays except for the most critical condition when the RF carriers were 180° out of phase. This 2-to-I ratio for synchronous operation is comparable to the usual 20-to-1 desired-to-undesired ratio commonly used in standard broadcast operation. With this ratio, the effect of audio delays is not particularly important until the delay time becomes

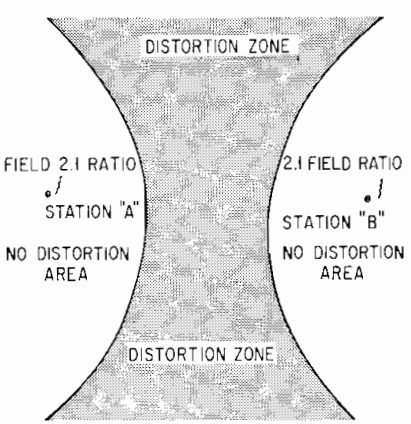


Fig. 7-1. Production of distortion zones, or "mush" areas, by signals from synchronized transmitters arriving 180° out of phase.

* See Ref. 7 under Bibliography on page 8-156.

sufficiently large to produce a noticeable echo. This aspect of the problem was not considered at all important for an emergency system, mainly in view of the improbability of the audio delays reaching such proportions over short lines.

The distortion zones computed using the 2-to-1 ratio of field strengths do not necessarily represent zones of total loss of service (see Fig. 7-1). The distortion actually occurs in narrow bands having the configuration of spherical hyperbolas, which at 1,000 kc are spaced approximately 500 ft apart. These zones are the areas where the signal strengths are of equal values and 180° out of phase, resulting in almost complete cancellation of the carrier. The width of these bands is reduced as the audio delay is reduced and as the field-strength ratio departs from the 1-to-1 value. With reasonable attention to these factors, the distortion bands actually represent only a small percentage of the possible area of distortion. Another factor which tends to discount the importance of these bands is the use of a receiving antenna which has a directivity factor of 6 db in favor of one of the signals.

Intelligibility Standard

The evaluation of these previously mentioned factors from an emergency-system standpoint was then approached. It was considered important that a 100 per cent intelligible signal be present over the entire metropolitan area of our cities so that survival information, such as evacuation instructions, might be received by the general public. Although the previous discussion would indicate that the distortion

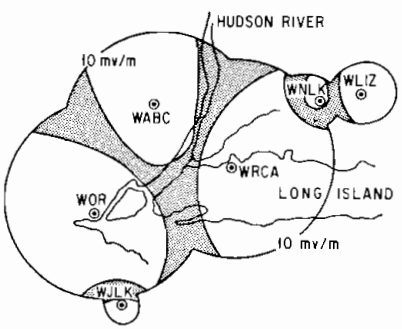


FIG. 7-2. Distortion zones produced by several transmitters operating synchronously.

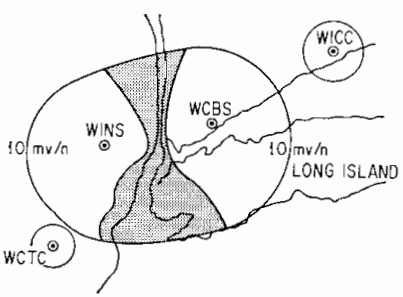


FIG. 7-3. Distortion zones from two stations on 750 kc.

zones for normal broadcast use of synchronous operation were not too serious, it was reasoned that in view of the large number of receivers which use short indoor antennas, the use of the area within the 2-to-1 ratio might be seriously restricted from the criterion of 100 per cent intelligibility. An attempt was made (on paper) to arrange broadcast stations in such a manner that the area encompassed by the distortion zone on one channel would lie either wholly or partly outside the distortion zone of the station arrangement on another channel. The initial attempt at such an arrangement used the frequencies 640, 750, and 870 kc. Actually, before an opportunity was presented to test the system from the standpoint of navigational deception, such an arrangement was completed on paper for all the standard broadcast stations on the eastern seaboard from Maine to Florida. It would be difficult to show a composite of that entire system. However, Figs. 7-2 to 7-4 show the manner of arrangement for one of the cities in the eastern part of the country.

Once consideration was given to other parts of the country, one of the difficulties encountered was the paucity of stations that could possibly be integrated into such a system. Density of standard broadcast stations varies considerably throughout the country, and it was found that almost abruptly first one and then the second channel had to be abandoned for this reason. This left much to be desired from the naviga-

tional aspect, for certain groups of stations were more or less left "high and dry" on the periphery of the area of use of the initial or second channel with no appreciable protection. Throughout the consideration of such an arrangement, it was also contemplated that the radiated powers of the various stations might be sufficiently equalized to provide whatever deception was needed with the common type of automatic direction finder used in most aircraft. Such a figure was not available in terms that could be reduced to field ratios. At this point in the development work, it became possible to conduct observations both on the ground and in an aircraft of such a contemplated system. Three standard broadcast stations, WRCA, WABC, and WOR, made the necessary transmitter changes and adjustments to permit rough synchronous operation (±3 or 4 cycles) on 640 kc utilizing a common program source. Unfortunately, equalization of their radiated powers was not feasible on this

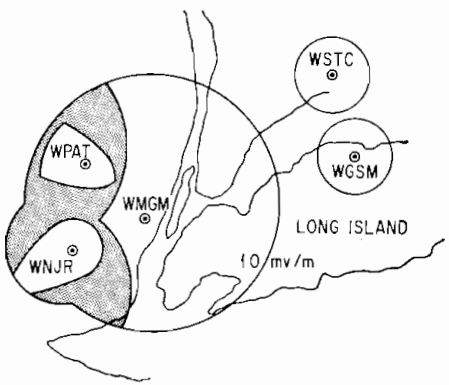


FIG. 7-4. Service areas and distortion zones from five stations.

test. Although both WOR and WABC were using powers in the range from 5 to 10 kw as against about 2 kw at WRCA, the antennas used by the first two stations mentioned were of the auxiliary variety and their efficiencies were quite low. WRCA was able to use its main antenna system for the test with consequent better efficiency.

Intelligible Signal

Observations on the ground showed that for the most part, an acceptable 100 per cent intelligible signal was provided over the areas of metropolitan New York City that could be covered by the mobile units during the test period. An interesting fact brought to light was that the distortion bands inside the 2-to-1 field ratio zones could not be detected by the human ear. It was mentioned earlier that the radio carrier frequencies were not in strict synchronism. This resulted in displacement of the distortion bands at a sufficient velocity that they could not be discerned by listening to ordinary speech. Of course, the beats between the carriers were present, but this did not appear to destroy the intelligibility appreciably.

In the air, observations were commenced from a 15,000-ft altitude at a distance of about 100 miles. A fairly good bearing indication was noted on the aggregate signal from the three stations at that point. This was to be expected in view of the small angle of separation of the stations. It was expected that as the aircraft approached New York City, the azimuth indicator on the ADF would become erratic and inaccurate. A constant check on the position of the aircraft was obtained by means of radar. Instead of becoming erratic, the homing signal became more useful, and the pilot, following instructions of the radio operator-navigator "homed" directly over the antenna system of WRCA as indicated on the radar screen. The route of the aircraft followed the track indicated in Fig. 7-5.

At the point indicated by the circled *X*, the ADF indicator shifted from WRCA to WOR. Subsequent information obtained on the powers and probable antenna efficiencies of the stations involved in this test resulted in calculations of the field ratio of 2 to 1 at the point where the ADF shifted from the control of one station to the other. This value, of course, has no relation to the same figure as it relates to the distortion zones but is a function of the automatic-direction-finder unit itself. Although a 6-db equalization of fields does not appear to be particularly difficult, a closer examination of the various metropolitan areas and the potentialities of their broadcast stations in this respect seemed to urge a further study of other possibilities. The most attractive that came to attention was merely a slight variation of the straight synchronous mode whereby, instead of all the transmitters being on the air continuously with a common program, they would be switched on and off in a random sequence. Such a procedure immediately eliminated any major concern over distortion zones, beats between carriers, equalization of radiated power, or any other such features which tend to complicate a system. Preliminary tests utilizing the same three stations mentioned before gave good ground coverage and in addition made orientation of an aircraft by means of the ADF extremely difficult within any reasonable period of time.

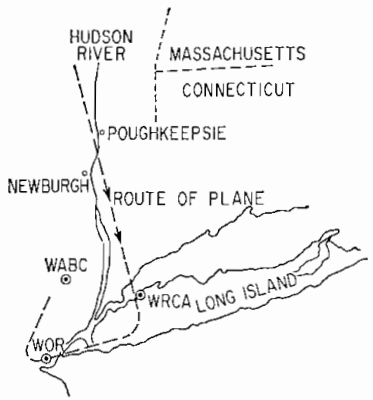


FIG. 7-5. Route of aircraft "homing" on signals from three stations.

Results Confirmed

Subsequent tests using a greater number of stations confirmed the results obtained, not only as to ground coverage but for both long-range and short-range navigational deception. During the past few years, the system has been initiated throughout the entire country, and today there are prepared for instant operation over 200 clusters of stations and approximately 500 single stations in the "on-off" category. Recent developments in the operation of the CONELRAD system seem to indicate that there will be less of the latter type of operation. This appears feasible in view of changes in the aircraft potential from an operational standpoint. Additional stations are being continuously added to the system.

ALERT SYSTEM

Ideally, the perfect alert system for such an emergency arrangement of broadcast stations would be one which instantaneously informed every station that a particular situation was in effect. While there is no technical reason that such a system is not available, the economics up to this time has made it necessary to be satisfied with something less than the perfect system.[1]

Air defense alerts can be initiated by various centers of command throughout the United States, depending upon the situation. It is purposely kept flexible, even though somewhat more complicated, because of the demands imposed upon even a passive defense aspect of the national complex. Basically, the Radio Alert is disseminated through a combination of wire lines to particular *key stations* and thence to other stations via off-the-air pickup by means of normal transmissions. All stations are aware of the particular means whereby the alert is received through information provided by the Federal Communications Commission. *It is the responsibility of each*

[1] An instantaneous type of alert system is now under consideration.

station to be able to obtain the alert signal whenever it is transmitted, either on a test basis or in an actual alert.[2] Should difficulty be experienced in the reception of the alert signal, such stations should immediately notify the appropriate FCC CONELRAD field supervisor, who is obligated to advise the stations of the remedial action to be taken. For obvious reasons, no specific information is given here concerning the actual alerting system for the broadcast service. Each station is aware of its own particular instructions, and information applicable to other stations is not pertinent. Those stations receiving information via wire lines are also required to maintain alert receivers as a backup method of receiving the information.

Alert Receivers

The FCC Rules specify that alerting information shall be preceded by carrier breaks followed by the transmission of a 1,000-cycle tone in a specific manner.[3] For convenience of operating personnel, it is important that such an alert receiver be muted for normal periods of operation and that it actually produce an alert signal during either test or actual alert conditions. Various arrangements have been devised to accomplish this. For the information of stations, some of the more satisfactory circuits and operating information applicable to these receivers are provided herein.

General Considerations

In determining the method to be used in an alerting system, consideration of relatively fixed parameters of the broadcasting system had to be taken into account. Theoretically, the use of subaudible, audible, and supersonic frequencies is possible in such an alert signal. The practical aspects, however, have generally precluded the establishment of such systems. The major shortcomings in this area relate to the characteristics of program lines, audio amplifiers, modulators, and the entire audio portion of a broadcasting plant. Frequencies below 20 cps and over 20 kc would be subject to extreme attenuation in passing through the audio equipment of a station, and considerable expense would be involved in making suitable modifications. The installation of additional oscillators would be another economic factor.

The alert method that was established and is still being improved utilizes a combination of carrier breaks and audio tone within the normal passband of both station equipment and ordinary receivers. Several devices have been developed based on those criteria. Essentially they are all variations of the fundamental circuit which makes use of a properly inserted device in the AVC circuit of the receiver and which operates one or more relays to provide the desired visual or audible signal notifying that an alert is being transmitted.

AM Alert Units. As mentioned previously, a great many variations of the fundamental circuit have been devised. No purpose would be served by providing all such modifications. A typical alert attachment device which has been used satisfactorily in conjunction with AM receivers is shown in Fig. 7-6. This was developed by Mr. Robert D. Linx, Federal Communications Commission.

Referring to Fig. 7-6, the receiver is tuned to a station providing the radio-alert signal. A signal voltage from the receiver applied to point *A* is amplified and actuates the plate circuit relay, making contact between points *B* and *C* to light the green light. When the signal voltage is interrupted, owing either to an interruption of the carrier of the alerting station or to failure of the receiver, minimum current will flow through the coil of the plate circuit relay, causing contact to be made between points *B* and *D*, which will, depending on individual treatment, light the red light or cause an audible alarm to operate.

Any relay designed to work in the plate circuit should be SPDT, with a coil having approximately 3,500 to 5,000 ohms' resistance, and provided with a locking arrange-

[2] See Subpart G, Part 3, Rules of the FCC.
[3] See Subpart G, Part 3, FCC Rules.

ment so that the alarm (or light) will continue to operate until the relay is manually reset.

In some cases, connection can be made directly to the grid of the first or second IF stage. Some experimentation may be required in order to secure maximum plate current variation.

It is suggested that the plate voltages be adjusted so as to provide a relay current of approximately 10 to 12 ma.

Another more elaborate alert attachment has been developed by Mr. David O. Cooper, Federal Communications Commission. Although the circuit is relatively

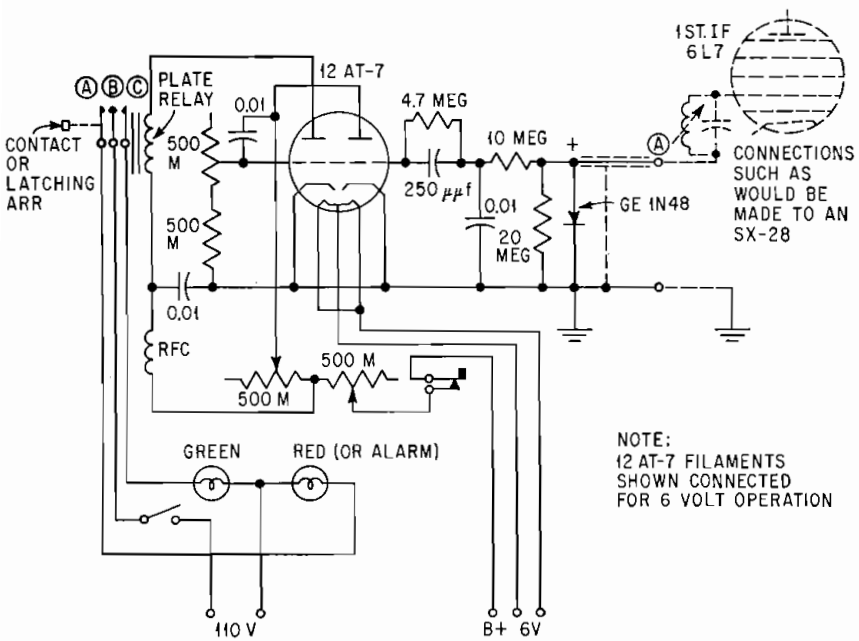
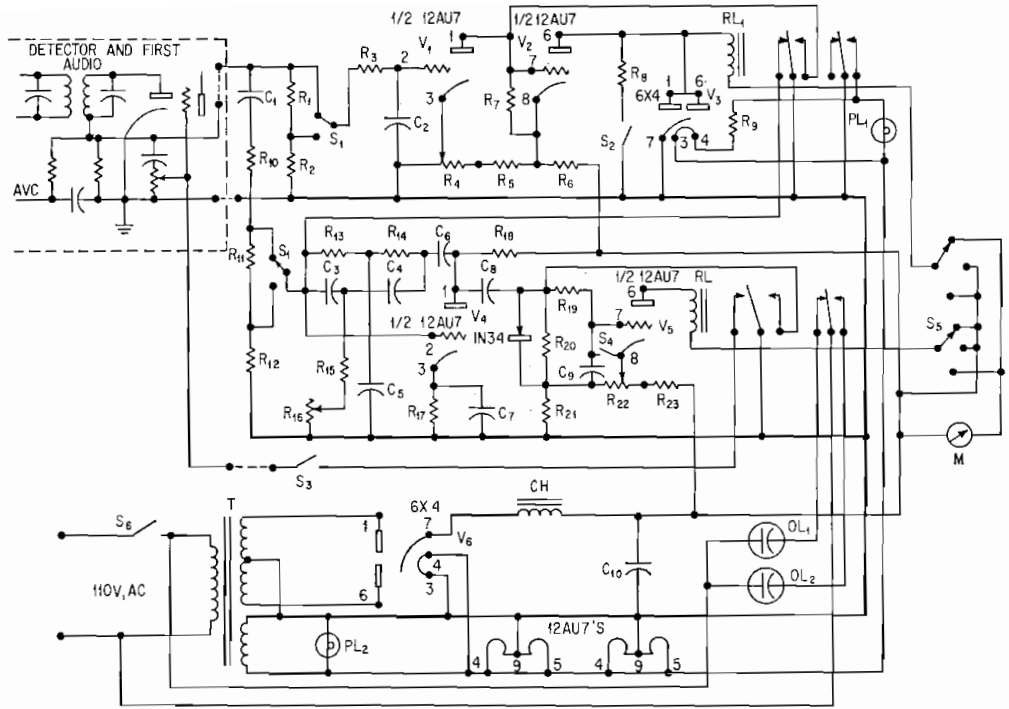


FIG. 7-6. Typical alert device which can be attached to any standard broadcast receiver to provide both a visual and audible alarm when the carrier of the alerting station is interrupted.

simple (see Fig. 7-7), the provisions incorporated in this attachment will appeal to many broadcasters who desire something more than just the basic requirements. In operation, the receiver associated with the attachment will be tuned to a key station but the speaker will be silent.

A clock connected to the 110-volt outlet OL_1 will operate and indicate the correct time. A visual or audible alarm connected to the other 110-volt outlet will not operate, and the red pilot light PL_1 will be off. When the carrier of the key station is interrupted, the red pilot light will come on but the clock will continue to run, the speaker will remain silent, and the alarm will not operate. If a 1,000-cycle tone is broadcast by the key station within 45 sec after the carrier interruption, the clock will stop, indicating the time the alert was received. The speaker will come on, so the 1,000-cycle tone and the alert message can be heard, and the visual or audible alarm will operate. If a 1,000-cycle tone is not broadcast within 45 sec after the carrier interruption, the red pilot light will go out and the circuit will return to normal. A 1,000-cycle tone broadcast at any time other than within 45 sec after a carrier interruption will not affect the alarm.

Connections are made using shielded wire between the alarm and the electrical



R_1, R_{11}, R_{19}—10 Meg, ½ watt
R_2, R_3, R_{10}, R_{12}—3.3 Meg, ½ watt
R_4, R_{22}—1,000-ohm control
R_5—8.2 K, 2 watts
R_6, R_{23}—27 K, 2 watts
R_7—270 K, ½ watt
R_8—18 K, 2 watts
R_9—7.5 ohm, 2 watts
R_{13}, R_{14}—160 K, ½ watt
R_{15}—22 K, ½ watt
R_{16}—10 K control
R_{17}, R_{21}—1.5 K, ½ watt
R_{18}—47 K, 1 watt
R_{20}—470 K, ½ watt
C_1, C_8—0.01, 400 volts
C_2—0.05, 400 volts
C_3, C_4—0.001; C_5—0.003 mic
C_6—0.1, 400 volts
C_7—25, 25 volts
C_9—0.25, 400 volts
C_{10}—10, 450 volts
S_1—rotary switch, 2 pole, 2 position
S_2, S_4, push-button switch
S_3, S_6, slide switch
S_5—rotary switch, 2 pole, 3 position
PL_1, PL_2—6.3-volt pilot light
OL_1, OL_2—110-volt outlets
M—meter, 0–10 ma
T—power transformer, Stancor PC8418 (460 VCT at 50 ma; 6.3 volts at 2.5 amp)
CH—filter choke, Stancor C-1003 (16 H at 50 ma; 580 ohms)
RL_1, RL_2—relay, Potter Brumfield LM-11 (5,000-ohm coil: DPDT contacts)

FIG. 7-7. More elaborate alert unit circuit used with any standard broadcast receiver.

ground, AVC, and grid of the first audio of the associated receiver. These connections can be made conveniently by use of a three-way plug. If the alarm is to be used in a weak signal area, the associated receiver should have good selectivity and sensitivity and be provided with an antenna located as far as practicable from sources of local interference.[4]

Resistor R_7 is a plate load for triode V_1 and a grid bias resistor for V_2. The voltage drop across R_7 caused by the plate current in V_1 is applied as a grid bias to V_2. When the receiver is tuned to a key station, maximum AVC voltage will be applied as grid bias to V_1; minimum current will flow in R_7, applying minimum bias to the grid of V_2; and maximnm plate current will flow in V_2, closing relay RL_1.

R_4 controls the fixed bias on V_1 and should be adjusted so that relay RL_1 will remain closed when the receiver is tuned to the key station but will open when the carrier is interrupted. In weak signal areas, it may be advantageous to increase C_2 to 0.25 μf in order to increase the time constant of the R_3, C_2 circuit. This will smooth out variations in the AVC voltage due to fast fading and reduce the number of false alarms.

When the carrier of the key station is interrupted, the AVC voltage is reduced to minimum, the plate current increases in V_1 and rednces in V_2, and relay RL_1 opens. When RL_1 opens, the gronnd is removed from the input to the 1,000-cycle amplifier, making this circuit operational. The grid of V_2 is grounded, holding relay RL_1 open; the pilot light PL_1 comes on; and the filament of the rectifier V_3 heats np.

Relay RL_1 can be manually reset by momentarily closing the push-button switch S_1. The conduction of current through the rectifier V_3 has the same effect as closing S_1. The normal time required for V_3 to heat up and start conducting is increased to 45 sec by inserting R_8 in the filament circuit. Thus, 45 sec after RL_1 opens, it will automatically reclose. When RL_1 closes, the filament circuit is opened and the rectifier cools.

Triode V_4 has a parallel-T network connected as a feedback circuit between its plate and grid and becomes a sharply tuned 1,000-cycle amplifier, the frequency of which can be changed within narrow limits to the exact frequency of the tone broadcast by the key station by adjusting R_{14}. Relay RL_1 will remain open for 45 sec following any carrier interruption. During this time the audio signal from the receiver is applied through C_1 to the 1,000-cycle amplifier, the output of which is rectified by the 1N34 crystal diode and applied as a negative voltage through the time-delay circuit R_{19}, C_9 to the grid of V. Normal program voltage occurs across R_{20}. These fluctuations are smoothed out by the R_{19}, C_9 circuit, and the average value is applied to the grid of V_5. R_{22} is adjusted so that RL_2 remains closed when RL_1 is open and normal program is being received. A sustained 1,000-cycle tone received during the time RL_1 is open will build up a negative bias on the grid of V_5 sufficient to open relay RL_2.

When RL_2 opens, the voltage across R_{21} is applied to the grid of V_5, biasing the tube to cutoff and holding RL_2 open. The ground is lifted from the grid of the first audio of the associated receiver, causing the loudspeaker to come on; the circuit to the 110-volt outlet OL_1 is opened, causing the clock to stop; and the circuit to OL_2 is closed, thus operating the visual or audible alarm.

Relay RL_2 will remain open until the reset push-button switch S_4 is momentarily closed, shorting the grid of V_5 to its cathode, discharging condenser C_9, and causing maximum plate cnrrent to flow through the relay.

The meter switch S_5 should be a shorting-type switch so the plate circuit of either V_2 or V_5 will not be momentarily opened when the meter is switched in or out of these circuits. When in series with RL_1, the meter can be used as a signal-strength meter to aid in tnning the receiver accurately to the key station.

The "local-distant" switch S_1 cau be omitted, and the circuit connected permanently for either local or distant station operation. For most installations, the circuit should be connected for distant reception with S_1 in the position shown in the diagram. If the receiver is very close to the key-station transmitter, improved operation will be obtained by reducing the signal input to both the d-c amplifier and the 1,000-cycle amplifier by connecting the circuit as it would be with S_1 in the lower or local position.

[4] Refer to information later in this part.

Still referring to Fig. 7-7, the resistor R_6 acts as a plate load for triode V_1 and as a grid bias resistor for triode V_2. The voltage across R_6 caused by the plate current in V_1 is applied as a grid bias to V_2. When the associated receiver is tuned to the key station, V_1 is biased to minimum plate current by the AVC voltage. A minimum bias is therefore applied to V_2, and a maximum current will flow in the plate circuit, energizing the relay. With the relay and S_2 closed, the grid of the first audio is shorted to ground, muting the speaker; the 110-volt outlet OL_1 is on, so the clock will run; and OL_2 is off, so a lamp or audible alarm plugged into this outlet will be off. The speaker can be operated at any time without affecting the circuit adjustment by opening S_2.

When the carrier of the key station is interrupted, the AVC voltage is reduced to minimum, the plate current increases in V_1 and reduces in V_2, and the relay opens. When the relay opens, the ground is removed from the grid of the first audio and the speaker operates, the clock stops, and the alarm light or bell goes on. In addition, the grid of V_2 is grounded, causing maximum current to flow in R_6 and minimum plate current in the relay, locking it out regardless of the control voltage at the grid of V_1.

The push-button switch S_1 is normally open. When it is momentarily closed, the relay closes, lifting the ground from the grid of V_2, and the circuit is back to normal.

R_3 controls the fixed bias on V_1. On strong local signals, it can be eliminated and the cathode of V_1 can be connected directly to ground, as the AVC voltage will be great enough to bias V_1 to cutoff. On weaker signals, R_3 should be adjusted to a point where the relay will remain closed when the receiver is tuned to the key station but will open when the carrier is interrupted. On weak signals it may also be advantageous to increase C_1 from 0.05 to 0.25 mf. This will smooth out variations in input signal and eliminate some operations due to fading.

FM Alert Unit. Another alert attachment which has been used with considerable satisfaction in conjunction with FM receivers and tuners was developed by Mr. Philip Whitney, chief engineer, WINC, Winchester, Va. The circuit shown in Fig. 7-8 will monitor any FM station for "carrier-off" condition by ringing a bell or lighting a warning flasher at the operating or control positions.

The audio output of the tuner can be applied to a 1,000-cycle filter circuit and relay control for the tone warning circuit. A 6,500-ohm plate relay is used, but most types of plate relays up to 10,000 ohms are satisfactory.

Negative voltage developed in the discriminator stage of this particular tuner keeps the 6C4 relay control tube biased to cutoff. The critical point can be reached by adjustment of the sensitivity control. It was found that in the WINC application this control was not needed but may be of advantage in some installations. It may be necessary in some remote locations to use a booster ahead of the tuner. Thus, a station 75 miles away can be monitored consistently. (It helps, of course, to use an efficient antenna.)

The relay and control tubes were mounted on the tuner chassis. An outlet plug on the rear of the chassis was utilized for the warning contact terminals. A 100-watt light above the operator at the control position increases room lighting perceptibly when the carrier of the monitored station is interrupted. This immediately attracts his attention and does not interfere with an open microphone.

The filter condenser across the negative voltage supply was eliminated to reduce the time constant of the circuit. If needed, a 0.1- to 0.5-μf capacitor (paper) can be installed across the relay coil to prevent chatter.

This attachment could also be utilized in the FM audio section of a television receiver should it be appropriate to utilize a TV station for the alert monitoring function.

Special antennas for FM reception can be constructed whenever necessary for reliable reception of a more distant FM station. Such antennas can be of the Yagi type, phased arrays, V or rhombic antennas, or low-band VHF television receiving antennas, which in most instances perform quite satisfactorily.

Commercial Equipment Available. In addition to the "home-brew" type of alert equipment, there are several commercially available attachment and entire receiver alert systems. In the attachment field, Heathkit's model CA-1 connects to the usual

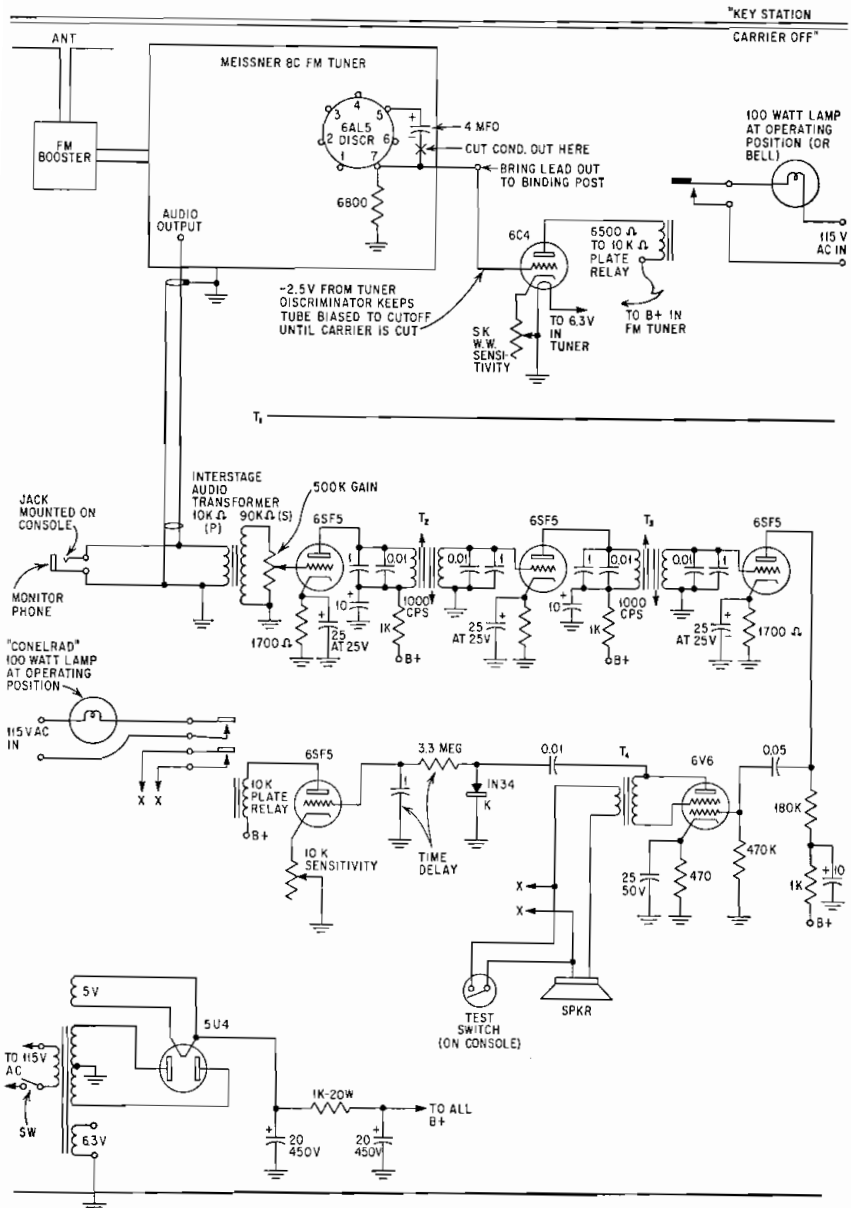


FIG. 7-8. Circuit of alert unit used with an FM tuner or receiver. T_2 and T_3 are surplus Hammarlund coils from the "Fleet Control" units. They normally tune from 3,000 to 6,000 cps with the 0.01-μf condensers contained inside the cans. They resonate at 1,000 cps when a 0.1-μf condenser is added. T_4 is a "garden variety" of output transformer.

AVC system in an ordinary receiver. It can be used on an a-c–d-c type receiver as well as others.

The following is a partial list of CONELRAD alert receivers which are on the market today.

Brand Designation	*Manufacturer*
AMECO	American Electronics Co., New York
Paul Revere	Allen B. Dumont Laboratories Inc., Mobile Communications Dept., Clifton, N.Y.
CONALERT II	Kaar Engineering Corp., 2995 Middlefield Road, Palo Alto, Calif.
Air Alert I	Miratel, 1080 Dionne St., St. Paul, Minn.
Air Alert II	Same
Moradco CONELRAD monitor	Morrow Radio Mfg. Co., P.O. Box 1627, Salem, Ore.
CONELRAD monitor, desk type DS9661-B, rack mount DS9660-B	Motorola Communications and Electronics Inc., 4501 W. Augusta Blvd., Chicago 51, Ill.
CONELRAD receiver, type CR-17B	Radio Corporation of America, Camden, N.J.

Special Reception Techniques

In certain instances either where stations are at a critical distance from another station or where receiving conditions are generally difficult by reason of directional operation, atmospherics, etc., extraordinary means are sometimes necessary to ensure the reception of the alert signal from another station. The Federal Communications Commission has provided information concerning the use of special receiving antennas which are applicable for such purposes.[5] The application of this information, in many situations, will enable satisfactory reception of stations which ordinarily are completely unintelligible.

Shielding and Filtering

In cases where applicable, it is advisable to locate the antenna as far from a source of interference (or radio transmitter antenna) as possible and use coaxial or shielded transmission line to the receiver input terminals. In extreme cases, the receiver itself may have to be enclosed in a shielded box with appropriate filtering and bypassing of power leads in order to eliminate the possible effect of high RF fields on the reception of the desired signal. The antenna transmission line to the receiver may have to incorporate trap circuits to filter out the local transmitter radiation. For low-impedance receiver input, the trap circuit may be a parallel-resonant trap connected in series with the inner conductor of the coaxial. For high-impedance receiver input, the trap will perform most satisfactorily if connected directly across the input terminals, tuned to the frequency of the local station. Sometimes, both traps are required when the local RF field is high and/or when the cross-modulation products produced in a superheterodyne receiver cause adverse reception effects or when the undesired radiation is on a different frequency from the desired.

Loop Antenna

When the desired and undesired stations are on the same or very nearly the same frequencies, a directional antenna is often necessary. Such an antenna is also necessary in areas of weak signal strength from the desired station. A simple type of such antenna is the loop antenna, which is of maximum effectiveness only when the signals under consideration are within the ground-wave area. When this antenna is used, the null (obtained broadside to the plane of the loop) is oriented toward the undesired

[5] From an FCC memorandum by Benjamin Wolf and Adolph Anderson.

station. Maximum voltage is induced in the loop when the plane of the loop points toward the desired station. Since the antenna is bidirectional, a station on the back side may produce sufficient signal to cause interference, in which case a more elaborate directional receiving antenna may be required (see Fig. 7-9).

Beverage, or "Wave," Antenna

A very effective receiving directional antenna is the Beverage type. The theory of this antenna has been well covered in texts for many years and is not included here. Among the desirable properties of the Beverage, or the "wave," antenna for reception are:

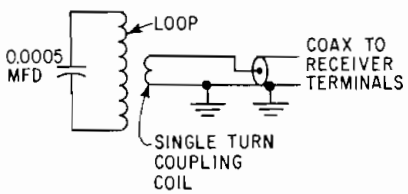


FIG. 7-9. Simplified schematic of a loop antenna with construction details. *Loop dimensions:* 13 turns of #20 wire wound on a 12-in. square form, with ⅛ in. spacing between turns. The coupling coil is a single turn wound inside the loop and spaced approximately 1 in. from the loop. The mechanical mounting is optional, but for best results the loop should be mounted in the clear and away from metallic objects. Experiments with various turns in the coupling coil and using a coaxial cable from the loop to the receiver might prove beneficial. Shielding the loop is important in direction-finding work but is not important for ordinary reception.

1. It delivers a stronger signal over the entire standard broadcast band than a good simple antenna of the single-wire variety.

2. When terminated, it is unidirectional but can be used as a bidirectional antenna either by switching the termination or by being unterminated.

3. Atmospherics and industrial interference are considerably reduced, especially when the source is in a direction other than that of the main lobe of the antenna.

4. The antenna is low in cost, has long life, and is usually easy and simple to erect provided the space is available.

Length. The optimum length for a broadcast band "wave" antenna is approximately 1,800 ft. This length delivers peak signal strength at close to 550 kc and again at one-half its wavelength in meters, or about 1,100 kc. The peaks are, however, rather broad, and the signal delivered is considerably stronger than that from a good simple antenna throughout the entire band. Near the antenna peaks, the increase in microvolts to a receiver may reach more than 400 per cent.

Whereas space is a consideration, the length can be reduced to 1,400 or even 1,000 ft, but the signal-strength delivery and directivity will be proportionately reduced, and at less than 1,000 ft the slight advantage of a wave antenna for the broadcast band over a good simple antenna does not warrant its erection.[6]

Conductor Height. The surge impedance of the wave antenna is determined by its height above the ground and by soil conditions in respect to moisture, etc. If the conductors are erected at a minimum of 10 ft above the ground, the surge impedance remains more nearly constant during all seasons than when they are erected at a lower height. If they are erected at a height greater than 15 ft, the pickup of the vertical leads at the far and near terminals may considerably reduce directive properties. If a greater height is required at gates or other passages, the higher poles should be erected at the sides of the opening and the conductors brought down vertically, proceeding at the selected height after the high point has been bridged. Reasonably uniform height of the conductors throughout their length is, of course, preferable.

Pole Erection. The standard practice of telephone-line construction is followed. The poles should be spaced approximately 100 ft apart, and for mechanical strength the conductors should be No. 12 B & S hard-drawn copper or copperweld. The line should generally follow the earth's contour, but small knolls are disregarded, and the

[6] Instances are known where ordinary Signal Corps field telephone wire strung out across trees and bushes provided a considerable increase in received field strength with a length of wire less than 1,000 ft.

tops of the poles after planting can be trimmed for general or even grading of the conductors.

For single, unidirectional reception or single-conductor antennas, the conductor can be mounted on ordinary pole brackets attached to the poles.

For unidirectional reception from front or rear or both, the two-conductor type of construction is required. The conductors are mounted on short, standard cross arms without braces, with the locust insulator pins spaced 16 in. between centers. This, with ordinary telephone-line glass insulator, gives the desired or adopted 18-in. spacing of conductors of the finished antenna.

Grounds. For maximum efficiency the resistance of the ground system at both the far and near ends of the antenna should approach zero or at least be less than 30 ohms. The ground resistance is best determined by the voltmeter-ammeter alternating-current method, but reasonably satisfactory results can be obtained by the use of the battery and voltmeter voltage-drop method.[7]

For measurement of a single ground, the planted conductors are divided into equal halves and measured and the result divided by 2 or the far and near terminal resistances measured through the antenna conductors for the combined resistance of the two terminals or the series resistance of the entire system.

If the voltage-drop method of measurement is used and should polarization or other direct-current effects produce absurd readings such as negative resistance, a resistance of 100 ohms or more can be placed in series with the circuit and two measurements taken with changed polarity. The average of the two recorded values divided by 2 in the case of a divided system less the added external resistance can then be considered a reasonable approach to the actual resistance. Because of polarization, readings of instruments should be taken at the moment of contact.

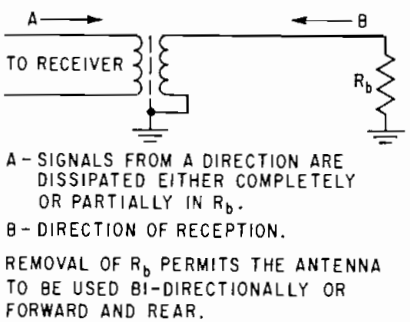


FIG. 7-10. Single-conductor Beverage antenna for forward reception.

In respect to the diagrams contained in Figs. 7-10 to 7-12, all factors are the same as the single-conductor type except that the surge impedance will be lower as a result of the two conductors in parallel. In reception, the signal builds up until it reaches *B*, where the phase is reversed by grounding one of the conductors and leaving the other free, after which it is reflected back to *T*, using the antenna conductors as an untransposed transmission line. The signals from the *B* direction are dissipated either completely or partially in impedance *R* connected from the center tap of *T* to ground. It will be noted that Figs. 7-10 and 7-11 are the same except with respect to far and near terminal connections. When it is changed as shown, the antenna can be made unidirectional for either forward or rear reception but not for both forward and rear reception simultaneously.

When the wavelength of the signal to be rejected is a multiple of one-half wave of the length of the antenna, it is either completely or largely absorbed in resistances R_b or R_m. Odd multiple frequencies of one-quarter wavelength of the antenna length deliver a greater residual or undesired signal to the receiver.

In order to balance out an undesired signal originating at an angle of more than 90° from the source of a desired signal originating in the direction of maximum reception of the antenna, a part of the undesired signal is reflected back to *T* in proper phase and magnitude to cancel itself out. This is accomplished by the insertion of a tuned circuit in series with a variable resistor at the far terminal, as in Fig. 7-13 for rear-signal rejection and as in Fig. 7-14 for forward-signal rejection.

[7] Normal considerations for obtaining low-resistance ground connections apply equally for receiving antennas. For a permanent installation requiring high efficiency, probably a buried ground radial system would be the most satisfactory.

Techniques have been developed to utilize the Beverage antenna for simultaneous reception in both the forward and backward directions on a unidirectional basis on either the same or different frequencies in the broadcast band. Such an application is not usual and probably would never be required in the reception of a key station in the CONELRAD system.

Transmission Lines. Transmission lines between the coupling and impedance matching devices should be coaxial cable.[8] It is unimportant whether they be 50 or

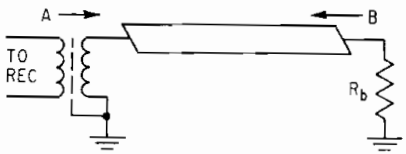


FIG. 7-11. Two-conductor Beverage antenna for forward reception.

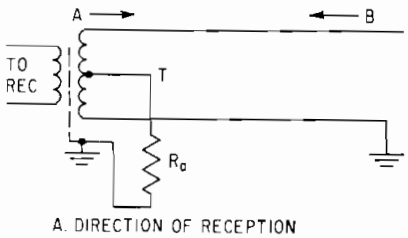


FIG. 7-12. Two-conductor Beverage antenna for rear reception.

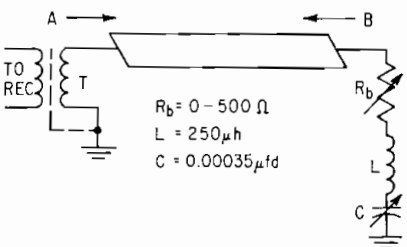


FIG. 7-13. Two-conductor Beverage antenna for forward reception with interference cancellation circuit.

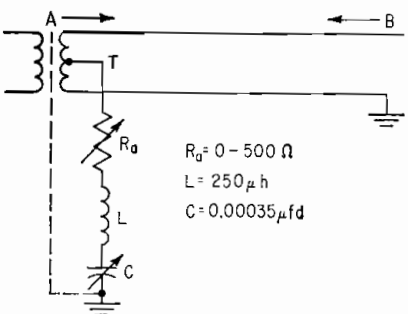


FIG. 7-14. Two-conductor Beverage antenna for rear reception with interference cancellation circuit.

75 ohms or even a higher impedance because the matching can take place regardless of the value of the transmission-line impedance. A convenient method of checking impedance matching would be to shock-excite the antenna with a local oscillator of a few watts power (or perhaps use the local broadcast station) and use an impedance bridge of the VSWR type, which can serve as an accurate check on matching and over-all adjustment of the antenna. A bridge of relatively high sensitivity should be used which would indicate values of current in the microampere range. In most cases with ordinary communications-type receivers, a satisfactory match to the receiver itself will occur without a matching transformer between the coaxial line and the receiver input terminals. Should this not be the case, a simple π-network coupler could be inserted.

Lightning Protection. Lightning protection to such an antenna will be found necessary. Rather high voltages can also be built up on the antenna during dust or snow storms, etc., when static potentials of several hundred volts will occur. Such voltages are apt to open the terminating resistors of the antenna. Therefore, if the

[8] From purely an operational standpoint, RG58 or RG59 coaxial cable would be satisfactory. However, the heavier types such as RG-8 or RG-11 would be mechanically more suitable and would provide more satisfactory over-all operation.

operation of the antenna should appear changed subsequent to a storm, those resistors should be checked for an "open." Ordinary inert-gas type of lightning arresters will be found satisfactory and should be inserted at both the near and far ends of the antenna itself. In some instances, it may be wise to take further precautions within the transmission lines, depending on their length and method of installation from the matching point to the receiver. Such coaxial-line lightning arresters are commercially available and can be adjusted to flash over at a relatively low voltage.

TRANSMITTER OPERATION ON CONELRAD CHANNELS

In the early stages of CONELRAD operation, a great many stations built composite transmitters of usually lower power than the licensed value of the main transmitter. Such transmitters enabled a quick shift to the assigned CONELRAD channel for emergency purposes. Difficulties in obtaining satisfactory coverage, particularly in the larger metropolitan areas, soon indicated that such lower power transmitters were not adequate for the type of emergency coverage required.

Various engineers throughout the country made conversions of existing transmitters to enable them to operate on the normal licensed frequency and on either 640 or 1,240 kc, whichever was assigned the station. The following information was submitted by station engineers to the Federal Communications Commission, who has made it available for reproduction.

Transmitter: Collins Type 20T, 1 Kw

Frequency Change: 1,600 to 1,240 Kc

Submitted by Radio Station KASH

This transmitter can be operated on the CONELRAD channel specified by insertion of the appropriate crystal and oven assembly and following the tuning procedure provided by the manufacturer. In this instance, no antenna tuning changes were required with a single tower, which resulted in a measured field strength of 120 mv/m at 0.75 mile with a power output of 500 watts.

Transmitter: Gates, Type BC-1-F, 1 Kw

Frequency Change: 1,150 to 1,240 Kc

Submitted by Radio Station KBKH

The 1,240-kc CONELRAD crystal is installed in the "spare" position. To retune the transmitter to 1,240 kc the filaments of the transmitter were first turned on; this also applies plate voltage to the oscillator and buffer (807) stages.

For operation on 1,240 kc it is necessary to screw out the slug in the oscillator plate inductance to make the crystal oscillate. The plate circuit of the 807 is then tuned to resonance.

The crystal trimmer and the oscillator plate inductance are adjusted so as to obtain a zero beat with the 1,240-kc signal from a nearby broadcast station. A small set-screw-type knob placed on the plate inductance screw makes it much easier to adjust.

Once the preliminary stages are tuned up, a plate lead to one of the 872's is disconnected, thus applying only half voltage on the amplifier tubes for tuning up the rest of the transmitter. The driver stage is easily tuned, but tuning of the final amplifier requires changing the tap on the tank coil to a marked position which has been previously determined.

In some cases it might be necessary to change the fixed tank condenser as well in order to tune the final amplifier to 1,240 kc. After the transmitter was tuned up the first time on 1,240 kc, readings of all tuning controls were noted in order to permit fast change-over in the future. Owing to the fact, however, that the oscillator

plate inductance is not calibrated, it is necessary to zero-beat the 1,240-kc crystal each time that the frequency is shifted, and a receiver should be available for this purpose.

Transmitter: Raytheon, Type RA-250-A, 250 Watts

Frequency Change: 1,340 to 640 Kc

Submitted by Radio Station KIHR

This transmitter consists of a 6J5 crystal oscillator, an 807 first RF amplifier, an 813 second RF amplifier, and push-pull 810's in the final RF amplifier.

The plate circuits of the 6J5 and the 807 are broadband untuned, so that additional capacitance is required across both plate coils. This was secured by mounting two 0- to 250-$\mu\mu$f variable condensers on a board, with attached leads about 2 ft long terminated with alligator clips. When in use, this unit is placed on top of the power transformer and the leads clipped onto the proper circuits. At resonance, adequate grid drive is provided for the 813 stage (the 640-kc crystal is left in the "spare" holder at all times).

The changes required to resonate the final amplifier tank circuit on 640 kc would be quite involved, so it was decided to use the 813 as the final amplifier for CONELRAD operation. To secure a modulated voltage on the plate of the 813, the plate caps of the 810's are removed and a clip lead is tapped onto the center of the 810 tank and brought down to the plate cap of the 813 (the regular plate cap lead of the 813 is, of course, left off).

A surplus antenna tuning unit (BC-306A) was modified to serve as an external π-network type of tank circuit, which was coupled directly to the plate of the 813 through a blocking condenser. This circuit also served to match the output to a 330-ft-long wire antenna used for CONELRAD operation.

The modulated signal from the transmitter operating in this manner, of course, is not of broadcast quality, since only the plate of the 813 is being modulated (this could be improved by applying the modulated plate voltage through a proper dropping resistor to the screen of the 813 as well).

When in operation, the external tuning unit is placed behind the transmitter and a lead run through the ventilating louvre in the door to the 813 tank circuit.

Transmitter: Collins, Type 21B, 5 Kw

Frequency Change: 1,150 to 1,240 Kc

Submitted by Radio Station KFJI

For CONELRAD operation an external oscillator operating on 1,240 kc is used. A switch is installed in the exciter bay to switch from the regular (1,150-kc) oscillator to the external (1,240-kc) oscillator. To change frequency for CONELRAD operation the procedure is as follows:

1. Push the plate on-off switch to cut the carrier.
2. If applicable, change the antenna from directional to nondirectional.
3. Turn on the external (1,240-kc) oscillator.
4. Throw the switch to feed the output of the external oscillator to the input of the first buffer amplifier.
5. Change the tap on the buffer plate tank coil located in the rear of the exciter bay on the back of the front panel. Move the tap up one turn so lower 14 turns are shorted out.
6. Change the tap on the final amplifier grid tank coil located in the rear of the exciter bay on the upper right-hand side. Move the tap 2 turns toward the front of the bay, leaving 25 turns in the circuit.
7. Change the tap on the final power-amplifier plate tank coil, which is reached

from the front of the final bay and is the inductance at the top of the bay. Move the tap two turns to the right, leaving 23 turns in the circuit.

8. Place the TUNE-HI-LO switch in the TUNE position and the exciter bay meter switch in the BUFFER CATHODE and TUNE position. Pull the plate on-off switch to turn on the intermediate voltage and tune for *minimum* on the test meter.

9. Place the exciter bay meter switch in the INT. AMP. GRID and TUNE position and tune for minimum intermediate amplifier plate current.

10. Place the TUNE-HI-LO switch in the LO position, and tune the final amplifier in the normal manner for minimum plate current. It will be necessary to increase the loading some so as to be able to tune the final amplifier properly.

The antenna has a resistance of 80 ohms at 1,150 kc. With no change in the antenna tuning, an antenna current of a little over 2 amp was obtained on 1,240 kc.

Transmitter: RCA, Type BTA-1-L, 1 Kw

Frequency Change: 590 to 640 Kc

Submitted by Radio Station KUGN

The following is a copy of the instructions posted for the station operators:

1. Turu off the plate switches on both the power amplifier and the exciter.

2. Turn off the frequency monitor and phase monitor, and switch to nondirectional.

After doing this you are ready to start the tuning procedure.

Go to the rear of the transmitter and open the doors of both the exciter and the power-amplifier unit. Start with the exciter, remove the 590-kc crystal from the socket in the oscillator unit, and install the 640-kc crystal. Put the 590-kc crystal in the crystal holder in the rear of the chassis to keep it warm. Next, turn the black knob on the 1-*L*-11 (upper left-hand corner) six turns counterclockwise. After doing this, close the doors on the exciter and go to the power-amplifier unit. There is only one change in the power amplifier—move the clip on the top of *L*-7 down five turns; then move the clip on the bottom of *L*-7 up five turns. This completes all changes in the rear of the transmitter, so be sure that all doors are closed.

Then go to the front of the transmitter and make the following dial settings:

Control	640 *kc*	590 *kc*
Buffer	57.5	38.1
Power amplifier neutralization	70.6	54.5
Power amplifier plate	50.1	33.6
Loading	50.0	42.0
Power amplifier plate (final)	33.1	39.1
Power	Maximum I_p [a]	Rated output

[a] In some cases this may be too much plate input. If this is the case, adjust the output until the input to the 833's is approximately 600 ma.

Now apply plate voltages to both units in the normal manner, and everything should be just about normal except for the plate voltage and plate current on the final. The current will be about 470 ma, and the plate voltage will be about 2,400 volts. After you are satisfied that all is well with the transmitter, go over to the modulation monitor, tune for the maximum on the carrier meter, and then adjust the carrier level in the normal manner. All should be in readiness, then, for CONELRAD operation.

Transmitter: RCA, Type BTA-10-F, 10 Kw

Frequency Change: 1,090 to 1,240 Kc

Submitted by Radio Station KING

It was unnecessary to change any of the transmitter components in order to shift frequency for CONELRAD operations.

The transmitter contains two separate crystal oscillators, one of which is main-

tained ready for operation on 1,240 kc. The oscillators are changed by pressing oscillator switch *S*-2, which operates relay *E*-1 to select the proper crystal. The buffer tank coil *L*-4, the driver neutralizing coil *L*-6, and the driver tank coil *L*-7 are rotated to predetermined positions (marked on coil) to resonate at 1,240 kc.

The final tank coil (*L*-13 and *L*-16 in series) is motor-operated and is all set so that when the motor hits the mechanical stop, the coil is resonated on 1,240 kc. This output circuit is a π network designed to work into a 70-ohm load on the licensed frequency.

The phasing unit feeding three towers is bypassed by lifting a switch to one of the towers and connecting the transmitter output to the transmission line for that tower. This is accomplished by moving two clips. The tower is tuned by moving two clips on a T-net matching network to predetermined positions.

The complete change requires only 5 min.

Transmitter: Western Electric, Type 355-E-1

Frequency Change: 560 to 640 Kc

Submitted by Radio Station KPQ

The oscillator in this transmitter is a WE 700-C plug-in type. A separate oscillator unit containing a 640-kc crystal is used for CONELRAD operation.

The first amplifier is untuned, and no change is required when switching to 640 kc.

In order to retune the second amplifier it is necessary to change the fixed capacitance, C-43A, to a slightly lower value (0.00025 mf). After making this change, it was possible to tune this stage to 560 kc by means of normal tuning controls.

The third amplifier is tuned to both frequencies without any changes being made, and since the grid circuit of the 343-A's is an integral part of the third tank, it should not be retuned. Hence, a change of C-18A on the front panel is all that is necessary to obtain grid drive to the final.

Retuning the final tank requires opening the doors and shifting the tank coil clips of L-1D inward two turns on each end to marked points. This makes it possible to resonate the circuit by means of the front-panel loop adjustment.

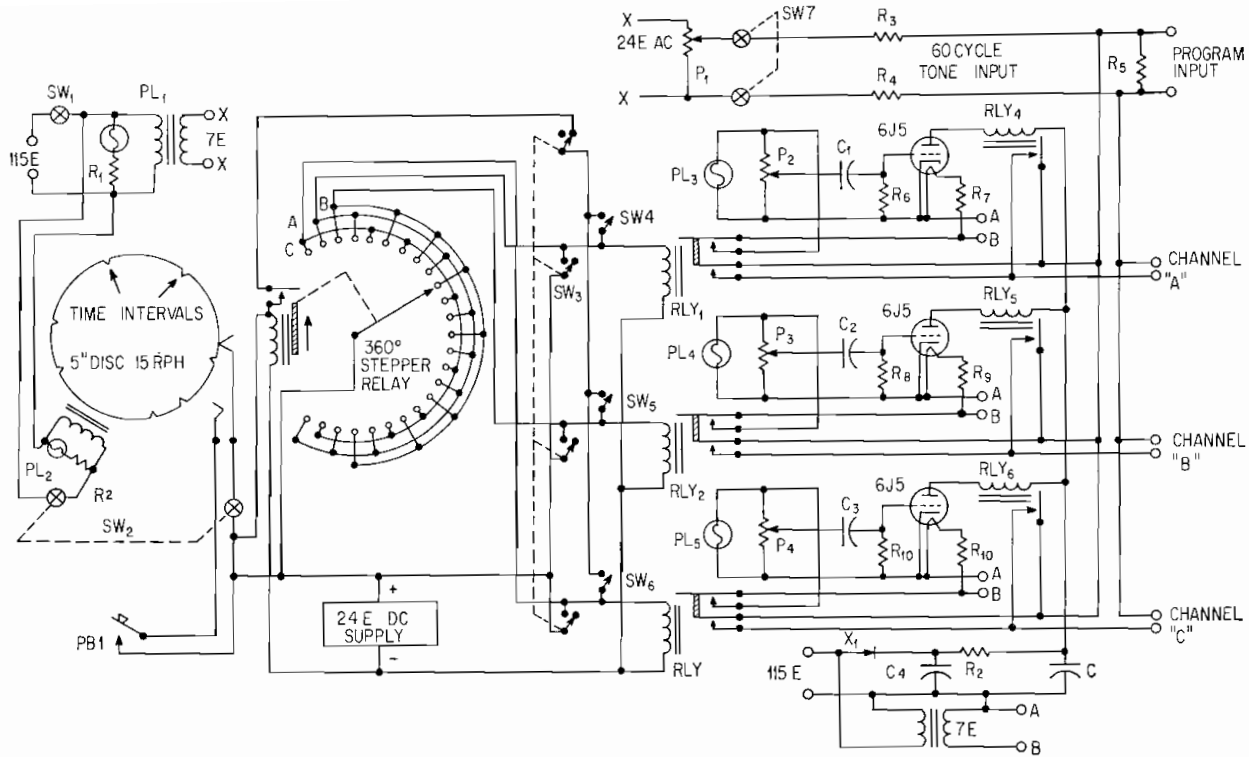
Reloading and retuning the antenna were accomplished by inserting a condenser in series with the nondirectional-antenna lead-in in the phase cabinet. The value of this condenser is such as to make the reflected load down the line look O.K. to the mismatched loading circuit.[9] In this instance a 0.0006-mf condenser was used; thus, in changing frequency it is not necessary to shift either the load adjustment or the antenna matching tuning.

The total cost for the CONELRAD conversion is about $46, plus about $125 for the additional oscillator unit if required.

SEQUENTIAL SWITCHING OF TRANSMITTERS

In the cluster mode of operation, transmitters are switched on and off automatically with practically a "no-repeat" sequence of operation. One such switcher has been designed and built by Mr. Ross Beville, vice-president for engineering, WWDC Inc., Washington, D.C. This switch, shown in Fig. 7-15, will presently handle three channels but can be extended to more if necessary. Six stations could be handled by paralleling two on each channel. The time disc shown on the drawing does not show the actual time intervals but has been constructed so as to vary the interval that each station will be on the air from 6 to 40 sec. The switch has been constructed so that it will run unattended for 1 hr 40 min before beginning to repeat the sequence. Manual operation of the stepper is provided in the operation of a push button appearing on the front panel and labeled PBI in Fig. 7-15. Means for eliminating any channel in the event of failure of a station is provided by the selective operation of *SW*4, *SW*5, or *SW*6 as required. Operation of the ganged switch *SW*3 provides dis-

[9] That is, it tends to cancel out the inductive reactance.



P1—1000-ohm pot, 3 watts
P2—50-ohm pot, 3 watts
P3—50-ohm pot, 3 watts
P4—50-ohm pot, 3 watts
PL1—pilot light (input)
PL2—pilot light (motor)
PL3—Ch. "A" Talley light
PL4—Ch. "B" Talley light
PL5—Ch. "C" Talley light
PB1—momentary push button for manual operation
SW1—power switch
SW2—motor switch
SW3—all channel switch
SW4—Ch. "A" on-off
SW5—Ch. "B" on-off
SW6—Ch. "C" on-off
SW7—tone, on-off
R1, R2—750 ohms, ½ watt
R3, R4—500 ohms, ½ watt
R5—250 ohms, ½ watt
R6, R8, R10—500 K, ½ watt
R7, R9, R11—7.5 ohms, 1 watt
R12—5,100 ohms, 1 watt
C1, C2, C3—1 μf
C4, C5—8 μf
X1—60 ma, selenium rectifier
RLY 1, 2, and 3—Guardian 200
RLY 4, 5, and 6—Potter Brumfield, Type LS, 10 K

FIG. 7-15. Circuit diagram of CONELRAD sequential switch designed by Ross Beville, WWDC, Washington, D.C.

tribution of program failures either sequentially or simultaneously. Simultaneous distribution is useful in test operations of cluster connecting lines and in transmitting "all clear" notices at the termination of an emergency.

The 6J5 vacuum tubes working in connection with relays 4, 5, and 6 provide the necessary overlap when switching from channel to channel. This is to prevent breaks in programming. Overlap time can be varied from ½ to 2 sec by the operation of *P*2, *P*3, or *P*4. The 60-cycle-tone input to each channel was included so as to make possible the use of *tone*-actuated relays at each transmitter in the cluster. Since *program*-actuated relays are presently being used, this feature is not operative but is available for use at a later date if necessary.

Figure 7-16 shows in block form the manner of operation of one of the clusters in a major city on the east coast. The radio stations *A* through *F* are connected to

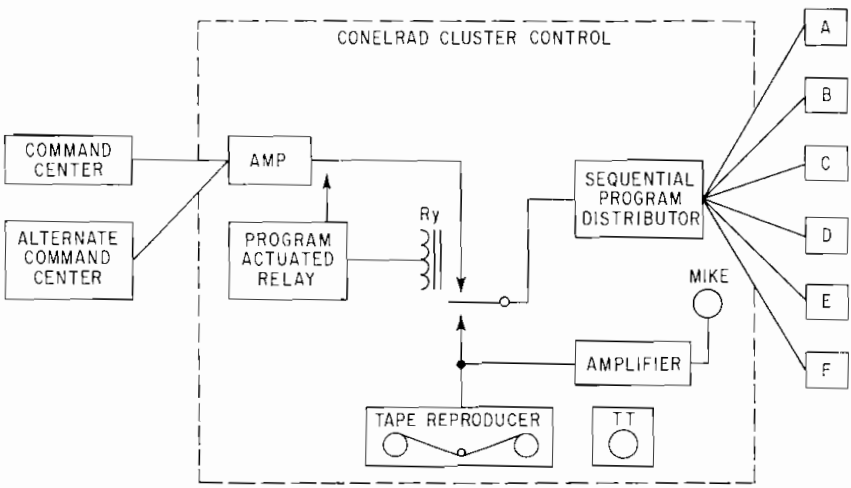


FIG. 7-16. Typical six-station CONELRAD cluster.

the sequential program distributor unit at the cluster control station by schedule *F* lines. The distributor unit automatically switches the program from one station to another. At the station end of each of the lines is a program-operated amplifier and associated relay with a time-delay circuit to hold the transmitter on for whatever period is desired so that pauses in speech or music will not cause the transmitter to go off the air. It will be seen that programs can be directed into the distributor from both sides of the relay. One side takes the program from the Industry Control Center or Alternate Center. The program-actuated relay shown has the feature of preempting the circuit whenever survival instructions or information are required. During pauses in speech, the relay switches over to the studio control and momentarily takes whatever program is being provided by the cluster control station.

Some difficulty has been experienced as a result of the time-delay feature utilized to keep the transmitters on the air during pauses in speech. The chief trouble occurs at the switch-over point from one station to another when the carrier of the first station is still on the air without modulation. This situation is particularly troublesome when the first carrier is somewhat stronger than the second, which results in the AVC action of the receiver holding down the volume, so that the received signal from the second station is below the easily readable level. Then, too, if there is any appreciable frequency difference between the two stations, the RF carrier beat note adds to the difficulty. It was also learned during one test of the system that in order to provide intelligible coverage of a large metropolitan area, a relatively effi-

cient antenna system must be used or the power must be increased to compensate for the inefficiency. In certain instances where the broadcast transmitters are located a considerable distance from the center of the city, it is quite impractical to expect a 250-watt station, even with an efficient antenna, to provide the needed coverage. This is chiefly a matter of limitation imposed by sky-wave signals on the same channel. It was calculated that the effective service area of a cluster of stations during CONELRAD operation would be within the 6- or 8-mv/m contour. Generally speaking, this has proved to be a practical value. There are a few areas where the intelligible service contours extended out to approximately the 2-mv/m contour. Where it is required to utilize stations in the 250-watt-power category for a cluster, it may be necessary to broadcast survival information on a sectionalized metropolitan area basis,[10] that is, broadcasting information designed for a particular section of the city only over the station that is known to give adequate coverage to that section. General types of programs such as music, etc., could then be broadcast in the usual manner for cluster operation without any particular regard for the 100 per cent intelligibility factor.

OVER-ALL CAPABILITIES

Although a detailed discussion of the navigational-deception aspects of the CONELRAD System is not appropriate here, it is proper to say just a few words about the system from the over-all standpoint of its potential capabilities. There has been some confusion on this point. The United States Air Force has integrated the entire program of electromagnetic radiation control into what they term "passive defense." It has never been thought of or intended that any such system of controlled operation of broadcast stations or those of any other service could prevent a good navigator from bringing an aircraft to within a very close distance from the desired point. We know our navigators are able to do it, so probably those of other countries can too. However, if any difficulties arise in other navigating methods or procedures, it is agreed that one of the most useful adjuncts to navigation would be the radio compass. Consequently, normal operation of standard broadcast stations would immediately provide a multitude of sources for orientation of aircraft. It is common procedure for certain types of navigation, both in the military and in commercial aviation, to use broadcast stations as a signal source for the ADF with excellent accuracy. In one section of our country where radio ranges and beacons are not too plentiful, even the 250-watt broadcast stations render an excellent navigational service. So the CONELRAD system was never intended to prevent an enemy flight from reaching its target but only to make it more difficult by rendering practically useless its radio facilities for direction finding.

USE OF REMOTE-PICKUP FACILITIES IN CONELRAD

Throughout the period of operation of the broadcast CONELRAD system, the program and control distribution to the various stations in the clusters has been via wire lines leased from the common carrier.[11] Such a system is most reliable under normal conditions, except for errors in patching up at the local exchange board. Such errors do not occur frequently, however, and the use of lines has proved satisfactory. Discussions within the National Industry Advisory Committee, the Federal Communications Commission, the Office of Civil and Defense Mobilization, and other agencies of the government have recognized the vulnerability of such a program-dissemination and control system should an emergency occur. In view of this, consideration is now being given to utilizing radio circuits for both the program dissemination and control and switching of the stations operating in CONELRAD clusters.

[10] That is, selected segment operation, which has proved most efficient in terms of providing good coverage.

[11] At no expense to the broadcaster.

A logical choice for the selection of both equipment and frequencies for this purpose would be that which could normally be used by the broadcaster in everyday operations whenever there is a requirement for a remote pickup. Vast experience in the practical operation of such equipment was available from the industry as well as the FCC. While over half of the remote-pickup authorizations to radio broadcast stations are for use of the 25- and 26-Mc band, it was considered advisable to utilize a higher order of frequency. The 153-Mc band is shared with the Industrial Service, which has first priority of use. With certain geographical limitations, 166.25 and 170.15 Mc are shared with the government. Therefore the next higher band(s) 450, and 455 Mc, which are allocated exclusively to the Broadcast Service, were considered the most appropriate choice.

Aside from the exclusivity feature of the 450- to 455-Mc allocation, the physical dimensions of antennas and equipment for such operation were additional attributes. Parabolic or other type of beam antennas can be used to concentrate the radiated signal and provide considerable power gain in the desired direction. Operational tests between mobile units and a base station indicated a good reliability figure even in a large metropolitan area such as New York City. Such tests were made without the benefit of "dish" antennas, and consequently the success of the contemplated fixed type of application for CONELRAD appeared technically assured. Those benefits would be equally applicable to the normal type of operation for remote-pickup use. Not only would it be possible in this manner but under developed conditions could be used for intercity relay as well as intracity purposes.

A system of utilizing such frequencies in the 450- to 455-Mc bands has been worked out and is commonly known as the "checkerboard" system (see Fig. 7-17). The name was derived from the letter designation of areas to which channels have been assigned for both transmitting and receiving to the contiguous areas. Referring to the letter block and the subsequent block diagrams of the areas (see Figs. 7-19 through 7-26), area *A* could transmit to area *B* on 450.15 Mc to area *D* on 450.35 Mc and receive from areas *B* and *D* on 455.15 and 455.75 Mc, respectively. In addition, transmission to a mobile news unit could be made on 450.25 Mc and for cluster control, programming and switching, cueing and calling, and communications to Weather Bureau, police, and local civil defense on 450.95 Mc. Provision is also made for mobile unit channels to both transmit and receive as indicated. Similar provision is made for the other areas shown.

Such use is not necessarily restricted to the 450- to 455-Mc bands. In some areas of the country the other remote-pickup frequencies allocated, even though shared with industry and government, might be usable on a noninterference basis. Frequencies in the 25- and 26-Mc bands could also be used, although the physical dimensions of the antennas make those bands less desirable. A similar assignment plan could be formulated for those frequency bands. Such systems are already in the process of being initiated in several areas of the country. It is believed that efficient use of the remote-pickup frequencies allocated to the Broadcast Service will not only provide an emergency communication and control system of high reliability but also enhance the pickup facilities of the normal broadcast program. As more information is being gathered concerning the use of the higher frequencies (450 Mc), their advantages are becoming more apparent.

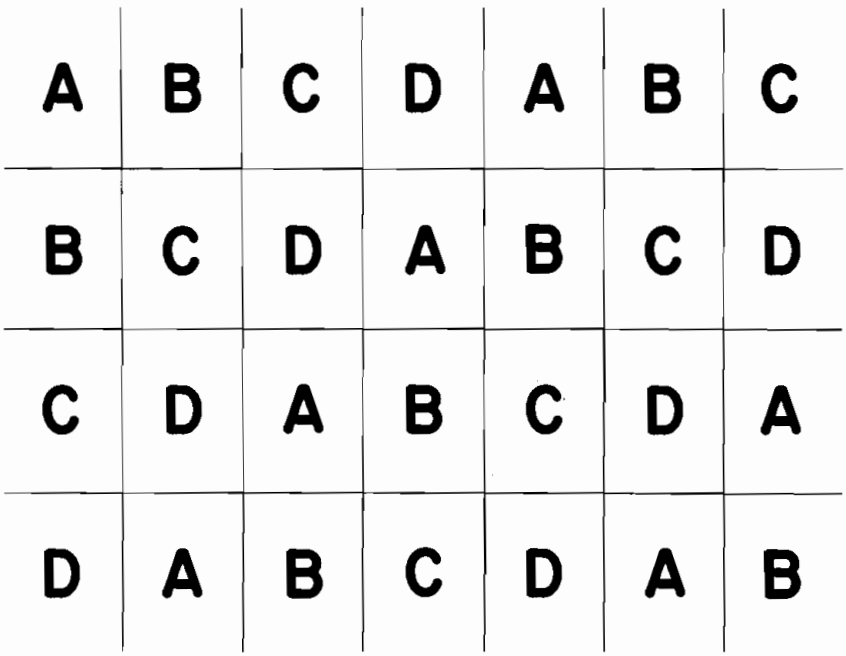


FIG. 7-17. "Checkerboard" area block diagram. See Fig. 7-18 for details of frequency use between areas designated by letters, and Figs. 7-19 through 7-26 for more detailed usage of channels in the 450- and 455-Mc bands.

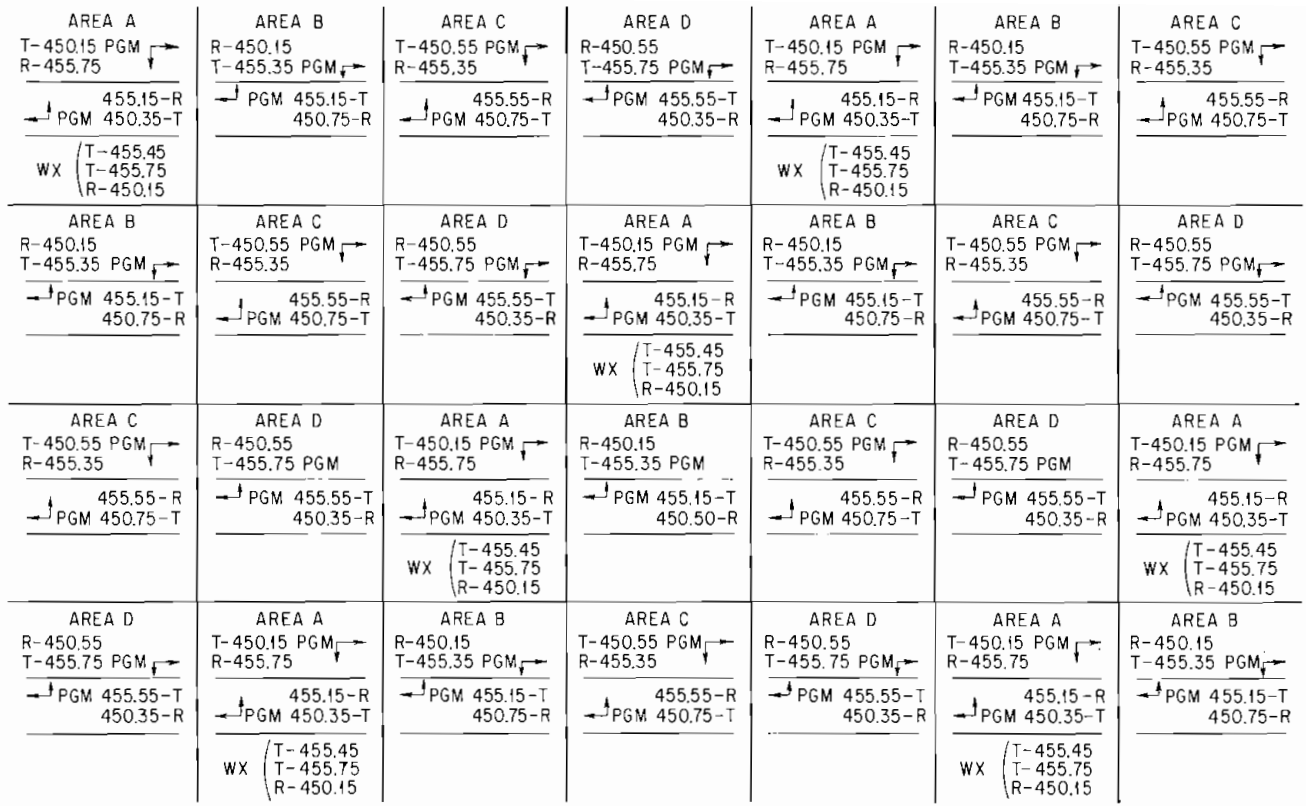
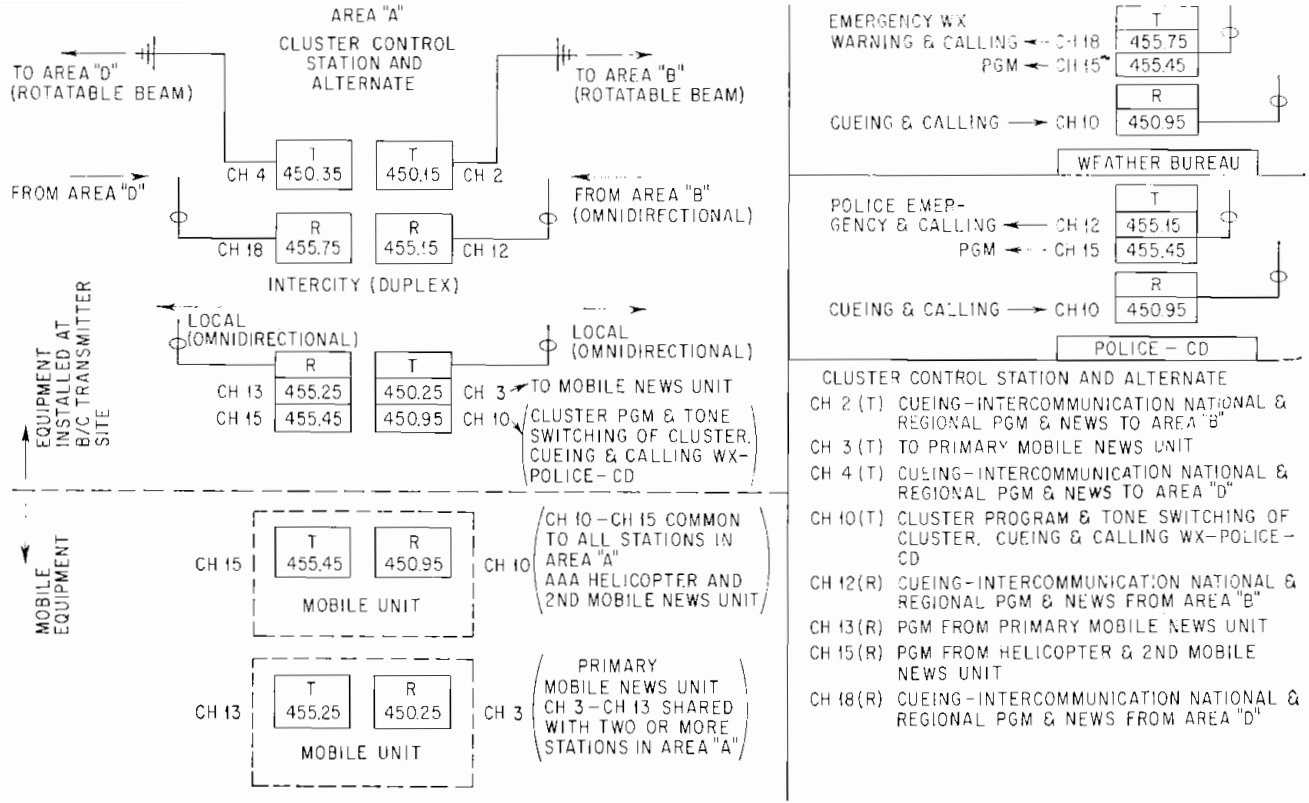

AREA A
T-450.15 PGM
R-455.75
455.15-R
PGM 450.35-T
WX T-455.45 T-455.75 R-450.15
AREA B
R-450.15
T-455.35 PGM
PGM 455.15-T
450.75-R
AREA C
T-450.55 PGM
R-455.35
455.55-R
PGM 450.75-T
AREA D
R-450.55
T-455.75 PGM
PGM 455.55-T
450.35-R
AREA A
T-450.15 PGM
R-455.75
455.15-R
PGM 450.35-T
WX T-455.45 T-455.75 R-450.15
AREA B
R-450.15
T-455.35 PGM
PGM 455.15-T
450.75-R
AREA C
T-450.55 PGM
R-455.35
455.55-R
PGM 450.75-T
AREA B
R-450.15
T-455.35 PGM
PGM 455.15-T
450.75-R
AREA C
T-450.55 PGM
R-455.35
455.55-R
PGM 450.75-T
AREA D
R-450.55
T-455.75 PGM
PGM 455.55-T
450.35-R
AREA A
T-450.15 PGM
R-455.75
455.15-R
PGM 450.35-T
WX T-455.45 T-455.75 R-450.15
AREA B
R-450.15
T-455.35 PGM
PGM 455.15-T
450.75-R
AREA C
T-450.55 PGM
R-455.35
455.55-R
PGM 450.75-T
AREA D
R-450.55
T-455.75 PGM
PGM 455.55-T
450.35-R
AREA C
T-450.55 PGM
R-455.35
455.55-R
PGM 450.75-T
AREA D
R-450.55
T-455.75 PGM
PGM 455.55-T
450.35-R
AREA A
T-450.15 PGM
R-455.75
455.15-R
PGM 450.35-T
WX T-455.45 T-455.75 R-450.15
AREA B
R-450.15
T-455.35 PGM
PGM 455.15-T
450.50-R
AREA C
T-450.55 PGM
R-455.35
455.55-R
PGM 450.75-T
AREA D
R-450.55
T-455.75 PGM
PGM 455.55-T
450.35-R
AREA A
T-450.15 PGM
R-455.75
455.15-R
PGM 450.35-T
WX T-455.45 T-455.75 R-450.15
AREA D
R-450.55
T-455.75 PGM
PGM 455.55-T
450.35-R
AREA A
T-450.15 PGM
R-455.75
455.15-R
PGM 450.35-T
WX T-455.45 T-455.75 R-450.15
AREA B
R-450.15
T-455.35 PGM
PGM 455.15-T
450.75-R
AREA C
T-450.55 PGM
R-455.35
455.55-R
PGM 450.75-T
AREA D
R-450.55
T-455.75 PGM
PGM 455.55-T
450.35-R
AREA A
T-450.15 PGM
R-455.75
455.15-R
PGM 450.35-T
WX T-455.45 T-455.75 R-450.15
AREA B
R-450.15
T-455.35 PGM
PGM 455.15-T
450.75-R

FIG. 7-18



CLUSTER CONTROL STATION AND ALTERNATE

- CH 2 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "B"
- CH 3 (T) TO PRIMARY MOBILE NEWS UNIT
- CH 4 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "D"
- CH 10 (T) CLUSTER PROGRAM & TONE SWITCHING OF CLUSTER, CUEING & CALLING WX-POLICE-CD
- CH 12 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "B"
- CH 13 (R) PGM FROM PRIMARY MOBILE NEWS UNIT
- CH 15 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
- CH 18 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "D"

FIG. 7-19

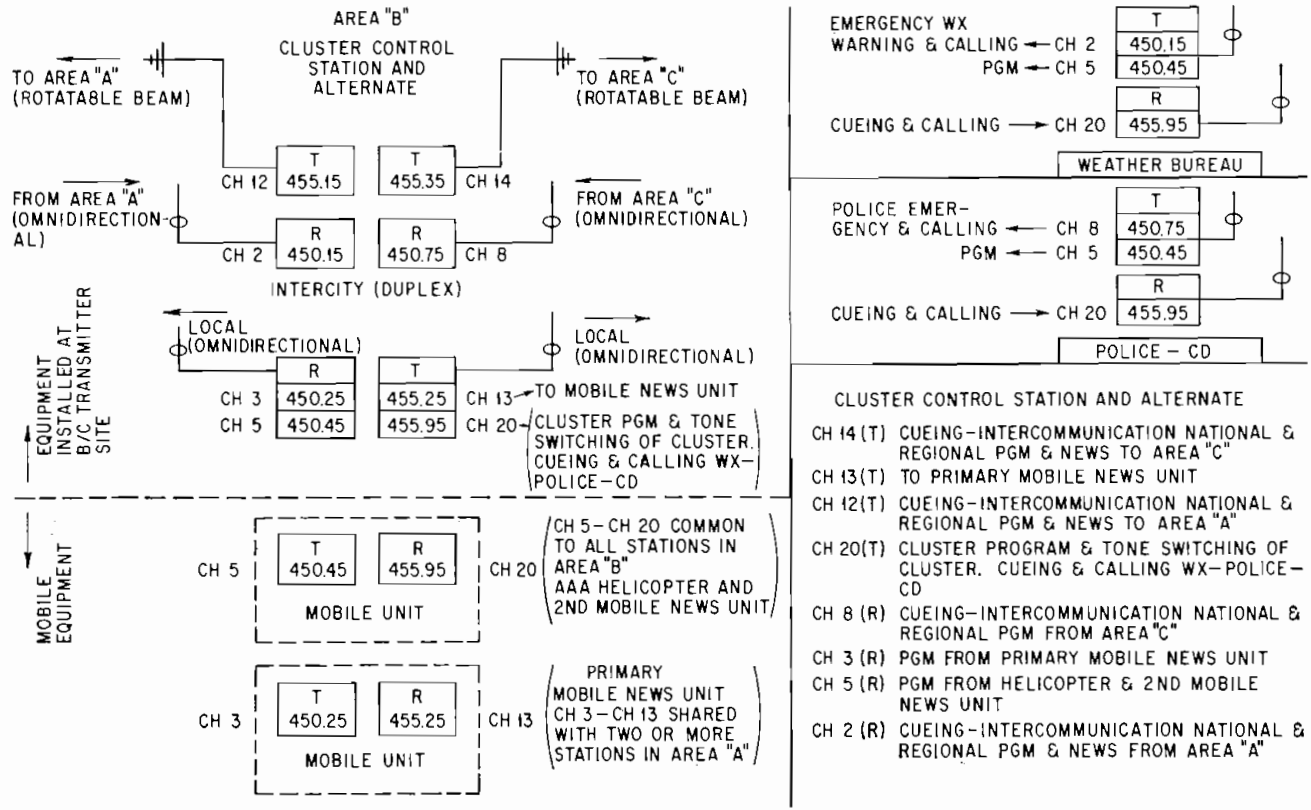
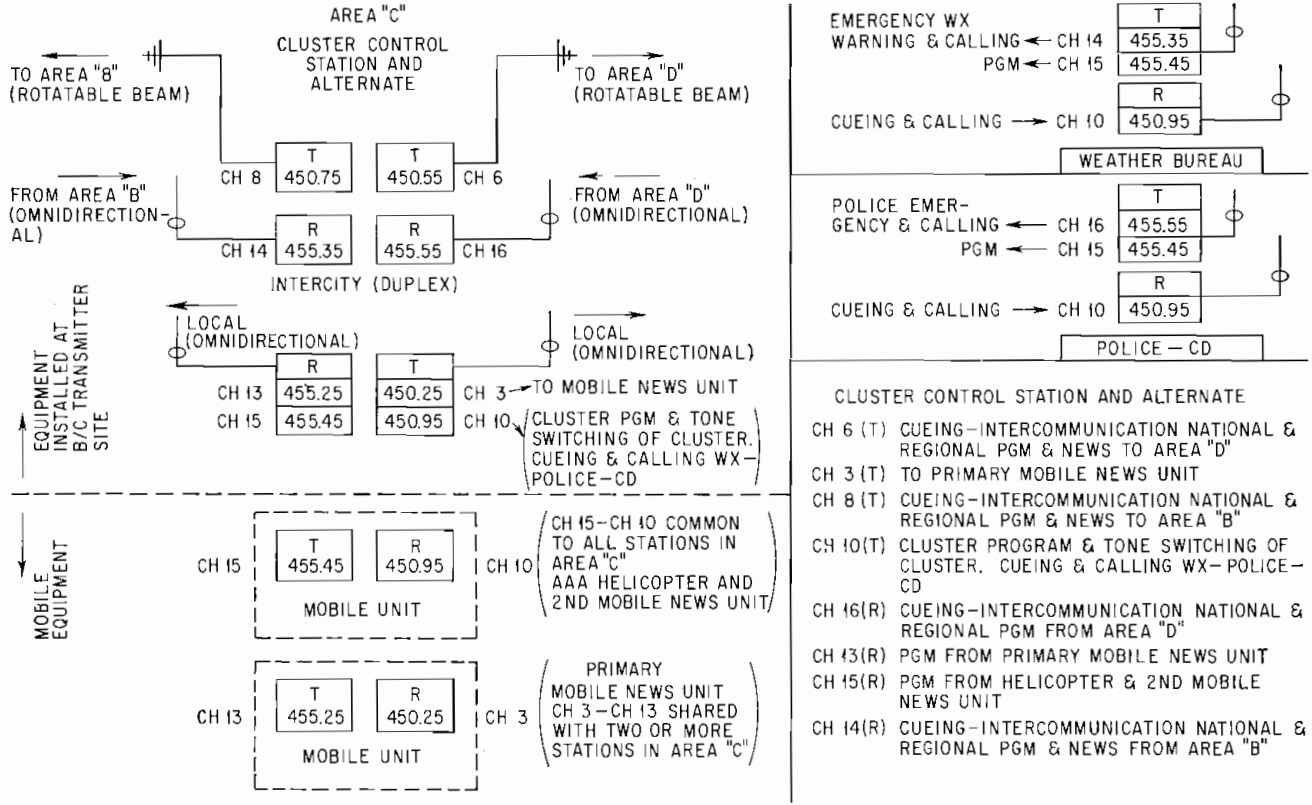

AREA "B"
CLUSTER CONTROL STATION AND ALTERNATE
TO AREA "A" (ROTATABLE BEAM)
TO AREA "C" (ROTATABLE BEAM)
FROM AREA "A" (OMNIDIRECTIONAL)
FROM AREA "C" (OMNIDIRECTIONAL)
CH 12 T 455.15
T 455.35 CH 14
CH 2 R 450.15
R 450.75 CH 8
INTERCITY (DUPLEX)
LOCAL (OMNIDIRECTIONAL)
LOCAL (OMNIDIRECTIONAL)
CH 3 R 450.25
CH 5 450.45
T 455.25 CH 13 TO MOBILE NEWS UNIT
455.95 CH 20 CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX-POLICE-CD
EQUIPMENT INSTALLED AT B/C TRANSMITTER SITE
MOBILE EQUIPMENT
CH 5 T 450.45 R 455.95 CH 20 CH 5-CH 20 COMMON TO ALL STATIONS IN AREA "B" AAA HELICOPTER AND 2ND MOBILE NEWS UNIT
MOBILE UNIT
CH 3 T 450.25 R 455.25 CH 13 PRIMARY MOBILE NEWS UNIT CH 3-CH 13 SHARED WITH TWO OR MORE STATIONS IN AREA "A"
MOBILE UNIT
EMERGENCY WX WARNING & CALLING ← CH 2 T 450.15
PGM ← CH 5 450.45
CUEING & CALLING → CH 20 R 455.95
WEATHER BUREAU
POLICE EMERGENCY & CALLING ← CH 8 T 450.75
PGM ← CH 5 450.45
CUEING & CALLING → CH 20 R 455.95
POLICE - CD
CLUSTER CONTROL STATION AND ALTERNATE
CH 14 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "C"
CH 13 (T) TO PRIMARY MOBILE NEWS UNIT
CH 12 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "A"
CH 20 (T) CLUSTER PROGRAM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX-POLICE-CD
CH 8 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM FROM AREA "C"
CH 3 (R) PGM FROM PRIMARY MOBILE NEWS UNIT
CH 5 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
CH 2 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "A"

FIG. 7-20



CLUSTER CONTROL STATION AND ALTERNATE

CH 6 (T) CUEING—INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "D"

CH 3 (T) TO PRIMARY MOBILE NEWS UNIT

CH 8 (T) CUEING—INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "B"

CH 10(T) CLUSTER PROGRAM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX—POLICE—CD

CH 16(R) CUEING—INTERCOMMUNICATION NATIONAL & REGIONAL PGM FROM AREA "D"

CH 13(R) PGM FROM PRIMARY MOBILE NEWS UNIT

CH 15(R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT

CH 14(R) CUEING—INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "B"

FIG. 7-21

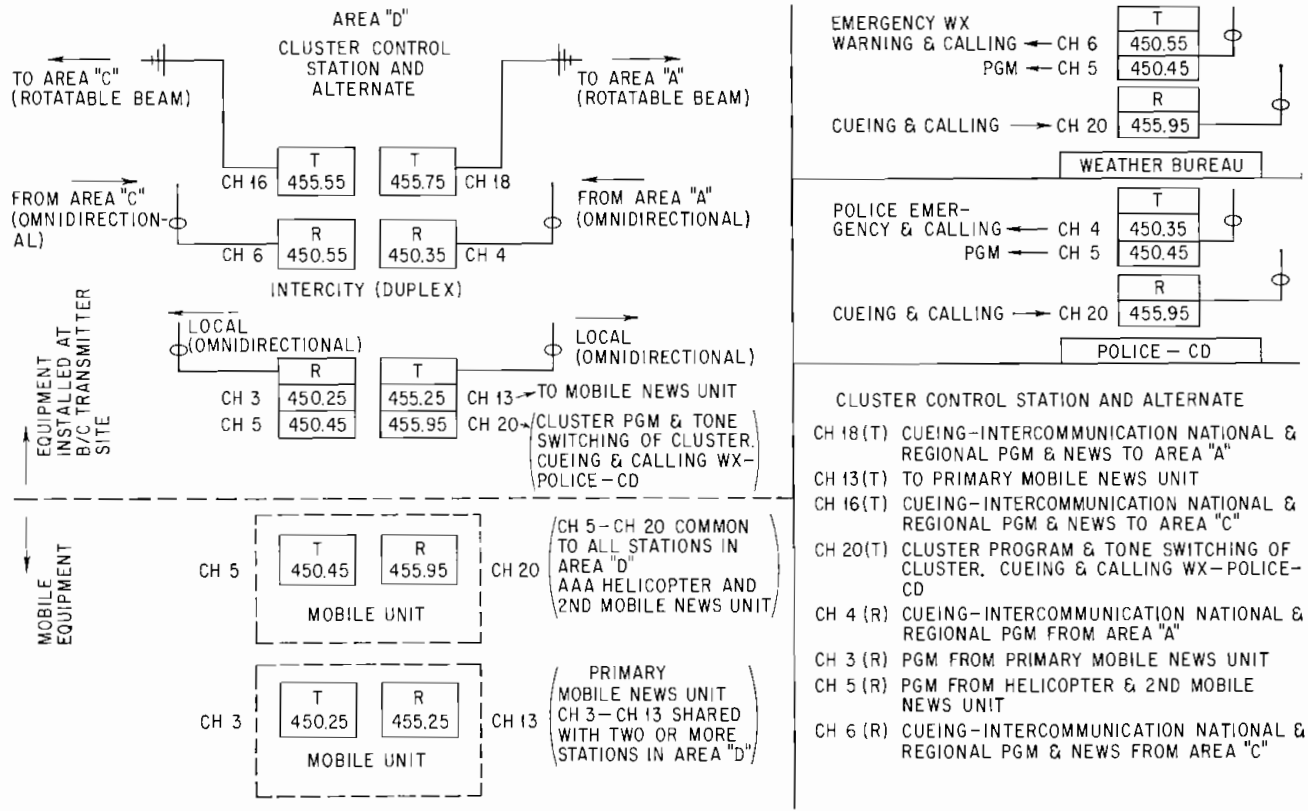
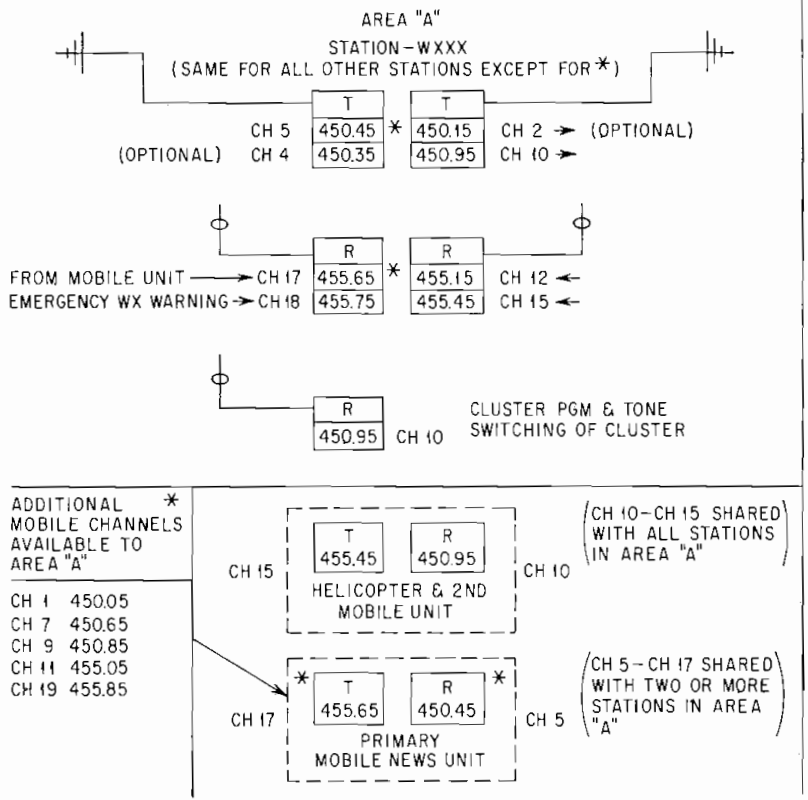

AREA "D"
CLUSTER CONTROL STATION AND ALTERNATE
TO AREA "C" (ROTATABLE BEAM)
TO AREA "A" (ROTATABLE BEAM)
CH 16
T 455.55
T 455.75
CH 18
FROM AREA "C" (OMNIDIRECTIONAL)
FROM AREA "A" (OMNIDIRECTIONAL)
CH 6
R 450.55
R 450.35
CH 4
INTERCITY (DUPLEX)
EQUIPMENT INSTALLED AT B/C TRANSMITTER SITE
LOCAL (OMNIDIRECTIONAL)
LOCAL (OMNIDIRECTIONAL)
R
T
CH 3
450.25
455.25
CH 13
TO MOBILE NEWS UNIT
CH 5
450.45
455.95
CH 20
CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX-POLICE-CD
MOBILE EQUIPMENT
CH 5
T 450.45
R 455.95
CH 20
MOBILE UNIT
CH 5-CH 20 COMMON TO ALL STATIONS IN AREA "D" AAA HELICOPTER AND 2ND MOBILE NEWS UNIT
CH 3
T 450.25
R 455.25
CH 13
MOBILE UNIT
PRIMARY MOBILE NEWS UNIT CH 3-CH 13 SHARED WITH TWO OR MORE STATIONS IN AREA "D"
EMERGENCY WX WARNING & CALLING
CH 6
PGM
CH 5
T
450.55
450.45
CUEING & CALLING
CH 20
R
455.95
WEATHER BUREAU
POLICE EMERGENCY & CALLING
CH 4
PGM
CH 5
T
450.35
450.45
CUEING & CALLING
CH 20
R
455.95
POLICE - CD
CLUSTER CONTROL STATION AND ALTERNATE
CH 18 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "A"
CH 13 (T) TO PRIMARY MOBILE NEWS UNIT
CH 16 (T) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "C"
CH 20 (T) CLUSTER PROGRAM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX-POLICE-CD
CH 4 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM FROM AREA "A"
CH 3 (R) PGM FROM PRIMARY MOBILE NEWS UNIT
CH 5 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT
CH 6 (R) CUEING-INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "C"

FIG. 7-22



CH 2 (T) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "B"

CH 4 (T) SAME TO AREA "D"

CH 5 (T) TO MOBILE NEWS UNIT

(ALTERNATE)

CH 10(T) CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX – POLICE – CD. CUEING 2ND MOBILE UNIT

CH 10(R) SAME AS ABOVE FROM CLUSTER CONTROL & ALTERNATE CLUSTER CONTROL

AAA HELICOPTER & 2ND MOBILE NEWS UNIT

CH 12(R) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "B" CALLING FROM POLICE & CD

CH 15(R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT

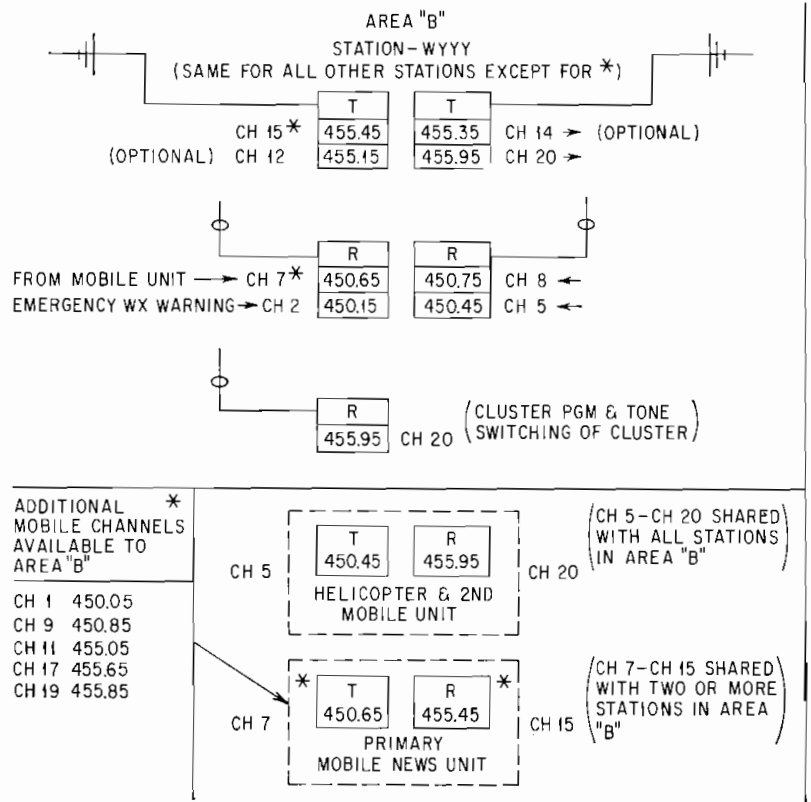
CH 17(R) PGM FROM PRIMARY MOBILE UNIT

CH 18(R) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "D"

CALLING FROM WX BUREAU

EMERGENCY WX WARNINGS

Fig. 7-23



CH 14 (T) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "C"

CH 12 (T) SAME TO AREA "A"

CH 15 (T) TO MOBILE NEWS UNIT

(ALTERNATE)

CH 20 (T) CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX – POLICE – CD. CUEING 2ND MOBILE UNIT

CH 20 (R) SAME AS ABOVE FROM CLUSTER CONTROL & ALTERNATE CLUSTER CONTROL

AAA HELICOPTER & 2ND MOBILE NEWS UNIT

CH 8 (R) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "C". CALLING FROM POLICE & CD

CH 8 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT

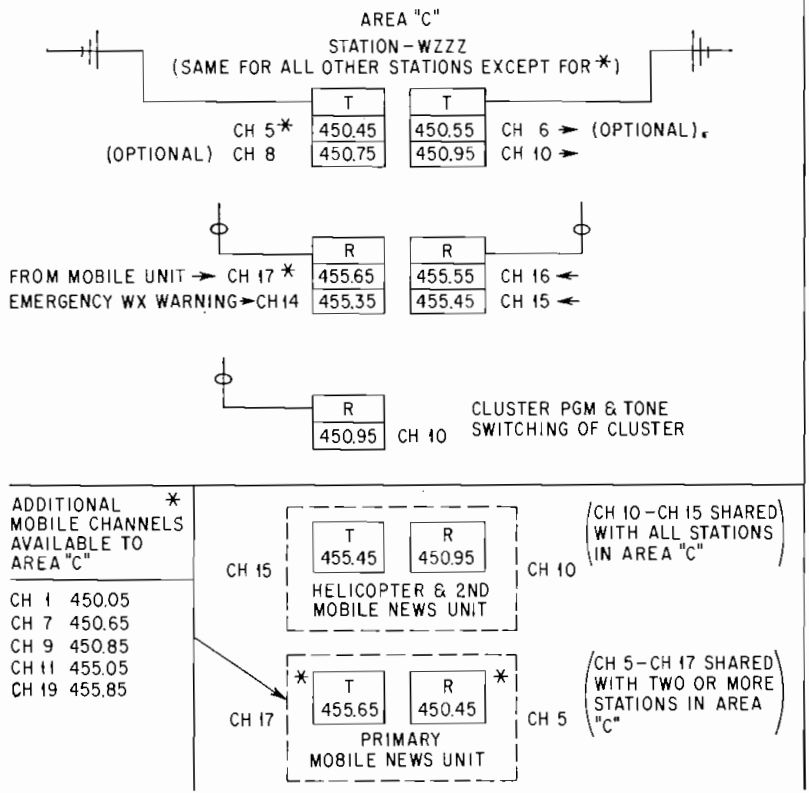
CH 7 (R) PGM FROM PRIMARY MOBILE UNIT

CH 2 (R) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "A"

CALLING FROM WX BUREAU

EMERGENCY WX WARNINGS

FIG. 7-24



CH 6 (T) CUEING–INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "D"

CH 8 (T) SAME TO AREA "B"

CH 5 (T) TO MOBILE NEWS UNIT

(ALTERNATE)

CH 10 (T) CLUSTER PGM & TONE SWITCHING OF CLUSTER. CUEING & CALLING WX–POLICE – CD. CUEING 2ND MOBILE UNIT

CH 10 (R) SAME AS ABOVE FROM CLUSTER CONTROL & ALTERNATE CLUSTER CONTROL

AAA HELICOPTER & 2ND MOBILE NEWS UNIT

CH 16 (R) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "D". CALLING FROM POLICE & CD

CH 15 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT

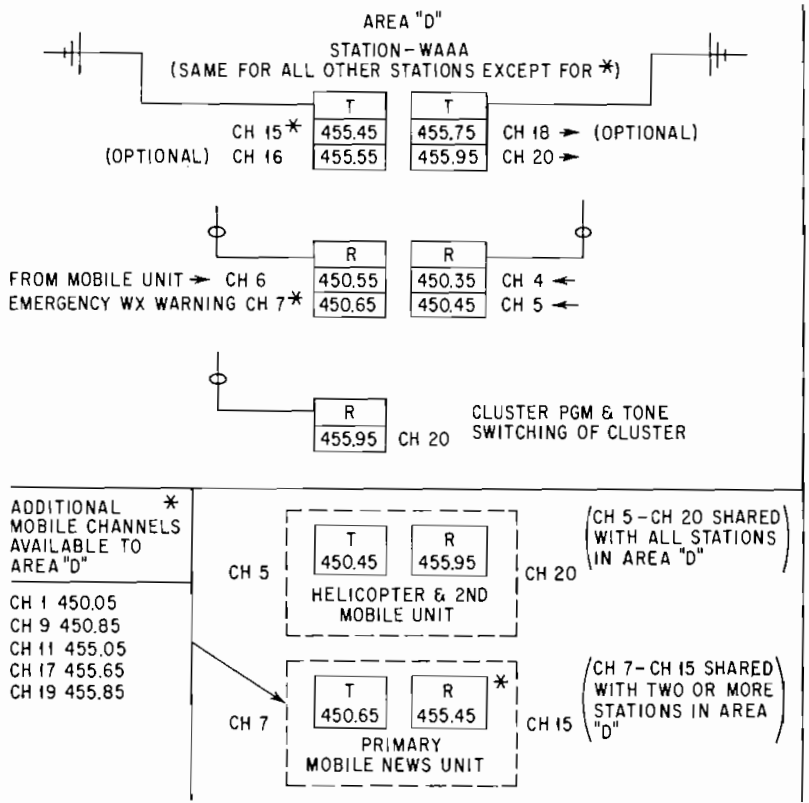
CH 17 (R) PGM FROM PRIMARY MOBILE UNIT

CH 14 (R) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "B"

CALLING FROM WX BUREAU

EMERGENCY WX WARNINGS

FIG. 7-25



CH 18(T) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS TO AREA "D"

CH 16(T) SAME TO AREA "C"

CH 15(T) TO MOBILE NEWS UNIT

(ALTERNATE)

CH 20(T) CLUSTER PGM & TONE SWITCHING OF CLUSTER – CUEING & CALLING WX – POLICE – CD. CUEING 2ND MOBILE UNIT

CH 20(R) SAME AS ABOVE FROM CLUSTER CONTROL & ALTERNATE CLUSTER CONTROL

AAA HELICOPTER & 2ND MOBILE NEWS UNIT

CH 4 (R) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "A". CALLING FROM POLICE & CD

CH 5 (R) PGM FROM HELICOPTER & 2ND MOBILE NEWS UNIT

CH 7 (R) PGM FROM PRIMARY MOBILE UNIT

CH 6 (R) CUEING – INTERCOMMUNICATION NATIONAL & REGIONAL PGM & NEWS FROM AREA "C"

CALLING FROM WX BUREAU

EMERGENCY WX WARNINGS

FIG. 7-26

METHODS FOR OBTAINING EQUIPMENT FOR CONELRAD BROADCAST STATIONS *

CONELRAD broadcast station equipment (e.g., CONELRAD crystals, emergency power generators, alternate CONELRAD transmitters) can be obtained through the Federal Contributions Program (whereby the Federal Government pays half of the cost). From time to time such equipment also may be available through the Surplus Property Program.

The following is a brief description of the procedures to follow in each of the two methods of obtaining the equipment. Additional details on acquiring civil defense equipment through the Federal Contributions Program may be found in the OCDM Federal Contributions Manual, M 25-1. Additional information on acquiring civil defense equipment through the Surplus Property Program may be found in the OCDM Surplus Property Manual, M 6-2.

A. Federal Contributions Method:
   1. Make sure the desired equipment is not available through the Surplus Property Program (see section B, 1, below). Equipment will not be approved for procurement on a matching-fund basis if it is available as surplus property.
   2. To get the equipment through the Federal Contributions Program, a CONELRAD broadcast station manager should provide his local civil defense director with the following information:
      (a) OCDM equipment item number. (Get this from the lists of civil defense equipment in Annex 9-B, Chapter 9, Federal Contributions Manual, M 25-1.)
      (b) Description of items.
      (c) Number of units and cost.
      (d) Conversion and installation costs. (In addition to the cost of the equipment, the Federal Government will pay half the cost of converting and installing CONELRAD crystals, and modifying transmitter, control, and antenna circuits.)
      (e) Total estimated cost.
   3. The local civil defense director should prepare the necessary OCDM project application forms, and submit them through the State civil defense office to the OCDM Regional Office. (The project application should be made out in the name of the local civil defense organization.)
   4. When the equipment is received, the State civil defense office may hold title to it or transfer the title to the local civil defense organization. Title may not be transferred to an individual, company or private organization (even though the CONELRAD broadcast station pays half the cost of the equipment). However, transfer of possession of the equipment to private concerns is permitted if such transfer is on custody receipts.

B. Surplus Property Method:
   1. To find out whether the CONELRAD equipment needed is available from surplus property, the broadcast station manager should contact his local civil defense director, whether Federal surplus property of the type requested is available.
   2. If the equipment is available, the State civil defense director makes a request for it through the State Agency for Federal Surplus Property.
   3. The State Agency for Federal Surplus Property makes out a warehouse issue sheet transferring the property title to the State civil defense organization. This warehouse issue sheet shows the following information:
      (a) Name and address of donee.
      (b) Quantity.
      (c) Description.
      (d) Original acquisition cost to the Government.
      (e) Handling charges (freight and warehouse costs).

* From information provided by the Office of Civil and Defense Mobilization.

4. Local handling and transportation charges must be paid by the recipient of the property.
5. When the equipment is received, the State civil defense office may hold title to it or transfer the title to the local civil defense organization. Title may not be transferred to an individual, company, or private organization. However, transfer of possession of the equipment to private concerns is permitted if such transfer is on custody receipts.
6. When surplus property is in such condition that it requires rehabilitation to meet a civil defense need, the costs are approvable under the Federal Contributions Program. However, these costs shall not exceed 50 per cent of the original acquisition cost as stated on the warehouse issue sheet or transfer document. (*Exception:* The Federal Government will not pay rehabilitation costs on equipment that had an original unit acquisition cost of less than $2,500.)

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1. Terman, F. E.: "Electronic and Radio Engineering," McGraw-Hill Book Company, Inc., New York, 1955.
2. "Automatic Alarm Receivers for Use in CONELRAD," Federal Communications Commission, Office of the Chief Engineer, No. 4519.
3. "Antennas for Reception of Standard Broadcast Signals," *FCC Publ. 19458.*
4. NAB Engineering Department: "CONELRAD Simplified."
5. "Emergency Control of Electromagnetic Radiation Concerning AM, FM and TV Broadcast Stations," Federal Communications Commission, Office of the Chief Engineer, No. 56999.
6. Keen, R.: "Wireless Direction Finding."
7. Walker, A. Prose: "CONELRAD—Practical Operating Considerations," *Tele-Tech and Electronic Industries*, June, 1954.

In addition to the above publications, considerable information was obtained from the U.S. Supervisor, CONELRAD, FCC, Kenneth W. Miller, and from Ernest C. Thelemann, Robert D. Linx, and David O. Cooper on the CONELRAD staff of the FCC. Appreciation for their assistance is hereby acknowledged.

Part 8

LIGHTNING PROTECTION FOR BROADCAST STATIONS

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Introduction

The sudden discharge of a large quantity of potential energy through the antenna system of a standard broadcast facility frequently produces considerable equipment damage and service interruption. It is for this reason that most broadcast engineers approach the seasons of intense electrical-storm activity with apprehension. This is an effort to present some practical ways that the broadcast engineer can arrange his equipment so that a minimum of equipment damage and service interruption will occur under such conditions.

The most commonly observed form of electrical discharge in nature is lightning. This type of discharge may contain potential energy of considerable magnitude. Many lightning strokes are repetitive in nature even though only one stroke appears to the eye. The duration of each stroke is generally a few microseconds. It is for this reason that the energy in a stroke of lightning has such destructive power. The amount of power involved can thus reach astronomical values involving large values of voltage and current. In view of this condition, all circuits where lightning is anticipated should have high insulation and current-carrying ratings.

The free-space charge generated in cloud formations will in turn induce an opposite charge in the earth below. For this reason the ground system associated with the antenna should have as much metallic surface in contact with the earth as practically possible in order to form a low-impedance path to redistribute the charge in the earth when the air space between earth and cloud breaks down. It is commonly believed that the lightning stroke begins in the clouds. However, it is not uncommon for the breakdown (ionization) of the air to start at the earth. High-speed motion pictures have been made to prove this point.

In addition to the lightning discharges, considerable trouble can develop from static generated in the antenna system. The discharge of static to ground often is accompanied by an RF power "follow-up" which will in some cases cause transmitter overloading, resulting in interruption. In some points in the circuit continuous arcing will follow static discharge and continue until a burnout failure occurs. If the static formed is kept continually drained off or discharged, the arcing may be avoided. The static may be generated in any metallic part of the antenna system. The highest rate of generation occurs during the blowing of cool, moist wind from an approaching rainstorm. The wind is charged and, owing to physical contact

* Supplemented by material from Continental Electronics Manufacturing Co.

with the tower and guys, generates a static charge therein. This charge builds up on insulated parts until a sufficiently high voltage is developed to rupture the air insulation at some point. This effect is most dramatically demonstrated by the flashover of guy-wire insulators.

It is the intention of the author to present here practical means for combating the damaging effects of electrical charges generated in nature and not to present the physical processes in nature by which such charges are generated. Should the reader be interested in this physical process, his attention is directed to an excellent paper The Electrification of Precipitation and Thunderstorms, *Proc. IRE*, vol. 45, pp. 1331–1357, October, 1957, by Ross Gunn.

Lightning Protection

For the sake of clarity it is thought that the practical aspects of the subject might be best presented by a description of a simple antenna system to which optimum protection features from electrical discharge have been incorporated. Such an antenna system is described below by presenting the salient items required.

Towers

Install a 6-ft whip of stainless steel (regular mobile antenna rod) on the top plate of the tower adjacent to the beacon light base. This whip protects the lamp from damage and also tends to ionize the air and provide a discharge of the air and cloud formations before the charge potential reaches a large magnitude. This will also discourage direct strikes to the lighting circuits.

Discharge gaps are generally supplied with the towers at installation. These gaps are in many forms, and no information is generally provided as a guide in setting the gap spacing. In order to make the gaps most useful, they should be set at the minimum usable spacing. The most practical method to set the spacing is to modulate the transmitter with a piece of the "wildest" music to be used until 100 per cent modulation on negative peaks is obtained. With this operating condition, reduce the gap spacing (do not take any chances of physical harm—use a special insulated tool) until arcing begins to occur. With the transmitter off, open the gap spacing an additional ⅛ in. and test again for arcing.

Guy Wires

Each tower guy should have at least three close-coupled insulators in series at the end where the guy is fastened to the tower, and the guy anchors should be electrically connected to the ground system. This will tend to make static discharge and direct strokes to the guys go to ground through the anchor end rather than to the tower. Insulator flashover from static build-up can be avoided by using insulators having some finite resistance to act as a leakage path. This applies to all insulators except those adjacent to the tower. This last item is not normally used owing to difficulty in procuring the special "lossy" insulators. In this manner, the gap may be set for minimum spacing. One of the problems with gaps is that when they are set to minimum spacing, freezing rain and snow will frequently cause the gap to discharge. It is well to remember that the larger the curvature of the gap surface, the smaller will be the spacing of the gap. For this reason, gaps made of large balls are not satisfactory for this type of setting. If it is necessary to use such gaps, then a protective weather covering should be placed above them. Horn-type gaps formed from ½- to ¾-in. copper tubing have been found to be very satisfactory. This type of gap will make a sustained arc rise until its length is such that it will not be self-sustaining. Figure 8-1 is a drawing of a typical horn gap. The use of a horn gap at both ends of the RF transmission line from tower

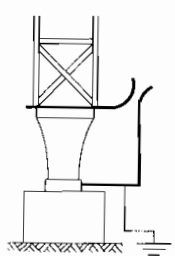

FIG. 8-1. Horn-gap installation.

to transmitter is desirable as backup protection. These gaps may be made of heavy wire and small in size. The method of setting is the same.

Most of the damage caused by lightning occurs in the tuning unit located at the base of the tower. The main reason for this is that most of the poorly insulated points in the system occur within this unit.

Meter Protection

Antenna ammeter switches of the shorting type should never be used if full ammeter protection is desired. Strange to say, this is the most commonly used type. The proper type of switch should be a "make-before-break" type, which completely disconnects both sides of the meter. This switch should be well insulated with porcelain- or glass-bonded type of insulation. Laminated phenolic insulation is not

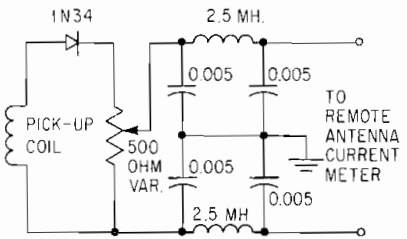

FIG. 8-2. Remote meter-protection circuit.

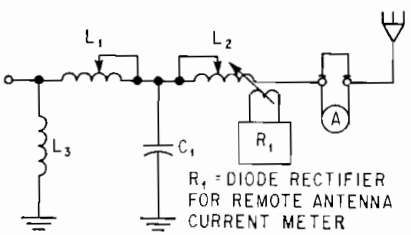

FIG. 8-3. Proper placement of pickup coil for remote antenna current meter.

satisfactory for use anywhere within this unit because of its affinity for moisture between layers. Many such failures of this material have been observed. The humidity in the tuning units is high at times. All meters should be mounted on a piece of appropriate insulation.

Another weak spot is the coupling unit for the remote-reading antenna current meter. The conventional thermocouple with its coupling transformer is the device most often damaged. This is because of the small air spacings used between primary and secondary. The secondary should contain more turns and have much higher spacing from the primary loop. All sharp corners and edges should be avoided. This problem can be alleviated by use of a small diode unit similar to that shown by Fig. 8-2. The pickup coil can be lightly coupled to the antenna input coil (L_2) as shown by Fig. 8-3. The use of this system has the great advantage of high-level isolation from the antenna circuit and is thus largely immune from lightning. Units of this type are available from the Rust Industrial Co. at a reasonable price with an appropriate meter supplied. A remote meter having a 200-μa movement with appropriate scale will be satisfactory for use with this circuit. This unit will read average current values and therefore will not follow the modulation as does the thermocouple. This is an advantage for reading during modulation of the transmitter.

The current rating of capacitor C_1 as shown by Fig. 8-3 should not be less than 20 kv. This will make the condenser rather large and expensive for low-power installations. However, the durability will repay this cost.

The static drain choke L_3 in Fig. 8-3 should be placed as shown. Most current installations will have this coil connected between antenna and ground. This placement next to the antenna has some disadvantages in that any change in the coil will affect the antenna impedance. Also on towers having impedance values in excess of 50 ohms the RF voltage across the choke will be higher with probable higher losses. In the proposed position, coils L_1 and L_2 will act as surge suppressors for the coil L_3 in case of a lightning surge and will drive the surge onto the tower base gaps instead of wrecking the choke L_3. Where it is necessary to use a series capacitor,

the position of L_3 should then be between the series capacitor and the antenna but never ahead of the antenna ammeter. In some cases a third winding on the lighting choke can be used as static drain, but this often produces higher than desirable antenna loading.

The use of a one- or two-turn coil in the connection between the antenna tower and the coupling unit is of dubious value. It has the disadvantage of the coil becoming deformed and changing the equivalent antenna impedance from the value originally measured. In some cases the input inductance value is very critical.

Grounding

A 4-in.-wide ground strap or its equivalent should be used to bond the coupling-unit housing to the common point of the ground radial system. It is desirable to provide the equivalent of a 4-in. strap to connect the common point of the ground radial system to the ground of transmitter building. This strap should form the ground bus to which all equipment is connected, including the power system neutral. Where it is possible to do so, the ground bus should be bonded carefully to the cold-water line leading to the building. This is often a better ground than the ground radial system. Do not permit the use of plastic pipe between the water main and the building. Single driven copper rods are nearly worthless!

Tower-light Protection

The use of an Austin-type lighting transformer in place of a conventional-type lighting choke is desirable to provide protective isolation of the lighting circuit. It also has the great advantage of less antenna loading than the choke, and it cushions the starting surge to beacon lamps. This surge cushioning will tend to increase lamp life and will also keep the modulation of power-line voltage to a minimum.

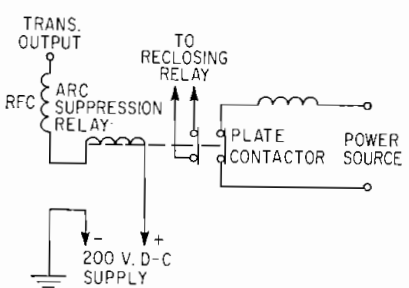

FIG. 8-4. Arc-suppression circuit.

Arc Suppression

Where power follow-up of a lightning surge will cause the transmitter to unload but continue arcing, an arc-suppression circuit can be used. Figure 8-4 shows the schematic diagram of a typical arc-suppression circuit. This circuit works on the principle of using the power arc to conduct the direct current through the arc to the arc-suppression relay, which in turn will open the plate contactor on the transmitter, thus interrupting the power arc. Following this operation a delayed-action relay can be used as recloser to reclose the plate contactor and thus restore the transmitter to normal operation.

"MAGNIPHASE" PROTECTION SYSTEM

Introduction

The Continental Electronics type 19876-B Magniphase line protection unit is an all-electronic device used to protect the radio-frequency transmission lines, antennas, and antenna tuning equipment from damage due to line faults or to arcs and overloads at any of these points. An arc-over is usually caused by a lightning discharge, which in itself may do little damage. The major damage occurs if the transmitter is allowed to remain on and to supply sustaining energy to this arc. This energy may be a

small percentage of the total output of the transmitter, and damage may therefore be done before it is detected by overload devices in the transmitter.

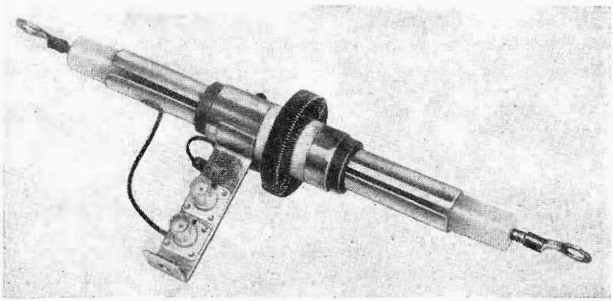

FIG. 8-5. Line coupler, 10 kw maximum.

The Magniphase system will detect an arc at any point in the antenna system and will convey this information to the transmitter and squelch the transmitter output in a matter of microseconds. It can be adjusted over a wide range of sensitivity to suit operating conditions and can be used over a wide range of frequency, transmission-line impedance, and transmitter power output.

The system consists of two units:

1. A line coupler, which is inserted in the transmission line at the transmitter output.
2. A bridge unit, which can be located on the transmitter front panel or at any other location near the transmitter.

The units are interconnected by two coaxial cables of the required length.

The Magniphase system is designed for use with any transmitter operating in the standard broadcast band, with output power of 5 to 50 kw, and into impedances from 50 to 250 ohms. Two coupler types are available which are basically the same, except for power-handling capacity. One is for use with power levels of up to 10 kw, and the other for 50 kw.

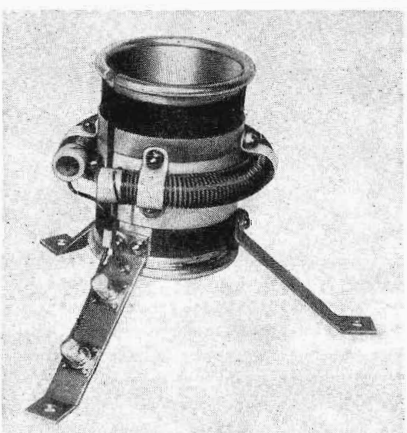

FIG. 8-6. Line coupler, 50 kw maximum.

In cases where power-cutback operation or directional-antenna systems are employed, combinations of several couplers may be desirable in order to obtain increased protection and sensitivity.

General Description

The Magniphase line-protection system is expressly designed to detect an impedance change in the load seen by the transmitter. The most usual disturbance in an antenna system is an arc-over caused by a nearby lightning discharge. Such an arc-over will cause an impedance change which is sensed by the Magniphase unit as an unbalanced condition at the bridge input, thereby cutting off the transmitter for a period of about 60 msec. The transmitter will then be reenergized, but if the arc

still exists, it will drop off again. The arc should burn itself out very rapidly without sustaining RF energy.

The line coupler unit is both capacitive and inductive in nature and can therefore sample both voltage and current. The two RF samples from the coupler are fed to a balanced bridge circuit which, with the remaining Magniphase circuitry, is mounted in a self-contained subchassis on the transmitter front panel. The two RF samples can be balanced from the unit front panel so that no direct current will flow in the bridge output circuit unless there is a change in one or both of the samples. In this manner, the bridge is sensitive either to a change in voltage and current magnitude or to a change in phase. An arc or other disturbance at any point in the system will cause either or both of the above changes to occur.

FIG. 8-7. Balanced bridge unit.

The bridge output network is connected to a thyratron which can be set to operate at any desired sensitivity. The thyratron plate circuit is usually connected directly to the transmitter RF buffer amplifier grid, so that as the thyratron fires, a high negative bias is applied to the buffer grid and is held on the grid by a relay for about 60 msec. When the relay releases, the bias is removed and the thyratron is ready to fire again if a fault is still present on the line. The bias is applied independently of the relay, which is necessary for the fast action required in this application.

Because of the fast action of the thyratron, cutoff bias is applied to the buffer amplifier in a matter of microseconds. (If biasing off a low-level stage is found to be impractical in some transmitters, auxiliary relay contacts are provided which can be used to remove excitation by other means. This involves an additional delay of only a few milliseconds, which is not objectionable in the majority of cases.)

In addition to the sensitivity control, there are two balancing controls and a "disable" switch on the front panel. The balancing controls are used for nulling an external meter during initial bridge balance. The disable switch prevents the transmitter from being cut off while the bridge balance or the sensitivity is adjusted.

Two BNC jacks are mounted on the bridge chassis for connection to the coupler. A terminal strip on the side is provided for connecting the meter, 117-volt a-c power, bias cable, and other auxiliary connections. A normally lighted neon lamp is mounted on the unit front panel. In case of a fault, the lamp will flash at a rapid rate until the fault clears or until the transmitter is manually cut off.

Circuit Description

The Magniphase line coupler unit consists of a capacitor and a toroid inductor which sample transmission-line voltage and current, respectively. These two RF samples are fed via coaxial cables to the bridge unit. At the bridge input circuit, the voltage sample is connected to a capacitive divider, and the current sample connects through a phase-shift network. A 6AL5 tube, V1, is used as a bridge rectifier, connected so that no current will flow when the bridge is balanced. A change in phase or voltage and current magnitude will then cause a bridge unbalance. When the tube is properly connected and balanced, the voltages measured on either side of V1, from pin 1 or pin 2 to ground, should be approximately equal as measured with a vacuum-tube voltmeter. The external null meter should produce minimum indication under these conditions.

A bridge unbalance causes a voltage difference across grid resistor *R*4 of the 2D21 thyratron V2. The voltage necessary to fire the thyratron depends on the tube bias,

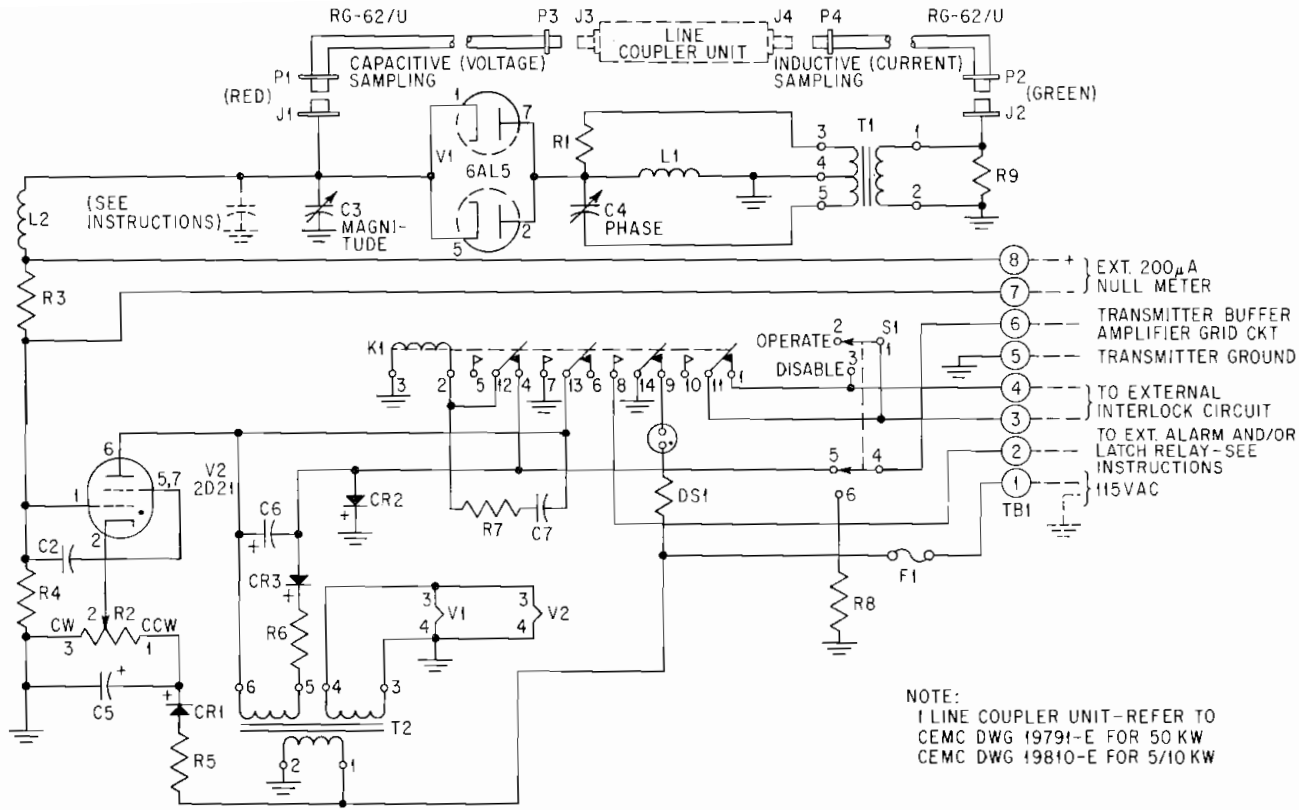

FIG. 8-8. Schematic, line-protection unit.

which is adjusted by sensitivity control *R*2. The point at which this control should be set is dictated by the conditions of operation.

Upon bridge unbalance, the thyratron will fire and will produce a voltage of approximately 100 volts negative at the Magniphase output. This voltage appears at terminal *TB*1-6 and can be connected via a shielded wire to the grid circuit of a low-level stage in the radio transmitter. This stage is usually the buffer amplifier following the crystal oscillator, and the grid bias developed is sufficient to remove transmitter excitation immediately.

In order to provide for instantaneous transmitter cutoff action, the negative bias is applied independently of the action of relay *K*1. The relay is then energized, shorting the thyratron and holding the bias present for about 600 msec. Upon relay release the transmitter excitation is restored, thereby resetting the sequence of operation. Should an unbalance still exist, the transmitter excitation will again be interrupted until the trouble is cleared.

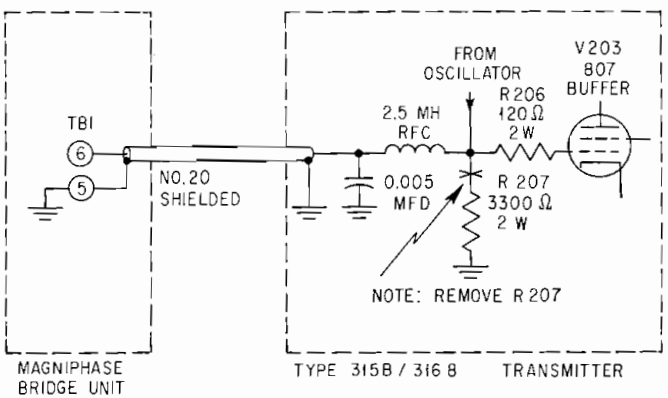

FIG. 8-9. Bias cutoff circuit, 315B/316B transmitter.

During normal operation, the coil of relay *K*1 serves as a grid resistor for the transmitter buffer amplifier stage. For test and balance procedures, OPERATE-DISABLE switch S1 is placed in the DISABLE position, thereby connecting grid load resistor *R*8 in place of the relay coil. Magniphase testing can then proceed without disturbing transmitter operation.

The connections and mode of operation described in the preceding paragraphs are applicable to Continental Electronics transmitters employing low-level Regulinear screen modulation and to other transmitters utilizing linear final amplifiers. In some transmitters, notably those using high-level plate modulation, it may be found that transmitter cutoff by instantaneous interruption of excitation is unsatisfactory. This is so because of the possibility of continuing modulation after the modulation transformer load has been removed. To prevent this occurrence and to prevent possible damage to the modulation components, an external relay circuit should be installed to interrupt the transmitter audio input before excitation is removed. Additional contacts are provided on relay *K*1 and are available at the Magniphase unit terminal strip for this purpose. A typical circuit for this connection is shown in the drawings section.

Special-purpose Arrangements

The operation of the Magniphase system in the event of an arc is quite rapid, and the resulting interruption is likely to go unnoticed by the transmitter operator. Since the frequency of operation of the protective system is an indication of antenna-system stability, it may be desirable to install a warning alarm system.

The Magniphase bridge unit has a spare relay contact appearing at unit terminal

*TB*1-2 which is available to actuate such an alarm. From this terminal, a simple bell or chime can be connected to sound at each operation of the unit. Alternately, a latching relay can be utilized to give a continuous alarm on unit operation until manually reset.

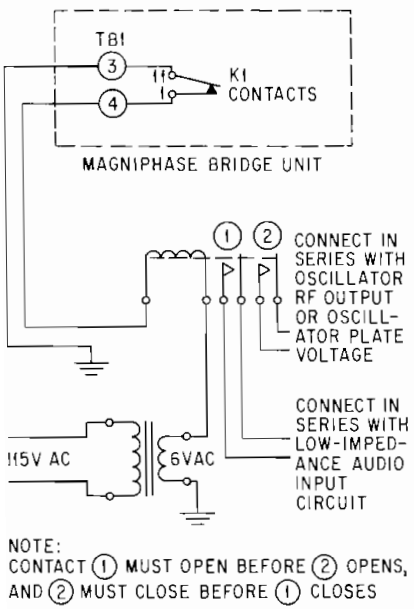

Fig. 8-10. Relay cutoff circuit.

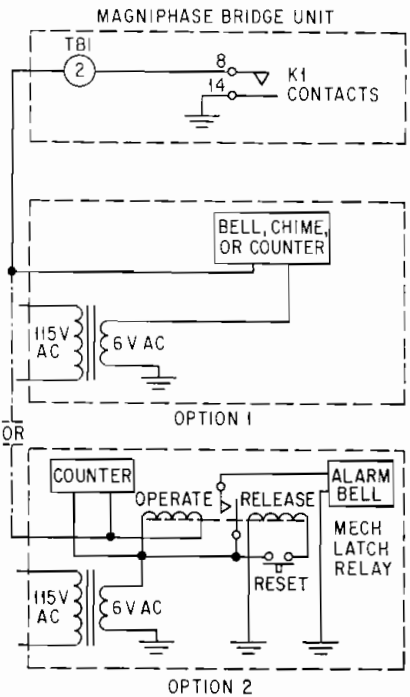

Fig. 8-11. External alarm and counter circuit.

A further variation of interest is the inclusion of an electrically operated counter to register the number of interruptions experienced within a given period. Typical circuits for these arrangements are shown in Fig. 8-11.

Magniphase Specifications

1. Frequency range: 0.54 to 1.6 Mc
2. Transmission-line impedance: 50 to 250 ohms, unbalanced
3. Transmission-line coupler: available in 5–10-kw and 50-kw models
4. Outputs:
   a. Instantaneous bias cutoff output for transmitter squelching
   b. Relay-contact cutoff circuit for externally operated transmitter cutoff
   c. Relay-contact output for operation of external alarm
5. Meter: externally mounted to indicate null at bridge balance
6. Tube complement: 6AL5, 2D21
7. Power input: 115 volts ±10 per cent, 60 cycles, 25 watts
8. Size:
   a. Bridge unit: front-panel size, 2½ by 9½ in.; projection behind panel, 5½ in.
   b. Line coupler: 5/10 kw, 2 in. diameter by 11½ in. long; 50 kw, 5 in. diameter by 6½ in. high
9. Shipping weight per system: 10 lb, approximate

Part 9

MAINTENANCE OF TELEVISION AND RADIO EQUIPMENT[1]

NAB Engineering Department

PREVENTIVE VS. CASUAL MAINTENANCE

Many television broadcasters have come into the field from AM-FM broadcasting bringing with them the same theories of operations which they followed in aural broadcasting. In a large number of areas, this thinking serves admirably—certain techniques are similar or, at most, require only such changes as come from adding sight to sound. There are fields, however, where the change experienced in transferring from audio to video seems to present much greater problems. One of these is maintenance. A study made by NAB in the early part of 1952 revealed that, of the 108 television stations then operating, a typical medium-sized station employed 61 people. Twenty-two of these were in the engineering department, and of the 22, 2 were full-time maintenance engineers. That is, two men were scheduled full time to check equipment in an attempt to prevent equipment failures. Hereafter, when the term "preventive maintenance" is used, it is this type of operation we mean. "Casual maintenance" is considered to be only routine checks or repairs made after equipment failures. The television broadcaster may wonder at first why a regular preventive-maintenance schedule should be necessary for television when he has been getting along very well with casual maintenance in aural broadcasting. The answer lies partly in the far more complex equipment needed for television and partly in the higher expense and income associated with television.

As an illustration of the latter reason, the failure of a single relay or contact in a switching system could result in the loss of a commercial spot announcement. Going back to the typical medium-sized station mentioned above, this means a loss in the neighborhood of $200, this loss being a little more than the amount needed to pay the maintenance man's salary for a week according to the same NAB survey mentioned above.

In all fairness to those broadcasters who firmly believe casual maintenance is enough in the television station, it must be pointed out that some highly successful operations have no maintenance engineers as such. An examination of their methods will reveal, however, that transmitter and studio technicians spend a certain amount of their time checking equipment not in use while the station is on the network or in other ways fitting some maintenance into their daily working schedules. Furthermore, these technicians will be found to be highly experienced men who are familiar with the circuitry of the equipment and excellent "troubleshooters." It will thus be seen that while no formal preventive-maintenance schedule is in force in the station, a

[1] Although this material was written with the stress on television equipment, practically all the information, where applicable to radio equipment, is equally valid for radio stations.

larger percentage of the working day is being spent in maintenance in the television station than is usually spent in maintenance in an FM or AM station. It remains a problem requiring a decision to be made by each broadcaster as to whether he will hire maintenance men who can keep the equipment in good operating condition and be able to use less experienced men at the transmitter and studio or he will hire technicians who have the experience, knowledge, and "feel" for maintenance and who can get the station back on the air quickly in the event of equipment failure. It may be mentioned, too, that his decision may have to be based on union classification.

In this part, a suggested preventive-maintenance schedule is shown and a few suggestions of a general nature are listed in the hope it may provide the prospective broadcaster with a beginning to which he can add such procedures as are pertinent to his particular type of equipment. Each piece of television equipment will have its own individual characteristics, and specific operating procedures for each equipment item are furnished by the manufacturer. It is suggested that a collection of all the instruction books for the equipment in the new station be gathered together, and from this collection, specific details can be drawn to supplement the general material which follows.

The object of any maintenance program, whether it be preventive or casual maintenance, is to keep the equipment operating at optimum—to satisfy the regulations set forth by the FCC—and to keep operating costs down. Although the most careful and thoughtful maintenance program cannot always prevent occasional equipment failures, the symptoms of impending failure can often be observed during the day's operation, and a well-defined system of reporting to the regular maintenance crew should be developed. At the transmitter, the log is the logical place. If it is a chart-recorded log, so much the better. At the studio, the workshop should have a regular place to put notices of equipment troubles. After the maintenance man checks the item noted as being faulty, he makes such adjustments or repairs as are necessary and initials the notice with the notation "adjusted," "tube changed," or whatever work was done. The sheets or logs are kept on file after completion of the work, and over a period of time they provide a good source of study for the idiosyncrasies of each equipment item. From a collection of this nature, conclusions can be drawn as to what type of trouble to expect from each piece of equipment, and in many cases equipment failures can be foreseen and corrected in advance of failure.

In the following pages, a general outline of preventive maintenance is given. Complete details applicable to all kinds and makes of equipment naturally cannot be given, nor is it the purpose of this part to replace the specific instructions given by the manufacturer for the care and maintenance of each equipment item. The purpose of the discussion is rather to supplement these specific instructions by a few notes and suggestions made by station operators as a means of gathering together in one place the beginning of a maintenance manual. The value of such a manual to each station depends entirely on supplementation by recommendations drawn from (1) the manufacturers' instruction manuals and (2) the experience of the chief engineer and his staff as the station develops.

STUDIO PREVENTIVE-MAINTENANCE SCHEDULE

Daily

Dust.

Check for signs of overheating on all equipment.

Check pickup equipment for abnormal conditions such as position of control knobs and poor picture quality which may not have been reported.[2]

Check cameras for geometric distortion, alignment, and resolution.

The scanning system of the film photographic sound track must be checked. The alignment of the exciter lamp filament with the optical assembly should be checked.

[2] During camera setups, need for unusual control settings should be observed by the operator and reported.

Optical assemblies and any apertures in the light path should be cleaned. Dust can be removed by blowing air across the lens faces with a syringe bulb and wiping with lens tissue. Photocells should be examined for oil on the glass.

Projection leuses should be wiped with lens tissue. Coated lenses should be cleaned very carefully in accordance with the manufacturer's instructions.

Check the need for unusual control-knob settings on the synchronizing generator.

Clean film projectors in accordance with manufacturers' instructions, checking especially for accumulations of dust, lint, and emulsion on gate, pressure shoe rollers, teeth, picture aperture, etc.

Visually check the microphone and other cables for serious abrasions from pinching, kinks, etc., which may lead to broken wires internally.

Weekly

Thorough internal and external cleaning of cameras, camera controls, monitors, and power supplies. Check insulation on lead wires to power lines and replace lines if necessary.

NOTE: On delivery or after a major repair job or change in equipment, a thorough inspection should be made of all connections, checking for rosin joints and poorly soldered connections by firmly pulling on wires and leads. Connections incapable of passing the required electrical current can be corrected before equipment failures.

Check and record cable socket voltages on cameras.

Run test checks on cameras and projectors using test charts, slides, or films such as those recommended by EIA or SMPTE.

Check the amplitude and pulse widths of the synchronizing generator.[3] Aging of tubes may cause some small variations which can be overcome by adjustment.

Oil film projectors.

Check and clean fader controls on both audio and video equipment.

Check microphones for proper output. *Warning:* Do not use an ohmmeter or other circuit checker, since they may damage the ribbon or diaphragm.

Check the air filter on the power supply, and clean or replace if it is clogged.

Lubricate the wheels and moving parts of camera dollies and booms, microphone booms, pulleys for studio lights, and mechanical parts of studio cameras (pan and tilt and optical focusing mechanisms, etc.).

Monthly

Record and compare cable socket voltages on all equipment. Check adjustment of all control knobs, and readjust where necessary.

Check tubes on all equipment, using a good mutual-conductance tube tester. Generally, tubes should be replaced in the same sockets from which they were removed. Tubes with weak emission should be replaced with spares known to be good. After tube checks, equipment should be operated and tests run to ensure that no unusual conditions have resulted from tube removals and replacements.[4]

Check and clean relays and switch contacts in all equipment. Some relays in more recent systems are protected sufficiently from dust and dirt and may not need such frequent inspection.

Low-level audio tubes and audio amplifiers with "plug-in" chassis should be moved in and out a few times to renew the contact between fins and sockets.

NOTE: Voltage and waveform charts for each type of equipment will be furnished by the manufacturer and should be regarded as standards by which to compare test checks.

[3] Some manufacturers recommend that this be done daily.

[4] An interesting discussion of tube testing in regard to spotting early failures is contained in *Electronics*, vol. 32, no. 30, July 24, 1959.

After 1,000 Hours

Blowers should be cleaned and oiled in accordance with instructions furnished by manufacturer.

FIELD PICKUP (REMOTE) PREVENTIVE-MAINTENANCE SCHEDULE

(This is also applicable to STL)

NOTE: These daily, weekly, and monthly schedules will naturally be revised in accordance with usage given equipment.

Daily

Check the switching system for abnormal conditions such as poor picture output when compared with input.

Check cameras for geometric distortion, alignment, and resolution.

Check pickup equipment for abnormal conditions (see Studio Preventive-maintenance Schedule).

Check all equipment for overheating.

Dust.

Weekly

Clean cameras and power supplies internally and externally (see notes on Studio Preventive-maintenance Schedule).

Check and readjust controls.

Inspect and tighten cable connectors and clamps.

Check amplitude and pulse widths of synchronizing generator. (Some manufacturers recommend that this be done daily.)

Lubricate moving parts of cameras (see Studio Preventive-maintenance Schedule).

Check and clean fader controls on both audio and video equipment.

Visually check weatherproofing of cables, connectors, and other parts of equipment subjected to weather.

Check batteries on audio equipment.

Monthly

Check tubes on all equipment (see Studio Preventive-maintenance Schedule).

Record and compare cable socket voltages.

Check the air filter on the power supply, and clean or replace if it is clogged.

Check and clean relays and switch contacts in all equipment (see Studio Preventive-maintenance Schedule).

After 1,000 Hours

Blowers should be cleaned and oiled in accordance with instructions furnished by the manufacturer.

If a field-power generating system is used, the internal-combustion engine and the generator should be given equal weekly and monthly attention. See manufacturer's instructions on this.

TRANSMITTER PREVENTIVE-MAINTENANCE SCHEDULE

Daily

Check the filament line voltages every hour, and adjust if required. FCC Rules governing transmitter logs require that the operating constants of the last radio stage of the aural transmitter (total plate current and plate voltage), transmission-line meter readings for both transmitters, and frequency monitor readings be observed and recorded half hourly.

Check visual and aural monitoring circuits, observing both voltage and current meters. Changing current or voltage indicates either deteriorating tubes or equipment. If the operator observes any rapid changes, a sufficient note should be left with the log as instructions for the maintenance crew.

Dust and generally inspect for overheating or other signs of abnormal operation.

Weekly

Check all tubes which are not metered in the transmitter.

Clean the internal parts of the transmitter (insulators, etc.). Check of noise, distortion, and frequency characteristics of aural transmitter generally. Check the visual frequency and broadband characteristics of the visual transmitter generally.

(On the last two mentioned checks, spot checks will ordinarily suffice on a weekly basis. However, in this case, a more thorough check should be made monthly.)

Inspect blowers and flow meters. Clean and/or lubricate if required.

Test door interlocks and disconnect switches, being certain that they result in interruption of high voltage when access doors and windows are opened.

Check and operate all relay contacts. Observe closely for heating.

Check transmission lines for tightness by observing gas or air pressure.

Add distilled water to cooler unit if required.

Correct all meter needles to normal nonenergized readings.

Monthly

Inspect and lubricate small blower motors.

Test spare tubes.

Clean socket contacts if necessary.

Service relay contacts if necessary.

Check air filters, and clean or replace as necessary.

Visually check the condition of the water in the cooling system.

Quarterly

Operate all spare mercury-vapor tubes for 30 min. (See instructions furnished by the manufacturer.)

Inspect every unit in transmitter in detail, using tests recommended by the manufacturer.

Service all power contactors if necessary after inspection. Flush and refill the water-cooling system.

Make a visual inspection of the physical condition of the antenna tower and transmission line.

Inspect and test tower-lighting equipment according to Part 17 of FCC Rules.

Semiannually

Tighten all connections, both electrical and mechanical, in the transmitter and associated equipment.

Lubricate exhaust fans.

Lubricate high-pressure blowers, and check the operation of the air interlocks.

Lubricate the water-cooling system.

Check the outdoor protection to the water-cooler intake before cold weather and for free circulation before summer.

SAFETY

Every possible means of affording maximum protection to personnel working in the television station should be considered. Television equipment has been designed to operate safely as long as reasonable care and judgment are exercised, but it cannot be too strongly impressed on every person coming into contact with the equipment that the safety rules for handling each item must be observed, since the

high voltage of certain components is sufficient to endanger life. Some general safety precautions are given below, and more will probably suggest themselves to the station operator and can be added.

1. Inspect safety interlocks regularly for proper functioning. Check leads and connections to grounding hooks.
2. Check ground connections for tightness.
3. Check insulation on all leads regularly. Never use leads with broken insulation.
4. All high-voltage capacitors should be discharged before they are touched by the operator. Although "bleeder" resistors do discharge capacitors after a reasonable time, in consideration of the voltages used, it will still be safer to discharge the capacitor with a shorting bar. Due precaution must be observed in the removal of the shorting bar.
5. Rubber gloves should be worn when working on high-voltage equipment, and a rubber sheet should be placed over the sill of the transmitter compartment or over any place where it is possible for the employee to come into contact with live equipment.
6. Before repairs are made on high-voltage areas of equipment, instruction books and schematics should be closely studied so that the maintenance man is thoroughly acquainted with the equipment before starting work. It may also be pointed out here that *high voltage sometimes appears at unexpected points in defective equipment.*
7. Ground leads of oscillographs should not be connected to a high-voltage point, since the ground lead of most instruments is connected internally to the case.
8. When high voltages are measured, consideration should be given to both a-c and d-c voltages present, and peak voltages should be taken into account when selecting voltmeters and multipliers.
9. Rubber gloves and blankets will not afford protection against high radio-frequency voltages. When work is done on circuits carrying high RF voltages, the circuit should be inoperative before work is begun.
10. Extreme care must be used when touching tubes that have been in operation for a considerable length of time, since serious burns can result. This is true even of small tubes.
11. Pressure developed on the envelope of large vacuum tubes is extremely high, and when the tube envelope is broken, it must be remembered that the tube will implode—not explode. This means that there is a possibility of the tube base being projected through another portion of the tube. For this reason, tubes should be kept in cartons until time for their actual use. Safety goggles and gloves should be worn when handling large vacuum tubes. Spectators should be kept at a safe distance whenever a tube is outside its carton.

A means of disposition of these tubes must be found, bearing the above hazards in mind, to prevent the scattering of shattered glass and the possibility of the tube elements and base flying free. One suggestion is that the tube should be placed in a shipping container, the container sealed, and a crowbar or similar instrument driven through its top. Another suggestion is that the tube should be placed in a shipping container, leaving the neck or gun end of the tube exposed. A tarpaulin or burlap bag is thrown over the neck to deflect any glass, and the neck is struck sharply with a hammer.

12. It is not generally known that carbon tetrachloride is a strong toxic chemical and that continued breathing of the fumes is cumulative and can become injurious to health. Its use as an open cleaning agent is not recommended. The Navy has discontinued its use for projector cleaning and recommends that alcohol be used wherever possible.

It must be remembered, however, that alcohol and naphtha are both inflammable, and proper precautions must be taken in using either.

GENERAL

In the following pages, some amplification of the preventive-maintenance schedules will be found. In some cases, it may seem that the emphasis has been shifted from

"preventive" to "casual" maintenance or from maintenance to operation principles. These are the areas where experience of presently operating stations has indicated a need for calling special attention of the technical staff of the new station.

Certain principles of maintenance are common to all types of equipment. For example, throughout this article, frequent mention is made of the removal of dust from equipment. This is extremely important because, among other things, excessive dust may lead to current leakage or arc-over between high-voltage points. Obviously, dust will do more damage to open equipment than to completely enclosed equipment, but daily efforts must be made to keep the collection of dust at a minimum on all equipment.[5] We are reminded of the story of a government agency which was said to have employed both "high dusters" and "low dusters," each having specified areas of work and each employing different tools and practices of dusting. The problem of dusting in the television station requires tools ranging from soft, lint-free cloths and absorbent pads to vacuum cleaners. A small hand-type vacuum which can be reversed and used as a blower may be a wise investment for the station. Various sizes of paint brushes will be helpful in removal of dust and lint from small equipment items. When cloths and brushes are used, they should be absolutely dry or moistened with a volatile liquid such as carbon tet, alcohol, naphtha, etc.[6]—never with oil.

All equipment tests should be made as soon as possible after the close of the day's programming or after the last use of the equipment item during the day. After tests or checks are completed, the equipment should be placed in operating condition to be sure that it is functioning properly. Before any tests are begun, instruction books and schematics should be closely studied and safety precautions observed. Inspection can be made by feel (for overheating), by smell (this often locates an overheated part such as a transformer or reactor), and visually inspection for loose, broken, warping, or cracked connections and broken parts, insulations, or wires.

Before dismantling any part of the equipment, be certain the correct input signals and voltages are being applied. (In other words, there is no use dismantling the engine of a car if it's just out of gas.) The correct input signals and voltages are supplied by the manufacturer as part of the operating instructions.

Be logical—check the obvious first. In the section relating to the synchronizing generator, it is pointed out that personnel should be briefed at least semiannually on the possible causes of failure. This same procedure may well be used with all other major equipment items in the station. Also, as mentioned above, instruction books, schematic drawings, and other technical data on the equipment should be readily available to all technical personnel.

The notes on tube checks found under Camera Chains apply to all tubes used in the television station as do the notes on regular cleaning and inspection of cable connectors and the measuring of cable socket voltages.

TESTS AND TEST EQUIPMENT

Many television stations initially going on the air have underestimated the need for appropriate test equipment only to find themselves later on faced with the need for purchasing more such equipment. In addition to the more common test equipment such as tube testers, volt-ohm meter, etc., normally associated with aural stations, television stations require one or more good oscilloscopes, video sweep generators, audio oscillators, noise and distortion meters, and a device for checking scanning linearity such as a grating or bar generator. Depending upon the complexity of the installation more or less equipment may be required. The FCC requires that certain standards with respect to the over-all attenuation characteristics of the visual transmitter must be maintained, and the aural transmitter and entire audio

[5] Many stations have installed electrostatic filters in the air-conditioning system to remove dust before it enters the building. Such filters are also installed in the blower system of air-cooled transmitting compartments and tubes.

[6] See Note 12 under Safety.

system must meet certain well-defined operational characteristics with respect to distortion and frequency response.

Film Projectors

Specific details for the operation and maintenance of each of the many types of film projectors will be furnished by the manufacturer. These instructions should be carefully read by every operator who handles the projector and kept handy for ready reference at all times. There are, however, a few general remarks that can be made on the subject of film projectors:

1. *Cleanliness.* The projector film path should be cleaned thoroughly daily, and accumulations of emulsion or other dirt removed with a toothbrush or flat, pointed toothpick and cloth moistened with carbon tetrachloride or alcohol, which must not leak into the mechanism. In cleaning lens surfaces, do not blow on the surface of the lens, as this may force vapor back into the lens mount. The lens tissue can be moistened with the breath or lens cleaning fluid.

2. *Oiling.* Always use the type of oil recommended by the manufacturer. Different weights of oils are recommended for different parts of the projector, and substitutions can cause trouble. Oil flows more freely and penetrates faster when the machine is hot. Be extremely careful not to overoil the projector, since the oil may leak onto the film. For the same reason, be careful not to spill oil about the projector.

3. *Handling lamps.* Before placing a new lamp in the projector, wipe off the lamp surface with a clean, lintless cloth. Fingerprints left on the surface of the lamp will bake into the glass and be difficult to remove later.

4. *Spares.* A complete set of tested spare lamps, tubes, fuses, belts, and other parts subject to wear should be kept on hand at all times. In replacing fuses, be sure that the new fuse does not have a higher power rating than the old one.

Following are some of the major "troubles" which occur in the film projector. It will be noted that many of these troubles arise from the presence of dirt, improper control settings, or tube failures—all of which can be anticipated to some extent by a sound preventive-maintenance schedule.

Loses film loops—tears sprocket holes: Feed the sprocket or film pressure shoe out of adjustment. Adjust as explained in manufacturer's instructions. Other possible causes are dirty or worn claws, claws out of adjustment, torn film, or bad splices. Daily cleaning will prevent accumulation of dirt and emulsion on claws, sprockets, and pressure shoes. Proper splicing and preediting will save time and trouble in the long run.

Noisy projector mechanism: Check the adjustment of claws, roller chain, drive chain, and gears. Adjust as recommended by the manufacturer.

Travel ghosts and picture jump: Check the projector synchronization of the shutter with the pull-down mechanism. The trouble may be a shutter out of adjustment, improper threading, claws worn or out of adjustment, worn rails or camshaft. Bad or poorly made film causes the same symptom. It is well to check the projector with standard film selected for this purpose.

Indistinct picture or low illumination: The projection lens, condenser lens, or reflector may be dirty, or the projection lamp may need replacement. Dense film may cause the trouble. Check with the standard film.

Film scratched: Film shoe, pressure roller, aperture plate, or guide rollers may be dirty or emulsion coated. On 35-mm projectors, check the fire rollers in the upper and lower magazines for accumulations of fuzz and grit, which will scratch film.

NOTE: *The last three troubles mentioned may be on the film in use. Previewing of all film is recommended.*

Picture, but sound weak or distorted or no sound: First, check the audio-level control and threading system. These are the principal causes. Open or shorted cables, burnt-out fuses or lamps, improper seating of photoelectric tubes, and improperly adjusted sound mirror are also frequent causes. Check for obstruction of light beam

by foreign matter. If the trouble is still not located, check further by manufacturer's instructions.

Sound, but no picture: The projection lamp may be burnt out.

Oscillation in preamplifier: Loose ground wires, output leads too near the input leads, or defective bypass capacitor may be the cause.

Hum level high: Check the shield on the audio line or photoelectric cell; filtering of photoelectric-cell voltage or bad tubes may be the cause.

No photoelectric-cell voltage: The a-c power may be off. Also check filter capacitors and rectifier tubes in the preamplifier and the fuse in the a-c line to the preamp and for open resistors and broken or shorted wires.

Microphonics: This may be caused by loose connections, poor contact between plug and socket, loose elements in PEC, or oil-soaked wiring. Also check the projector mechanism for excessive vibration. (Preamplifier tubes are often microphonic.)

Distortion: The cause is most often found to be tube trouble, defective PEC, or sound optics out of adjustment. Other causes are due to leakage in speech lines or open coupling capacitor.

Tone unsteady—wows: Check the tension of the pressure roller. The sound drum may be dirty or damaged. Check also for dirty pressure rollers and dirty guide rollers. The sound drum shaft or bearings may be loose or worn. A defective motor or drive mechanism could cause unsteady tone.

Motor Repairs

All adjustments and repairs to the film-projector motor should be made with *power turned off*. Try to avoid loosening the shutter from the rotor shaft, as this will require readjustment of the shutter for proper synchronization. Failure of the drive motor to start, not running at proper speed, acceleration time too long, or the drive motor starting then stopping usually indicates excessive loads or improper line or field voltages. Check for open switches, loose connections, or breaks in power wiring. Regular maintenance schedules should include proper cleaning and oiling to prevent overheating of bearings in the blower motor and drive motor. Check and tighten the motor coupling and attachment of the motor to the bed plate. (In tightening screws, avoid forcing them and damaging threads. If necessary, remove the screw and replace with a new one.) Included in the regular maintenance schedule should also be repairs and replacements of brake resistors and relays on projector mechanism.

The following section on Precision Adjustments was provided through the courtesy of the Society of Motion Picture and Television Engineers.

Precision Adjustments

Television Test Film. This film is designed to indicate the condition of operation of those portions of the television-film-reproducing system which depend upon the relation between the film projector and the television system.

Use of the test film on a routine operational basis is recommended, since it will indicate errors of adjustment and equipment malfunction before they might otherwise be detected and before they adversely affect the quality of the transmitted picture.

Several test sections and a selection of scenes comprise the complete film, which is available in 16- and 35-mm widths. The test sections are a series of geometrical patterns intended to present information on the factors most likely to be degraded in television-film reproduction. The test targets appear in the following order: alignment and resolution, low-frequency response, medium-frequency response, storage characteristic, gray scale, and brightness control. Each section is preceded by an explanatory title. For the following tests, 16-mm test films are used.

Sound Optical Assembly Adjustment. Two types of film are available, a 7,000-cycle record for precision adjustments following overhaul and a 5,000-cycle record for quick service adjustment. Both films are original recordings rather than print. Each carries a special square-wave track which was chosen because its ontput changes more

rapidly with changes in the focus of the assembly than the output from the usual sine-wave high-frequency track and also gives a sensitive indication of the errors in azimuth adjustment. Films are used as loops, and adjustments are made for maximum output meter readings.

Alignment of the Sound Record with the Scanning Beam. Buzz track test film is used for this purpose. The track consists of an 0.076-in. opaque center with a square-wave signal frequency of 300 cycles recorded just outside that area on the picture side and another of 1,000 cycles just outside that area on the side nearest the film edge. Guides should be adjusted so no sound is heard from either frequency.

Standard sound-record widths are 0.060 to 0.072 in. Some sound optical assemblies produce a light of sufficient length to reproduce both frequencies when the assembly is only slightly out of adjustment.

Buzz track film is an original recording made on a special machine built for that purpose.

Uniformity of Scanning-beam Illumination. This film requires the use of an output meter and a picture projected light on the screen. A narrow sound track 0.005 in. wide modulated at constant level by a 1,000-cycle tone sweeps across the scanning light beam from one end to the other at a uniform rate, the position of the sound track relative to the ends of the light beam at any instant being shown by an animated diagram appearing in the picture area.

If the scanning-beam illumination were absolutely uniform across the width of the scanned area, the output of the 1,000-cycle tone would be constant. In practice, however, some variation of the meter reading will always be observed. The film is made up into loops of 34 ft for the laboratory type and 3½ ft for the service type. By running a loop continuously and observing the indications of the output meter while adjustments are made, it is usually possible to correct unevenness of illumination and bring the variations of output within a limit of ±1.5 db. Sometimes a new exciter lamp will correct uneven meter readings.

Flutter. The 3,000-cycle flutter-test film is a direct positive original recording and carries a 3,000-cycle tone having extremely low flutter content for use in measuring the flutter introduced by sound reproducers. A flutter meter is required to make this measurement. The total flutter content of the film at the time of shipment is less than 0.1 per cent.

System Frequency Response. The multifrequency test film is a direct positive original recording and is used to obtain the electrical frequency response at the output of the power amplifier. Each film is individually calibrated and contains 14 frequencies each preceded by a spoken announcement. The deviation of the test-film record from the intended flat-response characteristic is stated as a correction for each frequency which will give a true level when it is added algebraically to the output level measurement obtained when using the film.

Calibration data and instructions are packed with each film.

System-gain Test. The 400-cycle signal-level test film is a direct positive original recording designed to furnish as nearly as is practicable an absolute standard of recorded signal level for use in measuring the effective amplification and output of sound systems, taking into account the sound optical system and phototube as well as the amplifier.

Travel-ghost Test. Travel ghost is a blurring effect in the picture as seen on the screen and evidenced by vertical tails or light streaks added to the projected images of the transparent area on the test film. It is caused by the projector shutter being out of synchronism with the intermittent mechanism.

The test-film travel-ghost target shows improper timing of the shutter quite readily and gives a clear indication of the correct adjustment.

Picture-steadiness Test. This film permits the unsteadiness of a projected film image to be measured. As a steadiness reference there are three round holes punched in the picture area. The two lower holes are produced by a single punch stroke that is indexed from the adjacent standard film perforation, the one that locates that particular frame in the aperture on many projectors. The upper hole is produced by the succeeding stroke. Relative motion between the upper hole and the lower pair is a

direct indication of inherent unsteadiness of the film resulting from expected inaccuracies in the perforating of the film because it is a plastic material.

Simultaneous motion of the upper hole with the lower pair permits the image unsteadiness produced by the projector under test to be observed. Residual unsteadiness of films approved for sale is no greater than 0.05 per cent of picture width.

Check of Final Results. A film containing picture and sound of known quality should be selected.

The Research Council sound-projector test film contains three dialogue samples, a female solo sample, and orchestral and piano music.

The SMPTE produces a sound service test film which contains title music, buzz track, sound focusing test, constant frequencies from 50 to 6,000 cycles, dialogue, and piano music. This film is intended to provide an inexpensive over-all quick test of projector performance.

A complete list of 35- and 16-mm test films is shown in the catalogue of the Society and is available for the asking.

Camera Chains

The most frequent cause of trouble here is small tube failure which can be prevented to a large extent by regular tube checks. Tubes with weak emission can be replaced by ones known to be good. Spares should be kept at hand at all times for quick replacement if trouble occurs while the camera chain is operating. In making replacements, be certain that power is *off*, and that capacitors are *discharged*. Here, as in most constantly operating equipment, serious burns can result from carelessly touching tube envelopes.

Another frequent source of improper operation is failure to check control settings. It is suggested here that the approximate control settings be written or typed on a small card to be fastened to the camera for the benefit of inexperienced personnel.

Tube Checks

One simple method of testing the tubes in a circuit for the presence of microphonics is to tap each tube lightly with the eraser end of a pencil. A "noisy" tube can be located by observing the raster of the picture monitor during the test.

When tube checks are made, tube testers of the emission type should be avoided, using mutual-conductance tube testers instead where applicable. A permanent log of the usage on all image orthicons, iconoscopes, etc., is suggested. Experience has shown that such logs (or card files) will often point out tubes likely to go bad in the near future and may often show up repeated failures of a certain tube which can then be traced to defective or partially defective circuitry or possibly to a defective lot of tubes.

Waveform and voltage charts will be furnished by the manufacturer of each type of camera and should be regarded as standards to be used in tests on each individual camera.

In addition to the monthly tube checks suggested in the preventive-maintenance schedule, frequent checks on cameras for geometric distortion are suggested. These may be effected by use of test pattern charts, slides, and film as recommended by EIA and SMPTE.

When faulty operation of the camera occurs, the four major circuits of the camera ordinarily can be checked quite easily as follows:

Vertical deflection: Check waveform.

Horizontal deflection: Check waveform.

Operating potentials of picture tube: Remove the tube and check voltage and control ranges.

Picture amplifier: Touching the grid terminal of the input stage with a screwdriver or other small "antenna" will usually produce oscillations if the amplifier is all right. If no activity is indicated, checking for lighted heaters in all stages or for cathode bias voltages will often lead to the trouble point.

With these relatively simple checks, the defective area can be isolated and a more detailed examination made. It will be found that the manufacturer's instructions in each case are very explicit.

Synchronizing Generator

The timing, formation, and shaping of a television picture signal which will conform to the standards set by the FCC start with the proper functioning of the synchronizing generator. Fortunately, the newer types of synchronizing generators give very little trouble over long periods of time. It has been suggested that since this is the case, an effort be made at least semiannually to acquaint personnel with the possible causes of failure so that when trouble is experienced, the operator will have some idea where to look for the cause.

Two of the most common causes of failure of the synchronizing generator are variations in the power supply and tube failures.

Deviations in the power supply will, among other results, cause the picture to "roll." This can be guarded against by regular checks on power supplies and tolerances in voltage-regulation equipment, which, in most cases, is required to ensure reliable operation.

As the tubes in the synchronizing generator grow old, they may cause small variations in the amplitude and pulse widths of the output signals or may cause unwanted pulses to appear in the positive region of the output signal. Unless tubes or voltages vary greatly from normal, pulse shapes can be returned to standard by adjustment of external controls.

The small vacuum tubes used in this equipment item are relatively stable, but quite often slight variations in operating characteristics of similar types of tubes dictate that each tube be replaced in its former socket after it has been removed for testing. (This may be found to be good practice throughout all other equipment in the station.) After a tube has completely failed or as a result of the tube tests is expected to fail soon and is replaced, the synchronizing generator should be checked for proper operation and adjustments made immediately rather than waiting until the next day's operation begins only to find that, owing to the change of one small tube, the generator is not functioning properly.

It has been considered a good policy in many stations to have a second synchronizing generator for use as a spare and to test both before beginning the day's programming to be certain they are both operating properly.

In all equipment of this nature where a large number of small tubes is employed, many stations have found it profitable from a standpoint of economics, as well as trouble-free operation, to keep the equipment running on a 24-hr basis. This practice is applicable in many sections of the equipment of the station where the daily thermal cycles definitely cause deterioration of tubes and parts.

Field Pickup (Remote) Equipment

Periodic inspection and cleaning of equipment used outside the studio is especially important, since it is constantly subjected to jolting, to conditions of excessive dust and moisture, and possibly to wide variations in primary sources of power.

Particular attention should be paid to the removal of dust, which may cause current leakage or arc-over between high-potential points. Needless to say, all surface dust should be removed before internal cleaning is begun in order to prevent dust particles from falling inside, where they may be hard to dislodge. All bushings and terminal boards should be kept free of dust.

Frequent visual electrical and physical inspection of wires and terminals becomes even more important on field equipment, where connections may become strained from jolting during moving from one location to another. Good, firm (but careful) pulls on lead wires may reveal high resistance or broken connections, which can then be repaired before failure occurs.

When fuses are renewed, fuse cartridge caps should be clean and dry to ensure good contact and to prevent fuse heating due to contact resistance.

One of the more frequent causes of trouble in field equipment is the improper setting of controls. Controls can be properly set before the equipment leaves the station, but it may be also found helpful to record the approximate settings on a small card, which can then be attached to the equipment item and referred to at the remote point. This is particularly true when the equipment is operated by several different technicians rather than by one man who always has the responsibility for remote setups.

Camera lenses should be removed before leaving the station, covered with the lens caps, and stored in felt-lined carrying cases. Such cases should be both moisture- and dustproof.

The remote vehicle should have spare tubes, cables, fuses, and other parts subject to wear within instant reach of the technicians.

Tubes

It has been found that a television station equipped for both film and live telecasting employs around 1,800 tubes in the over-all system of studios and transmitter. These tubes range from the inexpensive miniature type to the image orthicons, which cost about $1,200 each. Naturally, it is impossible in an article of this type to cover the idiosyncrasies of such a variety of tubes completely, but since tube failure is one of the major causes of equipment failure, it may be well to point out a few general precautions to be observed in their handling.

To begin with, the life expectancy of a tube used in video circuitry is not always so great as that of the same tube when used in audio equipment. However, many tubes can be transferred to audio service when they are found to be no longer useful in video, provided, of course, that the length of service in video has not been too great. A supply of pretested tubes should be instantly available to the operator for quick substitution when necessary. It may be found desirable to have certain tubes premarked for location.

A record of test readings and hours in use on all critical tubes is considered desirable. In addition to revealing tubes which are likely to fail in the near future,[7] such a record may also reveal types of tubes which are not giving satisfactory service and which should be studied closely to determine the cause of failures (see notes on Camera Chains). Either a card file or a loose-leaf notebook will be suitable for tube records.

Spare tubes, particularly of the transmitting, cathode-ray, and image-orthicon type, should be operated regularly to prevent them from becoming "gassy."

When transmitter tubes are first received at the station, they should be tested at a time outside the regular hours of operation or into a dummy antenna if this is available. The "tube biography" is then begun with the date of test and condition in which the tube was received being the first entries. Transmitter tubes are guaranteed for a minimum number of hours, and a prorated rebate is made by the manufacturer if failure occurs before the completion of the guarantee. Therefore, a record of the number of hours in operation and other pertinent data is essential for each tube until it is eliminated from service, since hundreds of dollars are involved.

Water-cooled Tubes

The proper care and maintenance of water-cooled tubes is of primary importance in ensuring good service. These suggestions are made as a general outline. They should be checked against the instructions given for different types of water-cooled tubes by the manufacturer, since such instructions will vary.

1. Installation of the water-cooling system and of each new tube placed in service should be in strict accordance with the manufacturer's instructions. Improper operation for only a few minutes can ruin a tube.

2. Always use distilled or water of equal purity in the system. Tap water or even the spring water used for office water coolers often contains impurities which become

[7] See previous note concerning monthly maintenance schedule.

electrostatically precipitated and form scale, which interferes with the proper operation of the system.

3. Remove the filter strainer regularly, and clean out any sludge that has formed. This should be done quite frequently during the run-in period and periodically thereafter.

4. After the system is cleaned, water should be circulated for a short time and then the entire system refilled with fresh distilled or equally pure water. Never allow chlorinated water to enter the system, as it greatly increases the corrosion rate of the pipes and ducts in the tubes.

5. Regular oiling and greasing of the system motor should be a part of the maintenance routine.

6. Avoid operating the water-cooling system at too high a pressure, since this will cause excessive water turbulence in the tube passages with the possibility of an increase in microphonics.

7. It is highly important to protect the outside intake of the water-cooling system before cold weather begins. (In one station, the intake system was installed in the basement of the transmitter house with no further protection. The first night the temperature dropped below freezing, the intake system froze, causing a great deal of damage and expense before the situation could be corrected.)

Air-cooled Tubes

In general, the maintenance of air-cooling systems is relatively simple. Air filters should be regularly inspected and cleaned or replaced when necessary. Small strips of cloth tied to the blower will give an instant visual check on whether or not the system is working. A suggestion has been made that when the system is first placed in operation, the temperature of the intake and outgo air should be noted and the differential established as an operating standard for the system. (Each system will be found to have its own differential.) The same temperature measurements can be made monthly, and as soon as a wide departure from the standard appears, a check on the system can be made to determine the cause. In making such a check, try the filters first. The cause will usually be found in a clogged filter. Periodically, jackets should be removed from the tubes and fins cleaned with a soft, lint-free cloth. Fins, of course, should be perfectly clean on initial installation. Fan and motor bearings must not be overlooked. Lubrication will depend on whether the bearings are sealed or open. Sealed bearings require attention only every few years.

High-power Radio Tubes

During the past several years, a substantial number of 50-kw radio stations (AM) have operated their transmitters 24 hr per day with only either a minimum maintenance period of a few hours each week or none for several weeks. These stations have reported to NAB that, contrary to expectation, their reliability of operation and outage records seem not to have deteriorated as a consequence of reduced maintenance.

Manufacturing techniques over the past years have greatly increased the reliability and life of high-power transmitting tubes. Stations in some foreign countries experience some difficulty in maintaining a stock of spare high-power tubes, and concern has been expressed at the consequence of placing spare tubes in operation for limited periods for purposes of degassing and to ensure satisfactory operation. There is always the risk involved of breakage, particularly of tubes that have been operated for several thousand hours, when such tubes are removed and replaced in a transmitter.

Experience over the years has indicated that one of the sources of tube failure is the mechanical stress resulting from repeated heating and cooling whenever the tubes are shut down. In certain installations, it is the accepted practice never to turn off the filaments of the tubes completely. Tubes are operated either continuously at rated filament voltage or at reduced voltage during the periods when no plate voltage is applied. During such periods care must be taken that adequate cooling of the seals is accomplished according to the manufacturer's specifications. It is suggested that for

stations subject to the previously mentioned situation, increased life of tubes can be accomplished by application of these general procedures.

Transistors

No specific maintenance procedures are included in this Part for transistors. The reader is referred to Part 1 of this Section for appropriate operating and handling criteria.

LIFE EXPECTANCY AND OPERATING NOTES ON THE IMAGE-ORTHICON TYPES 5820 AND 6474/1854

From time to time the question is raised of how long an image-orthicon tube can be expected to perform satisfactorily. This is an area where no hard-and-fast rules can be laid down, but instead the decision to remove the tube from service must be made on a subjective basis. During the month of January, 1954, the Engineering Department of NAB undertook a survey of 35 member operating television stations in an effort to determine the useful life which was being obtained from image orthicons. It was believed that an exchange of information on the subject would be helpful to station operators. The results of the original survey were acclaimed throughout the industry and were regarded as instrumental in a better understanding of correct operating techniques when using this particular tube.

Since our original report was published, much has happened in the television industry. Our first undertaking reported the findings of only 35 stations as against 225 in our latest survey. Color has now entered the picture, bringing with it a new image-orthicon tube, type 6474/1854. Manufacturers have made tremendous strides in tube development. After reviewing these facts we were of the opinion that the original survey should be revised, using more stations and citing the latest techniques.

It is not our intention to recommend the period of usable life to be expected from the tube. This must remain, as it has in the past, a period to be determined by weighing the picture quality against the cost of replacing the tube. We are merely providing the results of a survey conducted among some of the operating television stations so that you may know what other stations have found as answers to the "cost vs. quality" question.

The Questionnaire

Our questionnaire dealt with two types of tubes: the type 5820, which is used in black-and-white studio equipment, and the type 6474/1854, which is used in the color studio equipment. Our 5820 questionnaire covered seven questions dealing with average life experienced at the station, minimum and maximum life periods, the period of time used to determine these answers, and the criteria used for deletion of the tube from service. We also asked if there were any special techniques used which were believed to lengthen the useful life of the tube.

Our 6474/1854 questionnaire covered six questions dealing with approximately the same subjects as mentioned above.

The Sample

The 5820 questionnaire went to 320 of our member stations. The 6474/1854 questionnaire was sent to 26 of our member stations.

5820 Image-orthicon-tube Survey

201 replies:

11 were not used in this report because (*a*) they did not give filament time, (*b*) they employed *used tubes*, or (*c*) they gave insufficient information for tabulation.

190 questionnaires were used in this report.

#1. *The average life of image-orthicon tube (190 reported):*

	Range	
Average	*Low*	*High*
796 hr	375 hr	2,000 hr

#2. *The minimum life (excluding duds) (189 reported):*

	Range	
Average	*Low*	*High*
519 hr	100 hr	1,835 hr

#3. *The maximum life (189 reported):*

	Range	
Average	*Low*	*High*
1,188 hr	450 hr	3,035 hr

#4. *The criteria used for deletion of tube from service:*

1. Image retention or "sticking"	100%
2. Poor picture quality	46%
3. Lack of target control	8%

NOTE: This does not add up to 100 per cent because some gave more than one criteria. "Poor picture quality" included loss of sensitivity, resolution, poor gray scale, noise, and lack of contrast.

#5. *Have you noticed any difference in the quality of image orthicons during the last 3 years?*

5 stations gave no answer to this question.

55 answered little or no difference.

17 answered tubes were not as good for various reasons.

3 answered in detail via letters.

110 indicated improvements:

35 stations indicated an improvement in picture quality through use of the new 750 micro mesh tubes.

The main improvement of this tube is the elimination or lessening of moiré. Other improvements in this tube are as follows: better resolution; improved sensitivity; less initial alignment; improved gray scale, contrast, and definition; more uniform in operating characteristics; less noise; higher voltage output; crawling effect reduced; swirl effect reduced; and fewer duds.

A total of 75 stations indicated the following improvements:

	Stations	*Per cent*
Longer life	20	27
Increased sensitivity	16	21
Better gray scale or improved shading conditions	12	16
Better resolution	10	13
Less rejects or fewer duds	7	9

Approximately 15 per cent indicated better quality control and more consistent operating characteristics per tube and between tubes.

Approximately 23 per cent gave the following improvements: decrease in target spots or defects, fewer dynode spots, less noise, better definition, and better beam landing.

NOTE: This does not equal 100 per cent because of combination improvements.

#6. *Do you have any special technique that you believe prolongs the life of these tubes?*

85 stations reported "no" or no answer.

15 indicated used manufacturer's recommendations.

3 gave detailed answer in letters.

The majority of suggested techniques were much the same as those suggested by the manufacturer, i.e., capping of camera when not being used or when on standby and careful attention to lens stops, lighting, temperature, etc.

Approximately 15 stations use the rotation and rest method. The hours varied from 100 to 500 and the periods of rest varied too.

Approximately 12 stations found that resting the tube had no value or that tubes had longer life if used continually. One station indicated that taking tubes out to rest, etc., entails too much handling, which, in itself, could be detrimental to its life.

Other suggested techniques that may be of interest are as follows:

"We have a special flashlight mounted in a lens position on the turret to wipe off the retained image. It picks up 6.3 volts through the iris control connector. This enables us to use tubes that would otherwise be too sticky."

"For the past six months we have experimentally operated camera chains with filaments and plates ON 24 hr per day. Beam and target are turned down when cameras are out of service more than 1 hr. On the basis of limited experience to date, it appears life will be increased. Experiment will continue."

"Beam switch. Interrupts beam during warm up and standby periods. Seems to have increased average life slightly, probably due to operational procedures rather than any electrical effect on tube life."

"Do *not* burn out sticking images on a white background. This has made considerable difference in gray scale and resolution as the tube ages."

"Keep tube from overheating by cleaning out camera regularly. Try to keep light in studio well balanced and prevent overlighting on limbo's and easels. Watch iris openings closely. Never allow a camera to be left uncapped for a long period of time in a lighted area, or a camera to be pointed into lights, strong flares, or bright sunlight without filters on lenses. Also, I do not believe in resting the tubes because it does not help the burning problems. Check power-supply voltage and target control setting regularly. Also I have observed that in finding the knee of a new tube, the tube with the higher iris setting will last longer in service."

Electronic capping was mentioned several times and seems to be satisfactory.

Electronic lens capping is accomplished by replacing the present "target set" switch with a three-position switch. In the center and lower positions, the switch is wired to perform the present functions. In the "up" position, the switch is wired to connect 6–8 volts negative bias to the target and remove the voltage from and ground the photocathode.

A camera thus equipped can be set up on a scene ready to go on the air and the switch thrown to the "up" position, which activates the electronic lens cap, with no fear of burn-in on the orthicon. The switch can be thrown to "operate" position seconds before the director calls for the shot, and there are no adjustments to make. The video man thus has control of capping the cameras and does not have to depend on a cameraman to wave the camera around to prevent sticking.

The photocathode voltage must be removed and the photocathode grounded for the electronic lens cap to work in all cases. Cameras have been set up in bright sunlight for up to an hour with no trace of sticking.

6474/1854 Image-orthicon-tube Survey

24 replies:

11 indicated image-orthicon tube still in service or only one set of tubes used. These 11 gave insufficient information for tabulation; consequently only 13 questionnaires were used in this report.

#1. *The average life of image-orthicon tube:*

	Range	
Average	*Low*	*High*
714 hr	270 hr	1,306 hr

#2. *The minimum life (excluding duds):*

	Range	
Average	*Low*	*High*
460 hr	100 hr	825 hr

#3. *The maximum life:*

	Range	
Average	*Low*	*High*
1,000 hr	400 hr	2,080 hr

#4. *The criteria used for deletion of tube from service:*

1. Image retention or "sticking" ..... 12 out of 13, 92%
2. Poor picture quality ..... 7 ont of 13, 54%

NOTE: Some gave more than one criterion.

"Poor picture quality" included loss of sensitivity and resolution, poor gray scale, etc.

#5. *Special techniques (4 reported):*

The following comments were made in relation to improvement of usable life:

1. Not overheating. Do not leave on unnecessarily. Proper scanning. Gentle handling.
2. Do not stay uncapped on gray scale for excessive periods.
3. Operate as few hours per show as possible.
4. Cut beam on standby. Switch on each camera to energize protection circuit for beam cutoff.

Operating Precautions

By no means all the sources of difficulty with the image orthicon arise from the tube itself. There are many important precautions and considerations which have been pointed out by the manufacturer and the users. One of these is the position of the tube, not only during its operations but also during shipment and storage. During the manufacture, it is sometimes unavoidable that minute particles become loose and lodge in the neck of the tube. If the tube is placed in a vertical position with the base upward, it is possible that such particles might fall on the target and become adhered. It has been recommended that the tube never be positioned so that the axis of the tube makes an angle of less than 20° with the perpendicular. It is also suggested that all personnel handling the tubes be cautioned never to rest the tube on the optical face of the image end for the above reason as well as the possibility of scratching the surface.

Recommended operating temperatures should be closely followed and checked frequently. Variations from such tolerances may produce afterimage effects and reduced resolution. Recommended temperature range from the target area is from 35 to 50°C, and the bulb temperature should not be more than 5°C hotter at any point. Under ordinary circumstances, the focus and deflection coils and amplifier tubes will maintain proper operating temperatures which can be controlled by forced-air cooling along the entire bulb envelope. Under conditions of extreme cold it may be necessary to use target heating to keep within the temperature tolerance specified, but care should be exercised not to heat the target excessively, thus causing cesium evaporation and reduced tube performance.

The manufacturer (RCA) provides a list of "Do's" and "Don'ts" which apply to the 5820 and the 6474/1854 and which *do not appear per se in the technical bulletin for either type.*

Do's

1. Allow the tube to warm up for ¼ to ½ hr with the camera lens capped and with grid 1 voltage adjusted to give a small amount of beam current.
2. Hold the temperature of the tube within specified operating range.
3. Make sure the alignment coil is properly aligned.
4. Check scene illumination and uniformity of illumination before televising.
5. Determine the proper operating point with the target voltage adjusted to exactly 2 volts above target cutoff.
6. Select a lens stop to permit operation with the highlights above the knee of the light-transfer characteristic for the 5820 in black-and-white cameras and below the knee for the 6474 in color cameras.
7. Use the lowest beam current for best signal-to-noise ratio and gray-scale reproduction.
8. Adjust the beam-focus control for best usable resolution.
9. Cap the lens during standbys.
10. If the lens is left uncapped during standbys, cut off the voltage applied to the photocathode and to the target in order to prevent unnecessary aging of the tube.
11. Give the tube an idle period every 200 hr.
12. Condition spare tubes by operating several hours once each month.

Don'ts.

1. Don't force the tube into its shoulder socket.
2. Don't operate the tube without scanning.
3. Don't underscan the target.
4. Don't focus the tube on a stationary bright scene.
5. Don't turn off the beam while voltages are applied to photocathode, grid 6, target, dynodes, and anode during warm-up or standby operation.
6. Don't operate a tube having an ion spot.

Type 6474/1854 in Black-and-white TV Cameras Gives Outstanding Picture Quality

Use of the 6474/1854 image orthicon in black-and-white TV cameras can give greatly improved picture quality. The 6474, usually referred to as the "color image orthicon," has a target-to-mesh spacing much closer than that in the 5820 image orthicon, and therefore, it has a higher target capacitance. As a result, the 6474 has a light-transfer characteristic featuring a longer dynamic range (gray scale) and an improvement in signal-to-noise ratio.

When used with gamma correction or "black-stretch" circuits for the lowlights, the 6474 can produce pictures with excellent tone rendition and a pleasing photographic effect. Aperture correction can be used to advantage and results in excellent resolution.

TV stations desiring outstanding picture quality should experiment with the 6474 for black-and-white pickup. Such use of the 6474 is common practice in many European TV studios in order to meet the public demand for TV pictures of superior quality.

Discussion of the image-orthicon tube would not be complete without reference to a recent development known as the image-orthicon saver. It has several different trade names depending on the manufacturer. Through the work of Mr. John Wilner, vice-president for engineering, the Hearst Stations, such a device was offered to television stations by these manufacturers. Mr. Wilner's "orthicon saver" used a rotating lens plate with electronic compensation for the mechanical motion. It was for his work which led to the introduction to the industry of this equipment that he was awarded the first NAB engineering award at the 13th NAB Broadcast Engineering Conference, Chicago, Ill., Mar. 18, 1959. The equipment, installed on a television camera, has extended the life of image orthicons substantially and enabled reuse of tubes which had previously been discarded for "sticking."

Hitherto unpublished information indicates that "freezing" of retired image-orthicon tubes at 0°F for periods of 60 days or more fantastically reduces signal-to-noise output and to some extent relieves sticking. The scientific explanation for the phenomenon is not yet clear. It is known that engineers of the American Broadcasting Company and the Westinghouse Broadcasting Company, Inc., have experimented extensively with this new technique.

References

Neuhauser, R. G.: "Optimum Performance of Image Orthicons and Vidicons in Broadcast Service," Reprint ST-893.

Rotow, A. A.: "Reduction of Spurious Signals in Image Orthicons," Reprint ST-752.

Copies of these reprints can be obtained on request to RCA Commercial Engineering, Harrison, N.J.

Miscellaneous

A few other general suggestions on studio equipment maintenance may be mentioned here.

Switching Systems

If a switching system is properly installed and adjusted, little or no maintenance is required. Most modern relay systems are enclosed and have a self-cleaning feature for

contacts. Such systems should be tampered with as little as possible. Covers are to be kept dust-free so that, should it become necessary to open them, dust will not fall into the relays. A daily routine of operating each relay will be found of great use in improving the operating record of the equipment and in showing up other equipment failures. Switches in a push-button electronic system require the same care. This should, of course, be done after regular operation hours. Audio faders must be wiped clean frequently, using a soft, lint-free cloth moistened by carbon tet. If relay contacts in either audio or video circuits must be cleaned, this should be done with a blower using clean air and with a burnishing tool made for the purpose.

Monoscope Camera

Other than dusting and cleaning and the regular tube checks, little maintenance is required for the monoscope. Checks on its nonlinearity are easily made during the time the camera is being used to show the test pattern.

Monitors

The monitors are of extreme importance to studio personnel; both technical and production people depend on them for producing programs of optimum quality. In addition to the regular dusting, cleaning, and tube checks, frequent tests should be made for nonlinearity as well as tests for resolution and gray scale. It has been observed in some stations that monitors are poorly maintained as to linearity and focus and are very often made of broken-down or cast-off receivers. Such practice is deemed improper, not only from the technical standpoint but from the psychological effect on producers, directors, actors, and others who may not have the technical knowledge to evaluate the resultant picture.

Stabilizing Amplifier

Improperly adjusted controls and tube drift account for most of the troubles here. Correct signal voltages (as recommended by the manufacturers) should always be available at the input jacks. Regular cleaning and inspection of cable connectors and tube checks will avoid most failures. In addition to the tube checks, cable socket voltages should be regularly measured.

Capacitors

Dust must be removed regularly from high-voltage capacitors, since its accumulation tends to cause arc-overs and increases chances of equipment failure. If the method of cleaning with lint-free cloths is used instead of a bellows, extreme caution must be exercised to see that the capacitor is inoperative and *discharged* before handling. Leads and terminal connections must be regularly checked for loose or broken connections, and the insulators checked for cracks.

An excessive rise in the temperatnre of a high-voltage capacitor can be detected by placing the palm of the hand against it after a long period of operation. Be certain that the capacitor is inoperative and *discharged* and that the case is grounded before touching these capacitors. High-resistance paths to ground have been known to develop, and a normally "grounded" case conductor can become very "hot" electrically. This may be an indication of impending failure from dielectric leakage or improper ventilation. Prompt replacement will avoid loss of air time from overheated capacitors.

Low-voltage capacitors do not require so much care as those of the high-voltage type but should be kept free of dust, oil deposits, and other foreign matter. Since the leads used here are not so rugged as those in the high-voltage type, greater care is necessary in inspection for loose or poorly soldered connections.

Different organizations have found widely differing lengths of service for electrolytic units. Twelve to thirty months seems to be the minimum and maximum periods of service. Dried-out capacitors are one cause of hum bars in the television image. Ex-

cessive temperature rises often result in nonlinear scanning, since the capacitance is known to vary with temperature changes.

Resistors

Check load resistors and terminating resistors at least once each year, and replace if there is a critical deviation. Dust should not be permitted to collect on any resistor, especially in high-voltage circuits. Snap-in resistors should have firm, clean contacts to prevent heating at the terminals. If a resistor is removed for cleaning, be certain to follow through, making sure that it is properly replaced; otherwise damage may result to the equipment when it is energized.

Patch Panels and Cables

In both video and audio systems, jacks and plugs should, of course, be maintained in perfectly clean condition. If a faulty cable develops, it should be removed from service and sent to the repair shop immediately. Plugs in audio equipment should be polished regularly. Visual inspection of the connections is very important.

FIRST AID AND RESUSCITATION POLICY [8]

It should be required that each and every man in technical operations be thoroughly familiar with first aid procedures in the event of an emergency so that his life or the life of one of his coworkers can be saved. *He should be ready to act immediately in any emergency.*

Heads of the technical divisions should *be held responsible* for the carrying out of the program which includes the proper setting up of training classes at regular intervals (preferably every three months), the insistence that each man under his direction duly attends and qualifies, and the maintenance of safety bulletin boards and distribution of pertinent safety information.

The training should include a thorough instruction in resuscitation by a competent instructor, also training in *first aid* with particular emphasis on the type of injuries likely in our operations such as control of bleeding and treatment of burns and general injuries.

General Foreword

Experience, particularly in use of electrical equipment, has shown that all engineers, at times, expose themselves to danger: new engineers because of inexperience, older ones because of overconfidence and habits of work which they have formed. In an endeavor to reduce such exposures, these suggestions have been included.

Although these suggestions cover most of the common accidents, it would be practically impossible to make them cover all, especially those of changing conditions and methods. The purpose is to create the tendency always to *think and act in terms of safety.* In case of electrical shock, it is always important when attempting to free the victim to

1. *Protect yourself* with dry insulating material.
2. *Break the circuit* by opening the power switch or by pulling the victim free of the live conductor. *Be careful and move fast—seconds count. Don't touch the victim with your bare hands until the circuit is broken.*

Procedure to Follow for Prone Pressure Method of Resuscitation

As soon as possible, feel with your fingers in the patient's mouth and throat and remove any foreign body (tobacco, false teeth, etc.). If the mouth is shut tight, pay

[8] Much of this material was obtained from the NBC Engineering Department "Safety Handbook."

no more attention to it until later. Do not stop to loosen patient's clothing, but immediately begin actual resuscitation. Every moment of delay is serious. Proceed as follows:

1. Lay the patient on his belly, one arm extending directly overhead, the other arm bent at the elbow and with the face turned outward and resting on hand or forearm so that the nose and mouth are free for breathing.

2. Kneel, straddling the patient's thighs. Place the palms of the hands on the small of the back with fingers resting on the ribs, the little finger just touching the lowest rib, with the thumb and fingers in a natural position, and the tips of the fingers just out of sight (see Fig. 9-1*a*).

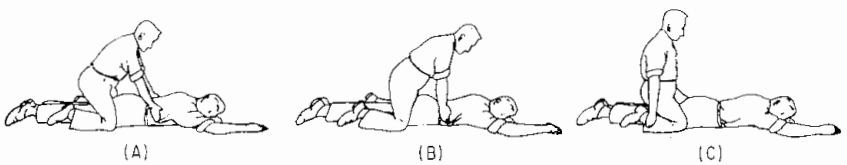

FIG. 9-1. Prone pressure method of resuscitation.

3. With arms held straight, swing forward slowly so that the weight of your body is gradually brought to bear upon the patient. The shoulder should be directly over the heel of the hand at the end of the forward swing. *Do not bend your elbows!* This operation should take about 2 seconds (see Fig. 9-1*b*).

4. Now immediately swing backward so as to remove the pressure completely (see Fig. 9-1*c*).

5. After 2 seconds swing forward again. Thus repeat deliberately 12 to 15 times a minute the double movement of compression and release, a complete respiration in 4 or 5 seconds.

6. Continue artificial respiration without interruption until natural breathing is restored, if necessary 4 hours or longer, or until a physician declares that the patient is dead.

7. As soon as artificial respiration has been started and while it is being continued, an assistant should loosen any tight clothing about the patient's neck, chest, or waist. *Keep the patient warm. Send for a doctor.* Do not give any liquids whatever by mouth until the patient is fully conscious.

8. To avoid strain on the heart, when the patient revives, he should be kept lying down and should not be allowed to stand or sit up. If the doctor has not arrived by the time the patient has revived, he should be given some stimulant, such as one teaspoonful of aromatic spirits of ammonia in a small glass of water or a hot drink of tea or coffee. Keep him warm!

9. Resuscitation should be carried on at the nearest possible point to where the patient received his injuries. He should not be moved from this point until he is breathing normally of his own volition and then moved only in a lying position.

10. A brief return of natural respiration is not a certain indication for stopping the resuscitation. Not infrequently the patient, after a temporary recovery of respiration, stops breathing again. Watch, and if breathing stops, resume artificial respiration.

11. In carrying out resuscitation it may be necessary to change the operator. This change must be made without losing the rhythm of respiration. By this procedure no confusion results at the time of change of operator and a regular rhythm is kept up.

It is important that resuscitation effort continue when a patient does not revive. *Sometimes a period of 4 hours may be required.*

Control of Severe Bleeding in the Event of an Emergency

Severe bleeding requires immediate and prompt action, and its control may save a life. All stations should be provided with suitable tourniquets, and all personnel

should be ready to act in any emergency. A second person should send immediately for a doctor.

1. *Venous bleeding:* When a vein has been cut, the blood is *dark red* and flows steadily. Pressure, if required, should be applied *below* the wound, or *away* from the heart, to stop bleeding.

2. *Arterial bleeding:* When an artery has been cut, the blood is *bright red* and flows in *spurts.* Pressure should be applied *above* the wound, or *between* the wound and the heart, to stop bleeding. Pressure is best applied by a *tourniquet,* although the fingers and hand can be used temporarily (see Fig. 9-2).

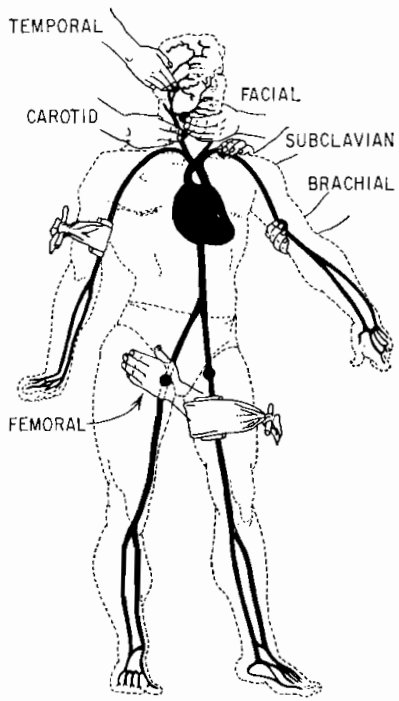

FIG. 9-2. Pressure points for control of severe bleeding.

3. *A tourniquet* is a strip of cloth, bandage, or other material tied above the wound. Place a thick pad, such as a folded handkerchief, on the inside of the arm or leg and under the tourniquet. Loosely tie a simple double knot in the cloth, place a stick or other rigid member between the knots, and tighten the outer knot by pulling the outer ends of cloth. Twist the stick or rigid member until bleeding stops. *Do not* maintain such pressure longer than 15 minutes at a time.

4. *If bleeding continues* after the tourniquet is loosened, allow blood to flow for 30 to 60 seconds and then reapply pressure. Continue this procedure until bleeding has stopped.

5. *Obtain medical services as soon as possible.*

Treatment and Avoidance of Electrical Injuries

Electric shock may be induced either by currents of high voltage or by comparatively low voltage. More people are killed on 110 volts a-c than any other voltage. We are all well aware of cases of shock and burns which result from high voltages, yet the vast majority of serious electrical injuries come from currents of low voltage. The severity of an electrical burn depends upon whether the current is alternating or direct, the voltage and amperage of the current, the character of the ground connection (remember, a concrete floor is *not* an insulator), duration of contact, and the extent of surface involved.

Electrical injuries can be classified as follows:

1. Shock, animation suspended and arrested respirations
2. Electrical flashes or glare injuries to the eyes
3. First-degree burns, with red dry skin as in sunburn followed early by blister formation and pain
4. Second-degree burns, where skin continuity is destroyed
5. Third-degree burns, where there is destruction en masse of the tissue, perhaps including muscle, nerve, and bone.

In shock due to low voltage, such as used for our domestic household appliances, using 110 to 120 volts, the usual cause of accident is neglect to dry hands or other portions of the body properly.

An accident was reported where a woman answered the telephone and neglected to

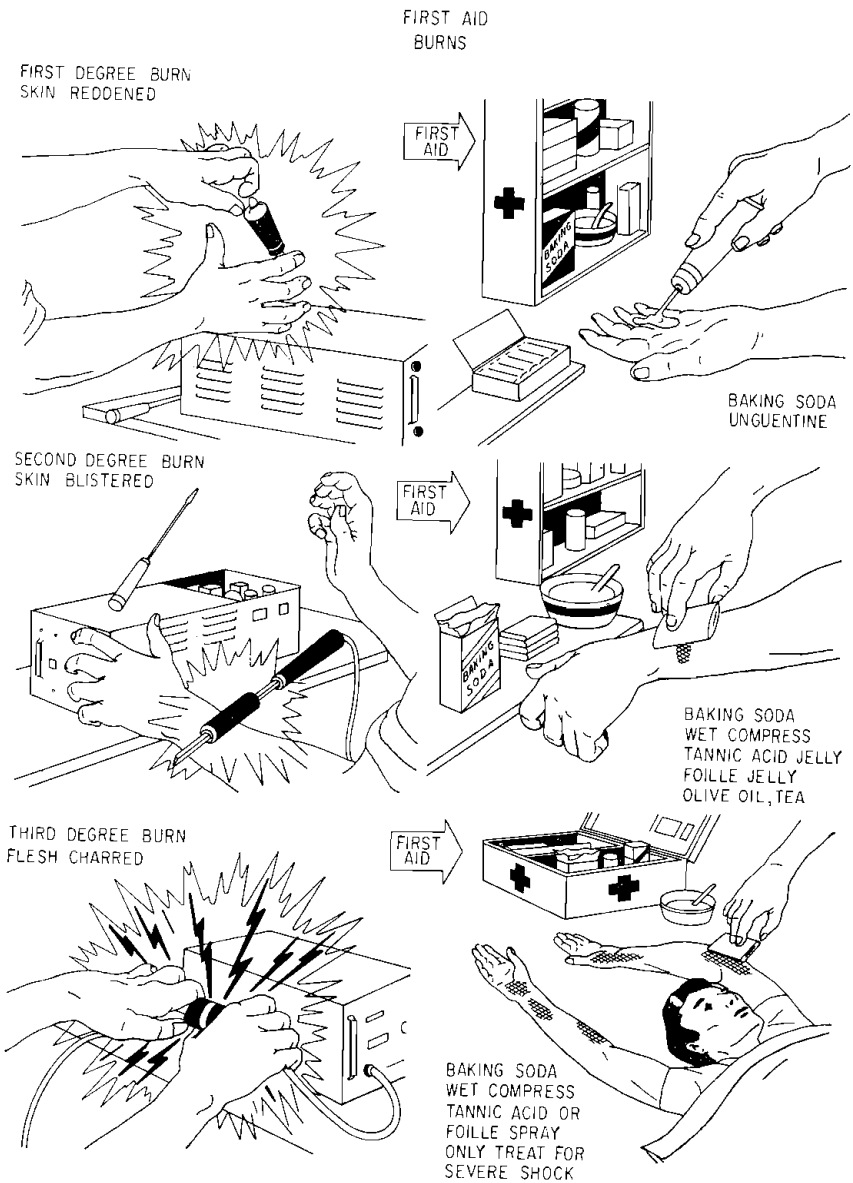

FIG. 9-3. Treatment for burns.

dry her hands. As she reached up to turn on a light, she received a severe shock and had intense pains in her right shoulder. As she was unable to move her arm, her doctor ordered an X ray. There was no history of a fall or other injury. The picture revealed a dislocation of the shoulder joint and complete avulsion of the greater tubercle. Attempts to reduce the dislocation resulted in fracture of the neck of the humerus. Open reduction through surgery was resorted to, and it was found that the electric current had completely changed the character of the bone, which now was filled with thousands of tiny fissures. Similar effects have been noted in inorganic substances such as glass, porcelain, and metal.

Both *high-* and *low-*tension currents have the same lethal effect, and death is produced, not by amperage or voltage, but by a combination of several physiochemical and physiological phenomena. *Alternating currents are more dangerous than direct. A good rule to follow when working on or servicing "live" equipment is to keep one hand in your pocket, thus reducing the possibility of a ground return through the upper portion of the body.*

One point which cannot be stressed too often is the importance of dry skin when working around any electrical apparatus. Never touch any electrical fixture when your hands or other parts of your body are wet, especially when there are cuts or abrasions of the skin and particularly where there is a ground current.

These higher voltages usually cause an immediate violent contraction of the muscles, and if the hand has grasped the wire, it cannot be released. Such unfortunates are said to be "frozen" as long as the current continues. Under no circumstances attempt to pull such a victim free or you may share his fate. Rush for the main switch if it is at hand, or otherwise disconnect all current first. Dry wood, dry rope, or a dry coat may help in pulling a victim free, but the location of the switch should be known to everyone in the laboratory. Such an electric shock may and usually does produce severe burns and, if the current is not shut off in time may even char the bones.

In severe cases of electric shock, leaving out burns and their treatment for the moment, we find that the patient has become unconscious. Respiration has stopped completely, but the heart continues to beat until asphyxia intervenes. A certain number of cases develop a ventricular fibrillation; that is, the electrical impulses which regulate the heartbeat are thrown out of order so that the pacemaker is no longer in control, and instead of a normal of 70 to 80 beats per minute, we have 200 to 400. These cases, as a rule, end fatally.

Fortunately, in most cases, there is merely a prolonged apnea—stoppage of breathing. *Artificial respiration by the prone or Schaefer method must be started at once and continued if necessary for* 8 *to* 10 *hours. Cases pronounced dead by all medical tests have suddenly been revived as late as* 8 *hours after the accident.* Injections of cardiac or respiratory stimulants are worthless and a waste of time in electrical shock.

After electric-shock treatment has been started, there is time to treat any burns. However, severe bleeding must be stopped before proceeding with resuscitation.

Radiation Hazards

Excessive exposure to X rays produced by high-voltage electronic equipment and by radioactive materials may produce serious burns and permanent internal injury.

A periodic physical examination should be made on all personnel having occasion to expose themselves to X rays. Blood counts should be made every 6 weeks or as the medical staff physician designates.

A definite value of 0.1 r (roentgens) is the permissible daily dose. If this value is exceeded or the measurement is greater than 0.0002 r/min, steps should be taken to shield the equipment in order to keep the dosage rate down to the safe limit. Measurements should be made at the normal position of the operating personnel and the surrounding area.

All equipment with electronic-tube devices having potentials in excess of 10,000 volts should be checked for the presence of X rays.

Treatment for Shock (Not Electrical)

Cots and blankets should be provided for caring for the patient until the doctor arrives. Shock cases require the use of blankets as stated below.

1. Any person severely injured is potentially a patient in shock and should be regarded and treated as such. It is important to conserve body heat, particularly in cold weather; prevent added injury or danger; and get medical services as soon as possible.

2. *Keep the patient lying down* in a comfortable position. Never permit him to stand or walk.

3. *Keep the patient warm.* In many cases the only first aid measure necessary and possible is to wrap the patient underneath, as well as on top, to prevent further loss of heat. Blankets, robes, coats, or any other available woolen material can be used.

General Rules

1. Unconscious persons take cold very easily. Pneumonia is a very frequent complication. Keep the patient warm by use of hot pads or hot-water bottles, but remember that an unconscious man cannot tell you when he is being burned.

2. If necessary to move the patient, keep him lying down and do not permit him to help himself.

3. Never try to give an unconscious person a drink. It will choke him.

4. Never stop artificial respiration in less than 4 hours if the patient has not fully recovered, and if there has been any sign of recovery, continue at least 8 hours.

5. Start artificial respiration at once, and have someone telephone for the emergency squad.

Part 10

THE POSSIBLE USE OF FACSIMILE IN BROADCASTING

A. G. Cooley

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Times Facsimile Corp.

INTRODUCTION

Several attempts have been made since 1928 to establish broadcast facsimile services. The principal obstacles to success were the unavailability of radio channels and low-cost equipment and the lack of supporting revenues. Through the device of FM multiplexing, channels are now available.

Prospects for low-cost equipment are improving as production increases to meet the growing needs for military and commercial applications. Substantially all major weather stations and airfields in the United States depend upon weather maps transmitted by facsimile. Approximately 40,000 offices are equipped with facsimile for transmitting or receiving messages. Although the use is growing rapidly, at the present stage of equipment development, recorders suitable for broadcast service (synchronized independently of power lines) would have to sell for around $2,500.

Supporting revenues for facsimile broadcasters would depend upon the type of market served and the type of service rendered. All attempts of facsimile broadcasting up to the present time were directed at the urban areas, where newspapers were readily available. The material transmitted was of a news-bulletin type, which included a generous display of pictures. The number of homes equipped with facsimile was never large enough to interest advertisers. The cost of equipment and recording paper was high enough to discourage general usage. A different market must be served. There is good reason to believe that this market exists if provided with a full program of weather maps, market reports, and information on factors which affect the markets.

To transmit so much information in detail, the speed of transmission must be greater than that previously employed. The amount of copy would be far greater than most subscribers would be interested in. An automatic control system, however, could be provided that would be set by a subscriber to key-out any type of unwanted material.

TRANSMISSION MATERIAL

Weather bureaus are able to deliver only a small portion of their observation and forecast information to the public. Generalized forecasts made five or six times a day are voice-recorded and made available over telephone facilities. This information is usually not adequate to guide the many industries and activities which are vitally affected by weather, such as the planning of building construction, ship loading,

private plane flying, winter trucking, highway snow removal, generation of electric power, etc. In many cases private weather-forecast services are engaged because the Weather Bureau cannot maintain a sufficiently large staff with adequate telephone facilities to answer all the inquiries.

Weather maps showing the conditions and forecasts in a region could be transmitted on multiplexed FM channels to subscribers. When hazardous weather conditions develop, special maps could be transmitted to pin-point the areas to be affected.

Prompt reception of stock market and commodity market reports is important to many business offices. A graphical presentation such as a facsimile recording is very desirable, particularly because facsimile is substantially error-free in operation.

It is probable that within a short time facsimile equipment can be sold at a reasonable price. There is a limited but financially strong market waiting to be served. Revenue derived from subscribers and supplemented by advertisers would probably be sufficient to support a facsimile service. The supersonic-control-tone system would make it possible to charge for the service on the basis of the type of program material used.

FACSIMILE EQUIPMENT

There are several types of facsimile transmitters in production that are suitable for broadcast work. Prices are in the $2,500 to $5,000 range for single units. For broadcast work it is helpful to employ two transmitters and use them alternately.

The facsimile receivers in production at the time of publication are considered too expensive for most broadcast services. Design simplifications and mass production are prerequisites to wider use of facsimile.

Direct-recording facsimile receivers are generally classified by the kind of recording paper used. Marking signals are recorded on *electrolytic* process recorders by the passage of current through a damp paper saturated with an electrolyte that changes color by the passage of current. Blackness of the record can be increased by electroplating metal on the paper.

Marking signals are recorded on *dry electrosensitive paper* recorders by the passage of current through a white masking coating over a black conducting paper (Teledeltos). A thin black conducting layer of carbon on a white bond paper constitutes a modified type of dry recording paper (Timefax). The recording is localized to an area under the point of a stylus.

Pressure recording is accomplished in a variety of ways. In one case a magnetically actuated stylus presses on a carbon paper, causing a transfer of the carbon wax to a white sheet of paper behind or underneath. In another case a stylus, helix wire, or small wheel is inked. The ink is pressed into the recording paper. In another form, a blackened paper is covered with a wax or soaplike masking coating. The cover coating is made to appear white by minute air bubbles. Pressure applied to the coating collapses the bubbles and reveals the black undercoating. A similar paper has a dye in the bubbles or cells. In this case the coating is on a white paper. Pressure will break the bubbles and expose the dye.

Photographic recording cannot be ruled out as a possible method for broadcast service. Recently developed rapid developers and fixers provide 2-sec processing. Other favorable developments are expected. Photographic recordings can be made at video speeds with existing equipment at the rate of more than 2,000 words per second.

SPEED OF TRANSMISSION

The scanning process in the facsimile transmitter in effect divides the copy into elemental areas similar to the dots in a half-tone picture which are then transmitted at a speed determined by the capacity of the communications channel. An 8-kc channel can handle approximately 6,500 elemental areas per second. When scanning at the rate of 100 lines per inch, this channel capacity is approximately 40 sq in./min. If the scan is at the rate of 200 lines per inch, the channel capacity is approximately 10 sq in./min. The 100-line scanning rate is the most commonly used as a compromise between speed and detail sharpness. It is satisfactory for elite typewriter type.

It is marginal in transmitting newspaper copy of 7½-point type size. Two-hundred-line scanning is required to reproduce the fractions of the financial pages properly. A rough formula for speed of transmission is:

$$\text{Sq in./min} = \frac{(f_2 - f_1)60}{d^2}$$

where $f_2 - f_1$ = usable channel width
d = definition of lines per inch

The usable channel width is generally 80 to 90 per cent of the nominal channel width when single-sideband transmission is used.

This is only an approximation, because the requirements for sharp printing vary considerably with opinion. The style of type as well as the size also influences the speed-determining factors.

Usable channel width is limited by cross talk from or into other channels and by phase distortion. Phase distortion is created primarily by channel-separation filters. For example, a 48-kc telephone channel containing several sections may have a usable bandwidth for facsimile purposes of only 12 kc. In radio work a relatively large percentage of the channel can be used if only a transmitter and receiver are involved. If a radio relay chain is employed, the usable bandwidth will be considerably less unless phase-correcting devices are employed.

SYNCHRONIZATION

When a certain elemental area is scanned and transmitted, the recorder must record this area in its correct position on the recording paper. To do this within acceptable displacement tolerances (a skew of ⅛-in. in an 8½- by 11-in. copy), the transmitter and recorder mechanisms must be synchronized to an accuracy of 0.001 per cent, which corresponds to a time error of less than 1 sec per day. If the error is divided equally between the transmitter and recorder, the requirement for each machine is 0.0005 per cent. Such an error can be tolerated only when transmitting letter-size copy at 100-line-per-inch scanning. Precision of synchronization requirements increases in proportion to the area and the square of the lines per inch.

The driving motors are generally controlled by tuning-fork oscillators unless the transmitter and recorder are operated from synchronized a-c power lines. In some parts of the country, very large areas, covering several states, have synchronized power systems. In other cases, it is not possible to use the power lines for synchronizing short distances. New York City is not synchronized with Jersey City across the river, although it is synchronized with Detroit, Mich.

Another method is signal synchronizing, and there are various ways of transmitting synchronizing signals along with the picture signals. There is work yet to be done to determine whether signal synchronizing is competitive with a fork oscillator system.

Power-line synchronizing was used for the home-broadcast facsimile systems. It is satisfactory in many areas. It is quite probable, however, that it would not be considered satisfactory in many important metropolitan areas. It is desirable because of equipment simplicity and cost. One system that has been proposed is to transmit a synchronizing signal that is required and used only by the recorders that are not connected to the same power grid as the transmitting station.

FM MULTIPLEXING EQUIPMENT

Facsimile transmissions have been successfully made through FM multiplexing systems supplied by both Hogan Laboratories and Multiplex Services Corporation. The Hogan system made use of amplitude modulation of the subcarrier frequency. The Multiplex Services equipment employed the Halstead system, which frequency-modulated the subcarrier.

Multiplexing equipment is now commercially available through several companies including:

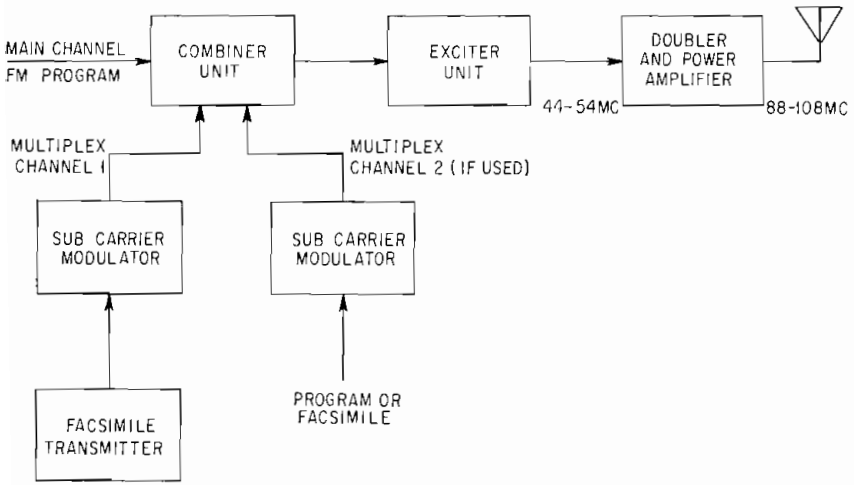

FIG. 10-1. FM and multiplex facsimile using direct mixing system.

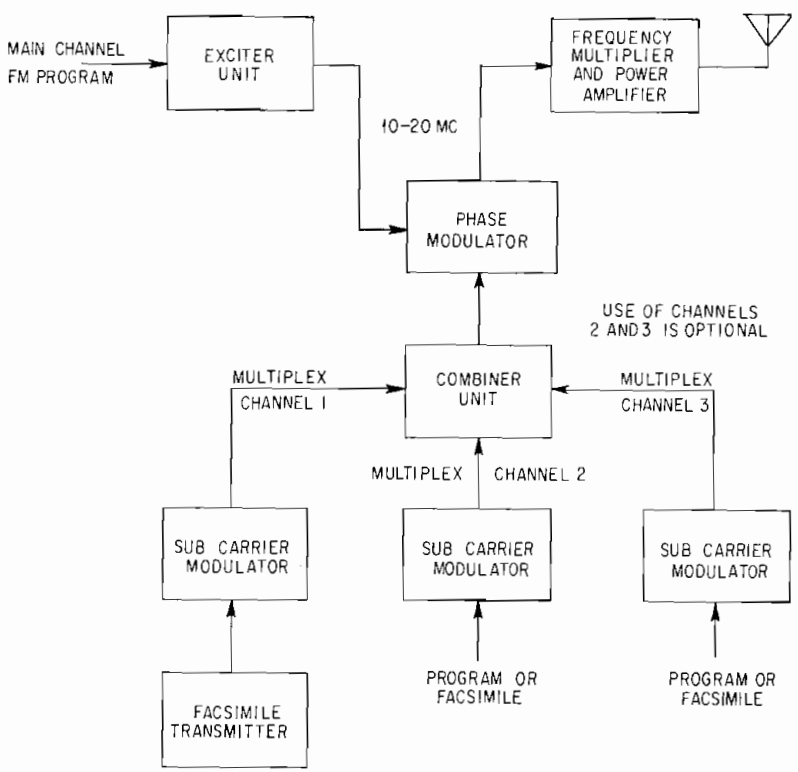

FIG. 10-2. FM and multiplex facsimile using phase modulation.

Crosby Laboratories, Inc., Syosset, N.Y.
Gates Radio Company, Quincy, Ill.
General Electronic Laboratories, Inc., Cambridge 42, Mass.
Harkins Radio Company, Phoenix, Ariz.
Multiplex Transmitter Corporation, New York 68, N.Y.
Radio Corporation of America, Camden, N.J.
Radio Engineering Laboratories, Inc., Queens, N.Y.

If the entire multiplex spectrum of the FM channel is employed for facsimile, a theoretical working speed of 250 sq in./min could be expected at 100-line scanning. This is equal to approximately two 8½- by 11-in. pages per minute. Sufficient tests

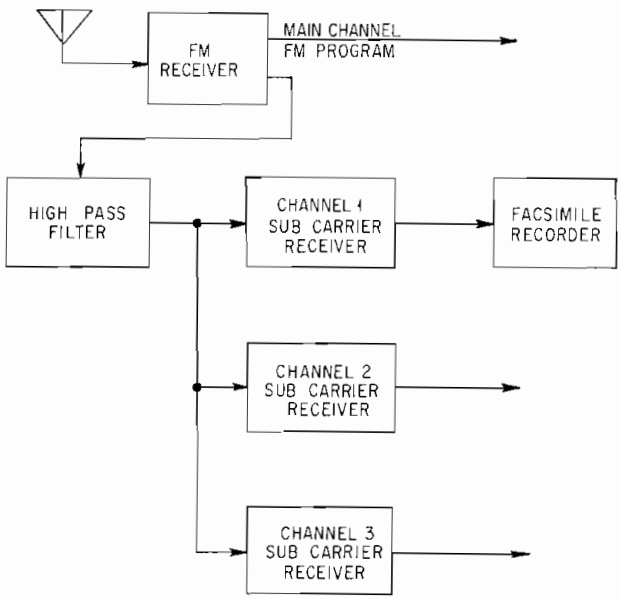

FIG. 10-3. FM and multiplex facsimile receiver.

have not as yet been made to determine the limiting speeds when repeating through a series of FM stations.

Subcarrier FM multiplex can be used to provide two or three channels in addition to the regular main-channel program source. The additional channels are provided by supersonic frequencies in the range of 20 to 75 kc, which cause only a small deviation of the main FM carrier frequency.

The signals needed to operate the facsimile receiver are taken directly from the discriminator of the FM receiver. A high-pass filter in the multiplex receiving equipment removes the main program frequencies from the multiplex channels. If more than one multiplex channel is used, the individual channels are separated by bandpass filters. Each channel is demodulated by its individual discriminator to deliver the same type of signal used at the FM transmitting station. Better signal-to-noise ratios are obtained if only one multiplex channel is used.

The direct mixing system (Fig. 10-1) combines these supersonic frequencies with the main program sound before the FM portion of the transmitter is reached. The combining is usually done at a high level point to ensure proper response to these supersonic frequencies and to prevent intermodulation. A typical installation uses frequencies in the range of 30 to 70 kc with a subcarrier deviation of 7.5 kc for 100 per cent modulation. The signal-to-noise ratio in the facsimile channel of 50 db

with a maximum distortion of 2 per cent is feasible. Two additional channels may be provided with this system.

A second system (Fig. 10-2) will handle up to three additional channels. A deviation of 6 kc is used with typical subcarrier frequencies of 26.5, 47.5, and 68.5 kc. These subcarrier frequencies are combined and used to phase-modulate the main-channel FM signal between two multiplier stages of the transmitter which are in the range of 10 to 20 Mc. This type is suitable for relaying through a chain of FM stations. No demodulation and remodulation of the multiplex subcarriers is required at the relay stations, which can be operated on an unattended basis. The multiplex frequencies do not pass through the main-channel equipment at a relay station but are again recombined by phase modulation in the same manner as at the originating station.

FCC Regulations

The first FCC rules (Docket 9425) pertaining to multiplexing of facsimile signals on an FM channel made provisions for both amplitude and frequency modulation of the subcarrier. Apparently, these rules have not been rescinded, although subsequent rulings state that frequency modulation must be employed in subsidiary communications multiplex operations. Section 3.310(i) states that "multiplex transmission as applied to FM broadcast stations means the transmission of facsimile or other signals in addition to regular broadcast signals." For complete details of the FCC Rules governing facsimile transmission, refer to Section 1 of this handbook.

Part 11

AUDIO-FREQUENCY PROOF-OF-PERFORMANCE MEASUREMENTS

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GENERAL

The Federal Communications Commission's Rules and Regulations require that certain measurements of aural characteristics be made at yearly intervals by AM and FM broadcast stations and that such measurements be submitted as a part of the application for licenses to cover construction permits of FM broadcast stations. While in general the same information and measurements are required for both, there are distinct differences in the measurements required and the method of making such measurements; differences in the response, distortion, and other characteristics; differences in the time required for making the measurements; and differences as to what are to be done with the measurements after making them. Therefore, engineers responsible for making such measurements should be fully familiar with all requirements for the type of station concerned. In the following pages a sincere effort is made to digest the requirements for each type of station for the convenience of station engineers and to set up step-by-step procedures for making the measurements. Texts of the pertinent rules are included in Section 1 of this handbook. However, each engineer concerned with such measurements should obtain and have available for reference up-to-date copies of Parts 1, 2, and 3 of the Federal Communications Commission's Rules and Regulations.

Reason for Measurements

The ultimate reason for the measuring procedure is to afford a means of locating and correcting defective equipment and to make certain the equipment is performing at its maximum capabilities. This may be termed a "preventive-maintenance procedure." Obviously, preventive maintenance is best carried out as a continuing process rather than an intermittent one where test equipment is available only for a short period once a year.

Who May Make Measurements

Any qualified engineer may make the measurements. A station may purchase the equipment and the station engineer make the measurement, or a qualified consulting engineer may be employed. Since it is desirable that the measurements be a continuing process, the FCC recommends that stations purchase their own equipment.

However, a word of caution is not out of order here: The equipment purchased must have the minimum requirements, must be maintained so as to be kept in proper calibration, and must be properly used. Measurements are made preferably by the same engineer each time. However, it may be desirable to have the measurements checked every two or three years by a qualified consulting engineer. Following the procedures set forth later, almost any engineer should be able to make the measurements without difficulty. The difficulties arise when the measurements show inadequate performance, and while often simple adjustments will correct this, sometimes correction is extremely difficult and time consuming, particularly where the equipment is barely capable of meeting the FCC requirements when adjusted for top performance.

When to Make Required Measurements

For AM Stations

The rules for AM stations require that measurements be made yearly and that one such set of measurements shall be made during the 4-month period preceding the date of filing the application for renewal of license. As the application for renewal of license must be filed at least 90 days before the expiration date of the license, this means that the measurements for that year must be made from 7 to 3 months prior to the expiration date. Where measurements are made once a year, it is suggested that they be made the first year during the period to coincide with that required for the renewal year. The periods for making measurements to comply with the renewal requirements for AM stations are as follows by location:

Delaware, Indiana, Kentucky, Pennsylvania, Tennessee, and Texas: Jan. 1 to Apr. 30.

Arizona, District of Columbia, Idaho, Maryland, Michigan, New Mexico, Nevada, Ohio, Utah, Virginia, West Virginia, and Wyoming: Mar. 1 to June 30.

California, Illinois, North Carolina, South Carolina, and Wisconsin: May 1 to Aug. 31.

Alaska, Florida, Guam, Hawaii, Iowa, Missouri, Oregon, Puerto Rico, Virgin Islands, and Washington: July 1 to Oct. 31.

Alabama, Colorado, Connecticut, Georgia, Maine, Massachusetts, Minnesota, Montana, New Hampshire, North Dakota, Rhode Island, South Dakota, and Vermont: Sept. 1 to Dec. 31.

Arkansas, Kansas, Louisiana, Mississippi, Nebraska, New Jersey, New York, and Oklahoma: Nov. 1 to Feb. 28.

For FM Stations

The time for making measurements to comply with the renewal requirements for FM stations is the same as for AM stations, except that in addition, measurements must be made and filed with the application for license to cover the construction permit. Therefore, unless the times happen to coincide, two sets of measurements will be required for the year when such application is filed.

What to Do with Measurements

For AM Stations

Measurements of AM stations should be kept on file at the station for presentation to the FCC inspector if he so requests. Do not file them with the FCC unless specifically requested.

For FM Stations

Measurements of FM stations made during equipment tests under a construction permit must be filed, together with diagrams and descriptions of measurement pro-

cedures, with the application for license to cover the construction permit. The yearly measurements should be kept in the station file for presentation to the FCC inspector if he so requests. Do not file them with FCC unless specifically requested.

What Measurements Are Required

For AM Stations

1. Over-all audio-frequency response from 30 to 7500 cps for approximately 25, 50, 85, and 100 (if obtainable) per cent modulation
2. Audio-frequency harmonic content for 25, 50, 85, and 100 per cent modulation for fundamental frequencies of 50, 100, 400, 1,000, 5,000, and 7,500 cps (either arithmetical or root-sum-square values up to tenth harmonic or root-sum-square values up to tenth harmonic or 16,000 cps
3. Percentage carrier shift for 25, 50, 85, and 100 per cent modulation with 400-cps tone
4. Carrier hum and extraneous noise generated within the equipment
5. Spurious radiations including radio-frequency harmonics
   (See Section 3.47 of FCC Rules)

For FM Stations

1. Audio-frequency response from 50 to 15,000 cps for approximately 25, 50, and 100 per cent modulation. Measurements must be made for at least 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 cps. (Frequency swing of plus and minus 75 kc is considered 100 per cent modulation.)
2. Audio-frequency harmonic distortion for 25, 50, and 100 per cent modulation for the fundamental frequencies of 50, 100, 400, 1,000, and 5,000 cps and audio-frequency harmonic distortion for 100 per cent modulation for the fundamental frequencies of 10,000 and 15,000 cps. Measurements shall include harmonics to 30,000 cps.
3. Output noise level (frequency modulation) in the band 50 to 15,000 cps in decibels below the audio-frequency level representing a frequency swing of 75 kc.
4. Output noise level (amplitude modulation) in the band 50 to 15,000 cps in decibels below the audio-frequency level representing 100 per cent amplitude modulation. [See Section 3.254 of FCC Rules and Section II-B (11) of FCC Form 302.]

What Equipment Is Required

The Commission does not attempt to set up the procedures or to recommend the equipment to be employed. There are a number of methods of making the required measurements, and numerous makes and models of equipment which are suitable for this purpose are available. In general, however, means must be provided for an audio input signal of known frequency and level and means for measuring the output in the terms desired. The specifications for such equipment must necessarily be considered in connection with the performance standards established by the Commission. It is obvious that the equipment must have such accuracy as to be well within the limits of the operation specifications for the station. (In general it should be noted that radio-service-type equipment will not meet these specifications.)

The following equipment is suggested:

1. Audio Oscillator. This instrument should preferably have a fundamental range of 30 to 17,000 cps or more. The audio-frequency harmonic content over the entire range should not exceed 1 per cent. (Instruments are available where the distortion does not exceed 0.1 to 0.25 per cent.) Accuracy of calibration should be within 3.0 per cent, although much greater accuracy will be found in the higher grade instruments. Both high- and low-impedance outputs are desirable.

2. Attenuator or Pad. To control the signal fed to the microphone terminals from the audio oscillator an accurate attenuator or pad is required. It must be capable of

attenuating the signal from at least 50 to 80 db. (Some audio oscillators have a suitable attenuator built into the unit.)

3. Level Indicator. The purpose of this item is to measure the input level and/or output level. It is usually available at the station in the form of a VU meter or vacuum-tube voltmeter. It is also included in some audio signal generators.

4. Isolation and Matching Transformer. This is used to isolate the test equipment from the station circuits and to match the impedances of the two. The requirements for this unit depend on the input impedance (normally 600 ohms) and the output impedance of the attenuator.

5. Distortion and Noise Meter. This instrument should have a scale permitting distortion readings as low as 0.5 and as high as 20 to 30 per cent. For carrier noise and hum measurements the meter reading should extend to at least 60 db (preferably lower) below an audio-frequency signal of 0 dbm (the term dbm means the power level expressed in decibels referred to 1 mw). High and low input impedance must be available, and the low input impedance is preferably of the bridging type.

6. Modulation Monitor. This item is required by the FCC in each broadcast station and is, therefore, assumed available.

7. Field-strength Meter or Communications-type Receiver. With regard to the observations required on the radio-frequency transmissions of the standard stations, the Commission's Rules state that field-strength measurements are preferred but that observations made with a communications-type receiver will be accepted. To conduct such observations considerable care must be exercised in the selection of the receiver as well as in its actual use. As a general rule this receiver should have at least one stage of RF ahead of the first detector. It should be well shielded, and the frequency range should permit observations to at least the tenth or fifteenth harmonic of the fundamental frequency of the station. A means of making comparative signal-strength checks such as an "S meter" is very desirable and almost essential if suitable and meaningful observations are to be made. Amateur communications receivers will often meet these requirements. Although such observations are not required with respect to FM stations, it is a wise precaution to check spurious and harmonic radiations. Particular attention should be given to the second harmonic to avoid causing interference to television stations.

8. Oscilloscope. Although an oscilloscope is not essential, it is often very useful in analyzing and correcting difficulties which prevent compliance with the requirements.

Estimated Cost of Equipment

Equipment of various grades is now available upon order, and these purchases should be carefully considered on the basis of what use is to be made of the various components, as well as to the cost. Suitable and satisfactory equipment will have the following approximate price ranges:

Audio oscillator or signal generator, $115 to $600
Calibrated attenuator, from a few dollars to several hundred
Level indicator, $50 to $100 and up
Isolation and matching transformer, $10 to $25
Distortion and noise meter, $400 to $650
Communications-type receiver, $125 and up
Oscilloscope, $75 and up

HOW TO MAKE MEASUREMENTS

Detailed instructions for the operation of the particular piece of equipment are normally supplied by the manufacturer and should be followed. Some manufacturers include procedures for making the measurements required by the FCC, but this practice is far from universal. To assist in overcoming this lack and for the benefit of stations assembling the equipment from units purchased from different manufacturers, a step-by-step procedure for making the required measurements is set forth below,

together with precautions that should be taken in setting up the equipment and making the measurements.

Precautions

1. All measurements shall be made with the equipment adjusted for normal program operation and shall include all circuits between the main studio microphone terminals and the antenna output, including telephone lines, preemphasis circuits, and any equalizers employed except for microphones, and without compression if a compression amplifier is installed unless otherwise noted.

Where an AM station operates DA-2 or DA-N, it is not required to make measurements under both conditions of antenna operation unless there is reason to believe some unusual condition exists. The practice of making two sets of measurements, however, is considered advisable. If the antenna systems are adjusted so that the transmitter is feeding in exactly the same impedances under both conditions, there should be no difference. (Some difficulty may be experienced at the higher audio frequencies when the common-point impedance(s) for sidebands is greatly different from that at the carrier frequency.)

2. Audio systems of most broadcast stations use balanced 600-ohm ungrounded circuits. This, however, is not universal, and before attempting to make measurements, the facts in this regard must be determined. Otherwise, the measurements obviously will be in error and serious damage may result to the station equipment, the measuring equipment, or both.

3. It is very important to guard against stray fields affecting the accuracy of the measurements. This is particularly true with respect to use of the distortion and noise meter and of the VTVM when used in the presence of the transmitter. Difficulties of this nature are usually evidenced by residual readings. It is suggested that:

a. Use short power cord and bypass it; also reverse plug for lowest residual reading.

b. The chassis of the instrument must be firmly grounded with as short a lead as possible to the station ground bus.

c. Use short voltmeter leads with RF chokes, and bypass. It may also be necessary to shield the terminals and the instrument itself. In some cases shielding the front will be adequate.

Procedure for AM Stations

Audio-frequency Response

1. Adjust all equipment from microphone preamplifier input terminals to the antenna for normal program operation.

2. Bypass any limiting amplifiers.

3. Connect the audio-signal-generator equipment as shown in Fig. 11-1. Details of

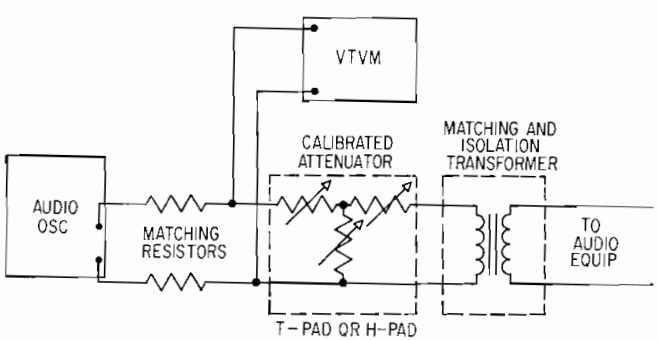

FIG. 11-1. Basic method of connecting audio-signal-generator equipment.

this will depend on the type and impedances of the oscillator, attenuator, and the station audio circuits. (*Do not connect to input terminals yet.*)

4. Adjust the oscillator to 1,000 cps.

5. Adjust the oscillator amplitude control until the VTVM reads zero.

6. Adjust the attenuator to approximately 40 or 50 db.

7. Connect the signal generator to the microphone preamplifier input circuit.

8. Adjust the amplitude control until the VTVM reads approximately 15 dbm.

9. Adjust the attenuator until the station modulation monitor indicates 25 per cent modulation, at the same time making certain that the VTVM still reads the same as step 8. If it does not, readjust the amplitude control and attenuator until the modulation monitor shows 25 per cent at the same time that the VTVM shows the same as in step 8.

10. Record the attenuator setting in all the upper spaces of the form shown on Form AFP-1 for 25 per cent modulation and also in the second space under 1,000 cps.

11. Adjust the oscillator to 30 cps.

12. Adjust the amplitude control and attenuator until the modulation monitor reads 25 per cent at the same time the VTVM reads the same as in step 8.

13. Record the attenuator setting in the second space down under 30 cps in Form AFP-1.

14. Subtract the entry in the second space down from that in the first space, and enter the difference in the third or lower space.

15. Repeat steps 11 to 14 for 100, 400, 5,000, and 7,500 cps. There should not be more than approximately 0.2-db difference between any two successive readings. If there is, readings should be taken at intermediate frequencies.

16. Repeat steps 9 through 15 for 50, 85, and 100 per cent modulation. (If 100 per cent modulation is not obtainable, use the highest percentage that is obtainable.)

17. Plot all readings in the lower spaces for each percentage of modulation on the graph sheets on Form AFP-2.

18. If the decibel variation between 100 and 5,000 cps is greater than 2 db from that at 1,000 cps, operation is in violation of the Commission's Rules. Appropriate corrective steps should be taken, and the measurements repeated.

Audio-frequency Harmonic Distortion

1. Repeat steps 1 through 9 above.

2. Connect the distortion and noise meter to the output of the transmitter. This connection depends on the instrument employed, and the instructions of the manufacturer should be followed. In general, there are two principal types: one in which the detector circuit is built into the meter and the other where a separate detector must be provided. In the latter case it is normal to use the detector in the modulation monitor.

3. Following the instructions of the manufacturer of the distortion and noise meter determine the harmonic content for 1,000 cps and record in the space provided on Form AFP-3.

4. Repeat steps 9 through 12 under Procedure for AM Stations and step 3 above for 30, 50, 100, 400, 5,000 and 7,500 cps.

5. Repeat steps 4 through 12 under Audio-Frequency Response and steps 3 and 4 above for 50, 85, and 100 per cent modulation.

6. Plot the data on graphs on Form AFP-3.

7. If the harmonic content is greater than 5 per cent from 0 to 84 per cent modulation or 7.5 from 85 to 95 per cent modulation, operation is in violation of the Commission's Rules. Appropriate corrective steps should be taken and the measurements repeated.

Percentage Carrier (Current) Shift

1. Adjust all equipment from the microphone preamplifier input terminals to the antenna for normal program operation.

2. Bypass any limiting amplifiers.

3. Connect the audio signal generator equipment as shown in Fig. 11-1. Details of this will depend on the type and impedances of the various units and of the station audio circuits. (*Do not connect to the input terminals yet.*)

4. Adjust the oscillator to 400 cps.

5. Adjust the oscillator amplitude for minimum output.

6. Adjust the attenuator to 40 or 50 db.

7. Connect to the microphone preamplifier input.

8. Connect a d-c voltmeter having a very high input impedance so as to read the d-c potential in the detector circuit used in the output of the transmitter as described under Audio Harmonic Distortion.

9. If the detector in the distortion and noise meter is used, adjust the control until maximum d-c voltage is obtained.

10. Read and record in the spaces provided on Form AFP-4. (This is the "no-modulation" reading.)

11. Increase the input by adjusting the oscillator amplitude control and the attenuator until the modulation monitor reads 25 per cent.

12. Read the d-c voltage and record it in the space provided on Form AFP-4. (This is the reading with 25 per cent modulation.)

13. Enter the difference between the reading without modulation and the reading with modulation in the space provided.

14. Calculate and enter in the space provided in the per cent carrier shift for 25 per cent modulation. Per cent carrier shift is the difference between the readings with and without modulation divided by the reading without modulation and multiplied by 100.

15. Repeat for 50, 85, and 100 per cent modulation.

16. If the carrier shift is greater than 5 per cent at any percentage of modulation, operation is in violation of the Commission's Rules. Appropriate corrective steps should be taken and the measurements repeated.

Carrier Hum and Extraneous Noise

1. Adjust all equipment from the microphone amplifier input terminals to the antenna for normal program operation.

2. Bypass any limiting amplifiers.

3. Connect the audio-signal-generator equipment as shown in Fig. 11-1. Details of this will depend on the type and impedances of the various units and of the station audio circuits. (*Do not connect to the input terminals yet.*)

4. Adjust the oscillator to 400 cps.

5. Adjust the amplitude control to 15 db.

6. Adjust the attenuator to approximately 40 db.

7. Connect to the input of the microphone preamplifier.

8. Adjust the attenuator until the modulation monitor indicates 100 per cent modulation.

9. Connect the distortion and noise meter to the output of the transmitter. This connection depends on the instrument employed, and the instructions of the manufacturer should be followed. In the event the instrument does not have a detector circuit built into it, the detector of the modulation monitor can be employed provided it has a low hum and noise level, as this will be added to that of the transmitter in the readings.

10. Follow the instructions of the manufacturer, which will be, in general, to adjust the sensitivity so as to obtain a full-scale reading with the output meter set for maximum reading.

11. Disconnect the audio signal generator, and connect a 600-ohm (wire-wound) resistor across the input terminals of the main studio amplifier. If the input impedance is other than 600 ohms, use the corresponding value of resistor. (The signal generator can be turned off and 20 to 30 db inserted by the attenuator, but the resistor connected across the input is the preferred method.)

12. Increase the sensitivity of the output meter until a reading is obtained. Read and record.

13. Calculate the combined hum and noise. In per cent this is the reading obtained in step 12 divided by the reading in step 10 and multiplied by 100. The hum and noise ratio to the 100 per cent value can be converted to decibels in the usual manner. Both should be recorded on Form AFP-4.

14. If the hum and noise is less than 50 db below 100 per cent modulation between 150 and 5,000 cycles or less than 40 db below 100 per cent modulation outside that range operation, it is in violation of the Commission's Rules. Appropriate corrective steps should be taken and the measurements repeated.

Spurious Radiations

1. All equipment, including any limiting amplifiers, should be in normal adjustment with a program or test tone at as high a percentage of modulation as is ever used.

2. With the communications receiver, make observations at a distance of approximately ½ mile from the antenna or closer if possible for spurious emissions including harmonics. With the gain control turned to a maximum, tune around the frequency of the station and on up to the tenth or fifteenth harmonic of the assigned frequency. By means of the S meter determine and record the approximate signal strength of the spurious emissions that are found.

3. In the event any of consequence are found, steps should be taken to eliminate or reduce them as far as possible. In the event that any disagreement arises with the Commission, it may be necessary to take actual field measurements. It is not acceptable for the radiations on other than the assigned frequency to exceed 60 db below the fundamental, and they should be 70 or 80 db down.

Procedure for FM Stations

Audio-frequency Response

1. Repeat the procedure outlined under Procedure for AM Stations *except:* Use audio frequencies of 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 cps at 25, 50 and 100 per cent modulation.

(These measurements should be made without deemphasis; however, standard 75-μsec deemphasis can be employed in the measuring circuit or in the system provided the accuracy of the deemphasis circuit is sufficient to ensure that the measured response is within the prescribed limits.)

2. Record in the spaces provided on Form AFP-5.

3. Plot the data on Form AFP-6.

4. Reference should be made to Appendix B, Section 3.317, to determine whether the operation is satisfactory.

Audio-frequency Harmonic Distortion

1. Repeat the procedure outlined under Procedure for AM Stations, Audio-Frequency Harmonic Distortion, for AM stations *except:* Use audio frequencies of 50, 100, 400, 1,000, and 5,000 cps for 25 and 50 per cent modulation and audio frequencies of 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 cps for 100 per cent modulation. (These measurements should be made with standard 75-μsec deemphasis in the measuring circuit or system and should include harmonics to 30,000 cps.)

2. Record in the spaces provided on Form AFP-7.

3. Plot the data on Form AFP-7.

4. If this distortion exceeds the following values, operation is in violation of the Commission's Rules and the equipment should be readjusted and the measurements repeated: 50 to 100 cps, 3.5 per cent; 100 to 1,500 cps, 2.5 per cent; 7,500 to 15,000 cps, 3.0 per cent.

Output Noise (FM)

1. Repeat the procedure outlined under Carrier Hum and Extraneous Noise for AM stations using FM detection and standard 75-μsec deemphasis and VU meter.
2. Record in spaces provided on Form AFP-8.
3. If the noise is in excess of 60 db down from the audio level representing a frequency swing of ±75 kc, operation is in violation of the Commission's Rules and appropriate corrective steps should be taken and the measurements repeated.

Output Noise (AM)

1. Shunt the 600-ohm wire wound resistor across microphone preamplifier input.
2. Determine the audio voltage equivalent to 100 per cent modulation. This may be considered as equal to the d-c voltage across the meter determining the power level in the monitor.
3. By use of the distortion and noise meter with standard 75-μsec deemphasis and VU meter, determine the audio voltage at the same point for the same carrier level.
4. Compute the per cent AM modulation by dividing the andio voltage by the carrier level voltage and multiply by 100. Convert to decibels down from 100 per cent modulation. Record in spaces provided on Form AFP-8.
5. If the noise is in excess of 50 db below the audio level representing 100 per cent modulation, operation is in violation of the Commission's Rnles. Appropriate corrective steps should be taken and the measurements repeated.

HOW TO USE THE MEASUREMENTS

Compliance with the Commission's Rnles in regard to filing the measurements was covered earlier. However, the measurements were required in the first place to determine whether the emissions of the station are satisfactory and in accordance with the Rules and good engineering practice. Obviously, if the distortion, hum, noise, RF harmonics, or other spurious emissions are not within the Rules, appropriate corrective steps must be taken and new measurements made. Even if the measurements are within the requirements, there are very likely adjustments or changes that can be made with little or no expense which would materially improve the operation or correct a weakness or border-line operation which may otherwise cause off-the-air time later.

In other words, these measurements should not be considered just a necessary nuisance to comply with the Commission's requirements but should be used for station improvement. If the station purchases the equipment, a procedure should be established for making the measurements at regular intervals and the measurements kept on file, together with a record of the adjustments that have been made from time to time to maintain proper operation. This will often indicate potential sources of complete failure at inopportune times, particularly in bad weather, when lines and equipment are more prone to fail and more difficult to repair.

FORMS AFP-1 TO AFP-8

The following forms, reproduced for the sake of clarity here, are available in booklet form as a service to NAB member stations at no cost. This service has been initiated in an attempt to standardize audio proof-of-performance measurements and records.

Station KC , City State

OVERALL AUDIO FREQUENCY RESPONSE DATA

25% MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

50% MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

85% MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

100%(or %) MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

(1) RECORD THE ATTENUATOR READING FOR THE 1000 CPS REFERENCE SIGNAL IN EACH SPACE IN THIS ROW.

(2) RECORD THE ATTENUATOR READINGS FOR THE SPECIFIED FREQUENCIES IN THIS ROW.

(3) RECORD THE AUDIO FREQUENCY RESPONSE VARIATION IN THIS ROW WHICH IS OBTAINED BY SUBTRACTING ROW (2) FROM ROW (1) THESE FINAL FIGURES ARE TO BE USED IN PLOTTING THE GRAPHS.

_____ _____ 19____

Engineer

Form No. AFP-1

FIG. 11-2*a*. Form AFP-1.

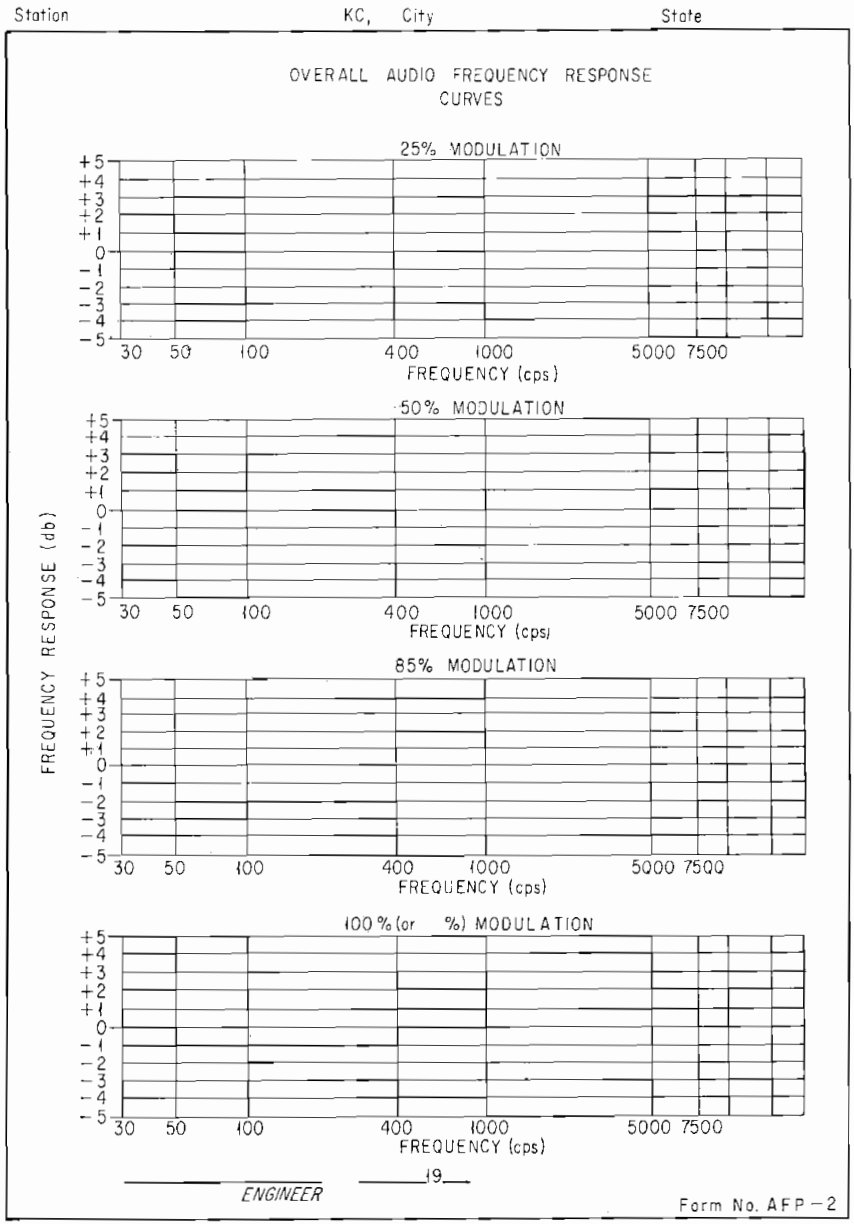

FIG. 11-2*b*. Form AFP-2.

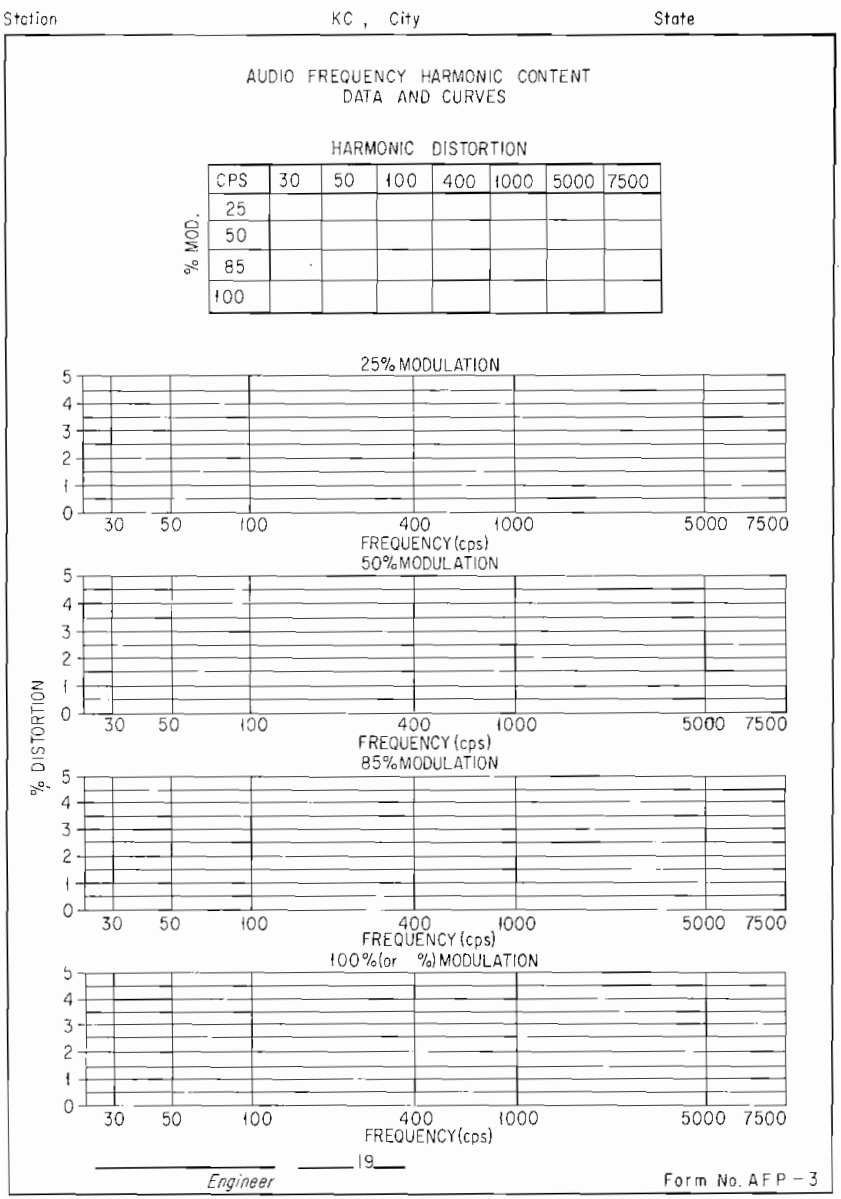

Fig. 11-2c. Form AFP-3.

Station KC, City State

CARRIER SHIFT AND COMBINED
NOISE AND HUM DATA

CARRIER SHIFT DATA (at 400 cps)

% MOD.	25	50	85	100
(1)				
(2)				
(3)				
(4)				

(1) RECORD DC VOLTMETER READING WITHOUT MODULATION IN EACH SPACE IN THIS ROW.

(2) RECORD DC VOLTMETER READINGS WITH MODULATION IN THIS ROW.

(3) SUBTRACT ROW (2) FROM ROW (1) AND RECORD DIFFERENCE IN THIS ROW.

(4) COMPUTE CARRIER SHIFT BY EQUATION: $\frac{\text{ROW (3)}}{\text{ROW (1)}} \times 100$, AND RECORD RESULTS IN THIS ROW.

COMBINED NOISE AND HUM READING

DB	%

_____ _____ 19____
Engineer

Form No. AFP – 4

FIG. 11-2*d*. Form AFP-4.

Station Ch. City State

OVERALL AUDIO FREQUENCY RESPONSE
DATA

25% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

50% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

100% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

——% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

(1) RECORD THE ATTENUATOR READING FOR THE 1000 CPS REFERENCE SIGNAL IN EACH SPACE IN THIS ROW.

(2) RECORD THE ATTENUATOR READINGS FOR THE SPECIFIED FREQUENCIES IN THIS ROW.

(3) RECORD THE AUDIO FREQUENCY RESPONSE VARIATION IN THIS ROW WHICH IS OBTAINED BY SUBTRACTING ROW (2) FROM ROW (1). THESE FINAL FIGURES ARE TO BE USED IN PLOTTING THE GRAPHS.

_____ ——19——
Engineer

Form No. AFP-5

Fig. 11-2*e*. Form AFP-5.

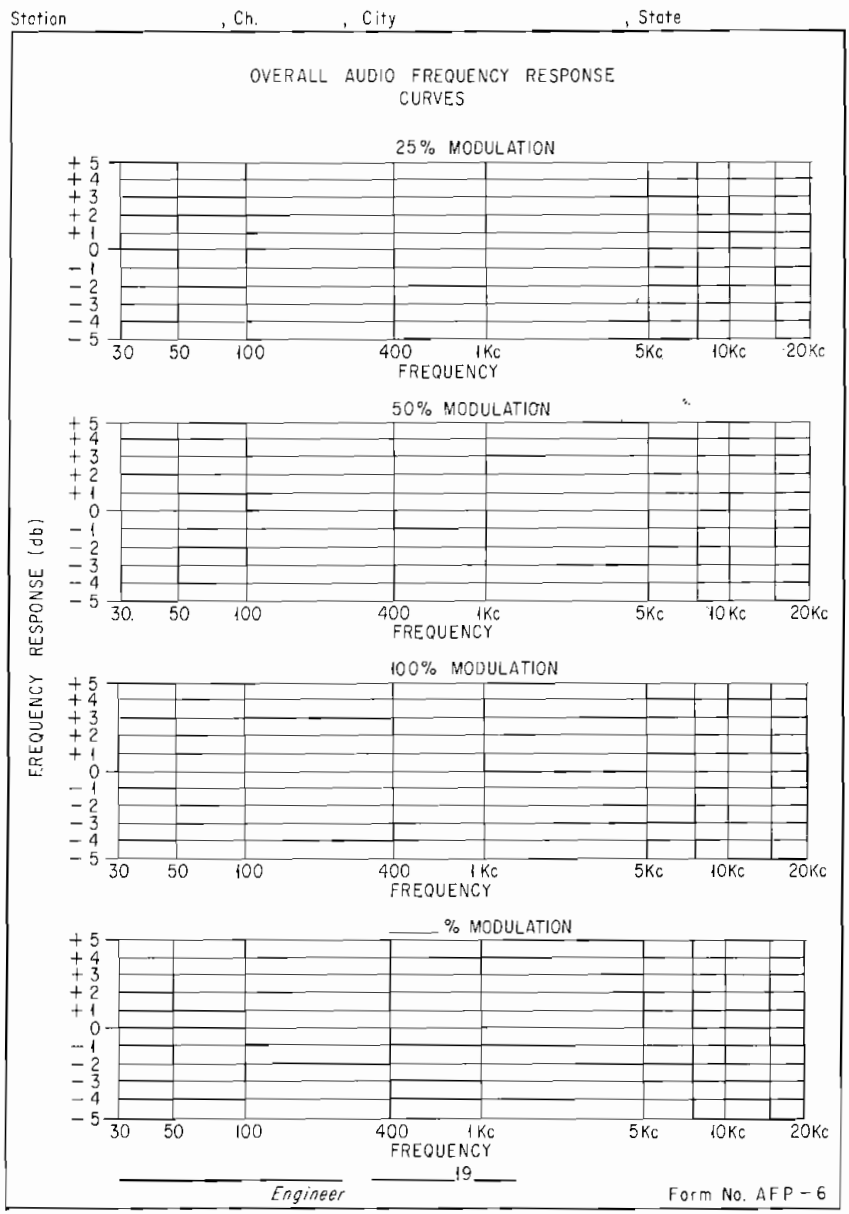

Fig. 11-2*f*. Form AFP-6.

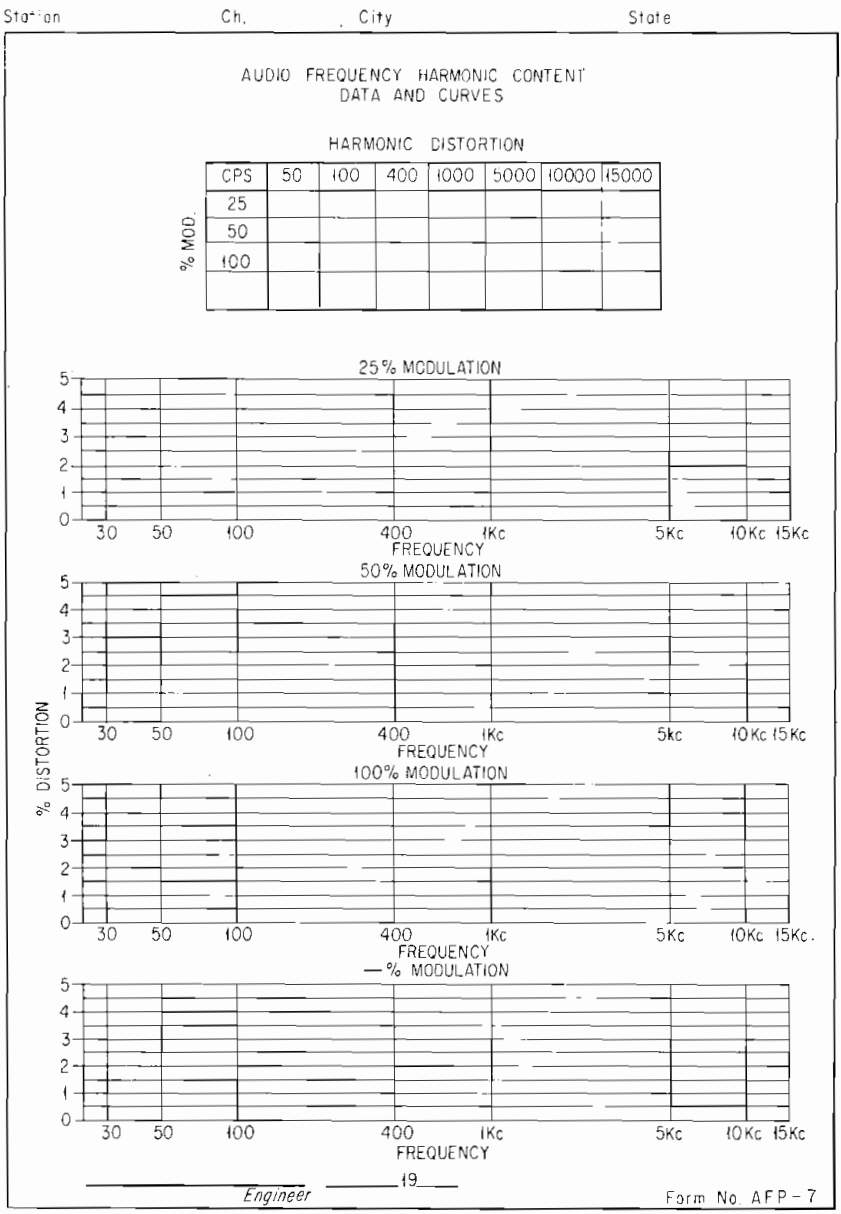

Fig. 11-2g. Form AFP-7.

Station Ch. City State

OUTPUT NOISE LEVEL DATA

OUTPUT NOISE LEVEL (Frequency modulation)

VM READING AT 100% MODULATION	NOISE VOLTAGE	% NOISE: $\frac{\text{COLUMN 2}}{\text{COLUMN 1}} \times 100$	DB DOWN

OUTPUT NOISE LEVEL (Amplitude modulation)

VM READING AT 100% MODULATION	NOISE VOLTAGE	% NOISE: $\frac{\text{COLUMN 2}}{\text{COLUMN 1}} \times 100$	DB DOWN

_____ 19____

Engineer

Form No. AFP – 8

FIG. 11-2*h*. Form AFP-8.

Part 12

PROOF OF PERFORMANCE FOR A TELEVISION STATION

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New York, N.Y.

WHY A PROOF OF PERFORMANCE

Proof of performance is required by the FCC when an application is filed for a license for a television broadcast station. It assures both the operator and the Federal Communications Commission that construction and operation have been in accordance with the formal authorizing instruments of the Commission. When modifications are made after the initial licensing, submission of a "proof" is required as evidence of continued compliance with the Regulations. In addition, the proof provides an opportunity for the station operator to assess the performance of his plant for his own benefit.

After a proof has been accepted by the Commission and the Program Test Authority granted, it is incumbent on the licensee to make periodic proof measurements for three reasons. This should be done in order (1) to have the information available as proof to an FCC inspector that the station is operating within the Rules and Regulations, (2) to have available as a reference in license renewal applications, and (3) to indicate to the operator that his equipment is operating at peak performance, transmitting pictures and sound of the highest possible quality at all times. The transmission of a "standard television signal" is a requirement of the Rules and the proof attests to compliance with the Rules.

In making a proof, the operator establishes a method of operational maintenance which will guide him in a continuous quality assessment. A properly executed proof, done with the full understanding of the operating staff, is a very valuable tool to the station. The measurements carried out for the proof can be established as required periodic maintenance measurements within the plant. The formal submission of these data or their inspection by the FCC can be equated to an audit of a carefully kept set of accounting records, confirming the soundness of the operation. For many operators a proof has the onus of something very special and difficult. It is often thought that unusual and obscure measurement techniques are required just to satisfy a special governmental regulation. The following explanation of the performance of a proof will show that the measurements are simple to undertake. These measurements not only satisfy the requirements of the FCC but in addition assure the operator that he is getting the maximum return from his equipment and manpower investment.

Broadcast Application — FEDERAL COMMUNICATIONS COMMISSION — Section II-C

LICENSE APPLICATION ENGINEERING DATA
TELEVISION BROADCAST

Name of applicant

1. Facilities authorized in construction permit

Call letters	Channel No.	File No. of construction permit

Frequency ——— Mc.

Carrier frequency
Visual ..... Mc
Aural ..... Mc

Effective Radiated Power (visual)	Effective Radiated Power (aural)	Antenna height above average terrain
In dbk:	In dbk:	feet
In kw:	In kw:	

2. Station location (principal community)

State	City or town

3. Transmitter location

State	County
City or town	Street Address (or other identification)

4. Main studio location

State	County
City or town	Street address

5. Transmitters Installed

Visual

Make	Type No.	Rated power
		In dbk:
		In kw:

Aural

Make	Type No.	Rated power
		In dbk:
		In kw:

Operating constants

Visual transmitter (while transmitting black)

D. C. plate current in last radio stage, in amperes	Applied D. C. plate voltage of last radio stage, in volts

Transmitter power output (after vestigial sideband filter, if used, and after multiplexer, if combined)	Multiplexer loss in db, if separate:	Input to transmission line in dbk:
In dbk:		
In kw:		

Transmission line power loss in db:	Antenna input power in dbk:	Antenna power gain in db:	Effective radiated power
			In dbk:
			In kw:

Attach as Exhibit No. ____ complete information concerning the method of power output determination. If power is measured at output of multiplexer, so state.

Reading of power output meter (transmission line voltage, current or power; indicate which) while operating at authorized power:

Aural transmitter

D. C. plate current in last radio stage, in amperes	Applied D. C. plate voltage of last radio stage, in volts
Plate input power to last radio stage in kilowatts	Efficiency factor F of transmitter at operating power, in percent
Transmitter power output In dbk: In kw:	RF transmission line meter reading

6. Antenna and transmission line

Antenna make and Type No.	Number of sections	Power gain in db

Antenna supporting structure

Overall height of antenna system above ground in feet

Geographical coordinates of antenna (to nearest second)
North latitude ° ' " West longitude ° ' "

If directional antenna is used, give full details including horizontal and vertical plane radiation patterns, as Exhibit No.

Is electrical or mechanical beam tilting employed? Yes ☐ No ☐
If so, describe fully in Exhibit No. ____, including horizontal and pertinent vertical radiation patterns.

Has antenna been altered to provide null fill-in? Yes ☐ No ☐
If so, describe fully in Exhibit No.

Transmission line

Make	Type No.	Coaxial or waveguide
Size (nominal inside transverse dimensions) in inches	Length in feet	Power loss in db for this length

Multiplexer

Make	Type No.

If emergency antenna or transmission line measures are provided, describe in Exhibit No.

7. Modulation monitors

(a) Visual monitor or monitoring equipment

Make	Type No. (or describe in Exhibit No.)

(b) Aural monitor

Make	Type No.

8. Frequency monitors

(a) Visual monitor

Make	Normal limits of deviation of carrier frequency shown by monitor
	cps. high/low to cps. high/low
Type No.	

FIG. 12-1*a*. FCC Form 302, Sec. II-C, p. 1.

Broadcast Application	TELEVISION BROADCAST ENGINEERING DATA	Section II-C, Page 2

8. (Continued)

(b) Aural monitor

Make	Normal limits of deviation of carrier frequency shown by monitor
Type No.	high ____ high cps. to cps. low ____ low

If either frequency monitor indicates any carrier deviation in excess of the permissible tolerance, describe in Exhibit No. and state the corrective measures taken.

If the carrier frequencies have been measured by other means, describe in Exhibit No. , giving the date, method used or frequency measuring service employed, the results obtained and the monitor readings (high or low) at the time.

9. Performance data - Visual transmitter

a. Attach as Exhibit No. data showing the following:

1. Overall attenuation versus frequency of the visual transmitter;
2. Field strength or voltage of the lower side-band for a modulating frequency of 1.25 mc. or greater, and of the upper side-band for a modulating frequency of 4.75 mc. or greater;
3. A description of the equipment and technique used in making these measurements.

b. Attach as Exhibit No. data demonstrating that the waveform of the transmitted signal conforms to that specified by the standards. Until the form of those measurements may be specified by the Commission, the character of this data is left to the discretion of the applicant.

c. Attach as Exhibit No. a photograph of a test pattern taken from a receiver or monitor connected to the transmitter output.

10. Performance data - Aural transmitter

Attach as Exhibit No. data, diagrams, and appropriate graphs together with description of measurement procedures and instruments with regard to the following: (All measurements shall be made with the equipment adjusted for normal program operation and shall include all circuits between the main studio microphone terminals and the antenna output, including telephone lines, pre-emphasis circuits and any equalizers employed except for microphones, and without compression if a compression amplifier is installed.)

a. Audio frequency response from 50 to 15,000 cycles for approximately 25, 50 and 100 percent modulation. Measurements shall be made on at least the following audio frequencies: 50, 100, 400, 1000, 5000, 10,000 and 15,000 cycles. The frequency response measurements should normally be made without de-emphasis; however, standard 75 microsecond deemphasis may be employed in the measuring equipment or system provided the accuracy of the deemphasis circuit is sufficient to insure that the measured response is within the prescribed limits.

b. Audio frequency harmonic distortion for 25, 50 and 100 percent modulation for the fundamental frequencies of 50, 100, 400, 1000 and 5000 cycles. Audio frequency harmonics for 100 percent modulation for fundamental frequencies of 10,000 and 15,000 cycles. Measurements shall normally include harmonics to 30,000 cycles. The distortion measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

c. Output noise level (frequency modulation) in the band of 50 to 15,000 cycles in decibels below the audio frequency level representing a frequency swing of 25 kilocycles. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

d. Output noise level (amplitude modulation) in the band of 50 to 15,000 cycles in decibels below the level representing 100 percent amplitude modulation. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

11. In what respect, if any, does the apparatus constructed differ from that described in the application for construction permit or in the permit?

I certify that I am the Technical Director, Chief Engineer or Consulting Engineer for the applicant of the radio station for which this application is submitted and that I have examined the foregoing statement of technical information and that it is true to the best of my knowledge and belief. (This signature may be omitted provided the engineer's original signed report of the data from which the information contained herein has been obtained is attached hereto.)

Date _____

_____

Technical Director, Chief Engineer or Consulting Engineer

FIG. 12-1*b*. FCC Form 302, Sec. II-C, p. 2.

THE PERFORMANCE OF A PROOF

As an absolute minimum, the proof is a series of exhibits detailing information requested in Section II-C of FCC Form 302, License Application Engineering Data—Television Broadcast as amended (Fig. 12-1*a* and *b*). As a practical minimum, the "proof" is what the name implies, proof (1) that the facility for which license application has been made is, in fact, constructed in accordance with the Construction Permit and (2) that the facility is capable of operating in conformance with the Rules and Regulations—that it has transmitted a "standard television signal."

To measure the performance of the television plant, all the normal segments of the plant must be included. The main studio, as well as the transmitting plant, should be included in the measurement, for this is the source of the original signals. While program content is not a part of the reported measurements, the handling of program material, both audio and video, is the object of the measurements.

Most of the visual transmitter characteristics described in the Rules specify the transmitter as the item being measured but, at the same time, define the transmission standards as applying to the radiated signal. Thus, it is incumbent on the operator to prove the performance of the transmitter where it is specifically requested and to prove that the entire system can meet the transmission standards. If it is not possible to measure the complete system at one time, an attempt should be made to provide the transmitting plant with operating tolerances more stringent than those in the Rules, allowing for some degradation in the studio plant and studio-to-transmitter circuits.

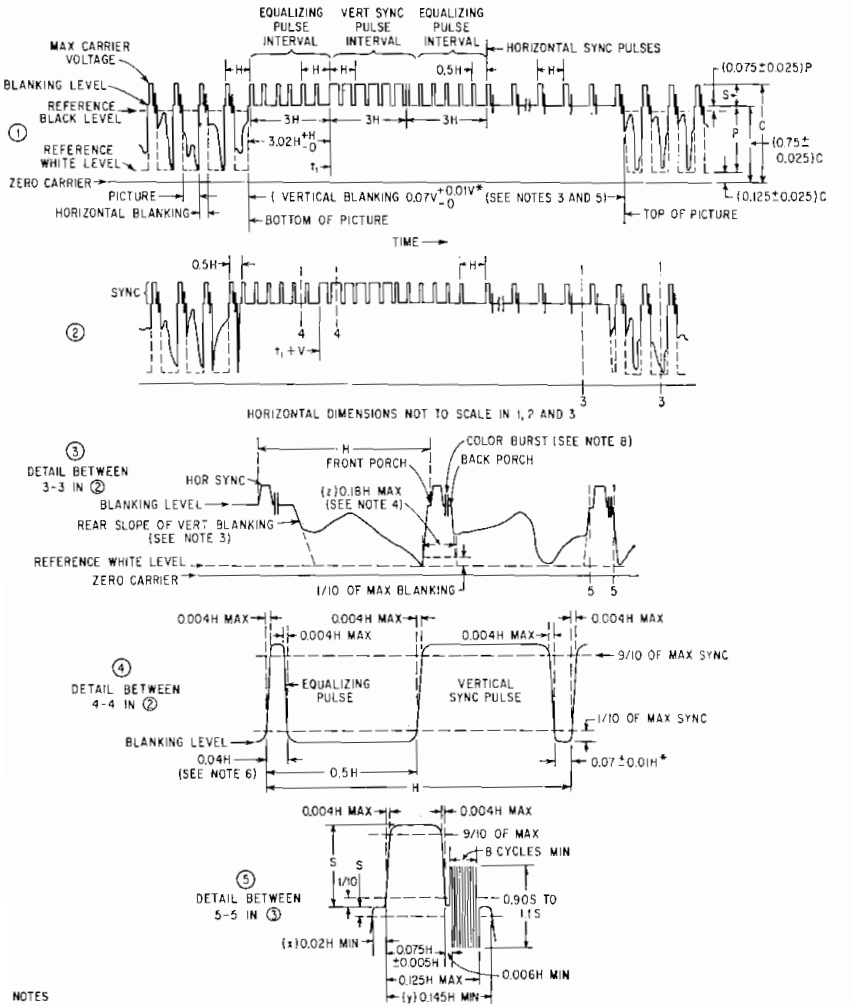
The aural transmitter is defined in two ways: as a transmitter for some measurements and as a transmitting system for others. Transmission measurements for the aural system must be made through this entire system starting with the microphone preamplifier, while the operating characteristics of the aural transmitter alone can naturally be measured on the aural transmitter itself. In all cases, however, for both the aural and visual transmitters, it must be remembered that the "transmitter" input terminals are the *input terminals of the "plant"* and not those physically on the transmitter cabinet. Here the intent of the regulations is quite clear: Those normally used preemphasis and auxiliary components required for proper operation of the transmitter, within the transmitting plant, *are all considered as being a part of the transmitter.*

Examination of FCC Form 302, Section II-C (Fig. 12-1*a* and *b*) will aid in demonstrating the performance of a "proof." All information that can be definitely listed is requested in the blank form but the information that requires detailing is requested in exhibit form.

Determination of Transmitter Power Output

The first exhibit requested is complete information concerning the method of power-output determination (II-C-5). The Rules and Regulations (3.689-a-1) [1] stipulate that the peak output power of the visual transmitter shall be measured at the output of the vestigial-sideband filter (if one is used) while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission-line surge impedance while transmitting a standard black picture. The object is simply to provide a means for measuring the output power of the transmitter while operating into a load substantially equal to the load normally seen by the transmitter. To accomplish this end it is necessary to know the impedance characteristics both of the antenna and of the dummy load being used. This can be ascertained by standard impedance-measuring techniques utilizing bridges, admittance meters, or RF sweep techniques. Once the similarity of the antenna and the dummy load wattmeter have been established, a simple power reading can be made. It should be recognized during this measurement, however, that there are many components between the transmitter output and the antenna system input that can have small losses. The use of harmonic filters, lower sideband notch filters, diplexers, and triplexers must be taken into consideration, and

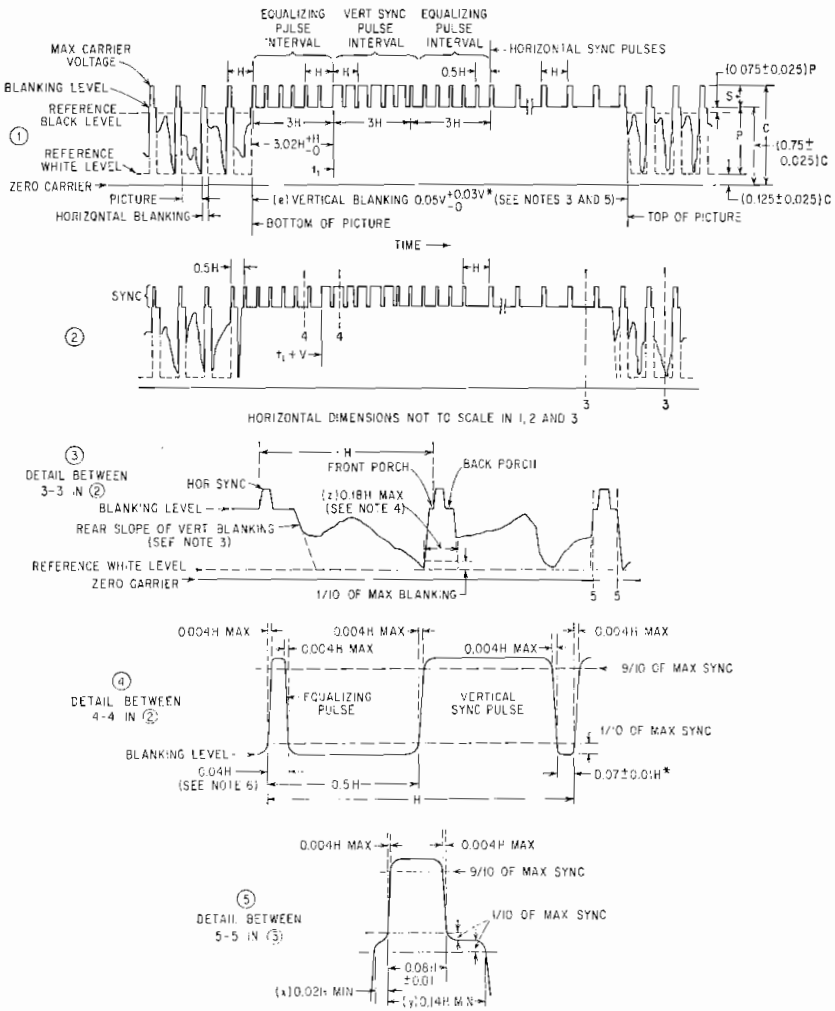
[1] Here and in the following pages, applicable paragraphs of the FCC Rules and Regulations, effective Jan. 2, 1956, are referenced parenthetically (see Sec. I).



NOTES

1. H = TIME FROM START OF ONE LINE TO START OF NEXT LINE.
2. V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD.
3. LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1H.
4. LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MINIMUM AND MAXIMUM VALUES OF (x+y) AND (z) UNDER ALL CONDITIONS OF PICTURE CONTENT.
5. DIMENSIONS MARKED WITH ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES.
6. EQUALIZING PULSE AREA SHALL BE BETWEEN 0.45 AND 0.5 OF AREA OF A HORIZONTAL SYNC PULSE.
7. COLOR BURST FOLLOWS EACH HORIZONTAL PULSE, BUT IS OMITTED FOLLOWING THE EQUALIZING PULSES AND DURING THE BROAD VERTICAL PULSES
8. COLOR BURSTS TO BE OMITTED DURING MONOCHROME TRANSMISSION.
9. THE BURST FREQUENCY SHALL BE 3.579545MC. THE TOLERANCE ON THE FREQUENCY SHALL BE ±10 CYCLES WITH A MAXIMUM RATE OF CHANGE OF FREQUENCY NOT TO EXCEED 1/10 CYCLE PER SECOND PER SECOND.
10. THE HORIZONTAL SCANNING FREQUENCY SHALL BE 2/455 TIMES THE BURST FREQUENCY.
11. THE DIMENSIONS SPECIFIED FOR THE BURST DETERMINE THE TIMES OF STARTING AND STOPPING THE BURST, BUT NOT ITS PHASE. THE COLOR BURST CONSISTS OF AMPLITUDE MODULATION OF A CONTINUOUS SINE WAVE.
12. DIMENSION "P" REPRESENTS THE PEAK EXCURSION OF THE LUMINANCE SIGNAL FROM BLANKING LEVEL, BUT DOES NOT INCLUDE THE CHROMINANCE SIGNAL. DIMENSION "S" IS THE SYNC AMPLITUDE ABOVE BLANKING LEVEL. DIMENSION "C" IS THE PEAK CARRIER AMPLITUDE
13. REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES

FIG. 12-2*a*. FCC television synchronizing waveform for color transmission.



NOTES

1. H=TIME FROM START OF ONE LINE TO START OF NEXT LINE
2. V=TIME FROM START OF ONE FIELD TO START OF NEXT FIELD
3. LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1H
4. LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MINIMUM AND MAXIMUM VALUES OF (x+y) AND (z) UNDER ALL CONDITIONS OF PICTURE CONTENT
- *5. DIMENSIONS MARKED WITH ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES
6. EQUALIZING PULSE ARE SHALL BE BETWEEN 0.45 AND 0.5 OF AREA OF A HORIZONTAL SYNC PULSE
7. REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES

FIG. 12-2b. FCC television synchronizing waveform for monochrome transmission.

their losses attributed to the antenna or transmitter system (as was originally outlined in the equipment description included in the application for construction permit).

When the power measurement is made on the visual transmitter, the peak output power of the transmitter, operating with black picture and standard sync (Fig. 12-2*a* and *b*), is determined by reading the average power directly from the dummy load wattmeter and multiplying this value by 1.68.[2] It is advisable to make this measurement at a number of different power levels so that it will be possible to plot a graph of peak power output vs. the reading of the power-output monitor device of the transmitter. This graph will allow the operating staff to determine readily that they are always operating within the plus 10 minus 20 per cent output power variation permitted by the Rules and Regulations (3.689-b-1).

Paragraph II-C-5 of Form 302 requests information to allow determinations of the output power of the aural transmitter by the indirect method (3.698-a-2). Unfortunately, this method does not take into account possible tube-efficiency variations due to the varying loading conditions possible for the final stage of the transmitter. For the condition of operation for which the transmitter is tuned, the correct stage efficiency can be determined from a power measurement with a dummy load wattmeter, as above. This dummy load measurement also allows the power to be measured at varying levels to obtain a plot of output power vs. RF transmission-line meter readings to allow for conformance with the plus 10 minus 20 per cent power limits allowed (3.689-b-2). Information developing the output power by the indirect method must be supplied on Form 302, Section II-C-5, and the direct measurement determination may also be supplied.

Antenna and Transmission Line

The next portion of Form 302 requesting exhibit information asks for data on the antenna system. Full information recording the special characteristics of the antenna, if any, should be included here. The same holds true for the case where emergency antennas or transmission lines are provided.

Frequency Monitors

Section II-C-8-6 requests an exhibit explaining any difficulties that may have caused the frequency monitor of the station to indicate excessive frequency deviation and the measures that have been taken to correct this deficiency. In addition, information is requested as to "outside" readings of the operating frequencies that may have been taken by means other than the station's own frequency monitor. Even though the station will be using a type-approved frequency monitor, it is still necessary to check against an "outside" standard to ensure that the long-time drift of the monitor is periodically corrected. This can be done at the station by comparing the station monitor readings with a signal received from WWV or WWVH [3] or by having the frequency of the station measured by an independent frequency-measuring service. For either of these cases the "outside" measurement should be described in detail and, of course, the station monitor should be corrected if found in error.

The performance of the visual transmitter is the subject of Sec. II-C-9. In addition to the information requested in II-C-9 there are further data required for color transmitters. These additional items have been detailed in FCC memoranda issued in 1954 and are included in the Rules and Regulations, dated effective Jan. 2, 1956. In essence, the exhibits submitted in response to II-C-9 should show that the visual transmitter meets all the required transmitter and operational characteristics outlined in Part 3 of the Rules.

Variation of Output

Variation of output (3.682-a-16) is the peak-to-peak change in signal amplitude during a period not exceeding one field in length. Variation of output results from such things as hum, noise, and incorrect low-frequency response. The Rules state that

[2] The factor 1.68 is valid only if standard sync height and width are maintained.

[3] See Section 1 of this handbook.

the variation of output at sync peak level and at blanking level shall not exceed 5 per cent of the average of the peak signal amplitude.

Method of Measurement. A sample of the transmitter output signal shall be detected, and the resulting video signal viewed on an oscilloscope. Means for establishing a zero reference must be provided. The sync peak should be calibrated in terms of peak power. The height of the highest and lowest sync peaks and the highest and lowest blanking levels shall be measured. Their respective differences shall not exceed 4.5 per cent of the highest sync peak. This will assure less than 5 per cent variation of the average peak signal amplitude. The over-all accuracy of the measuring equipment shall be sufficient to allow measurement of variation of amplitude with an accuracy of ± 1 per cent of the total peak amplitude. The input test signal shall contain a slightly nonsynchronous 60-cycle sine wave whose peak-to-peak amplitude is not less than 75 per cent of the excursion from reference black to reference white.[4]

(It should be noted that the FCC does not enforce this requirement at this time, per 3.682-a-16).

Over-all Attenuation

A measurement of over-all attenuation vs. frequency (3.687-a-1, 2; 3.699-Fig. 5) is requested for frequencies from zero to 4.75 Mc. This measurement is detailed in the Rules and Regulations and is, in essence, a diode measurement of the transmitter output when the transmitter is fed a video sweep signal. The limits of this measnrement are also established in the Rules. It is specified that this measurement be made into the antenna system (for color), but if the characteristics of the antenna and the dummy load have been measured to be substantially the same (as in the power measurement), a case can be made for the use of the dummy load in place of the antenna if this makes the measurement more convenient.

Method of Measurement. A modulating signal shall be applied to the transmitter input terminals in place of the normal composite television video signal. The signal applied shall be a composite signal composed of a synchronizing signal to establish peak output voltage plus a variable-frequency sine-wave voltage occupying the interval between synchronizing pulses. The axis of the sine wave in the composite signal observed in the output monitor shall be maintained at an amplitude of 0.45 of the voltage at synchronizing peaks. The amplitude of the sine-wave input shall be held at a constant value with this constant value such that at no modulation frequency does the maximum excursion of the sine wave observed in the composite output signal monitor exceed the value of 0.75 of reference-white to reference-black voltage in the double-sideband region. With a 200-kc modulating signal applied to the transmitter, the amplitude of the detected signal should be measured and designated 0 db as a basis for comparison. The frequency of the modulating signal shall then be varied over the desired range, and the detected signal measured.

As an alternate method of measuring in those cases in which the automatic d-c insertion can be replaced by manual control, the above characteristic can be taken by the use of a signal generator and without the use of blanking and synchronizing pulses. The transmitter operating level shall be set for mid-characteristic operation at 0.45 of the voltage corresponding to synchronizing peak.[5]

Field Strength or Voltage of Upper and Lower Sidebands

The field strength or voltage of the upper and lower sidebands (3.687-a-4) is to be measured for modulation frequencies from 200 kc to 5 Mc for the lower sideband and from 200 kc to 8 Mc for the upper sideband. It should be noted at this time that the rules require measurements of spurious emissions removed in frequency in excess of 3 Mc above or below the respective channel edge (3.687-i-1), and these measurements can often be performed at the same time as the upper and lower sideband measurements. In that it may be extremely difficult to make actual field-strength measurements to obtain the above data reliably, it is noted in the Rules that measure-

[4, 5] This method of measurement is currently being considered by the Electronics Industries Association.

ments made using a probe in the transmission line feeding a dummy load will be accepted. In the measurement of the upper and lower sidebands it is imperative that the input to the transmitter be held constant throughout the measurement. The detector for this measurement can be an accurately calibrated field-strength meter or a receiver system ntilizing a substitution signal generator for calibration. In either case care must be taken to ensure that the field-strength meter or the receiver has a passband characteristic sufficiently narrow to allow only the sideband being measured to register. This is particularly important when the 200-kc component is being measnred, for this is the reference for the entire measurement. The upper and lower sideband measurement can also be made using a sideband analyzer, but if this is done, great care must be taken to calibrate the device for amplitude linearity. The analyzer is not a perfectly linear device, and if it is used for this measurement, the use of calibrated attenuators is required to obtain the accuracy of measurement desired. The receiver or field-strength meter provides a much more rigorous proof of performance than the analyzer, but the analyzer is most helpful in making a rough check of the system prior to making precise measurements.

Throughout the measurement of the upper and lower sidebands the transmitter is adjusted to operate at mid-characteristic and the output is monitored to ensure that 0.75 peak output voltage is never exceeded. Ideally there should be an oscilloscope bridged across the input to the transmitter to monitor the input level at a constant voltage and a demodulator and a modulation monitor on the output to make sure that the modulation limits are not exceeded.

During the setup for this measurement special attention shonld be paid to the frequencies of minus 1.25, minus 3.58, minus 4.25, plus 4.75, and plns 7.75 Mc. These frequencies are the boundaries of the sideband characteristics (-1.25 and $+4.75$ Mc down 20 db), lower sideband of the color subcarrier (-3.58 Mc down 42 db) (3.687-a-3), and out-of-band radiation beyond 3 Mc above and below the assigned band edges (-4.25 and $+7.75$ Mc 60 db *below peak power*) (3.687-i-1). The region beyond minus 4.25 and plus 7.75 Mc should then be checked to ascertain that there are no spurious signals in these regions. This out-of-band measurement can also be made by applying test-pattern modulation to the transmitter and searching the out-of-band region with the receiver or field-strength meter used above.

Method of Measurement. It is recommended that the sideband characteristic of a visual transmitter be measured by the application of a modulating signal to the input terminals of the transmitter in place of the normal composite television video signal. The signal applied shall be a composite signal consisting of the normal television synchronizing pulses plus a variable-frequency sine wave occupying the intervals between pulses. The axis of the sine wave observed in the output monitor shall be maintained at an amplitude of 0.45 of the voltage of the synchronizing pulse peaks. The amplitude of the applied sine wave shall be maintained at a constant value such that at no modulation frequency does the maximum peak of the sine wave exceed 0.75 of the peak output voltage. The amplitude of the upper 200-kc sideband when using a 200-kc modulating frequency shall be measured by means of a field-strength meter or equivalent and used as the reference level. The modulating frequency shall then be varied over the range from 200 kc to 8 Mc, and the corresponding amplitudes of the upper and lower sidebands measured.

As an alternate method of measuring in those cases in which automatic d-c insertion can be replaced by manual control, the above characteristics can be taken by the use of a signal generator and without the use of blanking and synchronizing pulses. The transmitter operating level shall be set for mid-characteristic operation—0.45 of the voltage corresponding to synchronizing peak.[6]

Out-of-band Emissions

The Rules state that "all emissions removed in frequency in excess of 3 Mc above or below the respective channel edge shall be attenuated no less than 60 db below the

[6] This method of measurement is currently being considered by the Electronics Industries Association.

visual transmitted power" (3.687-i-1). The measurements described above determine the voltage of the upper and lower sidebands and not the relationship of these values to the transmitter peak power. To relate measurements of this type to the transmitter peak power for the purpose of determining compliance with the out-of-band requirements, additional calculations are required. It is necessary to (1) add an additional 6 db to the measured value to cover the case of one sideband of a 100 per cent modulated amplitude-modulation system, (2) add 3.5 db to compensate for the modulation index of 75-15/90, and (3) add 6.9 db to correct for the fact that the axis of the modulation is at a point equal to 45 per cent of carrier peak and not at carrier peak. Thus, the emission below peak transmitted power is determined by establishing the voltage level below the 200-kc point (assuming that it is the maximum point) as above and adding to that value a correction of 16.4 db to relate this figure to emission below the peak transmitted power.

Attenuation of RF Harmonics

The out-of-band emissions requirements also cover radio-frequency harmonics for both aural and visual transmitters. It is specified that these shall be as low as the state of the art permits and in no case attenuated less than 60 db below the visual peak transmitted power. There are a number of methods that can be used to measure the level of the radio-frequency harmonics, and the simplest is the use of a field-strength meter that has sufficient selectivity and rejection of the fundamental to allow accurate measurements. It is also possible to use a fundamental rejection filter with a field-strength meter that does not have sufficient isolation at the fundamental frequency. A second method which can be used is the substitution method wherein a calibrated receiver, fundamental rejection filter, and a substitution signal generator are used to simulate a calibrated field-strength meter. A third method is the General Radio Company's system utilizing rejection notch filters, heterodyning oscillators, IF amplifier, and detector. Any of the above systems are acceptable to the FCC provided sufficient data are included with the measurement to attest to the accuracy of the method used.

In all cases the harmonic measurements should be made in the transmission line following the harmonic filters, if used. In the case of UHF transmitting plants the FCC has indicated that they will accept transmitter measurements provided by the manufacturer. Measurements are not required beyond 1,000 Mc for transmitters on Channels 2 to 13 or beyond 3,000 Mc for Channels 14 to 83.

Transmitted Signal Waveform

Transmission standards for the transmitted signal waveform are fully detailed in the Rules (3.687-a-7, 8; 3.682-a-5, 6; 3.699-Figs. 5, 6, and 7). Section II-C-9-b of Form 302 requests an exhibit demonstrating conformance to these standards. It also notes that "Until the form of these measurements may be specified by the Commission, the character of this data is left to the discretion of the applicant."

As in all other data required, the burden of proof is on the applicant. The FCC has accepted many different presentations covering this proof of conformity to the Rules, but not all of them are of the type that gives definite informaiton. It has been thought by some that the submission of a waveform or pulse-cross photograph (Figs. 12-3 and 12-4) taken from the CRO fed by the station demodulator will suffice to show conformity to the transmitted-waveform requirement. A careful check of the resolution possible in such a photograph and an analysis of the technique involved show that the errors possible in interpreting such a display are far greater than the tolerances allowed in the Rules.

A simple and straightforward method of preparing such an exhibit is simply to extend the normal maintenance techniques for the sync generator. Measure all the pertinent waveforms accurately on an oscilloscope having the facility for the addition of timing pulses and having sufficient rise time, magnification, and line-selection ability to show individually the section of the signal being studied (Figs. 12-5 to 12-7). A

Tektronix type 524, Dumont type 280, or similar oscilloscopes serve this purpose adequately.

Since the source of the synchronizing waveform is the main studio sync generator,

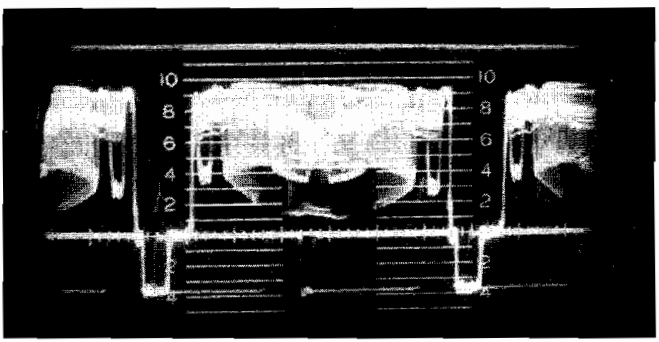


FIG. 12-3. CRO photograph of *H* presentation same as or similar to photograph presented in KMOX-TV proof.

the first part of this test should carefully measure the signals as they arrive at the transmitting plant. This is a normal maintenance procedure of the television plant and checks out not only the alignment of the sync generator but the processing and distribution amplifiers that may be used in the master control location and the studio-to-transmitter circuit. After it has been determined that the sync signal arriving at

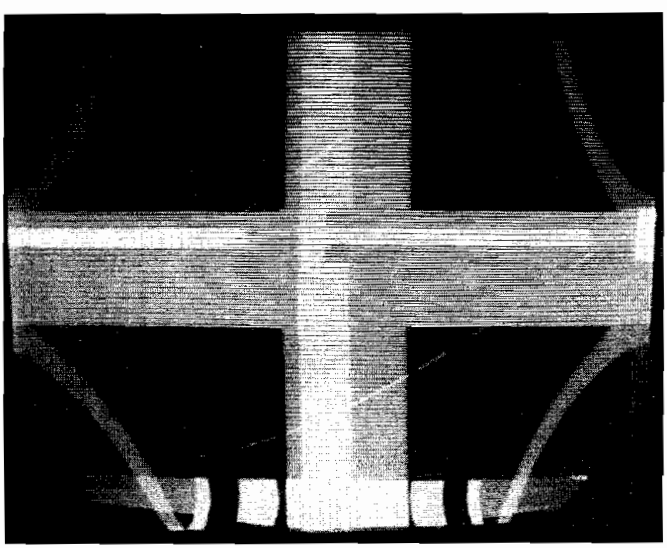


FIG. 12-4. Photograph of pulse cross display obtained from A/V.

the transmitter plant is "standard," it is fed to the transmitter. The transmitted characteristics can then be measured using a probe in the output transmission line to the antenna or the dummy load. An example of this technique and a method of reporting the measurement are shown in the sample "proof" below.

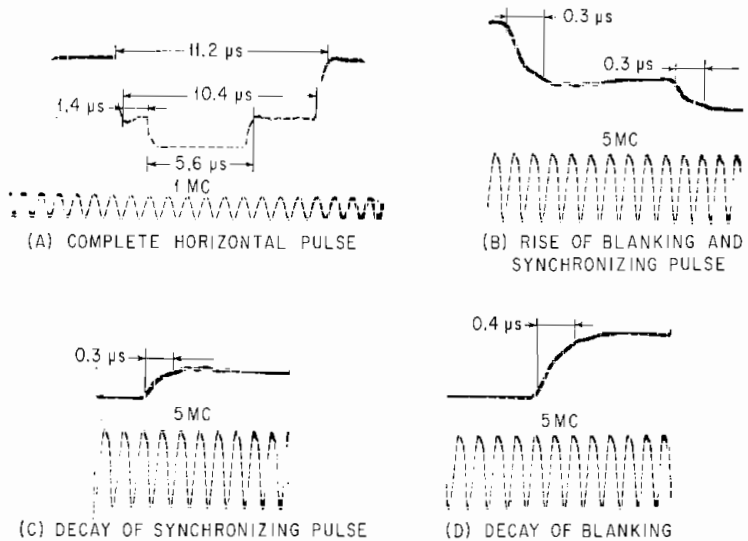


FIG. 12-5. Waveform times of horizontal synchronizing pulses.

Transmitted Test Pattern

Section II-C-9-e of Form 302 requests that an exhibit be prepared containing a photograph of the transmitted test pattern from a receiver or a monitor connected to the transmitter output. This is a straightforward task easily accomplished. The addition of one other photograph, that of the test pattern signal that is fed to the input of the transmitter, will add a wealth of information to the proof. A comparison of the "in" and the "out" can then be made to see if any degradation in the out test pattern is caused by the transmitter or is present in the incoming signal.

For color transmission there are a number of measurements required that are not listed on Form 302 but are noted in FCC mimeographs and detailed in the Rules (3.687-a-5, 9; 3.682-a-5, 20-VII). Conformity to the color-transmission standards requires measurements of transfer characteristic, differential gain, differential phase, and envelope delay as well as all the previously measured transmission characteristics.

Transfer Characteristic

Low-frequency linearity and differential gain, defined in the Rules as the transmitter transfer characteristic (3.687-a-9), can be measured rather simply. The Rules state that the transfer characteristic shall be substantially linear and assign no values to the degree of linearity. It behooves the color broadcaster to maintain maximum linearity for faithful color transmission. Extreme variations from linearity will also affect the fidelity of the monochrome transmissions. A stairstep generator is the simplest tool for this type of measurement. This unit along with a high-pass filter and an oscilloscope will allow accurate measurements of linearity or transfer characteristics to be made in very short order. Such a measurement is described below in the sample proof. Once again it is advisable, while making this measurement on the transmitter system, to make a similar measurement on the over-all studio-transmitter system for the information of the technical staff. Submission of this extra data is not required, but it allows a check to be made to ensure that there is no predistortion of linearity being used to compensate for the deficiencies of one or more elements of the transmitter-studio plant.

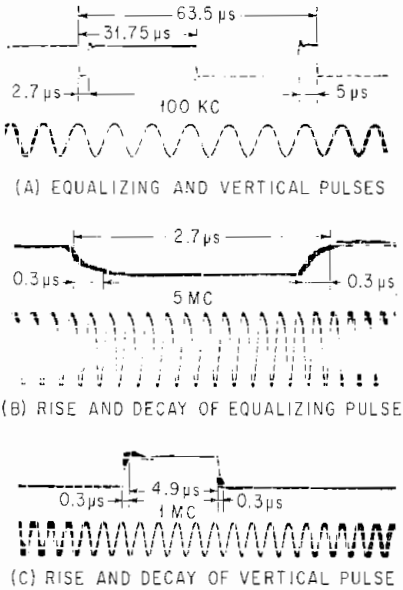


FIG. 12-6. Waveform times of vertical synchronizing pulses.

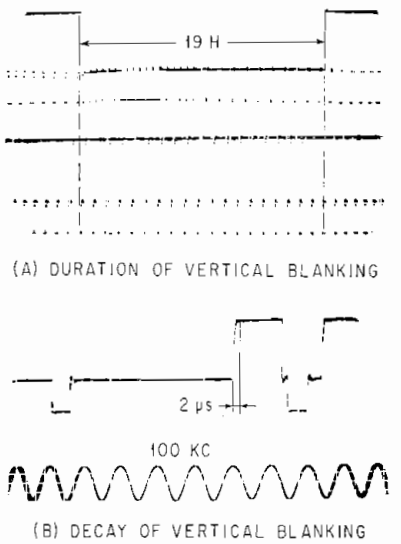


FIG. 12-7. Waveform times of vertical blanking pulse.

Low-frequency Linearity

The low-frequency linearity is defined as that characteristic which describes the change in RF output signal amplitude resulting from and corresponding to a change in input signal amplitude. No FCC specification is given, but it is advisable as a minimum standard to keep the linearity within 1.5 db for 10, 50, or 90 per cent average picture level when using a stairstep signal having 10 steps of equal amplitude covering the reference-white to blanking-level region.

Method of Measurement. The visual transmitter shall be fed a composite signal consisting of synchronizing pulses and a stairstep signal having at least 10 steps of equal amplitude. The test signal shall be sufficient to modulate the visual transmitter to reference white while maintaining rated blanking level and rated visual transmitter output power. With the use of a linear display monitor of the RF signal or of the RF envelope, the amplitudes of the different steps are compared using the greatest amplitude step as the reference. The linearity will be the ratio, expressed in decibels, of the amplitude of the tallest step to the amplitude of the shortest.[7]

Differential Gain

Differential gain is the difference in gain of the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal upon which it is superimposed. With no specific FCC specification but interpreting the color-signal specification in the Rules (3.682-a-20), it is advisable that the differential gain be maintained below 1.5 db for 10, 50, and 90 per cent average picture levels.

Method of Measurement. The visual transmitter shall be fed a composite signal consisting of synchronizing pulses and a low-frequency signal with a superimposed 3.58-Mc sine-wave signal whose peak-to-peak amplitude is 20 per cent of the low-

[7] This method of measurement is currently being considered by the Electronics Industries Association.

frequency signal amplitude between blanking and reference white. This composite test signal shall be sufficient to modulate the visual transmitter to reference white while maintaining rated blanking level and rated visual transmitter output power. With the use of a linear demodulator, the visual transmitter output is sampled, detected, and passed through a high-pass filter to an oscilloscope or any other suitable means of observing the 3.58-Mc component of the test signal. Any deviation from a constant amplitude display of the 3.58-Mc signal when viewed at the line-rate frequency is the differential-gain variation. The differential gain at any point is the ratio, expressed in decibels, of the amplitude of the maximum amplitude region referred to the amplitude of the point under consideration.[8]

Differential Phase

Conformity with the color-signal specifications of the Rules (3.682-a-20) can be further assured by a measurement of differential phase. Differential phase is the difference in phase shift through the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal on which it is superimposed. Interpreting these color standards it is advisable to adjust the station equipment so that the differential phase shall be less than 7° at 3.58 Mc when the reference burst region of a 50 per cent average picture level signal is used as reference. In addition, the total differential phase between any two levels shall not exceed 10°.

Method of Measurement. The visual transmitter shall be fed a composite signal consisting of synchronizing pulses and a low-frequency signal with a superimposed 3.58-Mc sine-wave signal whose peak-to-peak amplitude is 20 per cent of the low-frequency-signal amplitude between blanking and reference white. This composite test signal shall be sufficient to modulate the visual transmitter to reference white while maintaining rated blanking level and rated visual transmitter output power. With the use of a diode demodulator, the visual transmitter output is sampled, detected, and passed to any suitable phase-measuring equipment. The differential phase error is the difference in phase of the 3.58-Mc wave between the burst region of the composite signal and any other level under consideration.[9]

If the station is capable of generating local color signals and has a color-bar generator and Vectorscope, compliance with the color-signal specifications can be proved by a measurement of the phase and amplitude of the transmitted color bar, I and Q signals.

Although color specifications are under Transmission Standards in the Rules and not specifically listed as a transmitter characteristic, it is usually satisfactory to make these measurements at the transmitter plant. The same measurements should, however, be made from the studio plant to ensure that the transmission of color signals will be proper under the normal program routing. If it can be done, these measurements should be made from the main studio, checking the entire system for conformity to the transmission standards as the synchronizing waveforms were checked above.

As an added reminder—care must be taken during all the above measurements to assure that the transmitter and all the input equipment in the transmitting plant and in the component links between the studio and the transmitter are operating at their normal settings. The input to the transmitter modulator should be adjusted for the normal program excursions, and the output signal as viewed from the station demodulator should indicate that there is no overloading of the circuits. In brief, normal conditions should prevail.

Envelope Delay

At this writing, the only practical method of making envelope-delay measurement is through the use of a device known as an envelope-delay curve tracer. This measurement is outlined briefly in the sample proof below and more fully in the instructions for the use of the instrument.

[8, 9] This method of measurement is currently being considered by the Electronics Industries Association.

There are instruments presently under development which will provide simpler methods of making this measurement, and industry committees are at work attempting to develop simple coincidence checks to ascertain compliance with the requirements of the Rules (3.687-a-5). Graphical analysis of square-wave measurements can be used in making this check, but it is an extremely time-consuming effort, requiring a host of accurate measurements and resulting in answers whose possible errors may exceed the tolerances allowed in the Rules.

If equipment to measure the envelope-delay characteristics of the transmitter is not available, reference can be made to the fact that the envelope-delay-correction filters installed for the particular transmitter have been designed and adjusted by the manufacturer to provide the proper over-all envelope-delay characteristic. The approximate accuracy of this adjustment can be checked by observing the fidelity of a color-bar test signal and also by checking a square-wave signal for equality of "ringing" before and following a transition when the signal is observed through an ideal demodulator. Even though the envelope-delay-correction filters are passive, an attempt should be made at the earliest opportunity to make an actual measurement of the over-all system to ensure that the proper predistortion and correction are being made. It is hoped that new devices for this measurement will be available shortly.

Envelope delay is the first derivative of the phase vs. angular velocity characteristic at a particular frequency. In essence it is a measure of the coincidence of arrival of chrominance and luminance information and, per the FCC specifications, the predistortion introduced to produce this coincidence in a color receiver.

Method of Measurement. Envelope-delay measurements shall be made with commercial envelope-delay-measuring equipment under the same operating conditions as described above for over-all attenuation measurements. The RF demodulator shall be an ideal vestigial demodulator with sound trap switched out. An RF diode can be used for measurements above 1.25 Mc. (Further information is given in the sample proof below.) [10]

It must be kept in mind here, as above, that even though the specifications in the Rules are for the transmitter, the envelope delay in the entire studio and link system should be kept within the FCC tolerances in order to provide the highest fidelity of color transmission within the specifications of the NTSC system. For the benefit of the station the envelope delay of this entire system should be measured periodically as both a maintenance tool and a proof of performance.

Section II-C-10 of Form 302 requests exhibits describing fully measurements of performance of the aural system including "all circuits between the main studio microphone terminals and the antenna output, including telephone lines, pre-emphasis circuits and any equalizers employed except for microphones, and without compression if a compression amplifier is installed." The Rules list the operational characteristics required of the system (3.687-b-1,2,3,4,5,6,7) and further recommend that none of the three main divisions of the system (transmitter, studio-to-transmitter circuit, and audio facilities) shall contribute more than half of the allowable total degradation for the entire system. This requires that not only the system as a whole be measured but that measurements be made separately on each of the three main divisions.

Audio-frequency Response

The measurement of the audio-frequency response of the aural system is a straightforward type of measurement but requires modifications of the usual "amplifier" testing techniques truly to measure the performance of the aural transmission system. Since there is a difference in peak voltages reached by pure sine-wave and normal program signals for equivalent volume-indicator readings, adjustments of the input level of the test signals should be made to compensate for this difference. One method is to use an "elevated" level 10 db above normal (-50 dbm at microphone input) to simulate 100 per cent modulation. This technique will measure the frequency re-

[10] This method of measurement is currently being considered by the Electronics Industries Association.

sponse for normal program transmission and not simply the response of the system to sine waves. The detailed procedure for this measurement is described in the sample proof below.

Distortion

System distortion should be measured with the same setup used for the frequency-response measurement above in order to save time and minimize setup errors.

FM and AM Noise

Frequency-modulation noise on the carrier is the residual frequency modulation resulting from disturbances produced in the transmitter itself within the band of 50 to 15,000 cycles. The level is expressed as the ratio of the residual frequency swing in the absence of modulation to the full frequency swing with modulation as weighted by the effect of a standard 75-μsec deemphasis circuit. FM-noise-level measurements can be made with the distortion-measurement equipment used for the above measurement.

Method of Measnrement. The frequency-modulation noise level can be obtained by demodulating a sample of RF output of the transmitter and comparing the rms voltage developed by the demodulator in the absence of modulation voltage to the rms voltage obtained with 100 per cent, 400-cycle modulation. The audio input terminals of the transmitter shall be shunted by a resistance equal to the transmitter input impedance. The frequency-response characteristic of the demodulator shall be within ± 1 db of the standard 75-μsec deemphasis curve from 50 to 15,000 cycles.[11]

The amplitude-modulation noise level on an aural transmitter carrier is the ratio of the rms value of the amplitude-modulation component (50 to 15,000 cycles) of the carrier envelope to the rms carrier value in the absence of applied modulating voltage.

Measurement of the carrier amplitude-modulation noise level can be accomplished by the use of a linear peak-carrier-responsive AM detector with 75-μsec deemphasis coupled to the output of a transmitter. Readings are made of the d-c voltage and the rms value of the a-c component across the detector load resistor. The d-c voltage must be multiplied by 0.707. These measurements shall be made in the absence of modulating voltage. The audio input terminals of the transmitter shall be shunted by a resistance equal to the transmitter input impedance. Equipment for this measnrement is commercially available or can be assembled by the station.

In all cases, the equipment used for any of the measurements should be described by manufacturer, type, and serial number, and if composite, a general description of the device shonld be included in the "proof."

THE PROOF OF PERFORMANCE

Herein follows a composite sample "proof" made up from six "proofs" submitted to the FCC by CBS over the past ten years. A composite of these "proofs" was chosen rather than a sample of one proof in order to illustrate as comprehensively as possible the method of proving performance.

[11] This method of measurement is currently being considered by the Electronics Industries Association.

(SAMPLE PROOF OF PERFORMANCE)

CBS Television Network

Engineering Department

(station call, city)

Aural and Visual Performance

Report (Number)

(EXAMPLE)

STATE OF NEW YORK }
COUNTY OF NEW YORK } SS:

JOSEPH L. STERN, being duly sworn upon his oath, deposes and says:

1. That he is employed by the Columbia Broadcasting System as a Senior Project Engineer in the CBS Television Network Division, 485 Madison Avenue, New York 22, New York.
2. That he is a graduate of the University of Conneeticut with the degree of B.S.E.E.
3. That his qualifications as an engineer are known to the Commission, having been accepted in many previous applications and engineering reports filed with and acted upon by the Federal Communications Commission.
4. That he has prepared the attached engineering report and that the adjustments, measurements, and calculations discussed therein were made by him personally or under his supervision and direction.
5. That the facts stated herein are true of his own knowledge, except such facts as are stated to be on information or belief, and as to such facts, he believes them to be true.

_____
Joseph L. Stern

Subscribed and sworn to before
me this _____ day of _____

(Note: Affidavit not required if engineer performing or directing measurements signs Form 302, Section II, page 2, attesting to validity of measurements.)

(SAMPLE)

Report (Number)

Summary

This report details aural and visual performance measurements made at television station (*call*), (*city*), (*state*), following the installation of _____ in accordance with Television Broadcast Station Constructing Permit _____, dated _____. The measurements reported herein are submitted as engineering exhibits associated with application for television broadcast station license for station (*call*), and establish that the (*call*) transmitter and studio equipments are operating in full conformity with the Rules and Regulations as established by the Federal Communications Commission.

Introduction

In association with Section II of subject application for license this exhibit answers fully all questions pertaining to the operation and technical performance of (*call*). All of the measurements reported herein were made on the complete transmitting plant and reflect the true and normal operation of television station (*call*) for the effective radiated power specified in Construction Permit _____, dated _____. Construction authorized by this permit was begun on _____ and was completed on _____.

In addition to the measurements specified in Form 302 additional measurements have been made to ensure that the entire plant meets the more rigid requirements for color transmission and they are described herein.

Transmitter Power-output Determination (II-C-5)—(Example)

The power output of both the visual and aural transmitters was measured by the use of a calibrated dummy-load wattmeter, the impedance of which was measured and found to be substantially equivalent to the transmitting-antenna impedance. Impedance measurements of the dummy-load wattmeter and the antenna system were made with a General Radio type 1602-A admittance meter to establish that the impedance of the antenna system was equivalent to that of the dummy load wattmeter for power-determination purposes. The VSWR of the dummy load was found to be less than 1.05 in a 51.5-ohm line over the 54- to 60-Mc band, and the antenna system VSWR was 1.11 or less over the 54- to 60-Mc band as shown in Fig. P-1. The wattmeter (General Electric Co. model 19193) contains a calibrated voltmeter which reads average power directly. The visual transmitter is equipped with a peak-reading voltmeter coupled to the output transmission line as well as a reflectometer which indicates the forward and reverse voltage in the transmission line. The aural transmitter also contains a reflectometer unit for the measurements of forward and reverse voltage in the output transmission line. Figure P-2 shows the voltage standing-wave ratio of the antenna system and transmission lines. This figure was obtained from the data given in Fig. P-1.

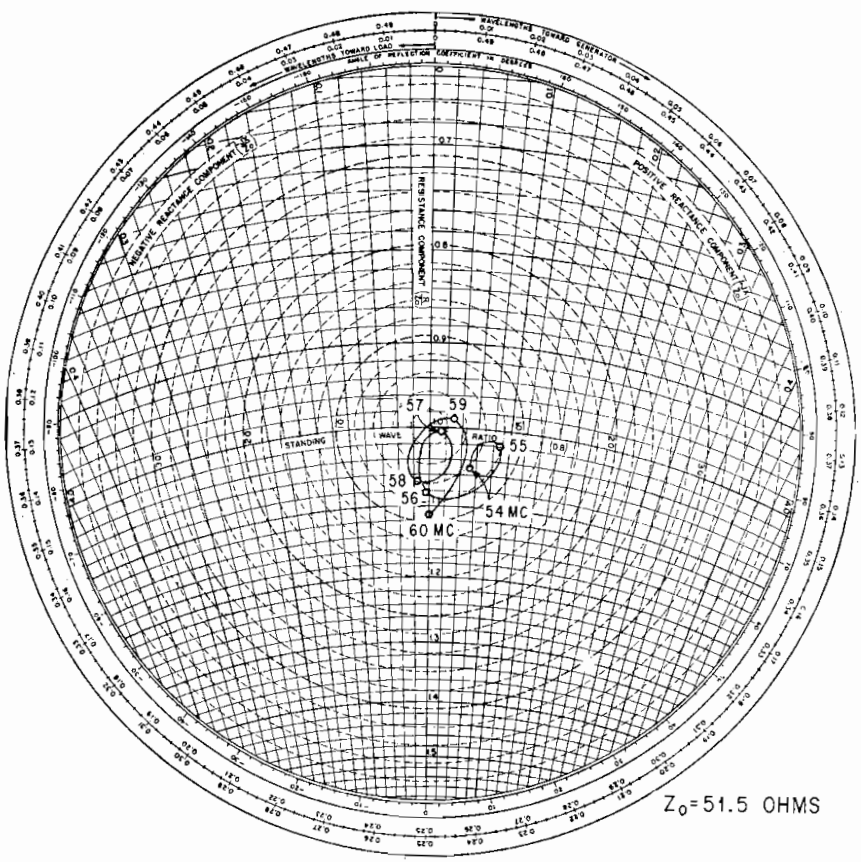


Fig. P-1. Measured impedance of KNXT antenna at diplexer input.

In measuring the power output of the visual transmitter, the output of the transmitter was connected directly to the dummy-load wattmeter. The transmitter was then modulated with an all-black picture and the standard 25 per cent sync. The average power was read on the wattmeter indicator, and the peak power (power during sync pulse) was obtained by multiplying the average power by a factor of 1.68. Reflectometer readings were noted for several adjustments of transmitter power output, and a graph of the relationship was prepared. This graph is presented in Fig. P-3 and serves as a calibration of transmitter peak power output during normal operation.

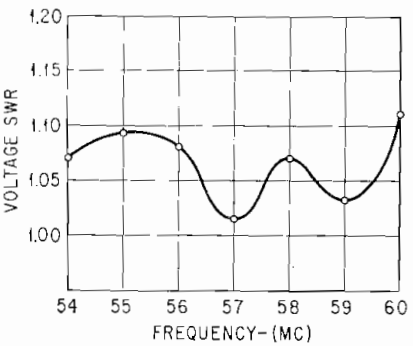


FIG. P-2. Voltage standing-wave ratio of antenna and transmission line.

The power output of the aural transmitter was measured by connecting the transmitter output directly to the dummy-load wattmeter, described above. The efficiency factor F was determined from this measurement and used in completing paragraph II-C-5 of FCC Form 302. The transmitter was adjusted for a number of different operating levels, and the average power was read directly from the indicating meter of the dummy-load wattmeter. A plot of the transmitter output vs. aural reflectometer reading is presented as Fig. P-4. Thus calibrated, the reflectometer reading serves as an indication of transmitter output power during normal operation.

The (*call*) antenna system has a VSWR of 1.11 or less over the 54- to 60-Mc band. This means that the reflection coefficient is less than 0.052 and that the power reflected from the antenna system is less than $(0.052)^2$, or 0.27 per cent of the power reaching the antenna. Therefore, the reflectometer and peak-reading voltmeter give a true measure of the power entering the antenna system.

After the measurements described above had been made, the visual transmitter was adjusted to give a peak output power of 11.7 dbk (14.8 kw) at the output of the diplexer. The power gain of the antenna system is 5.65 db at visual frequency, and the transmission-line efficiency is 86 per cent, representing a loss of 0.67 db. The diplexer being a hybrid device has a negligible loss and, accordingly, this combination results in an effective radiated power of 16.7 dbk (46.8 kw) as specified in the construction permit.

The aural transmitter was adjusted for an output of 8.7-dbk (7.4 kw) average power with an antenna gain of 5.65 db and a transmission-line efficiency of 86 per cent, representing a loss of 0.67 db, thus giving an effective radiated power of 13.7 dbk (23.4 kw).

ANTENNA AND TRANSMISSION LINE (SECTION II-C-6)—(EXAMPLE)

There are complete regular and auxiliary transmitting facilities at the (*call*) plant as well as complete regular and auxiliary antenna and transmission lines. Either transmitter can be

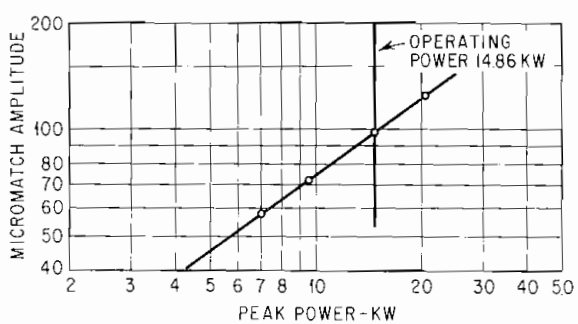


FIG. P-3. Reflectometer calibration visual transmitter.

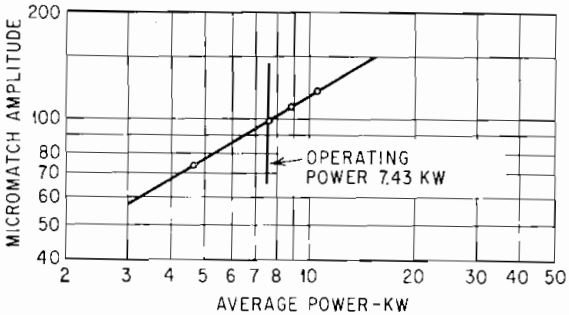


FIG. P-4. Reflectometer calibration aural transmitter.

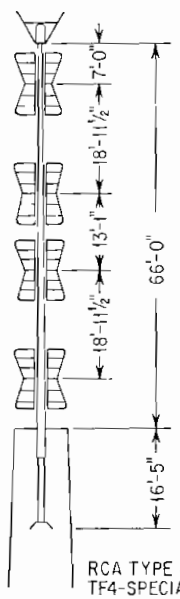


FIG. P-5. Transmitting antenna (designed for null fill-in).

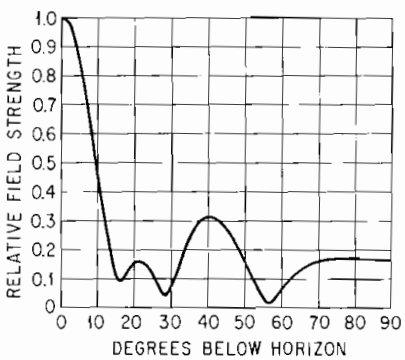


FIG. P-6. Calculated vertical radiation pattern.

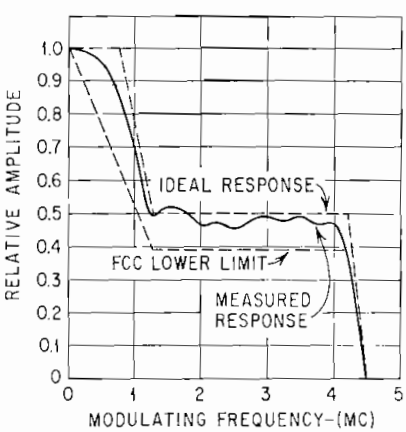


FIG. P-7. Over-all attenuation vs. frequency of visual transmitter (as measured with a diode on the RF transmission line).

fed to either antenna by means of a patch panel. The auxiliary antenna and transmission line are described in the application for construction permit BPCT-1802 (File No.) dated Feb. 2, 1954.

The regular transmitting antenna is an RCA type CB-TF4-special. The essential details of this antenna are shown in Fig. P-5. This antenna is designed for null fill-in, and the calculated vertical-radiation pattern is shown in Fig. P-6.

Frequency Monitors (II-C-8)—(Example)

In addition to regular readings of the station visual and aural frequencies made on the station monitors, measurements have been made by (*Name*) Measurements Company, (*Address*), (*City*), (*State*), for the purpose of adjusting the station monitors, with the following results:

Date and time	*Transmitter*	*T and T Measurements Company, cycles*	*Station monitor measurement, cycles*
Nov. 6, 1958 1:38 A.M.	Visual	55,249,912	55,250,900
Nov. 6, 1958 1:40 A.M	Aural	59,750,330	59,750,200
Nov. 20, 1958 2:05 A.M.	Aural	59,750,317	59,750,300
Nov. 20, 1958 2:08 A.M.	Visual	44,249,939	55,249,930

The assigned frequency is 55,250,000 cycles for the visual transmitter and 59,750,000 cycles for the aural transmitter.

Performance Data—Visual Transmitter (II-C-9)

Variation of Output—(Example)

The peak-to-peak variation of transmitter output within one frame of the video signal was measured while the transmitter was being fed with a 60-cycle sine wave and standard synchronizing signals and was found to be 4 per cent of the average sync peak amplitude.

Over-all Attenuation vs. Frequency (II-C-9-a-1)—(Example)

Figure P-7 is a plot of the measured over-all attenuation vs. modulation frequencies from 0 to 5 Mc. These data were obtained by feeding the transmitter input system (containing all corrective equipment required to meet the FCC Rules and Regulations) with a video sweep signal and observing the output of a diode coupled to the RF transmission line feeding the antenna system. This plot was prepared by taking data from the CRT of a Tektronix type 524-D oscilloscope using inserted single-frequency marker signals for frequency determinations. Figure P-8 is a block diagram of the equipment setup used in making these measurements.

Field Strength or Voltage of Upper and Lower Sidebands (II-c-9-a-2)—(Example)

Figure P-9 is a plot of the relative voltage amplitude of the (*call*) transmitter upper and lower sidebands from 5 Mc below carrier to 8 Mc.

These measurements were all made at the output of the transmitter which was connected to the dummy load. The measuring equipment was set up as shown in Fig. P-10. The field-strength meter was tuned successively to the upper and lower sideband for each modulating frequency used, the input being held constant at all frequencies, and the amplitude was recorded. As shown by Fig. P-9 the attenuation of the upper and lower sidebands of the (*call*) transmitter fully meets the Commission's Rules concerning the relative levels of upper and lower sidebands also shown on Fig. P-9.

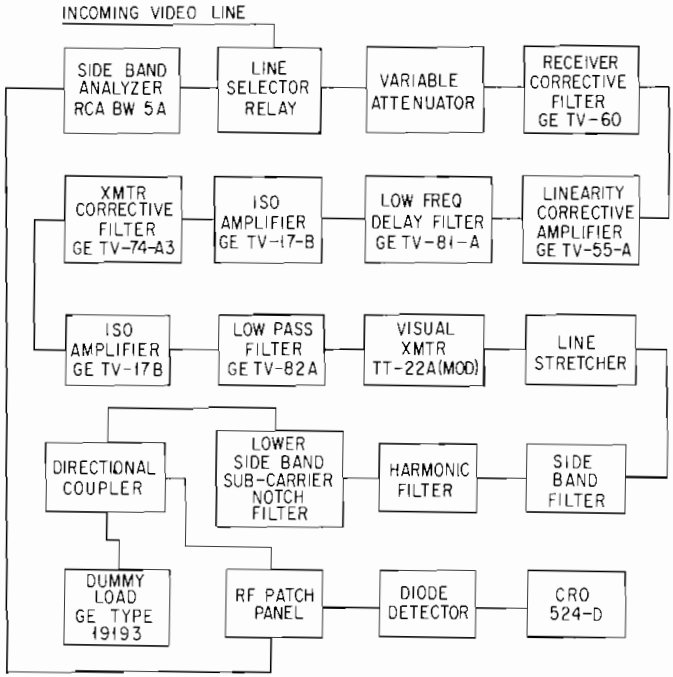


FIG. P-8. Block diagram for over-all attenuation measurements.

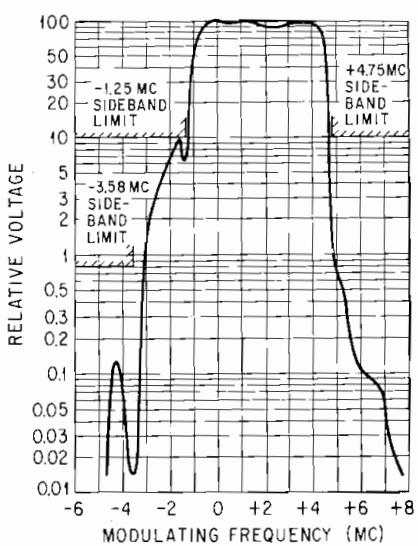


FIG. P-9. Measured voltage amplitude of upper and lower sidebands.

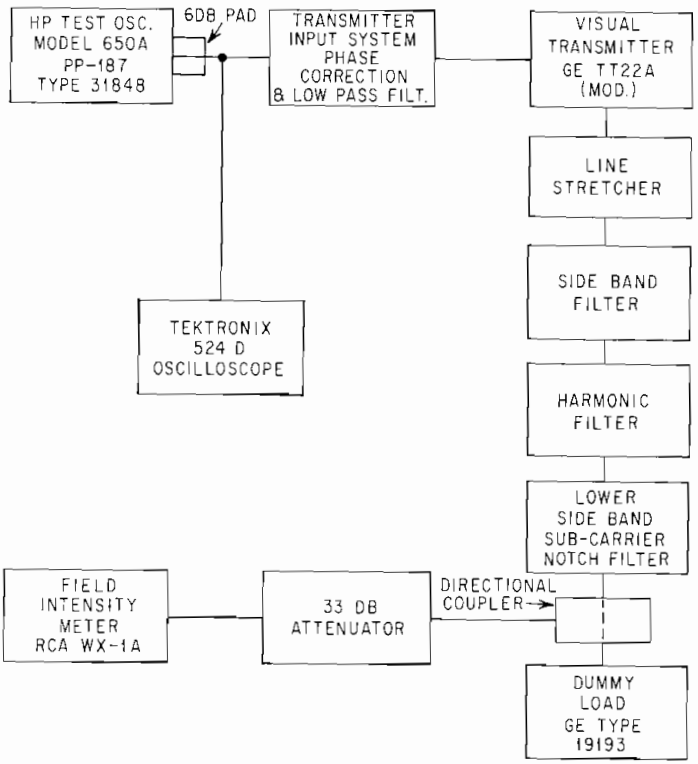


FIG. P-10. Block diagram of equipment used for measuring voltage of upper and lower sidebands.

Out-of-band Emissions—(Example)

Section 3.687 (i) 1 of the Rules states that "all emissions removed in frequency in excess of 3 Mc above or below the respective channel edge shall be attenuated no less than 60 db below the visual transmitter power." As shown in Fig. P-9 the voltage amplitude for a frequency 4.25 Mc below carrier, relative to a 200-kc reference, is 57.8 db down. To relate this measured value to the actual emission, relative to visual transmitted peak power, it is necessary to (1) add an additional 6 db for the case of one sideband of a 100 per cent modulated amplitude-modulation system, (2) add 3.5 db to compensate for the modulation index of 75-15/90, and (3) add 6.9 db to correct for the fact that the axis of the modulation is at a point equal to 45 per cent of carrier peak and not at carrier peak. Thus, the emission at −4.25 Mc is at least 57.8 db + 6 db + 3.5 db + 6.9 db = 74.2 db below visual transmitted peak power.

In the case of the upper-band-edge requirement, Fig. P-9 shows a measured value of −77.2 db for a frequency 7.75 Mc above visual carrier. Adding the correction factors, as above, the emission is 77.2 db + 6 db + 3.5 db + 6.9 db = 93.6 db below transmitted peak power.

Attenuation of RF Harmonics—(Example)

Figure P-11 shows the equipment setup that was used for the measurement of the attenuation of RF harmonics in the output of the aural and visual transmitters. The operation of the equipment shown herein was carefully checked in the CBS-TV Network Engineering Laboratory, and data were obtained to prove that this heterodyning technique is sufficiently accurate for measurements of this type. The notching filters shown in Fig. P-11 were

measured in the laboratory, and their characteristics are shown in Fig. P-12 with the curve extrapolated using data provided by the manufacturer. An investigation was also made of the variation of indicated level with variations in the heterodyning oscillator amplitude, the results of which are shown in Fig. P-13. In addition, the accuracy of this method of measurement was checked at the second and third harmonics of Channel 2, nsing an RCA WX-1A field-strength meter. In this check the two measurement methods agreed within 3 db,

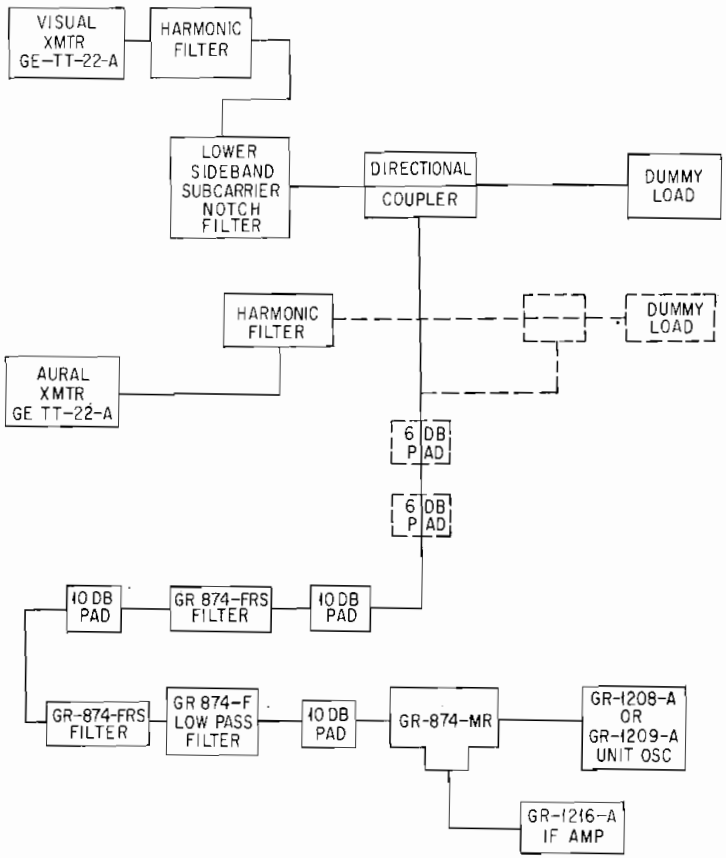


FIG. P-11. Block diagram of equipment used to measure attenuation of RF harmonics.

which indicated that the heterodyning method was entirely usable as long as the indicated level exceeded the Commission Requirements by at last 3 db.

Using the equipment shown in Fig. P-13, measurements were made of the attenuation of the aural and visual harmonics with the transmitters feeding a General Electric type 19193 dummy load. A directional coupler was used to probe the transmission line in these measnrements. The variations of output voltage vs. frequency of this coupler were compensated for during these measurements. The results of these measurements are shown in Fig. P-14 and P-15 and prove that the harmonic attenuation of the (*call*) transmitters are well within the Commission's requirements.

TRANSMITTED SIGNAL WAVEFORMS (II-C-9-b)—(EXAMPLE)

The FCC Rules and Regulations specify that the transmitted waveforms shall conform to paragraphs 3.682-a-5, 6; 3.687-a-7, 8; 3.699 Fig. 2 5, 6, and 7, as modified by vestigial

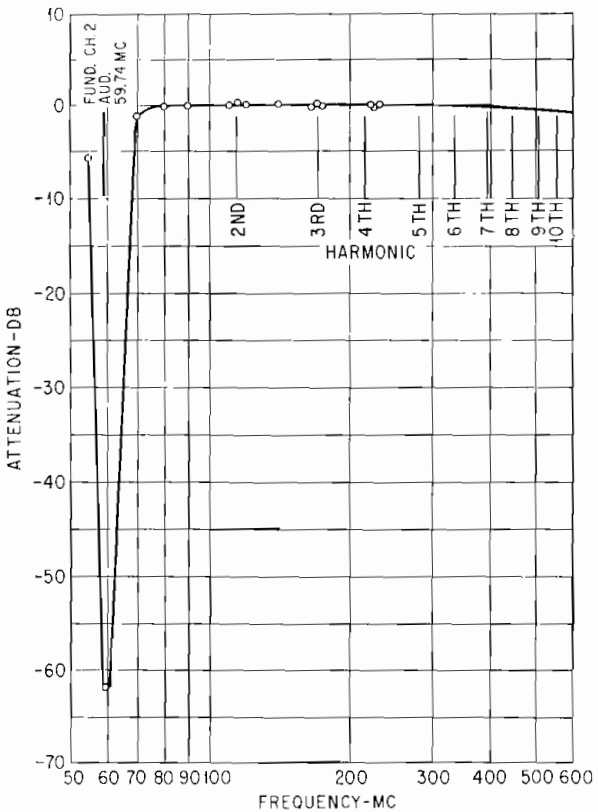


FIG. P-12. Response characteristics of two-section General Radio type 874 FRS filter.

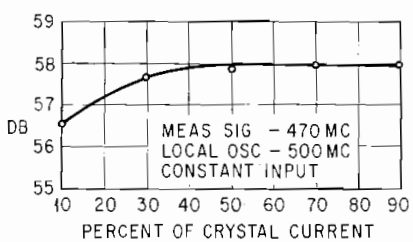


FIG. P-13. Detector characteristic for RF harmonic measurements using General Radio Type 1216-A unit I.F. amp. and G.R. type DNT detector.

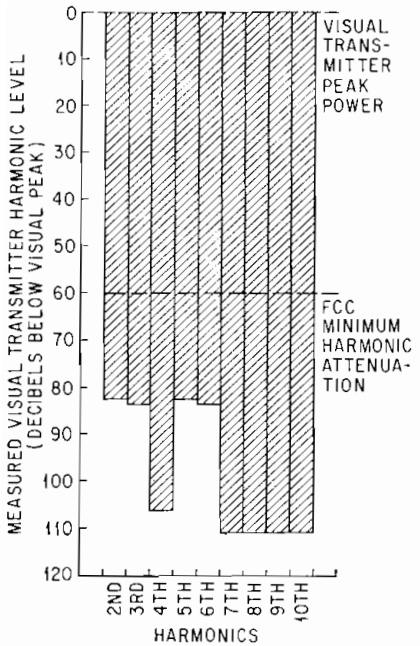


FIG. P-14. Measured visual transmission-line harmonic content.

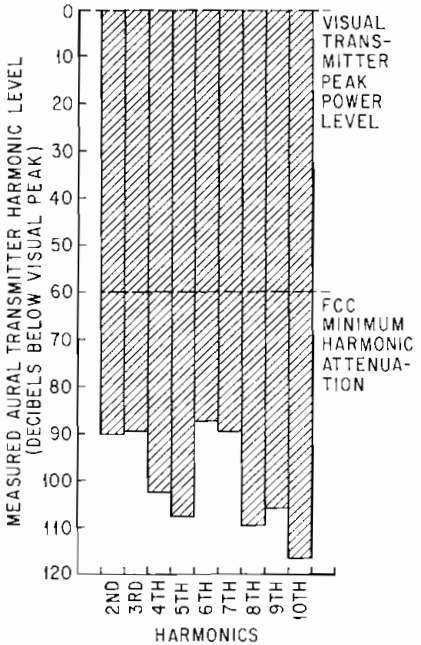


FIG. P-15. Measured aural transmission-line harmonic content.

sideband operation. Synchronizing and blanking pulse durations and slopes are specified, not taking into account the effects of vestigial sideband operation.

A studio camera was set up in typical fashion, but with the pedestal control adjusted to give a maximum white picture and the gain reduced to eliminate noise. This signal with sync was fed to the transmitter through the normal master control routing, and the transmitter was modulated in the normal fashion. The signal was so adjusted that blanking was 75 per cent of sync and white was 10 per cent of sync. An RF diode probe in the antenna transmission line was used to feed a Tektronix 524-D oscilloscope, and photographs were taken of pertinent waveforms. Timing signals were also inserted in the oscilloscope. These photographs were enlarged to a convenient size, and graphical measurements made of the pertinent durations and slopes. These data are presented in Table I along with the requirements of the Rules. Some of the rise and decay times do not conform exactly with those specified in the Rules, and these discrepancies are attributable to the vestigial-sideband operation which is known to lengthen the rise and decay times of pulses of this type. These rise and decay times of the signals fed into the transmitter system were measured and found to be within the specifications of the Rules and Regulations. Table I lists the output-waveform characteristics only.

Photograph of Transmitted Test Pattern (II-C-9-c)—(Example)

Figure P-16 is a photograph of a (*call*) test pattern, taken from a monitor connected to the input of the visual transmitter. Figure P-17 is a photograph of a (*call*) test pattern, taken on a monitor fed by the station demodulator coupled to the output transmission line feeding the dummy load.

Transfer Characteristics—(Example)

The transmitter transfer characteristic was measured using a stairstep generator and associated equipment as shown in Fig. P-18. During this test a 50 per cent duty cycle was maintained, as preliminary checks showed no significant differences in transmitter transfer

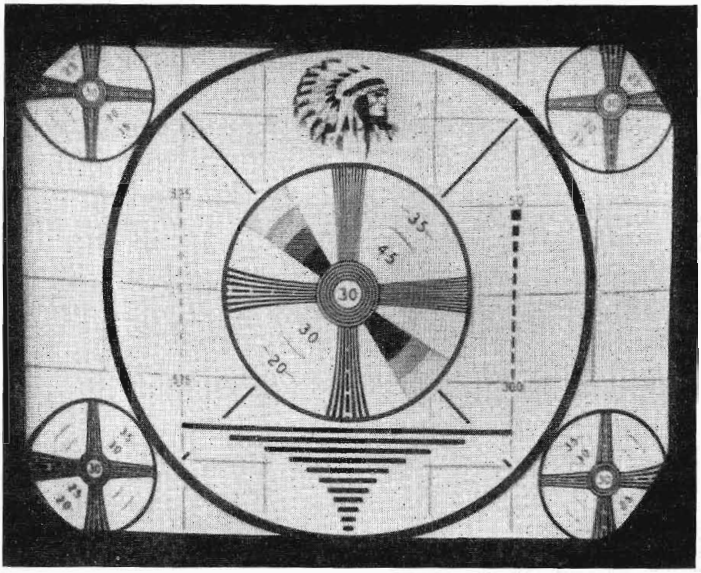


FIG. P-16. Photograph of test pattern—transmitter input.

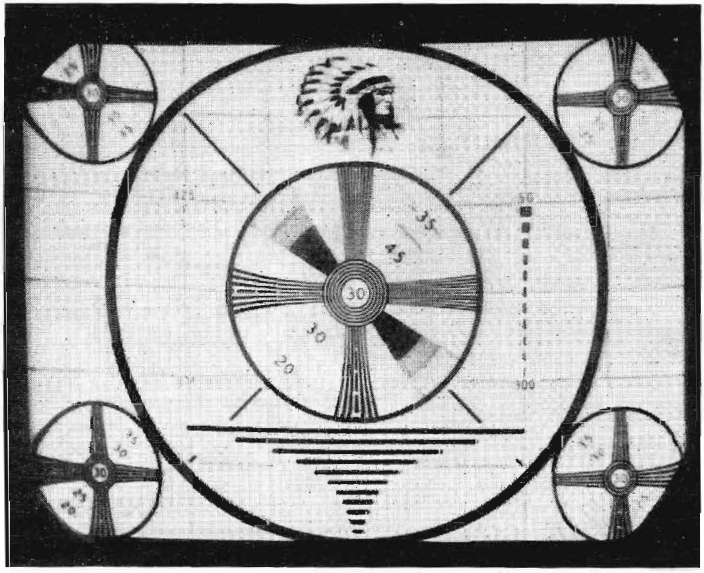


FIG. P-17. Photograph of test pattern—transmitter output.

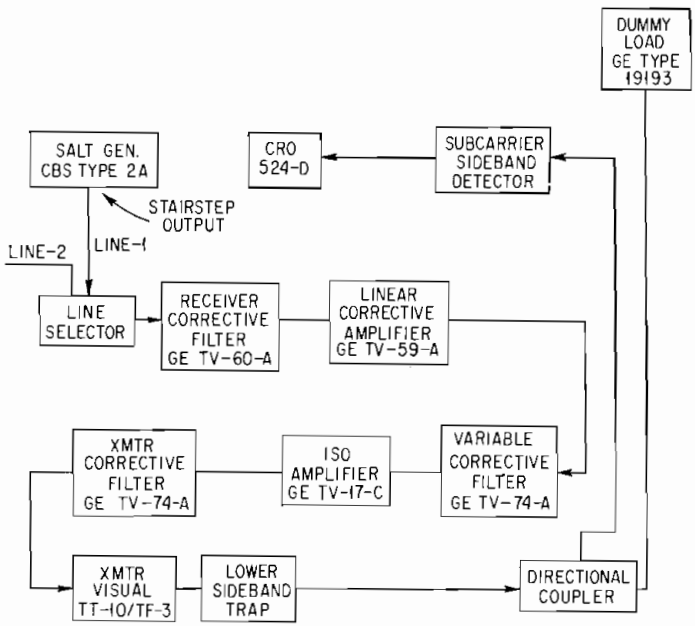


FIG. P-18. Block diagram for transfer-characteristic measurements.

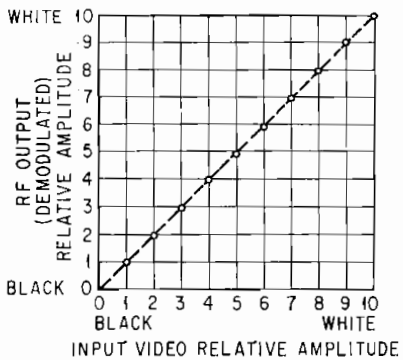


FIG. P-19. Measured transfer characteristic.

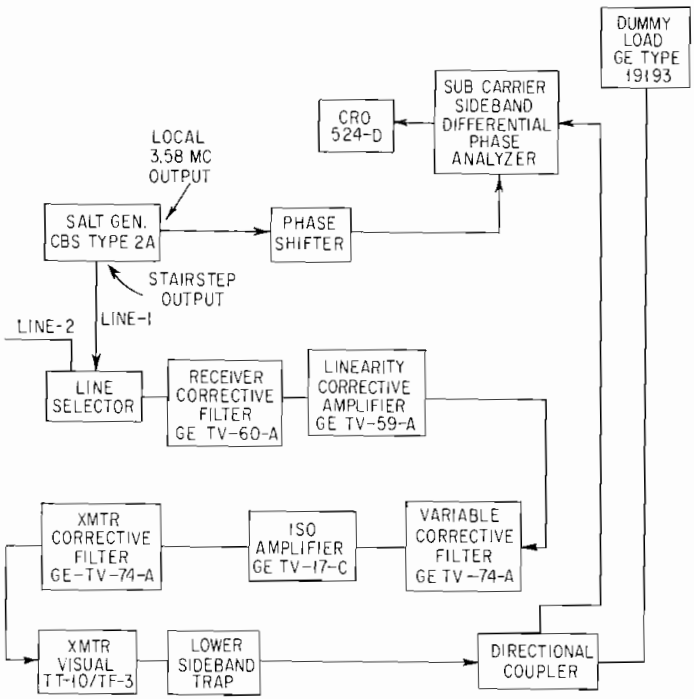


FIG. P-20. Block diagram of equipment for phase vs. amplitude characteristics.

characteristic for the 10, 50, or 90 per cent duty cycle. The results shown in Fig. P-19 indicate that the relationship between the RF output and the video signal input is substantially linear between reference-black and reference-white levels.

Differential Phase—(Example)

The differential phase or phase-vs.-amplitude characteristic of the transmitter was measured using a CBS-2A SALT (sweep-amplitude-linearity-test) generator feeding the video system input as shown on Fig. P-20. Using a stair-step signal (sync with 10 steps, each step containing a superimposed 3.58-Mc sine wave with a peak-to-peak amplitude of 20 per cent of the total amplitude of the 10 steps) feeding the input system, the output of the dummy-load directional coupler is fed into the sideband phase detector, where the "stripped" 3.58-Mc signal is "bucked out" by an external 3.58-Mc signal from the SALT generator through the use of a calibrated phase shifter. The balancing of these signals is observed on the cathode-ray tube of a Tektronix type 524-D oscilloscope. Measurements were made at three different duty cycles, 10, 50, and 90 per cent, and the maximum phase shift between the black step and the white step was measured and is listed below.

	Phase shift between steps 1 and 10	
Duty cycle, %	*Modulator output, deg*	*Transmitter output, deg*
10	1.0	6.5
50	2.0	9.0
90	2.0	4.5

COLOR-SIGNAL CHARACTERISTICS—(EXAMPLE)

Color-bar amplitudes and phase angles were measured at the input to the transmitter and compared with signals taken from the station demodulator connected to the output trans-

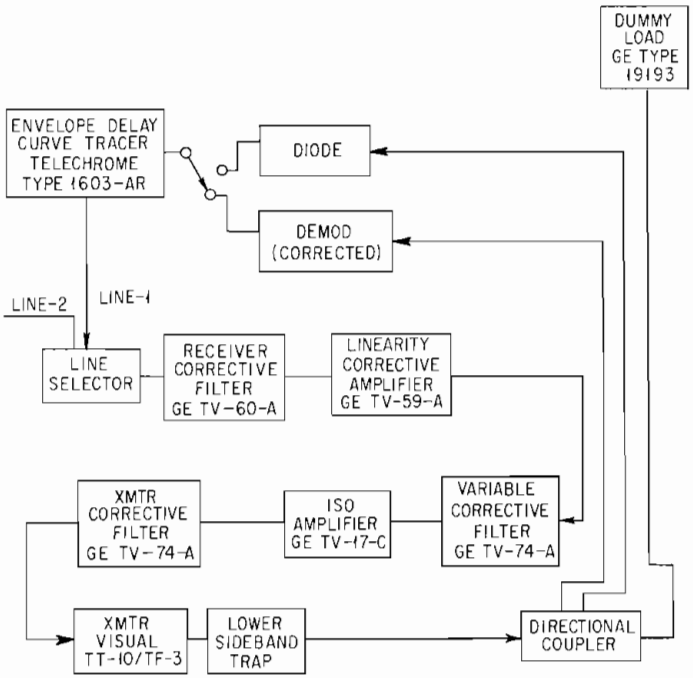


FIG. P-21. Block diagram for phase envelope-delay measurements.

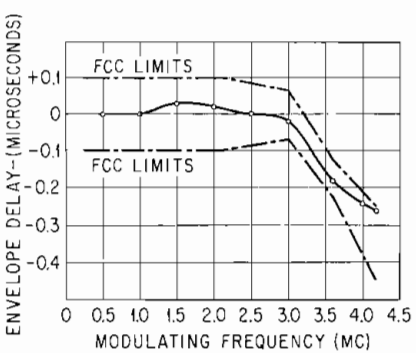
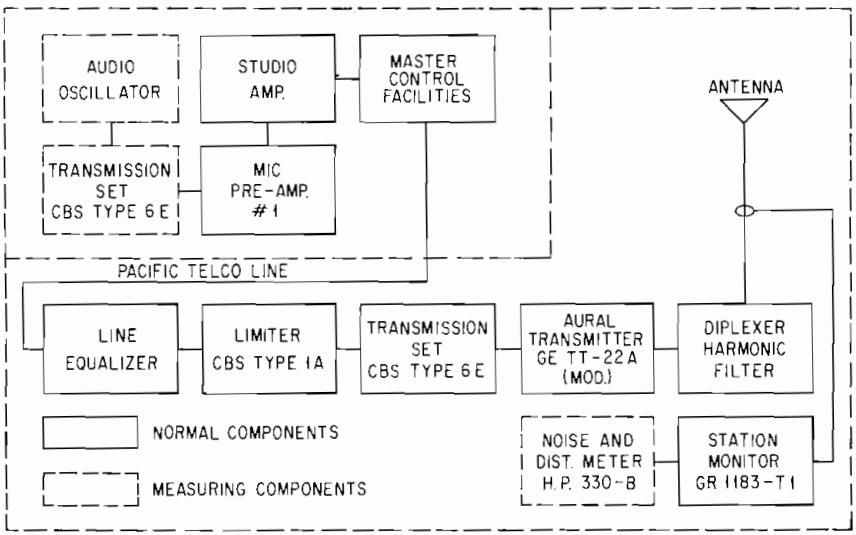


FIG. P-22. Envelope delay of radiated signal.



BLOCK DIAGRAM OF MEASURING SET-UP

CONDITIONS FOR MEASUREMENT

STUDIO	TRANSMITTER	ANTENNA
NO. 0	TYPE GE TT-22A	TRANSMISSION LINE
INPUT TO PREAMP. NO. 1	POWER 7.43 KW	OUTPUT POWER 7.43 KW
GAIN SETTING (MIXER) 11	PLATE VOLTAGE 7300 VLTS	TYPE RCA CB-TF-4 SPEC.
GAIN SETTING (MASTER) 11	PLATE CURRENT 2.6 AMPS	POWER GAIN 3.66
PROGRAM LINE REGULAR (REGULAR OR SPARE)	FIL. VOLTAGE 12.0 VLTS	

MEASURING EQUIPMENT

	MANUFACTURER	TYPE	SERIAL NO.
AUDIO OSCILLATOR	HEWLETT-PACKARD	201-B	815
DISTORTION AND NOISE METER	HEWLETT-PACKARD	330-B	
TRANSMISSION MEASURING SET	DAVEN	6-E	E-75092
DECADE ATTENUATOR			
AM DEMODULATOR	GENERAL RADIO	1932 P-1	149

FIG. P-23. Measurement data, TV aural data sheet 1.

25% MODULATION

		30 CPS	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10000 CPS	15000 CPS
ATTENUATOR READING–DB	*		2.8	3.0	4.3	5.0	11.6	19.2	21.4
CONSTANT**	*		5.5	5.5	5.5	5.5	5.5	5.5	5.5
FREQUENCY RESPONSE	*		−2.3	−2.5	−1.2	−0.5	6.1	13.7	15.9

50% MODULATION

		30 CPS	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10000 CPS	15000 CPS
ATTENUATOR READING–DB	*		2.5	3.0	4.3	5.1	11.5	19.1	21.2
CONSTANT**	*		5.6	5.6	5.6	5.6	5.6	5.6	5.6
FREQUENCY RESPONSE	*		−3.1	−2.6	−1.3	−0.5	5.9	13.5	15.6

100% MODULATION

		30 CPS	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10000 CPS	15000 CPS
ATTENUATOR READING–DB	*		2.7	3.6	4.2	5.1	11.5	19.1	21.3
CONSTANT**	*		5.6	5.6	5.6	5.6	5.6	5.6	5.6
FREQUENCY RESPONSE	*		−2.9	−20	−1.4	−0.5	+5.9	+13.5	15.7

* NOT REQUIRED BY FCC

** ADD OR SUBTRACT AN ARBITRARY CONSTANT TO BRING THE RESPONSE CURVE WITHIN THE REQUIRED TOLERANCE SHOWN ON FM DATA SHEET–3

OUTPUT NOISE LEVEL (FM) 58 db BELOW 100% MODULATION
(± 25 Kc FM at 400 cps)

OUTPUT NOISE LEVEL (AM) 55 db BELOW 100% MODULATION
(AM at 400 cps)

FIG. P-24. Over-all audio-frequency-response data and output-noise-level data, TV aural data sheet 2.

mission line. The results, listed below, indicate that amplitudes and phase angles fall within the limits specified in the Commission's Rules and Regulations.

	Transmitter input		*Demodulator output*	
Color bars	*Amplitude*	*Angle*	*Amplitude*	*Angle*
Burst	0.40	0	0.40	0
Yellow	0.65	+1	0.62	+1
Red	1.0	+3	1.0	+4
Magenta	0.98	0	0.96	+2
Q	0.40	−2	0.45	−2
Blue	0.65	−3	0.65	−1
I	0.40	0	0.45	+1
Cyan	1.0	+3	0.96	+4
Green	0.98	−1	0.90	0

Envelope-delay Measurements–(Example)

Figure P-21 is a block diagram of the equipment setup used for measuring the phase envelope delay of the visual transmitter. Figure P-22 shows the measured envelope delay and the FCC limits for color transmission.

Aural-transmitter Performance (II-C-10)–(Example)

Performance measurements of aural transmitters are to include a typical chain of equipment from a microphone input to transmitter output. Figure P-23 contains a block diagram

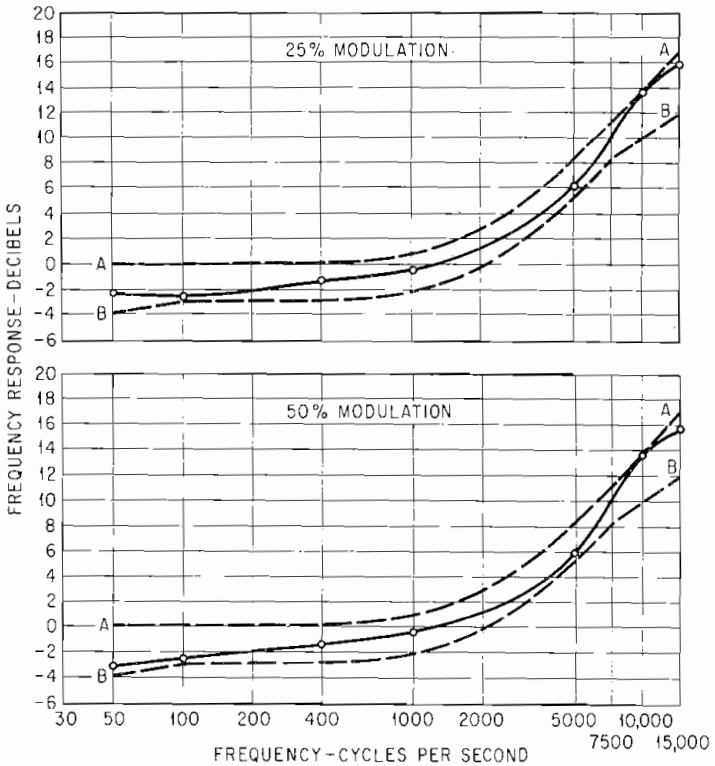


FIG. P-25. Over-all audio-frequency-response graphs, TV aural data sheet 3A.

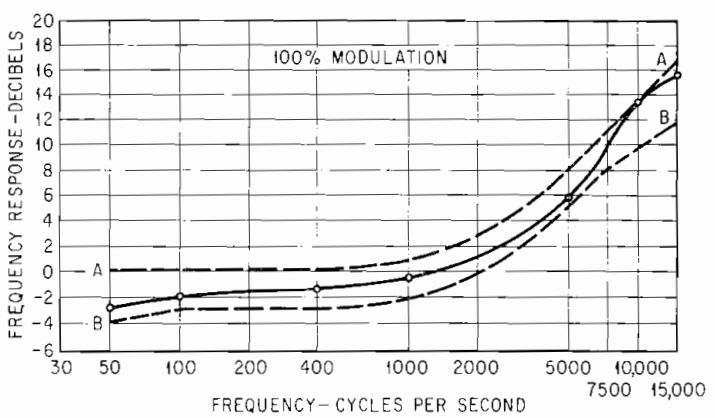
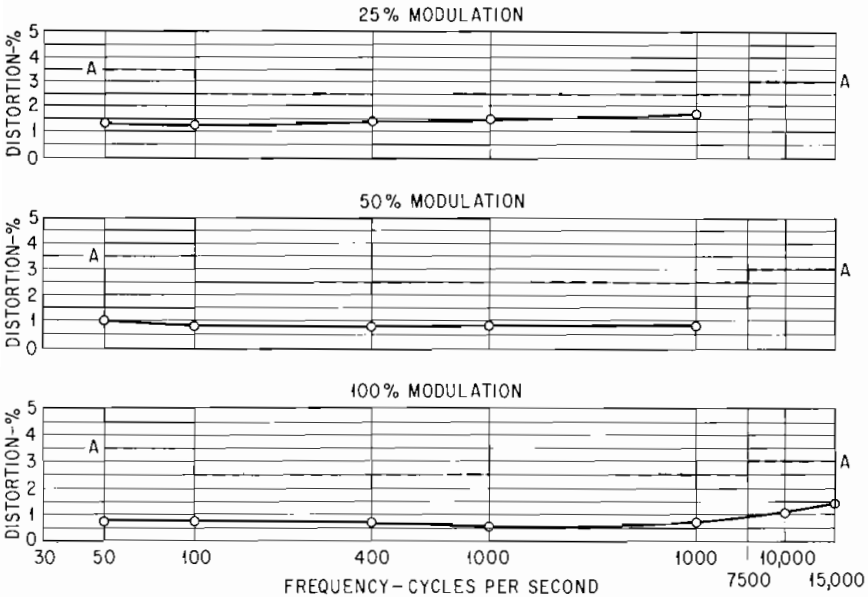


FIG. P-26. Over-all audio-frequency-response graph, TV aural data sheet 3B.

	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10,000 CPS	15,000 CPS
25% MODULATION	1.4	1.3	1.4	1.5	1.7	*	*
50% MODULATION	1.0	0.8	0.8	0.9	0.9	*	*
100% MODULATION	0.8	0.8	0.7	0.6	0.7	1.0	1.4



*–NOT REQUIRED BY FCC

A–FCC STANDARD OVERALL SYSTEM TOTAL HARMONIC DISTORTION LIMITS

FIG. P-27. Audio-frequency harmonic distortion, TV aural data sheet 4.

of the equipment setup and pertinent data concerning the conditions under which these performance measurements were made.

Frequency Response, Distortion, AM and FM Noise (II-C-7-a, b, c, d)–(Example)

Since there is a difference in peak voltages reached by pure sine-wave and normal program signals for equivalent volume indicator readings, an "elevated" level of 10 db above normal (–50 dbm at microphone input) was used throughout the system shown in Fig. P-23 to simulate 100 per cent modulation. With sine-wave input the normal settings of all controls produced 100 per cent modulation. The limiting circuit of the limiting amplifier (CBS type 1-A) was completely disabled during all of these measurements.

A constant level of –50 dbm (for the condition of 100 per cent modulation) was fed to the microphone preamplifier at all frequencies involved, and the CBS transmission set attenuator at the transmitter input was adjusted so that the modulation as indicated on the General Radio type 1183-Tl modulation monitor was always 100 per cent. The attenuator settings were recorded for each measurement frequency, and the distortion was measured for each frequency using the Hewlett Packard 330B noise and distortion meter. This procedure was repeated with microphone input levels reduced so as to produce transmitter modulation levels of 50 and 25 per cent, respectively. Figures P-24, P-25, and P-26 are plots of the system frequency response, and Fig. P-27 shows the system distortion for the three modulation levels used.

AM and FM noise levels were measured with a reference frequency of 400 cycles, and the data are shown in Fig. P-23.

It is recommended in the Rules and Regulations that none of the three parts of the system, studio, studio-transmitter link, and transmitter, contribute more than half of the total degradation allowed for the entire system. Each part of the system was measured, and it was determined that no one part of it does contribute more than half of the allowable degradation.

(EXAMPLE)

TABLE 1

ANALYSIS OF SYNCHRONIZING WAVEFORMS

Portion of synchronizing signal	*Measured * times*		*FCC Rules and Regulations specifications*	
Duration of horizontal blanking (10% black)	11.0	μsec	11.44	μsec max
Duration of horizontal blanking (90% black)	10.9	μsec	10.48	μsec min
Duration of horizontal pulse	5.8	μsec	5.08 4.45	μsec
Rise of horizontal pulse	0.183	μsec	0.254	μsec max
Decay of horizontal pulse	0.196	μsec	0.254	μsec max
Rise plus decay of horizontal blanking	0.62	μsec	0.957	μsec max
Duration of front porch	1.42	μsec	1.27	μsec min
Duration of equalizing pulse	2.6	μsec †	2.54	μsec
Rise of equalizing pulse	0.195	μsec	0.254	μsec max
Decay of equalizing pulse	0.152	μsec	0.254	μsec max
Rise of vertical pulse	0.21	μsec	0.254	μsec max
Decay of vertical pulse	0.21	μsec	0.254	μsec max
Duration of serration in vertical pulse	4.7	μsec	3.81 5.08	
Duration of vertical blanking	20	H	17.8 20.4	H H
Decay of vertical blanking	2.5	μsec	6.355	μsec max
Back porch from horizontal pulse to start of color burst	0.6	μsec	0.381	μsec min
Number of cycles in color burst	8½	cycles	8	cycles min

Rise of vertical blanking not listed but observed to be same as decay.

* The measured times are for waveforms at the output of the transmitter and, therefore, include the effects of the vestigial sideband system.

† The area of the equalizing pulse should be 45 to 50 per cent of the horizontal pulse. It was measured from the photograph to be 49 per cent of the horizontal pulse.

Part 13

AUDIO PROGRAM TRANSMISSION STANDARDS FOR TELEVISION

CBS Television Network

New York, N.Y.

INTRODUCTION

Late in 1957, as a result of continuing listener complaints of abnormal audio volume levels of television commercials, CTD Engineering undertook an extensive study of CTD volume-level practices. On Dec. 6 of the same year, Engineering Report E-2179-A, "Audio Transmission Level Study—Interim Report," containing recommendations based on the first few weeks of observation was released.

This present report summarizes the findings of the completed study and presents recommendations which will substantially improve television audio program levels and make our programs more pleasing to the listener in so far as sound levels are concerned.

OBSERVATIONS AND FINDINGS

It is standard practice in both radio and television broadcasting to transmit audio program material at a uniform peak volume level as read on the standard volume indicator. Under these circumstances, it is reasonable to expect that various portions of the program material should sound equally loud. However, quite early in this study it became evident that, as listeners had reported, some television program material sounded louder than other material. Commercials were a frequent offender in this respect, although they were not the only portion of programs that sounded too loud. Other offending material included some program opening and closing announcements and station-break announcements.

Reasons for Loudness Discrepancies

As the study continued, it was found that there are three distinct reasons for differences in the loudness of various portions of programs, viz.,

1. *Program Peaking Practices.* The first and most significant factor (and the one which will provide by far the greatest improvement in correcting loudness discrepancies) is the correct peaking of program levels at the audio console of the studio control room. Over ten years ago, after an extensive investigation, program transmission standards were established by CBS [1] in order to make the audio portion of our pro-

[1] Howard A. Chinn and Philip Eisenberg, New CBS Program Transmission Standards, *Proc. IRE*, vol. 35, December, 1947.

grams as pleasing as possible to the listener. An early finding in the current study was that these program transmission standards were not always followed.

2. *Modification of Audio Signal.* Another factor that was found to influence the apparent loudness of audio program material is the use of techniques which alter the waveform (and hence the subjective effect) of an audio signal. The following practices all result in the altered audio signal sounding louder than the original, even though both are transmitted at the same peak value as measured by a standard volume indicator:

a. Volume Compression. Program material that has been compressed, thereby restricting its original amplitude range, will sound louder than similar uncompressed program material.

b. Reverberation. Reverberant program material will sound louder than acoustically "dead" material. This is true whether the reverberation is natural or artificial. This principle was the basis of J. P. Maxfield's "Liveness in Broadcasting" [2] technique introduced in 1947 and still in common use in radio broadcasting and phonograph-record manufacture. Maxfield reported the possibility of a 6- to 8-db apparent increase in loudness using acoustically live program pickup techniques.

c. Bandwidth Restriction. When wave filters are employed to attenuate low frequencies, a considerable portion of the energy is removed from an audio signal and its level, as read on a standard volume indicator, must often be raised if standard transmission level is to be maintained. Furthermore, most of the remaining sound energy occurs in the middle-frequency range, where the ear is most sensitive. Program material so restricted in bandwidth will, therefore, usually sound louder than full-bandwidth program material (although it suffers in faithfulness of reproduction). By the same token, sounds having predominantly mid-frequency components will exhibit a similar apparent increase in loudness.

All the above techniques are commonly employed (individually or severally) in making the sound track of sound-on-film commercials and other program inserts. To a considerable extent, these practices account for such material sounding louder than the unmodified live-studio sound pickup.

3. *Listener Reaction.* The third factor that influences the apparent loudness of program material is associated with listeners' subjective reactions to certain types of sound, viz.,

a. Irritating Sounds. An irritating voice, like any irritating sound, often seems louder than a pleasant one, even though both may be reproduced at the same volume level.

b. Strident Delivery. Speech delivered in a rapid-fire, strident, or "staccato" manner with few pauses, if any, sounds louder than speech delivered in a more conversational manner. It has been observed that commercials intended to attract attention are often delivered in a rapid, urgent manner by an announcer with a slightly irritating quality in his voice. The effective loudness of such announcements is greater than that of the accompanying studio program material.

DISCUSSION AND RECOMMENDATIONS

As indicated above, the place at which the greatest improvement can be made in balancing loudness discrepancies is the studio control-room audio console. Observations made during this study showed conclusively that careful adherence to existing CBS program transmission standards [3] will, in itself, overcome many of the sound-level discrepancies that were observed during this study.

However, strict adherence to transmission standards alone will not reduce the apparent loudness of the types of program material described under Reasons for Loud-

[2] See Section 6, Part 1.
[3] Chinn and Eisenberg, *loc. cit.*

ness Discrepancies, paragraphs 2 and 3, above. This type of program material, which includes most film and many live commercials, requires special treatment to make it match in loudness other portions of the show.

The recommended solution to this problem entails the use of an automatic-gain-control amplifier and associated gain-reduction meter in each studio audio channel.

Automatic Gain Control

An automatic-gain-control (AGC) amplifier is one which automatically reduces its gain when an audio signal passing through it exceeds a predetermined "threshold" level. By its fast and automatic action, the AGC amplifier provides an excellent means of holding varying audio signals at a safe level. An associated gain-reduction meter indicates in decibels the amount the gain of the amplifier has been reduced to handle an audio signal that exceeds the threshold level.

Such an automatic level-controlling device is of considerable help in controlling widely varying audio levels and helps the audio operator do a better job of gaining a show. However, the automatic level-controlling action, in itself, does nothing to balance loudness differences that do not indicate as such on a volume indicator. On the other hand, the gain-reduction meter associated with the AGC amplifier does provide a new monitoring means which supplies quantitative data that permits the operator to make simple adjustments that will equalize loudness discrepancies.

Assume that an AGC amplifier is installed in a studio audio channel and adjusted so that gain reduction takes effect just below the volume-indicator reference point. If the audio operator now gains the program in such a manner that 6 db of gain reduction is indicated on normal program material but no gain reduction is indicated on program material that is louder than normal, loudness discrepancies will be greatly alleviated or even entirely eliminated. This balancing of unequal loudness levels results because an amount of volume compression has been applied to the normal program material, thereby slightly increasing its apparent loudness.

The method of adjusting audio levels described above reduces itself to the following general operating procedures:

1. Use 6 db of gain reduction on live program material (except music and commercials)
2. Use no gain reduction on commercials, music, or recorded program material

These generalized procedures are set forth in more detail in the following discussion.

Revised CBS Program Transmission Standards

To cover operation in studios equipped with automatic-gain-control amplifiers and associated gain-reduction meters, revisions are necessary to the CBS program transmission standards. The revised standards are given in Table 13-1.

IMPLEMENTATION

Based on carefnl study and observation, the following action is recommended to correct existing discrepancies in CTD audio program levels.

1. Install an automatic-gain-control amplifier and associated gain-reduction indicating instrument in all CTD studios.
2. Adhere to the revised CBS program transmission standards (see Table 13-1). Pending installation of AGC equipment in CTD studios, adherence to the existing CBS program transmission standards should be observed.
3. Establish quality-control points at CTD plants where network programs regularly originate (including VTR delayed-broadcast operations) where levels of programs can be measured, recorded, and monitored. Assign a CBS engineer in charge with full responsibility for reviewing the recorded data and issuing the necessary orders to correct faulty practices.

ADDITIONAL BENEFITS

In addition to the improvement in sound transmission already described, the above recommendations will also provide the following additional benefits:

Table 13-1. Revised * CBS Audio Program Transmission Standards for Television

		VI peaks	*Gain reduction* †
A. Speech (live)	1. Normal passages	Peaks of 100	6 db
	2. Low-level passages	Not less than 40	None
B. Music (live) *C. Recorded programs* (film, transcriptions, and magnetic tape) *D. Commercials* (both recorded and live ‡) *E. Program openings and closings, station-break announcements*	1. Normal passages	Peaks of 100	None
	2. Low-level passages	Not less than 40	None
F. Symphonic music	1. Normal passages	Peaks of 100	None
	2. Pianissimo passages	Must always move VI	None
G. Applause and audience reaction		Maximum peaks of 70	None

H. Transition

The transition from a low-level passage to a normal-level passage (or vice versa) must be in steps of not more than 4 db, preferably less (i.e., peaks of 40, then 60, and finally 100, or vice versa). Similarly, two succeeding passages (voice, then music or voice, then a sound effect, etc.) must not differ in level by more than 4 db, preferably less, even when a contrast is intentional.

I. Peaking practice

Peaking program material according to the prescribed standards means gaining in such a manner that the maximum VI peaks reach the specified values as frequently as possible without being inconsistent with the program content. It is understood that occasional peaks beyond the prescribed values are unavoidable, but these are to be kept to a minimum.

* For original standard refer to Howard A. Chinn and Philip Eisenberg, New CBS Program Transmission Standards, *Proc. IRE*, vol. 35, December, 1947.

† Indication on gain-reduction meter of studio automatic-gain-control amplifier.

‡ Excluding live commercials presented in a conversational manner. These should be treated as in *A*.

1. Listeners have sometimes reported that musical portions of television programs sound too loud. The AGC amplifier, together with the revised program transmission standards, will also improve or entirely eliminate this loudness discrepancy.

2. By automatically controlling unanticipated high program peaks, the AGC amplifier permits the audio operator to do a better audio mixing job.

SUMMARY

This report has given an account of the findings made during a recently completed study of CTD audio program level practices. It was found that complaints of listeners are justified; portions of CTD programs, including commercials, are too loud. The reasons are analyzed, and specific recommendations made (involving both operating techniques and technical facilities) to overcome these loudness discrepancies.

ADDENDA

Subsequent to the completion of this report, automatic-gain-control amplifiers with transfer characteristics specially tailored for his application have been installed in all studios of the CBS Television Network. Since these new amplifiers were placed in operation (a period of several months), no complaints have been received from viewers regarding unbalanced audio levels. Furthermore, careful listening tests indicate that audio transitions on CBS programs are now quite pleasing and unobtrusive.

Part 14

STEREOPHONIC BROADCASTING

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INTRODUCTION

The word "stereophonic" is defined by Webster as "giving the effect of coming from two or more directions;—of sound reproduced." This directional quality of reproduced sound introduces an element of realism which is impossible to achieve with monaural sound. The most perfect high-fidelity system one could imagine, with each element perfectly matched with the other to reproduce any sound or combination of sounds audible to the human ear with no distortion and with unlimited dynamic range, would be lacking one important quality if it were not a stereophonic system, that of direction. A man blindfolded and led into the room would know immediately that the performance was not "live." However, if the element of direction was added, a quality of realism would be achieved which, under ideal conditions, would make it difficult to discern from the live performance.

Just as our two eyes transmit two images to our brain, making us conscious of depth in things we see, our two ears add direction to our sound perception by noting the differences in sound picked up by each. In order to reproduce electronically what our two ears would hear at a concert, we must have at least two sources of sound which must be kept separated through the entire chain of electronic equipment from microphones to speakers. If proper separation is maintained, along with correct placement of microphones and speakers, the realistic effect is often quite startling. Direction is as important to faithful reproduction of sound as is frequency response or dynamic range, and the art of stereophony will be applied more and more in a never-ending effort to bring the concert hall into the home.

Stereophonic broadcasting is, of course, not new. In the early 1950s KWKW in Pasadena, Calif., demonstrated the possibilities of stereo by using this technique to broadcast the sounds heard on a busy street corner in Pasadena, the sound of a train and sounds at a baseball game. Two microphones were used, one for AM and one for FM. Later live pickups were made from the Pasadena Civic Auditorium. One of the early pioneers in Los Angeles was Calvin Smith, general manager of KFAC-AM and FM, who has broadcast the opening concert at the Philharmonic Auditorium via stereo each year, starting in October of 1953. This AM-FM outlet has also broadcast the opening event at the famous Hollywood Bowl stereophonically since July 1954. One Bowl concert was broadcast on three channels, KFAC-AM and FM with KHJ-FM carrying the third leg. In 1956, KABC-AM and FM broadcast a live

stereo pickup each week from the Aragon Ballroom in Santa Monica, Calif., featuring Lawrence Welk. Los Angeles has also heard stereo via AM-TV using the facilities of KRCA (TV) and KFI (AM) and via FM-TV using KTTV (TV) and KFAC (FM).

In 1957 the first regularly scheduled daily stereophonic broadcast using the facilities of two high-fidelity FM stations was inaugurated in Los Angeles. The two stations, KMLA and KCBH, are ideally situated for this type of broadcast, since they both use the same tower for antenna mounting and both transmit power in excess of 60 kw. The regular stereo programs from these two stations are from stereophonic tapes and records, on which they also claim a "first." This type of stereo transmission, FM-FM, combined with high-quality receiving equipment, offers the ultimate in high-fidelity listening for those who demand the finest. In 1957, on an experimental basis, KMLA in Los Angeles broadcast stereo with multiplex, using only the one station. Later in 1958 other multiplex stereo broadcasts were presented by KBMS in Glendale, Calif., and WGHF in Brookfield, Conn. There have been many other pioneers in stereophonic broadcasting in other parts of the country who deserve credit, such as WQXR in New York. We happen to be more familiar with the picture in Los Angeles and offer it as an example of what has been done in the past—with all due respect to others who have devoted much time and money to further the cause of this form of broadcasting.

PROGRAM SOURCES

The source of material for stereophonic broadcasting is the same as for monaural broadcasting: tape recordings, disc recordings, and live pickups. Stereo tapes entered the high-fidelity field prior to stereo discs and obviously excel in quality. Practically all the major recording companies were producing and distributing stereo tapes by 1957. In the fall of that year there were some 40 different stereo tape labels accounting for more than 500 stereo recordings with the prospect of approximately 100 new recordings each month. In addition to the quality advantage which stereo tapes enjoy, they offer a time advantage which is very important in the recording of lengthy musical works and also the factor of unlimited use without apparent loss of fidelity.

Tape

In order to broadcast stereophonic sound via tape, the originating station must have a stereo tape deck. The "stacked" head variety is preferable over the "staggered" type, since most of the new recordings are recorded for playback via the stacked (or "in-line") method. When stereo tapes are purchased, it is essential to note whether they are for stacked or staggered machines, since they are not compatible. If the tape deck contains the necessary preamps, no additional equipment is needed for stereophonic broadcasting. The output of one head through its preamp is fed into one transmitter, usually through a mixer for control, and the output of the second head to the other transmitter. If either of the transmitters is located at some distance from the originating point, it may be necessary to transmit one or both of the signals over land lines owned by the telephone company. In such cases proper equalization is essential in order to maintain fidelity.

Disc

Early in 1958, stereo discs began to appear on the market using the Westrex 45°–45° system of recording. This set off a chain reaction which revolutionized not only the recording industry but also the allied Hi-Fi component manufacturers. Later in the year most recording companies were making plans to produce stereo discs via this method in quantity for the mass market. This system of recording makes it possible to reproduce the sound on the disc with a single stylus. One channel is picked up by the lateral action of the stylus, and the other channel by its perpendicular action. The energy generated by each action is fed into separate coils and then passed on through a normal two-channel system. Stereo discs are particularly

well suited for stereophonic broadcasting, since conversion is very simple and inexpensive. A stereo cartridge and a preamplifier for feeding the second channel are the only items that need be added to a monaural system of broadcasting providing the second channel of transmission is available. The stereo cartridge is more susceptible to turntable rumble than is the monaural cartridge and should be used only on the best of tables if this factor is to be diminished. The cartridge and tone-arm assembly should be mounted so the stylus pressure is equally distributed on each side of the groove. Stereo cartridges are compatible with monaural LP recordings; however, the reverse is not true. A monaural cartridge can soon ruin a stereo recording.

LIVE PICKUPS

General Considerations

Live pickups are, of course, the most difficult to do stereophonically. Here we run headlong into a maze of problems which have plagued the recording industry for many years. In order to get first-hand information regarding some of these problems, we asked Mr. Russ Molloy, executive director of the Bel Canto Recording Company and a pioneer in the stereo recording field, to write the following:

Present day techniques of recording live Stereo have departed from the older style of "binaural" where the two microphones were spaced eight (8) inches apart and the playback system was earphones. Today we normally record (and here the factors are group size, room and effects desired) with microphones on booms at a height of 8 to 10 feet and sometimes 30 feet apart.

Normal recording presents the usual problems of instrument placement, but in Stereo work this becomes far more critical. Since the producer may demand the rhythm section on one channel, the physical distance the drummer (for example) is removed from his normal playing position often tends to break the coordination of the group. Fill-in mikes are used to obtain special instrument effect or presence; and in the case of large groups it is often necessary to record on ½ inch three channel tape. This method assures a completely controlled balance on the orchestra while the solos, (voice or instrument), are controlled on the third track. Final mixing will blend this "voice" to obtain either a center position or on either channel.

Artificial reverberation is not advised on the original recording, since damaging interchannel bleeding may occur. Final editing with test runs will allow the maximum degree of echo mixing.

Following specifications of master tape recording equipment is, of course, vital since we need the 55 DB separation between channels, (Ampex Corp. specs), for optimum recording characteristics. Bias problems are to be watched, since the operation of recording Stereo is now audible on two channels rather than the nominal one and differentials here are of grave importance.

It is well to remember that the philosophy of playing back Stereo is to create the audio illusion of "group width" and that the techniques required to produce this "sound illusion" are not the same for a trio as they are for an 86 piece orchestra. In attempting to explain basic principles of Stereo recording to the beginner, it almost seems that we are making the approach one of a witch-doctor, but in truth the art of Stereo is relatively new—one that has only been used to any extent since 1955. Those of us who have been recording Stereo even before that time are continually changing our philosophy and techniques.

These comments by Mr. Molloy will be particularly interesting to those who plan to make stereo recordings as well as those who are setting up live pickups for immediate broadcast release, since many problems such as microphone placement are common to both.

Microphone Placement

Definite rules regarding the positioning of microphones are impossible to formulate, since no two pickups are the same. The placement for a small group would be completely different from that necessary for a full orchestra. The size and acoustical quality of the room or auditorium would also make a difference. If there is time and the equipment is available, it is advisable to record a few test runs with

the microphones in different positions so the best placement can be determined by actually listening to the playback of the test tape. In most cases this method is not practical and rules of logic must be relied on. For the uninitiated, it is recommended that only two microphones be used in order to keep it as simple as possible and that a few general rules be followed. Generally speaking, it is easier to produce a realistic stereo effect with a large group than it is with a small group. This is true because "group width" already exists and the only problem is the placement of microphones to pick up what we already have, whereas, with a small group such as a trio, there is the additional problem of positioning the musicians in order to simulate group width. Here is a rule of thumb which can be used for positioning two microphones for a large group pickup such as a symphony orchestra: Draw an equilateral triangle, the base of which is the first row of chairs in the orchestra and the apex out toward the audience somewhere in the center aisle of the hall. The microphones would then be placed on the two lines forming the sides of the triangle, approximately 15 ft in front of the orchestra and elevated approximately 15 ft above the stage so as to increase the pickup from the back row of instruments in relation to the front row.

Channel Separation

Good channel separation is essential and often necessitates the use of directional microphones. However, care should be taken not to have too much "separation," which causes a "hole" in the middle. Separation is the difference in the volume of sound pickup from a given instrument by microphone *A* and microphone *B*. In order to check separation the gain control on each amplifier should be set the same. Then let us assume that we are standing at the front of the stage facing the orchestra with microphone *A* on our right. Now ask the musician in the front row on our extreme right to play a sustained note and check the level of each channel. Channel *A* should read 15 to 20 db higher than Channel *B* if there is good separation. Now ask for a tone from the center of the stage to be sure there are no holes. This should be the same level on each channel and approximately the same level as the first tone registered on Channel *A*. This is one method of checking separation. Of course, there are others, but regardless of the method used, adequate separation must be maintained if true stereophonic sound is to be achieved.

USE OF MULTIPLEX FOR STEREO

The advent of multiplex made it possible to broadcast stereo on a single station as opposed to the earlier two-station method. It also made possible "compatible stereo," the sum-and-difference technique which allows the monaural listener to hear a complete (both legs) program on the main channel while the stereo devotee enjoys the directional qualities he demands by listening to the main channel and a multiplex subchannel. Compatible stereo was developed by Mr. Murray G. Crosby, Crosby Laboratories, Inc., Hicksville, N.Y., and was described by Mr. Crosby in a paper presented before the Audio Engineering Society, New York, on Oct. 11, 1957, from which we quote.[1]

It is the object of this paper to describe an improved method of transmitting Stereophonic sound on an FM transmitter with many advantages for both the monaural and stereo listener. An outstanding advantage is obtained for the monaural listener who is equipped to receive only the main channel without the benefit of Stereo reception. With the system to be described, that listener has a compatible reception with the program properly balanced with respect to microphone pickup. The advantages obtained for the Stereo listener include a 6 DB improvement in signal-to-noise ratio realized from the relatively poor signal-to-noise ratio on the subcarrier channel, together with a balancing of the signal-to-noise ratios on the two channels so that a more pleasing response is obtained.

Figure 14-1 shows the conventional FM multiplexing system which has been used to demonstrate stereophonic transmission by Armstrong and Halstead. In this sys-

[1] One of many systems being considered by the National Stereophonic Radio Committee.

tem microphone *A* is fed to the main channel of the FM transmitter and microphone *B* is fed to the subcarrier generator which is applied as a multiplex modulation on the FM wave. Application of the subcarrier modulation can also be accomplished by the use of an auxiliary phase modulator following the main FM modulator with the same basic result in the wave transmitted. This transmitting system is shown in

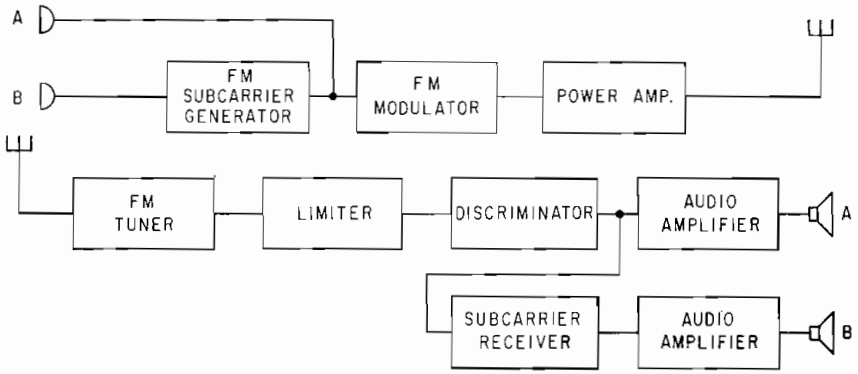


FIG. 14-1. A simplified FM multiplex system.

Fig. 14-2.[2] It utilizes a form of multiple phase modulation, applied to successive stages, so that the resultant modulation is the sum of the separate modulations. Use of this principle for subcarrier modulation is described by E. H. Armstrong.

The conventional techniques in which the separate microphone outputs are transmitted over the separate channels, as shown in Figs. 14-1 and 14-2, have several disadvantages. First of these is the lack of compatibility for the monaural listener. Since that listener will tune in the main channel only, a degraded program pickup is received by virtue of the reception of the output due to one microphone only. That single microphone will receive its pickup from one side of the stage only, so that the instruments near it will be overemphasized and those near the other microphone will be deemphasized. The pickup of a soloist who happens to be nearest to the opposite microphone will be especially degraded.

The second disadvantage of the conventional system is the unbalance of the signal-to-noise ratios on the main and subcarrier channels. The subcarrier channel has an

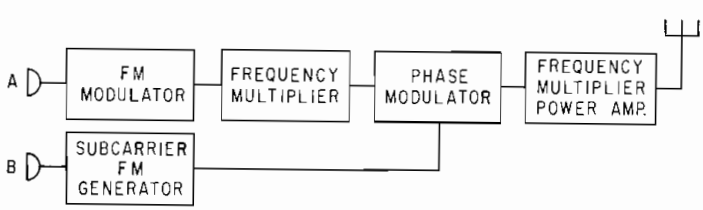


FIG. 14-2. A simplified FM multiplex transmitting system.

efficiency of transmission which is much less than that of the main channel, so that the signal-to-noise ratio on one loudspeaker may be as much as 25 db poorer than that on the other. This produces an annoying one-sidedness to noise disturbances

[2] Although this system is the only one included by the author, it should not be construed by the reader that this is in any manner a recommendation by NAB as superior to other similar systems. The FCC has not yet established stereo standards for broadcasting.

which impairs the pleasantness of reception. With the sum-and-difference technique to be described, the signal-to-noise ratios on both loudspeakers are the same and the effective transmission of the subcarrier channel is improved by 6 db. The 6-db improvement in subcarrier signal-to-noise ratio is equivalent to a 4-to-1 increase in power of the transmitter, since with the stereo system the performance is only as good as that of the poorest channel. Accordingly the sum-and-difference technique results in an increase in the effective range of the stereo transmission.

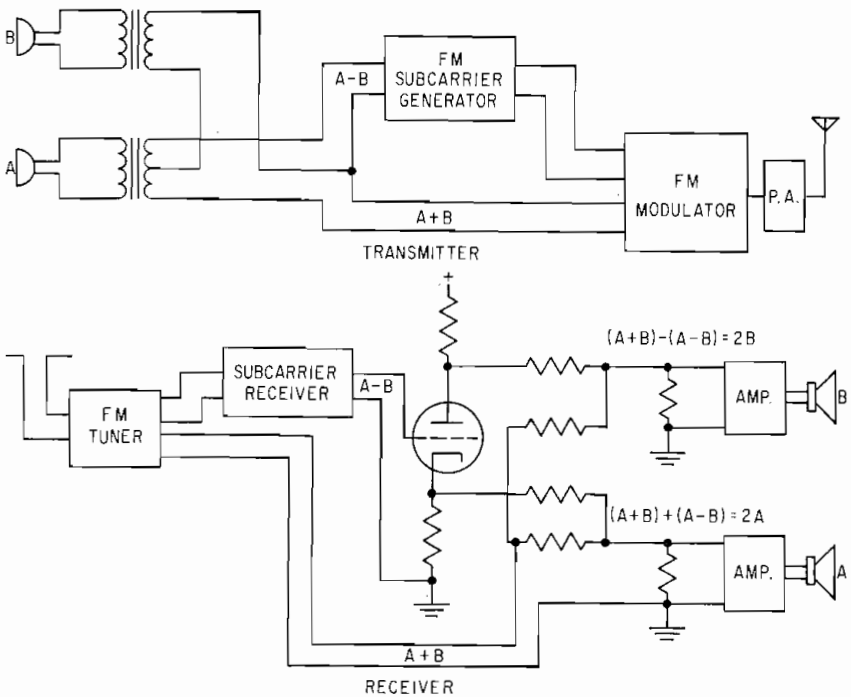


FIG. 14-3. Sum and difference technique in the production of a multiplex stereophonic signal.

This 6-db improvement in signal-to-noise ratio may, under certain conditions, be realized as a 6-db improvement in over-all hum and distortion. If it so happens that the hum is predominately from either the subcarrier channel or the main channel taken alone, the result is a 6-db reduction in hum. This is brought about by the signals from the sum-and-difference combinations adding in phase to produce twice the voltage while the hum remains at a value equal to that of the channel with the highest hum. The only condition in which this improvement would not be realized would be that of an equal hum level in both main and subcarrier channels which was so phased as to add up to twice voltage in the sum-and-difference combination. This would be a rare coincidence. In the case of distortion, the same situation exists; the channel with the lowest distortion aids the channel with the highest distortion by a factor of 6 db in the over-all system. In experimental work it has been observed that the subcarrier channel has the least distortion and hum. Under these circumstances the sum-and-difference combination is responsible for a 6-db reduction in both hum and distortion as well as noise in the over-all system response.

Figure 14-3 shows the sum-and-difference technique of applying a twin-channel stereo system to the FM multiplex system. Microphones *A* and *B* are mixed, so that

the sum combination $(A + B)$ is fed to the main channel of the FM transmitter and the difference combination $(A - B)$ is fed to the subcarrier channel. The sum combination is readily recognizable by its improved bass response, since the difference combination results in a microphone directive array which tends to cancel lower frequencies.

At the receiver the outputs of the main-channel discriminator and the subcarrier adapter are fed to a mixing system utilizing a phase inverter such that one amplifier and speaker receives the combination:

$$(A + B) - (A - B) = 2B$$

and the other amplifier and speaker

$$(A + B) + (A - B) = 2A$$

This addition and subtraction separate the individual microphone outputs from their sum-and-difference combinations just as though the A and B microphones fed the A and B speakers directly.

It will be noted that the program on the main channel of the transmitter is the desired $A + B$ combination of microphones which provides the compatible balanced program for the monaural listener. Since the subcarrier channel is superaudible, the monaural listening is unimpaired by the stereo transmission.

With the sum-and-difference technique, the resulting signal fed to one loudspeaker is an addition of the signal from the main channel and that from the subcarrier channel. This combination doubles the amplitude of the signal and adds the noises from the two channels by rms addition. The noise from the subcarrier channel is so much greater than that on the main channel that the rms addition of the two noises results in a noise having an amplitude equal to that of the subcarrier channel. Since the signals have been doubled and the noise is equal to that on the subcarrier channel, the resulting signal-to-noise ratio fed to either loudspeaker input is equal to 6 db above the normal signal-to-noise ratio on the sub-carrier channel.

Multiplex and a compatible system along with stereo tapes and discs and improved FM receivers in conjunction with high-quality amplifiers and speaker systems have made stereophonic broadcasting practical both technically and financially. The future of this form of broadcasting is very bright, and it is the belief of the author that FM-multiplex stereophonic transmission will eventually become the accepted method of broadcasting.

Editor's Note:

The reader may wonder why more stereophonic programming techniques have not been included. Radio broadcast programs of the type which would be suitable for stereophonic reproduction are seldom originated at the local station. Disc and tape have and undoubtedly will continue to provide the bulk of stereophonic program material for many years.

The basic considerations involved in the local production of a stereophonic broadcast are pointed out in this part. More detailed specifications for a particular production would be almost impossible because each production is a "custom installation" requiring individual evaluation.

The National Stereophonic Radio Committee has been established under the sponsorship of the Electronic Industries Association (EIA). The function of the NSRC is to make detailed technical studies of the several possible methods of providing compatible stereo sound for the AM, FM, and TV broadcast services. The objectives of these studies have been:

1. To clarify the technical issues as between the several possible systems for each of these services
2. To verify the technical conclusions through appropriate field tests and obtain such information as may be necessary for channel utilization purposes for the determination of the choice of standards
3. To delineate appropriate signal specifications for the several services based upon the best scientific information and field test data available to the committee

The NSRC is composed of six Panels which have been charged with particular objectives as follows:

PANEL 1—SYSTEM SPECIFICATIONS

Scope: Panel 1 shall consider system proposals for compatible stereophonic broadcasting; shall identify the technical issues in said proposals and refer them where necessary to other panels for detailed study; shall formulate a consistent set of transmission specifications for each form of broadcasting; and shall provide an over-all evaluation of the system performance implied in the specifications.

PANEL 2—INTERCONNECTING FACILITIES

Scope: Panel 2 shall study and recommend technical characteristics of interconnecting lines, networks, studio-transmitter links and related stereo-transmission facilities between program origination points and the transmitters proper, said characteristics to include tolerable limits on cross talk, relative time delay, frequency response, gain, and such other matters as must be controlled to assure a stereo signal of adequate quality at the transmitter input.

PANEL 3—BROADCAST TRANSMITTERS

Scope: Panel 3 shall study the system proposals referred to it by Panel 1 with particular regard to (1) the feasibility of the proposed transmission method and (2) methods of adapting the proposals to existing broadcast transmitters.

PANEL 4—BROADCAST RECEIVERS

Scope: Panel 4 shall study the system proposals referred to it by Panel 1 with particular regard to (1) the performance of existing monophonic receivers when tuned to the stereophonic signal (receiver compatibility), (2) the performance of stereophonic receivers designed for the stereophonic signal (stereo performance) and (3) the performance of stereophonic receivers when tuned to monophonic signals (reverse receiver compatibility).

PANEL 5—FIELD TESTING

Scope: Panel 5 shall study and compare the system proposals referred to it by Panel 1, with particular regard to coverage, interference effects, and other matters related to channel utilization; and shall conduct field tests with the advice and assistance of the other Panels.

PANEL 6—SUBJECTIVE ASPECTS

Scope: Panel 6 shall provide to the other panels scientific information on the subjective aspects of stereophonic sound.

The NSRC studies have been devoted to the study of compatible stereophonic radio systems. A compatible stereophonic radio signal might be defined as one that could be produced with existing monophonic equipment in such a manner as to provide an acceptable composite of the stereophonic signal. Before stereophonic broadcasting can be initiated nation-wide, it is necessary to establish uniform standards for each broadcast service. Except for the "two-facility" type of stereo broadcast (which is not a compatible system), stereophonic broadcasting is a "lock and key" type of system, similar to television. Obviously, the same system standards must be used nation-wide; otherwise a receiver purchased for one particular system would not function on another. The establishment of transmission standards is solely the responsibility of the Federal Communications Commission which has taken such steps in their proposed rule making, Docket 12517, for FM broadcasting. It would appear that it is the intent of the Commission to similarly establish stereophonic transmission standards for AM and TV broadcasting. The NSRC report to the FCC is now scheduled to be presented by March 15, 1960 (except for field tests), subsequent to which it is expected that the Commission will initiate concluding procedures leading to acceptable standards.

Section 9

CHARTS AND GRAPHS

Table 9-1. Decibels

Power ratio	Voltage or current ratio	−Db+	Voltage or current ratio	Power ratio	Power ratio	Voltage or current ratio	−Db+	Voltage or current ratio	Power ratio
10^{-1}		10		10	0.316	0.562	5.0	1.78	3.16
10^{-2}	10^{-1}	20	10	10^{2}	0.309	0.556	5.1	1.80	3.24
10^{-3}		30		10^{3}	0.302	0.550	5.2	1.82	3.31
10^{-4}	10^{-2}	40	10^{2}	10^{4}	0.295	0.543	5.3	1.84	3.39
10^{-5}		50		10^{5}	0.288	0.537	5.4	1.86	3.47
10^{-6}	10^{-3}	60	10^{3}	10^{6}	0.282	0.530	5.5	1.88	3.55
10^{-7}		70		10^{7}	0.275	0.525	5.6	1.91	3.63
10^{-8}	10^{-4}	80	10^{4}	10^{8}	0.269	0.519	5.7	1.93	3.72
10^{-9}		90		10^{9}	0.263	0.513	5.8	1.95	3.80
10^{-10}	10^{-5}	100	10^{5}	10^{10}	0.257	0.507	5.9	1.97	3.89
1.000	1.000	0	1.00	1.00	0.251	0.501	6.0	2.00	3.98
0.977	0.989	0.1	1.01	1.02	0.246	0.496	6.1	2.02	4.07
0.955	0.977	0.2	1.02	1.05	0.240	0.490	6.2	2.04	4.17
0.933	0.966	0.3	1.04	1.07	0.234	0.484	6.3	2.07	4.27
0.912	0.955	0.4	1.05	1.10	0.229	0.479	6.4	2.09	4.37
0.891	0.944	0.5	1.06	1.12	0.224	0.473	6.5	2.11	4.47
0.871	0.933	0.6	1.07	1.15	0.219	0.468	6.6	2.14	4.57
0.851	0.923	0.7	1.08	1.18	0.214	0.462	6.7	2.16	4.68
0.832	0.912	0.8	1.10	1.20	0.209	0.457	6.8	2.19	4.79
0.813	0.902	0.9	1.11	1.23	0.204	0.452	6.9	2.21	4.90
0.794	0.891	1.0	1.12	1.26	0.200	0.447	7.0	2.24	5.01
0.776	0.881	1.1	1.14	1.29	0.195	0.442	7.1	2.27	5.13
0.759	0.871	1.2	1.15	1.32	0.191	0.437	7.2	2.29	5.25
0.741	0.861	1.3	1.16	1.35	0.186	0.432	7.3	2.32	5.37
0.724	0.851	1.4	1.18	1.38	0.182	0.427	7.4	2.34	5.50
0.708	0.841	1.5	1.19	1.41	0.178	0.422	7.5	2.37	5.62
0.692	0.832	1.6	1.20	1.45	0.174	0.417	7.6	2.40	5.75
0.676	0.822	1.7	1.22	1.48	0.170	0.412	7.7	2.43	5.89
0.661	0.813	1.8	1.23	1.51	0.166	0.407	7.8	2.46	6.03
0.646	0.804	1.9	1.25	1.55	0.162	0.403	7.9	2.48	6.17
0.631	0.794	2.0	1.26	1.59	0.159	0.398	8.0	2.51	6.31
0.617	0.785	2.1	1.27	1.62	0.155	0.394	8.1	2.54	6.46
0.603	0.776	2.2	1.29	1.66	0.151	0.389	8.2	2.57	6.61
0.589	0.767	2.3	1.30	1.70	0.148	0.385	8.3	2.60	6.76
0.575	0.759	2.4	1.32	1.74	0.145	0.380	8.4	2.63	6.92
0.562	0.750	2.5	1.33	1.78	0.141	0.376	8.5	2.66	7.08
0.550	0.741	2.6	1.35	1.82	0.138	0.372	8.6	2.69	7.24
0.537	0.733	2.7	1.37	1.86	0.135	0.367	8.7	2.72	7.41
0.525	0.724	2.8	1.38	1.91	0.132	0.363	8.8	2.75	7.59
0.513	0.716	2.9	1.40	1.95	0.129	0.359	8.9	2.79	7.76
0.501	0.708	3.0	1.41	2.00	0.126	0.355	9.0	2.82	7.94
0.490	0.700	3.1	1.43	2.04	0.123	0.351	9.1	2.85	8.13
0.479	0.692	3.2	1.45	2.09	0.120	0.347	9.2	2.88	8.32
0.468	0.684	3.3	1.46	2.14	0.118	0.343	9.3	2.92	8.51
0.457	0.676	3.4	1.48	2.19	0.115	0.339	9.4	2.95	8.71
0.447	0.668	3.5	1.50	2.24	0.112	0.335	9.5	2.99	8.91
0.437	0.661	3.6	1.51	2.29	0.110	0.331	9.6	3.02	9.12
0.427	0.653	3.7	1.53	2.34	0.107	0.327	9.7	3.06	9.33
0.417	0.646	3.8	1.55	2.40	0.105	0.324	9.8	3.09	9.55
0.407	0.638	3.9	1.57	2.46	0.102	0.320	9.9	3.13	9.77
0.398	0.631	4.0	1.59	2.51	0.1000	0.316	10.0	3.16	10.00
0.389	0.624	4.1	1.60	2.57	0.0977	0.313	10.1	3.20	10.23
0.380	0.617	4.2	1.62	2.63	0.0955	0.309	10.2	3.24	10.47
0.372	0.610	4.3	1.64	2.69	0.0933	0.306	10.3	3.27	10.72
0.363	0.603	4.4	1.66	2.75	0.0912	0.302	10.4	3.31	10.96
0.355	0.596	4.5	1.68	2.81	0.0891	0.299	10.5	3.35	11.22
0.347	0.589	4.6	1.70	2.88	0.0871	0.295	10.6	3.39	11.48
0.339	0.582	4.7	1.72	2.95	0.0851	0.292	10.7	3.43	11.75
0.331	0.575	4.8	1.74	3.02	0.0832	0.288	10.8	3.47	12.02
0.324	0.569	4.9	1.76	3.09	0.0813	0.285	10.9	3.51	12.30

Table 9-1. Decibels (*Continued*)

Power ratio	Voltage or current ratio	—Db+	Voltage or current ratio	Power ratio	Power ratio	Voltage or current ratio	—Db+	Voltage or current ratio	Power ratio
0.0794	0.282	11.0	3.55	12.59	0.0251	0.159	16.0	6.31	39.81
0.0776	0.279	11.1	3.59	12.88	0.0246	0.157	16.1	6.38	40.74
0.0759	0.275	11.2	3.63	13.18	0.0240	0.155	16.2	6.46	41.69
0.0741	0.272	11.3	3.67	13.49	0.0234	0.153	16.3	6.53	42.66
0.0724	0.269	11.4	3.72	13.80	0.0229	0.151	16.4	6.61	43.65
0.0708	0.266	11.5	3.76	14.13	0.0224	0.150	16.5	6.68	44.67
0.0691	0.263	11.6	3.80	14.45	0.0219	0.148	16.6	6.76	45.71
0.0676	0.260	11.7	3.85	14.79	0.0214	0.146	16.7	6.84	46.77
0.0661	0.257	11.8	3.89	15.14	0.0209	0.145	16.8	6.92	47.86
0.0646	0.254	11.9	3.94	15.49	0.0204	0.143	16.9	7.00	48.98
0.0631	0.251	12.0	3.98	15.85	0.0200	0.141	17.0	7.08	50.12
0.0617	0.248	12.1	4.03	16.22	0.0195	0.140	17.1	7.16	51.29
0.0603	0.246	12.2	4.07	16.60	0.0191	0.138	17.2	7.24	52.48
0.0589	0.243	12.3	4.12	16.98	0.0186	0.137	17.3	7.33	53.70
0.0575	0.240	12.4	4.17	17.38	0.0182	0.135	17.4	7.41	54.95
0.0562	0.237	12.5	4.22	17.78	0.0178	0.133	17.5	7.50	56.23
0.0550	0.234	12.6	4.27	18.20	0.0174	0.132	17.6	7.59	57.54
0.0537	0.232	12.7	4.32	18.62	0.0170	0.130	17.7	7.67	58.88
0.0525	0.229	12.8	4.37	19.05	0.0166	0.129	17.8	7.76	60.26
0.0513	0.227	12.9	4.42	19.50	0.0162	0.127	17.9	7.85	61.66
0.0501	0.224	13.0	4.47	19.95	0.0159	0.126	18.0	7.94	63.10
0.0490	0.221	13.1	4.52	20.42	0.0155	0.125	18.1	8.04	64.57
0.0479	0.219	13.2	4.57	20.89	0.0151	0.123	18.2	8.13	66.07
0.0468	0.216	13.3	4.62	21.38	0.0148	0.122	18.3	8.22	67.61
0.0457	0.214	13.4	4.68	21.88	0.0145	0.120	18.4	8.32	69.18
0.0447	0.211	13.5	4.73	22.39	0.0141	0.119	18.5	8.41	70.79
0.0437	0.209	13.6	4.79	22.91	0.0138	0.118	18.6	8.51	72.44
0.0427	0.207	13.7	4.84	23.44	0.0135	0.116	18.7	8.61	74.13
0.0417	0.204	13.8	4.90	23.99	0.0132	0.115	18.8	8.71	75.86
0.0407	0.202	13.9	4.96	24.55	0.0129	0.114	18.9	8.81	77.62
0.0398	0.200	14.0	5.01	25.12	0.0126	0.112	19.0	8.91	79.43
0.0389	0.197	14.1	5.07	25.70	0.0123	0.111	19.1	9.02	81.28
0.0380	0.195	14.2	5.13	26.30	0.0120	0.110	19.2	9.12	83.18
0.0372	0.193	14.3	5.19	26.92	0.0118	0.108	19.3	9.23	85.11
0.0363	0.191	14.4	5.25	27.54	0.0115	0.107	19.4	9.33	87.10
0.0355	0.188	14.5	5.31	28.18	0.0112	0.106	19.5	9.44	89.13
0.0347	0.186	14.6	5.37	28.84	0.0110	0.105	19.6	9.55	91.20
0.0339	0.184	14.7	5.43	29.51	0.0107	0.104	19.7	9.66	93.33
0.0331	0.182	14.8	5.50	30.20	0.0105	0.102	19.8	9.77	95.50
0.0324	0.180	14.9	5.56	30.90	0.0102	0.101	19.9	9.89	97.72
0.0316	0.178	15.0	5.62	31.62	0.0100	0.100	20.0	10.00	100.00
0.0309	0.176	15.1	5.69	32.36					
0.0302	0.174	15.2	5.75	33.11					
0.0295	0.172	15.3	5.82	33.88					
0.0288	0.170	15.4	5.89	34.67					
0.0282	0.168	15.5	5.96	35.48					
0.0275	0.166	15.6	6.03	36.31					
0.0269	0.164	15.7	6.10	37.15					
0.0263	0.162	15.8	6.17	38.02					
0.0257	0.160	15.9	6.24	38.90					

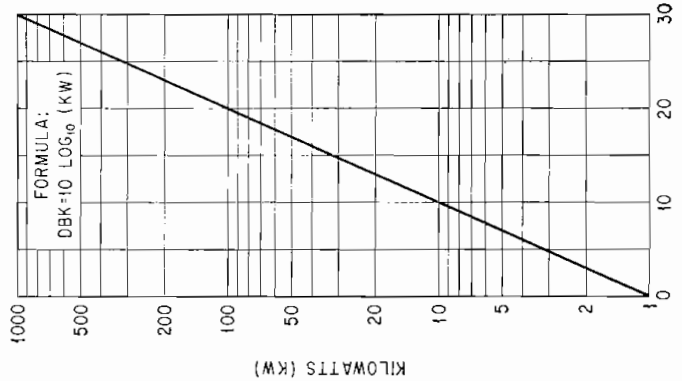


FIG. 9-2. Transformation of kilowatts to decibels above 1 kw.

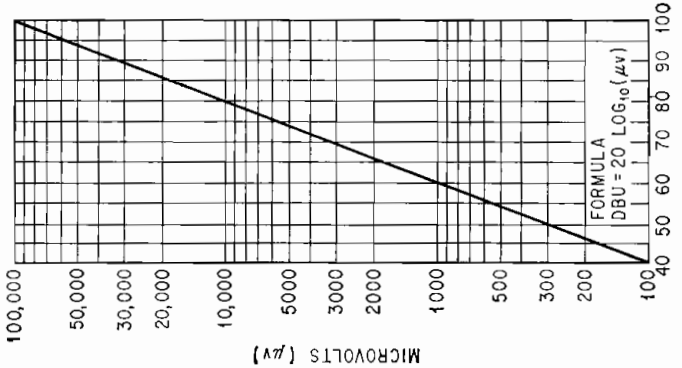


FIG. 9-1. Transformation of microvolts to decibels above 1 μv.

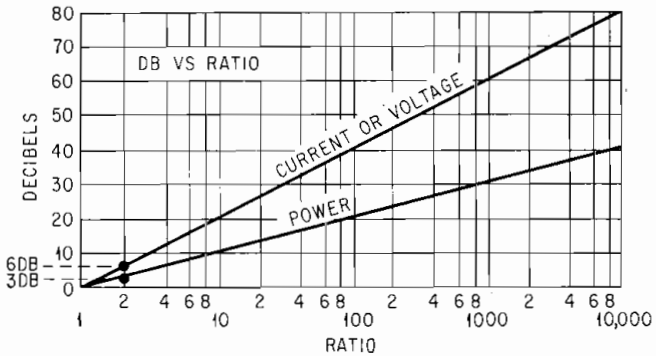


FIG. 9-3. Decibels vs. ratio.

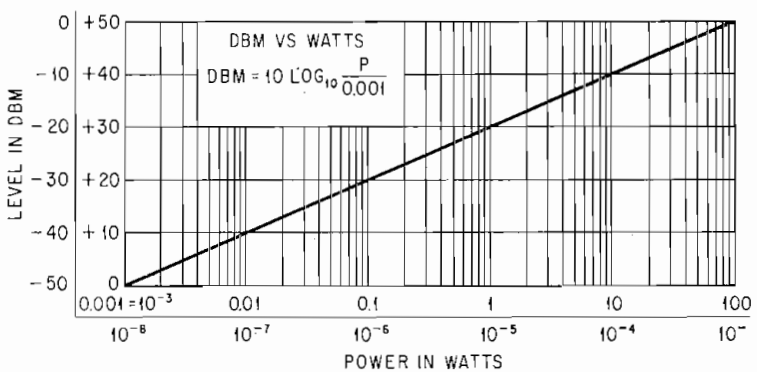


FIG. 9-4. Dbm vs. watts.

Table 9-2. Volume Level to Power and Voltage Conversion

Reference Level

0 dbm = 1 mw, 600 ohms

Milliwatts	Volts	Dbm
0.000001	0.0007746	−60
0.000010	0.002449	−50
0.000100	0.007746	−40
0.001	0.02449	−30
0.010	0.07746	−20
0.100	0.2449	−10
1.000	0.7746	0
Watts	**Volts**	**Dbm**
0.001000	0.7746	0
0.002512	1.228	+4
0.006310	1.946	+8
0.01000	2.449	+10
0.1000	7.746	+20
1.000	24.49	+30
10.00	77.46	+40

RESISTANCE VALUES OF SYMMETRICAL ATTENUATION NETWORKS *

For ready reference and to satisfy most of the practical needs of the various artificial line pads, the following charts have been prepared:

Figures 9-5 to 9-7, inclusive, are curves for determining the three components of pads which are symmetrical but have different input and output impedances. The curves are marked to indicate pad ratios for which it was calculated, and the values of *A* are for the higher pad series leg resistances shown in Fig. 9-5, while *C* values for the lower pad series leg resistances are shown in Fig. 9-7. *B* is for the shunt or transverse resistor shown in Fig. 9-6.

There is a minimum loss for each impedance ratio for which a pad can be designed and for convenience each curve on the figures is terminated by a circle at the lower value of resistance which corresponds to this minimum pad loss. For L networks double the values of *A* and *C*.

Figure 9-8 gives the resistance values for the series legs *A* of symmetrical pads having 1-to-1 impedance ratios. Figure 9-9 gives the transverse resistance values for these pads. For values not shown multiply the value shown for 100 ohms by the ratio of the desired value to 100. Double the series leg values for L networks.

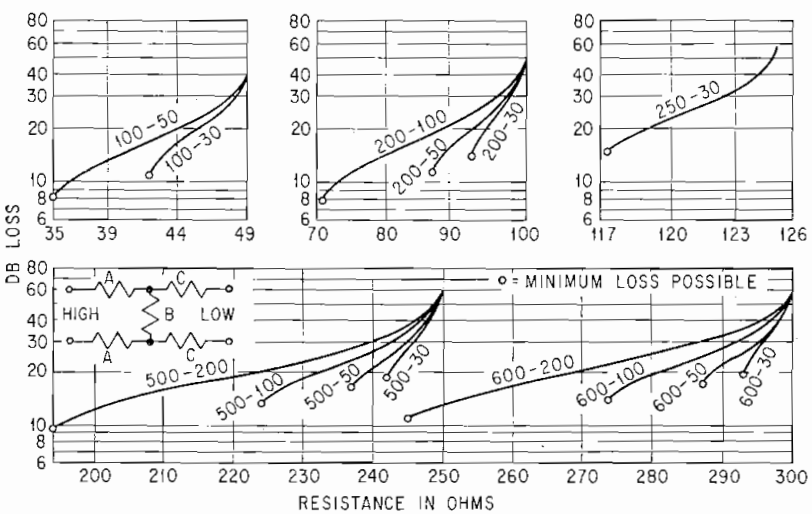


FIG. 9-5. Symmetrical attenuation networks for standard ratios—values of *A*.

* By Frank H. McIntosh, Consulting Radio Engineer, Washington, D.C.

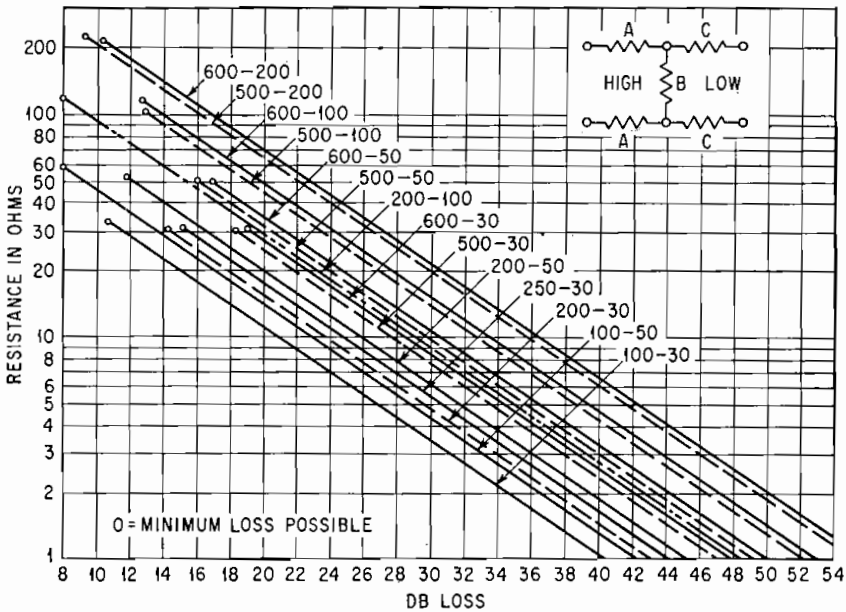


FIG. 9-6. Symmetrical attenuation networks for standard ratios—values of *B*.

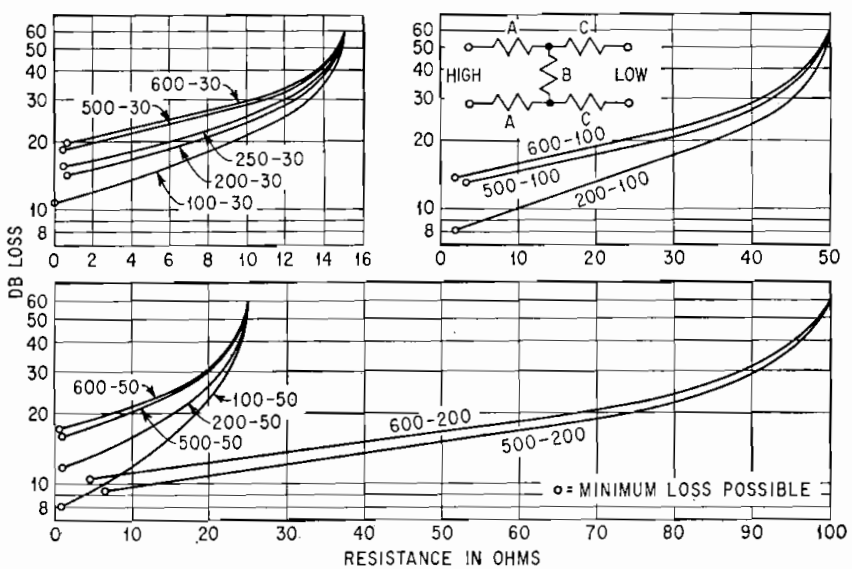


FIG. 9-7. Symmetrical attenuation networks for standard ratios—values of *C*.

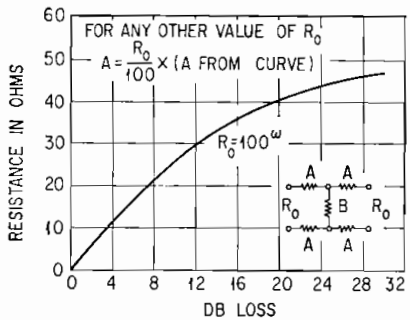


FIG. 9-8. *H*-type artificial line—value of series resistance *A*.

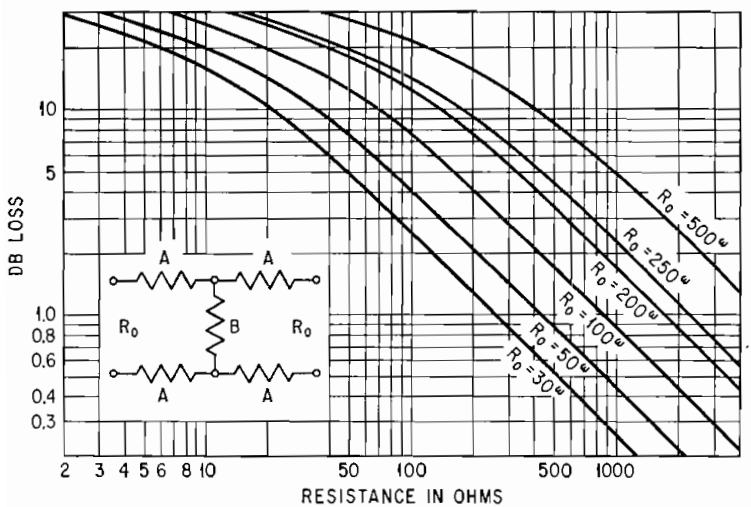
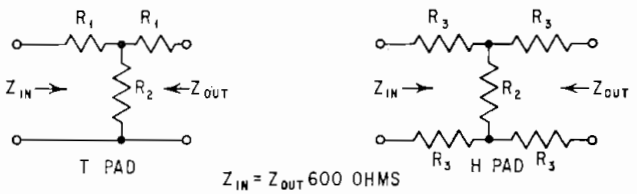


FIG. 9-9. *H*-type artificial line—value of transverse resistauce *B*.

Table 9-3. Resistive Pads



For impedances other than 600 ohms, multiply all resistors by factor $Zx/600$.

$Z_{in} = Z_{out} = 600$ ohms

Loss	EIA resistor values *			Loss	EIA resistor values *		
	R_1	R_2	R_3		R_1	R_2	R_3
½	18	10,000	8.2	16	430	200	220
1	36	5,100	18	17	470	180	220
2	68	2,700	36	18	470	150	240
3	100	1,800	51	19	470	130	240
4	130	1,200	68	20	510	120	240
5	160	1,000	82	22	510	100	270
6	200	820	100	24	510	75	270
7	220	680	110	26	560	62	270
8	270	560	130	28	560	47	270
9	300	470	150	30	560	39	270
10	300	430	160	32	560	30	300
11	330	360	160	34	560	24	300
12	360	330	180	36	560	18	300
13	390	270	200	38	560	15	300
14	390	240	200	40	560	12	300
15	430	220	200				

* EIA resistor values nearest to the exact values are given.

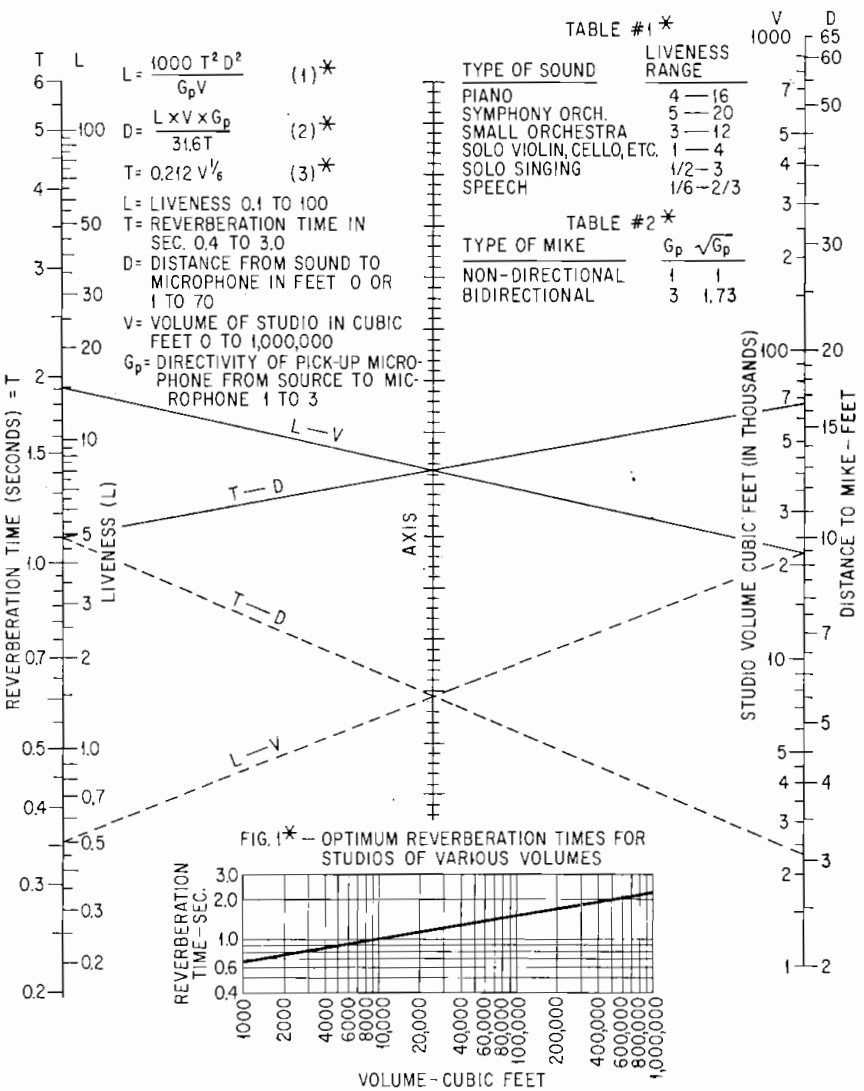


FIG. 1* — OPTIMUM REVERBERATION TIMES FOR STUDIOS OF VARIOUS VOLUMES

*COURTESY OF WESTERN ELECTRIC CO.

FIG. 9-10. Nomograph for microphone distances in liveness broadcasting. (*Reprinted from Tele-Tech.*)

Constants V = 22,000 cu ft; T = 1.1 sec.

Example 1 (solid lines): Placement of general microphone. From Table 1 use liveness of 15. Connect 22,000 on V and 15 on L. Mark reference on the axis. Then extend a line from 1.1 on T through reference on axis to 16.5 ft on D. *Answer:* 16½ ft from mike to sound source.

Example 2 (dash lines): Placement of solo vocal microphone. From Table 1 use liveness of ½. Connect 22,000 on V and ½ on L. Mark reference on the axis. Then extend line from 1.1 on T through this reference to 3 ft on D. For bidirectional mike multiply 3 ft by $\sqrt{3}$, or 1.73. This yields 5 to 6 ft for actual distance.

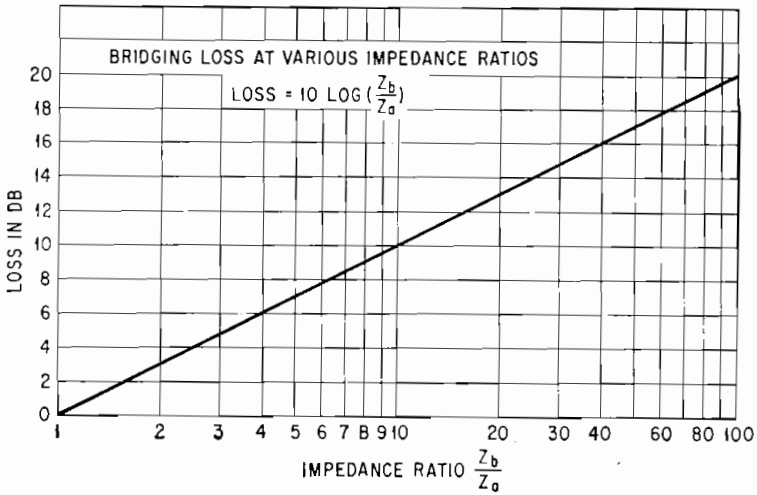


FIG. 9-11. Bridgiug loss at various impedance ratios. Loss = 10 log Z_b/Z_a.

PARALLEL-T NOMOGRAPH *

Summary: Values of five parameters for parallel-T networks are obtained directly with one setting of a straightedgc, for frequencies in audio and ultrasonic ranges, to expedite the design of the network used directly in an amplifier chain to eliminate a single frequency. The same network can be used in a negative feedback path to enhance a single frequency.

This nomograph (Fig. 9-12) facilitates calculating parallel-T networks for experimental work in multiplex FM equipment design. The subcarrier frequencies used are in the range from about 20 to 75 kc. With one setting of a straigbtedgc, all parameters of the parallel-T network needed to eliminate the undesired frequency f can be obtained to three significant figures.

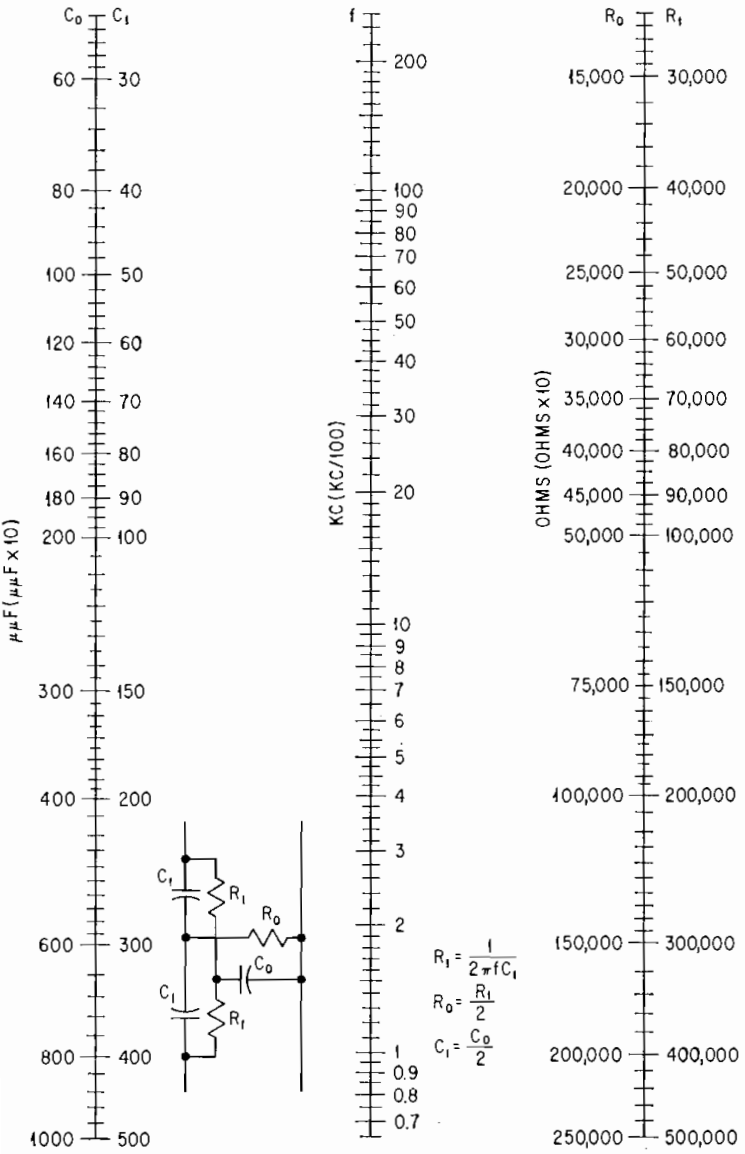
Example. If a specific frequency f of 10 kc is to be eliminated and C_1 is selected by the designer to be 100 $\mu\mu$f, run a straightedge from 100 $\mu\mu$f on the C_1 scale through 10 kc on the f scale. All other values can now be read directly from the nomograph. Thus, R_1 is 159,000 ohms, R_0 is 79,500 ohms and C_0 is 200 $\mu\mu$f.

Any two of the five parameters can be selected as the initial starting point of design. The other three can then be found with one setting of the straightedge.

If the f scale is divided by 100, the C and R scales must be multiplied by 10. This changes the range of the nomograph to cover from 7 cps at the low end to about 2,000 cps at the high end.

For a 100-cps elimination network and a value of 1,000 $\mu\mu$f for C_1, these scale-multiplying factors must be used. The other parameters are then R_1 = 1.59 megohms, R_0 = 795,000 ohms, and C_0 = 2,000 $\mu\mu$f.

* By Donald F. Carter, Chief Electrical Engineer, Harkins and Hershfield, Phoenix, Ariz.
Reprinted from *Electronics*, Nov. 1, 1957.



CENTER SCALE GIVES FREQUENCY ATTENUATED BY PARALLEL-T NETWORK

FIG. 9-12. Parallel-T nomograph.

MICROPHONE NOMOGRAPH *

Summary: The chart (Fig. 9-13) relates sound pressure level, microphone sensitivity, and output in decibels and volts as an aid in the design of microphone systems and related equipment. Typical sound levels for common sounds are indicated.

Microphone response is usually expressed in decibels referred to 1 volt/dyne/cm^2. Thus a microphone which produces 1 volt when exposed to a sound pressure of 1 dyne/cm^2 has a response of 0 db. Most microphones are far less sensitive than this.

Unless otherwise specified, the open-circuit voltage is used in arriving at the response figure.

The nomograph is based on the definition of pressure response in the American Standard Specification for Laboratory Standard Microphones.

Expressed symbolically, this definition becomes

$$\rho = 20 \log \frac{e_o}{p} \tag{9-1}$$

where ρ = pressure response
e_o = open-circuit output voltage
p = pressure, dynes/cm^2

Equation (9-1) can be rewritten

$$= 20 \log e_o - 20 \log p \tag{9-2}$$

Sound pressure is commonly expressed in decibels relative to a reference pressure $p_0 = 2 \times 10^{-4}$ dynes/cm^2. When so expressed it is called sound pressure level (SPL) and is defined by

$$SPL = 20 \log \frac{p}{p_0} \quad \text{db} \tag{9-3}$$

Equations (9-2) and (9-3) yield

$$\rho = 20 \log e_o - \text{SPL} + 74 \text{ db} \tag{9-4}$$

Should absolute sound pressures be required, they can be filled in on the left-hand scale by noting that 100 db = 20 dynes/cm^2, 80 db = 2 dynes/cm^2, 60 db = 0.2 dyne/cm^2, and so forth.

A microphone with a response of -50 db is to be used to measure sound levels of 35 db or more. For what minimum input voltage should the amplifier be designed?

A straight line drawn between 35 db on the SPL scale and -50 db on the ρ scale intersects the e_o scale at about 35 μv. This is the open-circuit microphone voltage.

Sound level in a jet-engine test control room is 112 db; a pneumatic chipper at a distance of 5 ft has a sound level of 122 db. At takeoff and 80 ft from the tail, an F-84 has a sound level of 130 db, all typical values.

* By William B. Conover, Transformer Laboratories Department, General Electric Company, Pittsfield, Mass. Reprinted from *Electronics*, October, 1955.

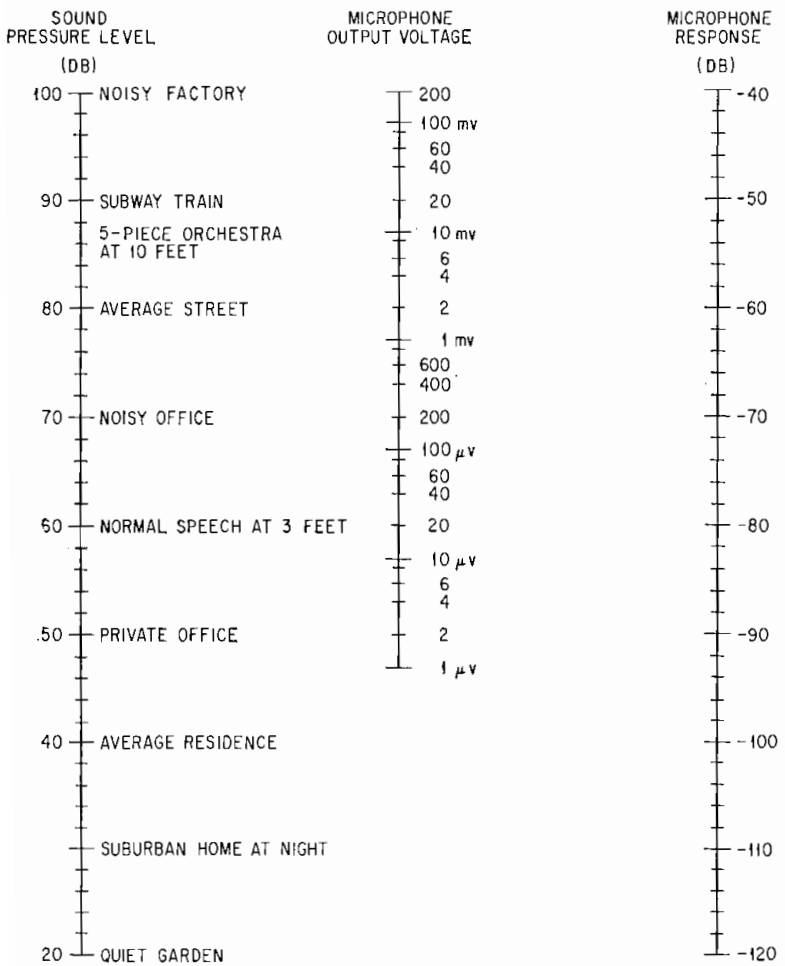

SOUND PRESSURE LEVEL (DB)
MICROPHONE OUTPUT VOLTAGE
MICROPHONE RESPONSE (DB)
100
NOISY FACTORY
90
SUBWAY TRAIN
5-PIECE ORCHESTRA AT 10 FEET
80
AVERAGE STREET
70
NOISY OFFICE
60
NORMAL SPEECH AT 3 FEET
50
PRIVATE OFFICE
40
AVERAGE RESIDENCE
SUBURBAN HOME AT NIGHT
20
QUIET GARDEN
200
100 mv
60
40
20
10 mv
6
4
2
1 mv
600
400
200
100 μv
60
40
20
10 μv
6
4
2
1 μv
-40
-50
-60
-70
-80
-90
-100
-110
-120

FIG. 9-13

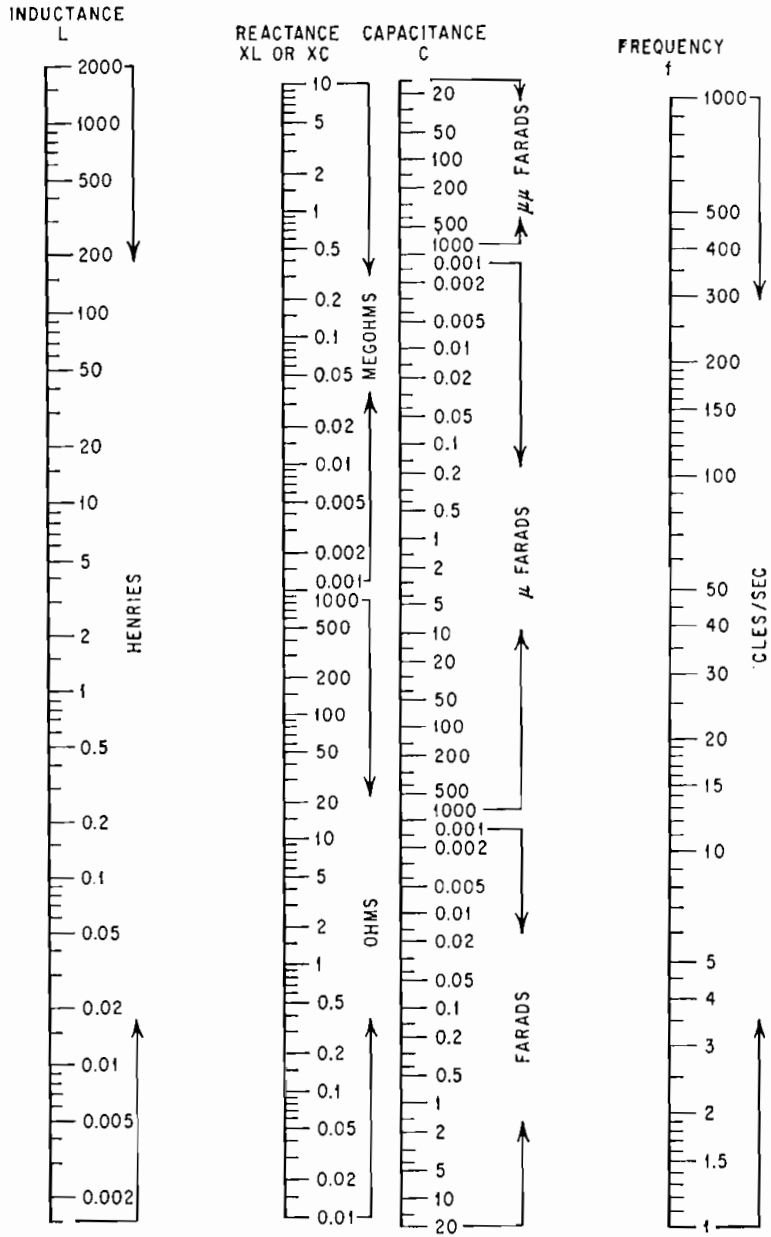

INDUCTANCE
L
2000
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
HENRIES
REACTANCE
XL OR XC
CAPACITANCE
C
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
MEGOHMS
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
OHMS
20
50
100
200
500
1000
μμ FARADS
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
μ FARADS
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
FARADS
FREQUENCY
f
1000
500
400
300
200
150
100
50
40
30
20
15
10
5
4
3
2
1.5
1
CLES/SEC

Fig. 9-14*a*

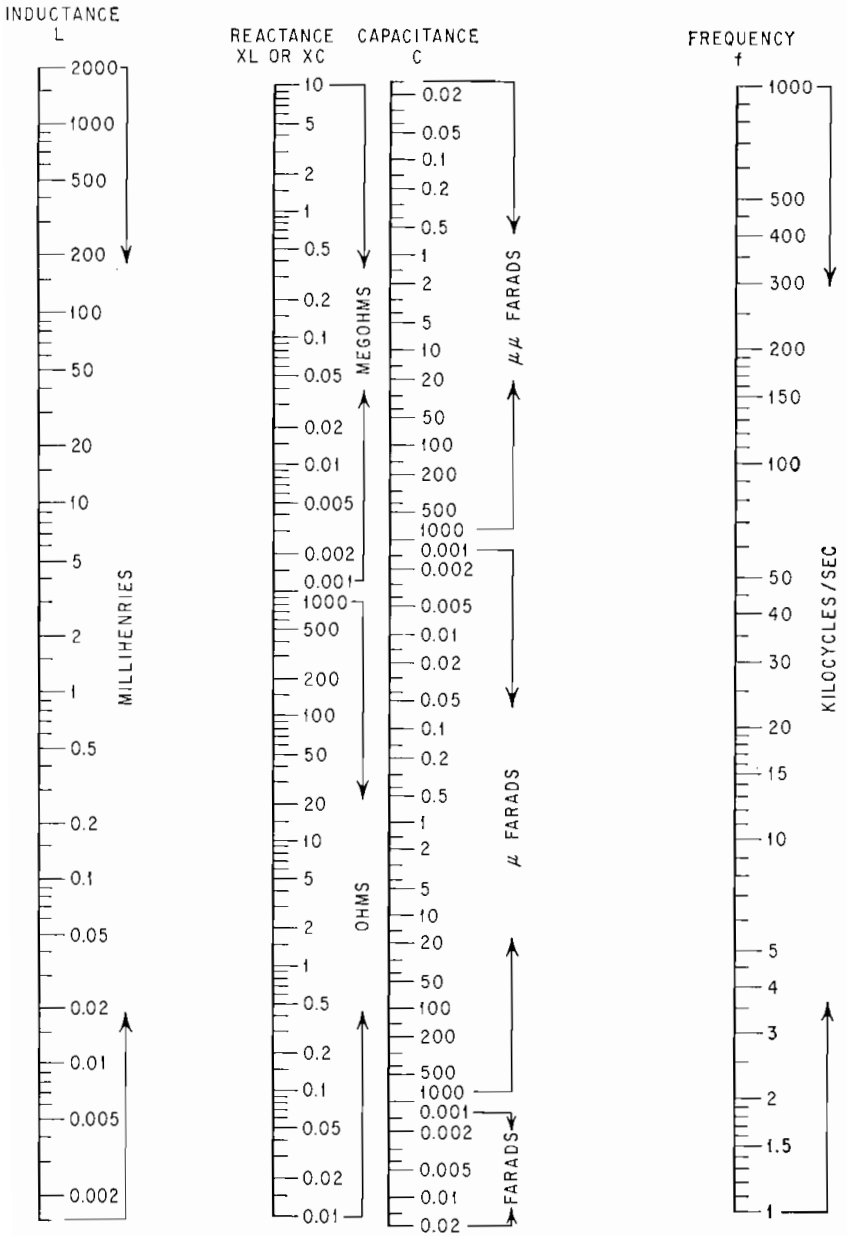

INDUCTANCE
L
2000
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
MILLIHENRIES
REACTANCE
XL OR XC
CAPACITANCE
C
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
MEGOHMS
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
OHMS
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
200
500
1000
μμ FARADS
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
200
500
1000
μ FARADS
0.001
0.002
0.005
0.01
0.02
FARADS
FREQUENCY
f
1000
500
400
300
200
150
100
50
40
30
20
15
10
5
4
3
2
1.5
1
KILOCYCLES/SEC

Fig. 9-14*b*

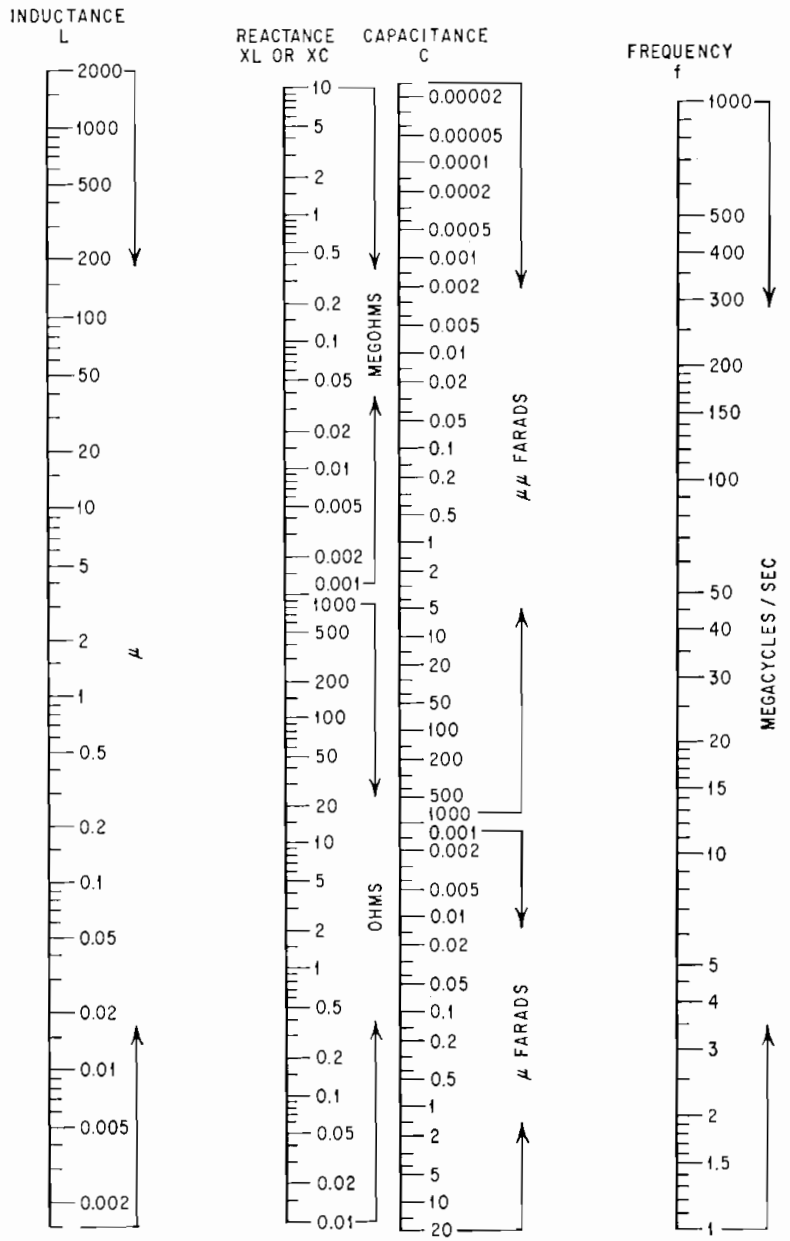

INDUCTANCE
L
2000
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
μ
REACTANCE
XL OR XC
CAPACITANCE
C
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
MEGOHMS
1000
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
OHMS
0.00002
0.00005
0.0001
0.0002
0.0005
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
200
500
1000
μμ FARADS
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
μ FARADS
FREQUENCY
f
1000
500
400
300
200
150
100
50
40
30
20
15
10
5
4
3
2
1.5
1
MEGACYCLES / SEC

Fig. 9-14c

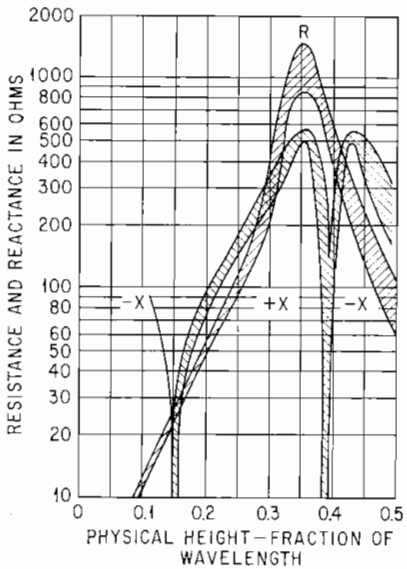


FIG. 9-15. Average characteristics for guyed radiators of uniform cross section. Data compiled from measurements of KNX and KIRO's 4-ft triangular radiators and a large number of 12- to 18-in. triangular radiators. (*Prepared by J. B. Hatfield.*)

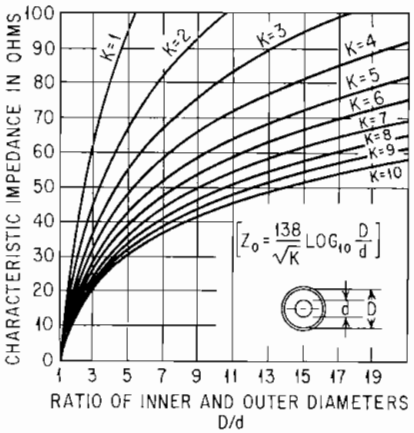


FIG. 9-16. Characteristic impedance of coaxial lines with various dielectrics.

COAXIAL-LINE IMPEDANCE CHART *

Summary: Characteristic impedances of coaxial lines are related graphically to dielectric constants and the ratios of outer to inner conductor diameters. Dielectric constants of common materials are also tabulated.

This chart (Fig. 9-16) simplifies the solution for the characteristic impedance of a single coaxial line.

Example. If a characteristic impedance of 50 ohms is desired and the insulating material is air, then from the chart the D/d ratio is 2.3. If metal tubing with an inside diameter $D = 0.250$ in. is chosen for the outer conductor, the outside diameter of the metal inner conductor is 0.109 in.

* By Herbert L. Levin, Electron Tube Laboratory, Federal Telecommunication Laboratories, Nutley, N.J. Reprinted from *Electronics*, Nov. 1, 1957.

Dielectric Constant K from 1 to 10,000 Mc at 25°C

Ceramics	
Alumina 85%	8.3–8.0
Alumina 95%	8.9–9.3
Alumina 97%	9.0–9.6
Aluminum silicate	5.5–5.2
Fosterite	6.2–6.0
Magnesium silicate	5.9–5.3
Steatite	6.5–5.3
Porcelain, standard electrical	5.5
Porcelain, zircon	9.2

Glasses	
Corning:	
7052	5.1
7070	4.0
7720 nonex	4.7
7740 Pyrex	4.6
7900 Vycor (96% silica)	3.8
8871 (lead potash)	8.4
9010 (lead free)	6.5
Quartz, fnsed	3.78
Sapphire, synthetic	8.6–10.6

Plastics	
Bakelite BM 120	3.7
Epoxy resin	3.1
Formica XX	3.6
Kel-F	2.3
Micarta 254	3.4
Nylon 610	2.8
Plexiglass	2.6
Polystyrene	2.6
Styrofoam 103.7	1.03
Teflon	2.1
Tenite II	2.9
Vinylite VG 5901	2.9

Miscellaneous	
Air	1
Butyl rubber	2.4
Mica	5.4
Neoprene 38% GN	4.0
Silastic 120	5.7
Silastic 152	2.9

If a ceramic such as Alumina 95 per cent with $K = 9$ were introduced as the dielectric and the Z_o of 50 ohms were still desired, then from Fig. 9-16 $D/d = 12.3$. If the D of 0.250 were also still desired, then $d = 0.020$ in.

The chart shows that if in this example d were not changed when the ceramic material replaced air, then Z_o would drop from 50 to 16.5 ohms.

COUPLING AND TUNING CAPACITOR FOR VARIOUS ANTENNAS

Figure 9-17 has been found to be a useful tool for adjusting the transmitter output circuit using capacity coupling to the antenna or transmission line. The values of capacity shown are approximate, but sufficiently close for practical purposes, since stray capacity of leads and components has not been taken into account. The capacity shown is the total capacity required for both the first and second sections of the low-pass filters.

The introduced resistance is the net resistance component when section is adjusted resulting from the effect of the R_a (antenna or line resistance) and the coupling capacity (CC).

The Z is the load impedance for the tubes determined by the dynamic characteristic for the particular tube and its operating voltages.

The value of introduced resistance used generally now lies between 50 and 100 ohms with the upper limit determined by the stray capacity. Formerly with high C ratios, introduced resistances were from 7 to 20 ohms, which resulted generally in higher circuit losses.

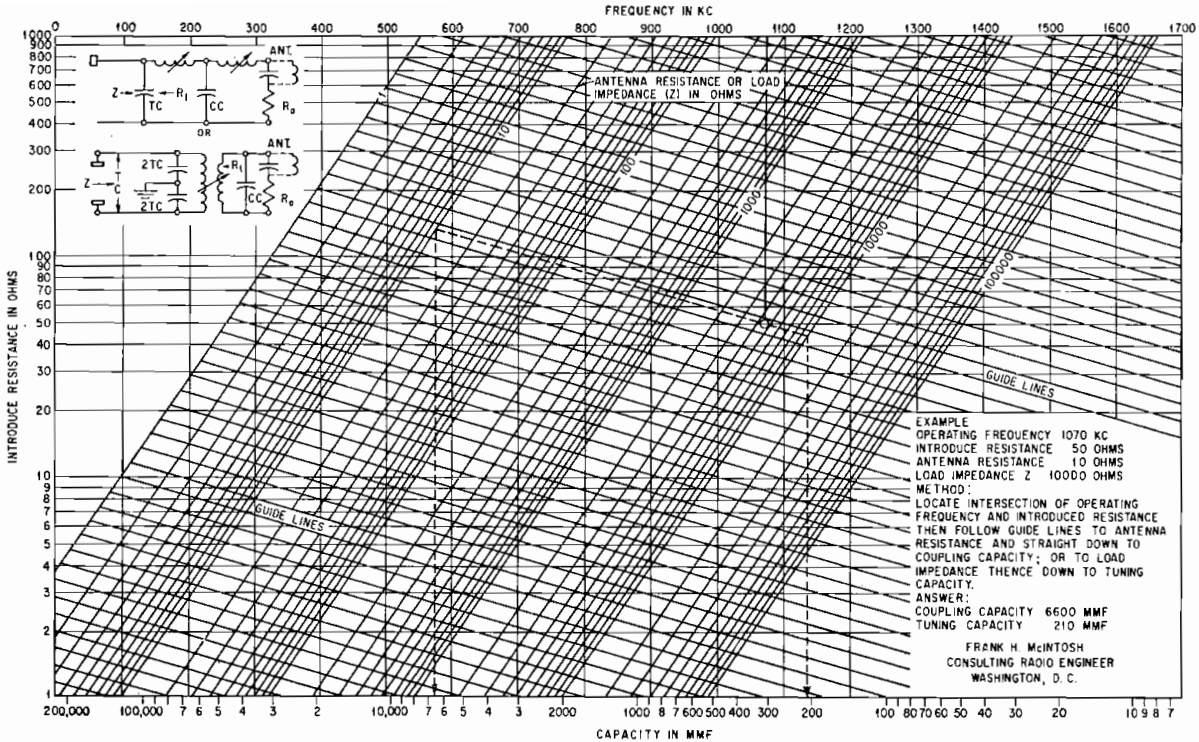


FIG. 9-17. Capacity-coupled circuits. Chart showing coupling and tuning capacities for various antenna resistances, tube load impedances, and introduced resistances for various given frequencies.

APPLICATION OF PROXIMITY-EFFECT CURVE *

1. The curve in Fig. 9-18 shows the amount by which the measured field strength, as measured by a field-strength meter which employs a shielded loop, will depart from an inverse distance function because of induction field or proximity effect due to measuring close to the antenna.

2. It is based upon the calculation of the horizontal component of magnetic field close to an antenna, after the manner of George H. Brown.

3. It can be used first as a guide determining how close one can measure to a given antenna before the correction due to proximity would be expected to exceed a given percentage.

4. It can be used to correct out the error due to proximity before plotting field-strength measurements to determine accurately the inverse distance field. This permits measurements to be made sufficiently close to the tower to eliminate the effects of conductivity.

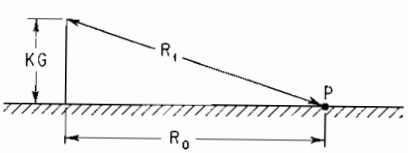
Derivation

1. G. H. Brown, Directional Antennas, *IRE*, January, 1937, on page 81 and in formula (7) gives the general formula for the magnetic flux density at any point in space from a vertical radiator over a perfectly conducting earth. By restricting this point P to the earth's surface, certain simplifications can be made in Brown's formula. Specifically Z goes to zero and $r_1 = r_2$ and $r_0 = x$.

2. The simplified formula becomes:

$$B_\phi = \frac{j2 \times 10^{-9} I_0}{r_0 \sin kG} [\epsilon^{-jkr_1} - \epsilon^{-jkr_0} \times \cos kG]$$

where $k = \dfrac{2\pi}{\lambda}$



3. Now when the distance r_0 becomes so great that $r_0 \approx r_1$

$$B_\phi(\text{far field}) = \frac{j2 \times 10^{-9} I_0}{r_0 \sin kG} [1 - \cos kG] \times \epsilon^{-jkr_0}$$

4. Now let $57.3kr_1 = r_1$ (degrees); $57.3kr_0 = r_0$ (degrees); $57.3kg = G$ (degrees).

5. Also convert from exponential to trigonometric form.

6. The resulting ratio is

$$\frac{B_\phi}{B_\phi \text{ (far field)}} = K = \frac{\{[\cos r_1 - \cos G \times \cos r_0]^2 + [\sin r_1 - \cos G \times \sin r_0]^2\}^{1/2}}{[1 - \cos G]}$$

7. Therefore:

$$\frac{\text{Field measurement}}{K} = \text{adjusted field}$$

* Silliman, Moffet, and Rohrer.

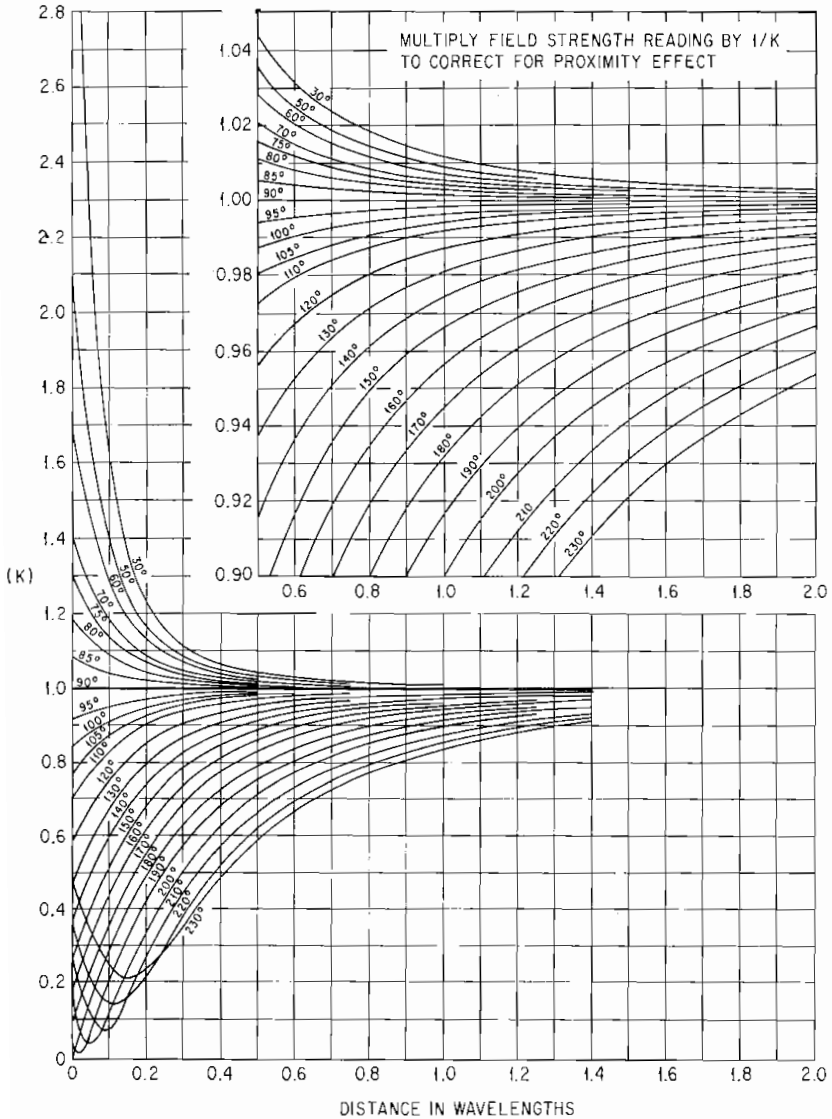


FIG. 9-18. Proximity effect for various tower heights.

WAVEGUIDE LOSS CHARTS *

Summary: Graphical presentation of attenuation values provides data for typical commercial microwave equipment. When effective resistivity is known or estimated, attenuation in decibels per foot can be determined at 1 to 75 kmc. Internal rectangular dimensions are also given.

Attenuation per foot of a particular commercial rectangular waveguide at a given frequency can be computed from published information, but for rapid extrapolation or comparison the accompanying charts (see Fig. 9-19) offer a ready solution.

One must know or be able to estimate the effective resistivity of the conducting surface. This is the product of d-c resistivity and a surface roughness factor K_T, which

Nominal Internal Dimensions for Standard Hollow Rectangular Waveguides

WR No.	*Wide*	*Narrow*	*WR No.*	*Wide*	*Narrow*
10	0.100	0.050	112	1.122	0.497
12	0.122	0.061	137	1.372	0.622
15	0.148	0.074	159	1.590	0.795
19	0.188	0.094	187	1.872	0.872
22	0.224	0.112	229	2.290	1.145
28	0.280	0.140	284	2.840	1.340
34	0.340	0.170	340	3.400	1.700
42	0.420	0.170	430	4.300	2.150
51	0.510	0.255	510	5.100	2.550
62	0.622	0.311	650	6.500	3.250
75	0.750	0.375	770	7.700	3.850
90	0.900	0.400	975	9.750	4.875

is unity for an ideal polished surface. Materials having low d-c resistivities require smooth surfaces for low effective resistivity and low loss. In materials having high d-c resistivities the current penetrates deeper into the material and K_T is near unity even for moderately rough surfaces. Thus surface roughness has almost no effect on high-resistivity materials.

Another factor is the size of the hollow waveguide cross section. Lowest losses are obtained by use of the largest possible waveguide. The chart shows the penalty resulting from use of a smaller size.

Measured attenuation of two sizes of rectangular copper waveguides shows that the effective resistivity is abont 2.2×10^{-6} ohm-cm from 4 to 6 kmc. This is about 28 per cent above the d-c resistivity of 1.72×10^{-6} ohm-cm. Measurements on WR-229 drawn of 90-10 brass show an effective resistivity of 4.3×10^{-6} ohm-cm at 4 kmc, which is about 7.5 per cent above the d-c resistivity of 4×10^{-6} ohm-cm.

Plotting points on the graph were determined from the equation

$$\alpha = \frac{5.963(RK_T/\lambda)^{1/2}(1/b + \lambda^2/2a^3)}{\sqrt{1 - \lambda^2/4a^2}}$$

where α = attenuation in rectangular waveguide, db/ft
R = d-c resistivity of conducting surface, ohm-cm
a = wide dimension of waveguide, in.
b = narrow dimension of waveguide, in.
λ = free-space wavelength, in.
K_T = surface roughness factor
RK_T = effective resistivity of conducting surface, ohm-cm

* By A. F. Pomeroy, Bell Telephone Laboratories, Murray Hill, N.J. Reprinted from *Electronics*, October 1, 1957.

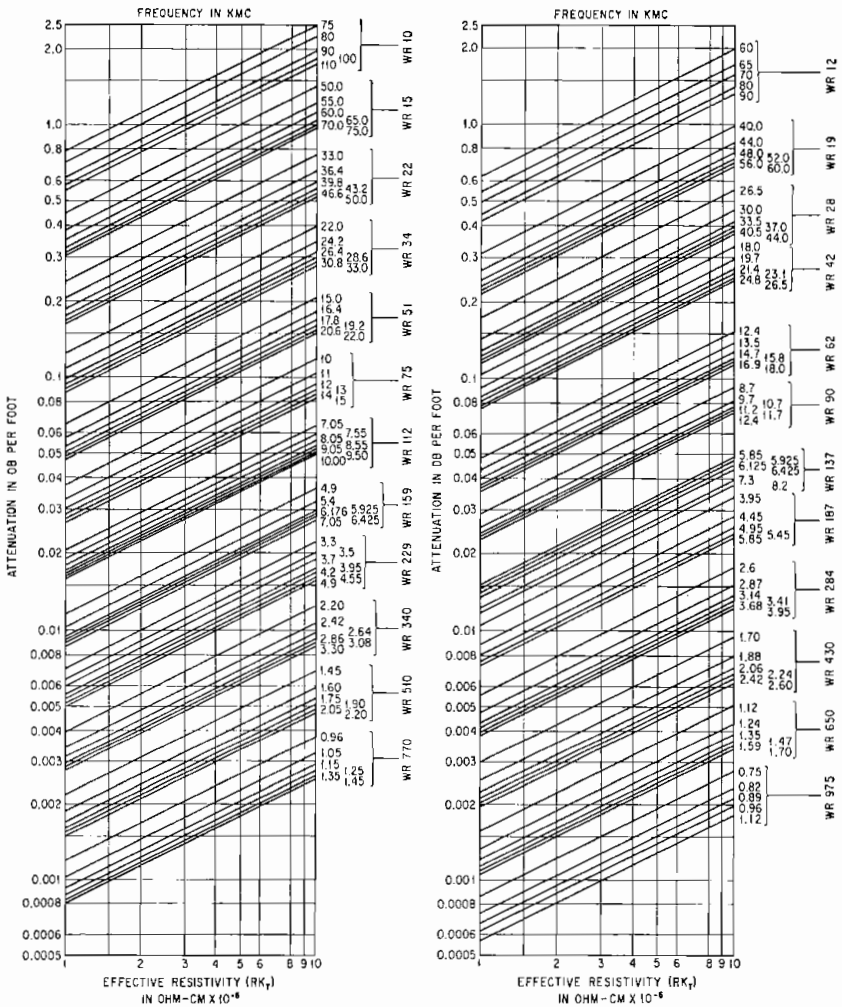


FIG. 9-19. Waveguide loss charts.

Example. Suppose it is necessary to find the attenuation of WR51 made of high-conductivity copper at frequencies from 16.4 to 20.6 kmc. Using 2.5×10^{-6} ohm-cm as an effective resistivity, we read on the chart 0.092 db/ft at 16.4 kmc and 0.078 db/ft at 20.6 kmc. The attenuation of other sizes can be found in a similar manner.

Representative frequencies in the recommended ranges were chosen for each size shown in Fig. 9-19. Interpolation between the characteristics to find the loss for other frequencies is straightforward.

The effective resistivity should be nearly constant over a small frequency interval, which leads to another use of these characteristics. To find an average effective resistivity over a band of frequencies, measured values of decibels per foot can be plotted on the characteristics and an ordinate drawn through the average value of effective resistivity. This result is probably more accurate than any one of the individual determinations.

Thanks are due Miss J. D. Goeltz and Mrs. Dolores G. Hill for their work in computing the attenuations used in plotting the characteristics.

Bibliography

Pomeroy, A. F., and E. M. Suarez: Determining Attenuation of Waveguide from Electrical Measurements on Short Samples, *IRE Trans. RGMTT*, April, 1956, p. 122.

Benson, F. A.: Waveguide Attenuation and Its Correlation with Surface Roughness, *Proc. IRE*, 100, part III, p. 85, March, 1953.

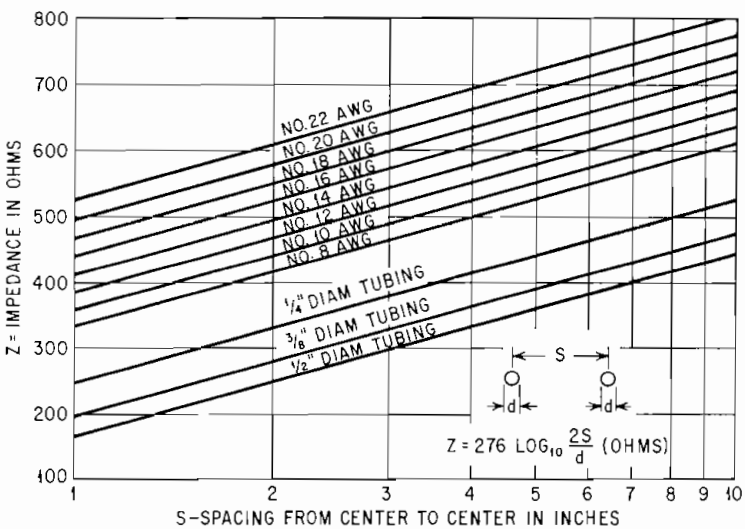


Fig. 9-20. Characteristic impedance of parallel-line wires.

L-NETWORK DESIGN *

Summary: Technique for using Smith chart to speed design of L matching networks for transmission lines and waveguides using lumped parameters. Shaded-area charts show at a glance impedance ranges that can be matched with each type of L network.

The familiar Smith chart for transmission lines is also a useful tool for designing matching networks. As an example, consider the case where it is desired to match an impedance $Z_L = (0.3 - j1.6)R_o$ to R_o with the L matching network shown in Fig. 9-21. It is assumed that the inductances are lossy so that $R_1 = X_1 \tan \theta = 0.2X_1$ and

* By H. F. Mathis, Goodyear Aircraft Corp., Akron, Ohio. Reprinted from *Electronics*, Feb. 1, 1957.

$G_2 = -B_2 \tan \theta = -0.2B_2$. All impedances and admittances are normalized with respect to R_o and $G_o = 1/R_o$, respectively.

Let $Z_A = Z_L + R_1 + jX_1$ and $Y_A = 1/Z_A$. Since $Y_A + G_2 + jB_2 = 1$, Y_A must lie on curve $Y = 1 - k(\tan \theta - j)$, where k is a real variable. This curve is circle OA' with center C. To locate C, lines OC and OD are drawn as indicated in Fig. 9-20. Point D bisects its line. Point C is located as indicated.

Point C is inverted to obtain C' on line OC so that $C'O = OC$. Since Y_A must lie on circle OA', Z_A must lie on circle OH whose center is C'. To determine Z_A, plot curve $Z = Z_L + p(\tan \theta + j)$, where p is a real variable. Point A, where this curve intersects circle OH, is the desired value of Z_A. The value of Y_A is found by inverting point A to obtain A'. Finally, $R_1 + jX_1 = (Z_A - Z_L)R_o = (0.498 - j0.610) - (0.3 - j1.6)R_o = (0.198 + j0.990)R_o$ and $G_2 + jB_2 = (1 - Y_A)G_o = 1 - (0.803 + j0.985)G_o = (0.197 - j0.985)G_o$.

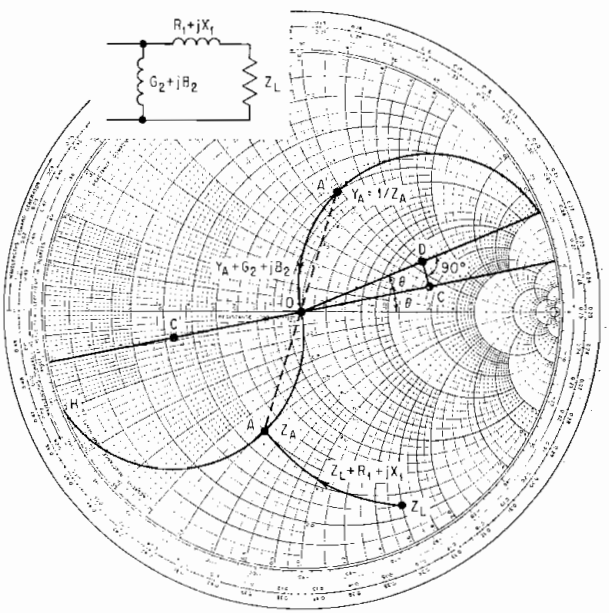


FIG. 9-21. Smith-chart procedure for determining parameters of L matching network.

General Procedure. In general, for L matching networks plot Z_L or Y_L first on the Smith chart. Next, plot the impedance or admittance into which Z_L is to be transformed, and find a suitable path connecting these points.

It is impossible to match all possible values of Z_L with a given type of L network. For example, if $Z_L = 0.5R_o$, the matching network shown in Fig. 9-21 could not be used. Impedances which can be matched with a given type of L network are shown as areas on Smith charts in Fig. 9-22. It is assumed that it is desired to transform Z_L into R_o and that Z_L is normalized with respect to R_o.

Bibliography

Smith, P. H.: Transmission-line Calculator, *Electronics*, January, 1939, p. 29.

Smith, P. H.: An Improved Transmission-line Calculator, *Electronics*, January, 1944, p. 130.

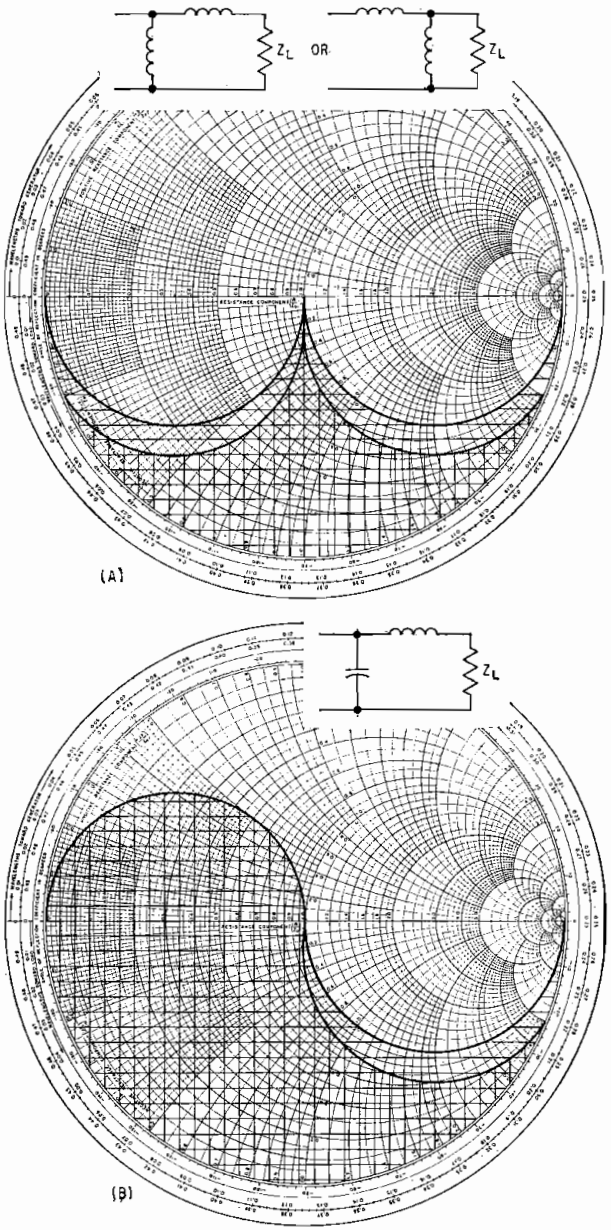
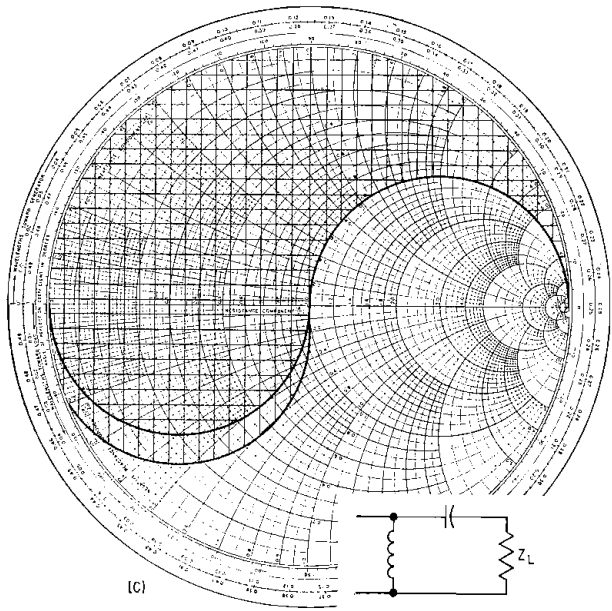


FIG. 9-22. For each network, horizontally shaded areas on the accompanying Smith chart show impedances which can be matched with lossless reactance. Vertically shaded areas can be matched with reactances for which tan $\theta = 0.2$.



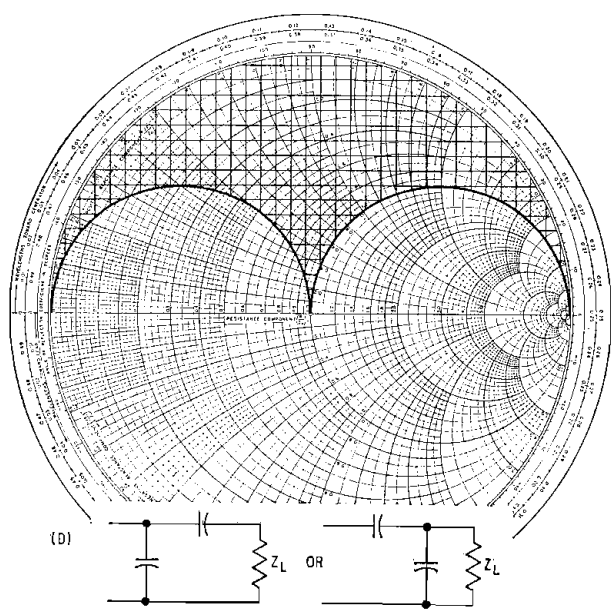


FIG. 9-22. (*Continued on next page.*)

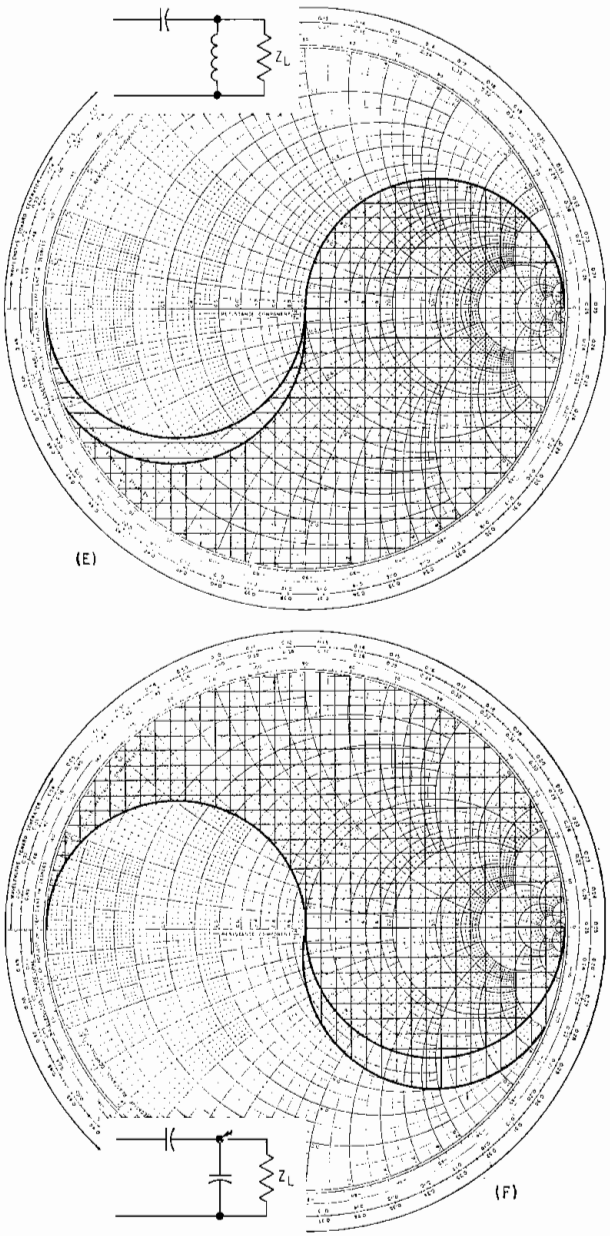


FIG. 9-22. (*Continued.*)

Table 9-4. Comparison of Open-wire Solid-dielectric Lines and Waveguides

Characteristics	Parallel open wires	Bead supported	Stub supported	Solid dielectric (Polyethylene)	Coaxial rubber	Waveguide	Pulse cables
Insulation resistance	O.K. in dry air, drops in rain	O.K. in dry air or nitrogen	O.K. dry or slightly wet	O.K. dry or wet	O.K. dry, drops when wet. Varies with temperature	O.K.	Same as rubber
Corona voltage and dielectric strength	Depends on dry air and spacing, low	Depends on dry air, depends on size, low	Depends on size, low	Depends on size, high	Depends on dry air, size, medium high	Depends on size, dry air, pressure, low	Depends on size, dry air, high
Dielectric constant	Low, air (1)	Low, air plus beads (1+)	Low, air (1)	Medium (2.3)	Medium high (3–4)	.....	High (5–6)
Power factor	Low in dry air, goes up in wet	Low in dry air, goes up in wet	O.K. dry or slightly wet	O.K. dry or wet	High dry, higher wet. No good for HF	.....	Same as rubber
D-c conductor resistance	Low, goes down with size	Same	Same	Higher than concentrics, goes down with size	High, goes down with size	Low, goes down with size	High, goes down with size
Ease of installation	Easy	More difficult	Difficult	Easier than concentric	Same as solid dielectric	Same as bead-supported	Same as rubber
Ease of maintenance	Easy	Very difficult	Not very	Easy	do	Easy	
Flexible	Somewhat, depends on size	Some, depends on size	No	Yes, flexibility goes down with size	Yes, more than solid dieleetric	No	Same as rubber
Mechanically strong	Yes, but separators are weak points	Yes, beads are weak points	Yes, but stubs are fragile	Yes, but can be mistreated	Yes	Yes, but can be crushed	Yes
Can be sealed	Yes	Yes, but you have to do the right job	Yes	Yes	Yes	Yes	Yes
Self-shielding (electrical)	No	Yes	Yes	Yes, depends on the braid construction	Same as solid dielectric	Yes	Same as solid dielectric
Fire resistive	Yes	Yes	Yes	Yes, except largest size	Not completely	Yes	Same as rubber
High-temperature resistant	Yes. depends on material of separators	Yes, depends on rubber gaskets or solder	Yes, same as bead supported	180–200°F for short time	220–250°F for short time	Yes, depends on rubber gasket or solder	Same as rubber
Transmission at high frequency	Limited by spacing	Good at low, medium frequency losses high at microwave	Good at high frequency not at low, need spec for each	Good, at low and medium not so good at microwave	Poor, loss too high	Best, but each frequency needs spec guide	Poor, loss too high
Stand shock vibration	Good	Fair, beads are weak points	Good, stubs are weak points	Very good	Very good	Very good	Very good
Low temperatures	Yes	Yes, but allow for expansion	Same as beaded	Yes	Yes	Yes, but allow for expansion	Yes

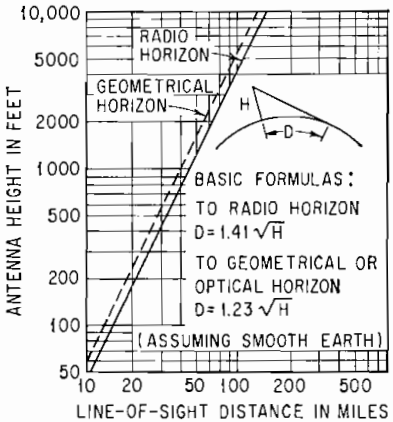


FIG. 9-23. Distance to horizon vs. height of transmitting antenna.

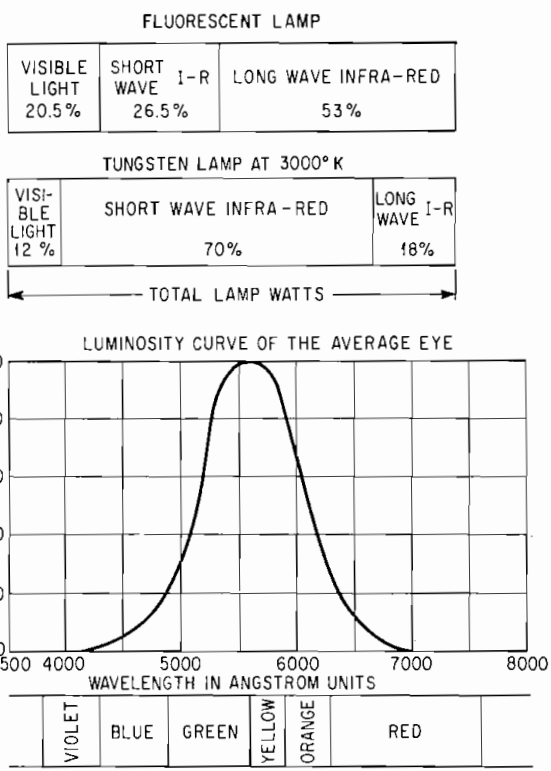


FIG. 9-24. Fluorescent and tungsten lamp spectral distribution and luminosity curve of the average human eye.

HEATER SURGE CHART *

Summary: The effect of heater current surges when voltage is applied to cold tube and efficiency of surge-restricting arrangements can be evaluated with this chart. Hot and cold characteristic curves are typical for most tubes.

To minimize damaging effects of high initial current when heater voltage is applied to a cold tube, starting current surges should be restricted.

The magnitude of heater current surges under various conditions can be calculated by use of the graph (Fig. 9-25), which consists basically of two curves plotted on coordinates of heater current and voltage relative to normal full-voltage conditions. The first curve, a straight line, represents the resistance of a cold heater. It represents a resistance which is 0.15 of the normal operating resistance. This is typical of most receiving tubes. The second curve shows the locus of points at which thermal equilibrium is obtained for steadily applied voltages. Deviations from this curve are relatively small for common receiving-type tubes.

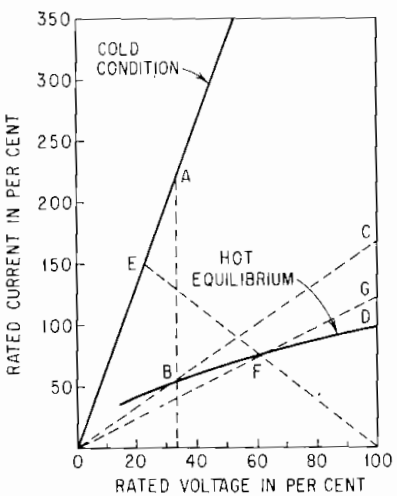


FIG. 9-25. Current-voltage plot for hot and cold tube conditions used to evaluate surge.

The results of applying heater voltage in steps can be shown by simple constructions. If a line is constructed at a chosen value of initial voltage, the magnitude of the initial cold-resistance surge is shown by point *A* and thermal equilibrium occurs at point *B*. A line through the origin and point *B* represents the heater resistance attained in the partially heated equilibrium condition. If 100 per cent voltage is then applied, a current surge of magnitude indicated by point *C* occurs, and final equilibrium is attained at the normal operating point *D*.

The effect of applying 100 per cent rated voltage through a series resistor can be shown by the construction of a line having a slope based on the ratio of the series resistance to the normal hot resistance of the tube. The cold-tube surge is indicated by point *E*, and equilibrium occurs at *F*. Construction of a line from the origin through point *F* then represents this equilibrium heater resistance. If the resistor is then shorted out, 100 per cent voltage will be applied and will result in a momentary current indicated by point *G*. Final equilibrium will occur at the normal operating point *D*.

* By M. P. Feyerherm, Defense Electronic Products, Radio Corporation of America, Camden, N.J. Reprinted from *Electronics*, June 1, 1957.

A CONVENIENT SLIDE-RULE SHORT CUT TO CONVERT ELECTRICAL DEGREES TO FEET, OR VICE VERSA WHEN FREQUENCY AND EITHER FEET OR DEGREES IS KNOWN

From the expression

$$\text{Feet} = \frac{\text{degrees}}{360°} \times \frac{300}{f(\text{Mc})} \times 3.281 = \text{degrees} \times \frac{2.734}{f(\text{Mc})}$$

the following ratio may be set up on the slide rule using C and D scales:

$$\frac{2.734}{f(\text{Mc})} = \frac{\text{feet}}{\text{degrees}}$$

Set 2.734 on scale C over frequency in megacycles on scale D; read feet and degrees on scales C and D, respectively. In some instances it may be convenient to use the folded scales CF and DF.

GREAT-CIRCLE DISTANCE AND BEARING CALCULATIONS

The need often arises in allocations problems for a simple and reliable method of computing the position of one radio station or area with respect to another expressed in degrees clockwise from true north. It is often equally important that the distance between these two points be known.

Bearings and distance can be computed in many ways. The method set forth here utilizes a table developed by Lieutenant Arthur A. Ageton, USN, which permits the simple solution of navigational problems. If the table is properly read and interpolations carefully made, the bearings and distances derived through use of the calculation sheet will be found to be in very close agreement with lengthy mathematical computations.

To use this method one must first obtain Hydrographic Office Publication No. 211, entitled "Dead Reckoning Altitude and Azimuth Table" from the Hydrographic Office, Washington, D.C., or the Superintendent of Documents, Government Printing Office, Washington, D.C.

The calculation sheet can be shortened in some respects if used only for determining bearings and distances between points within a limited area such as the United States or North America. As shown, bearings and distances can be calculated between any two points on the surface of the earth if the latitude and longitude of the two positions are known.

If a considerable number of calculations are to be made, it is suggested that the calculation sheet be duplicated in quantity. Furthermore, it is suggested that until one becomes thoroughly acquainted with the method the various *steps* be check-marked as they are completed.

Great Circle Distance and Bearing Calculation Sheet

(Based on Ageton, *H.O. Publ.* 211, Tables)

FROM: Location_____ (La)___° ___′ ___″ (Lo)___° ___′ ___″
TO: Location_____ (La′)___° ___′ ___″ (Lo′)___° ___′ ___″

Symbols Used

- *A* Numbers in the *A* columns of the H.O. 211 tables
- *B* Numbers in the *B* columns of the H.O. 211 tables
- *t* (*Lo* ~ *Lo′*) The smaller angle between the two meridians, *Lo* and *Lo′*
- *C* Bearing East or West of 0° true
- *D* Great-circle distance when converted to minutes of arc
- *K* An arc used in the calculations
- *Dn* The great-circle distance in nautical miles
- *Ds* The great-circle distance in statute miles
- (*K* ~ *La*) The magnitude of the difference between arc *K* and *La*

Rules

If *La* and *La′* are in the same hemisphere: (N or *S*)

- *K*: Take *K* from bottom of columns in H.O. No. 211 tables if *t* is greater than 90°.
- *D*: Take *D* from bottom of columns in H.O. No. 211 when *t* and (*K* ~ *La*) are each greater than 90°.
- *C*: Take *C* from bottom of columns in H.O. No. 211 when *K* is less than *La*.
- (*K* ~ *La*): Subtract *K* and *La* to find difference.

If *La* and *La′* are in different hemispheres: (N and *S*)

- *K*: Take *K* from bottom of columns in H.O. No. 211 tables if *t* is greater than 90°.
- *D*: If *t* and (*K* ~ *La*) are each less than 90°, take *D* from top of table, *otherwise*, from *bottom*.
- *C*: Take *C* from bottom of tables in H.O. No. 211 tables unless (*K* ~ *La*) is greater than 180°.
- (*K* ~ *La*): Add *K* and *La* to find magnitude. If (*K* ~ *La*) exceeds 180°, subtract 180° before entering H.O. No. 211 table to find *B*3.

Calculations

[Follow rules closely for *K*, *D*, *C*, and *B*3—also (*K* ~ *La*)]

	ADD	SUBTRACT	ADD	SUBTRACT
*Lo′*_____	*A*1_____	*A*3_____	*B*2_____	*A*2_____
*Lo*_____	*B*1+_____	*B*2−_____	*B*3+_____	*A*5−_____
t =_____	*A*2 =_____	*A*4 =_____	*B*4 =_____	*A*6 =_____
*La′*_____				
K =_____				
*La*_____				
(*K* ~ *La*) =_____				

D =___° ___′ ___″
D: ___° × 60 = ___′ + ___′ = *Dn* ___ miles
Dn ___ miles × 1.152 = *Ds* ___ miles

*C** = ___° ___′ ___″ $\frac{E}{W}$ of 0° true

* NOTE: When *Lo′* is *west* of *Lo*, *C* will indicate bearings in degrees *west* of 0° true. When *Lo′* is *east* of *Lo*, *C* will indicate bearings in degrees *east* of 0° true.

Steps

1. List coordinates for locations.
2. Subtract *Lo* and *Lo′* to find arc *t*.
3. Enter H.O. No. 211 with *t* to find *A*1.
4. Enter table with *La′* to find *B*1 and *A*3.
5. Add *A*1 and *B*1 for *A*2.
6. Enter table with *A*2 to find *B*2.
7. Subtract *B*2 from *A*3 for *A*4.
8. Enter table with *A*4 for arc *K*.
9. Determine arc for (*K* ~ *La*).
10. Enter table with (*K* ~ *La*) for *B*3.
11. Add *B*2 and *B*3 for *B*4.
12. Enter table with *B*4 to find *A*5 and arc *D*.
13. Subtract *A*5 from *A*2 for *A*6.
14. Enter table with *A*6 for bearing *C*.
15. Follow steps shown to find *Ds* and *Dn*.

Table 9-5. Temperature-conversion Chart *

°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
−200	−328.0	−100	−148.0	0	32.0	0	32.0	100	212.0	200	392.0	300	572.0	400	752.0	500	932.0	600	1,112.0	700	1,292.0
−201	−329.8	−101	−149.8	−1	30.2	1	33.8	101	213.8	201	393.8	301	573.8	401	753.8	501	933.8	601	1,113.8	701	1,293.8
−202	−331.6	−102	−151.6	−2	28.4	2	35.6	102	215.6	202	395.6	302	575.6	402	755.6	502	935.6	602	1,115.6	702	1,295.6
−203	−333.4	−103	−153.4	−3	26.6	3	37.4	103	217.4	203	397.4	303	577.4	403	757.4	503	937.4	603	1,117.4	703	1,297.4
−204	−335.2	−104	−155.2	−4	24.8	4	39.2	104	219.2	204	399.2	304	579.2	404	759.2	504	939.2	604	1,119.2	704	1,299.2
−205	−337.0	−105	−157.0	−5	23.0	5	41.0	105	221.0	205	401.0	305	581.0	405	761.0	505	941.0	605	1,121.0	705	1,301.0
−206	−338.8	−106	−158.8	−6	21.2	6	42.8	106	222.8	206	402.8	306	582.8	406	762.8	506	942.8	606	1,122.8	706	1,302.8
−207	−340.6	−107	−160.6	−7	19.4	7	44.6	107	224.6	207	404.6	307	584.6	407	764.6	507	944.6	607	1,124.6	707	1,304.6
−208	−342.4	−108	−162.4	−8	17.6	8	46.4	108	226.4	208	406.4	308	586.4	408	766.4	508	946.4	608	1,126.4	708	1,306.4
−209	−344.2	−109	−164.2	−9	15.8	9	48.2	109	228.2	209	408.2	309	588.2	409	768.2	509	948.2	609	1,128.2	709	1,308.2
−210	−346.0	−110	−166.0	−10	14.0	10	50.0	110	230.0	210	410.0	310	590.0	410	770.0	510	950.0	610	1,130.0	710	1,310.0
−211	−347.8	−111	−167.8	−11	12.2	11	51.8	111	231.8	211	411.8	311	591.8	411	771.8	511	951.8	611	1,131.8	711	1,311.8
−212	−349.6	−112	−169.6	−12	10.4	12	53.6	112	233.6	212	413.6	312	593.6	412	773.6	512	953.6	612	1,133.6	712	1,313.6
−213	−351.4	−113	−171.4	−13	8.6	13	55.4	113	235.4	213	415.4	313	595.4	413	775.4	513	955.4	613	1,135.4	713	1,315.4
−214	−353.2	−114	−173.2	−14	6.8	14	57.2	114	237.2	214	417.2	314	597.2	414	777.2	514	957.2	614	1,137.2	714	1,317.2
−215	−355.0	−115	−175.0	−15	5.0	15	59.0	115	239.0	215	419.0	315	599.0	415	779.0	515	959.0	615	1,139.0	715	1,319.0
−216	−356.8	−116	−176.8	−16	3.2	16	60.8	116	240.8	216	420.8	316	600.8	416	780.8	516	960.8	616	1,140.8	716	1,320.8
−217	−358.6	−117	−178.6	−17	1.4	17	62.6	117	242.6	217	422.6	317	602.6	417	782.6	517	962.6	617	1,142.6	717	1,322.6
−218	−360.4	−118	−180.4	−18	−0.4	18	64.4	118	244.4	218	424.4	318	604.4	418	784.4	518	964.4	618	1,144.4	718	1,324.4
−219	−362.2	−119	−182.2	−19	−2.2	19	66.2	119	246.2	219	426.2	319	606.2	419	786.2	519	966.2	619	1,146.2	719	1,326.2
−220	−364.0	−120	−184.0	−20	−4.0	20	68.0	120	248.0	220	428.0	320	608.0	420	788.0	520	968.0	620	1,148.0	720	1,328.0
−221	−365.8	−121	−185.8	−21	−5.8	21	69.8	121	249.8	221	429.8	321	609.8	421	789.8	521	969.8	621	1,148.8	721	1,329.8
−222	−367.6	−122	−187.6	−22	−7.6	22	71.6	122	251.6	222	431.6	322	611.6	422	791.6	522	971.6	622	1,151.6	722	1,331.6
−223	−369.4	−123	−189.4	−23	−9.4	23	73.4	123	253.4	223	433.4	323	613.4	423	793.4	523	973.4	623	1,153.4	723	1,333.4
−224	−371.2	−124	−191.2	−24	−11.2	24	75.2	124	255.2	224	435.2	324	615.2	424	795.2	524	975.2	624	1,155.2	724	1,335.2
−225	−373.0	−125	−193.0	−25	−13.0	25	77.0	125	257.0	225	437.0	325	617.0	425	797.0	525	977.0	625	1,157.0	725	1,337.0
−226	−374.8	−126	−194.8	−26	−14.8	26	78.8	126	258.8	226	438.8	326	618.8	426	798.8	526	978.8	626	1,158.8	726	1,338.8
−227	−376.6	−127	−196.6	−27	−16.6	27	80.6	127	260.6	227	440.6	327	620.6	427	800.6	527	980.6	627	1,160.6	727	1,340.6
−228	−378.4	−128	−198.4	−28	−18.4	28	82.4	128	262.4	228	442.4	328	622.4	428	802.4	528	982.4	628	1,162.4	728	1,342.4
−229	−380.2	−129	−200.2	−29	−20.2	29	84.2	129	264.2	229	444.2	329	624.2	429	804.2	529	984.2	629	1,164.2	729	1,344.2
−230	−382.0	−130	−202.0	−30	−22.0	30	86.0	130	266.0	230	446.0	330	626.0	430	806.0	530	986.0	630	1,166.0	730	1,346.0
−231	−383.8	−131	−203.8	−31	−23.8	31	87.8	131	267.8	231	447.8	331	627.8	431	807.8	531	987.8	631	1,167.8	731	1,347.8
−232	−385.6	−132	−205.6	−32	−25.6	32	89.6	132	269.6	232	449.6	332	629.6	432	809.6	532	989.6	632	1,169.6	732	1,349.6
−233	−387.4	−133	−207.4	−33	−27.4	33	91.4	133	271.4	233	451.4	333	631.4	433	811.4	533	991.4	633	1,171.4	733	1,351.4
−234	−389.2	−134	−209.2	−34	−29.2	34	93.2	134	273.2	234	453.2	334	633.2	434	813.2	534	993.2	634	1,173.2	734	1,353.2

−235	−391.0	−135	−211.0	−35	−31.0	35	95.0	135	275.0	235	455.0	335	635.0	435	815.0	535	995.0	635	1,175.0	735	1,355.0
−236	−392.8	−136	−212.8	−36	−32.8	36	96.8	136	276.8	236	456.8	336	636.8	436	816.8	536	996.8	636	1,176.8	736	1,356.8
−237	−394.6	−137	−214.6	−37	−34.6	37	98.6	137	278.6	237	458.6	337	638.6	437	818.6	537	998.6	637	1,178.6	737	1,358.6
−238	−396.4	−138	−216.4	−38	−36.4	38	100.4	138	280.4	238	460.4	338	640.4	438	820.4	538	1,000.4	638	1,180.4	738	1,360.4
−239	−398.2	−139	−218.2	−39	−38.2	39	102.2	139	282.2	239	462.2	339	642.2	439	822.2	539	1,002.2	639	1,182.2	739	1,362.2
−240	−400.0	−140	−220.0	−40	−40.0	40	104.0	140	284.0	240	464.0	340	644.0	440	824.0	540	1,004.0	640	1,184.0	740	1,364.0
−241	−401.8	−141	−221.8	−41	−41.8	41	105.8	141	285.8	241	465.8	341	645.8	441	825.8	541	1,005.8	641	1,185.8	741	1,365.8
−242	−403.6	−142	−223.6	−42	−43.6	42	107.6	142	287.6	242	467.6	342	647.6	442	827.6	542	1,007.6	642	1,187.6	742	1,367.6
−243	−405.4	−143	−225.4	−43	−45.4	43	109.4	143	289.4	243	469.4	343	649.4	443	829.4	543	1,009.4	643	1,189.4	743	1,369.4
−244	−407.2	−144	−227.2	−44	−47.2	44	111.2	144	291.2	244	471.2	344	651.2	444	831.2	544	1,011.2	644	1,191.2	744	1,371.2
−245	−409.0	−145	−229.0	−45	−49.0	45	113.0	145	293.0	245	473.0	345	653.0	445	833.0	545	1,013.0	645	1,193.0	745	1,373.0
−246	−410.8	−146	−230.8	−46	−50.8	46	114.8	146	294.8	246	474.8	346	654.8	446	834.8	546	1,014.8	646	1,194.8	746	1,374.8
−247	−412.6	−147	−232.6	−47	−52.6	47	116.6	147	296.6	247	476.6	347	656.6	447	836.6	547	1,016.6	647	1,196.6	747	1,376.6
−248	−414.4	−148	−234.4	−48	−54.4	48	118.4	148	298.4	248	478.4	348	658.4	448	838.4	548	1,018.4	648	1,198.4	748	1,378.4
−249	−416.2	−149	−236.2	−49	−56.2	49	120.2	149	300.2	249	480.2	349	660.2	449	840.2	549	1,020.2	649	1,200.2	749	1,380.2
−250	−418.0	−150	−238.0	−50	−58.0	50	122.0	150	302.0	250	482.0	350	662.0	450	842.0	550	1,022.0	650	1,202.0	750	1,382.0
−251	−419.8	−151	−239.8	−51	−59.8	51	123.8	151	303.8	251	483.8	351	663.8	451	843.8	551	1,023.8	651	1,203.8	751	1,383.8
−252	−421.6	−152	−241.6	−52	−61.6	52	125.6	152	305.6	252	485.6	352	665.6	452	845.6	552	1,025.6	652	1,205.6	752	1,385.6
−253	−423.4	−153	−243.4	−53	−63.4	53	127.4	153	307.4	253	487.4	353	667.4	453	847.4	553	1,027.4	653	1,207.4	753	1,387.4
−254	−425.2	−154	−245.2	−54	−65.2	54	129.2	154	309.2	254	489.2	354	669.2	454	849.2	554	1,029.2	654	1,209.2	754	1,389.2
−255	−427.0	−155	−247.0	−55	−67.0	55	131.0	155	311.0	255	491.0	355	671.0	455	851.0	555	1,031.0	655	1,211.0	755	1,391.0
−256	−428.8	−156	−248.8	−56	−68.8	56	132.8	156	312.8	256	492.8	356	672.8	456	852.8	556	1,032.8	656	1,212.8	756	1,392.8
−257	−430.6	−157	−250.6	−57	−70.6	57	134.6	157	314.6	257	494.6	357	674.6	457	854.6	557	1,034.6	657	1,214.6	757	1,394.6
−258	−432.4	−158	−252.4	−58	−72.4	58	136.4	158	316.4	258	496.4	358	676.4	458	856.4	558	1,036.4	658	1,216.4	758	1,396.4
−259	−434.2	−159	−254.2	−59	−74.2	59	138.2	159	318.2	259	498.2	359	678.2	459	858.2	559	1,038.2	659	1,218.2	759	1,398.2
−260	−436.0	−160	−256.0	−60	−76.0	60	140.0	160	320.0	260	500.0	360	680.0	460	860.0	560	1,040.0	660	1,220.0	760	1,400.0
−261	−437.8	−161	−257.8	−61	−77.8	61	141.8	161	321.8	261	501.8	361	681.8	461	861.8	561	1,041.8	661	1,221.8	761	1,401.8
−262	−439.6	−162	−259.6	−62	−79.6	62	143.6	162	323.6	262	503.6	362	683.6	462	863.6	562	1,043.6	662	1,223.6	762	1,403.6
−263	−441.4	−163	−261.4	−63	−81.4	63	145.4	163	325.4	263	505.4	363	685.4	463	865.4	563	1,045.4	663	1,225.4	763	1,405.4
−264	−443.2	−164	−263.2	−64	−83.2	64	147.2	164	327.2	264	507.2	364	687.2	464	867.2	564	1,047.2	664	1,227.2	764	1,407.2
−265	−445.0	−165	−265.0	−65	−85.0	65	149.0	165	329.0	265	509.0	365	689.0	465	869.0	565	1,049.0	665	1,229.0	765	1,409.0
−266	−446.8	−166	−266.8	−66	−86.8	66	150.8	166	330.8	266	510.8	366	690.8	466	870.8	566	1,050.8	666	1,230.8	766	1,410.8
−267	−448.6	−167	−268.6	−67	−88.6	67	152.6	167	332.6	267	512.6	367	692.6	467	872.6	567	1,052.6	667	1,232.6	767	1,412.6
−268	−450.4	−168	−270.4	−68	−90.4	68	154.4	168	334.4	268	514.4	368	694.4	468	874.4	568	1,054.4	668	1,234.4	768	1,414.4
−269	−452.2	−169	−272.2	−69	−92.2	69	156.2	169	336.2	269	516.2	369	696.2	469	876.2	569	1,056.2	669	1,236.2	769	1,416.2
−270	−454.0	−170	−274.0	−70	−94.0	70	158.0	170	338.0	270	518.0	370	698.0	470	878.0	570	1,058.0	670	1,238.0	770	1,418.0
−271	−455.8	−171	−275.8	−71	−95.8	71	159.8	171	339.8	271	519.8	371	699.8	471	879.8	571	1,059.8	671	1,239.8	771	1,419.8
−272	−457.6	−172	−277.6	−72	−97.6	72	161.6	172	341.6	272	521.6	372	701.6	472	881.6	572	1,061.6	672	1,241.6	772	1,421.6
−273	−459.4	−173	−279.4	−73	−99.4	73	163.4	173	343.4	273	523.4	373	703.4	473	883.4	573	1,063.4	673	1,243.4	773	1,423.4
−273.2	−459.7	−174	−281.2	−74	−101.2	74	165.2	174	345.2	274	525.2	374	705.2	474	885.2	574	1,065.2	674	1,245.2	774	1,425.2

Absolute zero.

Table 9-5. Temperature-conversion Chart * (*Continued*)

°C °F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F
Absolute Zero	−175	−283.0	−75	−103.0	75	167.0	175	347.0	275	527.0	375	707.0	475	887.0	575	1,067.0	675	1,247.0	775	1,427.0
	−176	−284.8	−76	−104.8	76	168.8	176	348.8	276	528.8	376	708.8	476	888.8	576	1,068.8	676	1,248.8	776	1,428.8
	−177	−286.6	−77	−106.6	77	170.6	177	350.6	277	530.6	377	710.6	477	890.6	577	1,070.6	677	1,250.6	777	1,430.6
	−178	−288.4	−78	−108.4	78	172.4	178	352.4	278	532.4	378	712.4	478	892.4	578	1,072.4	678	1,252.4	778	1,432.4
	−179	−290.2	−79	−110.2	79	174.2	179	354.2	279	534.2	379	714.2	479	894.2	579	1,074.2	679	1,254.2	779	1,434.2
	−180	−292.0	−80	−112.0	80	176.0	180	356.0	280	536.0	380	716.0	480	896.0	580	1,076.0	680	1,256.0	780	1,436.0
Formulas:	−181	−293.8	−81	−113.8	81	177.8	181	357.8	281	537.8	381	717.8	481	897.8	581	1,077.8	681	1,257.8	781	1,437.8
	−182	−295.6	−82	−115.6	82	179.6	182	359.6	282	539.6	382	719.6	482	899.6	582	1,079.6	682	1,259.6	782	1,439.6
	−183	−297.4	−83	−117.4	83	181.4	183	361.4	283	541.4	383	721.4	483	901.4	583	1,081.4	683	1,261.4	783	1,441.4
$C = \frac{5}{9}(F - 32)$	−184	−299.2	−84	−119.2	84	183.2	184	363.2	284	543.2	384	723.2	484	903.2	584	1,083.2	684	1,263.2	784	1,443.2
	−185	−301.0	−85	−121.0	85	185.0	185	365.0	285	545.0	385	725.0	485	905.0	585	1,085.0	685	1,265.0	785	1,445.0
$F = \frac{9}{5}C + 32$	−186	−302.8	−86	−122.8	86	186.8	186	366.8	286	546.8	386	726.8	486	906.8	586	1,086.8	686	1,266.8	786	1,446.8
	−187	−304.6	−87	−124.6	87	188.6	187	368.6	287	548.6	387	728.6	487	908.6	587	1,088.6	687	1,268.6	787	1,448.6
	−188	−306.4	−88	−126.4	88	190.4	188	370.4	288	550.4	388	730.4	488	910.4	588	1,090.4	688	1,270.4	788	1,450.4
	−189	−308.2	−89	−128.2	89	192.2	189	372.2	289	552.2	389	732.2	489	912.2	589	1,092.2	689	1,272.2	789	1,452.2
	−190	−310.0	−90	−130.0	90	194.0	190	374.0	290	554.0	390	734.0	490	914.0	590	1,094.0	690	1,274.0	790	1,454.0
	−191	−311.8	−91	−131.8	91	195.8	191	375.8	291	555.8	391	735.8	491	915.8	591	1,095.8	691	1,275.8	791	1,455.8
	−192	−313.6	−92	−133.6	92	197.6	192	377.6	292	557.6	392	737.6	492	917.6	592	1,097.6	692	1,277.6	792	1,457.6
	−193	−315.4	−93	−135.4	93	199.4	193	379.4	293	559.4	393	739.4	493	919.4	593	1,099.4	693	1,279.4	793	1,459.4
	−194	−317.2	−94	−137.2	94	201.2	194	381.2	294	561.2	394	741.2	494	921.2	594	1,101.2	694	1,281.2	794	1,461.2
	−195	−319.0	−95	−139.0	95	203.0	195	383.0	295	563.0	395	743.0	495	923.0	595	1,103.0	695	1,283.0	795	1,463.0
	−196	−320.8	−96	−140.8	96	204.8	196	384.8	296	564.8	396	744.8	496	924.8	596	1,104.8	696	1,284.8	796	1,464.8
	−197	−322.6	−97	−142.6	97	206.6	197	386.6	297	566.6	397	746.6	497	926.6	597	1,106.6	697	1,286.6	797	1,466.6
	−198	−324.4	−98	−144.4	98	208.4	198	388.4	298	568.4	398	748.4	498	928.4	598	1,108.4	698	1,288.4	798	1,468.4
	−199	−326.2	−99	−146.2	99	210.2	199	390.2	299	570.2	399	750.2	499	930.2	599	1,110.2	699	1,290.2	799	1,470.2

* Reprinted from *Electronics*, May 1, 1957.

Table 9-6. Conversion Table for Units of Length

MULTIPLY NUMBER OF → / TO OBTAIN NUMBER OF ↓	ANGSTROMS	MICRONS	MILS	INCHES	FEET	MILES	MILLIMETERS	CENTIMETERS	KILOMETERS
ANGSTROMS	1	10^{4}	2.540×10^{5}	2.540×10^{8}	3.048×10^{9}	1.609×10^{13}	10^{7}	10^{8}	10^{13}
MICRONS	10^{-4}	1	2.540×10	2.540×10^{4}	3.048×10^{5}	1.609×10^{9}	10^{3}	10^{4}	10^{9}
MILS	3.937×10^{-6}	3.937×10^{-2}	1	10^{3}	1.2×10^{4}	6.336×10^{7}	3.937×10	3.937×10^{2}	3.937×10^{7}
INCHES	3.937×10^{-9}	3.937×10^{-5}	10^{-3}	1	12	6.336×10^{4}	3.937×10^{-2}	3.937×10^{-1}	3.937×10^{4}
FEET	3.281×10^{-10}	3.281×10^{-6}	8.333×10^{-5}	8.333×10^{-2}	1	5.280×10^{3}	3.281×10^{-3}	3.281×10^{-2}	3.281×10^{3}
MILES	6.214×10^{-14}	6.214×10^{-10}	1.578×10^{-8}	1.578×10^{-5}	1.894×10^{-4}	1	6.214×10^{-7}	6.214×10^{-6}	6.214×10^{-1}
MILLIMETERS	10^{-7}	10^{-3}	2.540×10^{-2}	2.540×10	3.048×10^{2}	1.609×10^{6}	1	10	10^{6}
CENTIMETERS	10^{-8}	10^{-4}	2.540×10^{-3}	2.540	3.048×10	1.609×10^{5}	0.1	1	10^{5}
KILOMETERS	10^{-13}	10^{-9}	2.540×10^{-8}	2.540×10^{-5}	3.048×10^{-4}	1.609	10^{-6}	10^{-5}	1

TRANSISTOR CHARACTERISTICS FOR CIRCUIT DESIGNERS °

Summary: Tables indicate physical properties, maximum electrical ratings, small-signal low-frequency parameters, and average characteristics for grounded-base, grounded-emitter, grounded-collector, and switching circuits for 218 transistor types: 106 junction triodes, 46 high-frequency triodes, 6 tetrodes, 23 high-power units, 25 point-contact, and 12 phototransistors.

Abbreviations Used in Tables

α	Current gain	I_e	Emitter current
β	Base-current amplification factor	I_{eo}	Emitter cutoff current
BW	Bandwidth	NF	Noise figure
C_c	Collector capacitance	r_b	Base resistance
$f_{\alpha o}$	Alpha cutoff frequency	r_c	Collector resistance
g-b	Grounded base	r_e	Emitter resistance
g-c	Grounded collector	R_g	Generator resistance
g-e	Grounded emitter	R_i	Input resistance
I_b	Base current	R_L	Load resistance
I_{b2}	Second base current (tetrode)	R_o	Output resistance
I_c	Collector current	V_c	Collector voltage
I_{co}	Collector cutoff current		

° By Seymour Schwartz, Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Mass. Reprinted from *Electronics*, January, 1956.

Successful transistor circuit design requires not only familiarity with transistor equivalent circuits and characteristic curves but also an understanding of the behavior of the parameters describing the transistor and the variation of these parameters with bias and temperature. Tables 9-7 to 9-12 have been compiled as a systematic presentation of data necessary for transistor circuit design.

Each of the charts presents physical properties; maximum electrical ratings; typical small-signal low-frequency parameters; average characteristics for grounded-emitter, grounded-base, and grounded-collector circuits; and switching characteristics. Figure 9-27 illustrates the circuits referenced in Tables 9-8 and 9-9.

Small-signal parameters are expressed as resistances. This permits a familiar physical representation of the transistor in circuit design. The box on page 9-50 enables transformation between h and r parameters.

All the characteristics are for fixed-bias conditions. However, these values vary with operating conditions. Examples of these variations are shown in Fig. 9-26*a* to *c*.

Figure 9-26*a* illustrates how collector capacitance C_c varies with collector voltage V_c. In designing an IF tuned circuit, the tuning capacitor must be large enough to swamp out the effects of the variation of collector capacitance. If the IF stage is a grounded-emitter rather than a grounded-base stage, the collector capacitance is magnified by the base-current amplification factor β.

In IF stages where neutralization is used to maximize gain by balancing out C_c, instability may occur when the battery voltage decreases. This variation of C_c with V_c permits use of the transistor as a reactance element in FM applications.

At low current bias (Fig. 9-26*b* to *d*) the noise factor of the transistor decreases and emitter resistance r_e, base resistance r_b, and collector resistance r_c increase, providing increased power gain and larger values of input and output impedance. This is advantageous in hearing aids where low bias currents are used.

Temperature Effects

In the germanium transistor, noticeable changes in α, β, and I_{co} take place at approximately 60°C as shown in Fig. 9-26*e*. These changes can lead to instability at high temperatures by α becoming equal to or greater than unity or by I_{co} increasing and causing a collector runaway effect due to self-heating.

Temperature problems are minimized in silicon transistors as seen in Fig. 9-26*f*. The value I_{co} becomes almost negligible in design consideration as the upper limit or temperature range is above 100°C. In such special applications as d-c amplifiers, the slightest change in α over the normal temperature operating range can produce a significant change in d-c gain of the grounded-emitter stage.

The low-frequency low-power triode junction transistor, Table 9-7, is most commonly used. The majority are utilized in hearing aids, audio systems, low-power control systems, and low-speed computing circuits. Present units are available in the *p-n-p* and *n-p-n* fused germanium, the *n-p-n* grown silicon types. Of the fused type of transistor, the *p-n-p* is more available commercially and consequently has found a wider range of applications. The *n-p-n* fused type is suitable for complementary symmetry circuitry. The grown silicon type is used for high-temperature and low-I_{co} applications.

The germanium and silicon grown transistors are used in almost the same manner as the fused transistor. Frequently, the grown types, owing to their lower value of collector capacitance and higher value of a cutoff, can be employed as high-frequency transistors.

The maximum power ratings on most of the low-power transistors are of the order of 50-mw collector dissipation at room temperature. Some of these units have external heat sinks and are able to dissipate considerably more power.

The rating most commonly employed is the maximum power rating. Maximum current and maximum voltage ratings cannot be achieved simultaneously because the product of these two ratings usually exceeds maximum rating. The maximum voltage rating is set at a value safely below the collector voltage breakdown value while the maximum current is selected where β has not decreased to too low a value.

Table 9-8, high-frequency transistors, includes *p-n-p* and *n-p-n* fused junction, *n-p-n* grown junction, and *p-n-p* surface-barrier units. Except for the *n-p-n* grown type, which is of either germanium or silicon, all these units use germanium.

Physically, one of the main distinctions between these units and the low-frequency units is the closer spacing between emitter and collector junctions. Electrical characteristics are higher α cutoff, lower collector voltage breakdown, and in many units lower collector capacitance and lower base resistance. The widest application is in radio receivers and high-speed switching circuits.

In selecting a high-frequency transistor for a grounded-emitter IF amplifier, note that the β-cutoff frequency of the amplifier is equal to a cutoff frequency divided by β.

Table 9-9 lists tetrode junction transistors which are high-frequency triode *n-p-n* grown junction transistors with an extra base lead and a narrower base region. The electrical characteristics of the grown tetrode transistor are almost identical to the grown triode transistor except for a lower value of base resistance and higher value of α-cutoff frequency. The extra base lead makes the tetrode applicable in specialized control circuits and AVC applications. Bias for the extra base lead is usually obtained from a bleeder across the main supply.

High-power Units

The high-power transistor, Table 9-10, is in most cases the largest of all transistors. One element is attached to the container. In most units the case can be connected to the chassis either directly or through a thin mica spacer. The types used as power transistors are the germanium *p-n-p* fused and silicon *n-p-n* grown.

The *p-n-p* fused transistors are usually the high-power units whose larger physical size provides collector power dissipation up to 20 watts. The larger physical size also contributes a high collector capacitance and lower α-cutoff frequency. Medium-power *p-n-p* and *n-p-n* fused units which retain their smaller physical size and most of the electrical characteristics of the low-power transistors are used in applications requiring collector power dissipation below $\frac{1}{2}$ watt.

The characteristics peculiar to the high-power transistor are the lower values of input resistance, output resistance, and α, resulting from the higher values of bias currents employed. Bias stability techniques are used to minimize the effect of runaway due to self-heating of the collector.

The point-contact transistor, Table 9-11, is limited to high-speed switching circuitry. Phototransistor devices, Table 9-12, are divided into two basic types: the two-lead and three-lead devices. In the two-lead unit, one lead is attached to the base and the other to the collector. The three-lead device has leads going to the emitter, base, and collector, respectively.

The two-lead device is used in circuits providing d-c amplification for unmodulated light, while the three-lead device can be used in circuits employing a-c amplification for modulated light.

Acknowledgment is given to Ann M. Field and Elizabeth A. Sewell for their assistance in compiling these data.

Table 9-7. Junction-triode

Manufacturer	Type No.	Type	Max coll power, mw	Max coll voltage, volts	Max coll current, ma	Max ambient temp, °C	Small-signal low-			
							Bias			
							V_c, volts	I_e, ma	β	r_e, ohms
Amperex Electronic Corp.	OC70	*p-n-p* fused [a]	25 (45°C)	−10	−10	45	−2	0.5	30	39
230 Duffy Ave.	OC71	*p-n-p* fused [a]	25 (45°C)	−10	−10	45	−2	3	47	6.5
Hicksville, N.Y.										
CBS-Hytron	2N36	*p-n-p* fused	50	−20	−8	50	−6	1	45	30
Danvers, Mass.	2N37	*p-n-p* fused	50	−20	−8	50	−6	1	30	30
	2N38	*p-n-p* fused	50	−20	−8	50	−6	1	15	25
	HA-1	*p-n-p* fused	50	−20	−8	50	−3	0.5	40	24
	HA-2	*p-n-p* fused	50	−20	−8	50	−3	0.5	30	35
	HA-3	*p-n-p* fused	50	−20	−8	50	−3	0.5	35	30
	HC-1	*p-n-p* fused	50	−20	−8	50	−6	1	45	30
Germanium Prod. Corp.	NPN-3/ 2N103	*n-p-n* grown	50 (25°C)	35	10	75	4.5	−1	4	25
26 Cornelison Ave.	RD2517A/ 2N97	*n-p-n* grown	50 (25°C)	30	10	75	4.5	−1	13.3	25
Jersey City, N.J.	RD2518A/ 2N97A	*n-p-n* grown	50 (25°C)	40	10	85	4.5	−1	13.3	25
	RD2521A/ 2N98	*n-p-n* grown	50 (25°C)	40	10	75	4.5	−1	40	25
	RD2522A/ 2N98A	*n-p-n* grown	50 (25°C)	40	10	85	4.5	−1	40	25
	RD2523A/ 2N99	*n-p-n* grown	50 (25°C)	40	10	75	4.5	−1	40	25
	RD2525A/ 2N100	*n-p-n* grown	25 (25°C)	25	5	50	4.5	−1	140	25
General Electric Co.	2N43	*p-n-p* fused	150 (25°C)	−45 [e]	−50	100	−5	1	49	32
Electronics Park	2N44	*p-n-p* fused	150 (25°C)	−45 [e]	−50	100	−5	1	21.2	26.5
Syracuse, N.Y.	2N45	*p-n-p* fused	150 (25°C)	−45 [e]	−50	100	−5	1	11.5	20
	2N43A	*p-n-p* fused	150 (25°C)	−45 [e]	−50	100	−5	1	43.4	15
	2N43A USAF	*p-n-p* fused	150 (25°C)	−45	−50	100	−5	1	43.4	15
	2N76	*p-n-p* fused	50 (25°C)	−20 [e]	−10	60	−5	1	19	17
General Transistor Corp.	GT-14	*p-n-p* fused	70 (50°C)	−25	.....	85	−4.5	1	28	30
95-18 Sutphin Blvd.	GT-20	*p-n-p* fused	70 (50°C)	−25	.....	85	.....	.....	45	30
Jamaica, N.Y.	GT-34	*p-n-p* fused	70 (50°C)	−25	.....	85	.....	.....	15	30
	GT-81	*p-n-p* fused	70 (50°C)	−25	.....	85	.....	.....	65	30
	GT-83	*p-n-p* fused	70 (50°C)	−25	.....	85	.....	.....	45	30
	GT-87	*p-n-p* fused	70 (50°C)	−25	.....	85	.....	.....	28	30
	GT-88	*p-n-p* fused	70 (50°C)	−25	.....	85	.....	.....	65	30
	2N34	*p-n-p* fused	70 (50°C)	−25	.....	85	−4.5	1	40	30
	2N36	*p-n-p* fused	70 (50°C)	−25	.....	85	−4.5	1	45	30
	2N37	*p-n-p* fused	70 (50°C)	−25	.....	85	−4.5	1	30	30
	2N38	*p-n-p* fused	70 (50°C)	−25	.....	85	−4.5	1	15	30
	2N39	*p-n-p* fused	70 (50°C)	−25	.....	85	−4.5	1	45	30
	2N40	*p-n-p* fused	70 (50°C)	−25	.....	85	−4.5	1	28	30
	2N42	*p-n-p* fused	70 (50°C)	−25	.....	85	−4.5	1	13	30
Hughes Aircraft Co.	HA5001	*n-p-n* alloyed	500 (25°C)	30	100	85	5	1	65.6	16.5
Culver City, Calif.	HA5002	*n-p-n* alloyed	500 (25°C)	20	100	85	5	1	27.5	16
	HA5003	*n-p-n* alloyed	500 (25°C)	20	100	85	5	1	99	26
Hydro-Aire Inc.	J-1	*p-n-p* fused	150 (25°C)	−40	−10	50	−6	1	34	30
Burbank, Calif.	J-2	*p-n-p* fused	150 (25°C)	−40	−10	50	−6	1	15	30
	J-3	*p-n-p* fused	150 (25°C)	−40	−10	50	−6	1	9	30
	HA-1	*p-n-p* fused	100 (25°C)	−20	−10	50	−6	1	40	30
	CQ-1	*p-n-p* fused	150 (25°C)	−40	−10	50	−6	1	9	30
Nat'l Union Electric	2N39	*p-n-p* fused	47 (25°C)	−27	−12	60	−4.5	1	32.4	.....
350 Scotland Rd.	2N40	*p-n-p* fused	47 (25°C)	−27	−12	60	−4.5	1	15.7–32.4	.....
Orange, N.J.	2N42	*p-n-p* fused	47 (25°C)	−18	−12	60	−4.5	1	9	.....
	T34D	*p-n-p* fused [a]	56 (25°C)	−27	−12	70	−4.5	1	32.4	20
	T34E	*p-n-p* fused [a]	56 (25°C)	−27	−12	70	−4.5	1	15.7–32.4	20
	T34F	*p-n-p* fused [a]	56 (25°C)	−18	−12	70	−4.5	1	9	20
Philco Corp.	2N47	*p-n-p* fused [a]	50 (25°C)	−35	−20	...	−5	1	39	25
4700 Wissahickon Ave. Philadelphia, Pa.	2N49	*p-n-p* fused [a]	50 (25°C)	−35	−20	...	−5	1	39	25
RCA	2N104	*p-n-p* fused [b]	110 (25°C)	−30	50	85	−6	1	44	24.5
Harrison, N.J.	2N77	*p-n-p* fused [a]	35 (25°C)	−25	15	50	−4	0.7	40	36
Raytheon Mfg. Co.	CK721	*p-n-p* fused [c]	.....	−15 [f]	−10	70	−6	1	45	25
55 Chapel St. Newton, Mass.	CK722	*p-n-p* fused [c]	.....	−22 [f]	−10	70	−6	1	22	25
	CK725	*p-n-p* fused [c]	.....	−12 [f]	−10	70	−6	1	90	25
	CK727	*p-n-p* fused [c]	.....	−6 [f]	−10	70	−1.5	0.5	35	50
	2N63	*p-n-p* fused	.....	−22 [f]	−10	85	−6	1	22	25

Low-power Transistors

Frequency parameters						Grounded-emitter connection					Grounded-base				Grounded-collector			
r_b, ohms	r_c, megohms	$f_{\alpha co}$, Mc	C_c, $\mu\mu f$	I_{co}, μa	NF, db	I_b, ma	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db
1,000	1.43	.....	..	−8	10													
500	0.625	.....	..	−8	10													
450	0.95	0.5	..	....	..	.....	.....	30,000	1,000	40								
350	0.55	0.5	..	....	..	.....	.....	30,000	1,000	36								
350	0.5	0.5	..	....	..	.....	.....	30,000	1,000	32								
700	1.7	.....	..	−12	12	.....	.....	30,000	1,000	30								
350	0.8	.....	..	−12	27	.....	.....	30,000	1,000	30								
450	0.6	.....	..	....	..	.....	.....	1,200	1,000	35								
450	0.95	0.7	..	−12	..	.....	.....	30,000	1,000	40								
100	2.0	0.75	20	5	22	0.25	225	100,000 matched		33	45	250,000 matched		30	2,500	500 matched		7
100	3.0	1.0	19	2	20	0.07	400	100,000 matched		38	35	250,000 matched		32	7,000	500 matched		11
100	10.0	1.0	19	2	15	0.07	400	100,000 matched		38	35	250,000 matched		32	7,000	500 matched		11
150	5.0	2.5	14	2	20	0.025	850	100,000 matched		47	35	250,000 matched		35	20,000	500 matched		15
150	10.0	2.5	14	2	15	0.025	850	100,000 matched		47	35	250,000 matched		35	20,000	500 matched		15
150	5.0	3.5	10	2	15	0.025	850	100,000 matched		47	35	250,000 matched		35	20,000	500 matched		15
400	5.0	5.0	14	2	20	0.007	3,500	100,000 matched		53	45	250,000 matched		35	70,000	500 matched		20
400	1.0	1.0	40	−10	22	.....	1,000	30,000	600	39	60	50,000	100	28	30,000	600	30,000	15
300	1.0	1.0	40	−10	22	.....	700	30,000	600	38	55	50,000	100	28	15,000	600	15,000	12
250	1.0	1.0	40	−10	22	.....	450	30,000	600	36	50	50,000	100	28	7,500	600	7,500	11
575	1.43	1.0	40	−5	10	.....	1,000	30,000	600	39	60	50,000	100	28	30,000	600	30,000	15
575	1.43	1.0	40	−5	30	.....	1,000	30,000	600	39	60	50,000	100	28	30,000	600	30,000	15
300	1.0	1.0	40	−5	18	.....	1,000	30,000	600	38	55	50,000	100	28	15,000	600	15,000	12
800	1.5	0.65	..	−10	16													
800	1.5	0.65	..	−10	16													
800	1.5	0.65	..	−10	16													
800	1.5	0.65	..	−10	16													
800	1.5	0.70	..	−10	16													
800	1.5	0.50	..	−10	16													
800	1.5	1.0	..	−10	16													
350	2.0	.....	..	−15	24													
850	2.0	.....	..	−15	24													
600	2.0	.....	..	−15	24													
400	2.0	.....	..	−15	24													
850	2.0	.....	..	−15	24													
600	2.0	.....	..	−15	24													
400	2.0	.....	..	−15	24													
900	2	2.5	15	5														
400	1	0.8	..	12	15													
400	1	1.5	..	10	15													
400	1.0	1.0	..	−10	11	.....	.....	.....	.....	40								
300	0.7	0.5	..	−15	22	.....	.....	.....	.....	35								
300	0.5	0.5	..	−20	33	.....	.....	.....	.....	30								
350	0.75	.....	..	−10	20													
200	0.5	0.5	..	−20	33													
.....	1–2	.....	..	−10	20	.....	.....	30,000	500	39								
.....	1–2	.....	..	−10	24	.....	.....	30,000	500	38								
.....	0.5–2	.....	..	−20	28	.....	.....	30,000	500	36								
.....	1–2	.....	..	−10	20	.....	.....	30,000	500	39								
.....	1–2	.....	..	−10	24	.....	.....	30,000	500	38								
.....	0.5–2	.....	..	−20	28	.....	.....	30,000	500	36								
600	1.0	1.0	49	−10	15	.....	1,000	50,000 matched		42								
600	1.0	1.0	49	−10	12	.....	1,000	50,000 matched		42								
750	2.25	0.7	..	−10	12	.....	1,200	50,000 matched		43	140	400,000 matched		32.8	500,000	20,000 matched		13.9
560	2.3	0.7	..	−10	9	.....	1,350	50,000 matched		42.6	130	400,000 matched		33.2	10,000	300 matched		16.2
700	2.0	.....	..	−6	22	.....	1,500	20,000 matched		41	70	100,000 matched		31	600,000	20,000 matched		15
250	2.0	.....	..	−6	25	.....	500	20,000 matched		36	45	100,000 matched		32	200,000	20,000 matched		10
1,500	2.0	.....	..	−6	20	.....	2,700	20,000 matched		42	110	100,000 matched		30	1,000,000	20,000 matched		16
500	2.0	.....	..	−6	12	.....	.....	20,000	1,000	36	...	200,000	100	28	540,000	10,000	100,000	14
350	2.0	.....	..	−6	25	.....	800	20,000 matched		39	50	100,000 matched		32	350,000	20,000 matched		13

Table 9-7. Junction-triode Low-

Manufacturer	Type No.	Type	Max coll power, mw	Max coll voltage, volts	Max coll current, ma	Max ambient temp, °C	Small-signal low-			
							Bias			
							V_c, volts	I_e, ma	β	r_e, ohms
Raytheon (*Continued*)	2N64	*p-n-p* fused	.....	−15[f]	−10	85	−6	1	45	25
	2N65	*p-n-p* fused	.....	−12[f]	−10	85	−6	1	90	25
Sylvania Electric	2N34	*p-n-p* fused	50 (25°C)	−40	−10	...	−6	1	40	26
1740 Broadway	2N35	*n-p-n* fused	50 (25°C)	−40	−10	...	6	−1	40	26
New York, N.Y.										
Texas Instruments	200	*n-p-n* grown	50 (25°C)	30	5	50	5	−1	9	22
6000 Lemmon Ave.	201	*n-p-n* grown	50 (25°C)	30	5	50	5	−1	19	22
Dallas, Tex.	202	*n-p-n* grown	50 (25°C)	30	5	50	5	−1	49	35
	206S	*n-p-n* grown[a]	50 (25°C)	30	5	50	2.5	−0.5	35	.....
	207S	*n-p-n* grown[a]	50 (25°C)	30	5	50	2.5	−0.5	19	.....
	208S	*n-p-n* grown[a]	50 (25°C)	30	10	50	2.5	−10	19	.....
	300	*p-n-p* fused	50 (25°C)	−30	−10	50	−5	1	9	.....
	301	*p-n-p* fused	50 (25°C)	−30	−10	50	−5	1	19	.....
	903	*n-p-n* grown	150 (25°C)	30	10	150	5	−1	9–19	150
	904	*n-p-n* grown	150 (25°C)	30	10	150	5	−1	19–39	150
	905	*n-p-n* grown	150 (25°C)	30	10	150	5	−1	VM 39	150
	904A	*n-p-n* grown	150 (25°C)	30	10	150	5	−1	VM 19	150
	210	*n-p-n* grown	50 (25°C)	30[g]	5	50	22.5	−2	.....	.....
	302	*p-n-p* fused	50 (25°C)	−30	−10	50	−5	1	44	.....
	350	.....	50 (25°C)	−12						
Transitron	2N85	*p-n-p* fused	750	−45	−100	100	−12	10	40	2.5
407 Main St.	2N86	*p-n-p* fused	750	−60	−100	100	−12	10	20	2.5
Melrose, Mass.	2N87	*p-n-p* fused	750	−30	−100	100	−12	10	20	2.5
	2N88	*p-n-p* fused[a]	25	−12	−10	85	−1.3	0.5	25	50
	2N89	*p-n-p* fused[a]	25	−12	−10	85	−1.3	0.5	25	50
	2N90	*p-n-p* fused[a]	25	−12	−10	85	−1.3	2.5	40	10
	2N91	*p-n-p* fused	125	−15	−500	85	−3	30	25	1.5
	2N92	*p-n-p* fused	125	−25	−200	85	−3	5	30	5
	2N34	*p-n-p* fused	125	−25	−20	100	−6	1	40	18
	2N36	*p-n-p* fused	125	−25	−20	100	−6	1	45	18
	2N37	*p-n-p* fused	125	−25	−20	100	−6	1	30	20
	2N38	*p-n-p* fused	125	−25	−20	100	−6	1	15	20
	2N43	*p-n-p* fused	375	−45	−50	100	−6	1	33	20
	2N44	*p-n-p* fused	375	−45	−50	100	−6	1	16	20
	2N45	*p-n-p* fused	375	−45	−50	100	−6	1	9	20
	2N63	*p-n-p* fused	125	−25	−20	100	−6	1	20	20
	2N64	*p-n-p* fused	125	−25	−20	100	−6	1	30	20
	2N65	*p-n-p* fused	125	−25	−20	100	−6	1	50	18
Tung-Sol Electric	DR126	*p-n-p* fused[d]	50 (25°C)	−10[g]	.....	85	−1.5	0.5	24	26
100 Eighth Ave.	DR128	*p-n-p* fused[d]	50 (25°C)	−10[g]	.....	85	−1.5	0.5	49	34
Newark, N.J.	DR129	*p-n-p* fused[d]	50 (25°C)	−25[g]	.....	85	−1.5	0.5	32.4	26
	DR130	*p-n-p* fused[d]	50 (25°C)	−25[g]	.....	85	−1.5	0.5	13	20.5
	DR154	*p-n-p* fused[d]	50 (25°C)	−25[g]	.....	85	−1.5	0.5	124	55
Western Electric	2N27	*n-p-n* grown	50 (60°C)	30	5	85	4.5	−1	19–198	50
120 Broadway	2N28	*n-p-n* grown	50 (60°C)	30	5	85	4.5	−1	5–198	125
New York, N.Y.										
Westinghouse	2N54	*p-n-p* fused[a]	200 (25°C)	−45	−10	60	−6	1	33	25
Box 284	2N55	*p-n-p* fused[a]	200 (25°C)	−45	−10	60	−6	1	20	20
Elmira, N.Y.	2N56	*p-n-p* fused[a]	200 (25°C)	−45	−10	60	−6	1	13	5

All sockets A to H except where otherwise noted.
[a] Socket type A.
[b] Socket types B to H.
[c] Socket types A, I, and J.
[d] Socket type not given.

power Transistors (*Continued*)

Frequency parameters						Grounded-emitter connection					Grounded-base				Grounded-collector			
r_b, ohms	r_c, megohms	$f_{\alpha co}$, Mc	C_c, μμf	I_{eo}, μa	NF, db	I_b, ma	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db	R_i, ohms	R_L, ohms	R_g, ohms	Gain, db
700	2.0	.....	..	−6	22	.....	1,500	20,000 matched		41	70	100,000 matched		31	600,000	20,000 matched		15
1,500	2.0	.....	..	−6	20	.....	2,700	20,000 matched		42	110	100,000 matched		30	1,000,000	20,000 matched		16
800	2.0	0.6	15	−5	18	−0.03	1,200	30,000	500	40	...	.....	...	....	20,000	500 matched		16
800	2.0	0.8	18	5	16	0.03	1,200	30,000	500	40	...	.....	...	....	20,000	500 matched		16
150	0.4	0.9	15	10	26	.....	480	20,000	500	37	35	100,000	60	30	9,500	500	15,000	12
170	0.4	1.1	17	10	23	.....	970	20,000	500	40	40	100,000	60	30	15,500	500	15,000	14.5
200	0.4	1.3	19	10	20	.....	1,250	20,000	1,250	43	45	100,000	60	31	32,000	500	15,000	17
.....	.....	.....	..	3	11	.....	.....	20,000	1,000	32								
.....	.....	.....	..	3.5	21	.....	.....	20,000	1,000	29								
.....	.....	.....	..	4	26	.....	.....	300	1,000	26								
550	0.4	.....	..	−10	25													
1,000	0.4	.....	..	−10	20													
500	0.5	3	..	1 (25°C)	23													
1,250	0.5	3	..	1 (25°C)	23													
2,500	0.5	3	..	1 (25°C)	23													
1,250	0.5	[g]	..	1 (25°C)	23													
.....	.....	.....	..	50 (25°C)	..	.....	.....	10,000	500	39								
.....	.....	.....	..	−10														
300	0.16	0.8	..	−10	20	.....	.....	1,000	500	30								
300	0.125	0.8	..	−10	20	.....	.....	1,000	500	26								
300	0.125	0.8	..	−20	20	.....	.....	1,000	500	26								
1,000	0.5	0.5	..	−10	10	.....	.....	20,000	1,000	36								
1,000	2.0	0.5	..	−10	20	.....	.....	20,000	1,000	36								
600	0.5	0.5	..	−10	20	.....	.....	600	1,000	26								
50	2.0	.....	..	−15														
500	1.0	.....	..	−10														
600	1.0	.....	..	−10	20	.....	.....	30,000	1,000	40								
700	1.0	.....	..	−10	20	.....	.....	30,000	1,000	40								
500	1.0	.....	..	−15	22	.....	.....	30,000	1,000	36								
250	1.0	.....	..	−25	24	.....	.....	30,000	1,000	32								
500	1.0	.....	..	−15	20	.....	.....	30,000	1,000	40								
300	1.0	.....	..	−15	22	.....	.....	30,000	1,000	37								
250	1.0	.....	..	−15	22	.....	.....	30,000	1,000	33								
350	2.0	.....	..	−10	25	.....	.....	30,000	1,000	38								
700	2.0	.....	..	−10	22	.....	.....	30,000	1,000	39								
1,500	2.0	.....	..	−10	20	.....	.....	30,000	1,000	41								
900	1.5	0.9	..	−9	14	−0.006	.....	30,000	1,000	33								
1,400	2.0	0.9	..	−8	18	−1.5	.....	300	.....	24								
1,200	2.0	0.7	..	−10	18	−0.006	.....	30,000	1,000	35								
650	1.3	0.5	..	−14	21	−0.006	.....	30,000	1,000	27								
600	1.2	0.7	..	−10	18	−0.006	.....	30,000	1,000	40								
700	2.0	2	17	10	30													
1,000	1.0	0.95	25	10	30													
400	1.0	0.5	..	−6	..	.....	700	50,000	700	39.5	125	300,000	125	31	35,000	1,000	35,000	15
400	1.0	0.5	..	−6	..	.....	550	67,000	550	39	125	300,000	125	31	27,000	1,000	27,000	13
400	1.0	0.5	..	−6	..	.....	450	85,000	450	37	125	300,000	125	31	20,000	1,000	20,000	11

Characteristics measured at 25°C unless otherwise noted.
[e] Characteristics measured at 30°C.
[f] Characteristics measured at 27°C.
[g] Temperature not given.

Table 9-8. High-

Manufacturer	Type No.	Type	Max coll power, mw	Max coll voltage, volts	Max coll current, ma	Max ambient temp, °C	Storage temp, °C	Typical small-signal			
								Bias			
								V_c, volts	I_e, ma	β	r_e, ohms
General Electric	2N78	*n-p-n* rate grown	50 (30°C)	15	20	100	100 max	5	−1	27.5	...
	2N123	*p-n-p* fused	150 (25°C)	−15	150	...	85	−5	1	30–150	...
	2N135	*p-n-p* alloyed	100 (25°C)	−20	−50	...	85	−5	1	20	...
	2N136	*p-n-p* alloyed	100 (25°C)	−20	−50	...	85	−5	1	40	...
	2N137	*p-n-p* alloyed	100 (25°C)	−10	−50	...	85	−5	1	60	...
Germanium Prod.	RD2523A (2N99)	*n-p-n* grown	50 (25°C)	40	10	75	.....	5	−1	40	25
	RD2525A (2N100)	*n-p-n* grown	25 (25°C)	25	5	50	.....	5	−1	100	25
	RD2521A (2N98)	*n-p-n* grown	50 (25°C)	40	10	75	.....	5	−1	40	25
	RD2517A	*n-p-n* grown	50 (25°C)	30	10	75	.....	5	−1	13	25
Hydro-Aire	HF-1	*p-n-p* fused	35 (25°C)	−15	−5	55	.....	−4.5	1	25	30
	IF-1	*p-n-p* fused	35 (25°C)	−15	−5	55	.....	−4.5	1	20	30
Philco	SB-100	surface barrier [a]	10 (40°C)	−4.5	−5	...	−55 to 85	−3	0.5	19	50
Raytheon	CK-760	*p-n-p* fused	.....	−6 [c]	−5	...	−55 to 85	−6	1	45	22
	CK-761	*p-n-p* fused	.....	−6 [c]	−5	...	−55 to 85	−6	1	50	22
	CK-762	*p-n-p* fused	.....	−6 [c]	−5	...	−55 to 85	−6	1	60	22
Sylvania	2N94	*n-p-n* alloyed	50 (25°C)	20	10	...	−55 to 85	6	−0.5	30	52
	2N94A	*n-p-n* alloyed	50 (25°C)	20	10	...	−55 to 85	6	−0.5	30	52
Texas Inst.	220	*n-p-n* grown [a]	50 (25°C)	30	5	50	.....	22.5	...	...	...
	221	*n-p-n* grown [a]	50 (25°C)	30	5	50	.....	22.5	...	...	...
	222	*n-p-n* grown [a]	50 (25°C)	30	5	50	.....	22.5	...	...	...
	223	*n-p-n* grown [a]	50 (25°C)	30	5	50	.....	22.5	...	...	...
	904A	*n-p-n* grown	150 (25°C)	30	10	150	.....	5	−1	≥19	150
	224–1	.....	.....	...	...	...	.....	...	...	...	...
	2	.....	.....	...	...	...	.....	...	...	...	...
	3	.....	.....	...	...	...	.....	...	...	...	...
	4	.....	.....	...	...	...	.....	...	...	...	...
	5	.....	.....	...	...	...	.....	...	...	...	...
	225–1	.....	.....	...	...	...	.....	...	...	...	...
	2	.....	.....	...	...	...	.....	...	...	...	...
	3	.....	.....	...	...	...	.....	...	...	...	...
	4	.....	.....	...	...	...	.....	...	...	...	...
	5	.....	.....	...	...	...	.....	...	...	...	...
	226–1	.....	.....	...	...	...	.....	...	...	...	...
	2	.....	.....	...	...	...	.....	...	...	...	...
	3	.....	.....	...	...	...	.....	...	...	...	...
	4	.....	.....	...	...	...	.....	...	...	...	...
	5	.....	.....	...	...	...	.....	...	...	...	...
	227–1	.....	.....	...	...	...	.....	...	...	...	...
	2	.....	.....	...	...	...	.....	...	...	...	...
	3	.....	.....	...	...	...	.....	...	...	...	...
	4	.....	.....	...	...	...	.....	...	...	...	...
	5	.....	.....	...	...	...	.....	...	...	...	...
Tung-Sol	DR-155	*p-n-p* fused [b]	50 (25°C)	−10	...	85	−55 to 85	−1.5	0.5	32	...
	2N112	*p-n-p* fused	50 (25°C)	−10	−8	85	−55 to 85	−6	1	32	31
	2N113	*p-n-p* fused	50 (25°C)	−10	−8	85	−55 to 85	−6	1	32	31
Western Electric	2N27	*n-p-n* grown	50 (60°C)	30	5	85	.....	4.5	−1	20–198	50

Socket types A to H unless otherwise noted.
[a] Socket type A only.
[b] Socket types A and J.

frequency Transistors

low-frequency parameters							HF parameters	High-frequency circuit conditions					High-speed switching characteristics			
r_b, ohms	r_c, megohms	$f_{\alpha co}$, Mc	C_c, $\mu\mu f$	I_{co}, μa	I_{eo}, μa	NF, db	$r_b C_c$, $\mu\mu$ sec	Application	R_i, ohms	R_o, ohms	Power gain, db	Circuit	Rise time, μsec	Fall time, μsec	Reverse emitter voltage, volts	Circuit
...	...	5.5	6	1	...	14	....	RF amp	1,000	6,000	20					
								IF amp	1,500	10,000	30					
...	...	7.5	14	−2	5	10	1,000	Switching	...	.....	..	..	0.1	0.2	5	
...	...	4.5	14	5	...	..	....	RF/IF amp	...	.....	29					
...	...	6.5	14	5	...	..	....	RF/IF amp	...	.....	31					
...	...	10	14	5	...	..	....	RF/IF amp	...	.....	33					
150	5.0	3.5	10	2	...	15	....	IF amp unneut	500	10,000	22	..	<0.2	<0.3		
400	5.0	5.0	14	2	...	20	....	IF amp unneut	750	10,000	23	..	<0.2	<0.3		
150	5.0	2.0	14	2	...	20	....	IF amp unneut	500	10,000	22	..	<0.2	<0.3		
100	3.0	1.0	19	2	...	20	....	IF amp unneut	350	10,000	20	..	<0.2	<0.3		
500	1.0	5.0	10	−10												
500	1.0	2.9	10	−10												
...	0.4	30 (osc)	2.2	−0.5	0.5	..	800									
70	1.0	5	14	−2	2	25	1,000									
70	1.0	10	14	−2	2	25	1,000									
70	1.0	20	14	−2	2	25	1,000									
500	2.0	3.5	10	3	−3	15	1,000	IF (g-b)	80	100,000	25 [d]	C	0.15	0.15	≥0	F
								IF (g-e)	500	25,000	32 [d]	D				
500	2.0	6.0	10	3	−3	15	1,200	IF (g-b)	80	100,000	25 [d]	C	0.1	0.1	≥0	
								IF (g-e)	800	25,000	35 [d]	D				
								RF (g-b)	80	15,000	20 [e]	E				
...	...	...	...	50	...	..	....	262-kc (g-e) IF	750	70,000	31	A				
...	...	...	...	50	...	..	....	262-kc (g-e) IF	750	70,000	33	A				
...	...	...	...	50	...	..	....	262-kc (g-e) IF	750	70,000	35	A				
...	...	...	...	50	...	..	....	262-kc conv	300	60,000	20	B				
1,250	0.5	≥8	...	1												
...	...	...	...	...	...	..	....	Neut 262-kc g-e IF	600	70,000	26	H				
...	...	...	...	...	...	..	....		...	.....	28					
...	...	...	...	...	...	..	....	.....	...	.....	30					
...	...	...	...	...	...	..	....	.....	...	.....	32					
...	...	...	...	...	...	..	....	.....	...	.....	34					
...	...	...	...	...	...	..	....	Neut 455-kc g-e IF	500	50,000	24	H				
...	...	...	...	...	...	..	....		...	.....	26					
...	...	...	...	...	...	..	....	.....	...	.....	28					
...	...	...	...	...	...	..	....	.....	...	.....	30					
...	...	...	...	...	...	..	....	.....	...	.....	32					
...	...	...	...	...	...	..	....	Neut 262-kc g-b IF	65	120,000	18	I				
...	...	...	...	...	...	..	....		...	.....	20					
...	...	...	...	...	...	..	....	.....	...	.....	22					
...	...	...	...	...	...	..	....	.....	...	.....	24					
...	...	...	...	...	...	..	....	.....	...	.....	26					
...	...	...	...	...	...	..	....	Neut 455-kc g-b IF	65	150,000	18	I				
...	...	...	...	...	...	..	....		...	.....	20					
...	...	...	...	...	...	..	....	.....	...	.....	22					
...	...	...	...	...	...	..	....	.....	...	.....	24					
...	...	...	...	...	...	..	....	.....	...	.....	26					
...	1.0	1.4	...	−15	...	28										
110	1.2	5	...	−10	...	28	....	IF	600	25,000	32	G				
110	1.2	10	...	−10	...	28	....	IF	600	25,000	33	G				
700	2.0	2	17	10												

Characteristics measured at 25°C unless otherwise noted.
[c] Characteristics measured at 27°C.
[d] Bandwidth 12 kc.
[e] Bandwidth 25 kc.

Table 9-9. Grown *n-p-n*

Manufacturer	Type No.	Max coll power, mw	Max coll voltage, volts	Max coll current, ma	Max base-to-base current, ma	Application
Germanium Prod.	RDX-302/3N23	50 (25°C)	30	5	5	Video amp, switching 10-Mc osc
	RDX-301/3N23A	50 (25°C)	30	5	5	Video amp, switching 20-Mc osc
	RDX-300/3N23B	50 (25°C)	30	5	5	Video amp, switching 35-Mc osc 20-Mc IF
	RDX-300A/3N23C	50 (25°C)	30	5	5	Video amp, switching 50-Mc osc 20- to 30-Mc IF
Texas Inst.	700	50 (25°C)	30	5	5	Low-level, low-freq age
Western Electric	3N22	30 (25°C)	12	5	5	Video amp, R-F

All sockets A, F, G, H, and M.

Table 9-10.

Manufacturer	Type No.	Type	Max power output, watts: Class A	Class B (push-pull)	D-C switch	Max coll power, watts	Max coll voltage, volts: Circuit e-c	Circuit g-b	Max coll current, amp	Small signal: $f_{alpha c}$, kc	Bias: V_c, volts	Bias: I_c, ma
Amperex	2N115	*p-n-p* fused *	1.5	2.5	...	2 (45°C)	−12(B) −6(A)	...	−1	300	...	...
	2-OC72	*p-n-p* fused *	...	...	...	0.045 (45°C)	13(B)	...	0.045	10	...	...
CBS-Hytron	HD-197	*p-n-p* fused *	...	...	...	0.5 (25°C)	−40	...	...	150	−10	50
Hydro-Aire	JP-1	*p-n-p* fused *	0.45	0.9	1.5	0.5 (25°C)	...	−45	−0.1	50	−22.5	20
Minneapolis-Honeywell Regulator Co. 2753 4th Ave. S Minneapolis, Minn.	H-1	*p-n-p* fused *	5	10	40	20 (21°C)	−30	−60	−0.8	20	−2	...
	2N57	*p-n-p* fused *	6	12	48	20 (21°C)	−30	−60	−1	20	−2	...
	H-2	*p-n-p* fused *	8.5	18	68	20 (21°C)	−30	−60	−1.4	20	−2	...
	H-3	*p-n-p* fused *	2	4	16	5 (21°C)	−30	−60	−0.35	20	−2	...
	H-4	*p-n-p* fused †	2	6	16	5 (21°C)	−30	−60	−0.5	20	−2	...
Sylvania	2N68	*p-n-p* alloyed †	0.75	10	...	4 (25°C)	...	−25	−1.5	...	−6	50
	2N95	*n-p-n* alloyed †	0.75	10	...	4 (25°C)	...	25	1.5	...	6	−50
	2N101	*p-n-p* alloyed	Electrically identical to 2N68									
	2N102	*n-p-n* alloyed	Electrically identical to 2N95									
Texas Inst.	X-2	*n-p-n* grown	...	...	...	...	...	35	0.075	225	5	−1
	951	*n-p-n* grown	...	0.45 (25°C)	...	1 (25°C)	50	...	0.06	...	...	...
		Silicon	...	0.3 (100°C)	...	0.5 (100°C)	...	...	...	...	...	...
				0.15 (150°C)	...	0.15 (150°C)						
	952	*n-p-n* grown	...	0.6 (25°C)	...	1 (25°C)	80	...	0.03	...	...	...
		Silicon	...	0.4 (100°C)	...	0.5 (100°C)	...	...	...	...	...	...
				0.15 (150°C)	...	0.15 (150°C)						
	953	*n-p-n* grown	...	1 (25°C)	...	1 (25°C)	120	...	0.04	...	...	...
		Silicon	...	0.5 (100°C)	...	0.5 (100°C)	...	...	...	...	...	...
				0.15 (150°C)	...	0.14 (150°C)						
Transistor Products 241-251 Crescent Ave. Waltham, Mass.	X-107	*p-n-p* fused *	1	...	...	2 (25°C)	−30	−60	−1	...	−24	80
	X-120	*p-n-p* fused *	7.5	...	...	15 (25°C)	−30	−60	−4	...	−28	360
Transitron	2N83	*p-n-p* fused ‡	5	15	40	10 (25°C)	−30	−45	−1	200	−20	100
	2N84	*p-n-p* fused ‡	5	10	30	10 (25°C)	−22	−30	−1	200	−20	100
Tung-Sol	DR-150	*p-n-p* fused	...	1	3.5	5 (25°C)	...	−25	−1	250	−15	10
Western Electric	2N66	*p-n-p* fused *	...	...	...	5 (25°C)	−40	−60	−0.8	500	−4.5	100
											−40	0

* Type A sockets.
† Socket types A to H.

Junction-tetrode Transistors

Small-signal low-frequency Parameters								Typical operation	
Bias									
V_c, volts	I_e, ma	I_{b2}, ma	α	r_e, ohms	r_b, ohms	r_c, megohms	I_{co}, μa	Freq. Mc Circuit *J*	Power-gain at 5 Mc Circuit *K*
4.5	1	0	0.95	30	70	2	10	10–20	12
4.5	1	0	0.97	30	100	2	10	20–35	14
4.5	1	0	0.98	30	200	2	10	35–50	15
4.5	1	0	0.99	30	300	2	10	50–80	17
5	−1	0	0.95	30	1,000	1	10		
9	−2	−4.5	0.90	25	100	1	10	15	
9	−2	0	0.975	25	1,000	1			

Characteristics measured at 25°C.

Power Transistors

low-frequency parameters						Typical operating conditions										
β	r_e, ohms	r_b, ohms	r_c, ohms	C_c, μμf	Rise time, μsec	I_{co}, μa	Class and circuit	Supply voltage, volts	Coll current, ma	Base current, ma	Zero signal current, ma	Power output, watts	Power gain, db	Driving power, mw	R_c, ohms	R_L, ohms	R_{g_1}, ohms
..	...	...	...	...	..	...	B(g-e)	−6	−1,280	...	−5	5 ¶	27				
..	...	...	...	...	..	...	B(g-e)	−6	...	...	...	0.2 ¶	27				
10	...	70	5,000	...	..	...	A	...	−50	...	...	...	30	...	...	5,000	100
9	2	150	100,000	...	..	−500	B(g-b)	−22.5	−40	...	...	0.7 ¶	20				
..	...	...	...	...	1.5	−8,000	A(g-e)	−28	400	50	...	5	15	158	20	70	4
							B(g-e)	−28	510	...	4	10 ¶	12	630	100	140	4
..	...	...	...	...	1.2	−8,000	A(g-e)	−28	500	45	...	6.25	16	156	35	56	4
							B(g-e)	−28	640	...	4	12.5 ¶	13	625	140	128	4
..	...	...	...	...	0.5	−8,000	A(g-e)	−28	600	30	...	7.5	20	75	40	47	4
							B(g-e)	−28	890	...	4	17.5 ¶	16	440	100	80	4
..	...	...	...	...	1.2	−1,000	A(g-e)	−28	150	15	...	1.9	16	48	100	187	4
							B(g-e	−28	220	...	0.5	4.4 ¶	12	278	240	320	4
..	...	...	...	...	0.6	−1,000	A(g-e)	−28	150	10	...	1.9	21	15	60	187	4
							B(g-e)	−28	318	...	0.5	6.25 ¶	14	250	200	224	4
40	1	30	100,000	300	..	−100	A(g-b)	−12	−150	...	...	0.6	23	...	75	100	50
							B(g-e)	−12	−550	...	−1	5 ¶	15	...	50	12	50
							B(g-e)	−12	−550	...	−1	5 ¶	10	...	250	12	100
							B(g-b	−24	−950	...	−1	10 ¶	10	...	2	24	2
40	1	30	100,000	300	..	100	A(g-b)	12	150	...	...	0.6	23	...	75	100	
							B(g-e)	12	550	...	1	5 ¶	15	...	50	12	
							B(g-e)	12	550	...	1	5 ¶	10	...	250	12	
							B(g-b)	24	950	...	1	10 ¶	10	...	2	24	
9	25	0.75	200,000	...	..	25	B(g-b)	22.5	40	...	...	0.5 ¶	9.5	...	...	1,000	
							B(g-b)	22.5	40	...	...	0.5	22.7	...	...	1,000	
..	...	...	...	...	..	5	B(g-e)	28	30	...	...	0.45 (25°C) ¶	20	...	...	1,500	1,000
..	...	...	...	...	..	...	...	...	...	...	...	0.15 (150°C)					
..	...	...	...	...	..	6	B(g-e)	45	25	...	...	0.6 (25°C) ¶	21	...	...	4,000	1,000
..	...	...	...	...	..	...	...	...	...	...	...	0.15 (150°C)					
..	...	...	...	...	..	8	B(g-e)	67.5	20	...	...	1 (25°C) ¶	23	...	...	8,000	1,000
..	...	...	...	...	..	...	...	...	...	...	...	0.15 (150°C)					
22	0.85	12	50,000	...	..	−120	A(g-b)	−28	−80	...	...	1	24	1	1.5	375	
20	0.65	1	10,000	...	..	−200	A(g-b)	−28	−360	...	...	5	20	50	0.8	100	
8	0.3	15	20,000	400	1.5	−100	B(g-e)	−30	−160	..	...	2.5 ¶	24	...	...	600	100
12	0.3	15	20,000	400	1.5	−100	B(g-e)	−20	−160	...	...	2.0 ¶	22	...	...	400	100
33	...	...	30,000														
45	...	...	...	400	..	75											
..	...	...	...	...	..	300											

‡ Socket types A and K.
¶ Push-pull connection.

Table 9-11. Point-

Manufacturer	Type No.	Application	Max coll power, mw	Max coll voltage, volts	Max coll current, ma	Max reverse emitter voltage, volts	Max emitter current, ma	Max emitter power, mw
Hydro-Aire	A-0	Amp, osc	0 (25°C)	−20	−8	...	...	...
	A-1	Amp, osc	50 (25°C)	−20	−8	...	...	...
	A-2	Amp, osc	50 (25°C)	−20	−8	...	...	...
	A-3	Amp, osc	50 (25°C)	−20	−8	...	...	...
	S-0	Switching	50 (25°C)	−40	−8	−30	...	...
	S-1	Switching	50 (25°C)	−40	−8	−30	...	...
	S-2	Switching	50 (25°C)	−30	−8	−30	...	...
Sprague Electric	5A	Switching	80 (25°C)	−50	−10	−50	...	...
Transistor Prod.	2A	Amp, osc, sw	120 (25°C)	−50	−8	−50		
	2C	Switching [a]	100 (25°C)	−50	−8	−50		
	2D	Amp, osc [a]	100 (25°C)	−50	−8	−50		
	2E	Amplifier [a]	100 (25°C)	−50	−8	−50		
	2G	Switching [a]	120 (25°C)	−50	−8	−50		
	2H	Amplifier [a]	100 (25°C)	−50	−8	−50		
	2L	Switching [a]	50 (25°C)	−50	−8	−50		
	2N32	Switching [a]	50 (25°C)	−40	−8	−40		
	2N33	Switching [a]	30 (25°C)	−8.5	−7			
	2N50	Switching [a]	50 (25°C)	−15	−1	−15		
	2N51	Sw, osc [a]	100 (25°C)	−50	−8	−50		
	2N52	Amp, osc [a]	120 (25°C)	−50	−8	−50		
	2N53	Switching [a]	120 (25°C)	−50	−8	−50		
Western Electric	2N21	Switching	120 (25°C)	−100	−60	−100	60	80 (25°C) [b]
	2N21A	Amp, osc, sw	120 (25°C)	−100	−60	−100	60	80 (25°C) [b]
	2N110	Switching	200 (25°C)	−100	−75	−100	75	100 (25°C) [b]
	2N67	High-speed sw	100 (25°C)	−100	−60	−100	60	60 (25°C) [b]

Socket types A to H unless otherwise noted.
[a] Socket types A and L
Maximum ambient temperature 50°C unless otherwise noted.
[b] Maximum ambient temperature 85°C.
Characteristics of A-0, A-1, A-2, A-3, 2N21, 2N21A, 2N110 and 2N67 measured at 25°C.

Parameter Conversion Formulas

$$H_{21} = \frac{R_{21}}{R_{22}} = -\alpha$$

$$H_{11} = R_{11} - \frac{R_{21}R_{12}}{R_{22}} \doteq r_e + (1 - \alpha)r_b$$

$$H_{12} = \frac{R_{12}}{R_{22}} \doteq \frac{r_b}{r_c}$$

$$H_{22} = \frac{1}{R_{22}} \doteq \frac{1}{r_c}$$

$$r_c = \frac{1}{H_{22}}$$

$$r_b = r_c H_{12}$$

$$|\alpha| = |H_{21}|$$

$$r_e = H_{11} - r_b(1 - \alpha)$$

Transistor Sockets

Code	Manufacturer	Type
A	Solder connections	.....
B	Elco Corp.	3-pin polarized 3-pin printed-circuit
C	Cinch Mfg. Corp.	3-pin polarized
D	Super-Ear Prod. Co.	3-pin polarized
E	Mycalex Tube Socket Corp.	3-pin polarized
F	Elco Corp.	4-pin polarized 4-pin printed-circuit
G	Super-Ear Prod. Co.	5-pin
H	Elco Corp.	5-pin 5-pin printed-circuit
I	Super-Ear Prod. Co.	3-pin equal spacing
J	Cinch Mfg. Corp.	5-pin
K	Amphenol Co.	.....
L	Cinch Mfg. Corp.	.....
M	Cinch Mfg. Corp.	4-pin polarized

contact Transistors

Small-signal low-frequency parameters										Large-signal parameters					
Bias															
V_c, volts	I_e, ma	$-\alpha$	r_e, ohms	r_b, ohms	r_c, ohms	$f_{\alpha co}$, Mc	C_c, $\mu\mu$f	NF, db	I_{co}, μa	Rise time, μsec	Turnoff time μsec	Off I_c, ma	On V_c, volts	Emitter rev resist., ohms	α (at max rise time)
−8	0.3	2	425	200	13,000	3	....	.....	−1,200						
−8	0.3	2	425	200	13,000	2	....	.....	−1,500						
−8	0.3	2	375	175	13,000	1	....	.....	−2,000						
−8	0.3	2	350	150	13,000	0.3	....	.....	−2,000						
....	...	....	...	...	.....	....	....	.....	...	0.2 [c]	...	−1	−2	50,000	
....	...	....	...	...	.....	....	....	.....	...	0.5 [d]	...	−1	−2	50,000	
....	...	....	...	...	.....	....	....	.....	...	1 [e]	...	−1	−2	50,000	
−10	1	3	...	...	.....	5	....	43	...	0.12	0.5				
−10	1	2.5 [f]	200	90	10,000	2	....	45	−1.1	0.2	1.3	−1.1	−1	200,000	5
−10	1	2.5 [f]	200	90	10,000	2	....	45	−1.1	0.2	1.3	−1.1	−1	200,000	5
−10	1	2.5 [f]	200	90	15,000	1.5	....	.....	−0.9	0.3	1.3	−0.9	−1	200,000	4
−10	1	3	900	500	20,000	20	....	.....	−0.9	0.02	0.9	−0.9	−0.8	2,000,000	7

[c] Fall time = 1 μsec.
[d] Fall time = 2 μsec.
[e] Fall time = 6 μsec.
[f] Large-signal α = 2.4.

Table 9-12. Phototransistors

Manufacturer	Type No.	Type	Max coll voltage, volts	Max coll current, ma	Max coll power, mw	Max dark current, μa	Max ambient temp., °C	Cutoff freq., kc	Noise, ft-c	Sensitivity, μa/ft-c
General Transistor	GT-66	Fused, 3 lead *	12	20	50 (25°C)	15	..	750	6×10^{-5}	25
Texas Inst.	800	Grown, 2 lead †	20	20	50 (25°C)	250	40	20	.....	35
Transistor Prod.	1N188	Grown, 2 lead	100	..	40 (25°C)	.....	50	...	3–10 μv	10 μa/millilumen
	1N189	Nonrect, 2 lead	...	..	30 (25°C)	20	50	...	.....	0.08%/ft-c
	10A	Grown, 2 lead	15	..	100 (25°C)	500	50	...	15–100 μv	4 ma for 300 ft-c
	10B	Grown, 2 lead	15	..	100 (25°C)	50	50	...	15–100 μv	50% for 10 ft-c
	5B	Grown, 2 lead	50	..	100 (25°C)	20	50	...	3–10 μv	1 ma for 300 ft-c
	5C	Grown, 2 lead	50	..	100 (25°C)	5	50	...	3–10 μv	50% for 40 ft-c
	11A	Nonrect, 2 lead	15	..	50 (25°C)	4,000 ohms	50	...	.....	2,000 ohms for 300 ft-c
	11B	Nonrect, 2 lead	15	..	50 (25°C)	4,000 ohms	50	...	.....	3,000 ohms for 300 ft-c
	17A	Grown, 2 lead	..	..	.....	...	..	...	Be ow 1 μv	
Western Electric	1N85	Grown, 2 lead *	90	1	50	20	85	25	2×10^{-6} μa	0.35 μa/μw

* Socket type A.
† Socket type A to H.

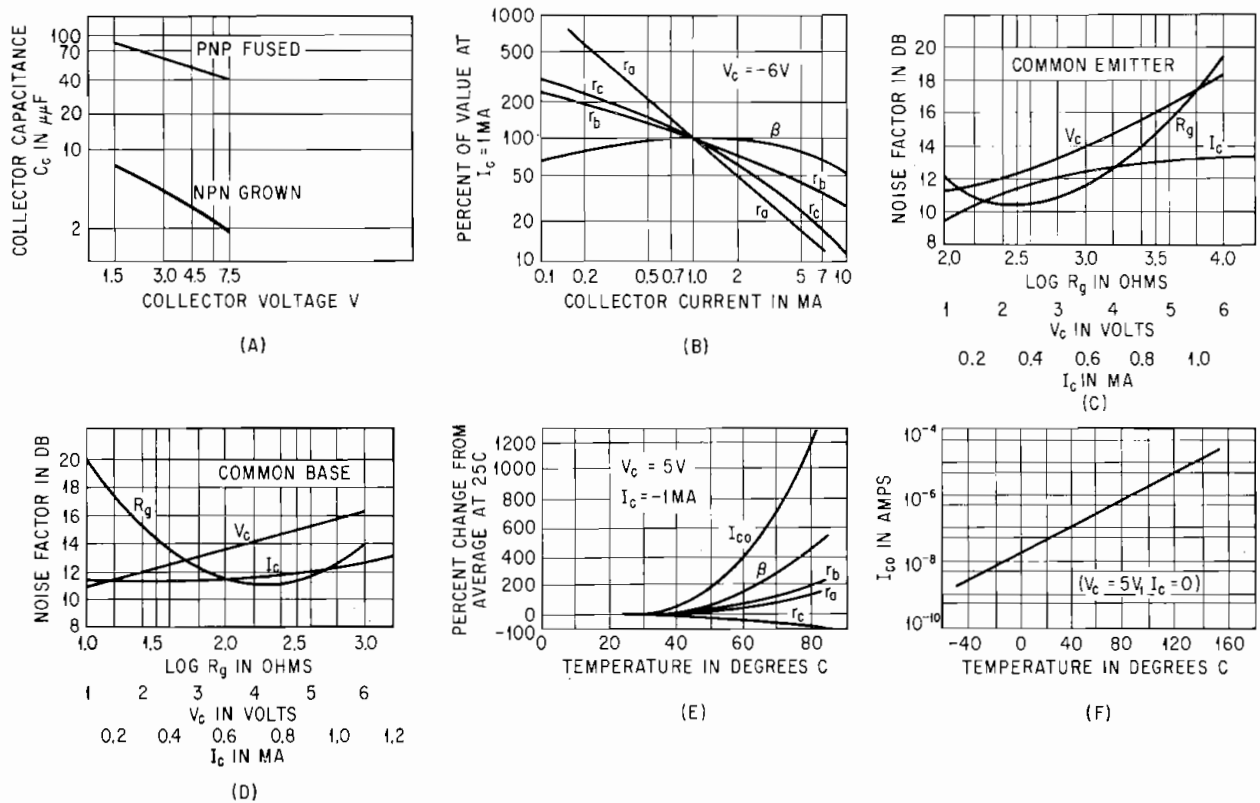


FIG. 9-26. Variation of transistor parameters with operating point (*A* to *D*) and ambient temperature (*E*, *F*).

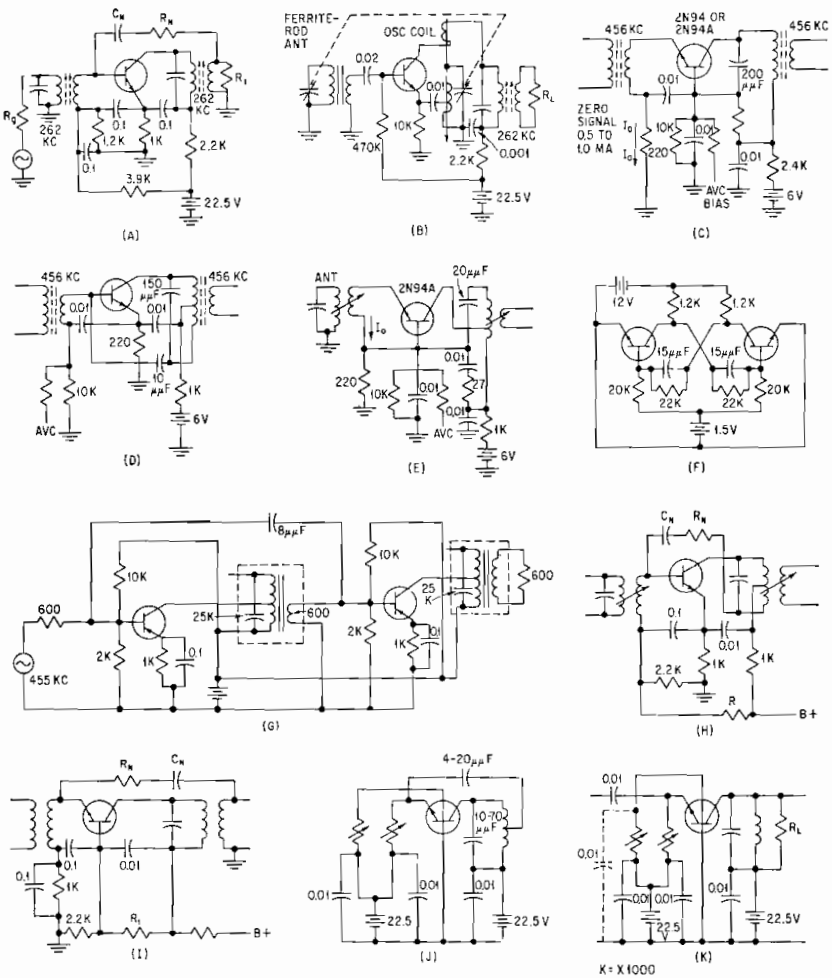


FIG. 9-27. Typical circuits for high-frequency transistors (*A* to *I*) and junction tetrode transistors (*J*, *K*) referred to in Tables 9-8 and 9-9.

Table 9-13. NAB Data Concerning Tower Failures

Information obtained from 298 television stations during 1958 indicated that 11 towers failed for various reasons. Briefly, 6 towers failed because of high winds, 2 fell during construction, and 3 failed because of structural weakness or faulty design. The following is a detailed breakdown of these 11 failures:

Height, ft	*Type*	*Weather conditions*	*Cause and comments*
826	SS	High wind	Broke in half during high wind
487	SS	97-mph wind	Failed at 125 ft above ground in wind
370	SS	Est. wind 190 knots	Due to gusty turbulence
570	SS	Hurricane "Carol"	Broke off TV tower at 200-ft level, Aug. 31, 1954
1250	G	50- to 60-mph winds	"Tower was completed to the 1,250 point. However, the top set of guys were not completely installed and in the process of tensioning these guys, high winds came up (50 to 60 m.p.h.), the unguyed portion of the tower began to oscillate, finally broke off at the 1150′ point and in falling, cut a permanent guy at the 1000′ level which in turn caused the entire structure to fail."
100	G	High winds	During process of erecting, 100 ft had been erected and temporary guy lines attached. Under high winds the temporary lines failed
450	SS	40-mile squall	Faulty design of tower
500	G	High level winds	Structural weakness
1262	G	. . . . .	Fell during erection, Feb. 4, 1957
649	G	. . . . .	Due to excessive strain during the process of attempting to lower a 12-bay antenna from it all at once. Actual cause of collapse not known, but it is not believed to have been caused by tower weakness
550	G	. . . . .	Collapsed during construction. Cause not fully determined, but accident was during guy tensioning

Table 9-14. Decimal Equivalents

1/32	0.03125	17/32	0.53125
1/16	0.0625	9/16	0.5625
3/32	0.09375	19/32	0.59375
1/8	0.125	5/8	0.625
5/32	0.15625	21/32	0.65625
3/16	0.1875	11/16	0.6875
7/32	0.21875	23/32	0.71875
1/4	0.25	3/4	0.75
9/32	0.28125	25/32	0.78125
5/16	0.3125	13/16	0.8125
11/32	0.34375	27/32	0.84375
3/8	0.375	7/8	0.875
13/32	0.40625	29/32	0.90625
7/16	0.4375	15/16	0.9375
15/32	0.46875	31/32	0.96875
1/2	0.5	1.0	1.0

Table 9-15. Standard Metal Gauges

No.	*American or B & S* *	*U.S. Standard* †	*Birmingham or Stubs* ‡
1	0.2893	0.28125	0.300
2	0.2576	0.265625	0.284
3	0.2294	0.250	0.259
4	0.2043	0.234375	0.238
5	0.1819	0.21875	0.220
6	0.1620	0.203125	0.203
7	0.1443	0.1875	0.180
8	0.1285	0.171875	0.165
9	0.1144	0.15625	0.148
10	0.1019	0.140625	0.134
11	0.09074	0.1250	0.120
12	0.08081	0.109375	0.109
13	0.07196	0.09375	0.095
14	0.06408	0.078125	0.083
15	0.05707	0.0703125	0.072
16	0.05082	0.0625	0.065
17	0.04526	0.05625	0.058
18	0.04030	0.050	0.049
19	0.03589	0.04375	0.042
20	0.03196	0.0375	0.035
21	0.02846	0.034375	0.032
22	0.02535	0.03125	0.028
23	0.02257	0.028125	0.025
24	0.02010	0.025	0.022
25	0.01790	0.021875	0.020
26	0.01594	0.01875	0.018
27	0.01420	0.0171875	0.016
28	0.01264	0.015625	0.014
29	0.01126	0.0140625	0.013
30	0.01003	0.0125	0.012
31	0.008928	0.0109375	0.010
32	0.007950	0.01015625	0.009
33	0.007080	0.009375	0.008
34	0.006350	0.00859375	0.007
35	0.005615	0.0078125	0.005
36	0.005000	0.00703125	0.004
37	0.004453	0.006640626	
38	0.003965	0.00625	
39	0.003531		
40	0.003145		

* Used for copper, brass, aluminum, etc.; nonferrous alloy sheets, rods, and wire.
† Used for iron, steel, nickel, and ferrous alloy materials.
‡ Used for seamless tubes and by some manufacturers for brass and copper materials.

Table 9-16. Drill Sizes

Number	*Will clear screw*	*Brass, iron, steel tapping* *
1		
2	12–24	
3	. . . . .	14–24
4	12–20	
5		
6		
7		
8		
9		
10	10–32	
11	10–24	
12		
13		
14		
15		
16	. . . . .	12–24
17		
18	8–32	
19	. . . . .	12–20
20		
21	. . . . .	10–32
22		
23		
24		
25	. . . . .	10–24
26		
27		
28	6–32	
29	. . . . .	8–32
30		
31		
32		
33	4–36, 4–40	
34		
35	. . . . .	6–32
36		
37		
38		
39	3–48	
40		
41		
42	. . . . .	4–36, 4–40
43	2–56	
44		
45	. . . . .	3–48
46		
47		
48		
49	. . . . .	2–56
50		
51		
52		
53		
54		

* For tapping plastic, bakelite, lucite, hard rubber, micalex, etc., use one size larger drill.

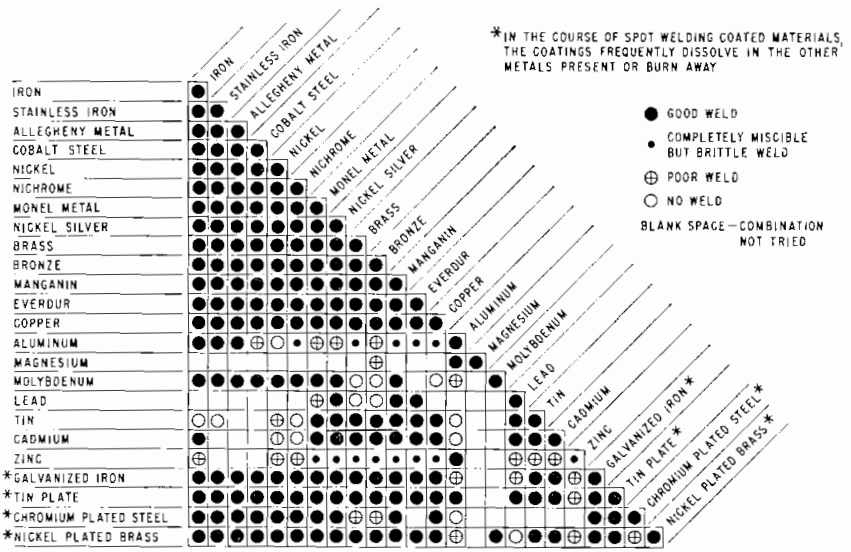


FIG. 9-28. The welding characteristics of some 250 combinations of metals.

STANDARD SYMBOLS FOR ELECTRONICS

The most-used schematic symbols for electronic components are collected here for convenient reference, as abstracted from the 54-page American Standards Association publication Y32.2-1954, "Graphical Symbols for Electrical Diagrams" and (for transistors) from MIL-STD-15A, "Military Standard Electrical and Electronic Symbols." (See Figs. 9-29*a*, 9-29*b*, and 9-29*c*.)

Symbols may have any orientation, size, and line weight. The open-circle terminal symbol can be added to leads if desired. Arrowheads can be either filled or open unless otherwise noted. Electrically actuated devices are normally shown in the power-off position. One-line symbolism has been adopted for waveguide diagrams, as indicated for microwave symbols.

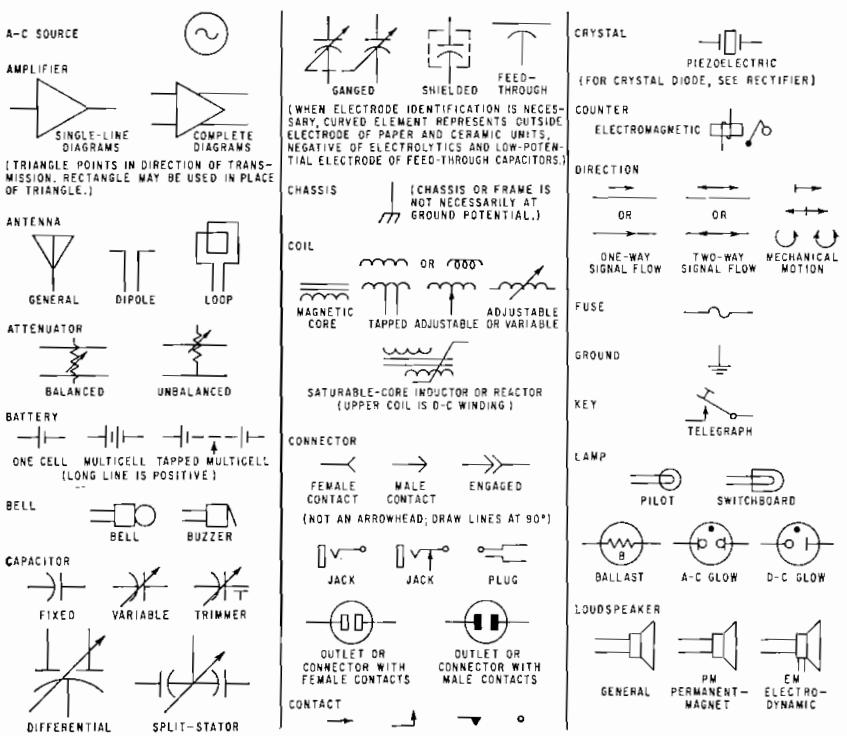


FIG. 9-29*a*

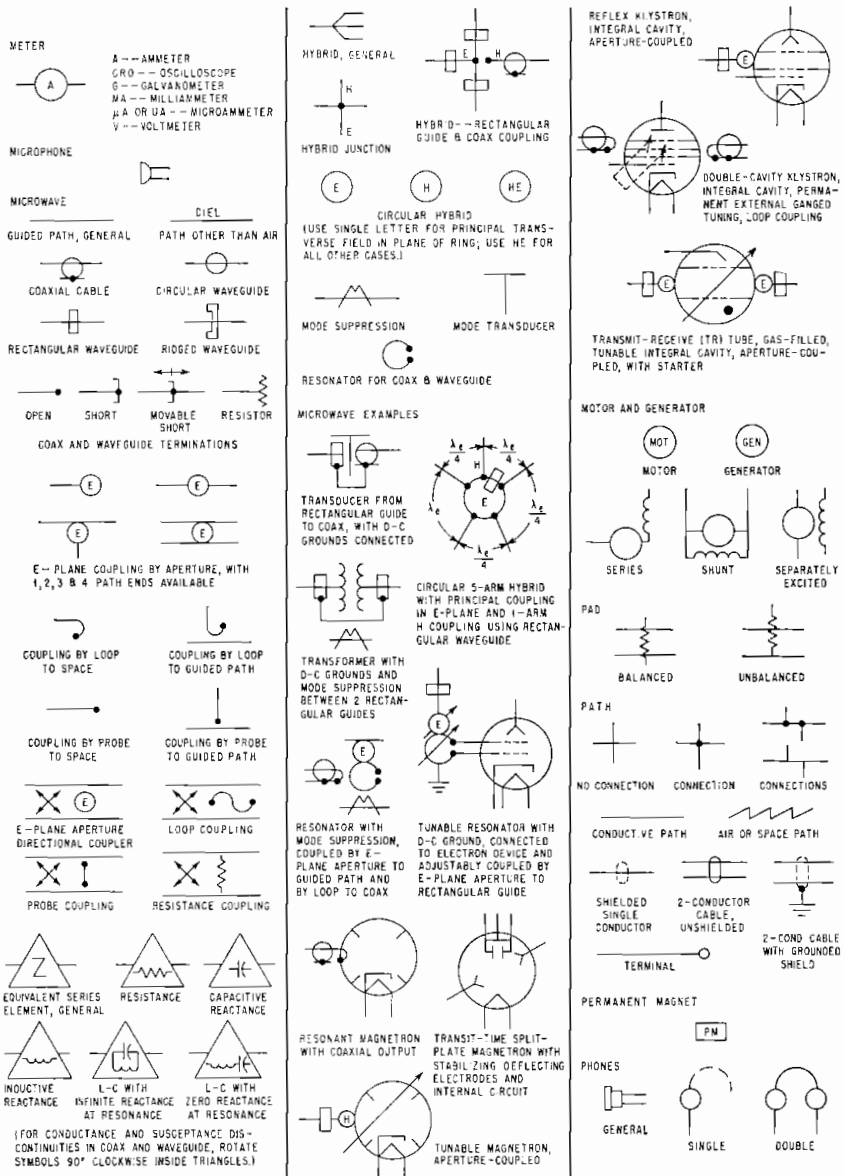

METER
A
A – – AMMETER
CRO – – OSCILLOSCOPE
G – – GALVANOMETER
MA – – MILLIAMMETER
μA OR UA – – MICROAMMETER
V – – VOLTMETER
MICROPHONE
MICROWAVE
DIEL
GUIDED PATH, GENERAL
PATH OTHER THAN AIR
COAXIAL CABLE
CIRCULAR WAVEGUIDE
RECTANGULAR WAVEGUIDE
RIDGED WAVEGUIDE
OPEN
SHORT
MOVABLE SHORT
RESISTOR
COAX AND WAVEGUIDE TERMINATIONS
E
E – PLANE COUPLING BY APERTURE, WITH 1, 2, 3 & 4 PATH ENDS AVAILABLE
COUPLING BY LOOP TO SPACE
COUPLING BY LOOP TO GUIDED PATH
COUPLING BY PROBE TO SPACE
COUPLING BY PROBE TO GUIDED PATH
E – PLANE APERTURE DIRECTIONAL COUPLER
LOOP COUPLING
PROBE COUPLING
RESISTANCE COUPLING
Z
EQUIVALENT SERIES ELEMENT, GENERAL
RESISTANCE
CAPACITIVE REACTANCE
INDUCTIVE REACTANCE
L–C WITH INFINITE REACTANCE AT RESONANCE
L–C WITH ZERO REACTANCE AT RESONANCE
(FOR CONDUCTANCE AND SUSCEPTANCE DISCONTINUITIES IN COAX AND WAVEGUIDE, ROTATE SYMBOLS 90° CLOCKWISE INSIDE TRIANGLES.)
HYBRID, GENERAL
H
E
HYBRID JUNCTION
E
H
HYBRID – – RECTANGULAR GUIDE & COAX COUPLING
E
H
HE
CIRCULAR HYBRID
(USE SINGLE LETTER FOR PRINCIPAL TRANSVERSE FIELD IN PLANE OF RING; USE HE FOR ALL OTHER CASES.)
MODE SUPPRESSION
MODE TRANSDUCER
RESONATOR FOR COAX & WAVEGUIDE
MICROWAVE EXAMPLES
TRANSDUCER FROM RECTANGULAR GUIDE TO COAX, WITH D–C GROUNDS CONNECTED
CIRCULAR 5–ARM HYBRID WITH PRINCIPAL COUPLING IN E–PLANE AND 1–ARM H COUPLING USING RECTANGULAR WAVEGUIDE
TRANSFORMER WITH D–C GROUNDS AND MODE SUPPRESSION BETWEEN 2 RECTANGULAR GUIDES
RESONATOR WITH MODE SUPPRESSION, COUPLED BY E–PLANE APERTURE TO GUIDED PATH AND BY LOOP TO COAX
TUNABLE RESONATOR WITH D–C GROUND, CONNECTED TO ELECTRON DEVICE AND ADJUSTABLY COUPLED BY E–PLANE APERTURE TO RECTANGULAR GUIDE
RESONANT MAGNETRON WITH COAXIAL OUTPUT
TRANSIT–TIME SPLIT–PLATE MAGNETRON WITH STABILIZING DEFLECTING ELECTRODES AND INTERNAL CIRCUIT
TUNABLE MAGNETRON, APERTURE–COUPLED
REFLEX KLYSTRON, INTEGRAL CAVITY, APERTURE–COUPLED
DOUBLE–CAVITY KLYSTRON, INTEGRAL CAVITY, PERMANENT EXTERNAL GANGED TUNING, LOOP COUPLING
TRANSMIT–RECEIVE (TR) TUBE, GAS–FILLED, TUNABLE, INTEGRAL CAVITY, APERTURE–COUPLED, WITH STARTER
MOTOR AND GENERATOR
MOT
GEN
MOTOR
GENERATOR
SERIES
SHUNT
SEPARATELY EXCITED
PAD
BALANCED
UNBALANCED
PATH
NO CONNECTION
CONNECTION
CONNECTIONS
CONDUCTIVE PATH
AIR OR SPACE PATH
SHIELDED SINGLE CONDUCTOR
2–CONDUCTOR CABLE, UNSHIELDED
2–COND CABLE WITH GROUNDED SHIELD
TERMINAL
PERMANENT MAGNET
PM
PHONES
GENERAL
SINGLE
DOUBLE

FIG. 9-29*b*

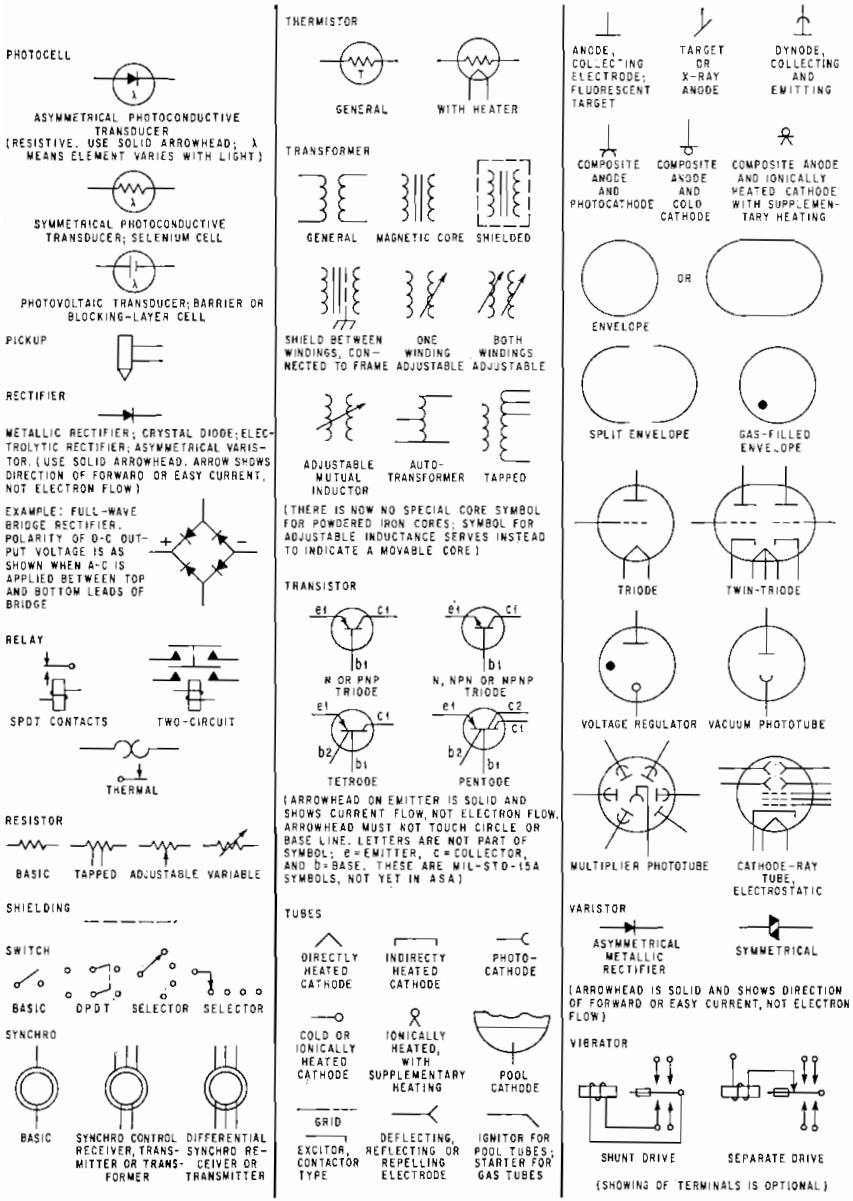

PHOTOCELL
ASYMMETRICAL PHOTOCONDUCTIVE TRANSDUCER (RESISTIVE. USE SOLID ARROWHEAD; λ MEANS ELEMENT VARIES WITH LIGHT)
SYMMETRICAL PHOTOCONDUCTIVE TRANSDUCER; SELENIUM CELL
PHOTOVOLTAIC TRANSDUCER; BARRIER OR BLOCKING-LAYER CELL
PICKUP
RECTIFIER
METALLIC RECTIFIER; CRYSTAL DIODE; ELECTROLYTIC RECTIFIER; ASYMMETRICAL VARISTOR. (USE SOLID ARROWHEAD. ARROW SHOWS DIRECTION OF FORWARD OR EASY CURRENT, NOT ELECTRON FLOW.)
EXAMPLE: FULL-WAVE BRIDGE RECTIFIER. POLARITY OF D-C OUTPUT VOLTAGE IS AS SHOWN WHEN A-C IS APPLIED BETWEEN TOP AND BOTTOM LEADS OF BRIDGE
RELAY
SPDT CONTACTS
TWO-CIRCUIT
THERMAL
RESISTOR
BASIC
TAPPED
ADJUSTABLE
VARIABLE
SHIELDING
SWITCH
BASIC
DPDT
SELECTOR
SELECTOR
SYNCHRO
BASIC
SYNCHRO CONTROL RECEIVER, TRANSMITTER OR TRANSFORMER
DIFFERENTIAL SYNCHRO RECEIVER OR TRANSMITTER
THERMISTOR
GENERAL
WITH HEATER
TRANSFORMER
GENERAL
MAGNETIC CORE
SHIELDED
SHIELD BETWEEN WINDINGS, CONNECTED TO FRAME
ONE WINDING ADJUSTABLE
BOTH WINDINGS ADJUSTABLE
ADJUSTABLE MUTUAL INDUCTOR
AUTO-TRANSFORMER
TAPPED
(THERE IS NOW NO SPECIAL CORE SYMBOL FOR POWDERED IRON CORES; SYMBOL FOR ADJUSTABLE INDUCTANCE SERVES INSTEAD TO INDICATE A MOVABLE CORE)
TRANSISTOR
P OR PNP TRIODE
N, NPN OR NPNP TRIODE
TETRODE
PENTODE
(ARROWHEAD ON EMITTER IS SOLID AND SHOWS CURRENT FLOW, NOT ELECTRON FLOW. ARROWHEAD MUST NOT TOUCH CIRCLE OR BASE LINE. LETTERS ARE NOT PART OF SYMBOL; e = EMITTER, c = COLLECTOR, AND b = BASE. THESE ARE MIL-STD-15A SYMBOLS, NOT YET IN ASA)
TUBES
DIRECTLY HEATED CATHODE
INDIRECTLY HEATED CATHODE
PHOTO-CATHODE
COLD OR IONICALLY HEATED CATHODE
IONICALLY HEATED, WITH SUPPLEMENTARY HEATING
POOL CATHODE
GRID
EXCITOR, CONTACTOR TYPE
DEFLECTING, REFLECTING OR REPELLING ELECTRODE
IGNITOR FOR POOL TUBES; STARTER FOR GAS TUBES
ANODE, COLLECTING ELECTRODE; FLUORESCENT TARGET
TARGET OR X-RAY ANODE
DYNODE, COLLECTING AND EMITTING
COMPOSITE ANODE AND PHOTOCATHODE
COMPOSITE ANODE AND COLD CATHODE
COMPOSITE ANODE AND IONICALLY HEATED CATHODE WITH SUPPLEMENTARY HEATING
OR
ENVELOPE
SPLIT ENVELOPE
GAS-FILLED ENVELOPE
TRIODE
TWIN-TRIODE
VOLTAGE REGULATOR
VACUUM PHOTOTUBE
MULTIPLIER PHOTOTUBE
CATHODE-RAY TUBE, ELECTROSTATIC
VARISTOR
ASYMMETRICAL METALLIC RECTIFIER
SYMMETRICAL
(ARROWHEAD IS SOLID AND SHOWS DIRECTION OF FORWARD OR EASY CURRENT, NOT ELECTRON FLOW)
VIBRATOR
SHUNT DRIVE
SEPARATE DRIVE
(SHOWING OF TERMINALS IS OPTIONAL)

FIG. 9-29*c*

Table 9-17. Standard Telephone-cable Color Code

Pair No.	*Color*	*Mate*	*Pair No.*	*Color*	*Mate*
1	Blue	White	26	Blue White	Red
2	Orange	White	27	Blue Orange	Red
3	Green	White	28	Blue Green	Red
4	Brown	White	29	Blue Brown	Red
5	Slate	White	30	Blue Slate	Red
6	Blue White	White	31	Orange White	Red
7	Blue Orange	White	32	Orange Green	Red
8	Blue Green	White	33	Orange Brown	Red
9	Blue Brown	White	34	Orange Slate	Red
10	Blue Slate	White	35	Green White	Red
11	Orange White	White	36	Green Brown	Red
12	Orange Green	White	37	Green Slate	Red
13	Orange Brown	White	38	Brown White	Red
14	Orange Slate	White	39	Brown Slate	Red
15	Green White	White	40	Slate White	Red
16	Green Brown	White	41	Blue	Black
17	Green Slate	White	42	Orange	Black
18	Brown White	White	43	Green	Black
19	Brown Slate	White	44	Brown	Black
20	Slate White	White	45	Slate	Black
21	Blue	Red	46	Blue White	Black
22	Orange	Red	47	Blue Orange	Black
23	Green	Red	48	Blue Green	Black
24	Brown	Red	49	Blue Brown	Black
25	Slate	Red	50	Blue Slate	Black

NOTE: The last pair in all cables is a red with white mate, viz.,

6-pair cable	6th pair	Red	White
11-pair cable	11th pair	Red	White
16-pair cable	16th pair	Red	White
26-pair cable	26th pair	Red	White
51-pair cable	51st pair	Red	White

RESISTOR COLOR CODE

The chart shown in Fig. 9-30*a* indicates the appropriate significant figure of resistance and the multiplier. The fourth colored band, if any, indicates the tolerance. If none is shown, the tolerance is 20 per cent, with other tolerances as follows: gold, 5 per cent; silver, 10 per cent.

CAPACITOR COLOR CODE

The value of capacitors is similarly shown by colored bands or dots as indicated in Figs. 9-30*a* and 9-30*b*. Note that the bands and dots (for disc ceramics) apply for the ceramic-type capacitors, while the various dot systems are applicable to mica- and paper-type condensers. The various systems that have been used in recent years are included, even though some of them are obsolete. The tolerances are indicated by the appropriate colored dot, and the voltage rating is obtained by multiplying the value of the appropriate dot by 100.

STANDARD COLOR CODE — RESISTORS AND CAPACITORS

INSULATED UNINSULATED COLOR	FIRST RING BODY COLOR FIRST FIGURE	SECOND RING END COLOR SECOND FIGURE	THIRD RING DOT COLOR MULTIPLIER
BLACK	0	0	NONE
BROWN	1	1	0
RED	2	2	00
ORANGE	3	3	,000
YELLOW	4	4	0,000
GREEN	5	5	00,000
BLUE	6	6	,000,000
VIOLET	7	7	0,000,000
GRAY	8	8	00,000,000
WHITE	9	9	000,000,000

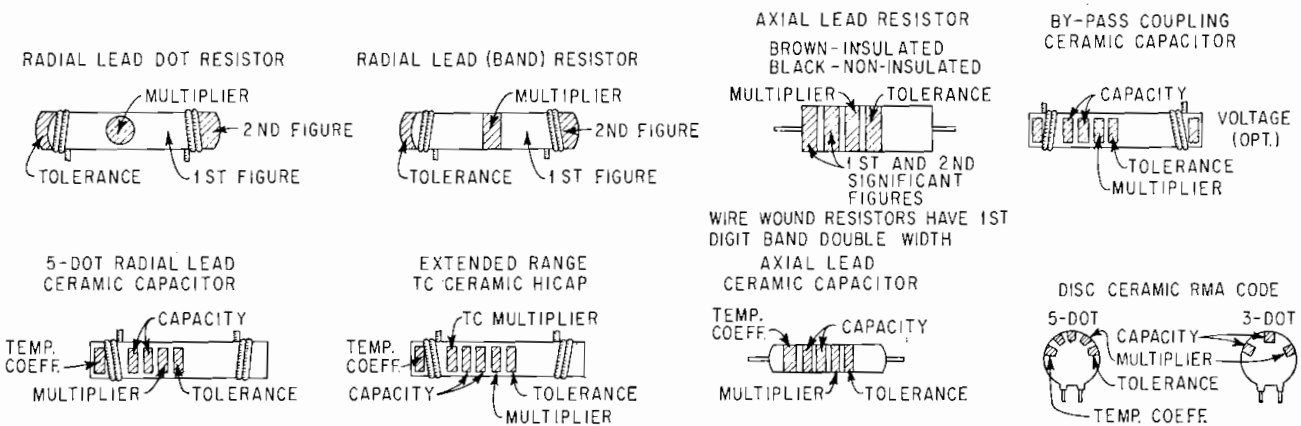


Fig. 9-30*a*. Standard color code—resistors and capacitors.

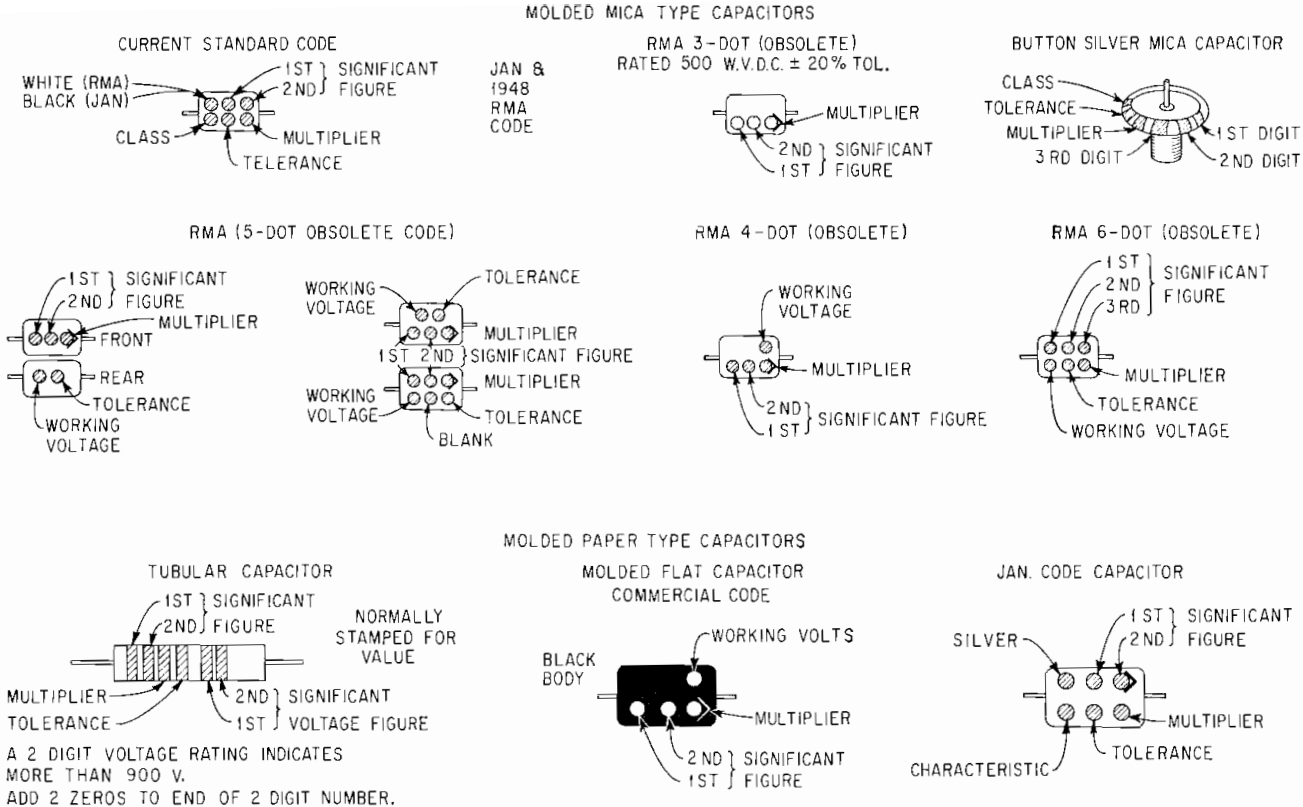


FIG. 9-30*b*. Standard color code.

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