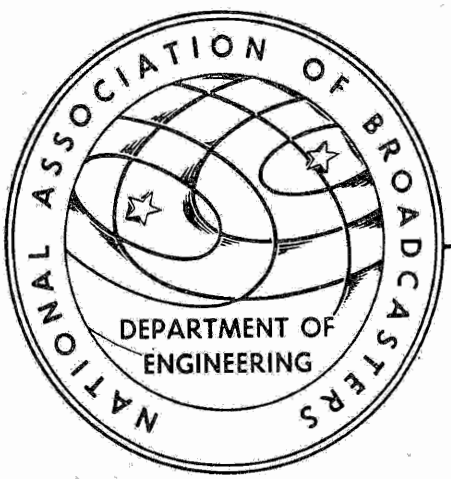
ENGINEERING HANDBOOK

NATL. ASSN. OF RADIO & TELEVISION BROADCASTERS



ENGINEERING HANDBOOK

NATIONAL ASSOCIATION OF BROADCASTERS

FOURTH EDITION • 1949

NATIONAL ASSOCIATION OF BROADCASTERS

1771 N STREET, NORTHWEST

WASHINGTON 6, D. C.

PREFACE

This the fourth edition of the NAB Engineering Handbook has been prepared by the Department of Engineering as a Member Service. Of the more than 650 pages included at time of release, 600 pages contain new or revised material. Those few sections reprinted from the third edition have been carefully revised or enlarged, where appropriate.

All information presented herein has been selected and prepared with two objectives in mind:

1) to present articles and data of a practical working nature; and
2) to present material which, if studied and applied, will permit the economical and more efficient installation, operation and maintenance of broadcast stations.

Lengthy and highly scientific material of an academic nature has not been included, since such data is readily available elsewhere and does not, in general, provide information lending itself to practical application.

The Department of Engineering acknowledges the valuable assistance provided so freely in the preparation of this Handbook by engineers associated with individual stations, government agencies, networks, manufacturers, radio consulting firms, trade journals, other trade associations and professional societies.

The post-type binder provided will permit the future addition of supplements, which may consist either of new or revised material. Supplements will be supplied to NAB Members as a Member Service. Non NAB Members may obtain supplements at a cost of $1.00 each.

The Department of Engineering will welcome constructive criticism or comments on the format and contents of the Handbook and will welcome, in particular, the submission of new and original material for consideration as supplements.

Additional copies of the NAB Engineering Handbook, complete with post-type binder, may be obtained from NAB Headquarters at $17.50 each, postpaid within the Continental limits of the United States.

Neal McNaughten, Director
Department of Engineering

August 15, 1949

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Furnishes the student with a sound mathematical foundation and shows how to apply this knowledge to practical problems.

MATHEMATICS FOR ENGINEERS by Raymond W. Dull. New York City, McGraw-Hill, Second Edition 1941, 780 pages, 5-1/2 x 8, 686 illustrations, $5.50.

A quick, convenient and reliable reference and text book for engineers who wish to review or extend their information on those phases of mathematics especially important in engineering work.

MEASUREMENTS IN RADIO ENGINEERING by Frederick E. Terman. New York City, McGraw-Hill, 1935, 400 pages, 6 x 9, 208 illustrations, $4.50.

A comprehensive discussion of measurements problems encountered in engineering practice, with emphasis on basic principles.

PRINCIPLES OF ELECTRON TUBES by Herbert J. Reich. New York City, McGraw-Hill, 1941, 398 pages, 6 x 9, Illustrated, $4.00.

The theory, characteristics and applications of electron tubes and their circuits.

PRINCIPLES OF TELEVISION ENGINEERING by Donald G. Fink. New York City, McGraw-Hill, 1940, 541 pages, 6 x 9, 313 illustrations, $5.50. Revised printing to conform to 525-line standard issued July 1947.

Covers the television system from the camera to the viewing screen in the receiver, with descriptions of modern equipment.

RADIO AMATEUR'S HANDBOOK. West Hartford, Conn., American Radio Relay League, 1949, 118 pages, U. S. $2.00, Foreign $2.50.

This Handbook is recommended since it contains many parts which will be found to be useful by engineering personnel of broadcast stations.

RADIO ENGINEERING by Frederick E. Terman. New York City, McGraw-Hill, Third Edition 1947, 951 pages, 6 x 9, 672 illustrations, $7.00.

A comprehensive treatment covering all phases of radio communication, written from the viewpoint of the engineer who is interested not only in qualitative descriptions of radio phenomena, but also in making quantitative analyses for facilitating design and research.

RADIO ENGINEERS' HANDBOOK by Frederick E. Terman. New York City, McGraw-Hill, 1943, 1019 pages, 6 x 9, 869 illustrations, $7.00.

An exceptionally thorough and comprehensive reference book presenting a wealth of sound, technical information especially selected and organized to meet the needs of the engineer dealing with practical radio and electronic problems.

THE RADIO MANUAL by George E. Sterling. New York City, D. Van Nostrand, (to be published 1949), cost approximately $10. (Third Edition consisted of 1120 pages, $6.00).

A practical handbook, especially valuable to the commercial and broadcast operator, covering structure, installation, upkeep, operation and control of all forms of radio apparatus and equipment. The new edition will contain large areas of new material and illustrations.

REFERENCE DATA FOR RADIO ENGINEERS. New York City, Federal Telephone and Radio Corporation, Second Edition 1946, 336 pages, 5-1/2 x 8-1/2, 400 charts, $2.00.

A new and greatly revised edition is expected to be available the latter part of 1949. The second edition of this widely accepted, pocket-size handbook included important radio technical data developed during the War.

TELEVISION STANDARDS AND PRACTICE edited by Donald G. Fink with the cooperation of the National Television System Committee Editorial Advisory Board. New York City, McGraw-Hill, 1943, 405 pages, 6 x 9, 115 illustrations, $5.50.

An authoritative compilation of material on television consisting of abstracts from the Proceedings of the National Television System Committee.

VACUUM TUBES by Karl R. Spangenberg. New York City, McGraw-Hill, 1948, 600 pages, 6 x 9, Illustrated, $7.50.

An exceptionally comprehensive survey of all the physical laws which contribute to the understanding of vacuum tube behavior.

Publishers' Addresses:

American Radio Relay League
38 La Salle Road
West Hartford, Connecticut

Cleveland Institute of Radio Electronics
4900 Euclid Avenue
Cleveland 3, Ohio

Electronics Research Publishing Company
161 West 18th Street
New York, 11, New York

Federal Telephone & Radio Corp.
67 Broad Street
New York 4, New York

Illuminating Engineering Society
51 Madison Avenue
New York 10, New York

McGraw-Hill Book Co., Inc.
330 West 42nd Street
New York 18, New York

Murray Hill Books, Inc.
232 Madison Avenue
New York 16, New York

D. Van Nostrand Co., Inc.
250 Fourth Avenue
New York 3, New York

John Wiley & Sons, Inc.
440 Fourth Avenue
New York 16, New York

II. Periodicals *(listing yearly subscription rates)*

AUDIO ENGINEERING published monthly by Radio Magazines, Inc., 342 Madison Ave., New York City 17. $3.00 U. S.; $4.00 Foreign.

THE BELL SYSTEM TECHNICAL JOURNAL published quarterly by American Telephone & Telegraph Co., 195 Broadway, New York City. $1.50 U. S.; $1.85 Foreign.

THE B. B. C. QUARTERLY published quarterly by British Broadcasting Corporation. Can be purchased from B. B. C., 630 Fifth Ave., New York City 20. $4.00 U. S.

BROADCAST NEWS published bi-monthly by the Radio Corporation of America, Engineering Products Department, Camden, N. J., $2.00 U. S.

COMMUNICATIONS published monthly by Bryan Davis Publishing Co., Inc., 52 Vanderbilt Avenue, New York City 17. $2.00 U. S. and Canada; $3.00 Foreign.

ELECTRICAL COMMUNICATION published quarterly by International Telephone and Telegraph, 67 Broad Street, New York City 4. $2.00 U. S.

ELECTRICAL ENGINEERING published monthly by the American Institute of Electrical Engineers, 33 West 39th Street, New York City 18. *Available to AIEE Members only.*

ELECTRONICS published monthly by McGraw-Hill Publishing Co., Inc., 330 West 42nd St., New York City 18. $6.00 U. S.; $7.00 Canada; $15.00 Latin America; Other $20.00.

FM-TV published monthly by FM Company, 246 Main Street, Great Barrington, Mass. $3.00 U. S.; $4.00 Foreign.

PROCEEDINGS OF THE IRE published monthly by the Institute of Radio Engineers, Inc., 1 East 79th St., New York City 21. *Available to IRE Members only.*

QST published monthly by American Radio Relay League, Inc., 38 LaSalle Road, West Hartford, Conn., $4.00 U. S.

RCA REVIEW published quarterly by Radio Corporation of America, RCA Labs. Division, Princeton, N. J. $2.00 U. S., Canada and Postal Union; $2.40 Other.

TELE-TECH published monthly by Caldwell Clements, Inc., 480 Lexington Ave., New York City 17. $5.00 U. S. and Possessions; $6.00 Canada; $7.00 Pan America; $9.00 Other.

WESTINGHOUSE ENGINEER published bi-monthly by Westinghouse Electric Corp., 306 Fourth Ave., Pittsburgh 30, Pa. $2.00 U. S. and Possessions; $2.50 Canada; $2.25 Other.

III. Government Information Sources

FEDERAL REGISTER published daily (except Sundays, Mondays and days following official Federal Holidays). The Register, which is obtainable from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., $1.50 monthly or $15.00 yearly, publishes official actions with respect to Rules and Standards of the Federal Communications Commission.

RADIO PROPAGATION LABORATORY, National Bureau of Standards, Washington 25, D. C., will furnish on request a list of its reports.

SUPERINTENDENT OF DOCUMENTS, Government Printing Office, Washington 25, D. C., will furnish on request a list of publications of the FCC and other Government Agencies or Departments. Copies of wanted data may then be ordered from GPO.

IV. Institutes and Societies

Note:

Any inquiries regarding membership in or publications of the following organizations should be addressed direct to the organization.

Acoustical Society of America
120 S. LaSalle Street
Chicago 3, Illinois

American Institute of Electrical Engineers
33 West 79th Street
New York 21, New York (see ELECTRICAL ENGINEERING under Periodicals above)

American Radio Relay League, Inc.
38 LaSalle Road
West Hartford, Connecticut

Institute of Radio Engineers
One East 79th Street
New York 21, New York (see PROCEEDINGS OF THE IRE under Periodicals above)

Society of Motion Picture Engineers
342 Madison Avenue
New York 17, New York

STANDARDS OF GOOD ENGINEERING PRACTICE CONCERNING STANDARD BROADCAST STATIONS

(550-1600 kc.)

EFFECTIVE AUGUST 1, 1939

(Revised to July 15, 1949)*

INTRODUCTION

There are presented herein the Standards of Good Engineering Practice giving interpretations and further considerations concerning the Rules and Regulations of the Communications Commission governing standard broadcast stations. While the 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.

The Rules and Regulations contain references to these standards; however, as further standards may be issued after the Rules and Regulations are published, the absence of such references does not relieve the responsibility of meeting the requirements specified herein. The Standards of Good Engineering Practice are collected in this publication for the convenience of all considering broadcast station operation and problems.

The Standards of Good Engineering Practice 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.

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.

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.

These Standards of Good Engineering Practice 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.

*This reproduction is based upon the Standards revised by the Commission to October 30, 1947, but also includes the following FCC Amendments (which actually bring the Standards up to date as of July 15, 1949:

FCC Amendment No. SGEP-AM-1 (Sunrise and Sunset Tables, Section 26)
FCC Amendment No. SGEP-AM-2 (Use of Common Antenna)
FCC Amendment No. SGEP-3 (Ground Wave Signals)
FCC Amendment No. SGEP-4 (Canadian Conductivity Map)

As additional amendments are made they will be indicated or printed in NAB MEMBER SERVICE.

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STANDARDS OF GOOD ENGINEERING PRACTICE CONCERNING STANDARD BROADCAST STATIONS

(550–1600 kc.)

1. ENGINEERING STANDARDS OF ALLOCATION

Section 3.28 requires that individual broadcast station assignments shall be made in accordance with the standards of good engineering practice prescribed and published from time to time by the Commission. These standards for each class of station are set out below.

Sections 3.21 to 3.34, inclusive, govern the allocation of facilities in the standard broadcast band of 550 to 1600 kc, inclusive. 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 section 3.22. The classifications of the standard broadcast stations are as follows:

Class I stations are dominant stations operating on clear channels as follows:

(1) Class I stations operate 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 [1] 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.[2] [3]

(2) From an engineering point of view, Class I stations may be divided into two groups:

(*a*) The Class I stations in Group 1 are those assigned to the channels allocated by section 3.25, paragraph (*a*), on which 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 United States (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.[2] The power of each such Class I station shall not be less than 50 kw.

(*b*) The Class I stations in Group 2 are those assigned to the channels allocated by section 3.25, paragraph (*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 operation.[2] The operating powers of Class I stations on these frequencies shall be not less than 10 kw nor more than 50 kw.

Hereafter, for the purpose of convenience, the two groups of Class I stations will be termed Class Ia or Ib in accordance with the assignment to channels allocated by section 3.25 (*a*) or 3.25 (*b*).

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.

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[1] See section 3.11 for the definitions of primary and secondary service areas.

[2] See tables IV and V.

[3] 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.

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 Class I stations will not limit the service area to greater than the 2500 uv/m groundwave contour, which is the value for the mutual protection of this class of station with other stations of the same class.[2]

Class III stations operate on regional channels and normally render primary service to the metropolitan district and the rural area contained therein and contiguous thereto, and are subdivided into two classes:

(*a*) 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.[2]

(*b*) 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.[2]

[2] See tables IV and V.

[3a] The following approximate method may be used. It is based on the assumption of 0.25 wavelength antenna height and 88 mv/m at 1 mile effective field for 250 watts power, using the 10 percent skywave field intensity curve of Figure 1–A. Zones defined by circles of various radii specified below are drawn about the desired station and the interfering 10 percent skywave signal from each station in a given zone is considered to be the value tabulated below. The effective interfering 10 percent 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	.12
C	80	100	.14
D	100	250	.16
E	250	350	.14
F	350	450	.12
G	450	500	.10

Where the power of the interfering station is not 250 watts, the 10 percent skywave signal should be adjusted by the square root of the ratio of the power to 250 watts.

Class IV stations operate on local channels normally rendering primary service only to a city or town and the suburban and rural areas contiguous thereto with powers not less than 0.1 kw or more than 0.25 kw. These stations are normally protected to 500 uv/m groundwave contour daytime. On local channels the separation required for the daytime protection shall also determine the nighttime separation. The actual nighttime limitation will be calculated.[3a] Class IV stations may be assigned to regional channels on condition that interference will not be caused to any Class III station in accordance with the above, that the channel is used adequately and properly for Class III stations[4], and that the Class IV station will be subject to such interference as may be received from the Class III stations. That is, the Class IV station assigned to a regional channel shall protect the Class III station to the required contour, but the Class III station is under no obligation to protect the Class IV station so assigned. However, it is recommended that the Class IV stations be so located that the interference received will not be greater than to the 4000 uv/m groundwave contour nighttime and 500 uv/m daytime.

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

[4] The assignment of a Class IV station to a regional channel normally is not considered as making the best usage of the assignment and will be made only when it is shown among other things that—

(1) There are no other transmission facilities in the town or towns in the proposed service area.

(2) There is no local channel assignment available for that area.

(3) Adequate economic support is not available for a Class III station.

(4) It is not practical from an engineering point of view to establish a Class III station and it would not prevent the establishment of any Class III station on that channel or an adjacent channel.

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.

When it is shown that primary service is rendered by any of the above classes of stations, beyond the normally protected contour, and when primary service to approximately 90 percent 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.

A Class II, III–B or IV station may be assigned to a channel available for such class, when a need therefor is shown, even though objectionable interference will be received to a field intensity contour greater than that specified as the normally protected contour for its class, provided that no objectionable interference will be caused by it to existing stations, and provided further, that the population residing in the area between the normally protected contour for its class and the contour to which objectionable interference will be received, does not exceed approximately 10 percent of the population in its actual primary service area. In case the station is located in a metropolitan area, the interference-free contour shall include 90 percent of the population of the metropolitan area.

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.

Tables IV and V give a complete summary of the protected service contours and permissible interference signals for broadcast stations on the same and adjacent channels, respectively.

The several classes of broadcast stations have in general three service areas;[4a] namely, primary, secondary, and intermittent service areas.

[4a] See section 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.

The signals necessary to render the different types of service are listed below.

TABLE I.—*Primary service*

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 appendix I for curves showing distance to various ground wave field intensity contours for different frequency and ground conductivities and annex I.

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 [5] 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.

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.

[5] 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.

TABLE II

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 Table I.

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 Table I shall apply except as individual consideration may determine.

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.

SECONDARY SERVICE

Secondary service is delivered in the areas where the skywave for 50 percent or more of the time has a field intensity of 500 uv/m or greater.[6] 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.[7] Class I stations only are assigned on the basis of rendering secondary service.

INTERMITTENT SERVICE

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.

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.

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.

Objectionable interference from another broadcast station [8] 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.

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 percent of the RSS value of the higher signals already included.

The RSS value will not be considered to be increased when a new interfering signal is added which is less than 50 percent 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.

It is recognized that application of the above "50 percent 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

[6] The secondary service area of a Class Ia station should be considered as having this limit only for determination of service in comparison with other stations.

[7] 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.

[8] See footnote 6.

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.

In the cases where it is proposed to add a new interfering signal which is not less than 50 percent 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.

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 percent exclusion" method without regard to this alternate method of calculation.

Examples of RSS interference calculations:

1. 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 percent of 1.31 mv/m
2. 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 percent 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 percent of 1.21 mv/m the RSS value of the new signal and No. 1.

3. 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 percent 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 percent of 1.21 mv/m.

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 Table IV 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 Table IV.

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 groundwave 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 Table V.

For the purpose of calculating the presence and the degree of objectionable interference, stations of the several classes shall be assumed, in the absence of actual measurements or data on the design of the antenna system, to pro-

duce effective fields, for 1 kw of input power to the antenna, as follows:

TABLE III

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, in the absence of actual interference measurements, 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.[9]

The existence or absence of objectionable interference from stations on the same or adjacent channels shall be determined by one of the following methods:

(*a*) By actual measurements made according to the method hereafter described;

or, in the absence of such measurements:

(*b*) By reference to the propagation curves in Figure 1 or Figure 1–A and Appendix I.

The existence or absence of objectionable interference may be proved by field intensity measurements or recordings made with suitable apparatus, duly calibrated. Such field intensity measurements of skywave shall be made for a period of time not less than 10 days and an adequate check shall be made on the skywave signal of other stations to determine the general conditions of propagation while such measurements are taken.[10] In computing the fifty (50) percent skywave field intensity values of a Class I station of a given power and also in computing the ten (10) percent skywave field intensity of an alleged interfering Class I or Class II station on a clear channel, use shall be made of the appropriate graph set forth in figure 1 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 on the horizontal plane from a 0.311λ antenna. In computing the ten (10) percent skywave field intensity of an alleged interfering station, other than Class I or Class II, at a specified distance, use shall be made of the appropriate curve in Figure 1-A 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, only for regional and local channels at the present time.[11] Adoption of revised skywave curves for use on clear channels will await the outcome of the Clear Channel Hearing (Docket No. 6741) and the negotiations for a new North American Regional Broadcasting Agreement.

The distance to any specified groundwave field intensity contour may be determined from appropriate groundwave curves plotted for the frequency under consideration and the conductivity and dielectric constant of the earth between the station and desired contour. The frequency and the conductivity of the earth must be considered in every case and where the distance is great, due allowance must be made for loss due to curvature of the earth. Figure 2 entitled "Groundwave Field Intensity," drawn for a frequency of 1000 kc, conductivity of 10^{-13} dielectric constant 15, and an effective field of 100 mv/m at 1 mile, may be employed when applicable.

[9] See annex II for further discussion and solution of a typical directional antenna case.

[10] See annex III for detailed requirements and also section on "Field Intensity Measurements in Allocation."

[11] The Commission will not authorize a directive antenna for a Class VI station assigned a local channel.

TABLE IV.—*Protected service contours and permissible interference signals for broadcast stations*

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 [4]
Ia	Clear	50 kw	SC 100 uv/m AC 500 uv/m	Not duplicated	5 uv/m	Not duplicated.
Ib	do	10 kw to 50 kw	SC 100 uv/m AC 500 uv/m	500 uv/m (50 percent sky wave).	5 uv/m	25 uv/m
II	do	0.25 kw to 50 kw	500 uv/m	2500 uv/m [5] (groundwave)	25 uv/m	125 uv/m [5]
III-A	Regional	1 kw to 5 kw	500 uv/m	2500 uv/m (groundwave)	25 uv/m	125 uv/m
III-B	do	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 [6]	0.1 kw to 0.25 kw	500 uv/m	4000 uv/m (groundwave)	25 uv/m	200 uv/m

[1] When it is shown that primary service is rendered by any of the above classes of stations, beyond the normally protected contour, and when primary service to approximately 90 percent 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, the contour to which protection may be afforded in such cases will be determined from the individual merits of the case under consideration. 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 Table V.

[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 Ib, 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 Ib stations will not exceed these values. If the Class II stations are limited by Class Ib stations to higher values, then such values shall be the established standard with respect to protection from all other stations.

[6] Class IV stations may also be assigned to regional channels according to section 3.29.

SC=Same channel.
AC=Adjacent channel.

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.

TABLE V.—*Interference ratios*

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] See footnote 3, p. 1.

From the above, it is apparent that in many cases stations operating on channels 10 and 20 kc apart may be operated with antenna systems side by side or otherwise in proximity without any indications of interference if the interference is defined only in terms of permissible ratios hereinbefore listed in Table V headed "Interference Ratios." 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 kc apart.

Accordingly, no station will be licensed for operation with less than 40 kc separation from another station, if the area enclosed by the 25 mv/m groundwave contours of the two stations overlap. Frequency separation of 20 kc and 10 kc are considered inappropriate for stations with the same general urban coverage and therefore no station will be licensed for operation with less than 30 kc frequency separation 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.

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.

Two stations operating with synchronized carriers [12] and carrying the identical program

[12] 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.

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.

ANNEX I

GROUNDWAVE SIGNALS

Interference that may be caused by a proposed assignment or an existing assignment during day time should always 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 Figure 4, interpolated for the desired frequency.

In determining the interference from field intensity measurements, two general steps are necessary: First, establish the outer boundary of the protected service area of the desired station in the direction of the station that may cause interference with it. Second, at this boundary, measure the interfering signal from the undesired station. The ratio of the desired to the undesired signal given on page seven should be applied to the measured signals and if the required ratio is observed, then no interference is contemplated. The effective field of the antenna in the pertinent directions of the stations must be established and all measurements must be made in accordance with the section on "Field Intensity Measurements in Allocation."

In all cases where measurements taken in accordance with the requirements are not available,[13] the groundwave intensity must be determined by means of the conductivity of the terrain 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, or in case such measurements are not available, then conductivity must be taken from the map of ground conductivity in the United States, Figure 3. This map shows the conductivity throughout the entire United States by general areas of reasonably uniform conductivity. In areas of limited size, or over a particular path, the conductivity may vary widely from the values given. This map is to be used only when accurate and acceptable measurements have not been made. Figure 3a is a similar map of ground conductivity in Canada prepared by the Canadian Department of Transport. It is considered to supercede Figure 3 as regards conductivity within the boundary of Canada. It is to be noted that at some locations there are differences in conductivity on either side of the border, which cannot be explained by geophysical cleavages. Pending adjustment in the maps for inconsistencies, all variations at the border will be treated as real.

Where a signal traverses a path over which different conductivities are shown to exist or are given by the map, 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. The technique is not intended to be used as a means of evaluating unattenuated field or ground conductivity by the analysis of measured data. The technique to be used for such determinations is given in section 2 of these Standards.

[13] The Commission will *not* authorize operation on a proposed assignment for the purpose of making measurements.

As an example of the use of the equivalent distance method suppose on a frequency of 1000kc an unattenuated field of 100 mv/m at one mile is radiated and that over a path having a conductivity of 10×10^{-14} e. m. u. for a distance 15 miles, 5×10^{-14} e. m. u. for the next 20 miles and 15×10^{-14} e. m. u. thereafter, it is desired to determine the distance to the 0.5 mv/m and 0.025 mv/m contours. By the use of the appropriate curves in figure 4 it is seen that at a distance of 15 miles on the curve labeled 10×10^{-14} e. m. u. the field is 3.45 mv/m. The equivalent distance to this field intensity for a conductivity of 5×10^{-14} e. m. u. 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 + 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 15×10^{-14} e. m. u. and from this curve the equivalent distance is determined to be 58 miles which is 27 miles more distant than would obtain had a conductivity of 5×10^{-14} e. m. u. prevailed. Using now the curve representing the conductivity of 15×10^{-14} e. m. u. 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 so that the actual distance to the 0.025 mv/m contour is determined to be 149 miles (172-23 miles).

Figure 4 gives the groundwave field intensity curves with field intensity plotted against distance for various values of conductivity and by blocks of frequencies. To cover the standard broadcast band some 20 graphs in all are required and are attached as Appendix I. In all cases the curves are plotted on the basis of 100 mv/m effective field at a mile. An example of determining the interference by this method follows:

It is desired to find the interference that a 5 kw Class III station on 990 kc may cause to a 1 kw class III station on 1000 kc. The stations are separated by 130 miles. It is assumed that both stations use nondirectional antennas [15] having such height as to produce an effective field for 1 kw of 175 mv/m.[16] From Figure 3, the conductivity at each station and intervening terrain is determined as 6×10^{-14}. The protection to Class III 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

[15] See Annex II in case of use of directional antennas.

[16] In all cases the effective field should be established from the dimensions of the radiating system. The value assumed here is in accordance with section 3.45 and the Standards of Good Engineering Practice promulgated pursuant thereto.

curves in Figure 4 as being 39.5 miles. Since these curves are 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 on the appropriate curve to the

$$\left(\frac{100\times500}{175}=285\right)$$

285 uv/m contour. Thus, the estimated radius of the service area for the desired station is established as 39.5 miles. Subtract this distance from the distance between the two stations, leaving 90.5 miles for the interfering signal to travel. Again from the appropriate curve in Figure 4 it is found that the signal from the 5 kw station at this distance would be 158 uv/m. Since the stations are separated by 10 kc, the undesired signal at that point can have a value up to 500 uv/m without interference, but if the interference signal had been found to be greater than this value, then interference would have been determined. For other channel separations the appropriate ratio of desired to undesired signal would have been used. This principle holds for all cases except where a skywave signal 10 percent or more of the time from the undesired station is in excess of 5 times the desired signal when the frequency separation is 10 kc. In this case the interference must be estimated on the basis of the skywave interference and the propagation curve in Figure 1 or Figure 1–A used to determine the interfering signals rather than Figure 4 for the groundwave signals.

Annex II

Computation on interfering signal from a directional antenna

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 apply these values to the groundwave curves set out in Annex I.

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 is predicated, it is necessary to compare the appropriate vectors in the vertical plane.

The skywave curves entitled "Average Skywave Field Intensity" (corresponding to the second hour after sunset at the recording station) as shown in Figure 1 are based on antenna systems having height of 0.311 wavelength (112°) and producing a vertical pattern as shown in Figure 5. 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 wavelength antenna having the same field intensity at the critical angle as does the pattern of the antenna involved. Example:

Figure 6 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 pattern as shown in Figure 5 and producing the same field intensity at 1 mile in the horizontal plane, the interfering signal would be 1.3 times that determined from Figure 1 for an antenna having the same field intensity in the horizontal plane. That is, if the field intensity in 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

$$140\times1.30\times\frac{124}{100}\text{ or }225\text{ uv/m}$$

and would cause interference to the 4.5 mv/m groundwave contour of the existing station.

For signals from stations on regional and local channels, in computing the ten (10) percent skywave (interference) field intensity values of

Class III and Class IV stations,[17] Figure 1–A is to be used in place of Figure 1. Since Figure 1–A is predicated upon a radiated field of 100 mv/m at 1 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 ten (10) percent skywave field intensity determined from Figure 1–A. 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.

Figure 1–A, "10 percent Skywave Signal Range Chart," shows the ten (10) percent 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° N. and latitude 50° should be used in case the midpoint of the path lies above 50° N.

Figure 6–A, 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 ten (10) percent skywave field intensity determined from Figure 1–A. (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.)

[17] Certain simplifying assumptions may be made in the case of Class IV stations on local channels: See footnote 3a.

In the case of nondirectional vertical antennas, the vertical distribution of relative fields for several heights, assuming sinusoidal distribution of current along the antenna, is shown in Figure 5. 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. The ratio of the largest value of radiated field occurring between these angles, to 100 mv/m (for which Figure 1–A is drawn) is then used as the multiplying factor for the value of the field read from the curves of Figure 1–A. 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.

For 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, Calif., which is radiating a signal of 560 mv/m unattenuated at 1 mile in the great circle direction of Portland, using a 0.5 wavelength antenna. The distance is 825 miles. From Figure 6–A the upper and lower pertinent angles are 7° and 3.5° and, from Figure 5 the maximum radiation within these angles is 99 percent of the horizontal radiation or 554 mv/m at 1 mile. The latitude of the path is 39.8° N. and from Figure 1–A, the 10 percent 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.

When the distance is large, more than one reflection may be involved and due considera-

tion 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.

Annex III

Interference from skywave signals

Set out below is the detailed method of making measurements of the skywave signals to determine an interfering signal for 10 percent of the time.

The signal must be received on an acceptable field intensity meter duly calibrated and recorded on a continuous recording meter of suitable accuracy and sensitivity. Measurements at distances less than 350 miles from the station should be made with a vertical antenna only. At greater distances either a vertical antenna, loop, or other suitable antenna may be used. Two complete recording units are required so that two signals can be recorded simultaneously.

A monitor station on which interference free measurements can be made must be selected for simultaneous recordings. This station should be in the general direction of the principal station to be recorded. Preferably, such monitor station should have known antenna characteristics and the conductivity of the surrounding terrain should be known. The transmitters should be located in the same general area and the frequencies of the stations as close as possible. The reception of the two stations should be on the same antenna or on antennas in the same area so that both are influenced by the same surrounding objects.

Recordings may be made on both stations from sundown over the entire path until midnight at the recording station. These records should be analyzed for each night and for the entire period of recording and graphs drawn which show field intensity versus percent time. The 10 percent signal determined for the principal station for the entire period must be modified by a correction factor determined from a comparison of the 10 percent signal from the monitor station to the value determined from the 10 percent curve of Figure 1 for the same distance, power, and pertinent antenna characteristic. Thus, if the 10 percent signal from the Figure 1 10 percent curve is 500 uv/m and the measured 10 percent signal on the monitor station 350 uv/m, then the 10 percent signal from the principal station should be multiplied by the factor of 500/350 or 1.43 to determine the interfering signal. Recordings for at least 10 nights are required. If it is not practical to follow this procedure, due to interference to the reception of the principal station recorded, the following procedure is required:

Record the monitor station and the principal station during the earliest hour that the principal station can be recorded. The measurements must be for at least 1 continuous hour each night and preferably not less than 2 hours each night. In all cases the monitor station must be recorded simultaneously. These measurements must be taken for at least 10 nights. Establish the 10 percent value of the fields during the period when both are measured. The 10 percent value of the field for the principal station must be corrected in the following manner:

Compare the 10 percent value of the signal for the monitor station with the 10 percent value determined from Figure 1 for the same distance reduced to the same power for comparable radiation at the appropriate angle. Thus, if the 10 percent signal from the Figure 1 10 percent curve is 500 uv/m and the measured 10 percent signal on the monitor station is 400 uv/m then the 10 percent signal from the principal station should be multiplied by the correction factor of 500/400 or 1.25. The value obtained in this way is to be considered the interference value of signals for use in all allocation problems.

When it is claimed that the propagation over the path involved is normally less than the average, measurements must be made on two or more other stations of different paths for at least 30 days and the signals of all stations involved recorded in the above manner to establish that propagation conditions in general were normal and that the path under consideration was low as claimed due to some natural conditions. A full explanation of the theory or practical findings must be made.

In all other cases where the signal is substantially greater or less than the average determined from Figure 1, complete informa-

tion must be supplied as to why the signal measured has departed from the average. If the reason for this condition is based on the location of the antenna, its characteristics, the conductivity of the surrounding area or other natural limitations, a full explanation of the nature and character of such conditions must be supplied and also information as to whether the licensee could, by moving its station or by making other changes within its control, alter the situation so that the abnormal condition of propagation would no longer exist.

The interference signal determined by the above methods should be used to determine interference to a station in the same manner as the groundwave signals were employed, as set out in Annex I. These methods of measurement should be used to determine skywave service signal for 50 percent of the time.

2. FIELD INTENSITY MEASUREMENTS IN ALLOCATION

A. Field Intensity Measurements to Establish Effective Field Intensity at 1 Mile

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:

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.[18]

These data should be plotted for each radial in accordance with either of the two methods set forth below:

(1) Using log-log coordinate paper, plot field intensities as ordinate and distance as abscissa.

(2) Using semi-log coordinate paper, plot field intensity times distance as ordinate on the log scale and distance as abscissa on the linear scale.

However, regardless of which of these methods is employed, the proper curve to be drawn through the points plotted shall be determined by comparison with theoretical curves as follows: Plot theoretical curves (see paper by Mr. K. A. Norton, October 1936, Proc. I. R. E.) for several values of conductivities and dielectric constants, approximating the conductivity and dielectric constants indicated by the measurements on another sheet of the same coordinate paper. Place this sheet over the sheet on which the actual points have been plotted, 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.

When all radials have been analyzed in this manner, a curve shall be plotted on polar coordinate paper from the fields obtained, which

[18] 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.

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 section 3.16.)

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.[19]

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 (see subsection B 5 *a*, *b*, and *c*).

(6) Antenna resistance measurement:

a. Antenna resistance at operating frequency.

b. Description of method employed.

c. Tabulation of complete data.

d. 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.

[19] See section 3.54 and "Further Requirements for Direct Measurement of Power" and "Indicating Instruments Pursuant to Section 3.58."

(9) Name, address, and qualifications of the engineer making the measurements.

(10) Any other pertinent information.

B. Field Intensity Measurements to Establish Performance of Directional Antennas

Section 3.33 (*b*) requires that proof of performance of directional antenna systems be submitted before any operation during the regular broadcast day may be permitted. These data shall be taken upon proper request and authorization therefor during the experimental period, and shall show that the pattern obtained 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.

To establish this performance, measurements shall be made in accordance with the preceding section A along sufficient number of radials to establish the effective field from the antenna system. In the case of a relatively simple directional antenna pattern, approximately eight radials in addition to the radials in the directions the field intensity values are specified by the authorization 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 additional radials as necessary to establish the pattern definitely.

In cases where the authorization requires a showing that actual field intensities of specified values be obtained in the various portions of the service area, sufficient measurements throughout these areas shall be made to show that at least the values specified are obtained. (See paragraph 2*d* of this section.)

In either of the above cases the following information shall be submitted in triplicate, even though such information was submitted with the original application:

(1) Complete description of antenna array.

a. Number of elements.

b. Manufacturer's name and type of each element (i. e., guyed or self-supporting, triangular or square, uniform cross-section or tapered, etc.).

c. If top loaded, give details.

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

e. Over-all height in feet of each element above ground level.

f. Over-all height in feet of each element above mean sea level.

g. Orientation of array with respect to true north and time (specify degrees leading or lagging) and space phasing of elements. (Space phasing should be given in feet as well as in degrees.)

h. Details of ground system for each element (length and number of radials, dimensions of ground screen, if used, and depth buried).

i. Current in each element (at point where antenna ammeter is located) and current and resistance at point of common input to the antenna system.[20]

j. Schematic sketch and description of method of feeding power to elements, including phasing and coupling equipment and locations of antenna ammeters (both regular, point of common input, and remote) in the circuits.

k. If not fully described above, give complete details and sketches if needed.

l. Full description of painting and lighting installed on each element.

m. If phase monitor is employed, state phase readings (specifying whether leading or lagging) and ratio of current indications for each element.[21]

(2) Horizontal field intensity patterns for each power involved showing:

a. Directional field intensity at 1 mile and effective field intensity from the antenna determined from the field intensity measurements as set forth above.

b. Direction true north shall be shown at zero azimuth.

c. Direction of each station or city specified in the instrument of authorization in which direction a limiting field was specified and the actual field intensity obtained in each of such directions (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 $\frac{1}{2,500,000}$ or map of equal accuracy. These may be obtained from the United States Coast and Geodetic Survey and from the United States Department of Interior, Geological Survey, for the sums of 40 cents and $1, respectively).

d. Actual field intensity contours for 25, 10, and 5 mv/m and any other contours specified by the instrument of authorization on a map having the largest practical scale. These contours need not be shown for distances over 15 miles from the antenna except that the field intensity contours on the far sides of the business and residential areas of the city in which the main studio is located shall be shown. This does not waive the requirement for measurements at greater distance under A above.

(3) Complete tabulation of all data used in plotting the above patterns.

(4) Any other pertinent information.

(5) Plotting of field intensity patterns:

a. All patterns shall be plotted on standard letter-size polar coordinate paper (main engraving approximately 7″ x 10″).

b. All patterns shall be plotted to the largest scale possible on the paper specified in (*a*) above, using divisions and subdivisions having values of 1, 2, 2.5, or 5 times 10^x. (No other values shall be used.)

c. All values of field intensity less than 10 percent of the r. m. s. field intensity of the pattern shall be shown on an enlarged scale in accordance with (*a* and *b*) above.

As a check on the shape of the field intensity pattern obtained in accordance with the above, it is suggested that measurements be taken on each of the radials at approximately 1 mile from the antenna system for operation, both directional and nondirectional, and the ratios of these values plotted on polar coordinate paper in accordance with the above specifications.

[20] See "Further Requirements for Direct Measurement of Power" and "Construction, General Operation, and Safety of Life Requirements."

[21] See "Indicating Instruments Pursuant to Section 3.58."

C. Measurement of the Field Intensity of Broadcast Stations for Presentation in Support of Applications or Evidence at Hearings Before the Commission

Section 3.24 requires that among other things an application for a new standard broadcast station or increase in facilities of an existing station make a satisfactory showing that objectionable interference will not be caused to an existing station or stations.

In the determination of such interference in accordance with section 3.28, actual measurements will take precedence over theoretical values provided such measurements are properly taken and presented.

When measurements of either groundwave signal intensity or skywave signal intensity are presented in evidence, they shall be supported by a field intensity survey of the station observed, which survey should be sufficiently complete in accordance with sections A and B above to determine the field at 1 mile in the pertinent directions for that station.

When measurements are made on skywave signal intensity (either service or interference) they shall be graphic recordings as follows:

(1) Recordings shall be made on 10 or more nights for sufficient periods each night to obtain reasonable average values.[22]

(2) Observations shall be made on other stations to determine whether skywave transmission conditions are normal or not.

(3) Scales on the graphic paper shall be such as to permit easy reading of both time and field intensity, and calibration shall be clearly indicated.

(4) Pertinent notes, such as predominance of signal of a certain station, when recording composite signals shall be made on the recording.

(5) Full description shall be given the point where recordings were made (geographically as well as field intensity of the station to which interference is being determined).

(6) Full explanation of to what extent signals from other stations on the same channel affected the accuracy of the recordings and what steps, if any, were taken to eliminate or compensate for such signals.

[22] See Annex III in section "Engineering Standards of Allocation" for detailed requirements.

If the observed station is owned or controlled by the party on whose behalf the measurements are made, then, in addition to the above, detailed reports on the measurement of the antenna resistance and on the amount of power actually radiated (as determined by the direct method) during the course of the field intensity measurements shall be presented. The applicant (or participant) shall also furnish a complete description of the antenna and ground system in use at the transmitting station during the period of observations and a statement as to whether or not this is the identical equipment regularly used by the station.

When measurements of both the "desired" and "undesired" station are made in one area to determine the point where objectionable interference from groundwave signals occurs, several measurements of each station shall be made within a few miles of the point where the ratio of signals is that selected as the appropriate ratio for the determination of objectionable interference.

All information on the above, including description and accuracy of equipment used, when and by whom last calibrated, and the name and qualifications of the engineer making the measurements, when filed with an application, shall be in affidavit form. At the time of the hearing on applications involving such observations, the applicant should be prepared to present, as sworn testimony, complete data on the above.

3. DATA REQUIRED WITH APPLICATIONS INVOLVING DIRECTIONAL ANTENNA SYSTEMS

Section 3.33 (a) requires that an application for authority to install a directional antenna specify a definite site and that full details of the directional antenna are given with the application. Any application not complete in these details will be returned to the applicant as "defective" under section 1.72.

In order to comply with the above and to permit proper consideration of any application involving a directional antenna, the following shall be submitted in triplicate, properly verified by the engineer designing the antenna, with each such application:

(1) Name, address, and qualifications of the engineer.

(2) Complete description of the proposed antenna system.

a. Number of elements.

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

c. If top loaded, give details.

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

e. Over-all height in feet of each element above ground level.

f. Over-all height in feet of each element above mean sea level.

g. Orientation of array with respect to true north and time phasing of fields from elements (specify degrees leading or lagging) and space phasing of elements (identifying elements). (Space phasing should be given in feet, as well as in degrees.)

h. Details of ground system for each element (length and number of radials, dimensions of ground screen, if used, and depth buried).

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

j. If not fully described above, give complete details and sketches if needed.

(3) Calculated horizontal field intensity patterns for each power involved showing:

a. Directional field intensity at 1 mile and effective field.

b. Direction true north shall be shown at zero azimuth.

c. Direction and distance to each existing station with which interference may be involved, operating either directional or nondirectional (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 $\frac{1}{2{,}500{,}000}$ 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, for the sums of 40 cents and $1, respectively).

d. Calculated field intensity contours for 250, 25, and 5 mv/m and the population residing within each of such contours in addition to the information required by section 29 (*d*) of F. C. C. Form 301, on a map having the largest practical scale.

(4) Calculated vertical field intensity patterns (for nighttime power) in the direction of each minimum and the maximum and in the direction of each station with which nighttime interference may be involved, operating either directional or nondirectional for angles from 0° to 90° above the ground plane, based on the groundwave field intensity at 1 mile from the antenna for the direction involved.

(5) Data used in computing the above patterns including:

a. Formula used for calculating both horizontal and vertical patterns, and sample calculations. (Derivation of formula if other than standard is used.)

b. All assumptions made and basis therefor, including electrical height, current distribution and efficiency of each element, and ground conductivities.

c. Complete tabulation of calculation data used in plotting patterns, including data for determination of r. m. s. value of horizontal and directional patterns.

(6) Any other pertinent information.

(7) Plotting of field intensity patterns:

a. All patterns shall be plotted on standard letter-size polar coordinate paper (main engraving approximately 7″ x 10″).

b. All patterns shall be plotted to the largest scale possible on the paper specified in section (*a*) above using scale divisions and subdivisions having values of 1, 2, 2.5, or 5 items 10^x. (No other values shall be used.)

c. All values of field intensity less than 10 percent of the effective field intensity of the pattern shall be shown on an enlarged scale in accordance with (*a* and *b*) above.

d. In the event actual inverse distance field intensities expected to be determined in practice (that is, the values determined from actual measurements particularly in sharp nulls) are different from the above calculated values, the expected values as well as the calculated values shall be shown on both the full patterns and the enlarged sections.

4. LOCATIONS OF TRANSMITTERS OF STANDARD BROADCAST STATIONS

Section 3.24 (*e*) requires that the location of the transmitter shall comply with the requirements of good engineering practice. There are set out below the general requirements considered appropriate at this time. These standards will change as the art progresses and changes will be made in accordance with the best information available.

All applications for approval of transmitter sites for regular broadcast stations must be submitted on F. C. C. Form 304. In some cases the applicant may be required to submit additional information, including the results of a field intensity survey, particularly where there is any question as to whether the area can be served properly from the proposed location or where the population of the blanket area is too large.

F. C. C. Form 304 requires among other things that triplicate copies of the following be submitted:

(*a*) Map or maps having reasonable scales (not less than one-half inch per mile) clearly showing:

(1) Proposed location and present location if existing station;

(2) The character of the surrounding areas, particularly the retail business, wholesale business, manufacturing, residential, and unpopulated areas (by symbols, cross-hatching, colored crayons, or other means);

(3) The density and distribution of population;

(4) The heights of all tall buildings or other structures in the vicinity of the antenna, indicating their location and how marked for air navigation;

(5) The location of airports, airways, and other radio stations, including receiving stations, except broadcast or amateur;

(6) The terrain and types of soil.

(*b*) Aerial photograph or photographs taken of the proposed location of the antenna showing clearly the character of the area within the 250 mv/m contour. (Ordinary photographs will be accepted if they clearly show the terrain to the 250 mv/m contour and are taken in at least eight directions from the site: north, northeast, east, etc.)

Where available, United States Geological Survey topography quadrangle sheets should be submitted. In the event the map submitted does not give the topography, the height above sea level of the proposed location, hills, ridges, and other obstructions should be shown. A statement as to whether or not other obstructions in the vicinity are painted and lighted or otherwise marked should always be made. In some cases additional maps, sketches, or descriptions may be necessary to show clearly the conditions. Attention is invited to the fact that the submission of complete and accurate information will materially expedite action on a proposed location, as well as enable the Commission to reach a correct decision thereon.

Aerial photographs of adequate scale are normally considerably superior to photographs taken from the proposed site. However, if the latter clearly show the character of the surrounding area, they are acceptable. Photographs taken from a location lower than the surrounding terrain or where the view is obstructed by immediately surrounding objects are of little value. Taking the photographs from a step ladder or other support will aid materially.

As a guide, the Engineering Department has established certain engineering principles based on the extensive experience of the Engineering Department and all data available along this line, including that presented at the informal engineering hearings of October 5, 1936, January 18, 1937, and June 6, 1938.

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.

The following table is offered as a general guide to be used in determining the approximate site of broadcast transmitters:

TABLE A

Power of station	Population of city or metropolitan area [1]	Approximate radius of blanket area 250 mv/m²	Site—distance from center of city (business or geographical)	Maximum percentage of total population in blanket area [1]
		Miles	*Miles*	*Percent*
100 w	5,000–50,000	0.15	½–1	1
100 w	50,000 or more	.15	[3]	
250–500 w	5,000–150,000	0.3– .5	1–3	1
250–500 w	150,000 or more	.3– .5	[3]	
1 kw	5,000 to 200,000	.6– .9	2–5	1
1 kw	200,000 or more	.6– .9	[3]	
5–10 kw	All	1.5–2.5	5–10	1
25–50 kw	All	3.0–4.5	10–15	1

[1] The total population is the population of the city sought to be served except in those instances when the station is to be located in an area classified by the Department of Commerce, Bureau of Census, as a metropolitan area, in which case the population of the metropolitan area shall apply: *Provided, however,* That when the power of the station is such that all the metropolitan area cannot be served, the population that will actually be served shall determine. The population figures are those determined by the latest official census and where greater population is claimed, the burden of proof is on the applicant.

[2] These radii are only approximate and the actual blanket area (area within the 250 mv/m contour) may be materially different depending on the antenna employed and other factors.

[3] In these instances it is usually necessary to locate the station within the city in order to render satisfactory service throughout the city. Such sites shall be in or near the center of the business district and under no circumstances will a site in the residential area be approved.

In case the power and the population of the city are such that it should be located at some distance from the center of the city, the approximate distance is given as well as the population of the so-called "blanket area." The "blanket area" of a broadcast station is defined as that area adjacent to the transmitter in which the usual broadcast receiver would be subject to some type of interference to the reception of other stations due to the strong signal from the station. The normal blanket area of a broadcast station is that area lying within the 250 mv/m contour line. The average radii of the blanket areas for broadcast stations of the various powers are given in the above table.

In those cases where it is impossible or impractical to locate a station in accordance with the above specifications, the Commission will give consideration to approving locations where not more than 1 percent of the population (as above specified) is included within the 500 mv/m contour, provided the applicant submits an affidavit setting forth the reasons why the normal specifications cannot be complied with, and further that the applicant will assume full responsibility for adjustment of any reasonable complaints arising from the excessively strong signals of the applicant's station. 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 between 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 tends 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.

Broadcast station transmitters will not be permitted to be located in these areas even though the population is within the requirements of Table A, unless the licensee assumes full responsibility for and it appears it can adjust all complaints satisfactorily.

If the city under consideration is of irregular shape, the station is of high power, a directional antenna system is employed, or if other unusual conditions obtain, the table may not apply and special consideration must be given. However, the general principles set out will still apply.

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.

If from Table A 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. The table gives the approximate distance from the center of the city. Three maps should be given consideration if available:

(1) Map of the density of population and number of people by sections in the area.

(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. (See Table B.)

From these maps a site should be selected that is approximately the required distance from the city, with a minimum population in the "blanket area" and 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.

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.

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.

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.

Table B indicates the values of inductivity and conductivity which it is recommended be used for various types of country in the absence of surveys over the particular area involved. Naturally, values obtained from the use of these figures will be only approximate and should, if possible, be replaced by actual measurements in the area under consideration.

TABLE B

Type of terrain	Inductivity	Conductivity	Absorption factor at 50 miles, 1000 kc.[1]
Sea water, minimum attenuation	81	4.64×10^{-11}	1.0
Pastoral, low hills, rich soil, typical of Dallas, Tex., Lincoln, Nebr., and Wolf Point, Mont., areas.	20	3×10^{-13}	0.50
Pastoral, low hills, rich soil, typical of Ohio and Illinois.	14	10^{-13}	0.17
Flat country, marshy, densely wooded, typical of Louisiana near Mississippi River.	12	7.5×10^{-14}	0.13
Pastoral, medium hills, and forestation, typical of Maryland, Pennsylvania, New York, exclusive of mountainous territory and sea coasts.	13	6×10^{-14}	0.09
Pastoral, medium hills, and forestation, heavy clay soil, typical of central Virginia.	13	4×10^{-14}	0.05
Rocky soil, steep hills, typical of New England.	14	2×10^{-14}	0.025
Sandy, dry, flat, typical of coastal country.	10	2×10^{-14}	0.024
City, industrial areas, average attenuation.	5	10^{-14}	0.011
City, industrial areas, maximum attenuation.	3	10^{-15}	0.003

[1] This figure is stated for comparison purposes in order to indicate at a glance which values of conductivity and inductivity represent the higher absorption. This figure is the ratio between field intensity obtained with the soil constants given and with no absorption.

Careful consideration must be given to selecting a site so that the number of people in the blanket area is a minimum. The last column of Table A gives the percentage of the total population of the city or metropolitan

area that may be permitted in the blanket area. 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 and at the same time maintain a minimum of people within the blanket area. 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.

Another factor to be considered is the relation of the site to airports and airways. There are no regulations or laws with respect to distance from airports and airways, but a distance of 3 miles from each is used as a guide. In case a suitable location is found at less distance than this, it may be satisfactory if the towers are suitably painted and lighted in conformity with the requirements of the Civil Aeronautics Administration, or if the towers are not higher than the surrounding objects. The latter is normally considered poor engineering practice; however, in selecting a site the local aeronautical authorities should always be consulted if there is any question concerning erecting a hazard to aviation, and in case of towers over 200 feet high this should always be done. In passing on a location and antenna installation, the Engineering Department refers each case to the Civil Aeronautics Administration for its recommendation. The action of the Administration will be materially expedited by the district airline inspector and local representatives of the airports and airlines forwarding their approval or comments to the Civil Aeronautics Administration, Washington, D. C.

In finally selecting the site, consideration must be given to the required space for erecting an efficient radiating system, including the ground or counterpoise (see section 3.45). 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.

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.

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 absorption 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 radius (250 mv/m) does not exceed that specified by Table A.

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.

5. MINIMUM ANTENNA HEIGHTS OR FIELD INTENSITY REQUIREMENTS

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.

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.

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 [23] that the present antenna system meets the mimimum requirements with respect to field intensity, before favorable consideration will be given thereto. 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.

These minimum actual physical vertical heights of antennas permitted to be installed are shown by curves A, B, and C of Figure 7 as follows:

A. Class IV stations, 150 feet [24] 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.

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.

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).

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 wavelength 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 wavelength in length and spaced 3° is considered an excellent ground system and in case of high base current, a base screen of suitable dimensions should be employed.)

It should be borne in mind that the above specifications are the minimum and where possible better antenna and ground systems should be installed.

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 [25] must be supplied to the Commission showing that the field intensity at a mile without absorption fulfills the minimum requirements. This field survey must be made by a qualified engineer using equipment of acceptable accuracy.

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 for operation on frequencies below 1000 kc., 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

[23] See Field Intensity Measurements in Broadcast Allocation, section A

[24] This height applies to a Class IV station on a local channel only. In case a Class IV station is assigned a regional channel Curve A shall apply.

[25] See Field Intensity Measurements in Broadcast Allocation, section A

by Figure 7 for operation on frequencies below 750 kc.

In all cases of new construction where concentric transmission line is used between the transmitter and antenna, such line shall be installed in duplicate with adequate switching facilities for immediate connection of the second line in case of failure of the first line, or permanently installed auxiliary facilities such as an auxiliary transmitter and antenna system, auxiliary antenna system or other means whereby operation may be continued in the event of failure of the transmission line.

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.

6. STANDARD LAMPS AND PAINTS

Section 3.45 (*d*) requires that 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.

These individual specifications are issued for and attached to each authorization for an installation.[26] The details of the specifications depend on the degree of hazard presented by the particular installation. The following standard lamps and paints shall be used for the type of marking specified:

(*a*) *Painting.*—Each tower shall be painted throughout its height with alternate horizontal bands of international orange and white, terminating with orange bands at both top and bottom. (Orange yellow No. 5 color card, supplement to U. S. Army Quartermaster Corps Specifications No. 3–1.) The width of the orange bands shall be approximately one-seventh of the height of any structure less than 250 feet in height, and between 30 and 40 feet for structures over 250 feet in height. The width of the white bands shall be one-half that of the orange bands.

(*b*) *Lighting.*—(1) Towers, the over-all heights of which do not exceed 200 feet, shall be lighted as follows:

At the top of each tower there shall be installed two 100-watt lamps, enclosed in aviation red prismatic obstruction light globes. At least one of these lamps shall burn continuously from sunset to sunrise. When only one lamp is operated, the circuit shall be equipped with a relay for instant automatic switchover to the other lamp in case of lamp failure.

[26] Specifications normally attached to authorization.

At both the one-third and two-thirds levels of each tower there shall be installed two 100-watt lamps enclosed in aviation red prismatic obstruction light globes, at each level, one each on diagonally opposite corners of the structure.

All 100-watt lamps shall be type A–21 clear bulb traffic signal lamps (2,000 hours or equal).

All lamps shall be enclosed in aviation red prismatic obstruction light globes, and all lighting shall be exhibited from sunset to sunrise.

* * * * *

Special conditions of terrain and location with respect to airports or airways may require additional lighting of the character hereinafter specified for towers the over-all height of which exceeds 200 feet.

* * * * *

(2) Towers, the over-all heights of which exceed 200 feet but do not exceed 300 feet, shall be lighted as follows:

At the top of each tower there shall be installed a hazard beacon similar and equal in effectiveness to the standard 300 m./m. airways electric lantern. This beacon shall flash and shall be equipped with two 500-watt lamps (both lamps to burn simultaneously) and aviation red color shades. The 300 m./m. electric code beacon shall be equipped with a flashing mechanism producing 40 flashes per minute, having a luminous period of 1 second, and a period of darkness of one-half second.

The one-third and two-thirds levels of the tower shall be marked by 100-watt obstruction lights the same as specified for towers not exceeding 200 feet in height.

* * * * *

Towers over 300 feet in height (and less than 300 feet in height where special conditions obtain) may be required to install additional marking as follows:

GENERAL

Under particularly hazardous conditions and in areas of heavy air traffic, it may be necessary to add a 24-inch, 500- or 1000-watt red rotating beacon equipped with an automatic lamp changer, to mark the installation. The beacon may be installed on the roof of the transmitter building, provided the point will afford proper visibility, otherwise it may be necessary to install the beacon on a separate tower of proper height or on the radio tower itself. The recommended setting of this rotating beacon is such that the center line of the light beam shall be approximately 3° above horizontal.

Adequate red warning lights shall be placed on the structure or structures during the period of construction and until the specified obstruction lights are installed and in operation.

Under certain conditions it may be required to have the lighting controlled by a light-sensitive control device, the adjustment being such that lights will be turned on at a north sky light intensity level of 20-foot candles and turned off at a north sky light intensity level of 40-foot candles.

Under certain conditions it may be required to install and operate a radio obstruction marker of a type to be specified.

Foregoing specifications require that at both the one-third and two-thirds levels of the structure there shall be installed two 100-watt lamps enclosed in aviation red prismatic obstruction light globes, at each level, one each on diagonally opposite corners of the structure.

Under certain conditions and in the case of triangular and other towers of unusual design, it may be required to install 100-watt lamps enclosed in aviation red prismatic obstruction light globes at various corners and levels throughout the height of the structure in such manner that adequate visibility and definition would be obtained from all angles of approach.

Towers of excessive height or peculiar (unusual) design will be made the subject of special investigation and analysis to determine proper marking and lighting.

In addition to the standard marking and lighting of the main structure, towers using guy wires will be made the subject of special study to determine proper marking and lighting of the guy wires.

The specifications relative to obstruction marking and lighting of radio towers of a certain height are general, and in locations of extreme hazard to air navigation, it may be required to install additional equipment on any height tower, in order to obtain suitable protection.

(*a*) Type A–21, 100-watt traffic signal, clear, medium screw base lamps enclosed in aviation red prismatic obstruction light globes shall be employed in all cases where 100-watt lamps are specified.

(*b*) Type PS–30, 200-watt general lighting service, clear, mogul prefocus base lamps shall be employed in all cases where code beacons with 200-watt lamps are specified.

(*c*) Type PS–40, 500-watt general lighting service, clear, mogul prefocus base lamps shall be employed in all cases where code beacons with 500-watt lamps are specified.

(*d*) Type T–24, 500-watt aviation lighting service, clear, mogul bi-post base lamps shall be employed in all cases where rotating beacons with 500-watt lamps are specified.

(*e*) Type T–20, 1000-watt aviation lighting service, clear, mogul bi-post base lamps shall be employed in all cases where rotating beacons with 1000-watt lamps are specified.

(*f*) The tower paint shall be kept in good condition and repainted as often as necessary to maintain this condition. Towers now painted black and yellow shall, when repainting is necessary, be painted in accordance with the present standards.[26]

7. FURTHER REQUIREMENTS FOR DIRECT MEASUREMENT OF POWER

Section 3.54 states that the antenna input power determined by direct measurement is the square of the antenna current times the antenna resistance at the point where the current is measured and at the operating frequency, and sets forth certain requirements relative to the determination of the resistance and measurement of the antenna current.

The Commission does not specify any particular method of making antenna resistance measurements. Measurements made by any standard method will be accepted, provided satisfactory evidence is submitted in accordance with the following as to the procedure used, accuracy of the instruments, and qualifications of the engineer conducting the measurements.

The resistance variation method, substitution method, and bridge method are acceptable methods for measuring the total antenna resistance and the following general instructions are given as a guide.

The apparatus required is as follows:

(*a*) Radio frequency generator to cover the frequency range necessary, power 50 watts or required power when using bridge method.

(*b*) Wavemeter for broadcasting frequency, accuracy 0.25 percent.

(*c*) Decade resistor having steps of units, tens, and hundreds ohms resistance, or equivalent, accuracy, 1.0 percent.

(*d*) Radio frequency galvanometer or milliammeter of approved type, accuracy 2.0 percent.

(*e*) Approved tuning condenser of approximately 0.001 MFD capacity and tuning inductance of approximately 60 MH.

(*f*) Or suitable bridge if this method is used.

The broadcast transmitter is not usually satisfactory for use as the source of radio frequencies. The maximum power dissipated in the antenna while making measurements should not be over 10 percent of the power available from the radio-frequency generator.

[26] Specifications normally attached to authorization.

An accurate determination of the antenna resistance can only be made by taking a series of measurements each for a different frequency. From 10 to 12 resistance measurements covering a band 50 to 60 kc. wide with the operating frequency near the middle of the band must be made to give data from which accurate results may be obtained. 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 intersects the operating frequency gives the value of the antenna resistance.

In order to comply with the provisions of section 3.54 the following data should be submitted in duplicate to the Commission in affidavit form, accompanied by duplicate copies of F. C. C. Form 306 properly executed:

(1) Complete data taken.

(2) The graph drawn.

(3) Description of method used to take readings (include schematic circuit diagrams of the measurement circuit and of the antenna system showing point of measurement and location in circuit of both regular and remote antenna ammeters).

(4) Manufacturer's name of each calibrated instrument used and manufacturer's rated accuracy.

(5) Accuracy, date and by whom each instrument was last calibrated.

(6) Qualifications of engineer making measurements.

Licensees of broadcast stations authorized to employ directional antenna systems desiring to determine the operating power by direct measurement of the antenna power shall determine the resistance by the following method:

Measure the resistance at the point of common radio frequency input to the directional antenna system. The following conditions and procedure shall obtain:

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

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

(*c*) Suitable radio-frequency bridge or other method shall be employed to determine the resistance and reactance at the point of common radio frequency input in the same manner as set forth above for a single antenna.

(*d*) 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 for a single-element antenna.

(*e*) A permanently installed antenna ammeter shall be placed in each element of the system as well as at the point of measurement of resistance, with the remote reading ammeters[27] located in the transmitter room. The application for authority to determine power by the direct method shall specify not only the current at the point of resistance measurement for the authorized input power (I^2R in accordance with section 3.54 and (*f*) below), but also the current of each element of the system when adjusted for the required pattern and for the authorized operating power.

(*f*) The license for a station of power of 5 kw. or under, which employs a directional antenna and determines the power by the direct method, will specify the antenna resistance as 92.5 percent of that determined at the point of common input in accordance with the above. The resistance specified for stations of a power over 5 kw. will be 95 percent of that determined at the point of common input.

8. POWER RATING OF VACUUM TUBES

Section 3.42 requires that 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. The approved power ratings of vacuum tubes for operation in the last radio stages of broadcast transmitters are fixed as set out in the following tables:

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[27] In all cases regular antenna ammeters and remote antenna ammeters shall comply with the requirements of section 3.58 and "Indicating Instruments Pursuant to Section 3.58."

TABLE A.[1]—*Power rating of vacuum tubes for high-level modulation or plate modulation in the last radio stage*

Power rating (watts)	Amperex	Collins	De-Forest	Eitel McCullough	Federal Telegraph	General Electric Co.	Heintz & Kaufman	Hygrade Sylvania	Machlett Labs.	R. C. A. Mfg. Co.	Raytheon Production Corp.	Sheldon Electric Co.	Taylor Tubes, Inc.	United Electronics	Western Electric	Westinghouse Electric & Mfg. Co.
50	----------	----------	----------	35-T 50-T	----------	GL-276-A	HK-54 158	----------	----------	808	RK-32 RK-35 RK-37 RK-47 RK-51 RK-52	35-T	T-40 T-55	----------	211-D 211-E 248-A 276-A	
75	HF-100 203-A 211 838 852 860	C-203-A C-211	503-A 511 552 560	----------	F-303-A F-311-A F-352-A	GL-203-A GL-211 GL-242-C GL-835 GL-838 GL-860	154	203-A 211 852 860	ML-203-A ML-211 ML-838	203-A 211 838 850 852 860	RK-58	----------	203-A 211	UE-100 203-A 211 261-A 303-A 311 361-A 838 852 938 952	242-A 242-B 242-C 260-A 261-A 284-A 295-A	WL-195 WL-196 WL-203-A WL-211 WL-469 WL-838 WL-850 WL-860
100	----------	----------	----------	100-TH 100-TL 75-T	F-102-A F-108-A	----------	152-L 254	----------	----------	----------	RK-36 RK-38 RK-48	100-TH	TW-75	----------	----------	WL-460 WL-468
125	HF-200 203-H 211-C 211-D 211-H 805 810 813	C-200 C-201 C-211-D	----------	150-T 4-125-A	F-123-A	GL-803 GL-805 GL-810	----------	----------	----------	4-125-A/4D21 803 805 810	RK-57 RK-28-A	----------	HD-203A T-125 TW-150 805	HV-18 805 810 905	----------	WL-463 WL-803 WL-805 WL-810
250	204-A HF-300 212-E	C-204-A C-300	504-A 561 571	4-250-A 152-TL 152-TH	F-127-A F-204-A F-212-E F-331-A	GL-204-A GL-806 GL-861	304-H 304-L 354 HK-354-A HK-354-C HK-354-D HK-354-E HK-354-F 454-H 454-L	204-A 212-D 831 861	ML-204-A	204-A 806 831 861	RK-63	----------	T-200 204-A 814 822	KU-23 204-A 212-E 304-A 312-E	212-D 212-E	WL-204-A WL-806 WL-861
350	270-A 849	----------	549	250-TH 250-TL 300-T	F-100-A F-849	GL-849	----------	849----	ML-849	849	----------	250-TH	----------	849 949	270-A	WL-849
500	251-A 833-A	----------	----------	304-TL 304-TH 450-TL 450-TH	----------	GL-833	255 654 854-H 854-L	----------	ML-833-A	833 833-A	----------	450-TH	----------	----------	251-A 357-A 357-B	WL-833 WL-833-A
750	279-A 849-A 849-H 851	C-849-A C-849-H	551	500-T	F-121-A F-351-A	GL-851	2054-A	851	ML-849-A ML-851	851	----------	----------	----------	949-A 949-H 851 951	279-A 379-A	WL-851
1000	846	----------	----------	750-TL 750-TH	F-128-A F-346-A	GL-846	1054-L 1554	846	ML-846	846	----------	----------	----------	846	----------	WL-846
2500	228-A 1652 HF-3000 ZB-3200	----------	520-B 520-M	1500-T	F-328-A F-328-B F-348 F-3652-A	GL-207 GL-889	3054	820-B	ML-889-A ML-889-RA ML-891-R	520-B 1652	----------	----------	----------	207	228-A	WL-473 WL-889-R

See footnote at end of table D.

TABLE A.[1]—*Power rating of vacuum tubes for high-level modulation or plate modulation in the last radio stage*—Continued

Power rating (watts)	Amperex	Collins	De-Forest	Eitel Mc-Cullough	Federal Telegraph	General Electric Co.	Heintz & Kaufman	Hygrade Sylvania	Machlett Labs.	R. C. A. Mfg. Co.	Raytheon Production Corp.	Sheldon Electric Co.	Taylor Tubes, Inc.	United Electronics	Western Electric	Westinghouse Electric & Mfg. Co.
5000	207 220-C 343-A 343-R 848 863 891 892 892-R	----	507 548 563	2000-T 3X2500A3 3X2500F3	F-126-A F-129-B F-129-R F-307-A F-320-A F-320-B F-343-A F-348-A F-363-A F-891 F-892 F-892-R	GL-891 GL-892 GL-892-R	----	207 848 863	ML-207 ML-891 ML-892 ML-892-R	207 848 863 891 892 892-R	----	----	----	----	220-B 220-C 343-A 220-CA 343-AA	WL-207 WL-891 WL-892 WL-892-R
10,000	232-B 342-A	----	----	----	F-101-B F-110-A F-110-X F-116-A F-131-A F-131-R F-328-B F-332-A F-332-B F-332-C F-342-A F-342-R F-358-A	GL-880 GL-893	----	----	ML-880 ML-893-A ML-893-AR	858 893-AR 839-R	----	----	----	----	232-A 232-B 232-BA 342-A	WL-858 WL-893 WL-893-R WL-899
25,000	----	----	----	3X12500A3	F-117-B F-124-A F-124-R 7C-30 9C-31	----	----	----	----	9C22	----	----	----	----	----	WL-880 WL-895-R
40,000	----	----	----	----	F-862 F-898	GL-862 GL-898	----	----	----	862 898	----	----	----	----	298-A	WL-862 WL-898
100,000	----	----	----	----	----	----	----	----	----	----	----	----	----	----	320-A	

TABLE B.[1]—*Power rating of vacuum tubes for low-level modulation or last radio stage operating as linear power amplifier*

Power rating (watts)	Amperex	Collins	De-Forest	Eitel Mc-Cullough	Federal Telegraph	General Electric Co.	Heintz & Kaufman	Hygrade Sylvania	Machlett Labs.	R. C. A. Mfg. Co.	Raytheon Production Corp.	Sheldon Electric Co.	Taylor Tubes, Inc.	United Electronics	Western Electric	Westinghouse Electric & Mfg. Co.
25	----	----	----	75-T	----	GL-203-A	154	----	ML-203-A	203-A	RK-32 RK-35 RK-37 RK-47 RK-51	----	T-55 TW-75 203-A 211 211-C	----	----	WL-203-A
50	HF-200 203-H 211-H 242-C	----	----	100-TH 100-TL 150-T 152-TH 152-TL	F-123-A	GL-242-C GL-803 GL-810	152-L HK-354 HK-354-A HK-354-C HK-354-D HK-354-E HK-354-F	----	----	803 806 810	RK-36 RK-38 RK-57 RK-58 RK-28-A RK-48	100-TH	T-125 TW-150 HD-203-A	----	242-B 242-C	WL-803 WL-810

1000, 5000 and 7500 cycles up to tenth harmonic or 16,000 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 1000 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 section 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 section 3.59.

a. The maximum temperature variation [31] at the crystal from the normal operating temperature shall not be greater than:

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

2. Plus or minus 1.0° C. when low temperature coefficient crystal [32] is employed.

b. 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.

[31] Explanations of excessive frequency deviations will not be accepted when temperature variations are in excess of the values specified below.

[32] See "Use of Low Temperature Coefficient Crystals by Broadcast Stations."

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

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

a. 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.

B. *Construction.*—In general, the transmitter shall be constructed either on racks and panels or in totally enclosed frames [33] protected as required by article 810 of the National Electrical Code [34] 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 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

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

[34] 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."

so as to prevent injury to operating personnel.

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

b. 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).

c. 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, section 3.46 does not apply.

d. 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. Lightning protection for the antenna system is not specifically required but should be installed.

e. 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.[35]

(4) Metering equipment:[36]

a. 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.)

b. 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 1000 volts above ground, no protective case is required. However, it is good practice to protect voltmeters subject to more than 5000 volts with suitable over-voltage protective devices across the instrument terminals in case the winding opens.

c. 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.

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[35] In all cases of new construction where a concentric transmission line is used between the transmitter and antenna, such line shall be installed in duplicate with adequate switching facilities for immediate connection of the second line in case of failure of the first line, or permanently installed auxiliary facilities such as an auxiliary transmitter and antenna system, auxiliary antenna system or other means whereby operation may be continued in the event of failure of the transmission line. It is also recommended that spare antenna and transmission line ammeters identical with those installed be kept on hand.

[36] In addition to the following requirements, instruments shall meet the requirements of section 3.58 and "Indicating Instruments Pursuant to Section 3.58."

ing 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).

(*i*) Remote reading antenna ammeters employing vacuum tube rectifiers are acceptable provided:

1. The indicating instruments shall meet all the above requirements for linear scale instruments.

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

3. The installation, calibration, and checking are in accordance with the above requirements.

(*j*) 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.

C. 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.

D. No instruments indicating the plate current or plate voltage of the last radio stage, the antenna current or the transmission line current when logged, in lieu of the antenna current, shall be changed or replaced without written authority of the Commission, except by instruments of the same make, type maximum scale readings, and accuracy. Requests for authority to change an instrument may be made by letter or telegram giving the manufacturer's name, type number, serial number and full scale reading of the proposed instrument and the values of current or voltage the instrument will be employed to indicate. Requests for temporary authority to operate without an instrument or with a substitute instrument may be made by letter or telegram stating the necessity therefor and the period involved.

E. 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 recalibrated 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.

F. 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.

G. 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.

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

14. REQUIREMENTS FOR TYPE APPROVAL OF BROADCAST TRANSMITTERS AND AUTOMATIC FREQUENCY CONTROL EQUIPMENTS

Sections 3.41 to 3.64 govern the design, construction, and technical operation of standard broadcast equipment. In order to facilitate

filing of and action on applications for construction permits specifying equipment of standard manufacture, the Commission will approve, as complying with the technical requirements, such equipment by type, subject to the following conditions and in accordance with the following procedure:

(*a*) Approval of equipment by the Commission is only to the effect that insofar as can be determined from the data supplied the equipment complies with the current requirements of good engineering practice and the technical Rules and Regulations of the Commission. The approval may be withdrawn upon subsequent inspection or operation showing the equipment is not as represented or does not comply with the technical Rules and Regulations of the Commission and the requirements of good engineering practice.

(*b*) Such approval shall not be construed to mean that the equipment will be satisfactory as the state of the art progresses and/or as the Rules and Regulations of the Commission may be changed as deemed advisable.

(*c*) Applicants specifying equipment of approved manufacture need not submit detailed descriptions and diagrams where the correct type number is specified, provided the equipment, including the antenna tuning unit, is identical with that approved.

(*d*) In passing on equipment, no consideration is given by the Commission to patent rights.

(*e*) For approval of standard broadcast transmitters, manufacturers shall submit F. C. C. Form 301, completed with respect to all pertinent sections and the data set forth below, both of which shall be verified before a notary public.

1. Photograph or drawings or any other evidence that construction is in accordance with the requirements of good engineering practice.

2. Data and curves showing over-all audio frequency response from 30 to 7500 cycles for approximately 25-, 50-, 85-, and 100- (if obtainable) percent modulation (reference frequency, 1000 cycles).

3. Data on audio frequency harmonics for 25-, 50-, 85-, and 100-percent modulation for the fundamental frequencies of 50, 100, 400, 1000, 5000, and 7500 cycles (either arithmetical sum or root-sum-square values up to tenth harmonic or 16,000 cycles).

4. Percentage carrier shift (current) for 25-, 50-, 85-, and 100-percent modulation.

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

6. Percentage of each measurable radio frequency harmonic generated under expected normal operating conditions or in the first installation.

7. How output power is varied to compensate for power supply voltage variations.

8. Data and curves on frequency stability for variations in ambient temperatures over the range encountered in practice.

9. Data and curves on frequency stability for variations in power supply voltage from 85 to 115 percent normal values.

10. Net sale price.

(*f*) For approval of automatic frequency control equipment or automatic temperature control chambers, manufacturers shall complete F. C. C. Form 305 with respect to all pertinent sections and the data set forth below, both of which shall be verified before a notary public.

1. Photograph or drawings or any other evidence.

2. Data and curves on frequency stability for variations in ambient temperatures over maximum range encountered in practice.

3. Data and curves on frequency stability for variations in power supply voltage from 85 to 115 percent normal values.

4. Net sale price.

15. REQUIREMENTS FOR APPROVAL OF FREQUENCY MONITORS

Section 3.60 requires that the licensee of each standard broadcast station have in operation at the transmitter a frequency monitor independent of the frequency control of the transmitter. The frequency monitor shall be approved by the Commission and shall have a stability and accuracy at least five parts per million.

A. General Requirements and Approval

There are several ways or means by which it can be determined whether the frequency

of the emitted carrier wave is within the required limits of the assigned frequency. However, one of the commonest ways is by means of a local piezo oscillator of known frequency producing a beat with the emitted wave used in conjunction with an instrument to indicate the resultant beat frequency. The visual indicator [37] is the only method now in common use by which it is considered that the frequency of the beat may be determined with the required degree of accuracy. Approval of a frequency monitor will be given based upon data taken by the Laboratory Division of the F. C. C. Any manufacturer desiring to submit a monitor for approval shall supply the Commission with full details. If the specifications appear to meet the requirements, the Commission will authorize the Laboratory Division to issue shipping instructions. The shipping charges to and from the Laboratory at Laurel, Md., shall be paid by the manufacturer.

In approving a frequency monitor, based upon the tests by the Laboratory, the Commission merely recognizes that the type of monitor has the inherent capability of functioning in compliance with section 3.60, if properly constructed, maintained, and operated. The Commission accepts no responsibility beyond this and further realizes that these monitors may have a limited range over which the visual indicator will determine deviations. Accordingly, it is necessary that adjunct equipment be used to determine major deviations.[37]

No change whatsoever will be permitted in the monitors sold under approval number issued by the Commission except when the licensee or the manufacturer is specifically authorized to make such changes.

When it is desired to make any change, either mechanical or electrical, the details shall be submitted to the Commission for its consideration.

Approval is given subject to withdrawal if the unit proves defective in service and cannot be relied upon under usual conditions of maintenance and operation encountered in the average standard broadcast station. Withdrawal of approval means that no further units may be installed by standard broadcast stations for the purpose of complying with section 3.60, but will not affect units already sold, unless it is found that there has been an unauthorized change in design or construction, or the material or workmanship is defective. All manufacturers of approved frequency monitors shall keep a list of sale numbers of the monitors sold to licensees of standard broadcast stations under the assigned approval number, and shall advise the Commission upon shipment of the monitor to the standard broadcast station.

[37] In addition to the visual indicator, the range of which is necessarily 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. When it is desired to make any change, either mechanical or electrical, the details shall be submitted to the Commission for its consideration.

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 50 cycles below to 50 cycles above the assigned frequency. (When used by stations required by section 3.59 to maintain an operating frequency within 20 cycles of the assigned frequency, the range may be less than from 50 cycles above to 50 cycles below zero deviation but in no event shall the scale be less than from 20 cycles above to 20 cycles below zero deviation.)

(3) The scale of the indicating device shall be so calibrated as to be read accurately 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,

(a) Plus or minus 0.05° C. when X or Y cut crystal is employed, or

(b) 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 ther-

mometer 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 by the Laboratory will include the determination of the following:

(1) *Accuracy.*—(*a*) Oscillator frequency, as received.

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

(*c*) Accuracy of readings of frequency-difference instrument.

(*d*) Functioning of frequency adjustment device.

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

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

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

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

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

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

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 kc.

16. REQUIREMENTS FOR APPROVAL OF MODULATION MONITORS

Section 3.55 (*b*) requires all broadcast stations to have in operation a modulation monitor approved by the Commission and section 3.55 (*d*) states that the Commission will from time to time publish the specifications, requirements, and list of approved modulation monitors. The specifications and requirements for approval are set out below. For a list of approved modulation monitors, attention is invited to Commission release "List of Approved Modulation Monitors."

Approval will be given based on the test data taken by the Laboratory Division of the F. C. C. Any manufacturer desiring to submit a monitor for approval shall supply the Commission with full details and if the specifications appear to meet the requirements, the Commission will authorize the Laboratory Division to issue shipping instructions. The shipping charges to and from the Laboratory at Laurel, Md., shall be paid by the manufacturer.

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:

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. 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.

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 10,000 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.

17. USE OF LOW TEMPERATURE COEFFICIENT CRYSTALS BY BROADCAST STATIONS

Section 3.62 requires that authority from the Commission shall be obtained before installing new automatic frequency control equipment or making changes in existing automatic frequency control equipment that may affect the precision of the frequency control. Therefore, licensees of standard broadcast stations desiring to install crystals of the low temperature coefficient type must obtain authorization therefor from the Commission. Requests for such authority may be made by letter specifying the manufacturer's name (see list of manufacturers of approved crystals below) and the guaranteed temperature coefficient and accuracy of calibration.

Use of a properly ground low temperature coefficient crystal normally materially increases the frequency stability, particularly where the equipment is subject to wide variations in ambient temperature. Where a crystal of this type is installed in the automatic frequency control unit but not in the approved frequency monitor, the stability of the control unit becomes considerably better than that of the monitor and unless care is exercised in making frequency adjustments, off frequency operation may occur. Therefore, it is recommended that when the crystal in the frequency control unit is changed to one of the low temperature coefficient type, a crystal of equal or better temperature coefficient and accuracy be installed in the monitor, authority for which may be requested by letter in the same manner as for installation in the automatic frequency control unit.

Manufacturers desiring approval of crystals of the low temperature coefficient type must submit under oath data on several such typical crystals manufactured by them showing that the temperature coefficient is not in excess of three parts per million per degree centigrade, and further affirming that no crystal of this type having a temperature coefficient in excess of this value will be supplied to any broadcast station and that all crystals so supplied will be ground to within five parts per million of the assigned frequency of the station for the normal operating temperature specified.

MANUFACTURERS OF LOW TEMPERATURE COEFFICIENT CRYSTALS WHICH HAVE BEEN ACCEPTED BY THE COMMISSION

American Piezo Supply Co., Kansas City, Mo.

Bellefonte Eng. Labs., Bellefonte, Pa.

Bliley Electric Co., Union Station Bldg., Erie, Pa.

Cambridge Thermonic Corp., Cambridge, Mass.

Collins Radio Co., Cedar Rapids, Iowa.

Commercial Radio Equipment Co., 216 East Seventy-fourth Street, Kansas City, Mo.

Electrical Products Corp., Oakland, Calif.

Hipower Crystal Co., 2035 West Charleston Street, Chicago, Ill.

Hollister Crystal Co., Merriam, Kans.

James Knights Co., Sandwich, Ill.

Piezo Electric Laboratories, New Dorp, N. Y.

Precision Crystal Laboratories, P. O. Box 326, Springfield, Mass.

Precision Piezo Service, Baton Rouge, La.

Premier Crystal Labs., Inc., 53–63 Park Row, New York, N. Y.

R. C. A. Mfg. Co., Camden, N. J.

Scientific Research Laboratories, Hyattsville, Md.

Silver City Crystal Co., Meriden, Conn.

Theodore S. Valpey, Holliston, Mass.

Western Electric Co., New York, N. Y.

William W. L. Burnett, San Diego, Calif.

18. MONEY REQUIRED TO CONSTRUCT AND COMPLETE ELECTRICAL TESTS OF STATIONS OF DIFFERENT CLASSES AND POWERS

Section 3.24 (*c*) requires that an applicant for standard broadcast station show that it is financially qualified to construct and operate the proposed station.

It is considered that the money specified below is required to construct and complete electrical tests of a new standard broadcast station of the class and power indicated, in accordance with the requirements of the Rules and Regulations of the Commission and good engineering practice.

Power and class of station:	*Money required*
100 watts, Class IV	$6,500
250 watts, Class IV	8,500
250 watts, Class II	10,000
500 watts, Class II and III	22,500
1,000 watts, Class II and III	25,000
5 kw, Class II or III	40,000
10 kw, Class I or II	65,000
25 kw, Class I or II	175,000
50 kw, Class I or II	200,000

Attention is invited to the fact that the above figures are considered the minimum required for satisfactory installation, including the transmitter, antenna system, monitoring equipment and equipment for one large and one small studio of average dimensions, and equipment including microphones, speech input equipment, and usual acoustical treatment, but exclusive of the cost of land and buildings and organization and development costs in more elaborate installations including directional antenna would increase the cost accordingly.

19. USE OF COMMON ANTENNA BY STANDARD BROADCAST STATIONS OR ANOTHER RADIO STATION

Section 3.45(e), under certain conditions, permits the simultaneous use of the same 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.

Prerequisites to an authorization for simultaneous use are:

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

(2) Compliance with Section 3.45(a) and (b) with respect to the minimum antenna height or field intensity for each standard broadcast station concerned.

20. USE OF FREQUENCY AND MODULATION MONITORS AT AUXILIARY BROADCAST TRANSMITTERS

Sections 3.60 and 3.55 (*b*) require that each standard broadcast station have approved frequency and modulation monitors in operation at the transmitter.

The following shall govern the installation of approved *frequency* and *modulation* monitors at auxiliary transmitters of standard broadcast stations in compliance with these rules:

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.

The licensee will be held strictly responsible for any frequency deviation of the auxiliary transmitter in excess of 20 cycles from the assigned frequency, even though exempted by the above from installing an approved frequency monitor. Furthermore, whenever 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.

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*.

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 switched readily from one transmitter to the other.

Standard broadcast stations not complying with these requirements cannot be considered as operating in compliance with the rules governing such operation.

21. APPROVED FREQUENCY MONITORS

Section 3.60 requires that each standard broadcast station shall have in operation at the transmitter an approved frequency monitor [38] independent of the frequency control of the transmitter.

The following frequency monitors have been approved as in compliance with the specifications issued pursuant to section 3.60:

Manufacturer's name	Type	Approval No.
General Radio Co.	25-A	1461
RCA Victor Co.	311-A, 311-AB	1462
General Radio Co.	25-AB	1463
Western Electric Co.	1-C	1464
Doolittle Radio, Inc.	FD-1A	1465
General Electric Co.	98X402	1466
General Radio Co.	1181-A	1467
RCA Manufacturing Co.	WF-48A	1468

22. APPROVED MODULATION MONITORS

Section 3.55 (*b*) requires that each standard broadcast station shall have an approved modulation monitor in operation at the transmitter.

The following modulation monitors have been approved as in compliance with the specifications issued pursuant to section 3.55 (*d*):

Manufacturer's name	Type	Approval No.
General Radio Co.	731-A or B	1551
RCA Manufacturing Co.	66A	1552
Do.	66B	1553
Do.	66D	1554
General Radio Co.	1931-A	1555
Gates Radio Co.	MO-2639	1556
RCA Manufacturing Co.	WM-43A	1557

[38] These monitors have a limited range over which the visual indicator will operate and accordingly it is necessary that auxiliary aural means be provided in conjunction with the monitor to indicate deviations beyond the range of the visual indicator such as may occur because of defective transmitting apparatus or other causes. In approving the monitors the Commission expects that this auxiliary equipment will be used by all broadcast licensees and will not accept as satisfactory explanations of any frequency deviation which may occur simply on the basis that it was not indicated by the monitor.

23. APPROVED EQUIPMENT

Sections 3.41 to 3.64 govern the design, construction, and technical operation of standard broadcast equipment. There is listed below the equipment which has been approved as in compliance with these rules in accordance with the provisions of "Requirements for Type Approval of Broadcast Transmitters and Automatic Frequency Control Equipment."

American Piezo Supply Co., P. O. Box 8112, Plaza Station, Kansas City, Mo.:

Type No. C-X-7-C, automatic frequency control unit.

Bliley Electric Co., 203 Union Station Building, Erie, Pa.:

Type No. BC46T, automatic temperature control unit.
Type No. TC92, automatic temperature control unit.
Type No. TC93, automatic temperature control unit.

Collins Radio Co., Cedar Rapids, Iowa.:

Type No. 10S-2, automatic frequency control unit.
Type No. 20H, 1000-watt, broadcast transmitter.
Type No. 20HA, 1000-watt, broadcast transmitter.
Type No. 20J, 1000-watt, broadcast transmitter.
Type No. 20K, 1000-watt, broadcast transmitter.
Type No. 20T, 500-1000-watt, broadcast transmitter.
Type No. 21A, 5000-watt, broadcast transmitter.
Type No. 21D, 5000-watt, broadcast transmitter.
Type No. 21DA, 5000-watt, broadcast transmitter.
Type No. 21DX, 5000-watt, broadcast transmitter.
Type No. 40DA, automatic frequency control unit.
Type No. 40E, automatic frequency control unit.
Type No. 300C, 250-watt, broadcast transmitter.
Type No. 300C-1, 250-watt, broadcast transmitter.
Type No. 300E, 100-watt, broadcast transmitter.
Type No. 300FA, 250-watt, broadcast transmitter.
Type No. 300G, 100-250-watt, broadcast transmitter

Doolittle Radio Inc., 7421 South Loomis Boulevard, Chicago, Ill.:

Type No. OB-5, automatic frequency control unit (includes Type TC-1 ATCU).
Type No. OB-6, automatic frequency control unit.
Type No. TC-1, automatic temperature control unit (includes Type 2-A ATCC).
Type No. 100-B, 100-watt, broadcast transmitter (includes Type OB-2 or OB-5 AFCU).
Type No. 250-B, 250-watt, broadcast transmitter (includes Type OB-2 or OB-5 AFCU).
Type No. 1000-B, 1000-watt, broadcast transmitter.

Federal Telegraph Co., Newark, N. J.:

Type No. 162-A, 50,000-watt, broadcast transmitter.
Type No. 163-A, 5,000-watt, broadcast transmitter.
Type No. 165-A, 5,000-watt, broadcast transmitter.

Type No. 196–A, 5,000-watt, broadcast transmitter.
Type No. 197–A, 50,000-watt, broadcast transmitter.

Gates Radio Co., Quincy, Ill.:

Type No. 25–A, automatic frequency control unit.
Type No. 100–A, 100-watt, broadcast transmitter.
Type No. 250–A, 250-watt, broadcast transmitter.
Type No. 500–A, 500-watt, broadcast transmitter.
Type No. BC–1E, 1000-watt, broadcast transmitter.
Type No. BC–250D, 250-watt, broadcast transmitter.
Type No. 250–C, 250-watt, broadcast transmitter.
Type No. 250–C–1, 250-watt, broadcast transmitter.
Type No. 1000–C, 1000-watt, broadcast transmitter.
Type No. 1–D, 1000-watt, broadcast transmitter.
Type No. S–101, 100-watt, broadcast transmitter.
Type No. S–251, 250-watt, broadcast transmitter.
Type No. BC–5A, 5000-watt, broadcast transmitter.

General Electric Co., Schenectady, N. Y.:

Type No. 32C401–G30, automatic temperature control unit.
Type No. BT–20–A, 250-watt, broadcast transmitter.
Type No. BT–21–A, 1000-watt, broadcast transmitter.
Type No. BT–22–A, 5000-watt, broadcast transmitter.
Type No. BT–23–A, 10,000-watt, broadcast transmitter.
Type No. BT–25–A, 50,000-watt, broadcast transmitter.
Type No. XT–1–A, 1000 watt, broadcast transmitter.

Piezo Electric Laboratories, 612 Rockland Avenue, New Dorp, N. Y.:

Type No. TC–210, automatic temperature control oven and relay unit.
Type No. TC–350, automatic temperature control oven and relay unit.
Type No. OB–10, oscillator and amplifier unit (oscillator and first buffer. No ATCU or crystal).

Precision Piezo Service, 427 Asia Street, Baton Rouge, La.:

Type No. 50M, automatic temperature control unit.

Premier Crystal Laboratories, Inc., 53–63 Park Row, New York, N. Y.:

Type No. 350–A, automatic frequency control unit.

R. C. A. Victor, Inc., Camden, N. J.:

Type No. UL–4292, automatic frequency control unit.
Type No. UL–4392, automatic frequency control unit.
Type No. 100–E, 100-watt, broadcast transmitter.
Type No. 100–G, 100-watt, broadcast transmitter.
Type No. 100–H, 100-watt, broadcast transmitter.
Type No. BTA–250L, 250-watt, broadcast transmitter.
Type No. 250–D, 250-watt, broadcast transmitter.
Type No. 250–E, 250-watt, broadcast transmitter.
Type No. 250–F, 250-watt, broadcast transmitter.
Type No. 250–G, 250-watt, broadcast transmitter.
Type No. 250–K, 250-watt, broadcast transmitter.
Type No. BTA–1L, 1,000-watt, broadcast transmitter.
Type No. BTA–1LA, 1,000-watt, broadcast transmitter.
Type No. 1–E, 1,000-watt, broadcast transmitter.
Type No. 1–E–A, 1,000-watt, broadcast transmitter.
Type No. 1–G, 1,000-watt, broadcast transmitter.
Type No. 1–K, 1,000-watt, broadcast transmitter.
Type No. ET–4300, 1,000-watt, broadcast transmitter.
Type No. BTA–5F, 5,000-watt, broadcast transmitter.
Type No. 5–D, 5,000-watt, broadcast transmitter.
Type No. 5–D–1, 5,000-watt, broadcast transmitter.
Type No. 5–D–2, 5,000-watt, broadcast transmitter.
Type No. 5–DX, 5,000-watt, broadcast transmitter.
Type No. 5–E, 5,000-watt, broadcast transmitter.
Type No. BTA–10F, 10,000-watt, broadcast transmitter.
Type No. 10–C–A, 10,000-watt, broadcast transmitter.
Type No. 10–C–B, 10,000-watt, broadcast transmitter.
Type No. 10–D, 10,000-watt, broadcast transmitter.
Type No. 10–DX, 10,000-watt, broadcast transmitter.
Type No. 10–E, 10,000-watt, broadcast transmitter.
Type No. BTA–50F, 50,000-watt, broadcast transmitter.
Type No. 50–D, 50,000-watt, broadcast transmitter.
Type No. 50–D, 50,000-watt, power amplifier.
Type No. 50–E, 50,000-watt power amplifier.

Raytheon Manufacturing Co., Chicago, Ill.:

Type No. RA–250, 250-watt, broadcast transmitter.
Type No. RA–1000, 1,000-watt, broadcast transmitter.
Type No. RA–5, 5,000-watt, broadcast transmitter.

Transmitter Equipment Mfg. Co., Inc., 345 Hudson Street, New York 14, N. Y.:

Type No. 250 BCA, 250-watt, broadcast transmitter.

Theodore S. Valpey, Holliston, Mass.:

Type No. CBC–0, automatic temperature control unit.

Western Electric Co., 195 Broadway, New York, N. Y.:

Type No. 700–B, automatic frequency control unit.
Type No. 700–C, automatic frequency control unit.
Type No. 702–A, automatic frequency control unit.
Type No. 310–A, 100-watt, broadcast transmitter.
Type No. 310–B, 250-watt, broadcast transmitter.
Type No. 310–C, 500-watt, broadcast transmitter.
Type No. 310–D, 1,000-watt, broadcast transmitter.
Type No. 350C–1, 100-watt, broadcast transmitter.

Type No. 351E-1, 250-watt, broadcast transmitter.
Type No. 451A-1, 250-watt, broadcast transmitter.
Type No. 352E-1 500-watt, broadcast transmitter.
Type No. 353E-1, 1 000-watt, broadcast transmitter.
Type No. 403A-1, 1,000-watt, broadcast transmitter.
Type No. 405A-1, 5,000-watt, broadcast transmitter.
Type No. 405A-2, 5,000-watt, broadcast transmitter.
Type No. 405B-1, 5,000-watt, broadcast transmitter.
Type No. 405B-2, 5,000-watt, broadcast transmitter.
Type No. 406A-1, 10,000-watt, broadcast transmitter.
Type No. 406A-2, 10,000 watt, broadcast transmitter.
Type No. 406A-3, 10,000-watt, broadcast transmitter.
Type No. 406B-1, 10,000-watt, broadcast transmitter.
Type No. 407A-1, 50,000-watt, broadcast transmitter.
Type No. 407A-2, 50,000-watt, broadcast transmitter.
Type No. 407A-3, 50,000-watt, broadcast transmitter.
Type No. 407A-4, 50,000-watt, broadcast transmitter.
Type No. 442A-1, 500-watt, broadcast transmitter.
Type No. 443A-1, 1000-watt, broadcast transmitter.

Westinghouse Electric and Mfg. Co., 2519 Wilkins Avenue, Baltimore, Md.:

Type No. LK-1, automatic frequency control unit.
Type No. LK-2, automatic frequency control unit.
Type No. 50-HG, 50,000-watt, broadcast transmitter.
Type No. 50-HG-1, 50,000-watt, broadcast transmitter.
Type No. 5-HV, 5,000-watt, broadcast transmitter.
Type No. 5-HV-1, 5,000-watt, broadcast transmitter.
Type No. 10-HV, 10,000-watt, broadcast transmitter.
Type No. 10-HV-1, 10,000-watt, broadcast transmitter.

24. STANDARD BROADCAST APPLICATION FORMS

The Communications Act of 1934, as amended, and the Rules and Regulations of the Commission require that application be made to the Commission for various authorizations. In order to be of aid to applicants, there are set out below the correct forms to be submitted in making application for various authorizations applicable to Standard Broadcast Stations.

F. C. C. Form 301, Application for Authority to Construct a New Broadcast Station or Make Changes in an Existing Broadcast Station.

F. C. C. Form 302, Application for New Broadcast Station License.

F. C. C. Form 303, Application for Renewal of Broadcast Station License.

F. C. C. Form 308, Application for Permit to Locate, Maintain, or Use Studio Apparatus for Production of Programs to be Transmitted or Delivered to Foreign Radio Stations.

F. C. C. Form 314, Application for Consent to Assignment of Radio Broadcast Station Construction Permit or License.

F. C. C. Form 315, Application for Consent to Transfer of Control of Corporation Holding Radio Broadcast Station Construction Permit or License.

F. C. C. Form 317, Application for Standard Broadcast Station Special Service Authorization or Extension Thereof (See Sec. 1.325).

F. C. C. Form 321, Application for Construction Permit to Replace Expired Permit.

F. C. C. Form 701, Application for Additional Time to Construct a Radio Station.

Informal requests (letters or telegrams) may be filed for requests:

(*a*) To operate additional time.

(*b*) To discontinue operation or services not covered by section 3.71.

(*c*) To operate with additional power.

(*d*) To operate with reduced power not covered by section 3.57.

(*e*) To operate for test purposes (to determine site, etc.).

(*f*) To rebroadcast programs of stations of other classes.

(*g*) Other special temporary operation beyond terms of existing license.

(*h*) Temporary operation without specified items of equipment, or with temporary, substitute, or auxiliary equipment.

(1) Operation without an approved frequency monitor.

(2) Operation without an approved modulation monitor.

(3) Operation without thermometer in automatic temperature control chamber.

(4) Operation without antenna ammeter, plate voltmeter, or plate ammeter.

(5) Operation with substitute ammeter, plate voltmeter, or plate ammeter.

(6) Operation with temporary antenna system.

(7) Operation with auxiliary transmitter as main transmitter.

(*i*) Operation with new or modified equipment pending repair of existing equipment, or pending receipt and action upon a formal application.

(*j*) Where formal application is not required, application for new or modified equipment or antenna system.

(*k*) Change of specifications for painting and lighting antenna towers where formal application is not required.

(*l*) Operation to determine power by direct method during program test period.

(*m*) Relocation of transmitter in same building.

(*n*) Operation with reduced power or time under sections 3.57 and 3.71.

(*o*) Approval of types of equipment as to compliance with outstanding rules or standards.

(*p*) All authorizations for equipment and program tests, or extensions thereof, where it appears that compliance has been had with the terms of the construction permit.

(*q*) Extensions of time within which to comply with technical requirements specified in authorizations, orders, and rules or releases of the Commission.

(*r*) Representations of compliance with technical requirements specified in authorizations, orders, rules, or releases (except formal applications).

(*s*) Operation with licensed, new or modified equipment at a temporary location with a temporary antenna system in case of an emergency when, due to causes beyond the control of the licensee, it becomes impossible to continue operating at the licensed location.

25. FIELD OFFICES OF THE COMMISSION

Section 3.57 and other rules of the Commission require that in certain instances, the inspector in charge of the district in which the station is located be advised of the conditions existing at the station. The following is a list of the radio districts, giving the address of each field office of the Commission and the territory embraced in each district:

Radio district	Address of the Engineer in charge	Territory within district	
		States	Counties
1	1600 Customhouse, Boston 9, Mass.	Connecticut	All counties.
		Maine	Do.
		Massachusetts	Do.
		New Hampshire	Do.
		Rhode Island	Do.
		Vermont	Do.
2	748 Federal Bldg., 641 Washington St., New York 14, N. Y.	New Jersey	Bergen, Essex, Hudson, Hunterdon, Mercer, Middlesex, Monmouth, Morris, Passaic, Somerset, Sussex, Union, and Warren.
		New York	Albany, Bronx, Columbia, Delaware, Dutchess, Green, Kings, Nassau, New York, Orange, Putnam, Queens, Rensselaer, Richmond, Rockland, Schenectady, Suffolk, Sullivan, Ulster, and Westchester.
3	1005 U. S. Customhouse, Philadelphia, 6, Pa.	Delaware	Newcastle.
		New Jersey	Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, Ocean and Salem.
		Pennsylvania	Adams, Berks, Bucks, Carbon, Chester, Cumberland, Dauphin, Delaware, Lancaster, Lebanon, Lehigh, Monroe, Montgomery, Northampton, Perry, Philadelphia, Schuylkill, and York.
4	508 Old Town Bank Bldg., Gay St. and Fallsway, Baltimore 2, Md.	Delaware	Kent and Sussex.
		District of Columbia	All.
		Maryland	All counties.
		Virginia	Arlington, Clark, Fairfax, Fauquier, Frederick, Loudoun, Page, Prince William, Rappahannock, Shenandoah, and Warren.
		West Virginia	Barbour, Berkeley, Grant, Hampshire, Hardy, Harrison, Jefferson, Lewis, Marion, Mineral, Monongalia, Morgan, Pendleton, Preston, Randolph, Taylor, Tucker, and Upshur.
5	Room 402, New Post Office Bldg., Norfolk 10, Va.	North Carolina	All except district 6.
		Virginia	All except district 4.
6	411 Federal Annex, Atlanta 3, Ga.	Alabama	All except district 8.
		Georgia	All counties.
	Suboffice, P. O. Box 77 (214-218 Post Office Bldg.), Savannah, Ga.	North Carolina	Ashe, Avery, Buncombe, Burke, Caldwell, Cherokee, Clay, Cleveland, Graham, Haywood, Henderson, Jackson, McDowell, Macon, Madison, Mitchell, Polk, Rutherford, Swain, Transylvania, Watauga, and Yancey.
		South Carolina	All counties.
		Tennessee	Do.
7	P. O. Box 150 (312 Federal Bldg.), Miami 1, Fla.	Florida	All except district 8.
	Suboffice, 409-410 Post Office Bldg., Tampa 2, Fla.		
8	400 Audubon Bldg., New Orleans 16, La.	Alabama	Mobile and Baldwin.
		Arkansas	All counties.
		Florida	Escambia.
		Louisiana	All counties.
		Mississippi	Do.
		Texas	City of Texarkana only.

Radio district	Address of the Engineer in charge	Territory within district	
		States	Counties
9	324 U. S. Appraisers Bldg., 7300 Wingate St., Houston 11, Tex. Suboffice, P. O. Box 1527 (329 Post Office Bldg.), Beaumont, Tex.	Texas	Angelina, Aransas, Atascosa, Austin, Bandera, Bexar, Blanco, Brazoria, Brazos, Burleson, Caldwell, Calhoun, Cameron, Chambers, Colorado, Comal, De Witt, Duval, Dimmit, Edwards, Fayette, Fort Bend, Frio, Galveston, Gillespie, Goliad, Gonzales, Grimes, Guadalupe, Hardin, Hays, Harris, Hidalgo, Jackson, Jasper, Jefferson, Jim Hogg, Jim Wells, Karnes, Kenedy, Kendall, Kerr, Kinney, Kleberg, La Salle, Lavaca, Lee, Liberty, Live Oak, Matagorda, Madison, Maverick, McMullen, Medina, Montgomery, Nacadoches, Newton, Nueces, Orange, Polk, Real, Refugio, San Augustine, San Jacinto, San Patricio, Sabine, Starr, Travis, Trinity, Uvalde, Val Verde, Victoria, Walker, Waller, Washington, Webb, Wharton, Willacy, Williamson, Wilson, Zapata, Zavala, and Tyler.
10	P. O. Box 5238 (U. S. Terminal Annex Bldg.), Dallas 2, Tex.	New Mexico	All counties.
		Oklahoma	Do.
		Texas	All except district 9 and the city of Texarkana.
11	539 U. S. Post Office and Courthouse Bldg., Temple and Spring Sts., Los Angeles 12, Calif.	Arizona	All counties.
		California	Imperial, Inyo, Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, San Luis Obispo, Santa Barbara, and Ventura.
	Suboffice, 230 U. S. Customhouse, San Diego 1, Calif.	Nevada	Clarke.
12	323-A Customhouse, San Francisco 26, Calif.	California	All except district 11.
		Nevada	All except Clarke.
13	406 Central Bldg., Portland 5, Oreg.	Idaho	All except district 14.
		Oregon	All counties.
		Washington	Wahkiakum, Cowlitz, Clark, Skamania, and Klickitat.
14	801 Federal Office Bldg., Seattle 4, Wash.	Idaho	Benewah, Bonner, Boundary, Clearwater, Idaho, Kootenai, Latah, Lewis, Nez Perce, and Shoshone.
		Montana	All counties.
		Washington	All except district 13.
15	521 Customhouse, Denver 2, Colo.	Colorado	All counties.
		Utah	Do.
		Wyoming	Do.
		Nebraska	Banner, Box Butte, Cheyenne, Dawes, Deuel, Garden, Kimball, Morrill, Scottsbluff, Sheridan, Sioux.
		South Dakota	Butte, Custer, Fall River, Lawrence, Meade, Pennington, Shannon, Washington.
16	208 Uptown Post Office and Federal Courts Bldg., 5th and Washington Sts., St. Paul 2, Minn.	Minnesota	All counties.
		Michigan	Alger, Baraga, Chippewa, Delta, Dickinson, Gogebic, Houghton, Iron, Keweenaw, Luce, Mackinac, Marquette, Menominee, Ontonagon, and Schoolcraft.
		North Dakota	All counties.
		South Dakota	All except district 15.
		Wisconsin	All except district 18.
17	838 U. S. Courthouse, Kansas City 6, Mo.	Iowa	All except district 18.
		Kansas	All counties.
		Missouri	Do.
		Nebraska	All except district 15.
18	246 U. S. Courthouse, Chicago 4, Ill.	Illinois	All counties.
		Indiana	Do.
		Iowa	Allamakee, Buchanan, Cedar, Clayton, Clinton, Delaware, Des Moines, Dubuque, Fayette, Henry, Jackson, Johnson, Jones, Lee, Linn, Louisa, Muscatine, Scott, Washington, and Winneshiek.
		Wisconsin	Brown, Columbia, Calmet, Crawford, Dane, Dodge, Door, Fond du Lac, Grant, Green, Iowa, Jefferson, Keewanee, Kenosha, Lafayette, Manitowoc, Marinette, Milwaukee, Ozaukee, Ocente, Outgamie, Racine, Richland, Rock Sauk, Sheboygan, Walworth, Washington, Waukesha, and Winnebago.
		Kentucky	All except district 19.
19	1029 New Federal Bldg., Detroit 26, Mich.	Kentucky	Bath, Bell, Boone, Bourbon, Boyd, Bracken, Breathitt, Campbell, Carter, Clark, Clay, Elliott, Estill, Fayette, Fleming, Floyd, Franklin, Gallatin, Garrard, Grant, Greenup, Kenton, Harlan, Harrison, Jackson, Jessamine, Johnson, Knott, Knox, Laurel, Lawrence, Lee, Leslie, Letcher, Lewis, Lincoln, Madison, Magoffin, Martin, Mason, McCreary, Menifee, Montgomery, Morgan, Nicholas, Owen, Owsley, Pendleton, Perry, Pike, Powell, Pulaski, Robertson, Rockcastle, Rowan, Scott, Wayne, Whitely, Wolfe, and Woodford.
		Ohio	All counties.
	Suboffice, 541 Old Post Office Bldg., Cleveland 14, Ohio.	Michigan	All except district 16.
		West Virginia	All except district 4.
20	328 Federal Bldg., Buffalo 3, N. Y.	New York	All except district 2.
		Pennsylvania	All except district 3.
21	609 Stangenwald Bldg., Honolulu 1, T. H.	Territory of Hawaii and outlying Pacific possessions, except Alaska and adjacent islands.	
22	P. O. Box 2987, (322-323 Federal Bldg.), San Juan 13, P. R.	Puerto Rico	
		Virgin Islands	
23	P. O. Box 1421, (7-8 Shattuck Bldg.), Juneau, Alaska. Suboffice, P. O. Box 644, (Room 39, Federal Bldg.), Anchorage, Alaska.	Alaska	

26. AVERAGE SUNRISE AND SUNSET TIMES

[Effective September 30, 1945; Revised to April 20, 1948]

Section 3.8 states that the terms "sunrise" and "sunset" mean for each particular station during any particular month, the average times of sunrise and sunset as specified in the license of a broadcast station. The following is a tabulation of the average times of sunrise and sunset for each month at various points:

[Average sunrise time (SR); average sunset time (SS); (TZ) time zone i. e. (E) Eastern; latitude and longitude (lat./long.); (*) metropolitan district; (A) Atlantic; (E) eastern; (C) central; (M) mountain; (P) Pacific; standard time]

	TZ	SR SS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Alabama														
Albertville,*34-16/86-12	C	SR	6:45	6:30	6:00	5:15	4:45	4:30	4:45	5:00	5:30	5:45	6:15	6:45
		SS	5:00	5:30	5:45	6:15	6:45	7:00	7:00	6:30	6:00	5:15	4:45	4:30
Alexander City 32-56/85-59	C	SR	6:45	6:30	6:00	5:15	4:45	4:30	4:45	5:00	5:30	5:45	6:15	6:45
		SS	5:00	5:30	5:45	6:15	6:30	7:00	7:00	6:30	5:45	5:15	4:45	4:45
Birmingham*	C	SR	7:00	6:30	6:00	5:15	4:45	4:30	4:45	5:15	5:30	5:45	6:15	6:45
		SS	5:00	5:30	6:00	6:15	6:45	7:00	7:00	6:30	6:00	5:15	4:45	4:45
Clanton, 32-50/86—40	C	SR	6:45	6:30	6:00	5:15	4:45	4:30	4:45	5:00	5:30	5:45	6:15	6:45
		SS	5:00	5:30	6:00	6:15	6:45	7:00	7:00	6:30	6:00	5:15	4:45	4:45
Decatur	C	SR	7:00	6:30	6:00	5:15	4:45	4:30	4:45	5:15	5:30	6:00	6:15	6:15
		SS	5:00	5:30	6:00	6:15	6:45	7:00	7:00	6:30	6:00	5:15	4:45	4:45
Dothan	C	SR	6:45	6:30	6:00	5:15	4:45	4:30	4:45	5:00	5:30	5:45	6:15	6:30
		SS	5:00	5:30	5:45	6:15	6:30	6:45	6:45	6:30	5:45	5:15	4:45	4:45
Gadsden, 34-02/85-56	C	SR	6:45	6:30	6:00	5:15	4:45	4:30	4:45	5:00	5:30	5:45	6:15	6:45
		SS	5:00	5:30	5:45	6:15	6:45	7:00	7:00	6:30	5:45	5:15	4:45	4:30
Mobile	C	SR	6:45	6:30	6:00	5:30	5:00	4:45	5:00	5:15	5:30	6:00	6:15	6:45
		SS	5:15	5:45	6:00	6:15	6:45	7:00	7:00	6:30	6:00	5:15	5:00	5:00
Montgomery	C	SR	6:45	6:30	6:00	5:15	4:45	4:30	4:45	5:15	5:30	5:45	6:15	6:45
		SS	5:00	5:30	6:00	6:15	6:30	7:00	7:00	6:30	6:00	5:15	4:45	4:45
Opelika	C	SR	6:45	6:30	6:00	5:15	4:45	4:30	4:45	5:00	5:30	5:45	6:15	6:30
		SS	5:00	5:30	5:45	6:15	6:30	6:45	6:45	6:30	5:45	5:15	4:45	4:30
Sylacauga,* 33-10/86-14	C	SR	6:45	6:30	6:00	5:15	4:45	4:30	4:45	5:00	5:30	5:45	6:15	6:45
		SS	5:00	5:30	6:00	6:15	6:45	7:00	7:00	6:30	6:00	5:15	4:45	4:45
Tuscaloosa	C	SR	7:00	6:30	6:00	5:15	4:45	4:45	4:45	5:15	5:30	6:00	6:15	6:45
		SS	5:00	5:30	6:00	6:15	6:45	7:00	7:00	6:45	6:00	5:15	4:45	4:45
Arizona														
Coolidge, 33-00/111-34	M	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:45	7:15	6:30	6:00	5:30	5:15
Phoenix	M	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:15	7:45	7:45	7:15	6:30	6:00	5:30	5:15
Tucson	M	SR	7:30	7:15	6:30	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:15
Yuma	M	SR	7:45	7:30	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:45	7:15	7:30
		SS	6:00	6:30	6:45	7:15	7:30	7:45	7:45	7:30	6:45	6:00	5:45	5:30
Arkansas														
Blytheville	C	SR	7:15	6:45	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:00	6:30	7:00
		SS	5:15	5:45	6:00	6:30	7:00	7:15	7:15	6:45	6:15	5:30	5:00	4:45
Fort Smith	C	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:00
Helena, 34-31/90-37	C	SR	7:00	6:45	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:00	6:30	7:00
		SS	5:15	5:45	6:00	6:30	7:00	7:15	7:15	6:45	6:15	5:30	5:00	4:45
Hot Springs	C	SR	7:15	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:45	5:15	5:00
Jonesboro	C	SR	7:15	6:45	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:00
		SS	5:15	5:45	6:15	6:30	7:00	7:15	7:15	7:00	6:15	5:30	5:00	4:45
Little Rock*	C	SR	7:15	7:00	6:15	5:45	5:00	5:00	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	5:00
Magnolia,* 33-15/93-14	C	SR	7:15	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:45	5:15	5:00
Siloam Springs	C	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:00
California														
Beverly Hills*	P	SR	7:00	6:45	6:00	5:30	4:45	4:45	4:45	5:15	5:30	6:00	6:30	6:45
		SS	5:00	5:30	6:00	6:30	6:45	7:00	7:00	6:45	6:00	5:15	4:45	4:45
Chico	P	SR	7:30	7:00	6:15	5:30	5:00	4:45	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Dinuba, 36-32/119-24	P	SR	7:15	6:45	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:45
Eureka	P	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	5:45	6:15	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	4:45
Fresno,* 36-44/119-47	P	SR	7:15	6:45	6:15	5:30	4:45	4:45	4:45	5:15	5:45	6:00	6:45	7:15
		SS	5:00	5:45	6:00	6:30	7:00	7:15	7:15	6:45	6:15	5:30	4:45	4:45
Glendale*	P	SR	7:00	6:45	6:00	5:30	4:45	4:45	4:45	5:15	5:30	6:00	6:30	6:45
		SS	5:00	5:30	6:00	6:30	6:45	7:00	7:00	6:45	6:00	5:15	4:45	4:45
Hanford, 36-19/119-35	P	SR	7:15	6:45	6:00	5:30	4:45	4:45	4:45	5:15	5:45	6:00	6:30	7:00
		SS	5:00	5:45	6:00	6:30	7:00	7:15	7:15	6:45	6:15	5:30	4:45	4:45
Kentfield, 37-57/122-32	P	SR	7:30	7:00	6:30	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Long Beach	P	SR	7:00	6:45	6:00	5:30	5:00	4:45	5:00	5:15	5:30	6:00	6:45	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:15	6:45	6:00	5:15	4:45	4:30
Los Angeles*	P	SR	7:00	6:45	6:00	5:30	4:45	4:45	4:45	5:15	5:30	6:00	6:30	6:45
		SS	5:00	5:30	6:00	6:30	6:45	7:00	7:00	6:45	6:00	5:15	4:45	4:45
Merced	P	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:30	7:00	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Modesto	P	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Oakland*	P	SR	7:30	7:00	6:30	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Ontario, 34-04/117-39	P	SR	7:00	6:30	6:00	5:15	4:45	4:30	4:45	5:15	5:30	6:00	6:30	6:45
		SS	5:00	5:30	6:00	6:15	6:45	7:00	7:00	6:45	6:00	5:15	4:45	4:45
Oroville, 39-31/121-33	P	SR	7:30	7:00	6:15	5:30	5:00	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Sacramento*	P	SR	7:30	7:00	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
San Bernardino, 34-04/117-17	P	SR	7:00	6:30	6:00	5:15	4:45	4:30	4:45	5:15	5:30	6:00	6:15	6:45
		SS	5:00	5:30	6:00	6:15	6:45	7:00	7:00	6:30	6:00	5:15	4:45	4:45
San Diego*	P	SR	6:45	6:30	6:00	5:15	4:45	4:45	4:45	5:15	5:30	6:00	6:15	6:45
		SS	5:00	5:30	6:00	6:15	6:45	7:00	7:00	6:30	6:00	5:15	4:45	4:45
San Fernando, 34-14/118-27	P	SR	7:00	6:45	6:00	5:30	4:45	4:45	4:45	5:15	5:30	6:00	6:30	6:45
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:45
San Francisco*	P	SR	7:30	7:00	6:30	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Sanger, 36-44/119-29	P	SR	7:15	6:45	6:15	5:30	4:45	4:45	4:45	5:15	5:45	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:30	4:45	4:45
San Jose*	P	SR	7:30	7:00	6:15	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Santa Barbara	P	SR	7:00	6:45	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:00	6:30	7:00
		SS	5:15	5:45	6:00	6:30	7:00	7:15	7:15	6:45	6:15	5:30	5:00	4:45

	TZ	SR SS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
California—Continued														
Santa Cruz, 36-57/121-58	P	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Santa Monica, 34-01/118-25	P	SR	7:00	6:45	6:00	5:15	4:45	4:45	4:45	5:15	5:30	6:00	6:30	6:45
		SS	5:00	5:30	6:00	6:30	6:45	7:15	7:00	6:45	6:00	5:15	4:45	4:45
Stockton	P	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Taft,* 35-08/119-27	P	SR	7:00	6:45	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:00	6:30	7:00
		SS	5:15	5:45	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:30	5:00	4:45
Tulare, 36-13/119-17	P	SR	7:15	6:45	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:45
Vallejo, 38-07/122-15	P	SR	7:30	7:00	6:15	5:30	5:00	4:45	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Vasalia, *36-20/119-17	P	SR	7:15	6:45	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:45
Colorado														
Cannon City, 38-27/105-13	M	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:00	6:30	7:00	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Denver*	M	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:15	5:15	4:45	4:30
Grand Junction	M	SR	7:30	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	5:45	6:15	6:45	7:15	7:45	7:45	7:15	6:30	5:30	5:00	5:00
Greeley	M	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:15	5:15	4:45	4:30
Pueblo	M	SR	7:15	6:45	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:00	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:15	7.00	6:15	5:15	4:45	4:45
Connecticut														
Bridgeport *	E	SR	7:15	6:45	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:30
Danbury, 41-22/73-26	E	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:30
Hartford *	E	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Meriden, 41-33/72-47	E	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
New Britain *	E	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
New Haven *	E	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:30
Norwalk,* 41-06/73-25	E	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:30
Torrington, 41-48/73-09	E	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Delaware														
Wilmington*	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
District of Columbia														
Washington*	E	SR	7:30	7:00	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Florida														
Belle Glade, 26-40/80-41	E	SR	7:15	7:00	6:30	6:00	5:30	5:15	5:30	6:00	6:15	6:15	6:45	7:00
		SS	5:45	6:15	6:30	6:45	7:00	7:15	7:15	7:00	6:30	6:00	5:30	5:30
Clearwater, 27-53/82-48	E	SR	7:30	7:15	6:45	6:00	5:45	5:30	5:45	6:00	6:15	6:30	7:00	7:15
		SS	6:00	6:15	6:45	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:45	5:30
Coral Gables, 25-43/80-18	E	SR	7:15	7:00	6:30	6:00	5:30	5:30	5:30	6:00	6:00	6:15	6:45	7:00
		SS	5:45	6:15	6:30	6:45	7:00	7:15	7:15	7:00	6:30	6:00	5:30	5:30
Crestview, * 30-45/86-35	C	SR	6:45	6:30	6:00	5:15	4:45	4:45	4:45	5:15	5:30	5:45	6:15	6:45
		SS	5:15	5:30	6:00	6:15	6:30	6:45	7:00	6:30	6:00	5:15	4:45	4:45
Daytona Beach, 29-13/81-03	E	SR	7:15	7:00	6:30	6:00	5:30	5:30	5:30	5:45	6:15	6:30	6:45	7:15
		SS	5:45	6:15	6:30	6:45	7:15	7:30	7:30	7:00	6:30	6:00	5:30	5:30
Gainesville	E	SR	7:30	7:15	6:45	6:00	5:30	5:30	5:45	6:00	6:15	6:30	7:00	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Hollywood, 25-55/80-08	E	SR	7:15	7:00	6:30	6:00	5:30	5:30	5:30	5:45	6:00	6:15	6:45	7:00
		SS	5:45	6:15	6:30	6:45	7:00	7:15	7:15	7:00	6:30	6:00	5:30	5:30
Jacksonville *	E	SR	7:30	7:15	6:45	6:00	5:30	5:30	5:30	6:00	6:15	6:30	6:45	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Jacksonville Beach, 30-17/81-24	E	SR	7:30	7:00	6:30	6:00	5:30	5:15	5:30	5:45	6:15	6:30	6:45	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Melbourne, * 28-04/80-36	E	SR	7:15	7:00	6:30	6:00	5:30	5:30	5:30	5:45	6:00	6:30	6:45	7:15
		SS	5:45	6:15	6:30	6:45	7:00	7:15	7:30	7:00	6:30	6:00	5:30	5:30
Miami, * 24-48/80-14	E	SR	7:15	7:00	6:30	6:00	5:30	5:30	5:30	5:45	6:00	6:15	6:45	7:00
		SS	5:45	6:15	6:30	6:45	7:00	7:15	7:15	7:00	6:30	6:00	5:30	5:30
Ocala, 29-12/82-10	E	SR	7:30	7:15	6:45	6:00	5:30	5:30	5:45	6:00	6:15	6:30	7:00	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Orlando	E	SR	7:15	7:00	6:30	6:00	5:30	5:30	5:30	6:00	6:15	6:30	6:45	7:15
		SS	5:45	6:15	6:30	6:45	7:15	7:30	7:30	7:00	6:30	6:00	5:30	5:30
Palatka, 29-38/81-38	E	SR	7:30	7:00	6:30	6:00	5:30	5:30	5:30	6:00	6:15	6:30	6:45	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Panama City	E	SR	7:45	7:30	7:00	6:15	5:45	5:45	5:45	6:15	6:30	6:45	7:15	7:30
		SS	6:00	6:30	6:45	7:15	7:30	7:45	7:45	7:30	6:45	6:15	5:45	5:45
Pensacola	C	SR	6:45	6:30	6:00	5:30	5:00	4:45	5:00	5:15	5:30	5:45	6:15	6:45
		SS	5:15	5:30	6:00	6:15	6:30	6:45	7:00	6:30	6:00	5:15	4:45	4:45
St. Petersburg*	E	SR	7:30	7:15	6:45	6:00	5:45	5:30	5:45	6:00	6:15	6:30	6:45	7:15
		SS	6:00	6:15	6:45	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Sarasota	E	SR	7:30	7:15	6:45	6:00	5:45	5:30	5:45	6:00	6:15	6:30	6:45	7:15
		SS	6:00	6:15	6:45	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:45	5:45
Tallahassee	E	SR	7:30	7:15	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:45	7:00	7:30
		SS	6:00	6:30	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:45	5:45
Tampa*	E	SR	7:30	7:15	6:45	6:00	5:45	5:30	5:45	6:00	6:15	6:30	6:45	7:15
		SS	6:00	6:15	6:45	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
West Palm Beach, 26-38/80-06	E	SR	7:15	7:00	6:30	6:00	5:30	5:30	5:30	5:45	6:00	6:15	6:45	7:00
		SS	5:45	6:15	6:30	6:45	7:00	7:15	7:15	7:00	6:30	5:45	5:30	5:30
Georgia														
Athens,* 33-57/83-23	E	SR	7:45	7:15	6:45	6:00	5:30	5:15	5:30	6:00	6:15	6:45	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Atlanta,* 33-46/84-22	E	SR	7:45	7:30	6:45	6:15	5:30	5:30	5:30	6:00	6:15	6:45	7:15	7:30
		SS	5:45	6:15	6:45	7:15	7:30	7:45	7:45	7:30	6:45	6:00	5:30	5:30
Albany	E	SR	7:45	7:15	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:45	7:00	7:30
		SS	6:00	6:30	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:45	5:30
Brunswick	E	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Buckhead,* 33-34/83-21	E	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:30	6:00	5:30	5:15
Carrollton, 33-35/85-03	E	SR	7:45	7:30	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:45	7:15	7:45
		SS	6:00	6:30	6:45	7:15	7:30	7:45	8:00	7:30	6:45	6:00	5:30	5:30
Columbus, 32-29/85-02	E	SR	7:45	7:30	6:45	6:15	5:45	5:30	5:45	6:00	6:30	6:45	7:15	7:30
		SS	6:00	6:30	6:45	7:15	7:30	7:45	7:45	7:30	6:45	6:15	5:45	5:30
Cordele	E	SR	7:30	7:15	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:45	7:00	7:30
		SS	6:00	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30

	TZ	SR SS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Georgia—Continued														
Dawson,* 31-46/84-26	E	SR	7:45	7:15	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:45	7:00	7:30
		SS	6:00	6:30	6:45	7:00	7:30	7:45	7:45	7:30	6:45	6:00	5:45	5:30
Decatur, 33-48/84-16	E	SR	7:45	7:30	6:45	6:00	5:30	5:30	5:30	6:00	6:15	6:45	7:15	7:30
		SS	5:45	6:15	6:45	7:15	7:30	7:45	7:45	7:30	6:45	6:00	5:30	5:30
Douglas, 31-30/82-48	E	SR	7:30	7:15	6:45	6:00	5:30	5:30	5:30	6:00	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:15	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Griffin	E	SR	7:45	7:30	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:45	7:15	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:30	6:45	6:00	5:30	5:30
Hartwell, 34-21/82-57	E	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	6:00	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Macon, 32-43/83-37	E	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	6:00	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Martinez	E	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Rome, 34-14/85-10	E	SR	7:45	7:30	7:00	6:15	5:45	5:30	5:45	6:00	6:30	6:45	7:15	7:45
		SS	6:00	6:30	6:45	7:15	7:30	8:00	8:00	7:30	6:45	6:00	5:30	5:30
Savannah*	E	SR	7:30	7:15	6:30	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:15
Thomaston, 32-53/84-20	E	SR	7:45	7:15	6:45	6:15	5:45	5:30	5:30	6:00	6:15	6:45	7:15	7:30
		SS	5:45	6:15	6:45	7:15	7:30	7:45	7:45	7:30	6:45	6:00	5:30	5:30
Thomasville, 30-50/83-57	E	SR	7:30	7:15	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:30	7:00	7:30
		SS	6:00	6:30	6:45	7:00	7:15	7:45	7:45	7:15	6:45	6:00	5:45	5:30
Valdosta	E	SR	7:30	7:15	6:45	6:00	5:45	5:30	5:45	6:00	6:15	6:30	7:00	7:30
		SS	6:00	6:15	6:45	7:00	7:15	7:30	7:45	7:15	6:45	6:00	5:30	5:30
Idaho														
Boise	M	SR	8:15	7:45	7:00	6:00	5:15	5:00	5:15	5:45	6:30	7:00	7:15	8:15
		SS	5:30	6:15	6:45	7:30	8:00	8:30	8:30	7:45	7:00	6:00	5:15	5:15
Idaho Falls	M	SR	8:00	7:30	6:45	5:45	5:00	4:45	5:00	5:30	6:00	6:45	7:15	8:00
		SS	5:15	6:00	6:30	7:15	7:45	8:15	8:15	7:30	6:45	5:45	5:00	4:45
Lewiston 46-23/116-59	P	SR	7:45	7:00	6:00	5:00	4:15	3:45	4:00	4:45	5:30	6:00	6:45	7:30
		SS	4:30	5:15	6:00	6:30	7:15	7:45	7:45	7:00	6:00	5:00	4:15	4:00
Pocatello	M	SR	8.00	7:30	6:45	5:45	5:15	4.45	5:00	5:30	6:15	6:45	7:15	8:00
		SS	5:15	6:00	6:30	7:15	7:46	8:15	8:00	7:30	6:45	5:45	5:15	5:00
Twin Falls	M	SR	8:00	7:30	7:00	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:30	8:00
		SS	5:30	6:15	6:45	7:15	7:45	8:15	8:15	7:45	6:45	6:00	5:15	5:00
Wallace	P	SR	7:30	6:45	6:00	5:00	4:15	3:45	4:00	4:45	5:15	6:00	6:45	7:30
		SS	4:15	5:00	5:45	6:30	7:15	7:45	7:45	7:00	6:00	5:00	4:15	4:00
Illinois														
Alton, 38-55/90-13	C	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:00	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Aurora	C	SR	7:15	6:45	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:30
Belleville, 38-31/90-00	C	SR	7:15	6:45	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Canton, 40-32/90-01	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:15	4:45	4:30
Carbondale, 37-43/89-16	C	SR	7:15	6:45	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:45
Carthage	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Centralia, 38-34/89-06	C	SR	7:15	6:45	6:15	5:15	4:45	4:30	4:45	5:15	5:30	6:00	6:45	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:30	4:45	4:30
Chicago *	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Clinton, 40-05/88-57	C	SR	7:15	6:45	6:15	5:15	4:45	4:15	4:45	5:00	5:30	6:00	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:45	4:30
Decatur	C	SR	7:15	6:45	6:15	5:15	4:45	4:30	4:45	5:00	5:30	6:00	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:45	4:30
De Kalb, 41-56/88-44	C	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:15	7:30	7:30	7:00	6:00	5:15	4:30	4:30
Effingham, 39-06/88-34	C	SR	7:15	6:45	6:00	5:15	4:45	4:30	4:45	5:00	5:30	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:15	6:45	6:00	5:15	4:45	4:30
Evanston, 42-01/87-42	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:15	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Freeport, 42-18/89-35	C	SR	7:15	6:45	6:15	5:00	4:15	4:00	4:15	4:45	5:15	6:00	6:30	7:00
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:15	4:15
Herrin	C	SR	7:15	6:45	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:45
Jacksonville	C	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:00	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Joliet	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	6:00	4:30	4:30
La Salle, 41-18/89-05	C	SR	7:30	7:00	6:15	5:15	4:45	4:15	4:30	5:00	5:30	6:15	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:15	7:30	7:30	7:00	6:00	5:15	4:30	4:30
Macomb, 40-27/90-38	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Mount Vernon, 38-22/88-55	C	SR	7:15	6:45	6:15	5:15	4:45	4:30	4:45	5:15	5:30	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:15	6:45	6:00	5:30	4:45	4:45
Olney, 38-42/88-04	C	SR	7:15	6:45	6:00	5:15	4:45	4:30	4:45	5:00	5:30	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:30
Peoria*	C	SR	7:15	7:00	6:15	5:15	4:45	4:30	4:45	5:00	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:15	7:30	7:30	7:00	6:15	5:15	4:45	4:30
Quincy	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Rockford*	C	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:15	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:15	7:30	7:30	7:00	6:15	5:15	4:30	4:30
Rock Island	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:15	6:45	7:15	7:45	7:30	7:00	6:15	5:15	4:45	4:30
Tuscola	C	SR	7:15	6:45	6:00	5:15	4:45	4:30	4:30	5:00	5:30	6:00	6:30	7:00
		SS	4:45	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:30
Urbana	C	SR	7:15	6:45	6:15	5:15	4:45	4:30	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:15	6:45	6:00	5:15	4:45	4:30
Indiana														
Anderson	C	SR	7:00	6:45	6:00	5:00	4:30	4:15	4:30	5:00	5:30	5:45	6:30	7:00
		SS	4:45	5:15	5:45	6:15	6:45	7:15	7:15	6:45	6:00	5:00	4:30	4:15
Bloomington, 39-06/86-31	C	SR	7:00	6:45	6:00	5:15	4:30	4:30	4:30	5:00	5:30	6:00	6:30	7:00
		SS	4:45	5:15	5:45	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:30	4:30
Connersville, 39-38/85-08	C	SR	7:00	6:30	6:00	5:00	4:30	4:15	4:30	4:45	5:15	5:45	6:30	7:00
		SS	4:45	5:15	5:45	6:15	6:45	7:15	7:15	6:45	5:45	5:00	4:30	4:15
Evansville*	C	SR	7:00	6:45	6:00	5:15	4:45	4:30	4:45	5:00	5:30	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:30
Fort Wayne*	C	SR	7:00	6:30	6:00	5:00	4:30	4:00	4:15	4:45	5:15	5:45	6:30	7:00
		SS	4:30	5:15	5:45	6:15	6:45	7:15	7:15	6:45	5:45	5:00	4:30	4:15
Gary*	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Hammond*	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Indianapolis*	C	SR	7:00	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:30	7:00
		SS	4:45	5:15	5:45	6:15	6:45	7:15	7:15	6:45	6:00	5:00	4:30	4:15

	TZ	SR SS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Indiana—Continued														
Kokomo,* 40-29/86-08	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:30	7:00
		SS	4:45	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:30	4:15
La Porte,* 41-36/86-43	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:30	7:15
		SS	4:45	5:15	6:00	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:30	4:15
Marion, 40-31/85-43	C	SR	7:00	6:45	6:00	5:00	4:30	4:15	4:15	4:45	5:15	6:00	6:30	7:00
		SS	4:45	5:15	5:45	6:15	7:00	7:15	7:15	6:45	6:00	5:00	4:30	4:15
Michigan City, 41-40/86-53	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:30	7:15
		SS	4:45	5:15	6:00	6:30	7:00	7:30	7:30	6:45	6:00	5:15	4:30	4:15
South Bend*	C	SR	7:15	6:45	6:00	5:00	4:30	4:15	4:15	4:45	5:30	6:00	6:30	7:00
		SS	4:45	5:15	5:45	6:30	7:00	7:15	7:15	6:45	6:00	5:00	4:30	4:15
West Lafayette	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:30	7:00
		SS	4:45	5:15	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:30	4:30
Iowa														
Ames	C	SR	7:45	7:15	6:30	5:30	5:00	4:30	4:45	5:15	6:00	6:30	7:00	7:30
		SS	5:00	5:45	6:15	7:00	7:30	7:45	7:45	7:15	6:30	5:30	5:00	4:45
Boone	C	SR	7:45	7:15	6:30	5:30	5:00	4:45	4:45	5:15	6:00	6:30	7:00	7:30
		SS	5:15	5:45	6:15	7:00	7:30	8:00	7:45	7:15	6:30	5:30	5:00	4:45
Cedar Rapids	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:45	6:15	6:45	7:15	7:45	7:45	7:15	6:15	5:30	4:45	4:30
Council Bluffs, 41-12/95-53	C	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:30	5:45	5:00	5:00
Creston, 41-02/95-36	C	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:30	5:45	5:00	4:45
Davenport*	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:15	6:45	7:15	7:45	7:30	7:00	6:15	5:15	4:45	4:30
Decorah	C	SR	7:45	7:15	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:30	6:15	6:45	7:30	7:45	7:45	7:15	6:15	5:30	4:45	4:30
Des Moines*	C	SR	7:45	7:15	6:30	5:30	5:00	5:45	4:45	5:15	6:00	6:30	7:00	7:30
		SS	5:00	5:45	6:15	7:00	7:30	7:45	7:45	7:15	6:30	5:30	5:00	4:45
Dubuque	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:30	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:30	6:15	6:45	7:15	7:45	7:45	7:00	6:15	5:30	4:45	4:30
Fort Madison,* 40-37/91-20	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:45	7:30	7:00	6:15	5:30	4:45	4:45
Iowa City	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:45	6:15	6:45	7:15	7:45	7:45	7:00	6:15	5:30	4:45	4:30
Keokuk, 40-25/91-24	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:45	7:30	7:00	6:15	5:30	4:45	4:45
Mason City	C	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:45	6:15	7:00	7:30	8:00	7:45	7:15	6:30	5:30	4:45	4:45
Muscatine, 41-26/91-04	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:30	6:15	6:45	7:15	7:45	7:45	7:00	6:15	5:30	4:45	4:30
Shenandoah	C	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	7:45	7:15	6:30	5:45	5:00	5:00
Sioux City	C	SR	8:00	7:30	6:45	5:45	5:00	4:45	5:00	5:30	6:00	6:45	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:45	8:00	8:00	7:30	6:45	5:45	5:00	5:00
Waterloo, 42-26/92-17	C	SR	7:45	7:00	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:45	6:15	6:45	7:30	7:45	7:45	7:15	6:15	5:30	4:45	4:30
Kansas														
Abilene	C	SR	7:45	7:15	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:45	5:45	5:15	5:15
Arkansas City, 37-05/97-01	C	SR	7:45	7:15	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Coffeyville	C	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Colby, 39-23/101-00	M	SR	7:00	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:30	7:00
		SS	4:45	5:15	5:45	6:15	6:45	7:15	7:15	6:45	6:00	5:00	4:30	4:15
Concordia, 39-26/97-39	C	SR	7:45	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:00	6:30	7:15	7:30	8:00	8:00	7:30	6:45	6:00	5:15	5:15
Dodge City	C	SR	8:00	7:30	7:00	6:00	5:30	5:15	5:30	6:00	6:15	6:45	7:15	7:45
		SS	5:45	6:15	6:45	7:15	7:45	8:00	8:00	7:30	6:45	6:00	5:30	5:30
Garden City, 37-59/100-53	M	SR	7:00	6:30	6:00	5:15	4:30	4:15	4:30	5:00	5:30	5:45	6:30	7:00
		SS	4:45	5:15	5:45	6:15	6:45	7:15	7:00	6:45	6:00	5:00	4:30	4:30
Goodland, 39-20/101-44	M	SR	7:00	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:30	7:00
		SS	4:45	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:30	4:30
Great Bend, 38-18/98-47	C	SR	7:45	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:15	7:15	7:45
		SS	5:30	6:15	6:45	7:15	7:30	8:00	8:00	7:30	6:45	6:00	5:15	5:15
Hutchinson, 38-06/97-56	C	SR	7:45	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	7:30
		SS	5:30	6:15	6:45	7:15	7:30	8:00	8:00	7:30	6:45	6:00	5:15	5:15
Independence, 37-13/95-43	C	SR	7:45	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Lawrence	C	SR	7:45	7:15	6:30	5:45	5:15	5:00	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Leavenworth,* 39-18/94-55	C	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Manhattan	C	SR	7:45	7:15	6:45	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	8:00	7:45	7:30	6:30	5:45	5:15	5:00
Pittsburg	C	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Salina	C	SR	7:45	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:45	6:00	5:15	5:15
Topeka	C	SR	7:45	7:15	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Wichita*	C	SR	7:45	7:15	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:30	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:30	6:45	6:00	5:15	5:15
Kentucky														
Bowling Green, 37-01/86-23	C	SR	7:00	6:30	6:00	5:15	4:30	4:30	4:30	5:00	5:30	6:00	6:30	7:00
		SS	4:45	5:30	5:45	6:15	6:45	7:15	7:00	6:45	6:00	5:15	4:30	4:30
Campbellsville,* 37-20/85-20	C	SR	7:00	6:30	5:45	5:15	4:30	4:15	4:30	5:00	5:30	5:45	6:15	6:45
		SS	4:45	5:15	5:45	6:15	6:45	7:00	7:00	6:30	5:45	5:00	4:30	4:30
Covington, 39-04/84-31	C	SR	7:00	6:30	5:45	5:00	4:30	4:15	4:30	4:45	5:15	5:45	6:15	6:45
		SS	4:45	5:15	5:45	6:15	6:45	7:00	7:00	6:30	5:45	5:00	4:30	4:15
Henderson	C	SR	7:00	6:45	6:00	5:15	4:45	4:30	4:45	5:00	5:30	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	6:45	7:15	7:15	6:45	6:00	5:15	4:45	4:30
Lawson, 37-36/83-26	C	SR	6:45	6:30	5:45	5:00	4:30	4:15	4:15	4:45	5:15	5:45	6:15	6:45
		SS	4:45	5:15	5:45	6:15	6:45	7:00	7:00	6:30	5:45	5:00	4:30	4:15
Lexington	C	SR	7:00	6:30	5:45	5:00	4:30	4:15	4:30	4:45	5:15	5:45	6:15	6:45
		SS	4:45	5:15	5:45	6:15	6:45	7:00	7:00	6:30	5:45	5:00	4:30	4:15
Louisville*	C	SR	7:00	6:30	6:00	5:15	4:30	4:15	4:30	5:00	5:30	5:45	6:30	7:00
		SS	4:45	5:15	5:45	6:15	6:45	7:15	7:00	6:45	6:00	5:00	4:30	4:30
Madisonville, 37-21/87-29	C	SR	7:00	6:45	6:00	5:15	4:45	4:30	4:45	5:00	5:30	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	6:45	7:15	7:15	6:45	6:00	5:15	4:45	4:30
Mayfield, 36-43/88-35	C	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Owensboro, 37-46/87-09	C	SR	7:00	6:45	6:00	5:15	4:45	4:30	4:30	5:00	5:30	6:00	6:30	7:00
		SS	4:45	5:30	6:00	6:30	6:45	7:15	7:15	6:45	6:00	5:15	4:30	4:30
Paducah, 37-01/88-40	C	SR	7:15	6:45	6:00	5:15	4:45	4:30	4:45	5:15	5:30	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:30

	TZ	SR SS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Louisiana														
Abbeville, 30-00/92-07	C	SR	7:00	6:45	6:15	5:45	5:15	5:00	5:15	5:30	6:00	6:15	6:30	7:00
		SS	5:30	6:00	6:15	6:30	7:00	7:15	7:15	6:45	6:15	5:45	5:15	5:15
Bastrop,* 32-47/91-55	C	SR	7:15	7:00	6:15	5:45	5:15	5:00	5:15	5:30	5:45	6:15	6:45	7:00
		SS	5:30	5:45	6:15	6:45	7:00	7:15	7:15	7:00	6:15	5:30	5:00	5:00
Baton Rouge	C	SR	7:00	6:45	6:15	5:45	5:15	5:00	5:15	5:30	5:45	6:00	6:30	7:00
		SS	5:30	5:45	6:15	6:30	6:45	7:15	7:15	6:45	6:15	5:30	5:15	5:00
Hammond, 30-29/90-27	C	SR	7:00	6:45	6:15	5:30	5:00	5:00	5:00	5:30	5:45	6:00	6:30	6:45
		SS	5:15	5:45	6:15	6:30	6:45	7:00	7:00	6:45	6:15	5:30	5:00	5:00
New Orleans*	C	SR	7:00	6:45	6:15	5:30	5:15	5:00	5:15	5:30	5:45	6:00	6:30	6:45
		SS	5:15	5:45	6:15	6:30	6:45	7:00	7:00	6:45	6:00	5:30	5:00	5:00
Opelousas, 30-32/92-07	C	SR	7:00	6:45	6:15	5:30	5:15	5:00	5:15	5:30	5:45	6:15	6:30	7:00
		SS	5:30	6:00	6:15	6:30	7:00	7:15	7:15	6:45	6:15	5:45	5:15	5:15
Shreveport	C	SR	7:15	7:00	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:15	6:45	7:00	7:30	7:30	7:00	6:30	5:45	5:15	5:15
Maine														
Bangor	E	SR	7:15	6:45	5:45	5:00	4:15	3:45	4:00	4:30	5:15	5:45	6:30	7:00
		SS	4:15	5:00	5:45	6:15	7:00	7:15	7:15	6:45	5:45	4:45	4:15	4:00
Portland	E	SR	7:15	6:45	6:00	5:00	4:15	4:00	4:15	4:45	5:15	6:00	6:30	7:15
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:15	4:00
Maryland														
Annapolis, 38-58/76-30	E	SR	7:30	7:00	6:15	5:30	5:00	4:45	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Baltimore*	E	SR	7:30	7:00	6:15	5:30	5:00	4:45	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Cumberland	E	SR	7:30	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	5:45	6:15	6:45	7:15	7:45	7:45	7:15	6:30	5:30	5:00	4:45
Easton,* 38-46/76-04	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Essex *	E	SR	7:30	7:00	6:15	5:30	5:00	4:45	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Frederick	E	SR	7:30	7:00	6:30	5:30	5:00	4:45	5:00	5:15	5:45	6:15	7:00	7:30
		SS	5:15	5:45	6:15	6:45	7:15	7:45	7:30	7:00	6:15	5:30	5:00	4:45
Havre de Grace,*, 39-32/76-05	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Preston, 38-44/75-55	E	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Salisbury, 38-23/75-24	E	SR	7:15	6:45	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Silver Spring, 39-02/77-02	E	SR	7:30	7:00	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Massachusetts														
Boston *	E	SR	7:15	6:45	6:00	5:00	4:30	4:00	4:15	4:45	5:30	6:00	6:30	7:00
		SS	4:30	5:15	5:45	6:30	7:00	7:15	7:15	6:45	6:00	5:00	4:30	4:15
Brockton, 42-04/71-02	E	SR	7:15	6:45	6:00	5:00	4:30	4:00	4:15	4:45	5:30	6:00	6:30	7:15
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:15	4:15
Fall River*	E	SR	7:15	6:45	6:00	5:00	4:30	4:15	4:15	4:45	5:30	6:00	6:30	7:00
		SS	4:45	5:15	5:45	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:30	4:15
Framingham, 42-17/71-25	E	SR	7:15	6:45	6:00	5:00	4:30	4:00	4:15	4:45	5:30	6:00	6:30	7:15
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:30	7:00	6:00	5:00	4:30	4:15
Lawrence*	E	SR	7:15	6:45	6:00	5:00	4:30	4:00	4:15	4:45	5:30	6:00	6:30	7:15
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:30	4:15
Lynn, 42-27/70-58	E	SR	7:15	6:45	6:00	5:00	4:15	4:00	4:15	4:45	5:15	6:00	6:30	7:15
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:15	4:15
North Adams, 42-41/73-06	E	SR	7:30	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:15	7:30	7:30	7:00	6:00	5:15	4:50	4:15
Quincy, 42-15/70-57	E	SR	7:15	6:45	6:00	5:00	4:15	4:00	4:15	4:45	5:15	6:00	6:30	7:15
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:15	4:15
Springfield*	E	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:15	6:00	6:30	7:00	7:30	7:30	6:45	6:00	5:15	4:30	4:15
Waltham, 42-21/71-15	E	SR	7:15	6:45	6:00	5:00	4:30	4:00	4:15	4:45	5:30	6:00	6:30	7:15
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:30	4:15
Ware, 42-14/72-12	E	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:15	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:15	6:00	6:30	7:00	7:30	7:30	6:45	6:00	5:15	4:30	4:15
Worcester *	E	SR	7:45	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:30	7:15
		SS	4:45	5:15	6:00	6:30	7:00	7:30	7:30	6:45	6:00	5:00	4:30	4:15
Michigan														
Adrian, 41-50/84-01	E	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:30	8:00
		SS	5:30	6:15	6:45	7:15	7:45	8:15	8:15	7:30	6:45	6:00	5:15	5:00
Battle Creek, * 42-19/85-11	E	SR	8:15	7:45	7:00	6:00	5:15	5:00	5:15	5:45	6:15	7:00	7:30	8:00
		SS	5:30	6:15	6:45	7:15	8:00	8:15	8:15	7:45	6:45	6:00	5:15	5:00
Bay City,* 43-35/83-53	E	SR	8:15	7:30	6:45	6:00	5:15	4:45	5:00	5:45	6:15	6:45	7:30	8:00
		SS	5:30	6:00	6:45	7:15	8:00	8:15	8:15	7:45	6:45	6:00	5:15	5:00
Benton Harbor, 42-04/86-28	E	SR	8:15	7:45	7:00	6:00	5:30	5:00	5:15	5:45	6:30	7:00	7:30	8:15
		SS	5:30	6:15	6:45	7:30	8:00	8:30	8:15	7:45	7:00	6:00	5:30	5:15
Dearborn, 42-20/83-14	E	SR	8:00	7:30	6:45	6:00	5:15	4:45	5:00	5:30	6:15	6:45	7:30	8:00
		SS	5:30	6:00	6:45	7:15	7:45	8:15	8:15	7:30	6:45	5:45	5:15	5:00
Detroit*	E	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:00	5:45	6:15	6:45	7:15	8:00
		SS	5:30	6:00	6:45	7:15	7:45	8:15	8:15	7:30	6:45	5:45	5:15	5:00
East Lansing	E	SR	8:00	7:30	7:00	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:30	8:00
		SS	5:30	6:15	6:45	7:15	8:00	8:15	8:15	7:45	6:45	6:00	5:15	5:00
Flint*	E	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:30	8:00
		SS	5:30	6:00	6:45	7:15	7:45	8:15	8:15	7:45	6:45	6:00	5:15	5:00
Grand Rapids*	E	SR	8:15	7:45	7:00	6:00	5:15	5:00	5:15	5:45	6:15	7:00	7:30	8:15
		SS	5:30	6:15	6:45	7:30	8:00	8:30	8:15	7:45	7:00	6:00	5:15	5:15
Kalamazoo, 42-19/85-31	E	SR	8:15	7:45	7:00	6:00	5:15	5:00	5:15	5:45	6:15	7:00	7:30	8:00
		SS	5:30	6:15	6:45	7:15	8:00	8:15	8:15	7:45	7:00	6:00	5:15	5:15
Lansing, 42-42/84-31	E	SR	8:15	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:30	8:00
		SS	5:30	6:15	6:45	7:15	8:00	8:15	8:15	7:45	6:45	6:00	5:15	5:00
Marquette, 46-32/87-24	C	SR	7:30	7:00	6:00	5:00	4:15	3:45	4:00	4:45	5:30	6:00	6:45	7:30
		SS	4:30	5:15	6:00	6:30	7:15	7:45	7:45	7:00	6:00	5:00	4:15	4:00
Muskegon, 43-16/86-15	E	SR	8:15	7:45	7:00	6:00	5:15	5:00	5:15	5:45	6:30	7:00	7:45	8:15
		SS	5:30	6:15	6:45	7:30	8:00	8:30	8:30	7:45	7:00	6:00	5:15	5:15
Owosso, 43-01/84-10	E	SR	8:15	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:30	8:00
		SS	5:30	6:00	6:45	7:15	8:00	8:15	8:15	7:45	6:45	6:00	5:15	5:00
Pontiac, 42-36/83-18	E	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:00	5:45	6:15	6:45	7:30	8:00
		SS	5:30	6:00	6:45	7:15	7:45	8:15	8:15	7:30	6:45	6:00	5:15	5:00
Port Huron, 42-57/82-28	E	SR	8:00	7:30	6:45	5:45	5:00	4:45	5:00	5:30	6:15	6:45	7:15	8:00
		SS	5:15	6:00	6:30	7:15	7:45	8:15	8:15	7:30	6:45	5:45	5:00	5:00
Saginaw	E	SR	8:15	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:30	8:00
		SS	5:30	6:00	6:45	7:15	8:00	8:15	8:15	7:45	6:45	6:00	5:15	5:00
Sault Ste. Marie	C	SR	7:15	6:45	6:00	5:00	4:00	3:45	4:00	4:30	5:15	6:00	6:45	7:15
		SS	4:15	5:00	5:45	6:30	7:00	7:30	7:30	6:45	5:45	5:00	4:00	3:45
Minnesota														
Austin, 43-37/92-39	C	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:00	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	7:45	7:15	6:30	5:30	4:45	4:30
Duluth*	C	SR	7:45	7:15	6:30	5:30	4:30	4:15	4:30	5:00	5:45	6:30	7:15	7:45
		SS	4:45	5:30	6:15	7:00	7:30	8:00	8:00	7:15	6:15	5:30	4:30	4:15
Faribault, 44-14/93-16	C	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:30
Fergus Falls	C	SR	8:00	7:30	6:45	5:45	4:45	4:30	4:45	5:15	6:00	6:45	7:30	8:00
		SS	5:00	5:45	6:30	7:15	7:45	8:15	8:15	7:30	6:45	5:45	4:45	4:45

	TZ	SR SS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Minnesota—Continued														
Minneapolis*	C	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:30
Northfield	C	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:30
St. Paul*	C	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:30
Wadena, 46–22/95–08	C	SR	8:00	7:30	6:30	5:30	4:45	4:30	4:45	5:15	6:00	6:30	7:30	8:00
		SS	5:00	5:45	6:30	7:00	7:45	8:15	8:15	7:30	6:30	5:30	4:45	4:30
Worthington, 43–37/95–40	C	SR	8:00	7:30	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	5:45	6:30	7:00	7:45	8:00	8:00	7:30	6:30	5:45	5:00	4:45
Mississippi														
Gulfport	C	SR	7:00	6:45	6:15	5:30	5:00	5:00	5:00	5:30	5:45	6:00	6:15	6:45
		SS	5:15	5:45	6:00	6:15	6:45	7:00	7:00	6:45	6:00	5:30	5:00	5:00
Hattiesburg	C	SR	7:00	6:45	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:00	6:30	6:45
		SS	5:15	5:45	6:00	6:30	6:45	7:00	7:00	6:45	6:00	5:30	5:00	5:00
Jackson	C	SR	7:00	6:45	6:15	5:30	5:00	5:00	5:00	5:30	5:45	6:00	6:30	7:00
		SS	5:30	6:00	6:15	6:30	7:00	7:15	7:15	6:45	6:15	5:30	5:15	5:00
McComb,* 31–14/90–27	C	SR	7:00	6:45	6:15	5:30	5:00	5:00	5:00	5:30	5:45	6:00	6:30	7:00
		SS	5:15	5:45	6:15	6:30	6:45	7:00	7:15	6:45	6:00	5:30	5:00	5:00
Meridian	C	SR	7:00	6:45	6:00	5:30	5:00	4:45	5:00	5:15	5:45	6:00	6:30	6:45
		SS	5:15	5:45	6:00	6:30	6:45	7:00	7:00	6:45	6:00	5:30	5:00	4:45
Vicksburg	C	SR	7:00	6:45	6:15	5:30	5:00	5:00	5:00	5:30	5:45	6:00	6:30	7:00
		SS	5:15	5:45	6:15	6:30	7:00	7:15	7:15	6:45	6:15	5:30	5:00	5:00
Missouri														
Cape Girardeau, 37–19/89–28	C	SR	7:15	6:45	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:15
Clayton*	C	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:00	6:30	7:00	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Columbia	C	SR	7:30	7:00	6:30	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Farmington, * 37–47/90–26	C	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Hannibal, 39–38/91–20	C	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Independence, 39–04/94–27	C	SR	7:30	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Joplin, * 37–05/94–31	C	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Kansas City,* 39–05/94–33	C	SR	7:30	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Kennett, 36–13/90–04	C	SR	7:15	6:45	6:15	5:30	5:00	4:45	4:45	5:15	5:45	6:00	6:45	7:00
		SS	5:00	5:45	6:00	6:30	7:00	7:15	7:15	6:45	6:15	5:30	4:45	4:45
Springfield	C	SR	7:30	7:00	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:00	5:00
St. Joseph	C	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
St. Louis*	C	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:00	6:30	7:00	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Montana														
Billings	M	SR	8:00	7:15	6:30	5:30	4:45	4:30	4:30	5:15	5:45	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:30	6:30	5:30	4:45	4:30
Butte	M	SR	8:15	7:30	6:45	5:45	5:00	4:45	5:00	5:30	6:00	6:45	7:30	8:00
		SS	5:15	6:00	6:30	7:15	8:00	8:15	8:15	7:45	6:45	5:45	5:00	4:45
Great Falls, 47–25/111–16	M	SR	8:15	7:30	6:45	5:45	4:45	4:15	4:45	5:15	6:00	6:45	7:30	8:15
		SS	5:00	5:45	6:30	7:15	8:00	8:30	8:30	7:45	6:45	5:45	4:45	4:30
Havre, 48–34/109–39	M	SR	8:15	7:30	6:30	5:30	4:30	4:15	4:30	5:15	6:00	6:30	7:30	8:00
		SS	4:45	5:45	6:30	7:15	8:00	8:30	8:15	7:30	6:30	5:30	4:45	4:15
Kalispell	M	SR	8:30	7:45	7:00	5:45	5:00	4:30	4:45	5:30	6:15	7:00	7:45	8:15
		SS	5:15	6:00	6:45	7:30	8:15	8:45	8:30	8:00	6:45	5:45	5:00	4:45
Missoula	M	SR	8:15	7:45	6:45	5:45	5:00	4:45	5:00	5:30	6:15	7:00	7:45	8:15
		SS	5:15	6:00	6:45	7:30	8:00	8:30	8:30	7:45	6:45	5:45	5:00	4:45
Wolf Point	M	SR	7:45	7:15	6:15	5:15	4:30	4:00	4:15	5:00	5:45	6:15	7:15	7:45
		SS	4:30	5:30	6:00	6:45	7:30	8:00	8:00	7:15	6:15	5:15	4:30	4:15
Nebraska														
Columbus, 41–26/97–23	C	SR	8:00	7:30	6:45	5:45	5:15	4:45	5:00	5:30	6:15	6:45	7:15	7:45
		SS	5:30	6:00	6:30	7:15	7:45	8:00	8:00	7:30	6:45	5:45	5:15	5:00
Freemont	C	SR	7:45	7:30	6:45	5:45	5:15	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:45	5:45	5:15	5:00
Grand Island	C	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:15	6:45	7:15	7:45	8:00	8:00	7:30	6:45	6:00	5:15	5:00
Lincoln	C	SR	7:45	7:30	6:45	5:45	5:15	5:00	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:45	5:45	5:15	5:00
Norfolk	C	SR	8:00	7:30	6:45	5:45	5:15	4:45	5:00	5:30	6:15	6:45	7:15	7:45
		SS	5:15	6:00	6:30	7:15	7:45	8:00	8:00	7:30	6:45	5:45	5:15	5:00
North Platte	C	SR	8:15	7:45	7:00	6:00	5:30	5:15	5:30	5:45	6:30	7:00	7:30	8:00
		SS	5:45	6:15	6:45	7:15	8:00	8:15	8:15	7:45	7:00	6:00	5:30	5:15
Omaha*	C	SR	7:45	7:15	6:45	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:30	5:45	5:00	5:00
Scotts Bluff	M	SR	7:15	6:45	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:30
Nevada														
Las Vegas, 36–11/115–07	P	SR	7:00	6:30	6:00	5:15	4:30	4:15	4:30	5:00	5:15	5:45	6:15	6:45
		SS	4:45	5:15	5:45	6:15	6:45	7:00	7:00	6:30	5:45	5:00	4:30	4:30
Reno	P	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:15	5:15	4:45	4:30
New Hampshire														
Manchester	E	SR	7:15	6:45	6:00	5:00	4:30	4:00	4:15	4:45	5:30	6:00	6:45	7:15
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:30	6:45	6:00	5:00	4:30	4:15
Nashua, 42–44/71–29	E	SR	7:15	6:45	6:00	5:00	4:30	4:00	4:15	4:45	5:30	6:00	6:45	7:15
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:30	6:45	6:00	5:00	4:15	4:15
Portsmouth	E	SR	7:15	6:45	6:00	5:00	4:15	4:00	4:15	4:45	5:15	6:00	6:30	7:15
		SS	4:30	5:15	5:45	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:15	4:15
New Jersey														
Atlantic City*	E	SR	7:15	6:45	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:00	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:15	5:15	4:45	4:30
Camden*	E	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4.30
Jersey City*	E	SR	7:15	6:45	6:15	5:15	4:45	4:30	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:45	4:30
Newark*	E	SR	7:15	6:45	6:15	5:15	4:45	4:30	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:45	4:30
Paterson	E	SR	7:15	6:45	6:15	5:15	4:45	4:30	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:45	4:30
Trenton*	E	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:15	5:15	4:45	4:30
Zarephath	E	SR	7:15	7:00	6:15	5:15	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:15	5:15	4:45	4:30

	TZ	SR SS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
New Mexico														
Albuquerque	M	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:00	7:15	7:15	7:00	6:15	5:30	5:00	5:00
Gallup	M	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:15	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:00
New York														
Albany*	E	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:15	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:15	7:30	7:30	7:00	6:15	5:15	4:30	4:15
Binghamton	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:30	6:15	6:45	7:15	7:45	7:45	7:00	6:15	5:30	4:45	4:30
Brooklyn*	E	SR	7:15	6:45	6:15	5:15	4:45	4:30	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:45	4:30
Buffalo*	E	SR	7:45	7:15	6:30	5:30	5:00	4:30	4:45	5:15	6:00	6:30	7:00	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	5:00	4:45
Canton	E	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:45	6:15	7:00	7:30
		SS	4:45	5:30	6:00	6:45	7:15	7:45	7:45	7:00	6:15	5:15	4:30	4:15
Cobleskill, 42-40/74-27	E	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:15	6:45	7:30
		SS	4:45	5:30	6:00	6:45	7:15	7:45	7:30	7:00	6:15	5:15	4:30	4:30
Cortland, 42-33/76-09	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:30	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:30	6:15	6:45	7:30	7:45	7:45	7:15	6:15	5:30	4:45	4:30
Elmira	E	SR	7:30	7:00	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:45	6:15	6:45	7:15	7:45	7:45	7:15	6:15	5:30	4:45	4:30
Hempstead, 40-41/73-36	E	SR	7:15	6:45	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:30
Ithaca	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:30	6:15	6:45	7:15	7:45	7:45	7:15	6:15	5:30	4:45	4:30
Jamestown, 42-03/79-14	E	SR	7:45	7:15	6:30	5:45	5:00	4:30	4:45	5:15	6:00	6:30	7:00	7:45
		SS	5:15	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	5:00	4:45
Kenmore, 42-59/78-49	E	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	6:00	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:45
Lackawanna, 42-49/78-47	E	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	6:00	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:45
Newburgh	E	SR	7:15	7:00	6:15	5:15	4:45	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:15	7:30	7:30	7:00	6:15	5:15	4:45	4:30
New York*	E	SR	7:15	6:45	6:15	5:15	4:45	4:30	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:45	4:30
Niagara Falls, 43-07/78-59	E	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:30	5:15	6:00	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:45
Olean	E	SR	7:45	6:15	6:30	5:30	5:00	4:30	4:45	5:15	6:00	6:30	7:00	7:30
		SS	5:00	5:45	6:15	7:00	7:30	7:45	7:45	7:15	6:30	5:30	5:00	4:45
Oneonta, 42-26/75-05	E	SR	7:30	7:00	6:15	5:15	4:45	4:15	4:30	5:00	5:45	6:15	6:45	7:30
		SS	4:45	5:30	6:00	6:45	7:15	7:45	7:45	7:00	6:15	5:15	4:30	4:30
Plattsburg, 44-39/73-26	E	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:15	5:00	5:30	6:15	6:45	7:30
		SS	4:45	5:15	6:00	6:45	7:15	7:45	7:45	7:00	6:15	5:15	4:30	4:15
Rochester*	E	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:00	7:30
		SS	5:00	5:45	6:15	6:45	7:30	7:45	7:45	7:15	6:15	5:30	4:45	4:30
Saranac Lake	E	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:15	6:45	7:30
		SS	4:45	5:30	6:00	6:45	7:15	7:45	7:45	7:00	6:15	5:15	4:30	4:15
Schenectady*	E	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:15	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:15	7:30	7:30	7:00	6:15	5:15	4:30	4:15
Syracuse*	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:30	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:30	6:15	6:45	7:15	7:45	7:45	7:15	6:15	5:30	4:45	4:30
Troy*	E	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:15	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:15	7:30	7:30	7:00	6:15	5:15	4:30	4:15
Utica, 43-07/75-14	E	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:45	6:15	7:00	7:30
		SS	4:45	5:30	6:00	6:45	7:15	7:45	7:45	7:00	6:15	5:15	4:30	4:30
Watertown	E	SR	7:30	7:00	6:15	5:30	4:45	4:15	4:30	5:00	5:45	6:15	7:00	7:30
		SS	4:45	5:30	6:15	6:45	7:15	7:45	7:45	7:15	6:15	5:15	4:45	4:30
North Carolina														
Ahoskie, 36-16/77-01	E	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	5:00
Albemarle, 35-22/80-11	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:15
		SS	5:30	6:00	6:30	7:00	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:15
Asheboro, 35-43/79-48	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	6:45	7:15	7:45	7:30	7:15	6:30	5:45	5:15	5:00
Asheville	E	SR	7:45	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:15
Burlington, 36-05/79-29	E	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:00
Charlotte	E	SR	7:30	7:15	6:30	6:00	5:15	5:15	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Clinton, 35-00/78-17	E	SR	7:15	7:00	6:30	5:45	5:15	5:00	5:00	5:30	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:45	5:15	5:00
Dunn, 35-17/78-35	E	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:15	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:00
Elizabeth City, 36-20/76-14	E	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Fayetteville	E	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:15	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:00
Forest City, 35-20/81-53	E	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:15	5:45	6:15	6:30	7:00	7:30
		SS	5:30	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:30	6:00	5:15	5:15
Gastonia, 35-15/81-08	E	SR	7:30	7:15	6:30	6:00	5:15	5:15	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Greensboro, 36-02/79-48	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Greenville	E	SR	7:15	7:00	6:15	5:45	5:00	5:00	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	5:00
High Point, 35-54/80-01	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Kannapolis, 35-25/80-36	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Kinston, 35-13/77-36	E	SR	7:15	7:00	6:15	5:45	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:00
		SS	5:15	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	5:00
Laurinburg, 34-45/79-25	E	SR	7:15	7:00	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	6:45	7:15
		SS	5:30	6:00	6:30	7:00	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:15
Lexington, 35-50/80-14	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Monroe, 34-58/80-30	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:15
		SS	5:30	6:00	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:15	5:15
Moorehead City, 34-43/76-41	E	SR	7:15	7:00	6:15	5:30	5:00	5:00	5:00	5:30	5:45	6:15	6:45	7:00
		SS	5:15	5:45	6:15	6:45	7:00	7:15	7:15	7:00	6:15	5:45	5:00	5:00
Mount Airy, 36-32/80-35	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:00
North Wilkesboro, 36-11/81-07	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Raleigh	E	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:15	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:00
Reidsville, 36-21/79-42	E	SR	7:50	7:15	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Rockingham, 34-55/79-44	E	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:15

	TZ	SR SS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
North Carolina—Continued														
Rocky Mount, 35-54/77-50	E	SR	7:15	6:45	6:30	5:45	5:15	5:00	5:00	5:30	6:00	6:15	6:45	7:15
		SS	5:15	6:00	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	5:00
Salisbury, 35-40/80-30	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Sanford, 35-26/79-12	E	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:00
Shelby,* 35-17/81-32	E	SR	7:30	7:15	6:45	6:00	5:15	5:15	5:15	5:45	6:15	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Southern Pines, 35-11/79-24	E	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	6:45	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:00
Tarboro, 35-55/77-34	E	SR	7:15	7:00	6:15	5:45	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	5:00
Thomasville, 35-53/80-05	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Wadesboro, 34-57/80-03	E	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:15
Washington	E	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	6:00	6:15	6:45	7:00	7:15	7:00	7:00	6:15	5:30	5:00	5:00
Wilmington	E	SR	7:15	7:00	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:45	5:15	5:00
Wilson,* 35-43/77-54	E	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	5:00
Winston-Salem	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:15
North Dakota														
Bismarck	C	SR	8:30	7:45	7:00	6:00	5:15	4:45	5:00	5:45	6:15	7:00	7:45	8:15
		SS	5:15	6:00	6:45	7:30	8:15	8:45	8:30	8:00	7:00	6:00	5:15	5:00
Fargo	C	SR	8:15	7:30	6:45	5:45	5:00	4:30	4:45	5:30	6:00	6:45	7:30	8:00
		SS	5:00	5:45	6:30	7:15	8:00	8:15	8:15	7:45	6:45	5:45	5:00	4:45
Grand Forks	C	SR	8:15	7:45	6:45	5:45	4:45	4:30	4:45	5:15	6:00	6:45	7:30	8:15
		SS	5:00	5:45	6:30	7:15	8:00	8:30	8:30	7:45	6:45	5:45	4:45	4:30
Mandon, 46-49/100-50	C	SR	8:30	7:45	7:00	6:00	5:15	4:45	5:00	5:45	6:15	7:00	7:45	8:30
		SS	5:15	6:00	6:45	7:30	8:15	8:45	8:45	8:00	7:00	6:00	5:15	4:45
Minot	C	SR	8:30	8:00	7:00	6:00	5:00	4:45	5:00	5:45	6:15	7:00	7:45	8:30
		SS	5:15	6:00	6:45	7:30	8:15	8:45	8:45	8:00	7:00	6:00	5:15	4:45
Ohio														
Akron*	E	SR	7:45	7:15	6:45	5:45	5:15	5:00	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:30	5:45	5:15	5:00
Ashtabula	E	SR	7:45	7:15	6:45	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:30	5:45	5:00	5:00
Bellaire, 40-02/80-46	E	SR	7:45	7:15	6:30	5:45	5:15	5:00	5:00	5:30	6:00	6:30	7:00	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	7:45	7:15	6:30	5:45	5:00	5:00
Cambridge,* 40-01/81-35	E	SR	7:45	7:15	6:45	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:30	5:45	5:15	5:00
Canton*	E	SR	7:45	7:15	6:45	5:45	5:15	5:00	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:30	5:45	5:15	5:00
Cincinnati*	E	SR	8:00	7:30	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:45	7:15	7:45
		SS	5:45	6:15	6:45	7:15	7:45	8:00	8:00	7:30	6:45	6:00	5:30	5:15
Cleveland*	E	SR	8:00	7:30	6:45	5:45	5:15	4:45	5:00	5:30	6:00	6:45	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:45	8:00	8:00	7:30	6:45	5:45	5:15	5:00
Columbus*	E	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:00	6:45	7:15	7:45	8:00	8:00	7:30	6:45	6:00	5:15	5:15
Dayton*	E	SR	8:00	7:30	6:45	6:00	5:30	5:15	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:15	6:45	7:15	7:45	8:00	8:00	7:30	6:45	6:00	5:15	5:15
Findlay,* 41-02/83-39	E	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	8:00
		SS	5:30	6:00	6:45	7:15	7:45	8:15	8:00	7:30	6:45	6:00	5:15	5:00
Mansfield	E	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:00	6:30	7:15	7:45	8:00	8:00	7:30	6:45	5:45	5:15	5:00
Middleton, 39-30/84-21	E	SR	8:00	7:30	6:45	6:00	5:30	5:15	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:15	6:45	7:15	7:45	8:00	8:00	7:30	6:45	6:00	5:15	5:15
Piqua, 40-08/84-16	E	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:15	6:45	7:15	7:45	8:15	8:00	7:45	6:45	6:00	5:15	5:15
Roscoe, 40-16/81-53	E	SR	7:45	7:15	6:45	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:45	5:45	5:15	5:00
Springfield, 39-56/83-50	E	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:15	6:45	7:15	7:45	8:00	8:00	7:30	6:45	6:00	5:15	5:15
Toledo*	E	SR	8:00	7:30	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:30	8:00
		SS	5:30	6:00	6:45	7:15	7:45	8:15	8:15	7:30	6:45	6:00	5:15	5:00
Wooster, 40-47/81-54	E	SR	7:45	7:30	6:45	5:45	5:00	5:00	5:00	5:30	6:00	6:45	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:45	8:00	8:00	7:30	6:45	6:00	5:15	5:00
Youngstown*	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	8:00	5:15	6:30	5:45	5:00	5:00
Oklahoma														
Ardmore	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:30	6:00	5:30	5:15
Chickasha,* 35-02/97-56	C	SR	7:45	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:15
Duncan, 34-31/97-58	C	SR	7:45	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Durant, 34-00/96-24	C	SR	7:30	7:15	6:30	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:15	7:45	7:45	7:15	6:30	6:00	5:15	5:15
Hobart, 35-01/99-05	C	SR	7:45	7:30	6:45	6:00	5:30	5:15	5:30	6:00	6:15	6:45	7:15	7:30
		SS	5:45	6:15	6:45	7:15	7:30	7:45	7:45	7:30	6:45	6:00	5:30	5:30
Lawton	C	SR	7:45	7:15	6:45	6:00	5:45	5:15	5:30	6:00	6:15	6:45	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:30	6:45	6:00	5:30	5:30
Norman	C	SR	7:45	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:15
Oklahoma City*	C	SR	7:45	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:15
Pauls Valley, 34-44/97-14	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:30	6:00	5:30	5:15
Seminole,* 35-14/96-40	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:15	5:45	6:15	6:30	7:00	7:30
		SS	5:30	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:30	6:00	5:15	5:15
Stillwater, 36-05/97-03	C	SR	7:45	7:15	6:45	6:00	5:15	5:15	5:15	5:45	6:15	6:30	7:00	7:30
		SS	5:30	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:30	6:00	5:15	5:15
Tulsa*	C	SR	7:30	7:15	6:30	6:00	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Oregon														
Baker	P	SR	7:30	7:00	6:00	5:15	4:30	4:00	4:15	4:45	5:30	6:00	6:15	7:15
		SS	4:30	5:15	6:00	6:30	7:15	7:45	7:30	7:00	6:00	5:15	4:30	4:15
Corvallis	P	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:30
Eugene, 44-03/123-03	P	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:30
Medford, 42-21/122-54	P	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:00	7:30
		SS	5:00	5:45	6:15	7:00	7:30	7:45	7:45	7:15	6:30	5:30	4:45	4:45
Portland *	P	SR	7:45	7:15	6:30	5:30	4:45	4:15	4:30	5:15	5:45	6:30	7:15	7:45
		SS	4:45	5:30	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:30

	TZ	SR SS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Oregon—Continued														
Roseburg	P	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:00	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	7:45	7:15	6:30	5:30	4:45	4:45
Salem	P	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:30
The Dalles	P	SR	7:45	7:15	6:15	5:15	4:30	4:15	4:30	5:00	5:45	6:15	7:00	7:45
		SS	4:45	5:30	6:15	6:45	7:30	8:00	7:45	7:15	6:15	5:15	4:30	4:15
Pennsylvania														
Allentown, 40-37/75-29	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:30
Altoona*	E	SR	7:30	7:15	6:30	5:30	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	5:45	6:15	6:45	7:15	7:45	7:45	7:15	6:30	5:30	5:00	4:45
Apollo, 40-35/79-31	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Bethlehem, 40-37/75-23	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:30
Bloomsburg, 41-01/76-25	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	4:45	5:45	6:15	6:45	7:15	7:45	7:45	7:00	6:15	5:30	4:45	4:30
Braddock, 40-24/79-51	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	8:00	7:45	7:15	6:30	5:45	5:00	5:00
Butler	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	8:00	7:45	7:15	6:30	5:45	5:00	5:00
Chambersburg, 39-55/77-41	E	SR	7:30	7:00	6:30	5:30	5:00	4:45	5:00	5:15	5:45	6:15	7:00	7:30
		SS	5:15	5:45	6:15	6:45	7:15	7:45	8:00	7:15	6:15	5:30	5:00	4:45
Chester, 39-52/75-22	E	SR	7:15	7:00	6:15	5:15	4:45	4:30	4:45	5:15	5:30	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Clearfield, 41-02/78-26	E	SR	7:45	7:15	6:30	5:30	5:00	4:45	4:45	5:15	6:00	6:30	7:00	7:30
		SS	5:15	5:45	6:15	7:00	7:30	7:45	7:45	7:15	6:30	5:30	5:00	4:45
Doylestown,* 40-18/75-08	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:15	4:45	4:30
Erie*	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	5:45	6:30	7:00	7:30	8:00	8:00	7:15	6:30	5:45	5:00	4:45
Glenside*	E	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:30
Greensburg	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Harrisburg*	E	SR	7:30	7:00	6:15	5:30	5:00	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:45	6:15	6:45	7:15	7:45	7:30	7:00	6:15	5:30	4:45	4:45
Johnstown*	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	5:45	6:15	7:15	7:30	7:45	7:45	7:15	6:30	5:30	5:00	4:45
Lebanon, 40-20/76-29	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:45	6:15	6:45	7:15	7:45	7:30	7:00	6:15	5:30	4:45	4:45
McKeesport, 40-18/79-50	E	SR	7:30	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Nanticoke, 41-13/75-59	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:30	6:15	6:45	7:15	7:45	7:45	7:00	6:15	5:30	4:45	4:30
New Castle	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	8:00	7:15	6:30	5:45	5:00	5:00
New Kensington*	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Norristown, 40-08/75-18	E	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:30
Philadelphia*	E	SR	7:15	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:30
Pittsburgh*	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Reading*	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Scranton*	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:15	6:45	7:15	7:45	7:30	7:00	6:15	5:30	4:45	4:30
Shamokin 40-45/76-31	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	7:00	7:30
		SS	5:00	5:45	6:15	6:45	7:15	7:45	7:30	7:00	6:15	5:30	4:45	4:45
Sharon*	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	8:00	7:15	6:30	5:45	5:00	5:00
Stroudsburg, 40-58/75-11	E	SR	7:30	7:00	6:15	5:30	4:45	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:15	4:45	4:30
Uniontown	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Warren, 41-49/79-06	E	SR	7:45	7:15	6:30	5:45	5:00	4:45	4:45	5:15	6:00	6:30	7:00	7:45
		SS	5:15	5:45	6:15	7:00	7:30	8:00	7:45	7:15	6:30	5:30	5:00	4:45
York	E	SR	7:30	7:00	6:15	5:30	5:00	4:30	4:45	5:15	5:45	6:15	6:45	7:15
		SS	5:00	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	4:45	4:45
Puerto Rico														
San Juan	A	SR	7:00	7:00	6:30	6:15	5:45	5:45	6:00	6:00	6:15	6:15	6:30	6:45
		SS	6:15	6:30	6:30	6:45	6:45	7:00	7:00	6:45	6:30	6:00	5:45	5:45
Ponce	A	SR	7:00	7:00	6:30	6:15	6:00	5:45	6:00	6:15	6:15	6:15	6:30	6:45
		SS	6:15	6:30	6:30	6:45	6:45	7:00	7:00	7:00	6:30	6:00	5:45	6:00
Mayaguez	A	SR	7:00	7:00	6:30	6:15	6:00	5:45	6:00	6:15	6:15	6:15	6:30	6:45
		SS	6:15	6:30	6:45	6:45	7:00	7:00	7:15	7:00	6:30	6:00	5:45	6:00
Rhode Island														
Providence*	E	SR	7:15	6:45	6:00	5:00	4:30	4:15	4:15	4:45	5:30	6:00	6:30	7:00
		SS	4:45	5:15	5:45	6:30	7:00	7:30	7:15	6:45	6:00	5:00	4:30	4:15
South Carolina														
Charleston	E	SR	7:30	7:00	6:30	5:45	5:15	5:15	5:15	5:45	6:00	6:30	6:45	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:15
Columbia	E	SR	7:30	7:15	6:30	6:00	5:30	5:15	5:30	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:15
Dillon, 34-22/79-24	E	SR	7:30	7:00	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:15
Florence, 34-13/79-47	E	SR	7:30	7:00	6:30	5:45	5:15	5:15	5:15	5:30	6:00	6:30	7:00	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:15
Gaffney, 35-02/81-38	E	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:15	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:30	6:00	5:15	5:15
Greenville	E	SR	7:45	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:15
Laurens, 34-30/82-01	E	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:30	6:00	5:30	5:15
Orangeburg* 33-29/80-51	E	SR	7:30	7:15	6:30	6:00	5:30	5:00	5:15	5:45	6:00	6:30	7:00	7:15
		SS	5:30	6:00	6:30	7:00	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:15
Rock Hill* 35-56/81-01	E	SR	7:30	7:15	6:30	6:00	5:15	5:15	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Spartanburg	E	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:30	7:45	7:45	7:15	6:30	6:00	5:30	5:15
Sumter	E	SR	7:30	7:15	6:30	6:00	5:15	5:15	5:15	5:45	6:00	6:30	7:00	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:15

	TZ	SR SS	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
South Dakota														
Aberdeen	C	SR	8:15	7:45	6:45	5:45	5:00	4:45	5:00	5:30	6:15	6:45	7:30	8:00
		SS	5:15	6:00	6:45	7:15	8:00	8:30	8:15	7:45	6:45	5:45	5:00	4:45
Brookings	C	SR	8:00	7:30	6:45	5:45	5:00	4:45	5:00	5:30	6:00	6:45	7:15	8:00
		SS	5:15	6:00	6:30	7:15	7:45	8:15	8:15	7:30	6:45	5:45	5:00	4:45
Pierre	C	SR	8:15	7:45	7:00	6:00	5:15	5:00	5:15	5:45	6:15	7:00	7:30	8:15
		SS	5:30	6:15	6:45	7:30	8:00	8:30	8:30	7:45	7:00	6:00	5:15	5:00
Rapid City	M	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:15	6:00	6:30	7:15	7:45	7:30	7:00	6:00	5:15	4:30	4:15
Sioux Falls	C	SR	8:00	7:30	6:45	5:45	5:00	4:45	5:00	5:30	6:00	6:45	7:15	8:00
		SS	5:15	6:00	6:30	7:15	7:45	8:15	8:00	7:30	6:45	5:45	5:00	4:45
Vermillion	C	SR	8:00	7:30	6:45	5:45	5:00	4:45	5:00	5:30	6:00	6:45	7:15	7:45
		SS	5:15	6:00	6:30	7:15	7:45	8:15	8:00	7:30	6:45	5:45	5:00	5:00
Yankton	C	SR	8:00	7:30	6:45	5:45	5:15	4:45	5:00	5:30	6:15	6:45	7:15	8:00
		SS	5:15	6:00	6:30	7:15	7:45	8:15	8:00	7:30	6:45	5:45	5:15	5:00
Tennessee														
Chattanooga*	C	SR	6:45	6:30	6:00	5:15	4:45	4:30	4:30	5:00	5:30	5:45	6:15	6:45
		SS	4:45	5:30	5:45	6:15	6:30	7:00	7:00	6:30	5:45	5:15	4:30	4:30
Gallatin,* 36-24/86-26	C	SR	7:00	6:30	6:00	5:15	4:45	4:30	4:30	5:00	5:30	6:00	6:30	6:45
		SS	5:00	5:30	6:00	6:15	6:45	7:00	7:00	6:45	6:00	5:15	4:45	4:30
Jackson	C	SR	7:00	6:45	6:15	5:30	4:45	4:45	4:45	5:15	5:30	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	6:45	7:15	7:15	6:45	6:00	5:15	4:45	4:45
Johnson City	C	SR	6:45	6:15	5:45	5:00	4:30	4:15	4:15	4:45	5:15	5:30	6:00	6:30
		SS	4:30	5:15	5:30	6:00	6:30	6:45	6:45	6:15	5:45	5:00	4:15	4:15
Knoxville*	C	SR	6:45	6:30	5:45	5:00	4:30	4:15	4:30	5:00	5:15	5:45	6:15	6:45
		SS	4:45	5:15	5:45	6:15	6:30	7:00	7:00	6:30	5:45	5:00	4:30	4:30
Memphis*	C	SR	7:15	6:45	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:00	6:30	7:00
		SS	5:15	5:45	6:00	6:30	7:00	7:15	7:15	6:45	6:15	5:30	5:00	4:45
Nashville*	C	SR	7:00	6:30	6:00	5:15	4:45	4:30	4:45	5:00	5:30	6:00	6:30	6:45
		SS	5:00	5:30	6:00	6:15	6:45	7:00	7:00	6:45	6:00	5:15	4:45	4:30
Paris, 36-16/88-17	C	SR	7:00	6:45	6:00	5:15	4:45	4:30	4:45	5:15	5:30	6:00	6:30	7:00
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:45
Pulaski, 35-12/87-03	C	SR	7:00	6:30	6:00	5:15	4:45	4:30	4:45	5:00	5:30	6:00	6:30	6:45
		SS	4:45	5:30	6:00	6:15	6:45	7:00	7:00	6:30	6:00	5:15	4:45	4:30
Tullahoma, 35-21/86-13	C	SR	7:00	6:30	6:00	5:15	4:45	4:30	4:45	5:00	5:30	5:45	6:15	6:45
		SS	5:00	5:30	5:45	6:15	6:45	7:00	7:00	6:30	6:00	5:15	4:45	4:30
Texas														
Alice, 27-47/98-04	C	SR	7:30	7:15	6:45	6:00	5:45	5:30	5:45	6:00	6:15	6:30	7:00	7:15
		SS	6:00	6:15	6:45	7:00	7:15	7:30	7:30	7:15	6:45	6:00	5:45	5:30
Amarillo	C	SR	8:00	7:30	7:00	6:15	5:45	5:30	5:45	6:00	6:30	7:00	7:15	7:45
		SS	6:00	6:30	7:00	7:15	7:45	8:00	8:00	7:30	7:00	6:15	5:45	5:30
Athens,* 32-12/95-51	C	SR	7:30	7:00	6:30	6:00	5:30	5:15	5:30	5:45	6:00	6:30	7:00	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	5:45	5:30	5:15
Austin,* 30-16/97-44	C	SR	7:30	7:15	6:45	6:00	5:30	5:30	5:45	6:00	6:15	6:30	7:00	7:15
		SS	5:45	6:15	6:45	7:00	7:15	7:30	7:30	7:15	6:45	6:00	5:30	5:30
Beaumont, 30-03/94-06	C	SR	7:15	7:00	6:30	5:45	5:30	5:15	5:30	5:45	6:00	6:15	6:45	7:00
		SS	5:45	6:00	6:30	6:45	7:00	7:15	7:15	7:00	6:15	5:45	5:15	5:15
Bonham,* 33-35/96-10	C	SR	7:30	7:15	6:30	6:00	5:30	5:15	5:30	5:45	6:00	6:30	7:00	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:15
Brady	C	SR	7:30	7:15	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:45	7:00	7:30
		SS	6:00	6:30	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:45	5:30
Breckenridge, 32-44/98-55	C	SR	7:45	7:15	6:45	6:00	5:30	5:30	5:30	6:00	6:15	6:45	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Brenham, 30-10/96-24	C	SR	7:30	7:00	6:30	6:00	5:30	5:30	5:30	5:45	6:15	6:30	6:45	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Brownsville	C	SR	7:15	7:00	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:30	6:45	7:15
		SS	6:00	6:30	6:45	7:00	7:15	7:30	7:30	7:00	6:30	6:00	5:45	5:45
Canyon, 34-59/101-58	C	SR	8:00	7:30	7:00	6:15	5:45	5:30	5:45	6:00	6:30	7:00	7:15	7:45
		SS	6:00	6:30	7:00	7:15	7:45	8:00	8:00	7:30	7:00	6:15	5:45	5:30
Childress, 35-25/100-13	C	SR	7:45	7:30	6:45	6:00	5:30	5:30	5:30	6:00	6:15	6:45	7:15	7:30
		SS	5:45	6:15	6:45	7:15	7:30	8:00	8:00	7:30	6:45	6:00	5:30	5:30
Cleburne, 32-23/97-24	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:15	7:45	7:45	7:15	6:30	6:00	5:30	5:30
Coleman, 31-51/99-25	C	SR	7:30	7:15	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:45	7:00	7:30
		SS	6:00	6:30	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:45	5:30
College Station	C	SR	7:30	7:15	6:30	6:00	5:30	5:15	5:30	5:45	6:15	6:30	6:45	7:15
		SS	5:45	6:15	6:30	6:45	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Corpus Christi	C	SR	7:30	7:15	6:45	6:00	5:45	5:30	5:45	6:00	6:15	6:30	6:45	7:15
		SS	6:00	6:15	6:45	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:45	5:30
Dalhart,* 36-04/102-31	C	SR	8:00	7:45	7:00	6:15	5:45	5:30	5:45	6:00	6:30	7:00	7:30	8:00
		SS	6:00	6:30	7:00	7:30	7:45	8:15	8:15	7:45	7:00	6:15	5:45	5:30
Dallas*	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:15
Dublin	C	SR	7:30	7:15	6:45	6:00	5:30	5:30	5:30	6:00	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Dumas,* 35-51/101-58	C	SR	8:00	7:30	7:00	6:15	5:45	5:30	5:45	6:00	6:30	7:00	7:30	7:45
		SS	6:00	6:30	7:00	7:15	7:45	8:00	8:00	7:45	7:00	6:15	5:45	5:30
Eastland 32-24/98-46	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	6:00	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Edinburg, 26-20/98-09	C	SR	7:30	7:15	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:30	7:00	7:15
		SS	6:00	6:30	6:45	7:00	7:15	7:30	7:30	7:15	6:45	6:00	5:45	5:45
El Campo 29-12/96-15	C	SR	7:15	7:00	6:30	6:00	5:30	5:30	5:30	6:00	6:15	6:30	6:45	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
El Paso*	C	SR	8:00	7:45	7:15	6:45	6:15	6:00	6:15	6:30	6:45	7:15	7:30	8:00
		SS	6:30	6:45	7:15	7:30	8:00	8:15	8:15	7:45	7:15	6:30	6:00	6:00
Fort Worth*	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:15	7:45	7:45	7:15	6:30	6:00	5:30	5:30
Gainesville, 33-37/90-06	C	SR	7:00	6:45	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:00	6:30	7:00
		SS	5:15	5:45	6:15	6:30	7:00	7:15	7:15	6:45	6:15	5:30	5:00	5:00
Galveston, 29-19/94-46	C	SR	7:15	7:00	6:30	6:00	5:30	5:15	5:30	5:45	6:00	6:15	6:45	7:00
		SS	5:45	6:00	6:30	6:45	7:00	7:15	7:15	7:00	6:30	5:45	5:30	5:15
Goose Creek, 29-43/94-56	C	SR	7:15	7:00	6:30	6:00	5:30	5:15	5:30	5:45	6:00	6:15	6:45	7:00
		SS	5:45	6:15	6:30	6:45	7:00	7:15	7:30	7:00	6:30	5:45	5:30	5:15
Graham,* 33-06/98-35	C	SR	7:45	7:15	6:45	6:00	5:30	5:30	5:30	6:00	6:15	6:45	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Henderson, 32-08/94-47	C	SR	7:15	7:00	6:30	5:45	5:15	5:15	5:15	5:45	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:15
Hillsboro, 32-01/97-06	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Houston*	C	SR	7:15	7:00	6:30	6:00	5:30	5:15	5:30	5:45	6:00	6:30	6:45	7:15
		SS	5:45	6:15	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:30	5:30
Huntsville	C	SR	7:15	7:00	6:30	6:00	5:30	5:15	5:30	5:45	6:00	6:30	6:45	7:15
		SS	5:45	6:15	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:30	5:30
Kingsville,* 27-31/97-52	C	SR	7:30	7:15	6:45	6:00	5:45	5:30	5:45	6:00	6:15	6:30	7:00	7:15
		SS	6:00	6:15	6:45	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:45	5:30
Lamesa, 32-42/101-56	C	SR	7:45	7:30	7:00	6:15	5:45	5:30	5:45	6:15	6:30	6:45	7:15	7:45
		SS	6:00	6:30	7:00	7:15	7:45	8:00	8:00	7:30	7:00	6:15	5:45	5:45
Longview	C	SR	7:15	7:00	6:30	5:45	5:15	5:15	5:15	5:45	6:00	6:30	6:45	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:15
Lubbock	C	SR	8:00	7:30	7:00	6:15	5:45	5:30	5:45	6:15	6:30	6:45	7:15	7:45
		SS	6:00	6:30	7:00	7:15	7:45	8:00	8:00	7:30	7:00	6:15	5:45	5:45

	TZ	SR SS	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Texas—Continued														
Lufkin	C	SR	7:15	7:00	6:30	6:00	5:30	5:15	5:30	5:45	6:00	6:15	6:45	7:15
		SS	5:45	6:00	6:30	6:45	7:15	7:30	7:30	7:00	6:30	6:45	5:15	5:15
McKinney, 33-11/96-39	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:15	7:45	7:45	7:15	6:30	6:00	5:30	5:30
Midland, 31-58/102-06	C	SR	7:45	7:30	7:00	6:15	5:45	5:45	5:45	6:15	6:30	6:45	7:15	7:45
		SS	6:00	6:30	7:00	7:15	7:45	8:00	8:00	7:30	7:00	6:15	5:45	5:45
Mineral Wells, 32-47/98-06	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	6:00	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Nacogdoches, 31-36/94-37	C	SR	7:15	7:00	6:30	5:45	5:15	5:15	5:15	5:45	6:00	6:15	6:45	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:15
Oak Cliff, 32-43/96-47	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:15
		SS	5:45	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:15
Odessa, 31-46/102-21	C	SR	7:45	7:30	7:00	6:30	6:00	5:45	6:00	6:15	6:30	7:00	7:15	7:45
		SS	6:15	6:30	7:00	7:30	7:45	8:00	8:00	7:45	7:00	6:15	5:45	5:45
Orange, 30-08/93-45	C	SR	7:15	7:00	6:30	5:45	5:15	5:15	5:30	5:45	6:00	6:15	6:45	7:00
		SS	5:30	6:00	6:30	6:45	7:00	7:15	7:15	7:00	6:15	5:45	5:15	5:15
Palestine	C	SR	7:30	7:00	6:30	6:00	5:30	5:15	5:30	5:45	6:00	6:30	6:45	7:15
		SS	5:45	6:15	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:30	5:15
Plainview	C	SR	8:00	7:30	7:00	6:15	5:45	5:00	5:45	6:00	6:30	6:45	7:15	7:45
		SS	6:00	6:30	7:00	7:15	7:45	8:00	8:00	7:30	7:00	6:15	5:15	5:15
Port Arthur	C	SR	7:15	7:00	6:30	5:45	5:15	5:15	5:15	5:45	6:00	6:15	6:30	7:00
		SS	5:30	6:00	6:15	6:30	7:00	7:15	7:15	7:00	6:15	5:45	5:45	5:15
San Angelo, 31-29/100-28	C	SR	7:45	7:30	7:00	6:15	5:45	5:30	5:45	6:00	6:30	6:45	7:15	7:30
		SS	6:00	6:30	6:45	7:15	7:30	7:45	7:45	7:30	6:45	6:15	5:45	5:45
San Antonio*	C	SR	7:30	7:15	6:45	6:15	5:45	5:30	5:45	6:00	6:15	6:30	7:00	7:15
		SS	6:00	6:30	6:45	7:00	7:15	7:30	7:30	7:15	6:45	6:00	5:45	5:30
Sherman	C	SR	7:30	7:15	6:45	6:00	5:30	5:15	5:30	5:45	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:30	7:00	7:15	7:45	7:45	7:15	6:30	6:00	5:30	5:15
Stephenville, 32-13/98-13	C	SR	7:30	7:15	6:45	6:00	5:30	5:30	5:30	6:00	6:15	6:30	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Taylor,* 30-34/97-24	C	SR	7:30	7:15	6:45	6:00	5:30	5:30	5:30	6:00	6:15	6:30	7:00	7:15
		SS	5:45	6:15	6:45	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Texas City, 29-25/94-56	C	SR	7:15	7:00	6:30	6:00	5:30	5:15	5:30	5:45	6:00	6:15	7:00	7:00
		SS	5:45	6:15	6:30	6:45	7:00	7:15	7:15	7:00	6:30	5:45	5:30	5:15
Tyler, 32-19/95-17	C	SR	7:30	7:00	6:30	6:00	5:30	5:15	5:15	5:45	6:00	6:30	6:45	7:15
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:15	5:15
Victoria	C	SR	7:30	7:15	6:45	6:00	5:30	5:30	5:45	6:00	6:15	6:30	6:45	7:15
		SS	6:00	6:15	6:30	7:00	7:15	7:30	7:30	7:15	6:30	6:00	5:30	5:30
Wichita Falls	C	SR	7:45	7:15	6:45	6:00	5:30	5:15	5:30	6:00	6:15	6:45	7:00	7:30
		SS	5:45	6:15	6:45	7:00	7:30	7:45	7:45	7:15	6:45	6:00	5:30	5:30
Territory of Hawaii														
Honolulu (local)	----	SR	6:45	6:30	6:15	5:45	5:30	5:15	5:30	5:45	5:45	6:00	6:15	6:30
		SS	5:45	6:00	6:15	6:15	6:30	6:45	6:45	6:30	6:00	5:30	5:15	5:15
Utah														
Blanding*, 37-37/109-29	M	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Brigham City, 41-31/112-02	P	SR	7:00	6:30	5:45	4:45	4:15	3:45	4:00	4:30	5:00	5:45	6:15	6:45
		SS	4:15	5:00	5:30	6:15	6:45	7:00	7:00	6:30	5:45	4:45	4:15	4:00
Ogden	M	SR	8:00	7:30	6:45	5:45	5:15	5:00	5:00	5:30	6:15	6:45	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:45	8:00	8:00	7:30	6:45	5:45	5:15	5:00
Provo, 40-12/111-40	M	SR	7:45	7:15	6:45	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:30	5:45	5:15	5:00
Richfield, 38-45/112-04	M	SR	7:45	7:15	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:30	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:45	5:45	5:15	5:00
Salt Lake City*	M	SR	7:45	7:30	6:45	5:45	5:15	5:00	5:15	5:30	6:15	6:45	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:45	5:45	5:15	5:00
Vermont														
Burlington, 44-31/73-12	E	SR	7:30	7:00	6:00	5:00	4:30	4:00	4:15	5:00	5:30	6:00	6:45	7:30
		SS	4:45	5:15	6:00	6:30	7:15	7:45	7:30	7:00	6:00	5:15	4:30	4:15
Rutland	E	SR	8:00	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:45	6:15	7:00	7:30
		SS	5:00	5:30	6:00	6:30	7:00	7:15	7:15	6:45	6:00	5:15	4:45	4:30
Springfield	E	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:15	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:15	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
St. Albans	E	SR	7:30	7:00	6:15	5:15	4:30	4:00	4:15	5:00	5:30	6:00	6:45	7:30
		SS	4:30	5:15	6:00	6:30	7:15	7:45	7:30	7:00	6:00	5:15	4:30	4:15
Waterbury	E	SR	7:30	7:00	6:00	5:15	4:30	4:00	4:15	4:45	5:30	6:00	6:45	7:15
		SS	4:30	5:15	6:00	6:30	7:15	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Virginia														
Bristol, 35-59/82-11	C	SR	6:45	6:15	5:45	5:00	4:15	4:00	4:15	4:45	5:15	5:30	6:00	6:30
		SS	4:30	5:15	5:30	6:00	6:30	6:45	6:45	6:15	5:45	5:00	4:15	4:15
Crewe, 37-11/78-10	E	SR	7:30	7:00	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	5:00
Danville	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	6:45	7:15	7:30	7:30	7:15	6:30	5:45	5:15	5:00
Farmville, 37-19/78-23	E	SR	7:30	7:00	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:15	7:00	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:30	5:45	5:00	5:00
Fredericksburg	E	SR	7:30	7:00	6:30	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Harrisonburg	E	SR	7:30	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:30	6:15	6:45	7:15	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Lynchburg, 37-24/79-09	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	6:45	7:15	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Martinsville	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Norfolk*	E	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Petersburg	E	SR	7:30	7:00	6:30	5:45	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	5:00
Portsmouth, 36-52/76-21	E	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:15	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Richmond*	E	SR	7:30	7:00	6:30	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:15	7:30	7:30	7:00	6:15	5:30	5:00	5:00
Roanoke*	E	SR	7:30	7:15	6:30	5:45	5:15	5:00	5:15	5:30	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:15	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Suffolk	E	SR	7:15	7:00	6:15	5:30	5:00	4:45	5:00	5:30	5:45	6:15	6:45	7:15
		SS	5:15	5:45	6:15	6:45	7:00	7:30	7:30	7:00	6:15	5:30	5:00	4:45
Washington														
Everett	P	SR	8:00	7:15	6:30	5:15	4:30	4:15	4:30	5:00	5:45	6:30	7:15	7:45
		SS	4:45	5:30	6:15	7:00	7:45	8:15	8:00	7:30	6:30	5:15	4:30	4:45
Kirkland, 47-40/122-12	P	SR	8:00	7:15	6:30	5:30	4:30	4:15	4:30	5:00	5:45	6:30	7:15	7:45
		SS	4:45	5:30	6:15	7:00	7:30	8:15	8:00	7:15	6:30	5:30	4:30	4:15
Mount Vernon	P	SR	8:00	7:15	6:30	5:15	4:30	4:00	4:15	5:00	5:45	6:30	7:15	8:00
		SS	4:45	5:30	6:15	7:00	7:45	8:15	8:00	7:30	6:30	5:30	4:30	4:15
Olympia	P	SR	8:00	7:15	6:30	5:30	4:30	4:15	4:30	5:00	5:45	6:30	7:15	7:45
		SS	4:45	5:30	6:15	7:00	7:45	8:15	8:00	7:30	6:30	5:30	4:45	4:15
Omak, 48-23/119-32	P	SR	7:45	7:15	6:15	5:15	4:15	3:45	4:15	4:45	5:30	6:15	7:00	7:45
		SS	4:30	5:15	6:00	6:45	7:30	8:00	8:00	7:15	6:15	5:15	4:15	4:00
Pullman	P	SR	7:30	7:00	6:00	5:00	4:15	4:00	4:15	4:45	5:30	6:00	6:45	7:30
		SS	4:30	5:15	6:00	6:30	7:15	7:45	7:45	7:00	6:00	5:00	4:15	4:00
Renton, 47-29/122-12	P	SR	8:00	7:15	6:30	5:15	4:30	4:00	4:15	5:00	5:45	6:30	7:15	7:45
		SS	4:45	5:30	6:15	7:00	7:45	8:15	8:00	7:30	6:30	5:15	4:30	4:15

	TZ	SR SS	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Washington—Continued														
Seattle*	P	SR	8:00	7:15	6:30	5:30	4:30	4:15	4:30	5:00	5:45	6:30	7:15	7:45
		SS	4:45	5:30	6:15	7:00	7:45	8:15	8:00	7:30	6:30	5:30	4:30	4:15
Spokane*	P	SR	7:30	7:00	6:00	5:00	4:15	3:45	4:00	4:45	5:30	6:15	7:00	7:30
		SS	4:30	5:15	6:00	6:45	7:15	7:45	7:45	7:00	6:00	5:00	4:15	4:00
Tacoma*	P	SR	8:00	7:15	6:30	5:30	4:30	4:15	4:30	5:00	5:45	6:30	7:15	7:45
		SS	4:45	5:30	6:15	7:00	7:45	8:15	8:00	7:30	6:30	5:30	4:30	4:15
Vancouver*	P	SR	7:45	7:15	6:30	5:30	4:45	4:15	4:30	5:15	5:45	6:30	7:15	7:45
		SS	4:45	5:30	6:15	7:00	7:30	8:00	8:00	7:15	6:30	5:30	4:45	4:30
Walla Walla, 46-04/118-24	P	SR	7:30	7:00	6:15	5:15	4:30	4:00	4:15	5:00	5:30	6:15	6:45	7:30
		SS	4:30	5:15	6:00	6:45	7:15	7:45	7:45	7:00	6:00	5:15	4:30	4:15
Wenatchee	P	SR	7:45	7:15	6:15	5:15	4:30	4:00	4:15	5:00	5:30	6:15	7:00	7:45
		SS	4:30	5:30	6:00	6:45	7:30	8:00	8:00	7:15	6:15	5:15	4:30	4:15
Yakima	P	SR	7:45	7:15	6:15	5:15	4:30	4:00	4:15	5:00	5:45	6:15	7:00	7:45
		SS	4:45	5:30	6:00	6:45	7:30	8:00	8:00	7:15	6:15	5:15	4:30	4:15
West Virginia														
Bluefield	E	SR	7:45	7:15	6:45	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Charleston*	E	SR	7:45	7:15	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:30	7:15	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:15
Clarksburg, 39-14/80-23	E	SR	7:45	7:15	6:30	5:45	5:15	5:00	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Fairmont	E	SR	7:45	7:15	6:30	5:45	5:15	4:45	5:00	5:30	6:00	6:30	7:00	7:30
		SS	5:15	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:00	5:00
Huntington*	E	SR	7:45	7:15	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:45	7:15	7:45
		SS	5:30	6:00	6:30	7:00	7:30	8:00	8:00	7:30	6:45	6:00	5:15	5:15
Logan	E	SR	7:45	7:15	6:45	6:00	5:15	5:00	5:15	5:45	6:15	6:30	7:15	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:30	6:45	6:00	5:15	5:15
Oak Hill, 37-57/81-08	E	SR	7:45	7:15	6:30	5:45	5:15	5:00	5:15	5:45	6:00	6:30	7:00	7:30
		SS	5:30	6:00	6:30	7:00	7:30	7:45	7:45	7:15	6:30	5:45	5:15	5:00
Wheeling*	E	SR	7:45	7:15	6:30	5:45	5:15	5:00	5:00	5:30	6:00	6:30	7:15	7:45
		SS	5:15	6:00	6:30	7:00	7:30	8:00	7:45	7:15	6:30	5:45	5:15	5:00
Wisconsin														
Beloit,* 42-30/89-02	C	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:15	6:45	7:15
		SS	4:45	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:15	4:30	4:15
Eau Claire	C	SR	7:45	7:15	6:15	5:30	4:45	4:15	4:30	5:00	5:45	6:15	7:00	7:30
		SS	4:45	5:30	6:15	6:45	7:30	8:00	7:45	7:15	6:15	5:30	4:45	4:30
Greenbay	C	SR	7:30	7:00	6:15	5:15	4:30	4:00	4:15	5:00	5:30	6:00	6:45	7:15
		SS	4:30	5:15	6:00	6:30	7:15	7:45	7:30	7:00	6:00	5:15	4:30	4:15
Kenosha, 42-35/87-49	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:15	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
La Crosse	C	SR	7:45	7:00	6:15	5:30	4:45	4:15	4:30	5:15	5:45	6:15	7:00	7:30
		SS	4:45	5:30	6:15	6:45	7:30	7:45	7:45	7:15	6:15	5:30	4:45	4:30
Madison	C	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:15	6:45	7:30
		SS	4:45	5:30	6:00	6:45	7:15	7:45	7:30	7:00	6:15	5:15	4:30	4:30
Marinette	C	SR	7:30	7:00	6:00	5:15	4:15	4:00	4:15	4:45	5:30	6:00	6:45	7:30
		SS	4:30	5:15	6:00	6:30	7:15	7:45	7:30	7:00	6:00	5:15	4:30	4:15
Milwaukee*	C	SR	7:30	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:15	6:00	6:30	7:15	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Neenah, 44-09/88-25	C	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:15	5:00	5:30	6:00	6:45	7:30
		SS	4:45	5:15	6:00	6:30	7:15	7:45	7:30	7:00	6:00	5:15	4:30	4:15
Racine*	C	SR	7:15	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:15	6:00	6:30	7:00	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Rice Lake	C	SR	7:45	7:15	6:30	5:30	4:45	4:15	4:30	5:00	5:45	6:15	7:00	7:45
		SS	4:45	5:30	6:15	6:45	7:30	8:00	8:00	7:15	6:15	5:30	4:45	4:30
Rolling, 45-06/89-08	C	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:15	5:00	5:30	6:15	7:00	7:30
		SS	4:45	5:30	6:00	6:45	7:15	7:45	7:45	7:00	6:15	5:15	4:30	4:15
Sheboygan	C	SR	7:30	6:45	6:00	5:15	4:30	4:15	4:15	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:15	6:00	6:30	7:15	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Stevens Point	C	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:15	7:00	7:30
		SS	4:45	5:30	6:00	6:45	7:15	7:45	7:45	7:00	6:15	5:15	4:30	4:15
Waukesha, 43-01/88-15	C	SR	7:30	6:45	6:00	5:15	4:30	4:15	4:30	5:00	5:30	6:00	6:45	7:15
		SS	4:45	5:30	6:00	6:30	7:15	7:30	7:30	7:00	6:00	5:15	4:30	4:15
Wisconsin Rapids	C	SR	7:30	7:00	6:15	5:15	4:30	4:15	4:30	5:00	5:30	6:15	7:00	7:30
		SS	4:45	5:30	6:00	6:45	7:15	7:45	7:45	7:00	6:15	5:15	4:30	4:15
Wyoming														
Cheyenne	M	SR	7:30	7:00	6:15	5:15	4:45	4:30	4:45	5:00	5:45	6:15	6:45	7:15
		SS	5:00	5:30	6:00	6:45	7:15	7:30	7:30	7:00	6:15	5:15	4:45	4:30
Powell, 44-47/108-47	M	SR	7:45	7:15	6:30	5:30	4:45	4:30	4:45	5:15	5:45	6:30	7:15	7:45
		SS	5:00	5:45	6:15	7:00	7:30	8:00	8:00	7:30	6:30	5:30	4:45	4:30
Rock Springs, 41-37/109-14	M	SR	7:45	7:15	6:30	5:45	5:00	4:45	5:00	5:30	6:00	6:30	7:00	7:45
		SS	5:15	5:45	6:15	7:00	7:30	8:00	7:45	7:15	6:30	5:30	5:00	4:45
Sheridan, 44-48/106-57	M	SR	7:45	7:15	6:15	5:30	4:45	4:15	4:30	5:15	5:45	6:15	7:00	7:45
		SS	4:45	5:30	6:15	6:45	7:30	8:00	7:45	7:15	6:15	5:30	4:45	4:30

[F. R. Doc. 48-5104; Filed, June 4, 1948; 12:24 p. m.]

APPENDIX I

GROUNDWAVE FIELD INTENSITY CHARTS

Graphs 1–20 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 electromagnetic units$\times 10^{14}$ or expressed in mhos per meter$\times 10^{3}$) 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.

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.

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 Atmosphere," 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, "Ergebrisse einer Theorie uber die Fortpflanzung elektromagnetischer Wellen uber 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 $(4/3)^{\frac{3}{2}}=1.21$. 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_s	1.53	1.43
Polar Continental—P_s	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.

Provided the value of the dielectric constant is near 15, the curves of Graphs 1–20 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 1–20 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 21 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 21, 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 $50/f_{mc}^{\frac{1}{2}}$ 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 21 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 21. 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 21 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.

$$x \cong \frac{\pi}{p_1} \cdot (R/\lambda)_1 \cdot \cos b \qquad (1)$$

$(R/\lambda)_1$=Number of wavelengths in 1 mile.

$$\sigma_{e.m.u.} = \frac{x f_{mc}}{17.9731} \cdot 10^{-14} \qquad (2)$$

$\sigma_{e.m.u.}$=Conductivity of the ground expressed in electromagnetic units.

f_{mc}=frequency expressed in megacycles.

$$\epsilon \cong x \tan b - 1 \qquad (3)$$

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 $50/f_{mc}^{\frac{1}{2}}$ miles the curves of Graph 21 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.

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 21 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 21, 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 21, calculate the value of the numerical distance, p, at 1 mile and the value of b. Then superimpose the log-log chart over Graph 21, 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 21 coincides with 1 mile on the log-log graph paper. The curve of Graph 21 corresponding to the calculated value of b is then traced on the log-log graph paper giving the field intensity versus distance in miles.

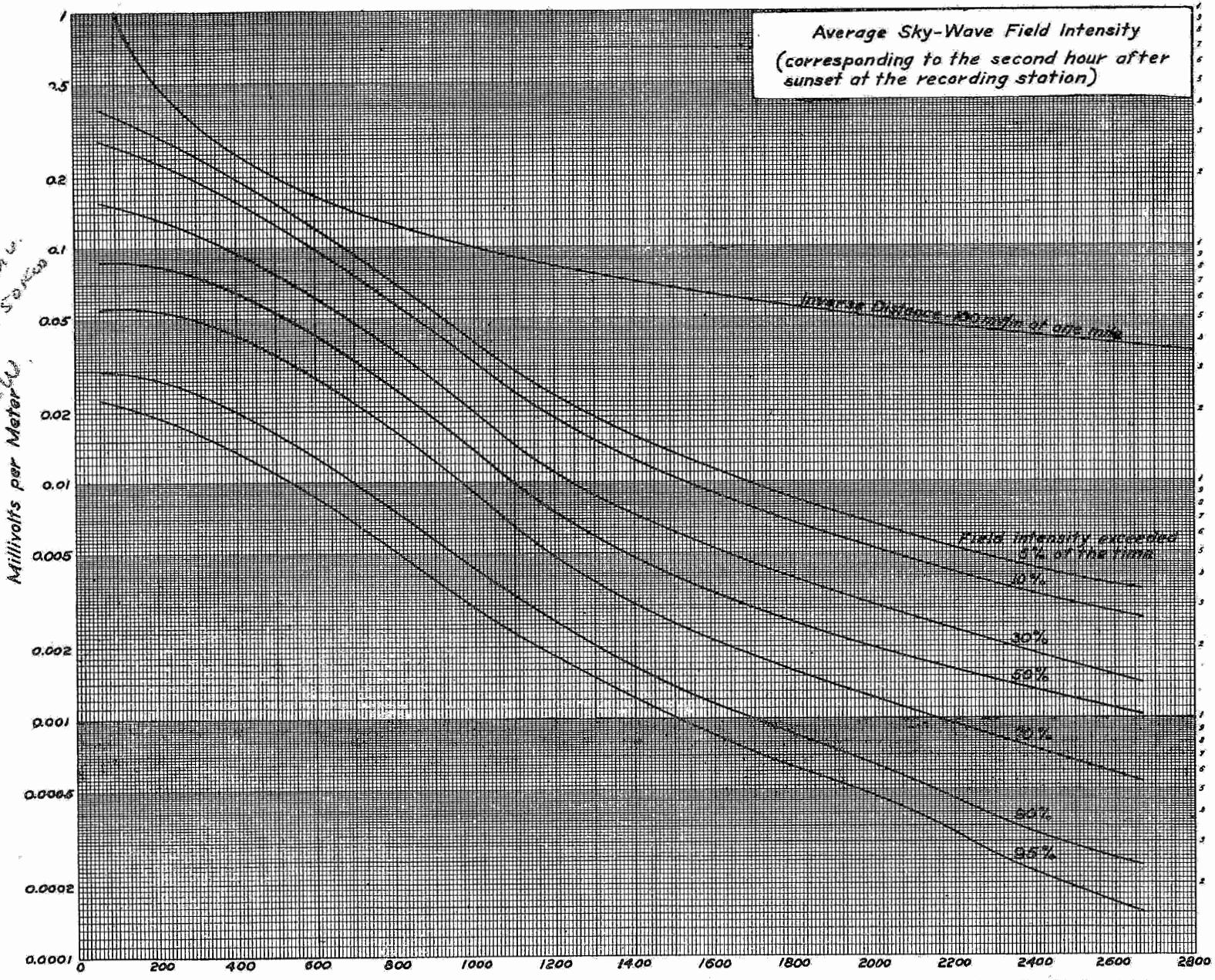
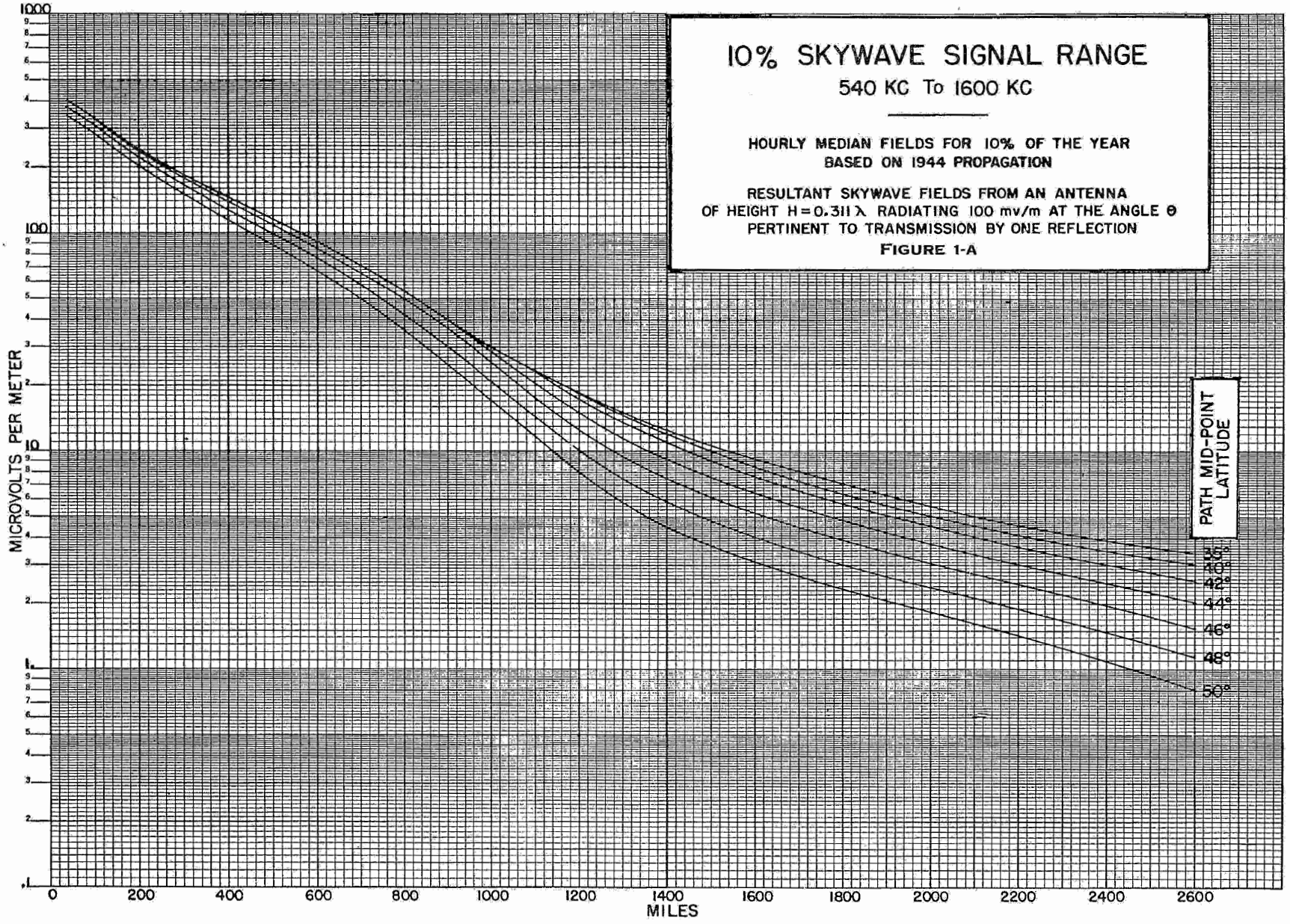


Figure 1

These curves are not considered to be sufficiently accurate for practical use for distances less than approximately 250 miles.


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 λ RADIATING 100 mv/m AT THE ANGLE θ
PERTINENT TO TRANSMISSION BY ONE REFLECTION
FIGURE 1-A
MICROVOLTS PER METER
1000
100
10
1
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
MILES
PATH MID-POINT LATITUDE
36°
40°
42°
44°
46°
48°
50°

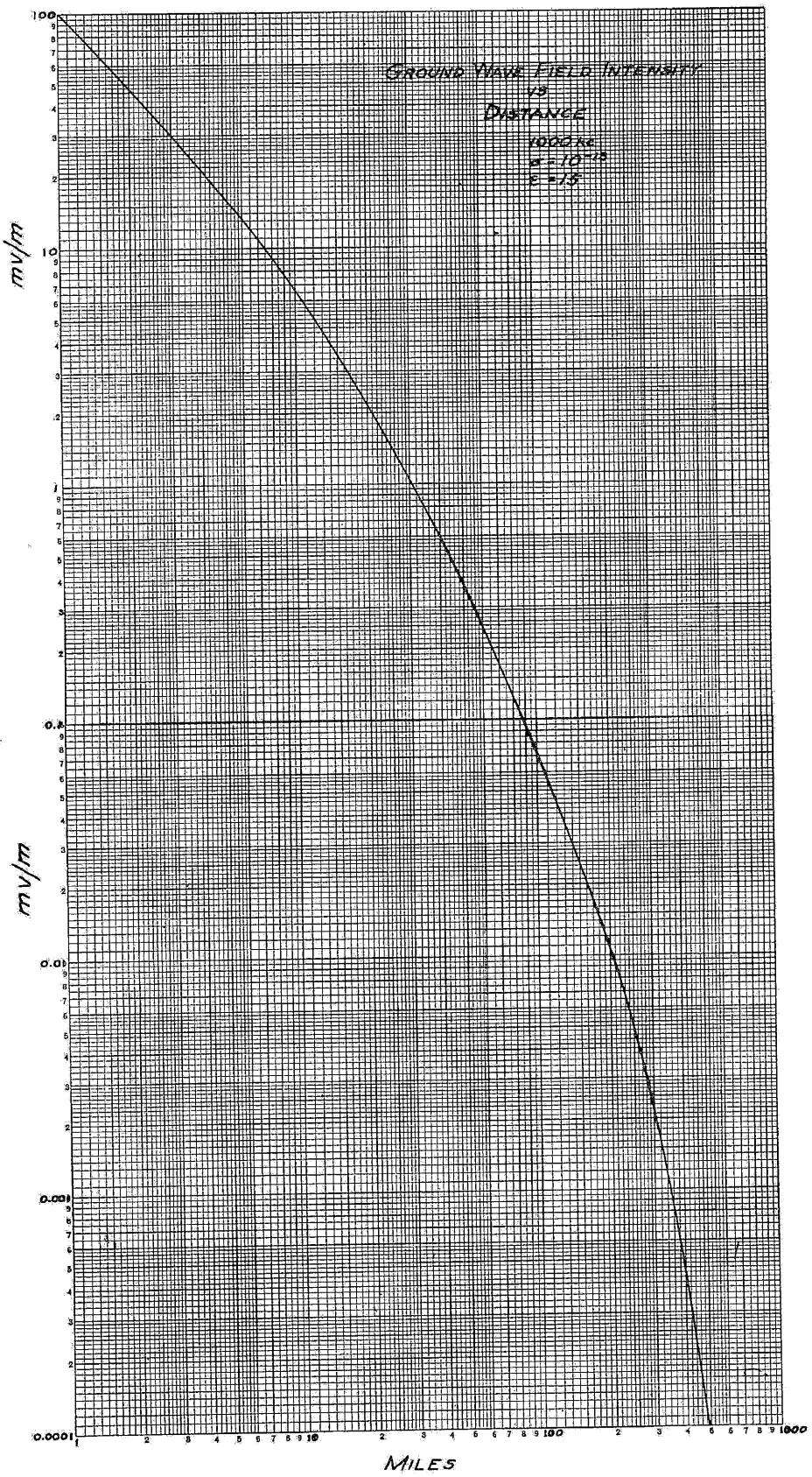

GROUND WAVE FIELD INTENSITY
VS
DISTANCE
1000 KC
σ = 10⁻¹³
ε = 15
mv/m
mv/m
100
10
1
0.1
0.01
0.001
0.0001
1
2
3
4
5
6
7
8
9
10
100
1000
MILES

Fig. 2

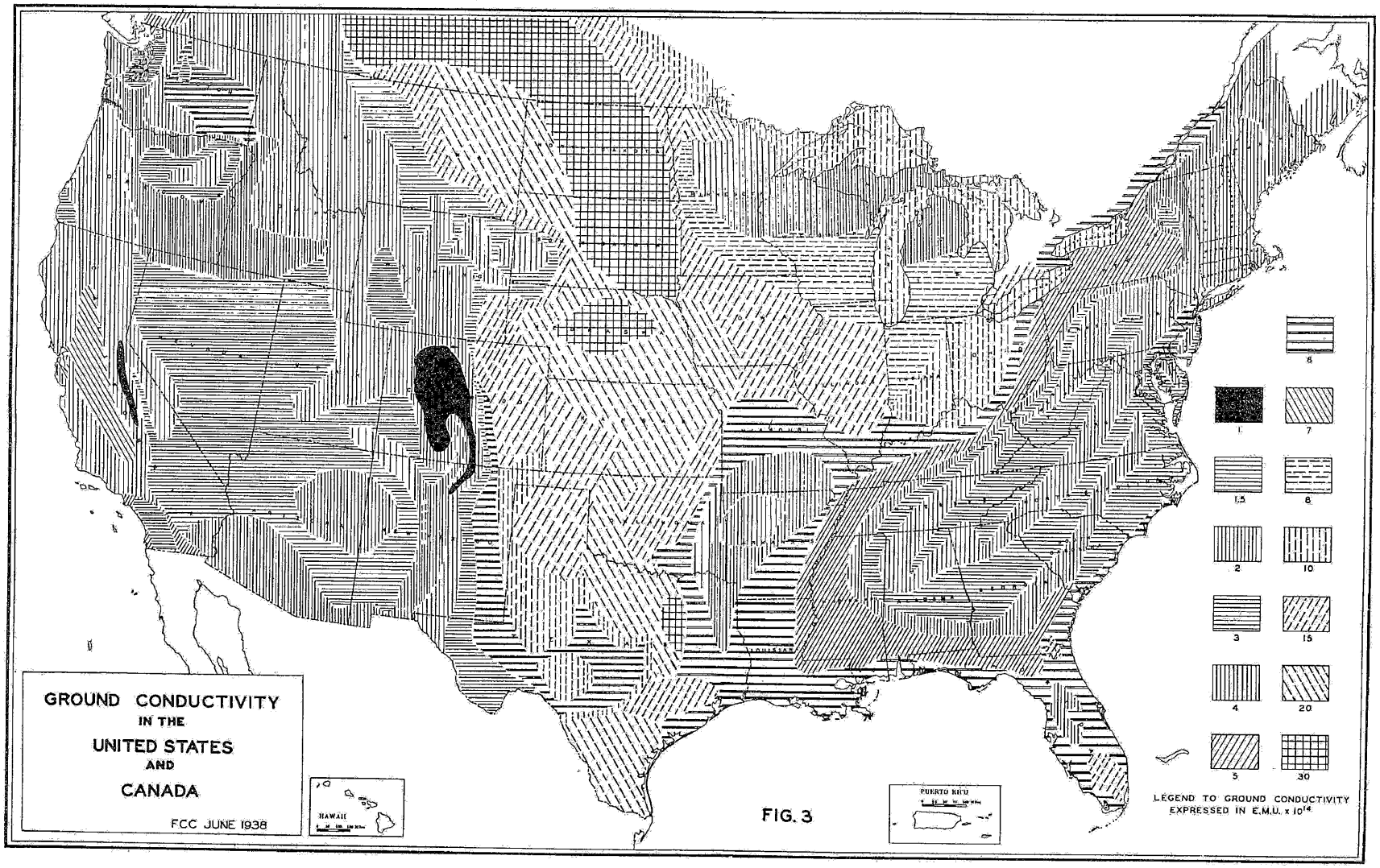

GROUND CONDUCTIVITY
IN THE
UNITED STATES
AND
CANADA
FCC JUNE 1938
HAWAII
PUERTO RICO
6
1
7
1.5
8
2
10
3
15
4
20
5
30
LEGEND TO GROUND CONDUCTIVITY
EXPRESSED IN E.M.U. x 10^14

FIG. 3

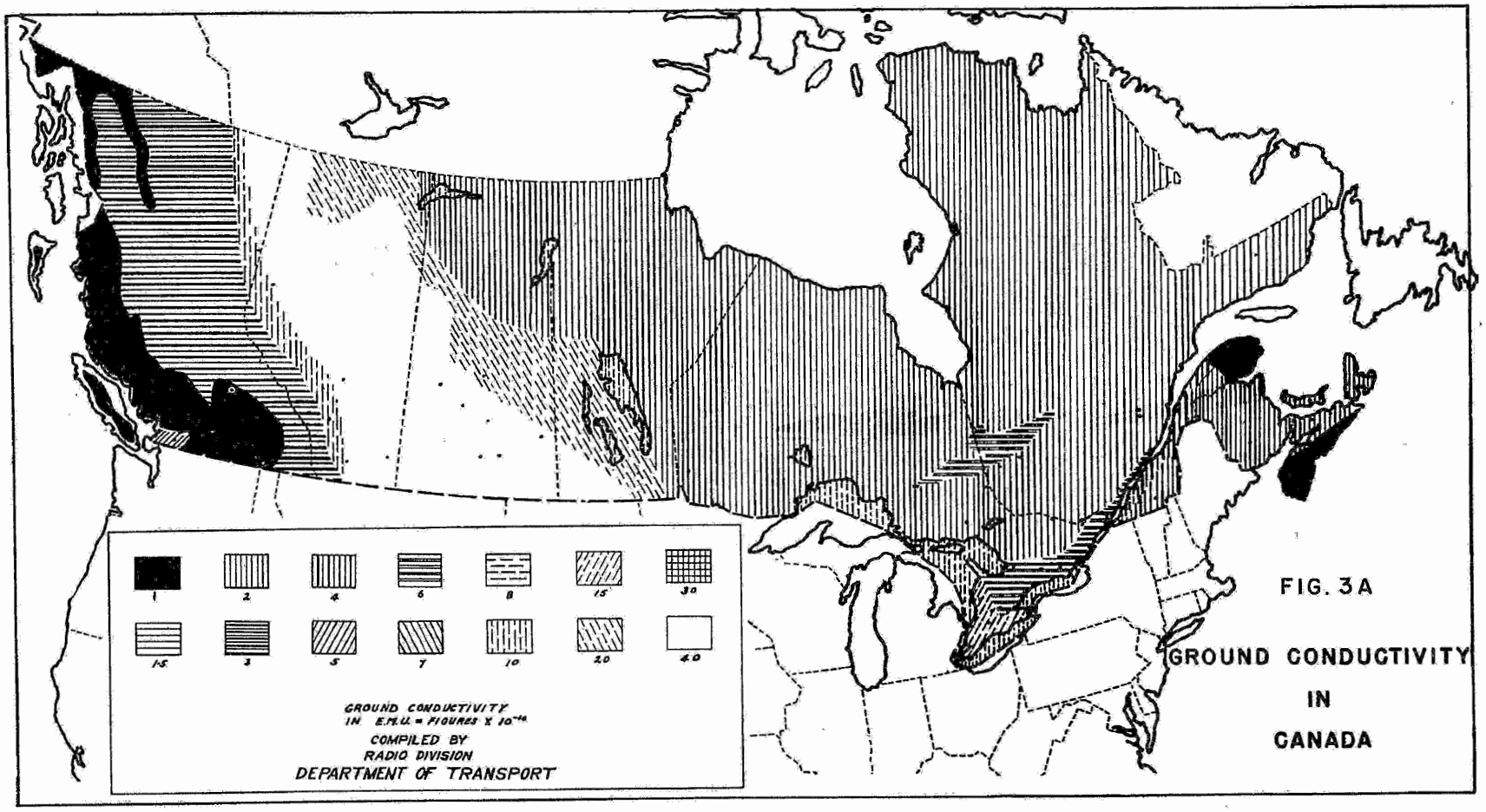


FIG. 3A

GROUND CONDUCTIVITY

IN

CANADA

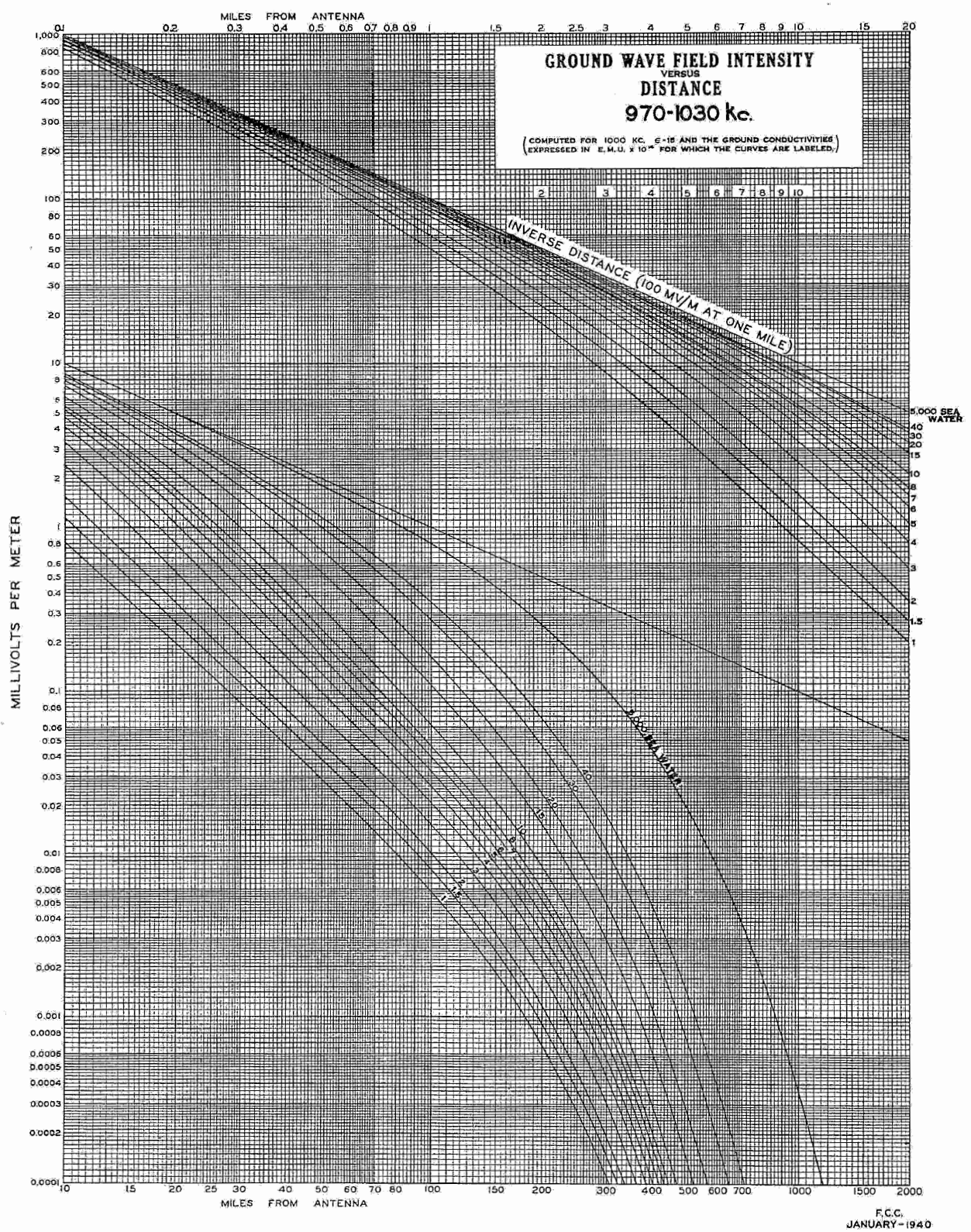
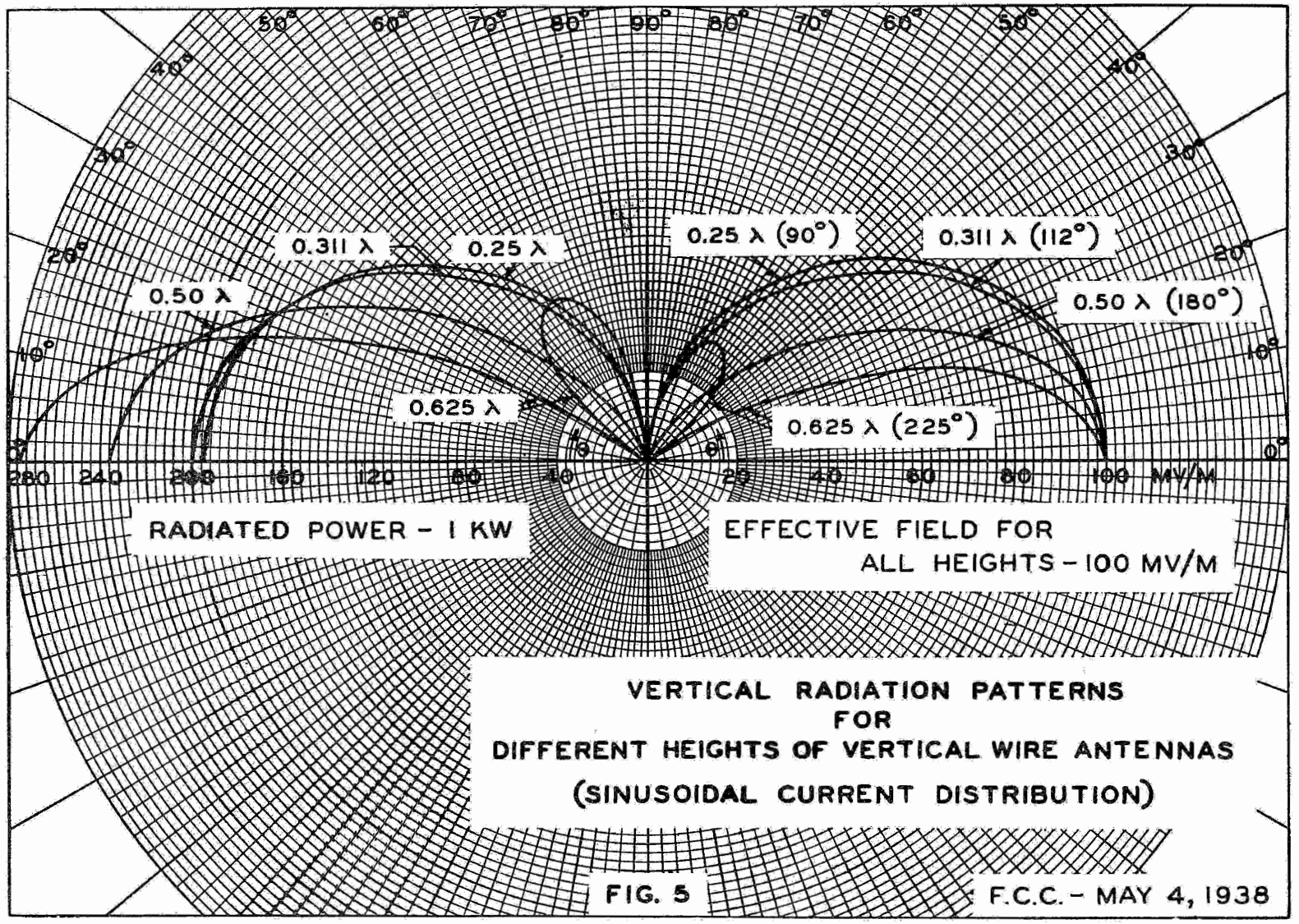

GROUND WAVE FIELD INTENSITY
VERSUS
DISTANCE
970-1030 Kc.
(COMPUTED FOR 1000 KC. ε-15 AND THE GROUND CONDUCTIVITIES EXPRESSED IN E.M.U. x 10^13 FOR WHICH THE CURVES ARE LABELED.)
INVERSE DISTANCE (100 MV/M AT ONE MILE)
SEA WATER
5,000
MILLIVOLTS PER METER
MILES FROM ANTENNA
MILES FROM ANTENNA
F.C.C.
JANUARY-1940

FIGURE 4


0.311 λ
0.25 λ
0.50 λ
0.625 λ
0.25 λ (90°)
0.311 λ (112°)
0.50 λ (180°)
0.625 λ (225°)
RADIATED POWER - 1 KW
EFFECTIVE FIELD FOR
ALL HEIGHTS - 100 MV/M
VERTICAL RADIATION PATTERNS
FOR
DIFFERENT HEIGHTS OF VERTICAL WIRE ANTENNAS
(SINUSOIDAL CURRENT DISTRIBUTION)
FIG. 5
F.C.C. - MAY 4, 1938

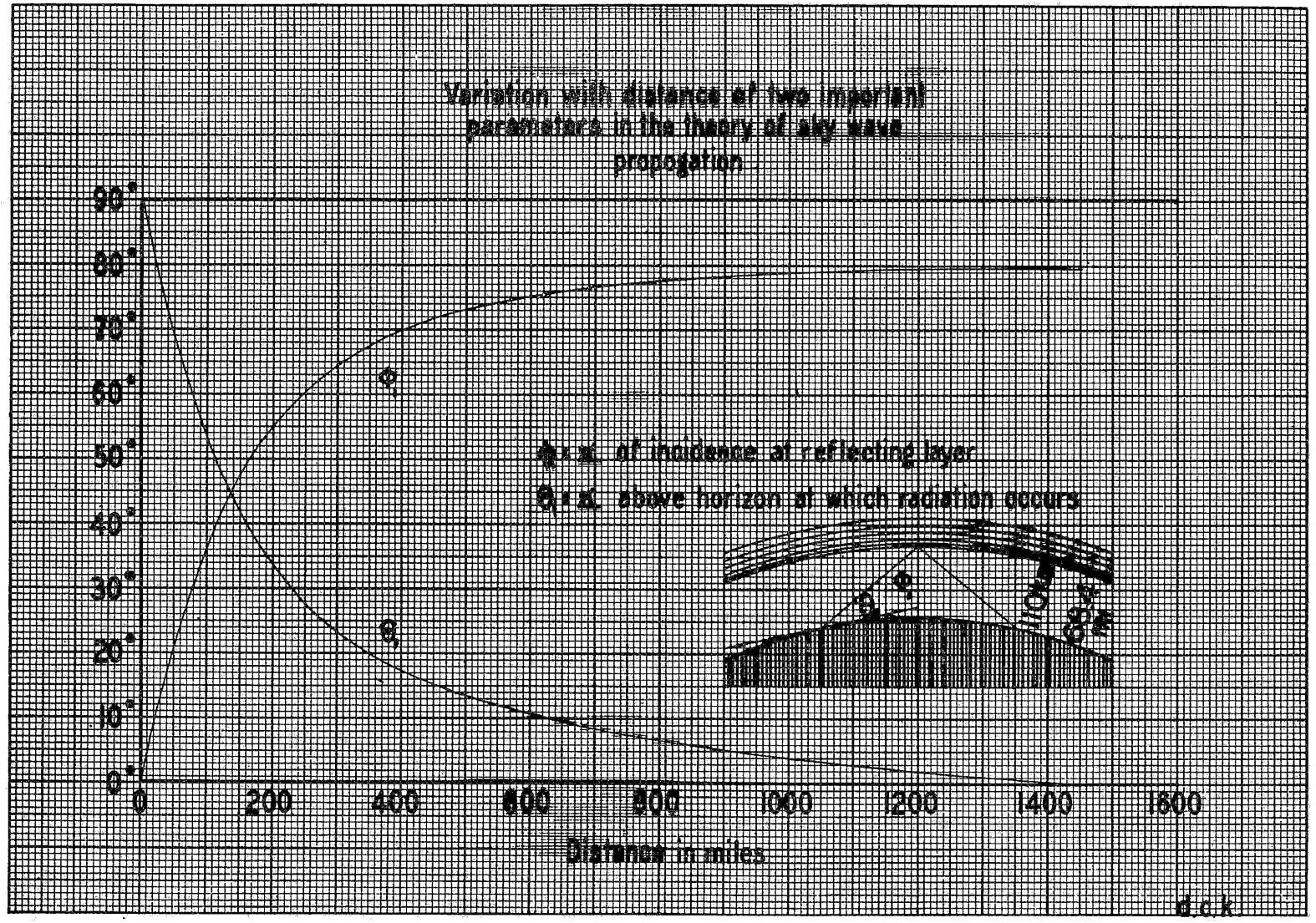
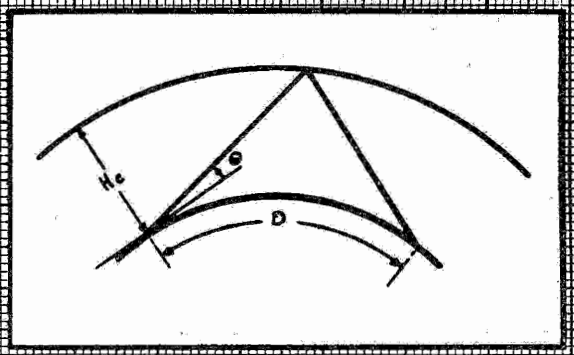

Variation with distance of two important parameters in the theory of sky wave propagation
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
0
200
400
600
800
1000
1200
1400
1600
Distance in miles
ϕ_1 = ∠ of incidence at reflecting layer
θ_1 = ∠ above horizon at which radiation occurs
ϕ_1
θ_1
d.c.k

Fig. 6

FIGURE 6a

ANGLES OF DEPARTURE VERSUS TRANSMISSION RANGE

① θ FOR 1000 KC AVERAGE H_e
② θ FOR 1000 KC MAXIMUM H_e
③ θ FOR 1000 KC MINIMUM H_e
④ AND ⑤ CONTAIN ALSO AN ESTIMATED CORRECTION FOR DEVIATION FROM MID-POINT REFLECTION



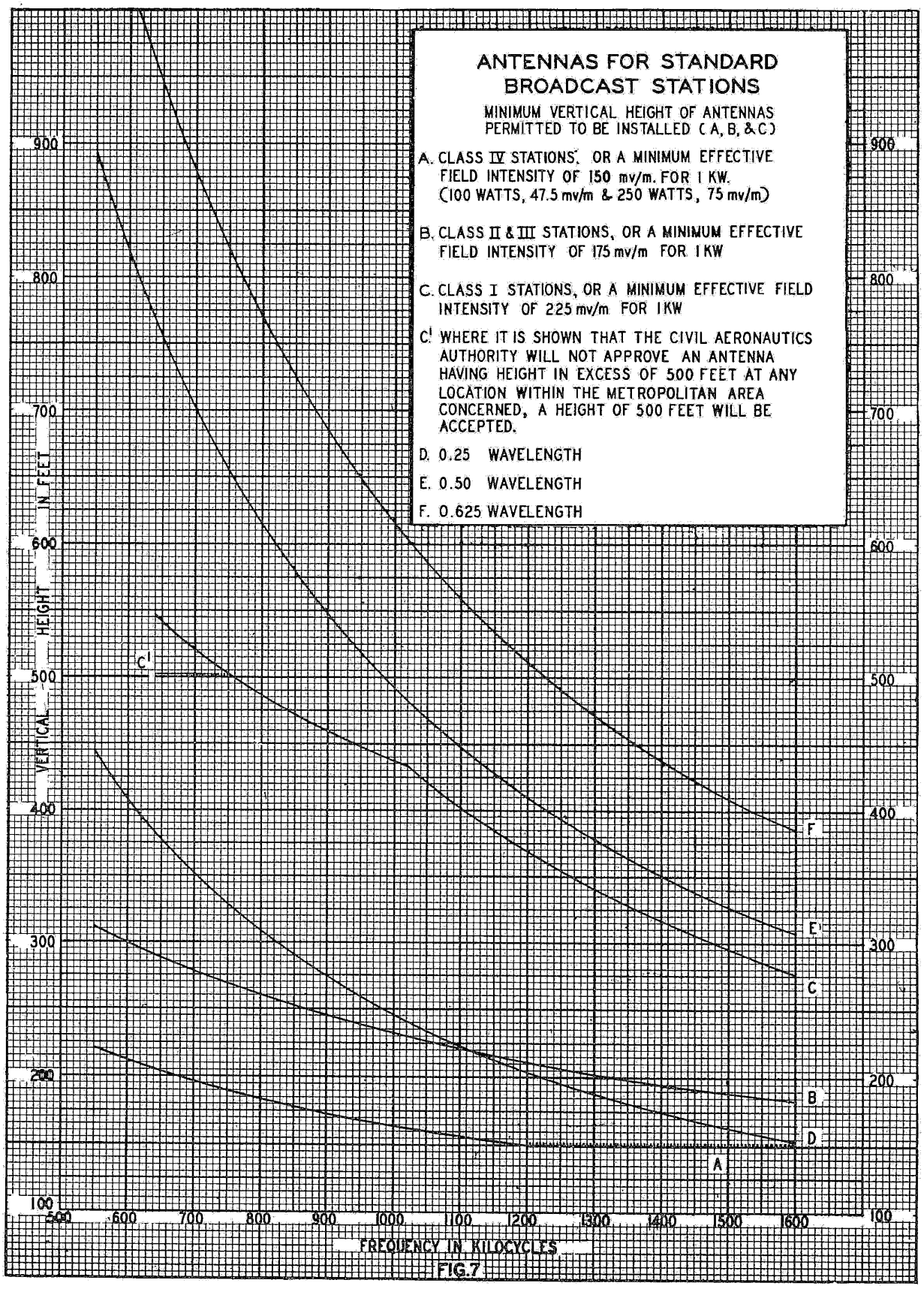
θ

90
80
70
60
50
40
30
20
10
0

0 200 400 600 800 1000 1200 1400

D — MILES

4040


ANTENNAS FOR STANDARD BROADCAST STATIONS
MINIMUM VERTICAL HEIGHT OF ANTENNAS PERMITTED TO BE INSTALLED (A, B, & C)
A. CLASS IV STATIONS, OR A MINIMUM EFFECTIVE FIELD INTENSITY OF 150 mv/m. FOR 1 KW. (100 WATTS, 47.5 mv/m & 250 WATTS, 75 mv/m)
B. CLASS II & 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 CIVIL AERONAUTICS AUTHORITY 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
VERTICAL HEIGHT IN FEET
900
800
700
600
500
400
300
200
100
C'
F
E
C
B
D
A
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
FREQUENCY IN KILOCYCLES
FIG.7

FEDERAL COMMUNICATIONS COMMISSION

STANDARDS OF GOOD ENGINEERING PRACTICE CONCERNING FM BROADCAST STATIONS

*EFFECTIVE SEPTEMBER 20, 1945**

INTRODUCTION

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.

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.

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.

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*This reproduction is based upon the Standards revised by the Commission to January 9, 1946, but also includes the following FCC Amendments (which actually bring the Standards up to date as of July 15, 1949):

FCC Amendment No. 307 - November 7, 1946
FCC Amendment No. 336 - June 12, 1947
FCC Amendment No. 363 - October 27, 1947
FCC Amendment No. 364 - October 16, 1947
FCC Amendment No. 367 - July 15, 1948

As additional amendments are made they will be indicated or printed in NAB MEMBER SERVICE.

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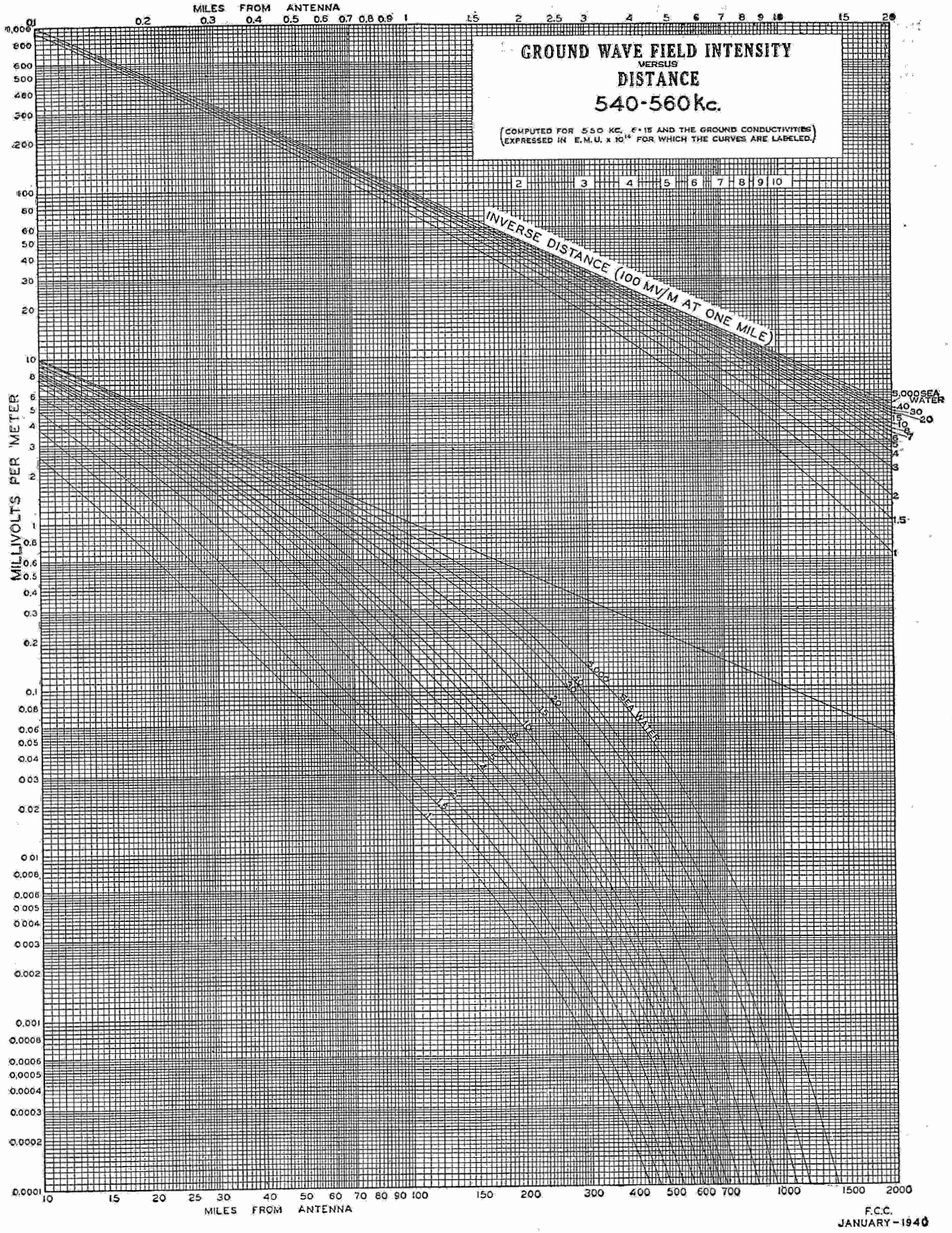
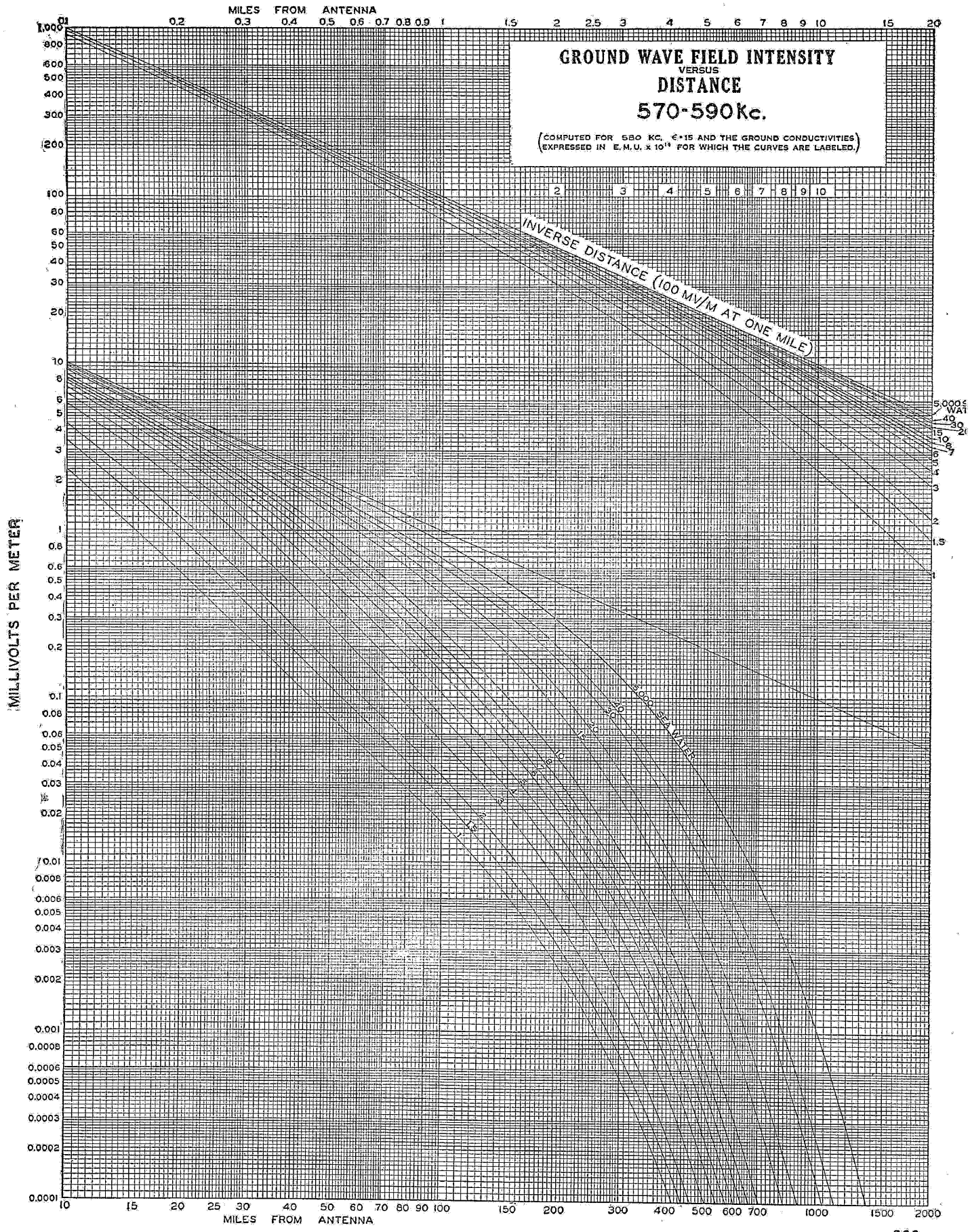
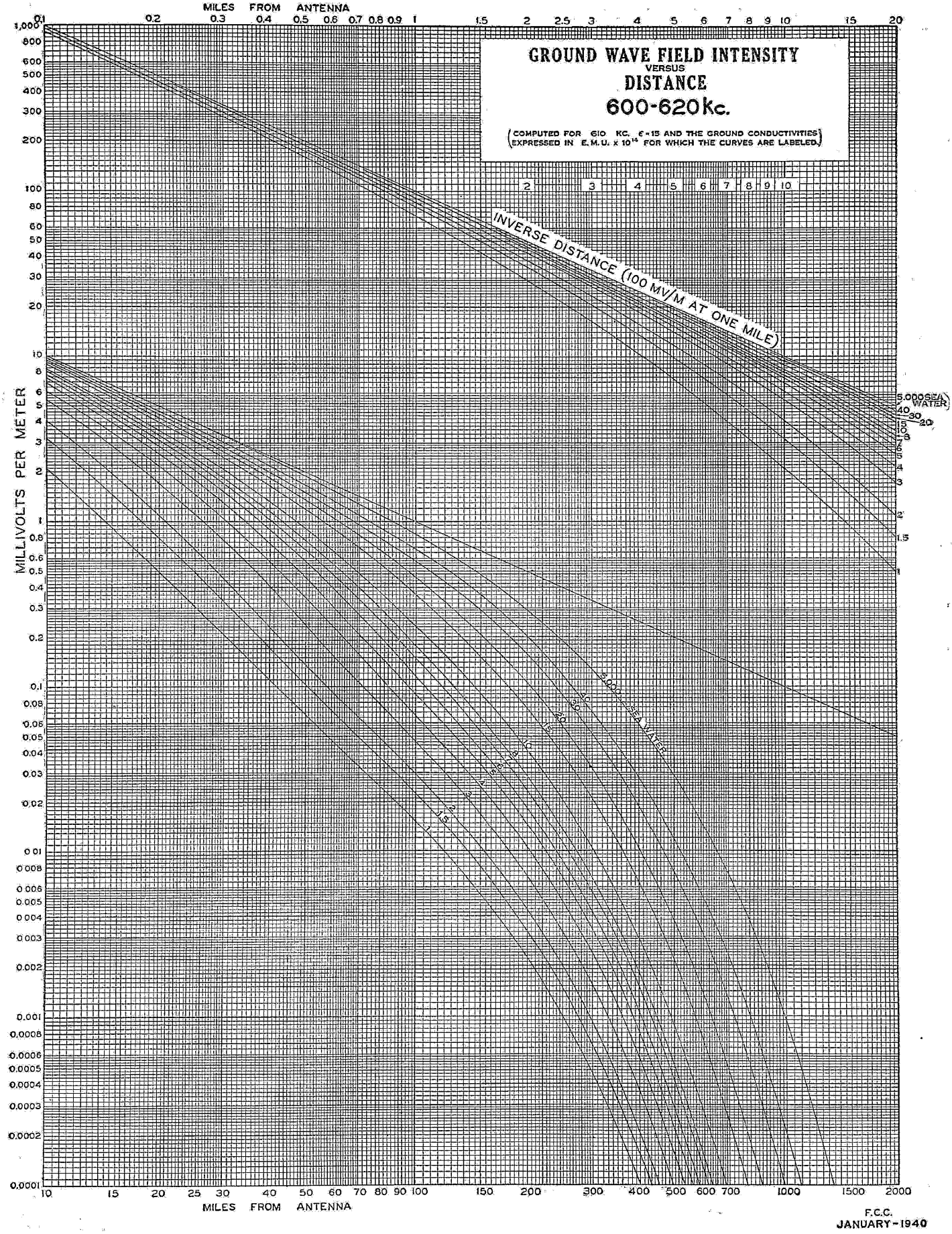


APPENDIX I - GRAPH 1



APPENDIX I - GRAPH 2



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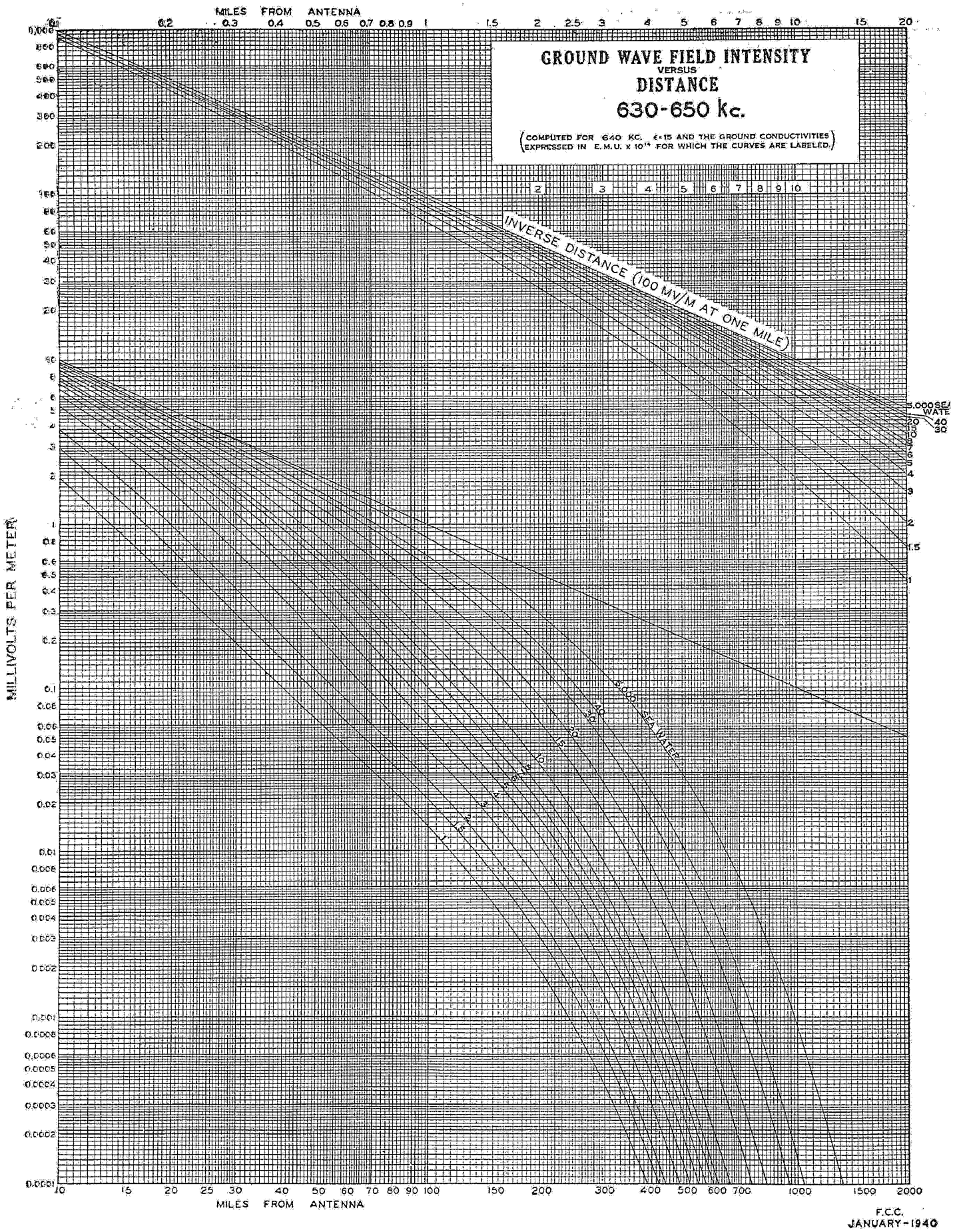

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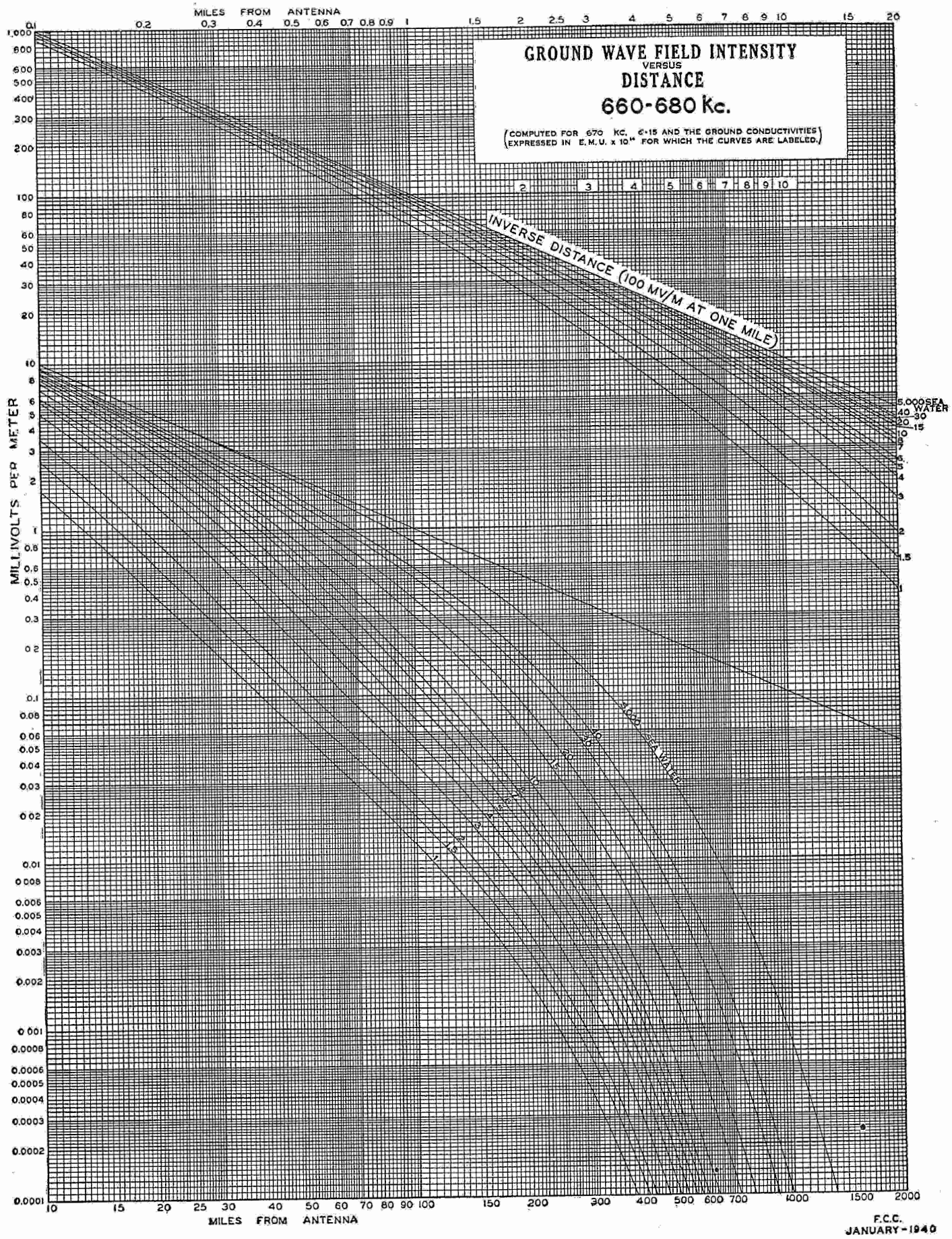
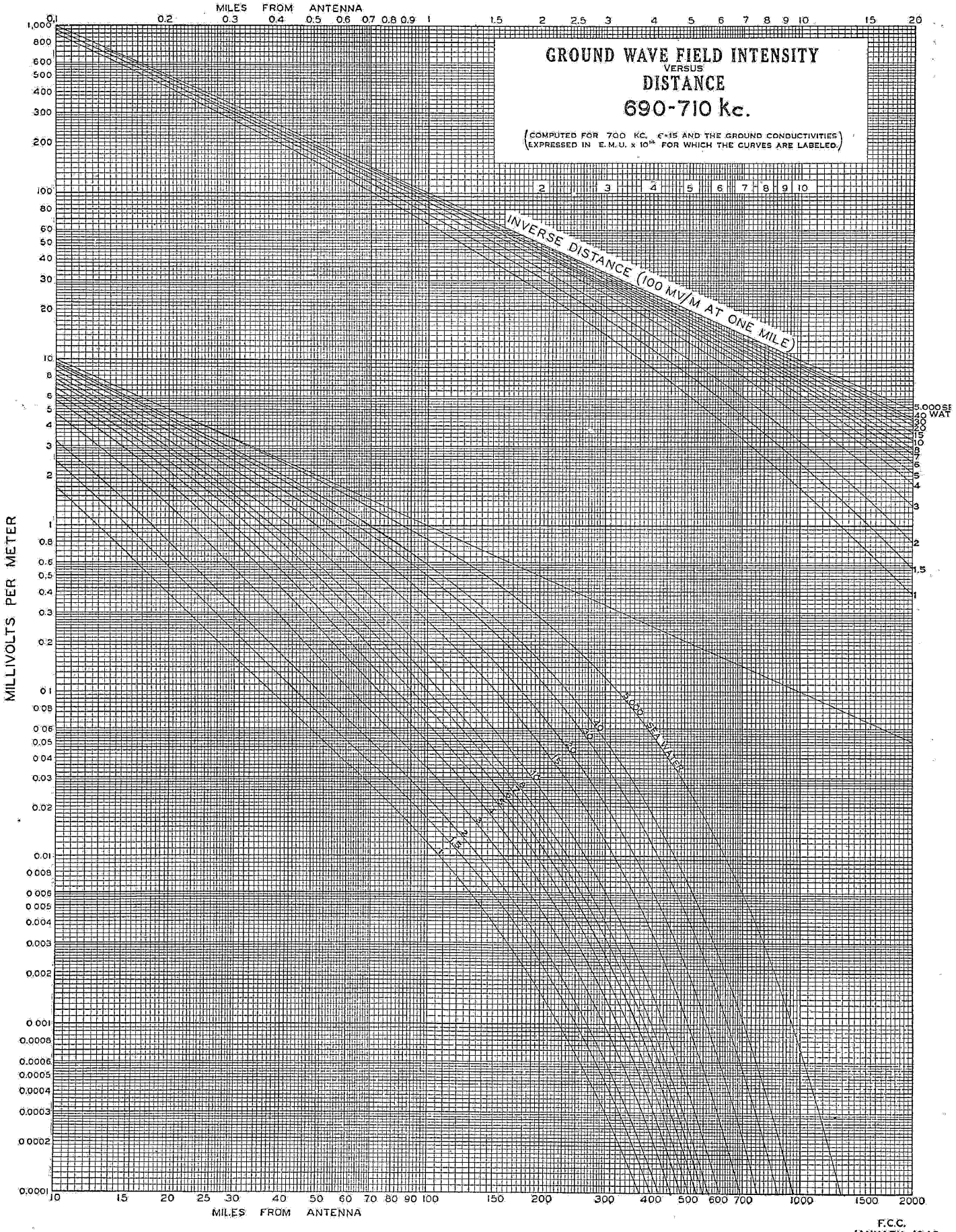


APPENDIX I - GRAPH 5



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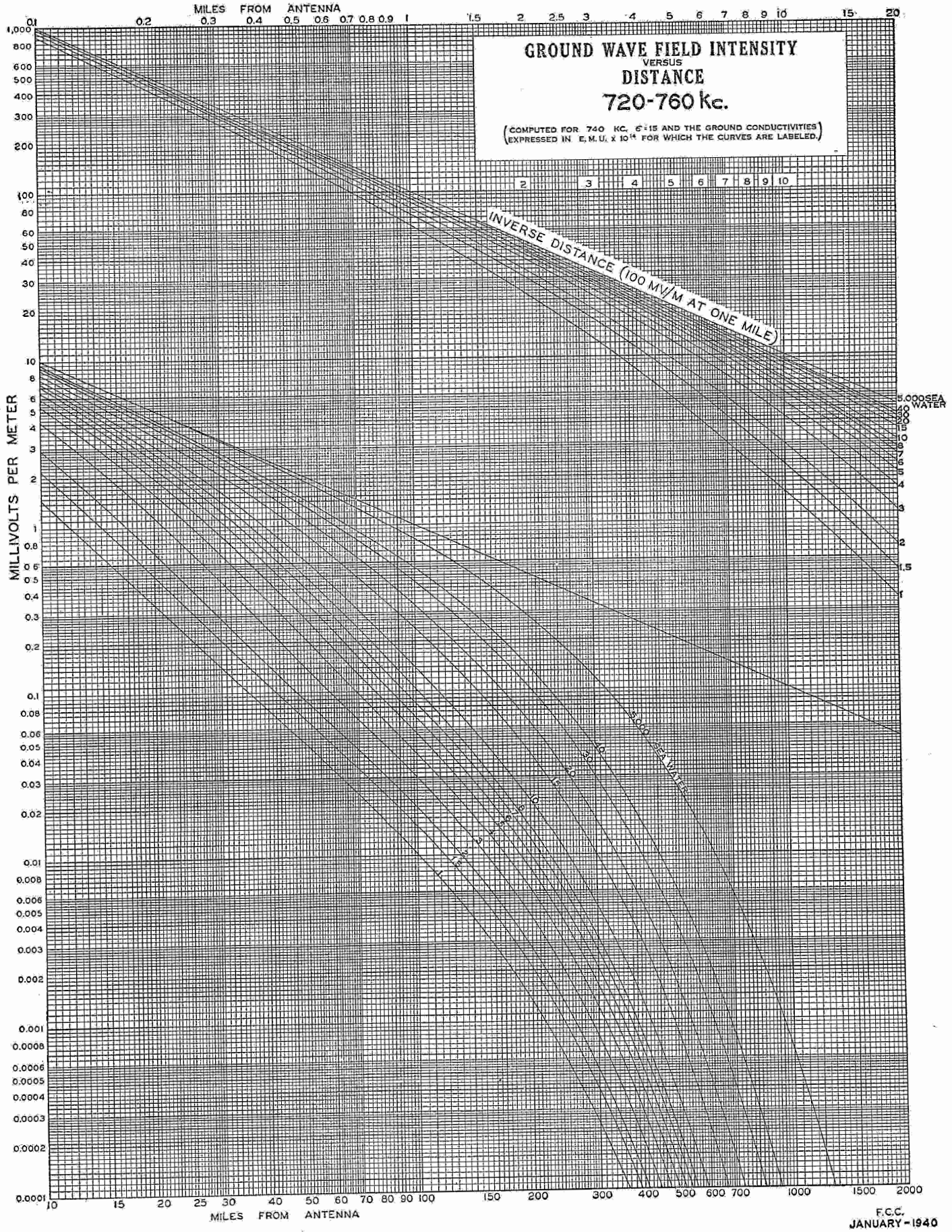
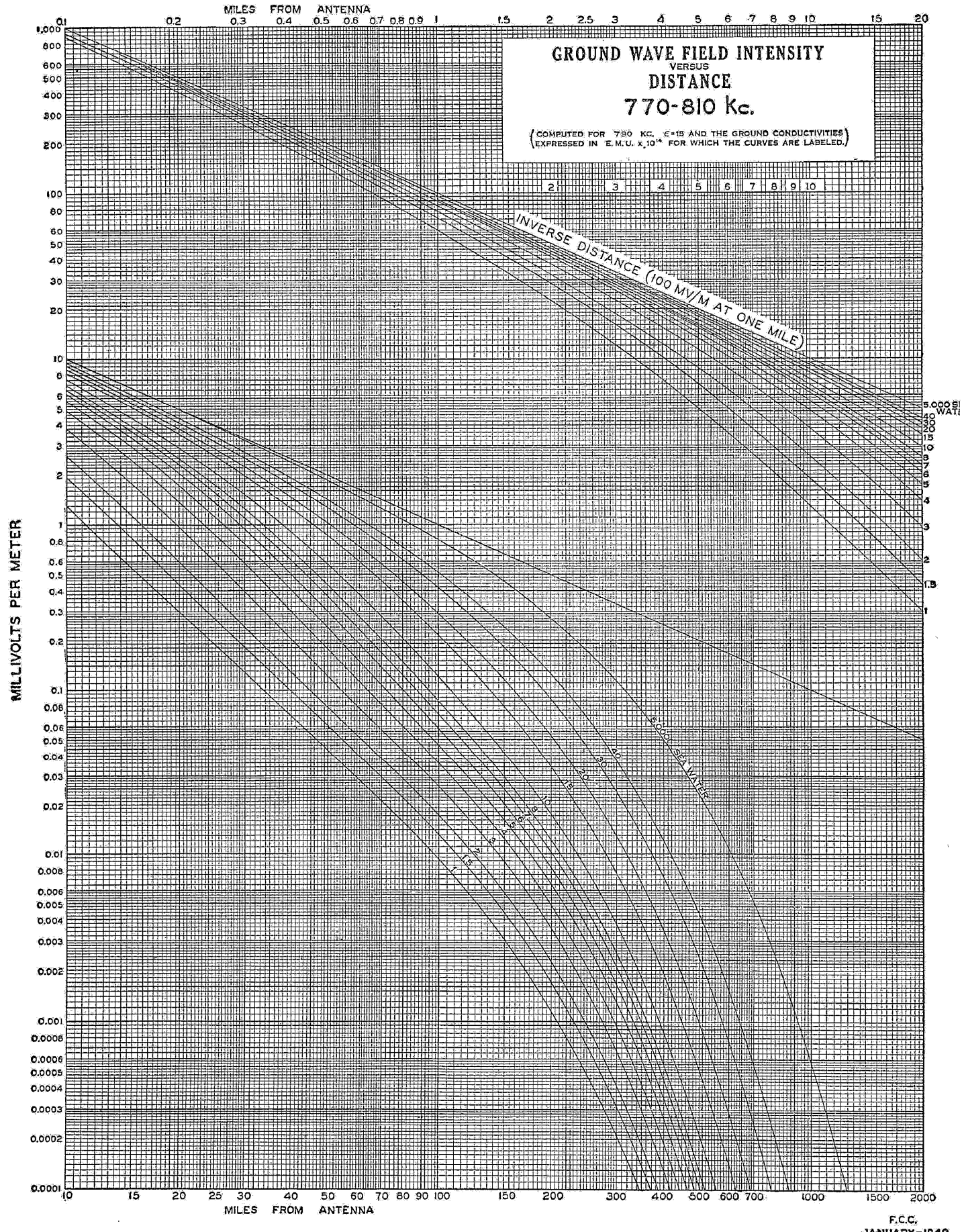
APPENDIX I - GRAPH 6



APPENDIX 1 - GRAPH 7



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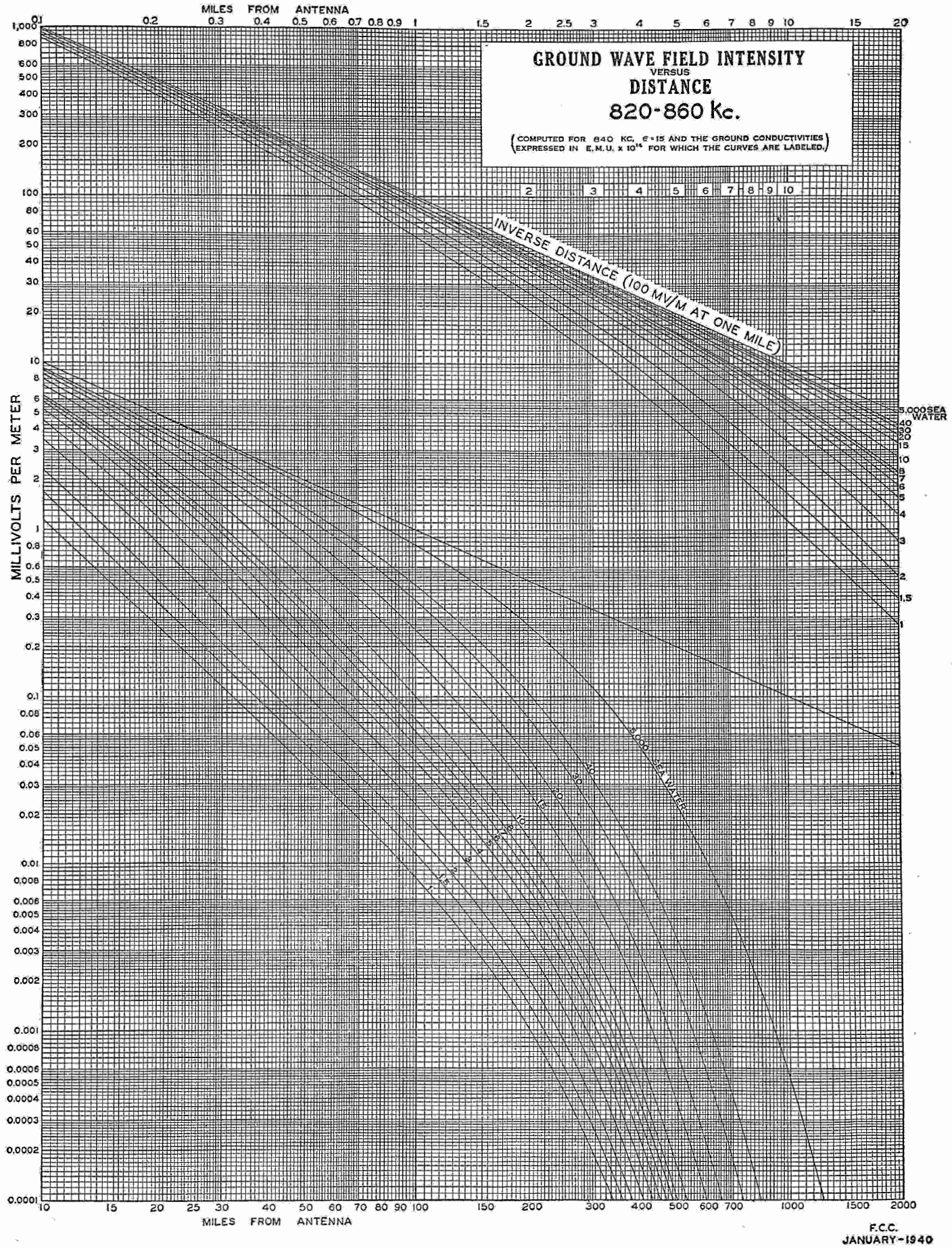

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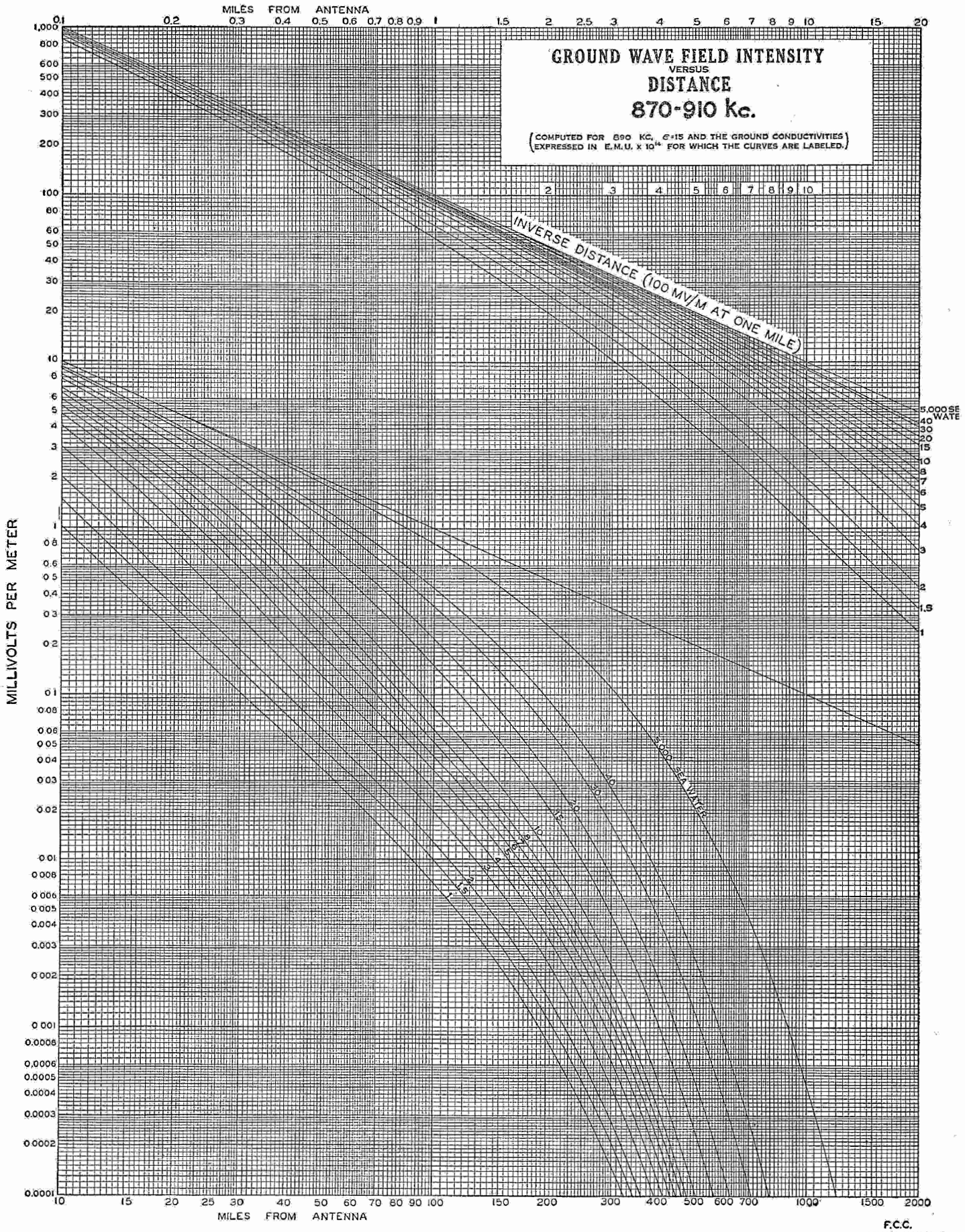

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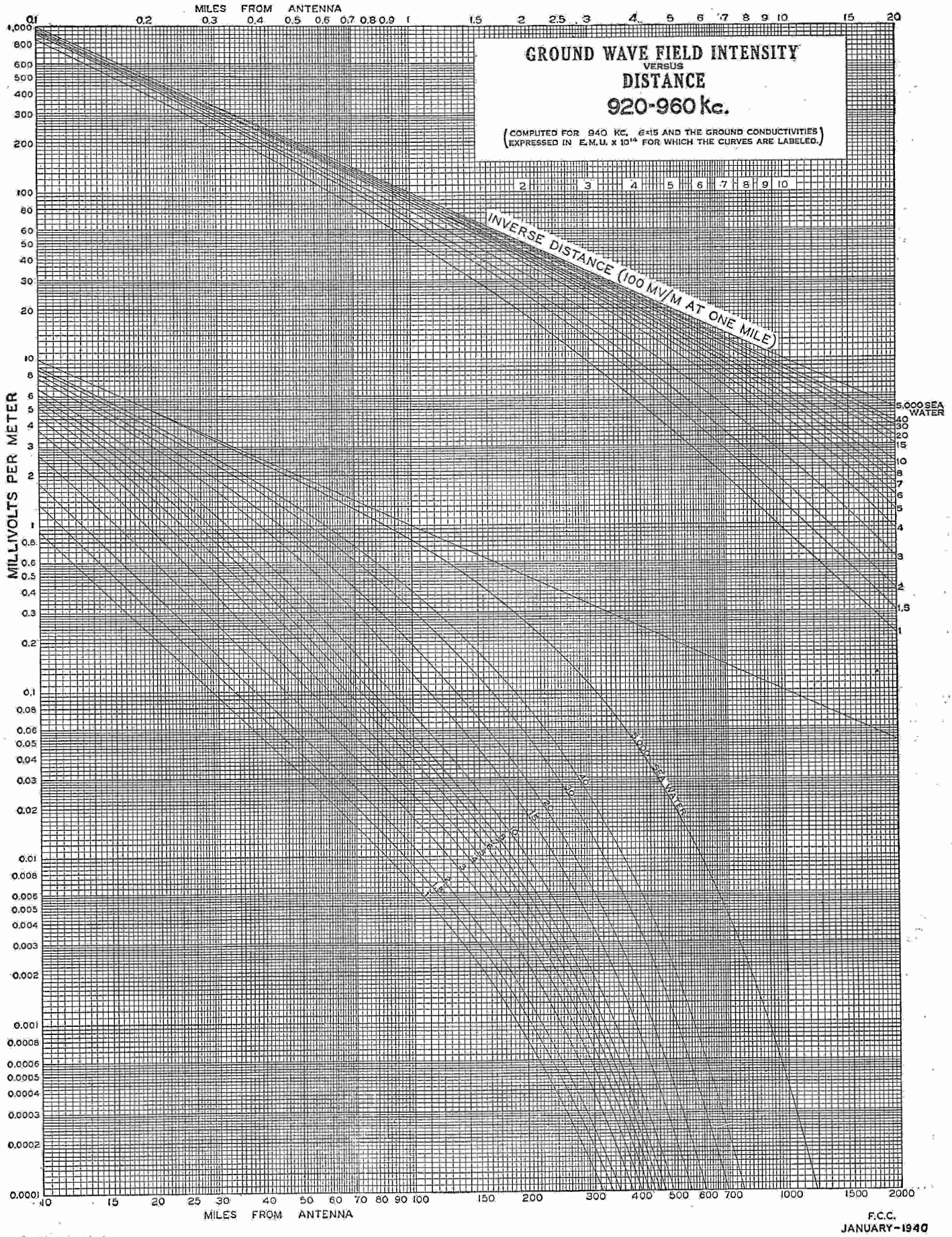

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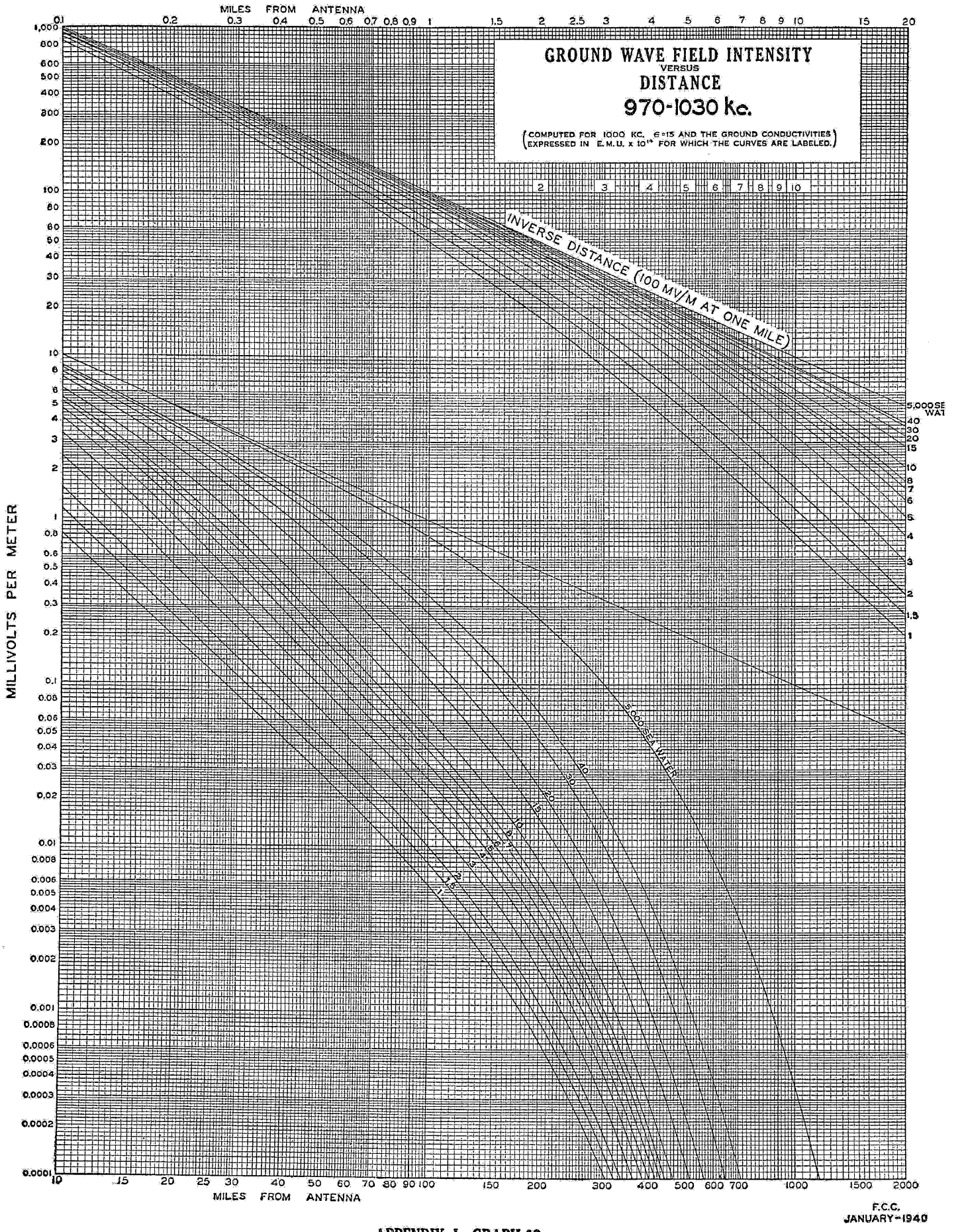

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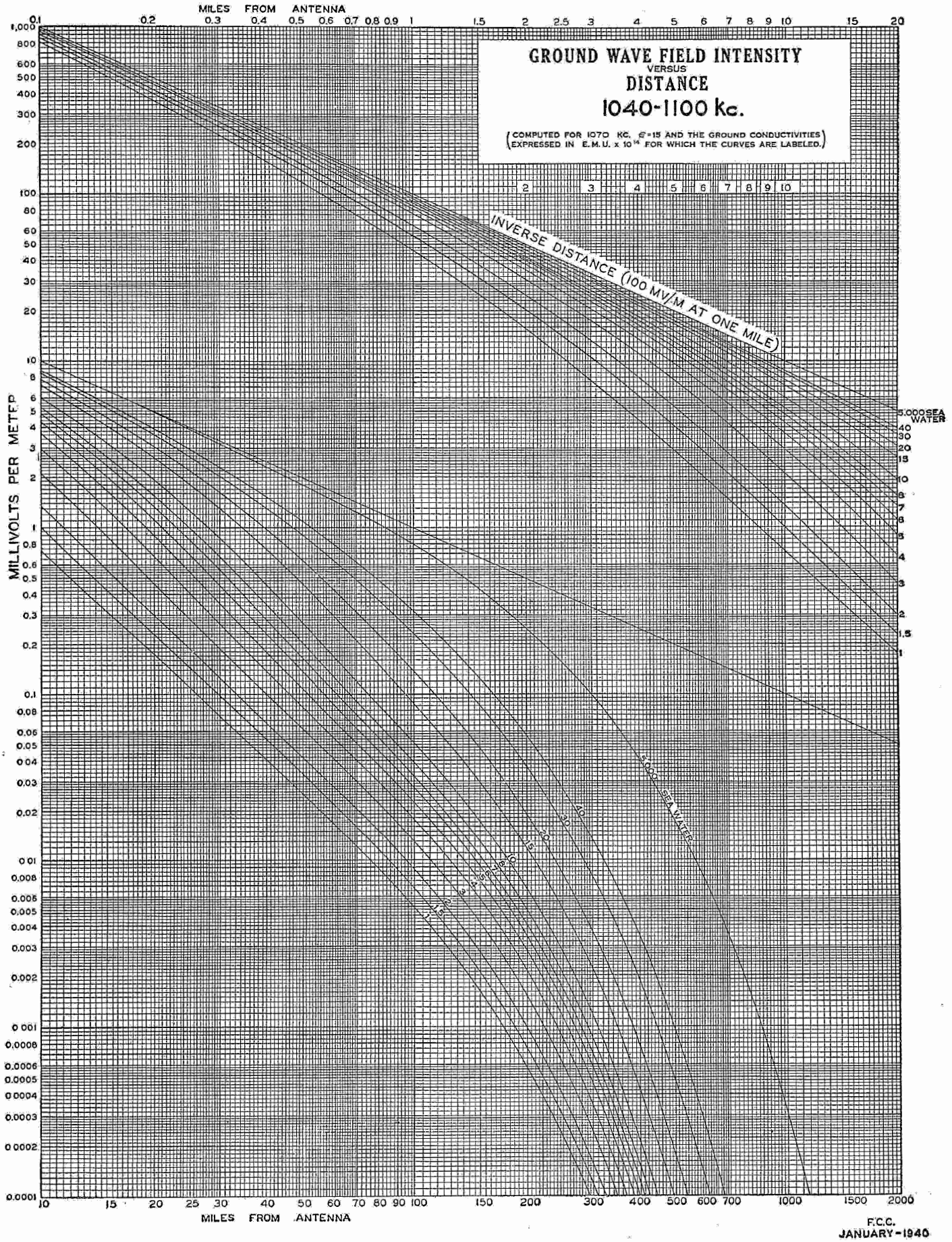
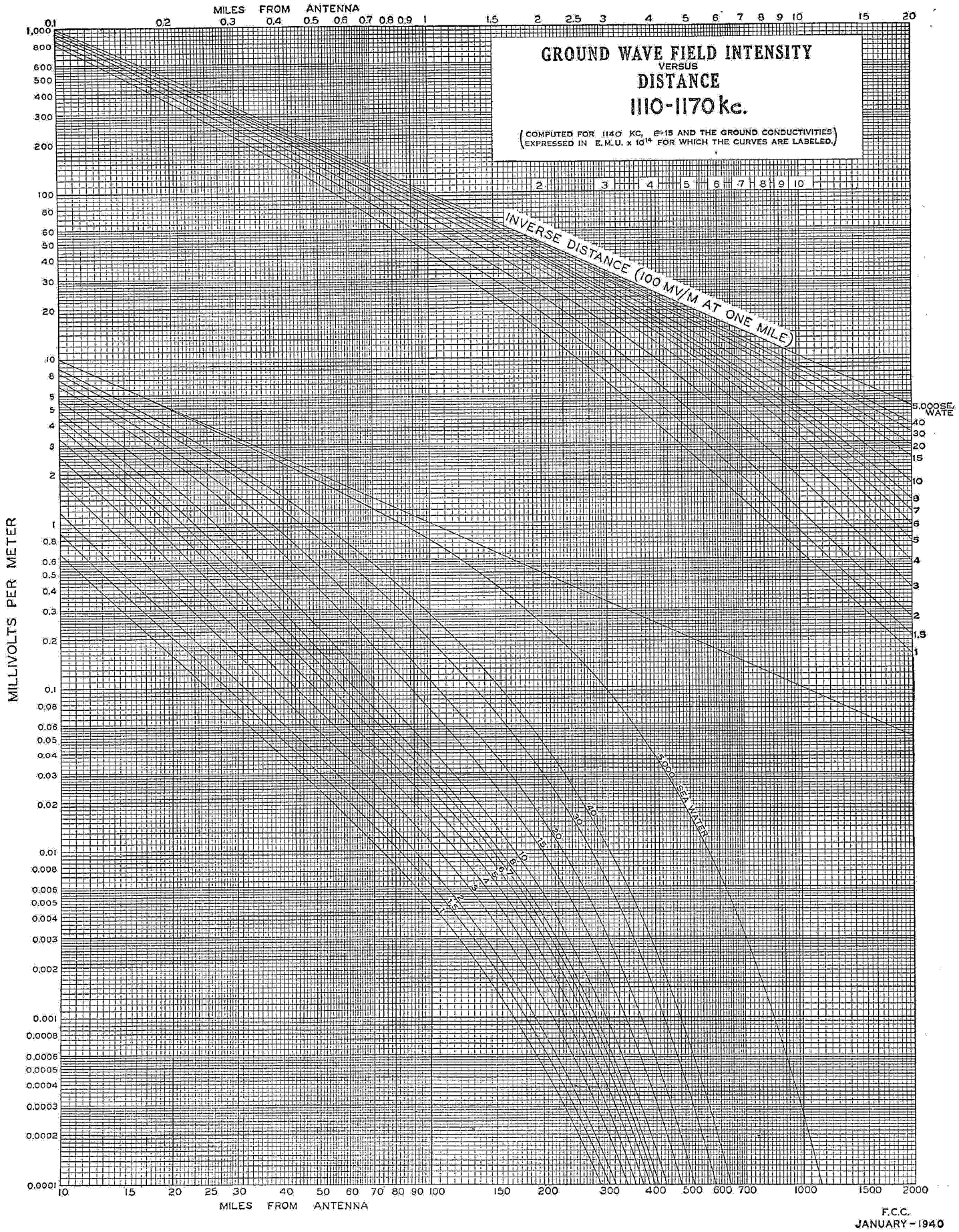
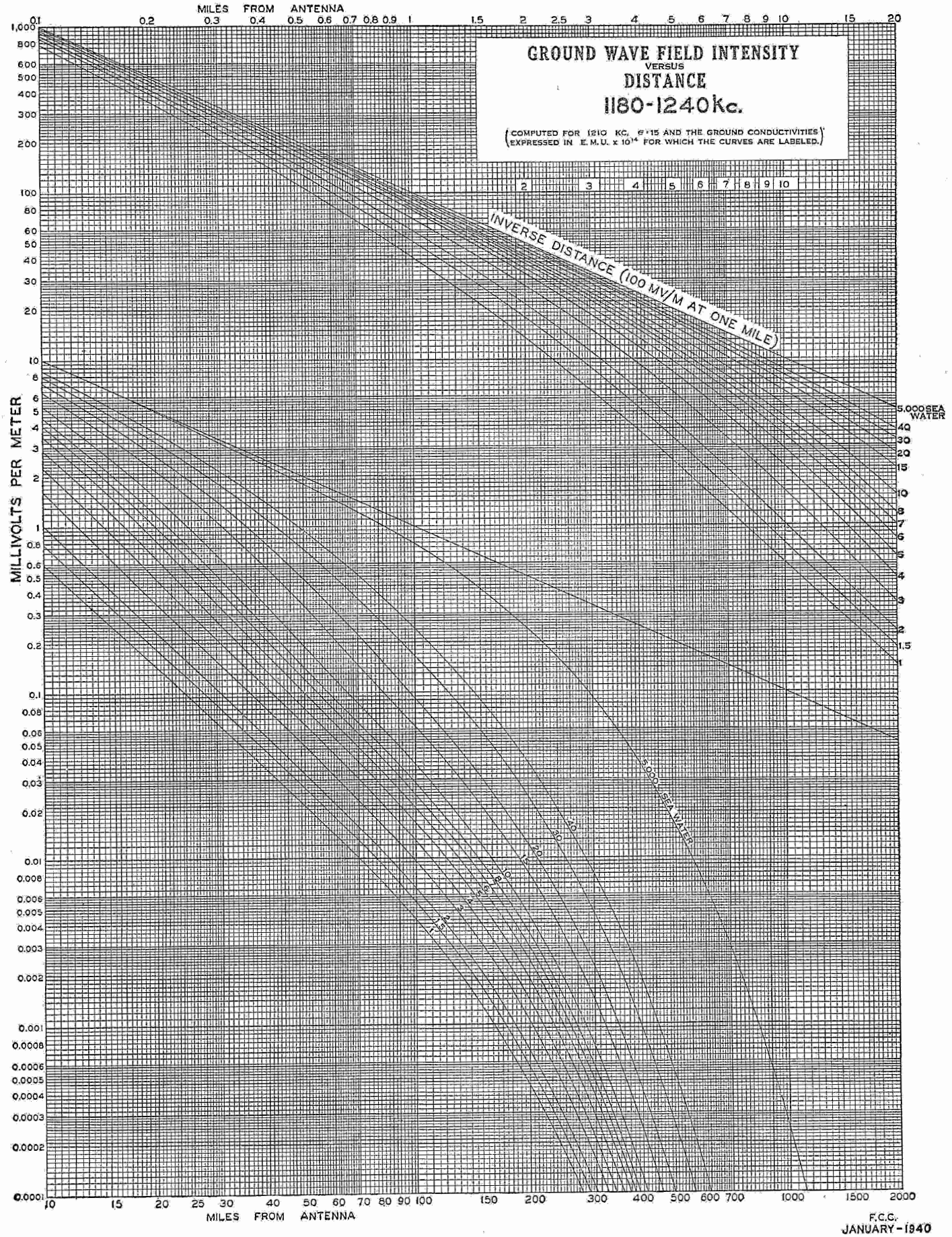


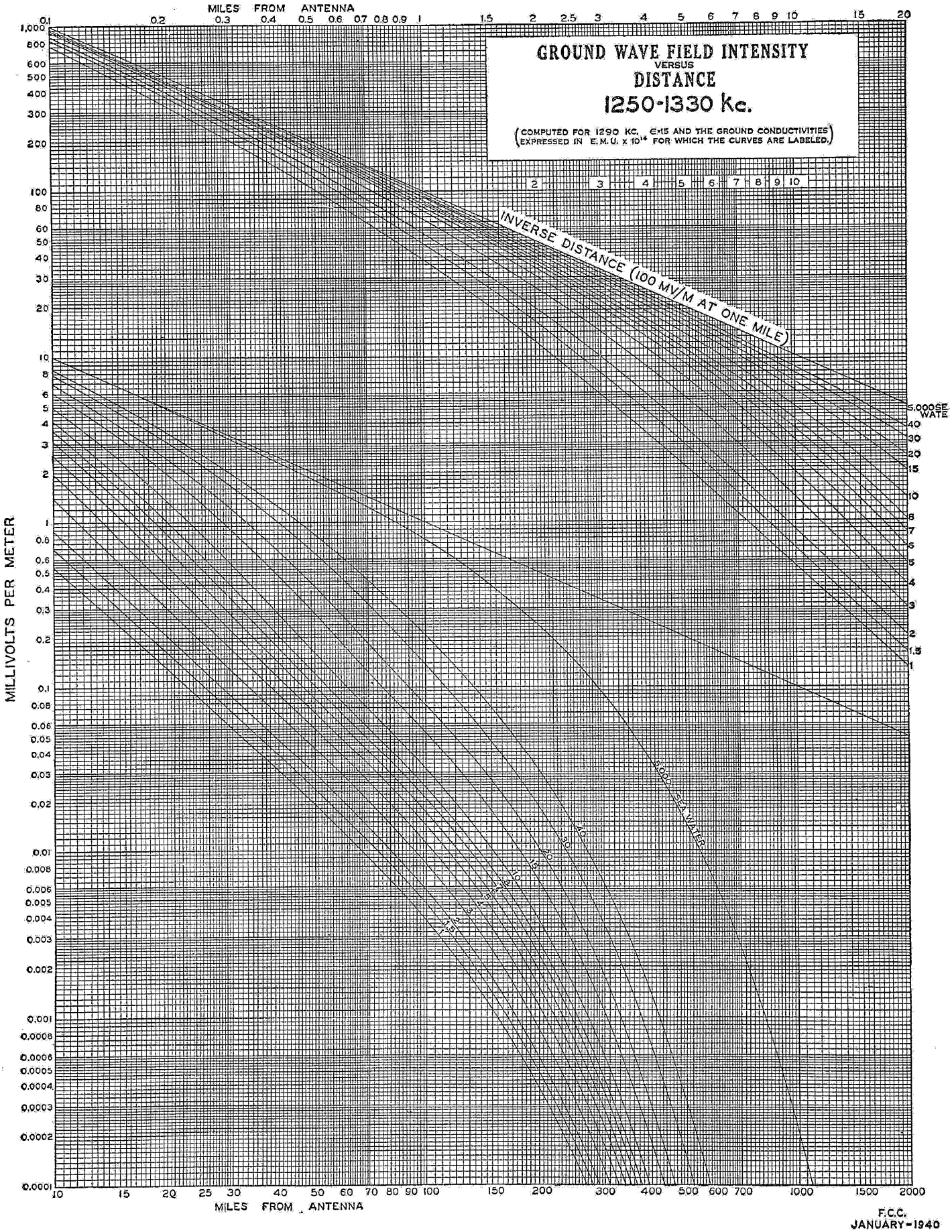
APPENDIX 1 - GRAPH 13



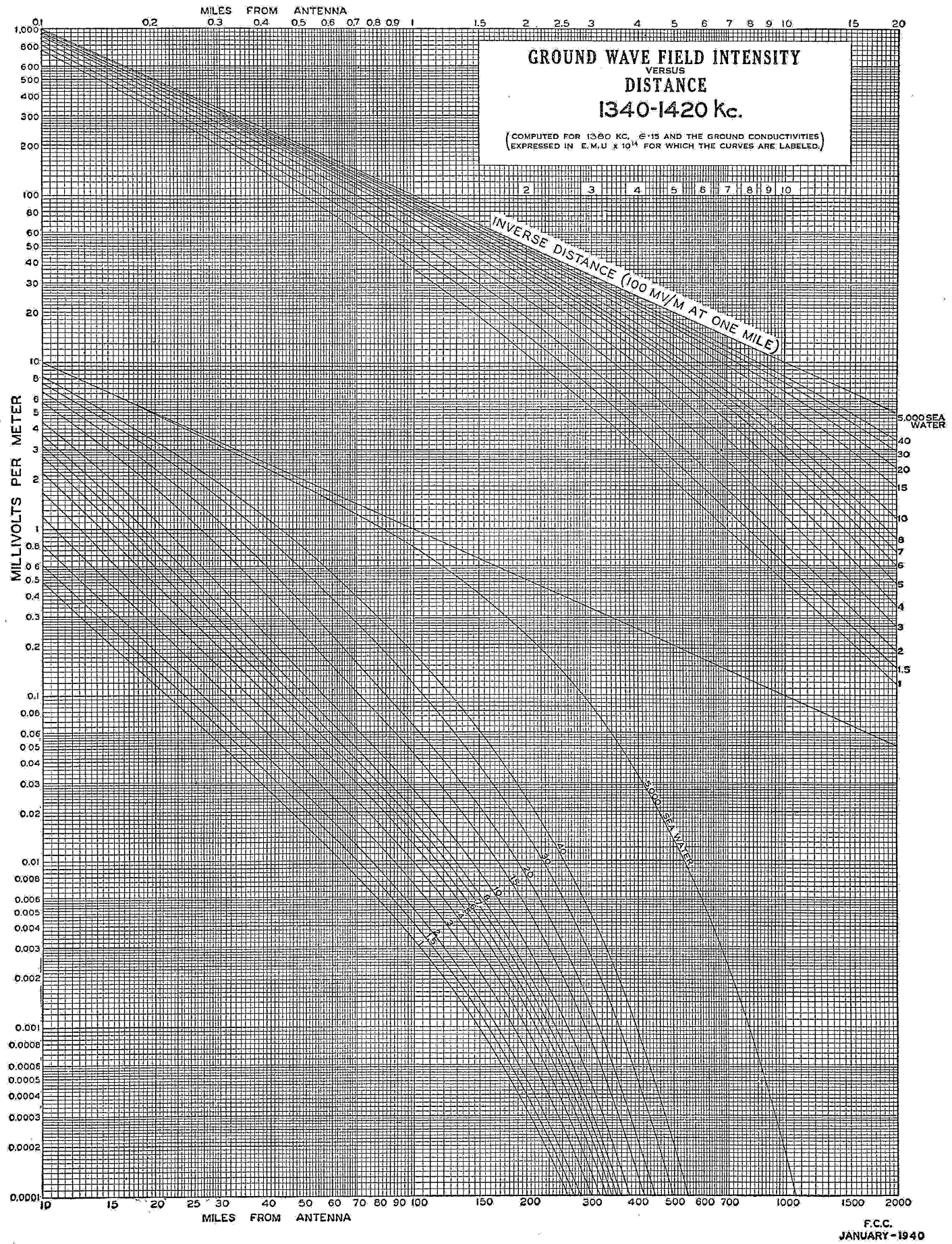
APPENDIX I - GRAPH 14



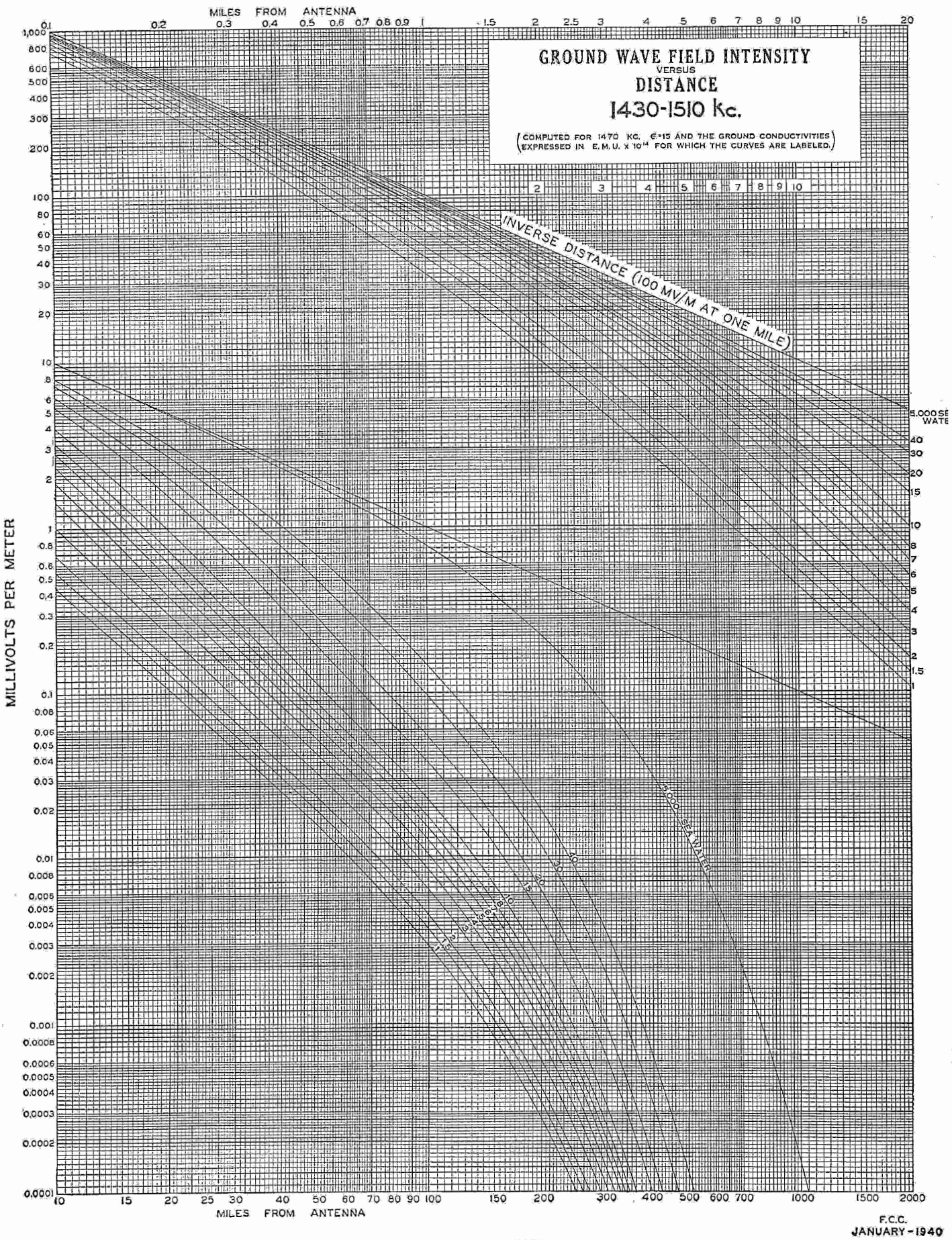
APPENDIX I - GRAPH 15



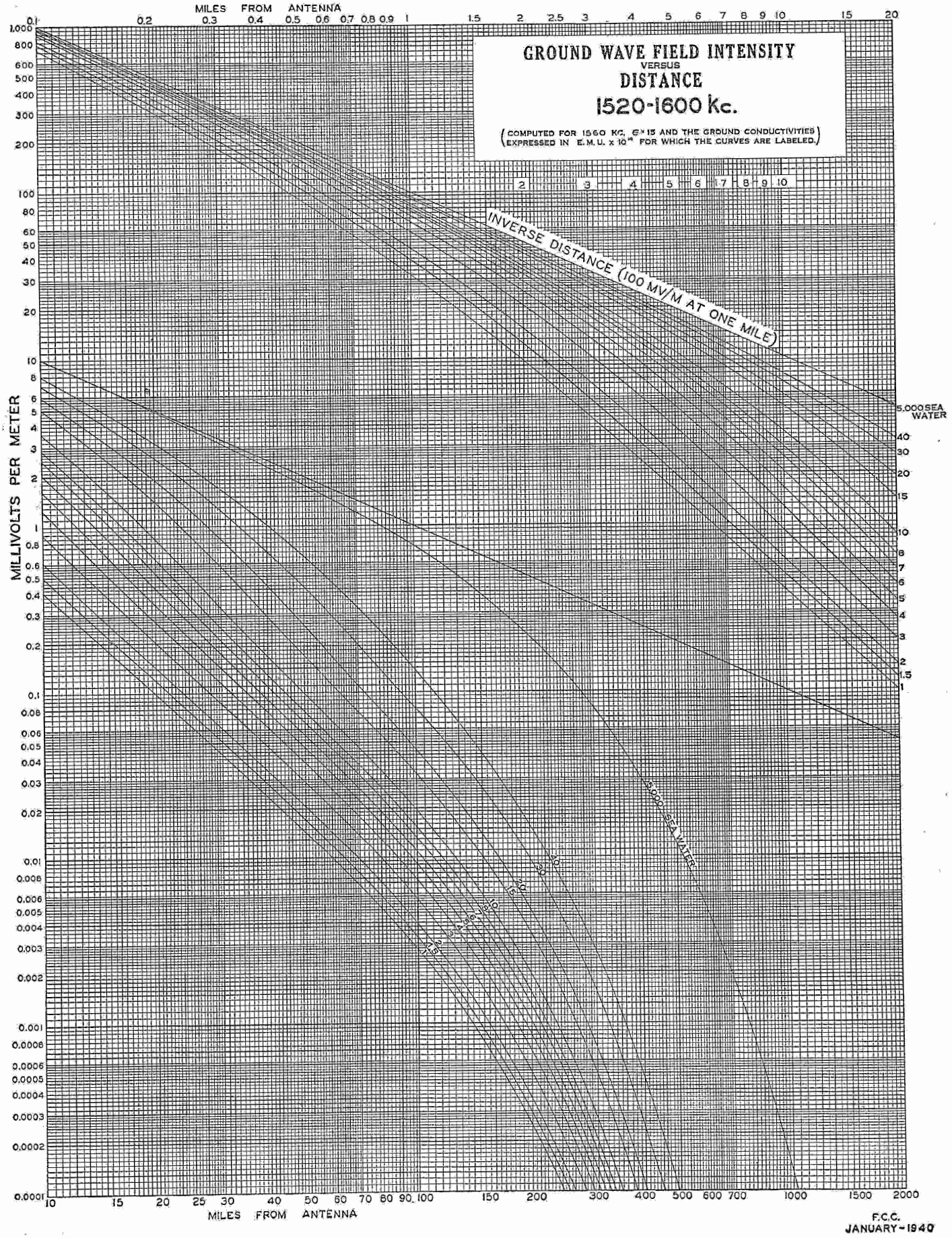
APPENDIX I - GRAPH 16



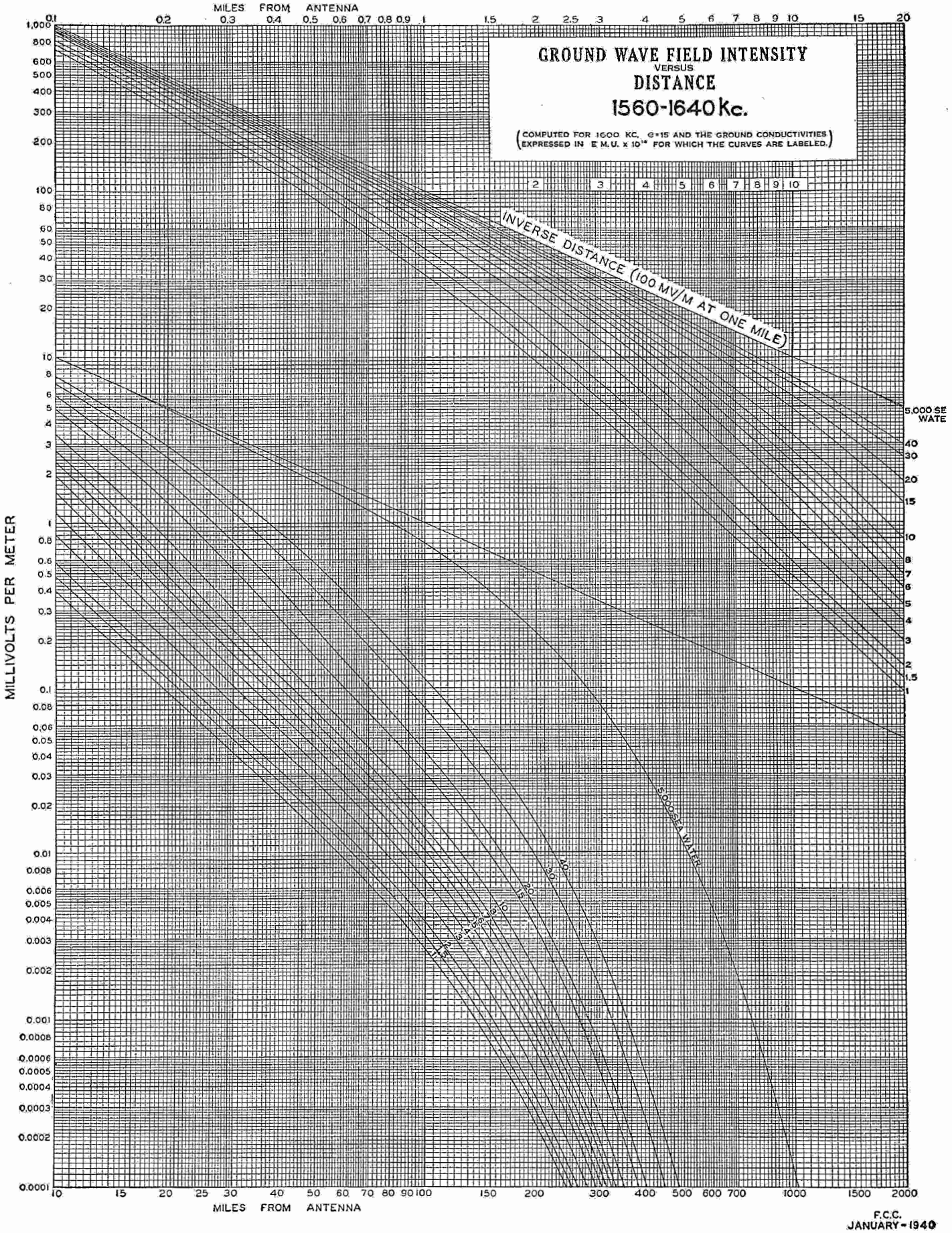
APPENDIX I - GRAPH 17



APPENDIX I - GRAPH 18



APPENDIX I - GRAPH 19



APPENDIX I - GRAPH 20

STANDARDS OF GOOD ENGINEERING PRACTICE CONCERNING FM BROADCAST STATIONS

I. Definitions

A. FM broadcast station.--The term "FM broadcsst 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 $\pm$ 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 x 8.2 x 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.

2. ENGINEERING STANDARDS OF ALLOCATION

A. Sections 3.202 to 3.206 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:

Table I

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 Section 3.205 of the Rules. The location of the main studio of a class A station is specified in Section 3.203 of the Rules. 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 used, 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).

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.

To determine the distance to a particular contour, figure 1 concerning 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 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 figure 1 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 gradation 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.

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 these classes of FM broadcast stations. 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.

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.

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 (1940 census) should be used in making population counts, 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. TOPOGRAPHICAL DATA

In the preparation of the profile graphs previously described, the elevations or contour intervals shall be taken from the U. S. Geological Topographical Quadrangle Sheets 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.

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.

The U. S. Geological Survey Topography Quadrangle Sheets may be obtained from the U. S. Geological Survey, Department of the Interior, Washington, D. C., for ten cents each. The Sectional Aeronautical Charts are available from the U. S. Coast and Geodetic Survey, Department of Commerce, Washington, D. C., for twenty-five cents each. Other sources of topographic maps or data will be furnished at a later date.

4. INTERFERENCE STANDARDS

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 sec. 5). In lieu of measurements, the interference should be predicted in accordance with the method described herein.

Objectionable interference is considered to exist when the interfering signal exceeds that

given by the ratios of Table II. In Table II the desired signal is median field and the undesired signal is the tropospheric signal intensity exceeded for 1 per cent of the time.

TABLE II

Channel Separation	Ratio of desired to undesired signals
Same channel	10:1
200 kc.	2:1
400 kc.	To be determined
600 kc.	To be determined
800 kc. and above	No restriction[1]

Standards have not been established for channel separations in excess of 200 kc; various types of present FM receivers are under study by the Commission to provide data for determining such standards. Pending the completion of such studies and the promulgation of such standards, 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.

In predicting the extent of interference within the ground wave service area of a station, the tropospheric signal intensity (from co-channel and adjacent channel stations) existing for 1 per cent of the time shall be employed. The 1 per cent values for 1 kilowatt of power and various antenna heights are given in figure 2, and values for other powers may be obtained by use of the sliding scale as for figure 1. The values indicated by figure 2 are based upon available data, and are subject to change as additional information concerning tropospheric wave propagation is obtained.[2]

[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.

[2]Fig. 2 will be available at some future date when sufficient measurements of tropospheric signals are available. Until that time, interference should be predicted on the basis of the ground wave chart. (Fig. 1).

In determining the points at which the interference ratio is equal to the values shown in Table II, 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.

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.

5. FIELD INTENSITY MEASUREMENTS IN ALLOCATIONS

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.

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 nondirectional and primarily responsive to the horizontal electric field.

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.

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.

In making measurements to establish the field intensity contours of a station, mobile recordings should be made along each of the radials drawn in section 2E above. Measurements should extend from the vicinity of the station out to the 1000 uv/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 1000 uv/m. with the predicted 1000 uv/m. contour will be used as a basis in determining adherence to authorized service areas within the 50 uv/m. contour. Adjustment of power or antenna may be required to fit the actual contours to that predicted.

In addition to the 1000 uv/m. contour, the map of measured coverage shall show the 50 uv/m. contour as determined by employing figure 1 and the distance to the 1000 uv/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 1000 uv/m. contour (as measured) and the 1000 uv/m. mark are opposite. The distance to the 50 uv/m. contour is then given opposite the 50 uv/m. mark on the scale.

In predicting tropospheric interference on the basis of the above measurements, such measurements shall be carried out in the manner indicated above to determine the 1000 uv/m. contour. Using figure 1 and its associated sliding scale, the equivalent radiated power shall be determined by placing the sliding scale on the chart (using the appropriate antenna height) and moving the scale until the distance to the 1000 uv/m. contour (as determined above), and the 1000 uv/m. mark are opposite. The equivalent radiated power is then read from the sliding scale where it crosses the lower line of the top edge of the chart. Changing to figure 2 and using the equivalent radiated power just determined, the distance to the interfering contour under investigation is read in the usual manner.

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.

Complete data taken in conjunction with field intensity measurements shall be submitted to the Commission in affidavit form, including the following:

(a) 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 a type showing topography in the area.)

(b) 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 sec. 7.)

(c) A full description of the procedures and methods employed including the type of equipment, the method of installation and operation, and calibration procedures.

(d) Complete data obtained during the survey, including calibration.

(e) Antenna system and power employed during the survey.

(f) Name, address, and qualifications of the engineer or engineers making the measurements.

All data shall be submitted to the Commission in triplicate, except that only the original or one photostatic copy need be submitted of the actual recording tapes.

6. 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

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.

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. 3.) The deviation of the system response from the standard preemphasis curve shall lie between two limits as shown in figure 3. 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

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.[3]

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 the audio frequency level representing a frequency swing of ± 75 kilocycles. 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 sec. 9).

(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.

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[4] of the National Electrical Code and 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 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] See Sec. 13 for measurement frequencies and other information.

(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.

(a) Commutator guards shall be provided on all high voltage rotating machinery. Coupling guards should be provided on motor generators.

(b) 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).

(c) 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 Section 3.254 does not apply.

(4) Metering equipment.

(a) 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.)

(b) 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 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.

(c) 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 during operation, suitable facilities for his welfare and comfort shall be provided.

E. Spare tubes.--A spare tube of every type employed in the transmitter and frequency and modulation monitors shall be kept on hand at the equipment location. When more than one tube of any type are employed, the following table determines the number of spares of that type required:

Number of each type employed:	*Spares required*
1 or 2	1
3 to 5	2
6 to 8	3
9 or more	4

[4]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."

monitors at auxiliary transmitters of FM broadcast stations in compliance with these rules:

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.

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.

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.

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.

13. REQUIREMENTS FOR TYPE APPROVAL OF TRANSMITTERS[6]

Section 3.254 of the Rules and section 8 of these Standards concern the design, construction, and technical operation of FM broadcast station equipment. In order to facilitate the filing of and action on applications for construction permits specifying equipment of standard manufacture, the Commission will approve, as complying with the technical requirements, such equipment by type, subject to the following conditions and in accordance with the following procedure:

A. Approval of equipment by the Commission is only to the effect that insofar as can be determined from the data supplied, the equipment complies with the current requirements of good engineering practice and the current technical Rules and Regulations of the Commission. The approval may be withdrawn upon subsequent inspection or operation showing the equipment is not as represented or does not comply with the technical Rules and Regulations of the Commission and the requirements of good engineering practice.

B. Such approval shall not be construed to mean that the equipment will be satisfactory as the state of the art progresses and/or as the Rules and Regulations of the Commission may be changed as deemed advisable.

C. Applicants specifying equipment of approved manufacture need not submit detailed descriptions and diagrams where the correct type number is specified provided that the equipment proposed is identical with that approved.

D. In passing on equipment, no consideration is given by the Commission to patent rights.

E. For approval of FM broadcast transmitters manufacturers shall submit FCC Form 319 completed with respect to all pertinent sections (two sworn copies). In addition or included therein shall be the data set forth below, all of which shall be verified before a notary public.[7]

(1) Photographs or drawings, or any other evidence that construction is in accordance with the requirements of good engineering practice.

(2) Data and curves showing over-all 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 modulation frequencies: 50, 100, 400, 5000, 10,000 and 15,000 cycles. This shall be plotted below a standard 75 microsecond preemphasis curve (see fig. 3).

(3) Data on audio frequency harmonics for 25, 50, and 100 percent modulation for the fundamental frequencies of 50, 100, 400, 1000, and 5000 cycles. Data on audio frequency harmonics for 100 percent modulation for fundamental frequencies of 10,000 and 15,000 cycles. Measurements shall include harmonics to 30,000 cycles. (Measurements at 10,000 and 15,000 cycles at 25 and 50 percent modulation are not practical at this time, due to the deemphasis in the measuring equipment.)

(4) Carrier hum and extraneous noise (AM and FM) generated within the equipment and measured as the level below 100 percent modulation.

(5) Means of varying output power to compensate for power supply voltage variations.

(6) Data and curves on mean frequency stability for variations in ambient temperatures over the ranges encountered in practice.

[6] Tentative standard.

[7] In connection with its type approval of FM equipment, the Commission may send a representative to observe tests made of such equipment by the manufacturer.

(7) Data and curves on frequency stability for variations in power supply voltage from 85 to 115 percent normal.

(8) Net sale price.

F. In case any manufacturer decides to produce a 100 kw. transmitter and submit data on it for approval, or any power rating not listed as standard, he shall give notice to the Commission which will release by public notice the manufacturer's name and the standard power rating of the transmitter to be produced at least 6 months prior to the delivery date or completion of such transmitter.

14. REQUIREMENTS FOR TYPE APPROVAL OF FREQUENCY MONITORS

Section 3.252 of the Rules requires each FM broadcast station to have in operation, at the transmitter, an approved frequency monitor independent of the frequency control of the transmitter. The frequency monitor shall be approved by the Commission and shall have a stability and accuracy of at least one-half (±1000 cycles) of the permitted frequency deviation of the FM broadcast station. Visual indication of the operating frequency shall be provided.

A. General requirements.--In general a frequency monitor for FM broadcast stations requires a stable source of radio frequency energy whose frequency is accurately known and a means of comparing the transmitter center frequency with this stable source. The visual indicator is calibrated to indicate the deviation of the transmitter center frequency from the frequency assigned.

Approval of a frequency monitor for FM broadcast stations will be considered on the basis of data submitted by the manufacturer. Any manufacturer desiring to submit a monitor for approval shall supply the Commission with full details (two sworn copies).

In approving a frequency monitor based on these tests and specifications, the Commission merely recognizes that the type of monitor has the inherent capability of functioning in compliance with section 3.252, if properly constructed, maintained and operated. The Commission accepts no responsibility beyond this and further realizes that monitors may have a limited range over which the visual indicator will determine deviations. Accordingly, it may be necessary that adjunct equipment be used to determine major deviations.

No change whatsoever will be permitted in the monitors sold under approval number issued by the Commission except when the licensee or the manufacturer is specifically authorized to make such changes. When it is desired to make any change, either mechanical or electrical, the details shall be submitted to the Commission for its consideration.

Approval is given subject to withdrawal if the unit proves defective in service and cannot be relied upon under usual conditions of maintenance and operation encountered in the average FM broadcast station. Withdrawal of approval means that no further units may be installed by FM broadcast stations for the purpose of complying with section 3.252; however, this will not affect units already sold unless it is found that there has been an unauthorized change in design or construction or that the material or workmanship is defective.

B. General specifications.--The general specifications that frequency monitors shall meet before they will be approved by the Commission are as follows:[8]

(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 corre-

[8] In connection with its type approval of FM equipment, the Commission may send a representative to observe tests made of such equipment by the manufacturer.

17. APPROVED FREQUENCY MONITORS

MANUFACTURER'S NAME	TYPE NO.
Doolittle Radio, Inc., Chicago, Ill.	FD11
General Electric Company, Schenectady, N. Y.	BM-1-A
Radio Engineering Laboratories, Long Island City, N. Y.	600
Hewlett-Packard Co., Palo Alto, Calif.	335B

18. APPROVED MODULATION MONITORS

MANUFACTURER'S NAME	TYPE NO.
Doolittle Radio, Inc., Chicago, Ill.	FD11
General Electric Company, Schenectady, N. Y.	BM-1-A
Radio Engineering Laboratories, Long Island City, N. Y.	600
Hewlett-Packard Co., Palo Alto, Calif.	335B

19. FM BROADCAST APPLICATION FORMS

FCC Form 301.--Application for Authority to Construct a New Broadcast Station or Make Changes in an Existing Broadcast Station.

FCC Form 302.--Application for New Broadcast Station License.

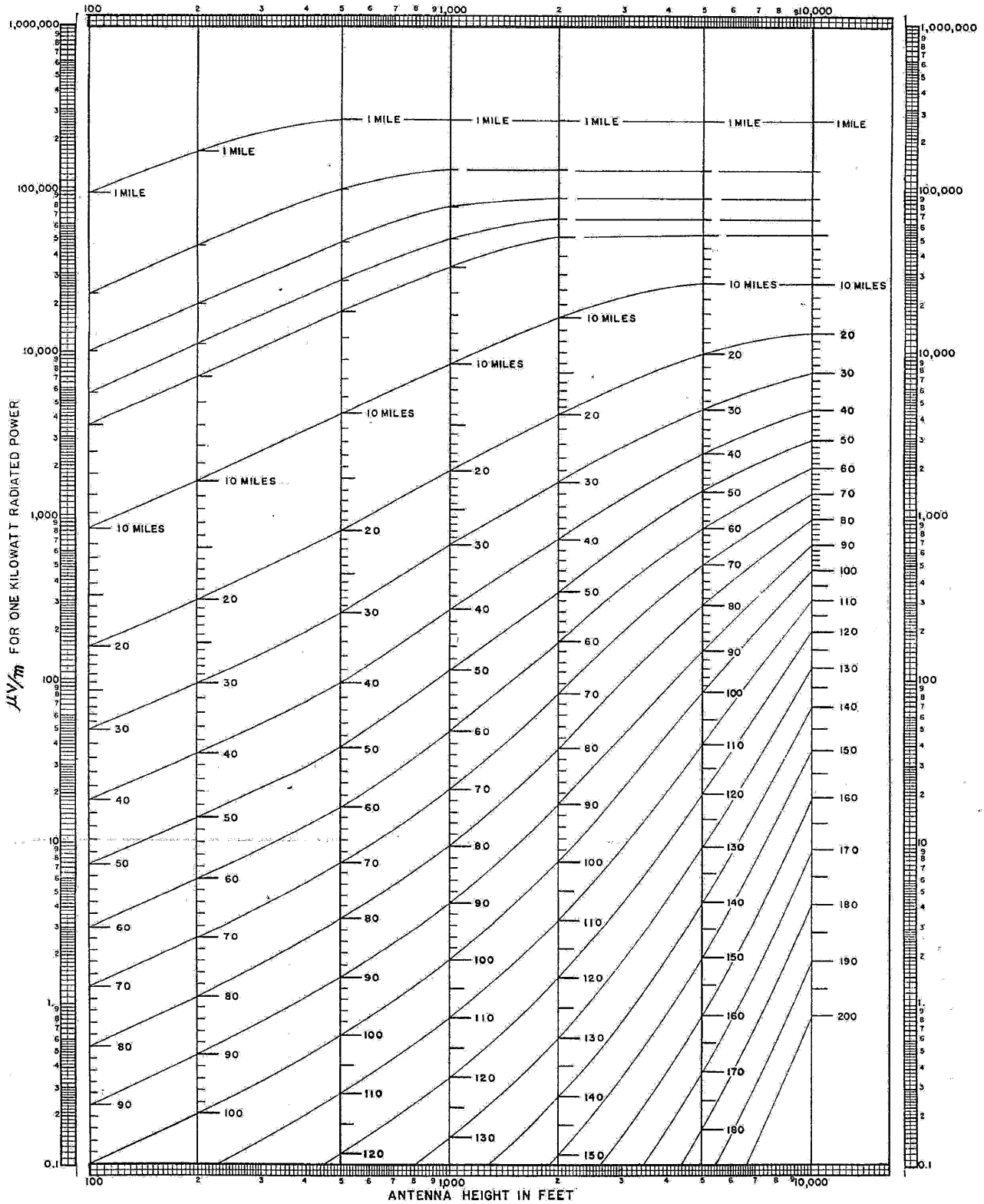
FCC Form 303.--Application for Renewal of Broadcast Station License.

FCC Form 314.--Application for Consent to Assignment of Radio Broadcast Station Construction Permit or License.

FCC Form 315.--Application for Consent to Transfer of Control of Corporation Holding Radio Broadcast Station Construction Permit or License.

FCC Form 321.--Application for Construction Permit to Replace Expired Permit.

FCC Form 701.--Application for Additional Time to Construct a Radio Station.



GROUND WAVE SIGNAL RANGE FOR F M BROADCASTING

98mc, $\sigma = 5 \times 10^{-14}$ e.m.u., $\epsilon = 15$, RECEIVING ANTENNA HEIGHT 30 FEET
FOR HORIZONTAL (AND APPROX. FOR VERTICAL) POLARIZATION

FIGURE 1.

1-FM-17

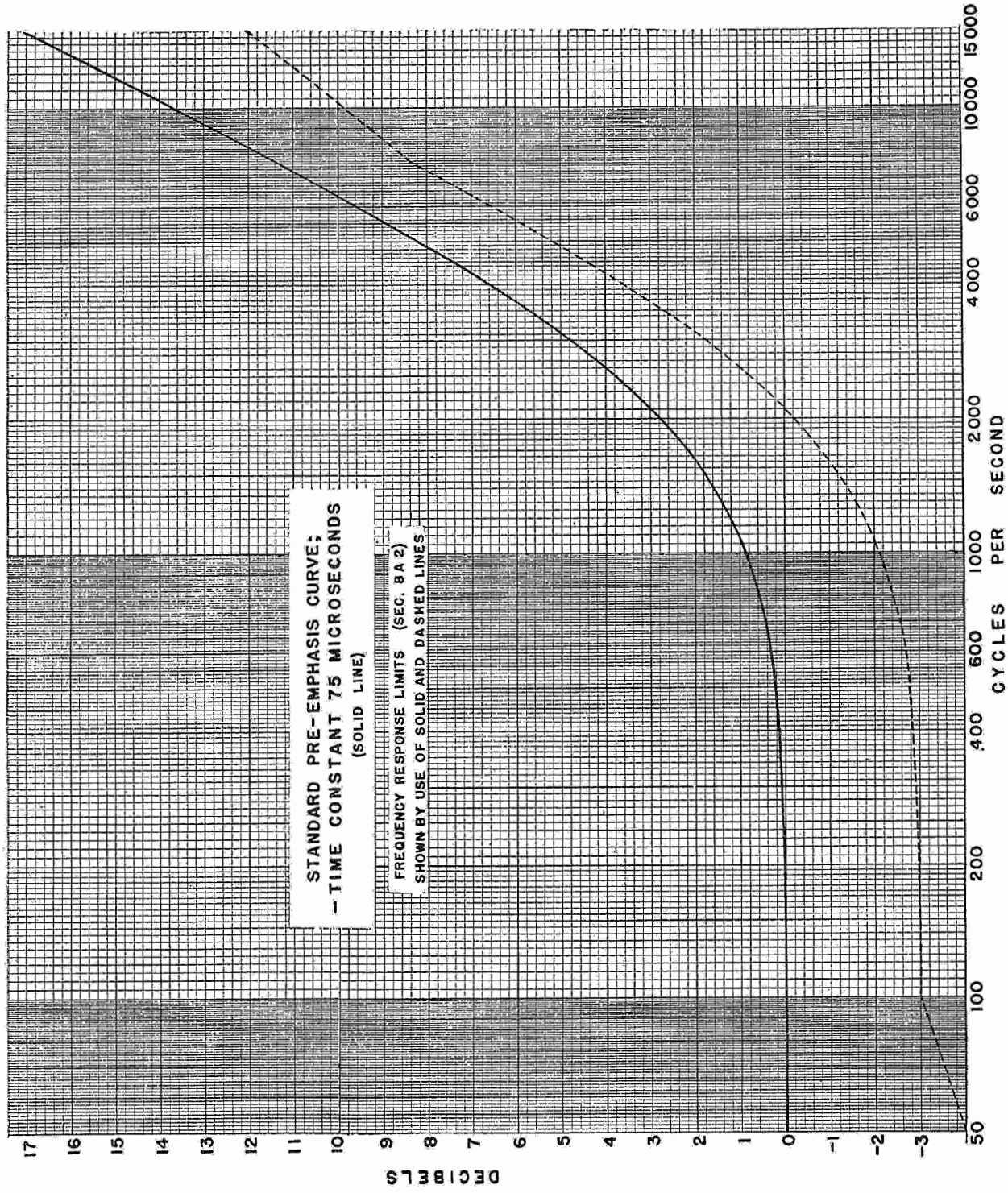

STANDARD PRE-EMPHASIS CURVE;
-TIME CONSTANT 75 MICROSECONDS
(SOLID LINE)
FREQUENCY RESPONSE LIMITS (SEC. 8A2)
SHOWN BY USE OF SOLID AND DASHED LINES
DECIBELS
CYCLES PER SECOND
50
100
200
400
600
1000
2000
4000
6000
10000
15000
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3

FIGURE 3.

FEDERAL COMMUNICATIONS COMMISSION

STANDARDS OF GOOD ENGINEERING PRACTICE CONCERNING TELEVISION BROADCAST STATIONS

*EFFECTIVE DECEMBER 19, 1945**

INTRODUCTION

There are presented herein the Commission's engineering standards relating to the allocation and operation of television broadcast stations. 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.

The standards set forth herein are those deemed necessary for the construction and operation of television 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 television broadcast stations. These standards are complete in themselves and supersede previous engineering standards or policies of the Commission concerning television 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.

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.

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*As of July 15, 1949, no amendments to these Standards have been issued. As amendments are made they will be indicated or printed in NAB Member Service.

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*Sections 13 to 20, inclusive, are to be supplied in a later printing.

(NAB Editor's Note: As of July 15, 1949, Sections 13 to 20, inclusive, have not been issued by the FCC. As these and other additions are made, they will be indicated or printed in NAB MEMBER SERVICE.)

1. DEFINITIONS

A. GENERAL

1. *Television broadcast station.*—The term "television broadcast station" means a station in the television broadcast band transmitting simultaneous visual and aural signals intended to be received by the general public.

2. *Television broadcast band.*—The term "television broadcast band" means those frequencies in the band extending from 44 to 216 megacycles which are assignable to television broadcast stations. These frequencies are 44 to 50 megacycles (channel No. 1), 54 to 72 megacycles (channels 2 through 4), 76 to 88 megacycles (channels 5 and 6) and 174 to 216 megacycles (channels 7 through 13).

3. *Television channel.*—The term "television channel" means a band of frequencies 6 megacyles wide in the television broadcast band and designated either by number or by the extreme lower and upper frequencies.

4. *Television transmission standards.*—The term "television transmission standards" means the standards which determine the characteristics of the television signal as radiated by a television broadcast station. (See section 2A.)

5. *Standard television signal.* — The term "standard television signal" means a signal which conforms with the television transmission standards.

6. *Television transmitter.*—The term "television transmitter" means the radio transmitter or transmitters for the transmission of both visual and aural signals.

7. *Antenna field gain.*—The term "antenna field gain" of a television antenna means the ratio of the effective free space field intensity produced at 1 mile in the horizontal plane expressed in millivolts per meter for 1 kilowatt antenna input power to 137.6 MV/m.

8. *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.

9. *Polarization.* — The term "polarization" means the direction of the electric vector as radiated from the transmitting antenna.

10. *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.

11. *Service area.*—The term "service area" as applied to television broadcasting means the service area resulting from an assigned effective radiated power and antenna height above average terrain.

12. *Antenna height above average terrain.*—The term "antenna height above average terrain" means the average of the antenna heights above the terrain from two to 10 miles from the antenna. (In general a different antenna height will be determined by each direction from the antenna. The average of these various heights is considered as the antenna height above average terrain.)

B. VISUAL TRANSMITTER

1. *Visual transmitter.*—The term "visual transmitter" means the radio equipment for the transmission of the visual signal only.

2. *Amplitude modulation.*—The term "amplitude modulation" (AM) means 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.

3. *Aspect ratio.*—The term "aspect ratio" means the numerical ratio of the frame width to frame height, as transmitted.

4. *Black level.*—The term "black level" means the amplitude of the modulating signal corresponding to the scanning of a black area in the transmitted picture.

5. *Color transmission.*—The term "color transmission" means the transmission of television signals which can be reproduced with different color values.

6. *Field frequency.*—The term "field frequency" means the number of times per second the frame area is fractionally scanned in the interlaced scanning.

7. *Frame.*—The term "frame" means one complete picture.

8. *Frame frequency.*—The term "frame frequency" means the number of times per second the picture area is completely scanned.

9. *Interlaced scanning.*—The term "interlaced scanning" means 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 scanning.

10. *Monochrome transmission.*—The term "monochrome transmission" means the transmission of television signals which can be reproduced in gradations of a single color only.

11. *Negative transmission.*—The term "negative transmissions" means that a decrease in initial light intensity causes an increase in the transmitted power.

12. *Positive transmission.*—The term "positive transmission" means that an increase in initial light intensity causes an increase in the transmitted power.

13. *Progressive scanning.*—The term "progressive scanning" means a scanning process in which scanning lines trace one dimension substantially parallel to a side of the frame and in which successively traced lines are adjacent.

14. *Scanning.*—The terms "scanning" means the process of analyzing successively, according to a predetermined method, the light values of picture elements constituting the total picture area.

15. *Scanning line.*—The term "scanning line" means a single continuous narrow strip containing highlights, shadows, and halftones which is determined by the process of scanning.

16. *Synchronization.*—The term "synchronization" means the maintaining of one operation in step with another.

17. *Vestigial side band transmission.*—The term "vestigial side band transmission" means a system of transmission wherein one of the generated side bands is partially attenuated at the transmitter and radiated only in part. (See Appendix II.)

18. *Visual frequency.*—The term "visual frequency" means the frequency of the signal resulting from television scanning.

19. *Visual transmitter power.*—The term "visual transmitter power" means the peak power output when transmitting a standard television signal.

20. *Peak power.*—The term "peak power" means the power over a radio frequency cycle corresponding in amplitude to synchronizing peaks.

C. AURAL TRANSMITTER

1. *Aural transmitter.*—The term "aural transmitter" means the radio equipment for the transmission of the aural signal only.

2. *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.

3. *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.

4. *Frequency swing.*—The term "frequency swing" means the instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

5. *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 the aural transmitter of television broadcast stations, a frequency swing of ±25 kilocycles is defined as 100-percent modulation.

2. TRANSMISSION STANDARDS AND CHANGES OR MODIFICATIONS THEREOF

A. TRANSMISSION STANDARDS

1. The width of the television broadcast channel shall be six megacycles per second.

2. The visual carrier shall be located 4.5 megacycles lower in frequency than the aural center frequency.

3. The aural center frequency shall be located 0.25 megacycles lower than the upper frequency limit of the channel.

4. The visual transmission amplitude characteristic shall be as shown in Appendix II.

5. The number of scanning lines per frame period shall be 525, interlaced two to one.

6. The frame frequency shall be 30 per second and the field frequency shall be 60 per second.

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 synchroniz-

ing signals, the two signals comprising different modulation ranges in amplitude. (See Appendices I and II.)

10. A decrease in initial light intensity shall cause an increase in radiated power (negative transmission).

11. The black level shall be represented by a definite carrier level, independent of light and shade in the picture.

12. The pedestal level (normal black level) shall be transmitted at 75 percent (with a tolerance of plus or minus 2.5 percent) of the peak carrier amplitude.

13. The maximum white level shall be 15 percent or less of the peak carrier amplitude.

14. The signals radiated shall have horizontal polarization.

15. A radiated power of the aural transmitter not less than 50 percent or more than 150 percent of the peak radiated power of the video transmitter shall be employed.

16.[1] *Variation of output.*—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 synchronizing peak and pedestal level, shall not exceed 5 percent of the average synchronizing peak signal amplitude.

17.[1] *Black level.*—The black level should be made as nearly equal to the pedestal level as the state of the art will permit. If they are made essentially equal, satisfactory operation will result and improved techniques will later lead to the establishment of the tolerance if necessary.

18.[1] *Brightness characteristics.*—The transmitter output shall vary in substantially inverse logarithmic relation to the brightness of the subject. No tolerances are set at this time.

B. CHANGE OR MODIFICATION OF 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) above.

3. ENGINEERING STANDARDS OF ALLOCATION

A. Sections 3.603 through 3.606 of the Commission's Rules prescribes the basis of assignment of television broadcast facilities. Section 3.601 indicates the groups of channels that are available for assignment to television broadcast stations. As indicated by these rules, the number of channels are limited and therefore have been allocated in advance to specific areas. This listing has been carefully planned with a view to providing the greatest service to a maximum number of people, and in general no departure from this plan will be made. However, where it can be shown that the public interest will be benefited by an alteration or rearrangement in this listing, the Commission will consider such adjustments as are necessary.

B. 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:

[1] These items are subject to change but are considered the best practice under the present state of the art. They will not be enforced pending a further determination thereof.

TABLE I

Area:	*Median field intensity*
City, business, or factor areas	5,000 μv/m
Residential and rural areas	500 μv/m

These figures are based upon the usual noise levels encountered in the two areas and upon the absence of interference from other television broadcast stations. The Commission will require that the transmitting antenna be so located as to provide a coverage area which is contiguous with the population density of the cities or metropolitan area with which the station is associated.

The field intensity indicated above for computing coverage is the visual transmitter operating peak power.

C. 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 predicated 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-feet 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 used, 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 charts showing signal intensities (Appendix IV).

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. To determine the distance to a particular contour concerning the range of television broadcast stations, Appendix IV should be used. These charts have been prepared for frequencies in the center of the various portions of the television band and are to be used as follows: Figure 1 for channel 1; Figure 2 for channels 2 through 4; Figure 3 for channels 5 and 6; and Figure 4 for channels 7 through 13. 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 Appendix IV 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 Appendix IV are based upon an effective radiated power of one kilowatt; 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 lower line of the top edge of the charts. The right edge of the scale is placed in line with the appropriate antenna height graduations and the charts then become 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.

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 5,000 μv/m and 500 μv/m contours must be determined and submitted with each application for television broadcast stations. 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 strength 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. Where interference is involved such areas shall be determined as indicated by section V.

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 miles 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.

In determining the population served by television 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 5,000 μv/m contour do not receive adequate service. Minor Civil Division maps (1940 census) should be used in making population counts, 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.

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4. TOPOGRAPHICAL DATA

In the preparation of the profile graphs previously described, the elevations or contour intervals shall be taken from the United States Geological Topographical Quadrangle Sheets 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.

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.

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 10 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. Other sources of topographic maps or data will be furnished at a later date.

5. INTERFERENCE STANDARDS

Field intensity measurements are preferable in predicting interference between television broadcast stations and should be used, when available, in determining the extent of interference. (For

methods and procedure, see sec. 6.) In lieu of measurements, the interference should be predicted in accordance with the method described herein.

Objectionable visual interference is considered to exist when the interfering signal exceeds that given by the ratios of table II. In table II the desired signal is median field and the undesired signal is the tropospheric signal intensity exceeded for 10 percent of the time.

TABLE II

Channel separation:	*Ratio of desired to undesired signals*
Same channel	100:1
Adjacent channel	2:1

It is considered that stations on alternate channels or on channels separated by 4 Mc can be operated in the same city or area without objectionable interference (i. e., on this basis channels 1 and 2 or 4 and 5 could be used in the same city or area).

As an example of the application of the data contained in table II, objectionable interference from a co-channel station is considered to exist at the 500 μv/m contour of a station if a tropospheric signal from the co-channel station equals or exceeds 5 μv/m for at least ten percent of the time. The ten percent values for 1 kilowatt of power and various antenna heights are given in Appendix V,[2] and values for other powers may be obtained by using the sliding scale as for Appendix IV. The values indicated by Appendix V are based upon available data, and are subject to change as additional information concerning tropospheric wave propagation is obtained.

At the present time it is considered sufficient to consider only the ground wave field intensities in determining the extent of adjacent channel interference.

In determining the points at which the interference ratio is equal to the values shown in table II, 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 contour where the same ratios are determined, are considered to be generally sufficient to predict the area of interference. Additional points may be required in case of irregular terrain or directional antenna systems.

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 500 μv/m contour.

6. FIELD INTENSITY MEASUREMENTS IN ALLOCATION

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.

Measurements made to determine the service and interference areas 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. 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 must be nondirectional and horizontally polarized.

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

[2] Charts for Appendix V will be available at some future date when sufficient measurements of tropospheric signals are available. Until such time as these charts are available, interference should be predicted on the basis of ground wave charts (Appendix IV).

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.

While making field intensity measurements the visual transmitter shall be used. It is recommended that a black picture be transmitted or that the transmitted 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. If other means of measurements are to be used a request should be made to the Commission stating the reasons therfor and the means to be used.

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 (medium 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.

In making measurements to establish the field intensity contours of a station mobile recordings should be made along each of the radials drawn in section 3C above. Measurements should extend from the vicinity of the station out to the 500 μv/m measured contour and somewhat beyond. These measurements would be made for the purpose of determining the variation of the measured contours from those predicted. Adjustment of power or antenna may be required to fit the actual contours to that predicted.

In predicting tropospheric interference on the basis of the above measurements, such measurements shall be carried out in the manner indicated above to determine the 500 μv/m contour. Using the appropriate figure in Appendix IV for the channel involved and the sliding scale, the equivalent radiated power shall be determined by placing the sliding scale on the chart (using the appropriate antenna height) and moving the scale until the distance to the 500 μv/m contour (as determined above), and the 500 μv/m mark are opposite. The equivalent radiated power is then read from the sliding scale where it crosses the lower line of the top edge of the chart. Changing to the corresponding figure in Appendix V and using the equivalent radiated power just determined, the distance to the interfering contour under investigation is read in the usual manner.

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 finding ratios.

Complete data taken in conjunction with field intensity measurements shall be submitted to the Commission in affidavit form, including the following:

A. 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.) The 5,000 and 500 μv/m contours shall be shown.

B. 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 sec. 8.)

C. A full description of the procedures and methods employed including the type of equipment, the method of installation and operation, and calibration procedures.

D. Complete data obtained during the survey, including calibration.

E. Antenna system and power employed during the survey.

F. Name, address, and qualifications of the engineer or engineers making the measurements.

All data shall be submitted to the Commission in triplicate, except that only the original or one photostatic copy need be submitted of the actual recording tapes.

7. 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 area. Inasmuch as service may be provided by signals of 5,000 μv/m or greater field intensities in metropolitan areas, and inasmuch as signals below 500 μv/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 5,000 μv/m contour encompasses the urban population within the area to be served and the 500 μv/m or the interference free from 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 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. Where it is found necessary to locate the transmitter in a residential area where blanketing problems may appear to be excessive, the application must include 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.

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. In passing on proposed construction, the Commission refers each case to the Civil Aeronautics Administration for its recommendations. Antenna painting and/or lighting may be required at the time of construction or at a later date.

8. ANTENNA SYSTEMS

A. An antenna which is high in respect to the average level of the territory it serves is desirable in order to reduce the effect of shadows. The antenna must be constructed so that it is as clear as possible of surrounding buildings or objects that would cause shadow problems.

B. 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) 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 tabulations of calculation data.

(4) Name, address, and qualifications of the engineer making the calculations.

C. Applications proposing (1) the use of television broadcast antennas in the immediate vicinity (i. e., 200 feet or less) of television broadcast antennas operating on a channel within 20 percent in frequency of the proposed channel, or (2) the use of television antennas on channels 5 or 6 in the immediate vicinity of FM broadcast antennas, must include a showing as to the expected effect, if any, of such proximate operation.

D. 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 application for construction permit (or modification of construction permit) for such station must be filed for consideration with the television application. An application may be required for other classes of stations when the tower is to be used in connection with a television station.

When a television 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 television 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 television license application will not be considered until the application form concerning resistance measurements is filed for the standard broadcast station.

When a television antenna is mounted on an element of a standard broadcast directional antenna, a full engineering study concerning the effect of the television 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 television antenna system.

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.

Information regarding data required in connection with standard broadcast directional antenna systems may be found in the Standards of Good Engineering Practice Concerning Standard Broadcast Stations.

E. 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 and/or lighting requirements,

In the event of shared ownership, one license shall assume such responsibility and advise the Commission accordingly.

F. STANDARD LAMPS AND PAINTS

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.

These individual specifications are issued for and attached to each authorization for an installa-

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tion. The details of the specifications depend on the degree of hazard presented by the particular installation. The tower paint shall be kept in good condition and repainted as often as necessary to maintain this condition.

General information regarding painting and lighting requirements is contained in the Obstruction Marking Manual available from the Civil Aeronautics Administration, Washington 25, D. C.

9. TRANSMITTERS AND ASSOCIATED EQUIPMENT

A. VISUAL TRANSMITTER DESIGN

The general design of television broadcast visual transmitting equipment shall be in accordance with the following principles and specifications:

(1) The over-all attenuation characteristics of the transmitter measured in the antenna transmission line after the vestigial side band filters shall not be greater than—

2 db at 0.5 Mc
2 db at 1.25 Mc
3 db at 2.0 Mc
6 db at 3.0 Mc
12 db at 3.5 Mc

below the ideal demodulated curve. (See Appendix III.) The curve shall be substantially smooth between these specified points exclusive of the region from 0.75 Mc to 1.25 Mc.[3]

(2) The field strength or voltage of the lower side band as radiated or dissipated and measured as described in (3) below shall not be greater than −20 db for a modulating frequency of 1.25 Mc or greater.[3]

(3) 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 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 100-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.[3]

(4) The radio frequency signal, as radiated, shall have an envelope as would be produced by a modulating signal in conformity with Appendix I, as modified by vestigial operation specified by Appendix II.

(5) The time interval between the leading edges of successive horizontal pulses shall vary less than one half of one percent of the average interval.

(6) 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 vertical blanking signal.

B. AURAL TRANSMITTER DESIGN

The general design of the aural transmitting equipment associated with a television station shall be in accordance with the following principles and specifications:

(1) The transmitter shall operate satisfactorily with a frequency swing of ±25 kilocycles, which is considered 100 percent modulation. It is rec-

[3] In the case of (1) above, output measurement 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 Appendix III.

In the case of (2) above, 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. The "synchronizing signal" referred to in these paragraphs means either a standard synchronizing wave form or any pulse that will properly set the peak.

ommended, 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 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 capable of transmitting a band of frequencies from 50 to 5,000 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 Appendix VI.) The deviation of the system response from the standard pre-emphasis curve shall lie between two limits as shown by Appendix VI. 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 percentage 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

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.[4]

[4] 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.

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.[5]

(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.[5]

(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.

C. DESIGN APPLICABLE TO BOTH VISUAL AND AURAL TRANSMITTERS

In addition to design features applicable to the individual transmitters, the general design of television broadcast (visual and aural) transmitting equipment shall be in accordance with the following principles and specifications:

(1) Automatic means shall be provided in the transmitters to maintain the authorized carrier frequencies within the allowable tolerance (±0.002 percent).

(2) The transmitters 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.

(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 powers.

(4) Adequate provisions shall be provided in all component parts to avoid overheating at the rated maximum output powers.

(5) Means should be provided for connection and continuous operation of approved frequency and modulation monitors.

[5] 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.

D. CONSTRUCTION

In general, the transmitters shall be constructed either on racks and panels or in totally enclosed frames protected as required by article 810 of the National Electrical Code,[6] 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.

(*a*) Commutator guards shall be provided on all high voltage rotating machinery. Coupling guards should be provided on motor generators.

(*b*) 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).

(*c*) 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 under the jurisdiction of the Commission; therefore section 3.654 does not apply.

(4) *Metering equipment.*—(*a*) 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.)

(*b*) In case the plate voltmeters are located on the low potential side of the multiplier resistors with the potential of 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.

(*c*) 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.

(*d*) It is recommended that component parts comply as much as possible with the component specifications designated by the Army-Navy Electronics Standards Agency.

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, concentric lines 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 either coaxial, two wire balance 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.

F. INSTALLATION

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

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

[6] The pertinent sections of article 810 of the National Electrical Code reads 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."

G. SPARE TUBES

A spare tube of every type employed in the transmitters and frequency modulation monitors shall be kept on hand at the equipment location. When more than one tube of any type are employed, the following table determines the numbers of spare of that type required:

Number of each type employed:	*Spares required*
1 or 2	1
3 to 5	2
6 to 8	3
9 or more	4

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.

H. OPERATION

In addition to specified requirements of the rules governing television broadcast stations, the following operating requirements are specified:

(1) Spurious emissions, including radio frequency harmonics, shall be maintained at as low a level as the state of the art permits.

(2) If a limiting or compression amplifier is used in conjunction with the aural transmitter, due operating precautions should be maintained in its use due to pre-emphasis in the transmitting system.

I. STUDIO EQUIPMENT

Studio equipment shall be subject to all the above requirements where applicable except as follows:

(1) If properly covered by an underwriters' 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.

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.

10. INDICATING INSTRUMENTS

A. A television broadcast station shall be equipped with suitable indicating instruments of accepted accuracy to measure the direct plate voltage and current of the last radio stage of the visual and aural transmitters and an instrument for reading the transmission line of both transmitters.

The following requirements and specifications shall apply to indicating instruments used by television broadcast stations in compliance with this rule:

(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.

No specifications are prescribed at this time regarding the peak indicating device required by section 11B (1) of these standards.

B. No instruments indicating the plate current or plate voltage of the last radio stage shall be changed or replaced without written authority of the Commission, except by instruments of the same maximum scale readings and accuracy. Requests for authority to use an instrument of different maximum scale reading and/or accuracy shall be made by letter or telegram giving the manufacturer's name, type number, and full scale reading of the proposed instrument and the values of current or voltage the instrument will be employed to indicate. Requests for temporary authority to operate without an instrument or with a substitute instrument may be made by letter or telegram stating the necessity therefor and the period involved.

C. No required instrument the accuracy of which is questionable shall 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 indicat-

ing 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.

11. OPERATING POWER—DETERMINATION AND MAINTENANCE

A. DETERMINATION

(1) *Visual transmitter.*—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 (Ep) and the plate current (Ip) of the last radio stage, and an efficiency factor, F; that is.

$$\text{Operating power} = Ep \times Ip \times F$$

The efficiency factor, F, shall be established by the transmitter manufacturer for each type of transmitter for which he requests FCC approval, 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 other voltage or current on the transmission line operating into the antenna, the meter to be calibrated during the measurement described in A (1) above. 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 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 A (1) above.

(2) *Aural Transmitter.*—The operating power of aural transmitters 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) 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 district in which the station is located shall be notified in writing immediately thereafter and also upon the resumption of the normal operating power.[7]

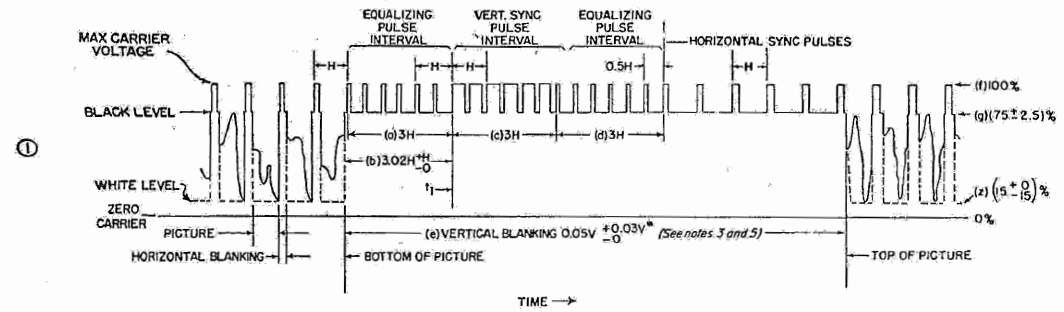
12. AUXILIARY TRANSMITTERS

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.

13 to 20, inclusive: These section to be supplied.

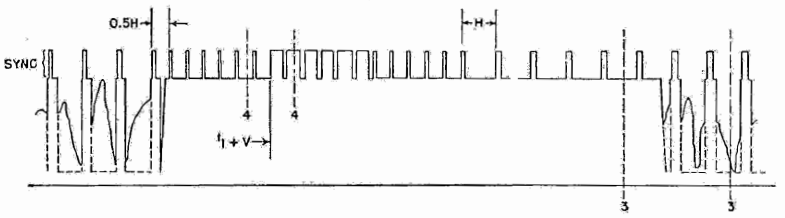
[7] See Appendix 3 of Part I of the Rules and Regulations for addresses of Field Offices.

TELEVISION SYNCHRONIZING WAVEFORM



①

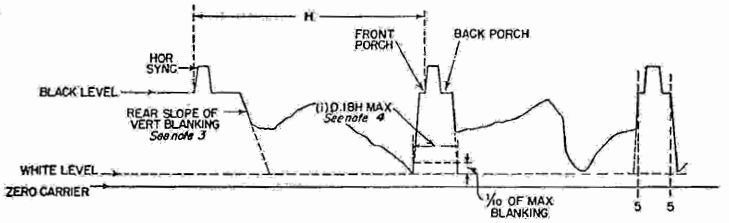
TIME →



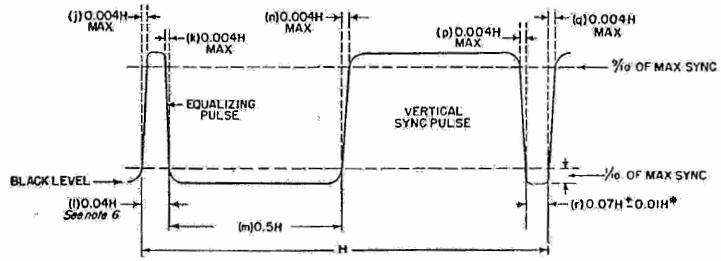
②

Horizontal dimensions not to scale in 1, 2 and 3

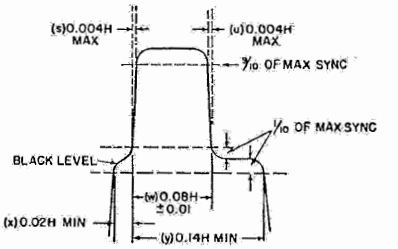
③ *Detail between 3–3 in ②*



④ *Detail between 4–4 in ②*



⑤ *Detail between 5–5 in ③*

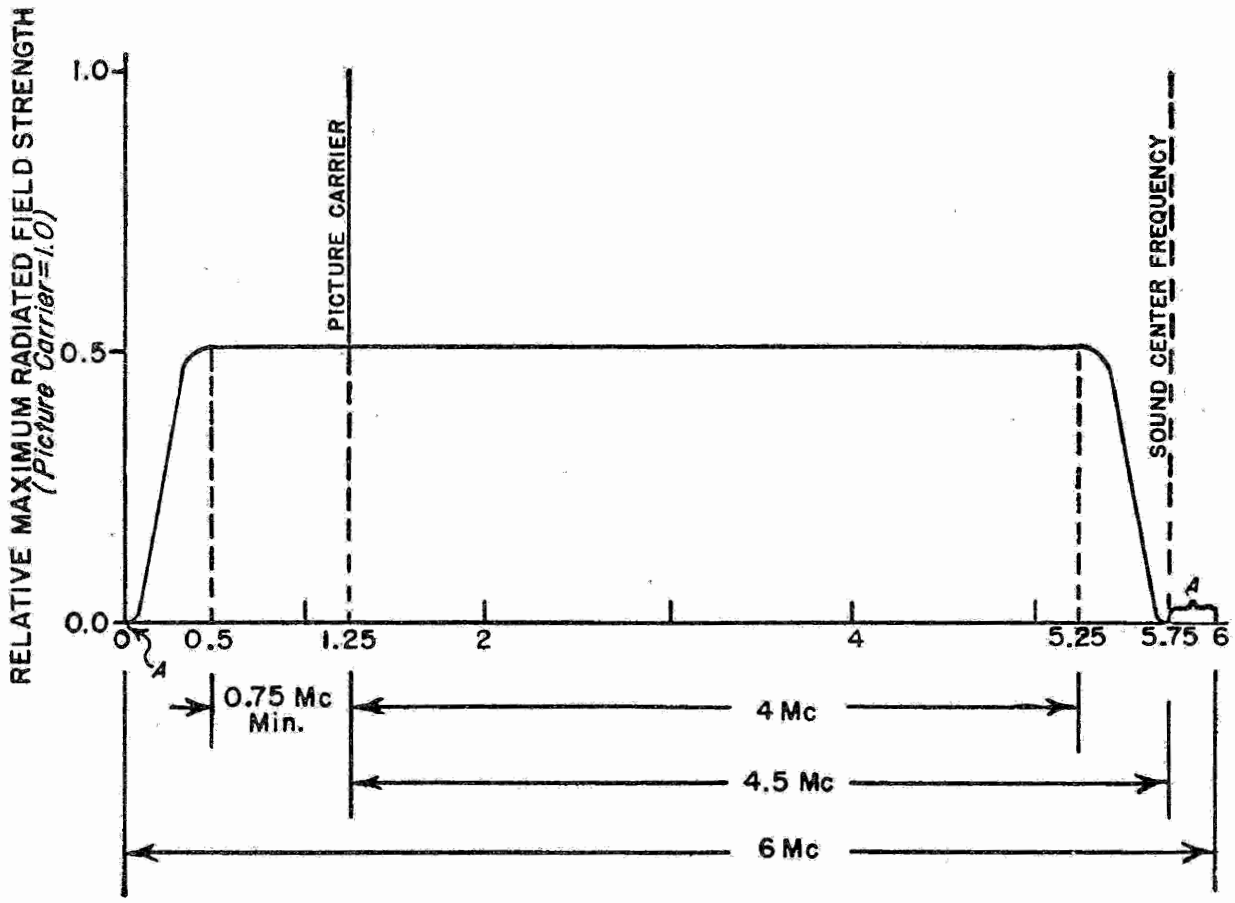


NOTE

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 0.1 H*
4 *Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values of (x+y) and (i) 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 *Refer to text for further explanations and tolerances*

APPENDIX I

IDEALIZED PICTURE TRANSMISSION AMPLITUDE CHARACTERISTIC



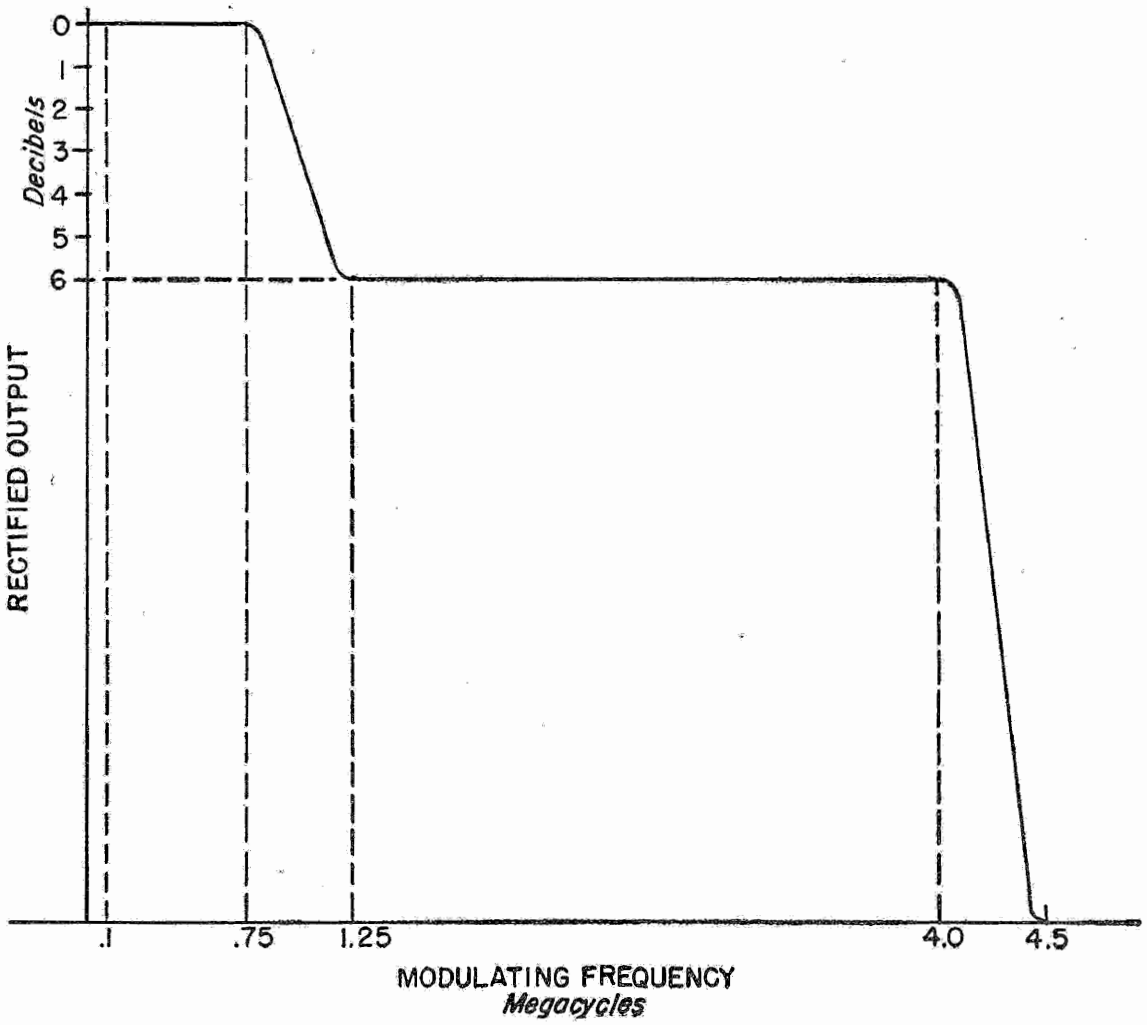
NOTES

A – *See section 9A(2) for field strength at these points*

Not drawn to scale

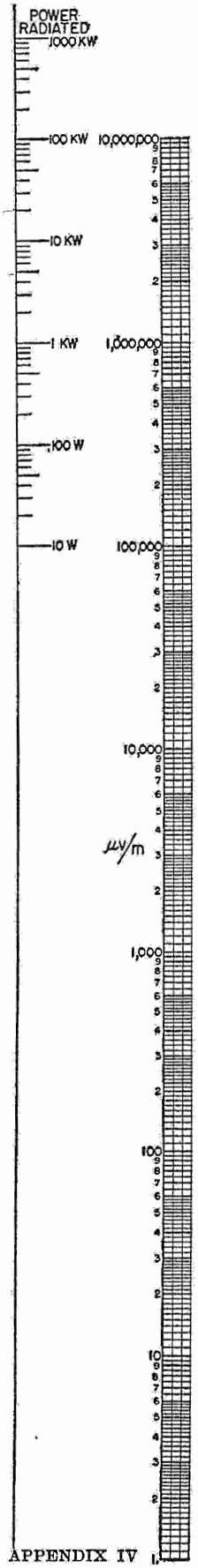
APPENDIX II

ASSUMED IDEAL DETECTOR OUTPUT

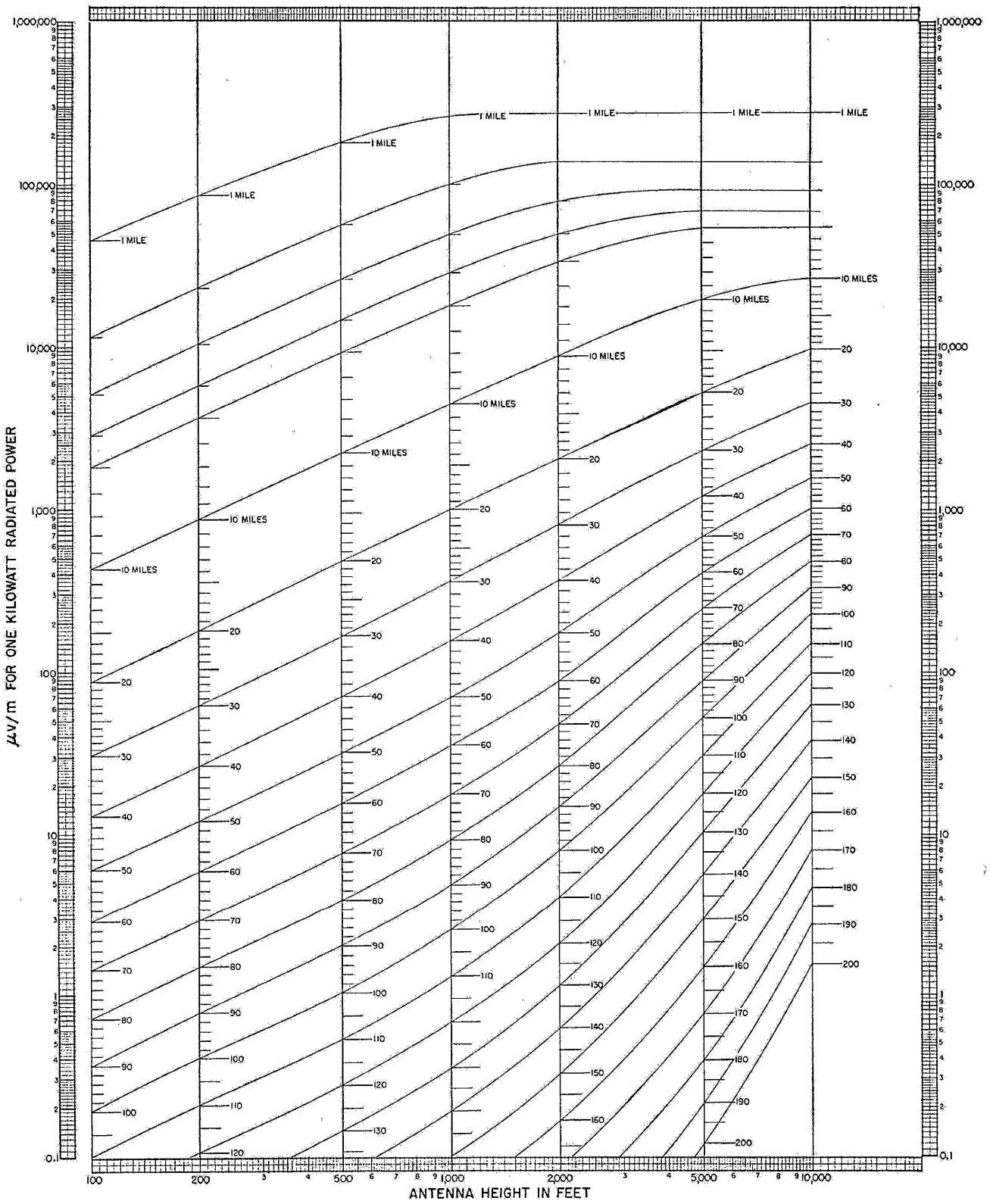


APPENDIX III

NOTE: Use the sliding scale on heavy-weight paper included with the HANDBOOK.



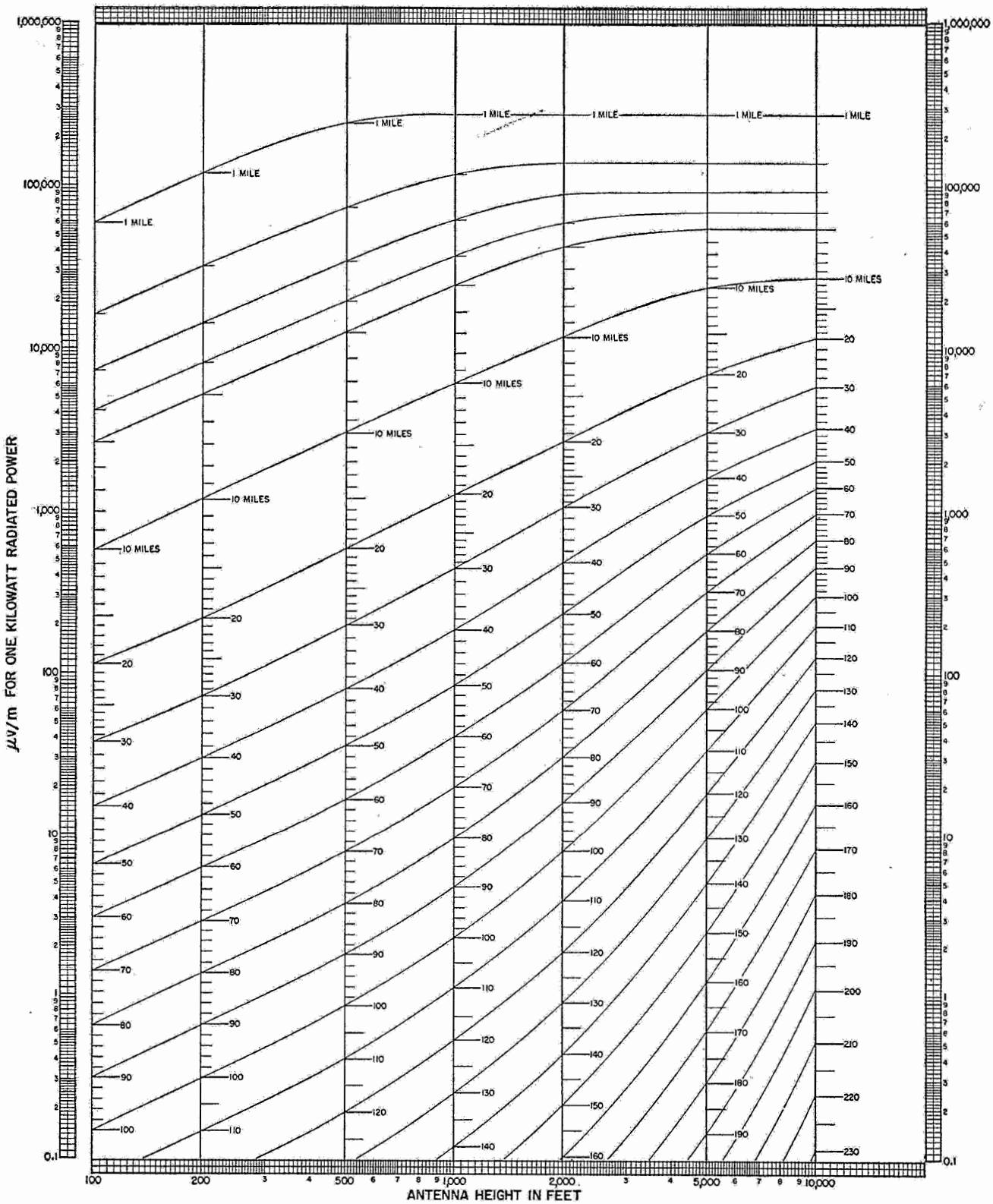
APPENDIX IV



GROUND WAVE SIGNAL RANGE FOR TELEVISION

46 mc, $\sigma = 5 \times 10^{-14}$ e.m.u., $\epsilon = 15$, RECEIVING ANTENNA HEIGHT 30 FEET
FOR HORIZONTAL (AND APPROX. FOR VERTICAL) POLARIZATION

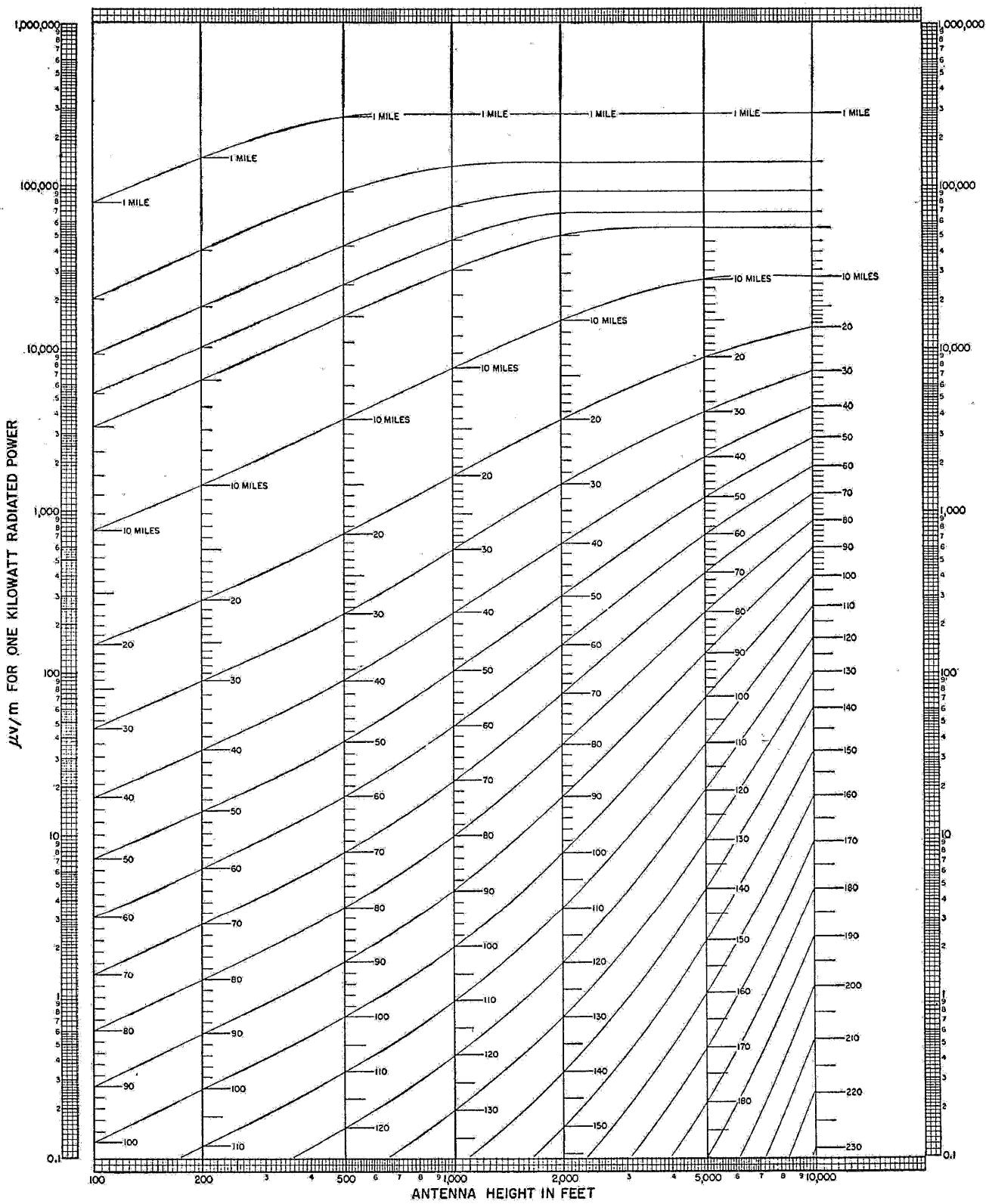
APPENDIX IV
FIGURE 1



GROUND WAVE SIGNAL RANGE FOR TELEVISION

63 mc, $\sigma = 5 \times 10^{-14}$ e.m.u, $\epsilon = 15$, RECEIVING ANTENNA HEIGHT 30 FEET
FOR HORIZONTAL (AND APPROX. FOR VERTICAL) POLARIZATION

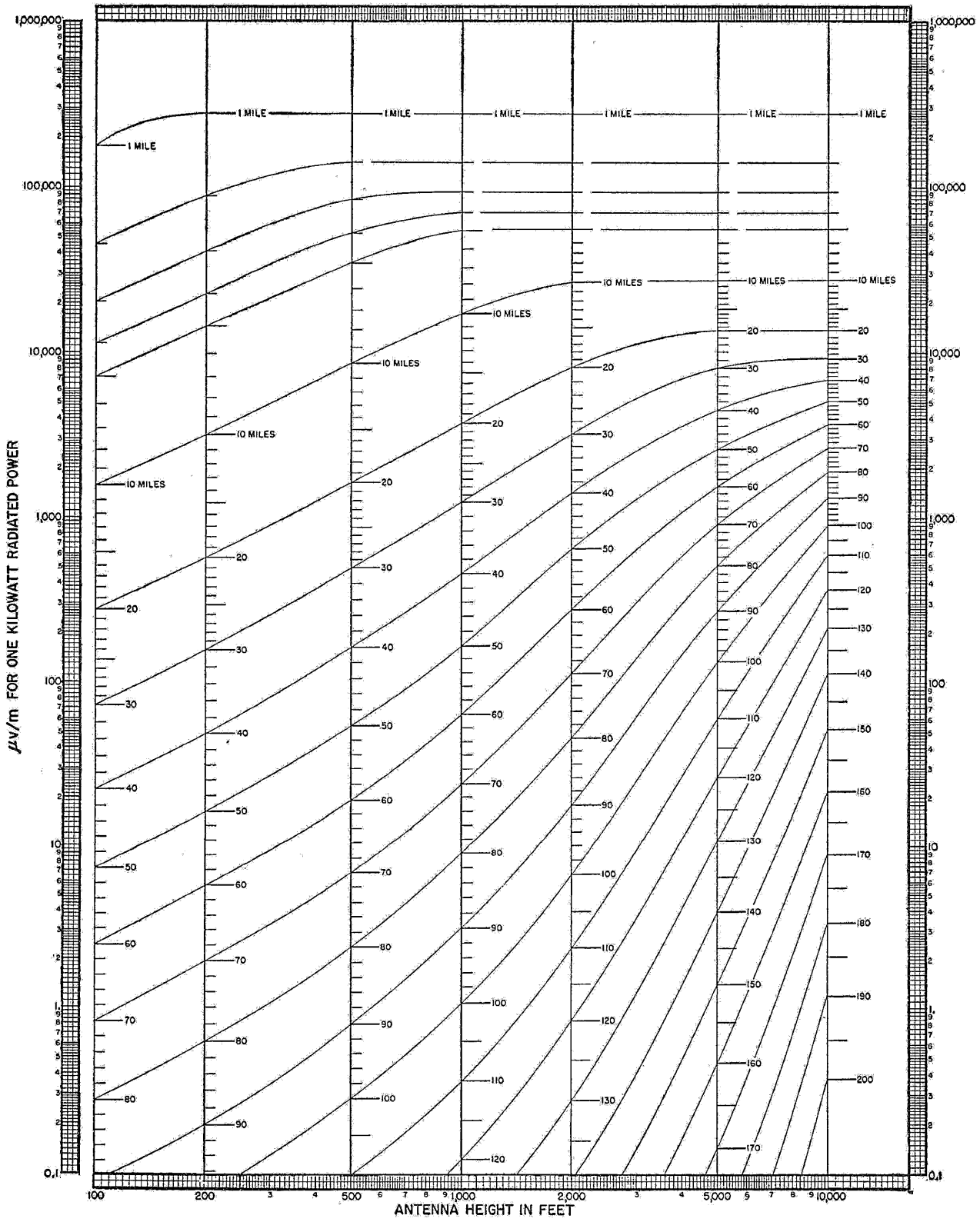
APPENDIX IV
FIGURE 2



GROUND WAVE SIGNAL RANGE FOR TELEVISION

82 mc, $\sigma = 5 \times 10^{-14}$ e.m.u., $\epsilon = 15$, RECEIVING ANTENNA HEIGHT 30 FEET
FOR HORIZONTAL (AND APPROX. FOR VERTICAL) POLARIZATION

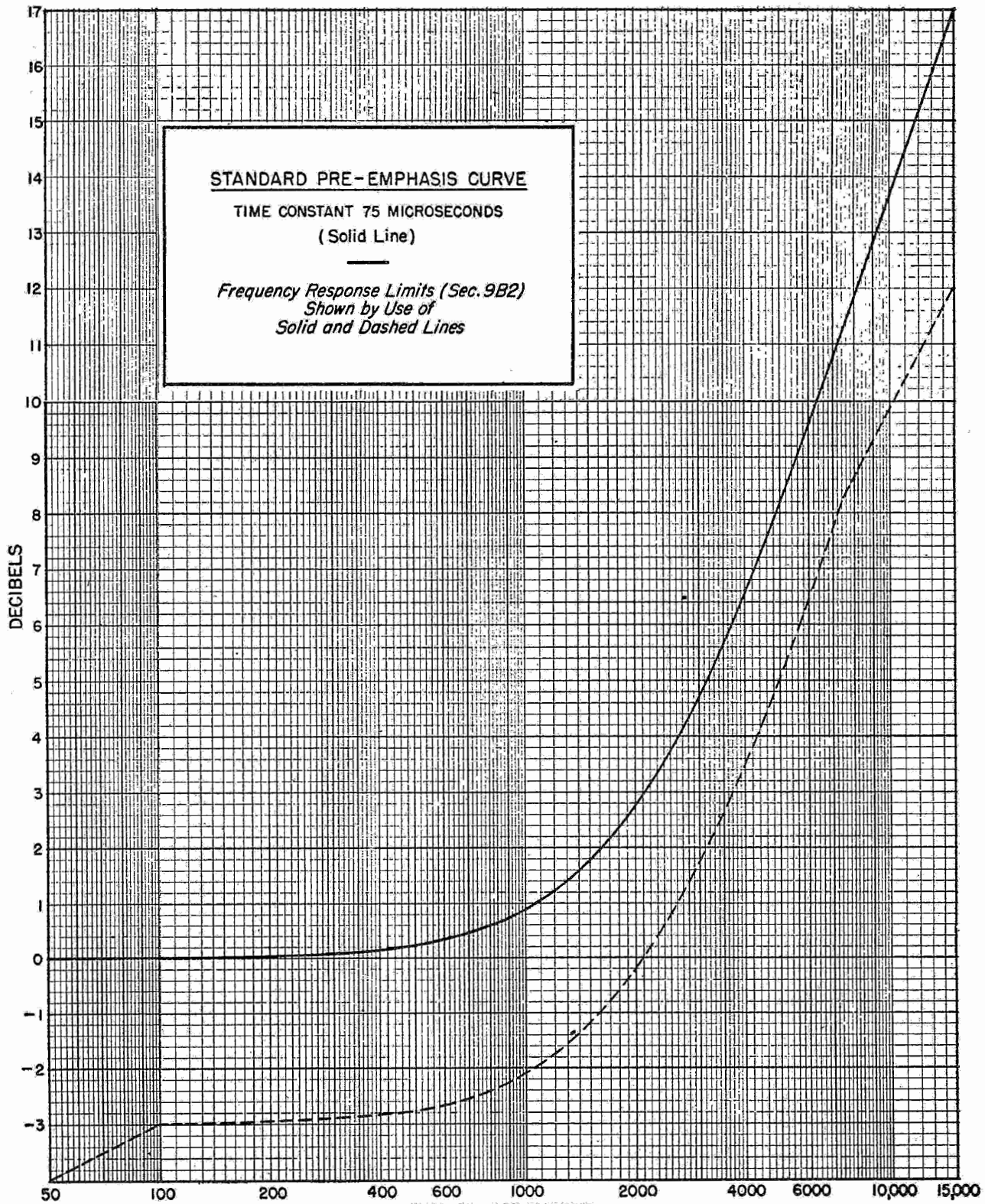
APPENDIX IV
FIGURE 3



GROUND WAVE SIGNAL RANGE FOR TELEVISION

195 mc, $\sigma = 5 \times 10^{-14}$ e.m.u., $\epsilon = 15$, RECEIVING ANTENNA HEIGHT 30 FEET
FOR HORIZONTAL (AND APPROX. FOR VERTICAL) POLARIZATION

APPENDIX IV
FIGURE 4


STANDARD PRE-EMPHASIS CURVE
TIME CONSTANT 75 MICROSECONDS
(Solid Line)
Frequency Response Limits (Sec. 9B2)
Shown by Use of
Solid and Dashed Lines
DECIBELS
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
50
100
200
400
600
1000
2000
4000
6000
10,000
15,000
CYCLES PER SECOND

APPENDIX VI

FEDERAL COMMUNICATIONS COMMISSION

PART 13

RULES GOVERNING COMMERCIAL RADIO OPERATORS

EFFECTIVE JULY 1, 1939

(Revised to June 30, 1949)

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GENERAL

Sec. 13.1 *Licensed operators required.*[1,2,3,4] 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.[5]

Sec. 13.2 *Classes of licenses.*[6,7] The classes of commercial operator licenses issued by the Commission are:

(a) Commercial radiotelephone group:
  (1) Radiotelephone second-class operator license.
  (2) Radiotelephone first-class operator license.

(b) Commercial radiotelegraph group:
  (1) Radiotelegraph second-class operator license.
  (2) Radiotelegraph first-class operator license.

(c) Restricted commercial group:
  (1) Restricted radiotelephone operator permit.
  (2) Restricted radiotelegraph operator permit.

Sec. 13.3 *Dual holding of licenses.* A person may not hold more than one radiotelegraph operator license (or restricted radiotelegraph permit) and one radiotelephone operator license (or restricted radiotelephone operator permit) at the same time.

Sec. 13.4 *Term of licenses.* Commercial operator licenses are normally issued for a term of 5 years from the date of issuance.

Sec. 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, or (2) who is involved in any pending litigation based on an alleged violation of the Communications Act of 1934, as amended.

Sec. 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.

Sec. 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, in the case of a station licensed for service other than broadcast, 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

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[1] Whenever the term "license" is used generally to denote an authorization from the Commission, it includes "license," "permit" and "authorization".

[2] By Order No. 126, dated August 21, 1945 certain railroad employees were authorized to operate radio transmitting apparatus for use in connection with railroad operations without an operator's license upon compliance by the affected employee and the employing railroad with the condition of the Commission's order.

[3] By Commission Order No. 133, dated May 10, 1946, effective June 1, 1946, the Commission waived the requirements for the operation of mobile or portable radio transmitting apparatus by a licensed operator in the Emergency, Miscellaneous, Railroad and Experimental Services (Parts 5, 10, 11 and 16 of the Commission's Rules) subject to certain conditions stated in the Order. Those provisions of Part 13 of the Commission's Rules that are inconsistent with the provisions of Order No. 133 are suspended.

[4] By Order, dated and effective December 15, 1947, and by subsequent orders effective March 15, 1948, June 15, 1948, November 15, 1948 and April 15, 1949, the Commission temporarily waived to a limited extent the requirement that ship radar stations licensed in the Ship Service be operated by licensed radio operators. See footnote 71, Sec. 8.195 of the Commission's Rules Governing Ship Service. See also Sec. 13.61.

[5] See Sec. 13.61.

[6] By Order No. 136, the Commission cancelled Order No. 97 effective June 30, 1946, *Provided, however,* That all Temporary Limited Radiotelegraph Second Class Operator Licenses outstanding at time of cancellation shall remain valid according to the respective terms thereof.

[7] By Order No. 136, the Commission cancelled Order No. 123 effective June 30, 1946: *Provided, however,* That all Temporary Emergency Radiotelegraph Second Class Operator Licenses outstanding at time of cancellation shall remain valid according to the respective terms thereof.

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.

APPLICATIONS

Sec. 13.11 *Procedure*-(a) *General.* 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 must be submitted during the last year of the license term, and if all prescribed service requirements are fulfilled,[8] the renewal license may be issued by mail. A renewal application shall also be accompanied by the license to be renewed.

(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.

Sec. 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.

[8] See Sec. 13.28

EXAMINATIONS

Sec. 13.21 *Examination elements.* Written examinations will comprise questions from one or more of the following examination elements:

1. *Basic law.* Provisions of law and regulation with which every operator should be familiar.

2. *Basic theory and practice.* Technical matters appropriate for every class of license except restricted radiotelephone operator permit.

3. *Radiotelephone.* Additional matters, both legal and technical, including radiotelephone theory and practice.

4. *Advanced radiotelephone.* Theory and practice applicable to broadcast station operation.

5. *Radiotelegraph.* Additional matters, both legal and technical, including radiotelegraph theory and practice.

6. *Advanced radiotelegraph.* Radiotelegraph theory and practice of wider scope, particularly with respect to ship radio matters (direction finders, ship radiotelephone stations, spark transmitters, etc.).

[9] 7. *Aircraft radiotelegraph.* Basic theory and practice in the operation of radio communication and radio navigational systems in general use on aircraft.

Sec. 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.

[9] Effective January 3, 1950.

(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) 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.

(f) Restricted radiotelegraph operator permit:

(1) Transmitting and receiving code test of sixteen (16) code groups per minute.

(2) Written examination elements: 1, 2, and 5.

Sec. 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.

Sec. 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.

Sec. 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 elements for the new class of license. However, 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 issuance of the permit based thereon, be relieved of qualifying by examination on any phase of the subject matter of the declaration when applying for any other operator license or permit for which examination on any subject matter is required.

Sec. 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.

Sec. 13.27 *Eligibility for reexamination.* An applicant who fails an examination element will be ineligible for 2 months[10] to take an examination for any class of license requiring, that element. Examination elements will be graded in the order listed,[11] and an applicant may, without further application, be issued the class of license for which he qualifies.

Sec. 13.28 *Renewal examinations and exceptions.* A restricted radiotelephone operator permit may be renewed without examination or showing of service and upon the same basis as an original permit of this class is issued. A license of any other class may be renewed without examination provided the service record on the license[12] shows at least 3 years' satisfactory service in the aggregate during the license term and while actually employed as a radio operator under that license, or shows at least 2 years' service in the aggregate, under the same conditions, of which 1 year must have been continuous and immediately prior to the date of application for renewal.

If the above requirements have not been fulfilled, but the service record shows at least 3 months' satisfactory service in the aggregate, while actually employed as a radio operator under the license during the last 3 years of the license term, a license may be renewed upon the successful completion of a renewal examination which may be taken at any time during the last year of the license term.

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[10] 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.

[11] See Sec. 13.21.

[12] See Secs. 13.91 to 13.94, inclusive.

Renewal examinations will consist of the same elements as for original licenses. However, the written examination will be directed toward a determination of the applicant's qualifications to continue to hold the license for which he has previously qualified. If the renewal examination is not successfully completed before expiration of the license sought to be renewed, or if the service is not acceptable, the applicant will be examined as for the original license.

CODE TESTS

Sec. 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.

Sec. 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.

Sec. 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.

Sec. 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.

Sec. 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

Sec. 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:[13]

(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.

[14](4) On an aircraft employing radio telegraphy, 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 radiotelegraph prior to January 3, 1950. The supplementary examination shall consist of:

(i) Written examination element: 7.

(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[15] vessel 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

[13]For temporary authority granted holders of valid first and second class operator licenses, either radiotelephone or radiotelegraph, to perform adjustments, servicing and maintenance of ship radar stations licensed in the Ship Service, see footnote 71, Sec. 8.195, of the Commission's rules governing ship service.

[14]Effective January 3, 1950.

[15]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.

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.

[16](5) On an aircraft employing radiotelegraph, 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 January 3, 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.

(c) *Restricted radiotelegraph operator permit.* 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) Ship stations licensed to use telephony for communication with coastal telephone stations, or

(4) Radiotelegraph stations on board a vessel required by treaty or statute to be equipped with a radio installation, or

(5) Ship telegraph, coastal telegraph or marine-relay stations open to public correspondence;

[17](6) Aircraft radio stations while employing radiotelegraphy. *Provided,* That in the case of equipment designed for and using telephone or facsimile transmissions: (1) Such operator is prohibited from making adjustments that may result in improper transmitter operation, and (2) the equipment is so designed that none of the operations necessary to be performed during the course of normal rendition of service may cause off-frequency operation or result in any unauthorized radiation, and (3) any needed adjustments of the transmitter which may affect proper operation of the station are regularly made by or in the presence of an operator holding a first- or second-class license, either radiotelephone or radiotelegraph, who shall be responsible for the proper operation of the equipment.

(d) *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.

(e) *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.

(f) *Restricted radiotelephone operator permit.* Any station except--

(1) Stations transmitting television, or

[16]Effective January 3, 1950.

[17]Effective January 3, 1950.

(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 and ST broadcast stations, or

(4) Coastal telephone stations or coastal harbor stations other than in the Territory of Alaska, or

(5) Ship stations licensed to use telephony for communication with coastal telephone station; *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 none of the operations necessary to be performed during the course of normal rendition of service 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 in the presence of an operator holding a first-or second-class license, either radiotelephone or radiotelegraph, who shall be responsible for the proper operation of the equipment.

Sec. 13.62 *Special privileges.* In addition to the operating authority granted under Sec. 13.61, the following special privileges are granted the holders of commercial radio operator licenses:

(a) The holder of any class of commercial radio operator license may operate any station in the experimental service while using frequencies solely above 300 megacycles.

(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.

Sec. 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.

Sec. 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.

Sec. 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.

Sec. 13.66 *Unnecessary, unidentified, or superfluous communications.* No licensed radio operator shall transmit unnecessary, unidentified, or superfluous radio communications or signals.

Sec. 13.67 *Obscenity, indecency, profanity.* No licensed radio operator or other person shall transmit communications containing obscene, indecent, or profane words, language, or meaning.

Sec. 13.68 *False signals.* No licensed radio operator shall transmit false 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.

Sec. 13.69 *Interference.* No licensed radio operator shall willfully or maliciously interfere with or cause interference to any radio communication or signal.

Sec. 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

Sec. 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.

Sec. 13.72 *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.

Sec. 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.[18] 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.

Sec. 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.[19]

(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:[18] *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.

Sec. 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 (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

Sec. 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.

Sec. 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.

Sec. 13.93 *Service acceptability.* Credit will be allowed only for satisfactory service

[18] Form 758-F.

[19] Form 759.

obtained under conditions that required the employment of licensed operators, or when obtained at United States Government stations.

Sec. 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, 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.

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. Requirements concerning logs of Standard Broadcast Stations appear in two parts of the Rules and Regulations, in the Standards of Good Engineering Practice, and in some instances in the instrument of authorization, i.e., license, construction permit, temporary authorization, etc. Requirements as to logs for FM and TV stations are confined to Part 3 of the Rules and Regulations.

The FCC does not place its official approval on any particular log as compared to 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.

Maintenance logs are not considered in this material. 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.

SECTION I

FCC Rules, Regulations and Standards of Good Engineering Practice Pertaining to Transmitter Logs

Rules and Regulations

Standard Broadcast Stations

3.181 LOGS. - The licensee 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:

*****

(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.
  - (iv) Temperature of crystal control chamber if thermometer is used.
- (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 supporting structure(s) is required to be illuminated the licensee shall make entries in the radio station log appropriate to the requirements of Section 2.82[1] (a), (b), and (c) as follows:
- (1) The time the tower lights are turned on and off if manually controlled.
- (2) The time the daily visual observation of the tower lights was made.
- (3) In the event of any observed failure of a tower light:
  - (i) Nature of such failure.
  - (ii) Time the failure was observed.
  - (iii) Time and nature of the adjustments, repairs or replacements made.

[1]See note on page 1-2-06 regarding Section 2.82.

(iv) Airways Communication Station (C.A.A.) notified of the failure of any tower light not corrected within 30 minutes and the time such notice was given.

(v) Time notice was given to the Airways Communication Station (C.A.A.) that the required illumination was resumed.

(4) Upon completion of the periodic inspection required at least once each 3 months:

(i) The date of the inspection and the condition of all tower lights and associated tower lighting control devices.

(ii) Any adjustments, replacements, or repairs made to insure compliance with the lighting requirements.

3.182 LOGS, RETENTION OF. - Logs of standard broadcast stations shall be retained by the licensee 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 has been notified, shall be retained by the licensee 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 has notice shall be retained by the licensee 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.

3.183 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.

3.184 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.

3.185 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.

3.186 ROUGH LOGS. - Rough logs may be transcribed into condensed form, but in such cases the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

FM Broadcast Stations

3.281 LOGS. - The licensee of each FM broadcast station shall maintain separate program and operating logs for such station; Provided, however, 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, one program log may be maintained for both stations for such periods as both stations simultaneously broadcast the same program. Such licensee shall require entries to be made as follows:

(a) In the program log:

* * * * *

(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.[2]

(iii) Frequency monitor reading.

(5) Log of experimental operation during experimental period (if regular operation is maintained during this period, the above log 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 to fully describe the operation.

(c) Where an antenna or antenna supporting structure(s) is required to be illuminated the licensee shall make entries in the radio station log appropriate to the requirements of section 3.270[3] as follows:

(1) The time the tower lights are turned on and off if manually controlled.

(2) The time the daily visual observation of the tower lights was made.

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[2]This wording proposed by FCC in Notice of proposed Rule Making June 1, 1949. Wording as of July 15, 1949 was "Transmission line current and voltage."

(3) In the event of any observed failure of a tower light:
  (i) Nature of such failure.
  (ii) Time the failure was observed.
  (iii) Time and nature of the adjustments, repairs or replacements made.
  (iv) Airways Communication Station (C.A.A.) notified of the failure of any tower light not corrected within 30 minutes and the time such notice was given.
  (v) Time notice was given to the Airways Communication Station (C.A.A.) that the required illumination was resumed.

(4) Upon completion of the periodic inspection required at least once each 3 months:
  (i) The date of the inspection and the condition of all tower lights and associated tower lighting control devices.
  (ii) Any adjustments, replacements or repairs made to insure compliance with the lighting requirements.

3.282 LOGS, RETENTION OF. - Logs of FM broadcast stations shall be retained by the licensee 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 has been notified, shall be retained by the licensee 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 has notice shall be retained by the licensee 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 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.

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.

Television Broadcast Stations

3.681 LOGS. - The licensee of each television station shall maintain program and operating logs and shall require entries to be made as follows:

(a) In the program log:

* * * * *

(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 current or voltage of both transmitters.
    (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 operations 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 or antenna supporting structure(s) is required to be illuminated, the licensee shall make entries in the radio station log appropriate to the requirements of section 3.669[3] as follows:
  (1) The time the tower lights are turned on and off if manually controlled.
  (2) The time the daily visual observation of the tower lights was made.
  (3) In the event of any observed failure of a tower light:
    (i) Nature of such failure.
    (ii) Time the failure was observed.

[3]See note on page 1-2-06 regarding Section 3.270 and Section 3.669.

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.

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

FM - TV Stations Standards

NOTE: The Standards of Good Engineering Practice pertaining to FM and TV stations contain no comment with respect to the use of logs.

Note: Regarding Sections 2.82, 3.270 and 3.669. Section 2.82 has been deleted from Part 2 of the Rules. As of July 15, 1949 the FCC had not amended Part 3 with a rule similar to Section 2.82 as regards Standard B/C stations. Amendment of the Rules as regards FM and TV stations, however, is reflected in Sections 3.270 (FM) and 3.699 (TV). Although 2.82 is no longer in effect and reference to it will no doubt be removed in the future, it is here quoted.

"2.82 INSPECTION OF TOWER LIGHTS AND ASSOCIATED CONTROL EQUIPMENT. - The licensee of any radio station which has an antenna or supporting structure(s) required to be illuminated pursuant to the provisions of Section 303(q) of the Communications Act of 1934, as amended:

(a) Shall make a visual observation of the tower lights at least once each 24 hours to insure that all such lights are functioning properly as required.

(b) Shall report immediately by telephone or telegraph to the nearest Airways Communication Station or office of the Civil Aeronautics Administration any observed failure of the tower lights, not corrected within 30 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 of at least once each 3 months all flashing or rotating beacons and automatic lighting control devices to insure that such apparatus is functioning properly as required.

SECTION II

Pertinent Facts Concerning the Format and Use of Transmitter Operating Logs

Sections 3.181 (b) and (c), 3.281 (b) and (c), and 3.681 (b) and (c), above, set forth the basic requirements as to the entries which must be made in the transmitter logs of AM, FM and TV stations.

(b)(1) To comply with paragraph (b)(1) the time (to the nearest minute) any amount of carrier is applied to the radiating system(s)[4] should be entered in Column 1 of the 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.

(b)(2) To comply with (b)(2) the time the program is applied to the carrier(s)[4] and the time the program is removed from the carrier(s)[4] 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.

(b)(3) 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.

(b)(4) This part requires that certain operating constants of the transmitter(s)[4] 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, Part III).

(b)(4)(i) In Column 2 of the sample log should be entered 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.

[4]Includes video and audio transmitters of TV Stations.

(b)(4)(ii) (NOTE: FOR AM STATIONS) Column 4 of the basic AM log is provided 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 Section 13 of the "Standards of Good Engineering Practice." 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.[5] 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 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 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) 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, Part (b)(4)(ii), which states that merely "antenna current" should be logged, must be considered not only with paragraph 13 of the "Standards of Good Engineering Practice" but with an interpretation of requirements appearing in the instrument of authorization (D.A.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_{cp}.

2. Paragraph 13, Part B, 3, a, 6 refers 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. 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.

(b)(4)(ii) (NOTE: FOR FM AND TV STATIONS) On FM and TV installations it is required 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, 8-9 may be deleted and one column under both audio and video transmitters added for transmission line voltage or current.

(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.

[5] Where convenient it is often advisable to check the calibration daily so that in the event of failure time would permit repair or replacement.

(b)(4)(iv) If a thermometer is used in the crystal chamber of the automatic frequency control equipment of the transmitter, the temperature reading should be entered in Column 6 (Figure 1 only).

SECTION III

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. Column 6, "Crystal Temperatures," is required only when a thermometer is used in connection with the crystal temperature control.

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 -- 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.

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.
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 off. (CON) (COF)
   c. Notation "Program" on and 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.

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	(6) CRYSTAL TEMP. °C	REMARKS:

1-2-09

FIGURE 1

BASIC AM SAMPLE

COLUMNS (1) TO (6) 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

TRANSMITTER OPERATING LOG

CALL LETTERS

LOCATION

FREQUENCY – POWER – TIME OF OPERATION

DATE _____ 19____

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	

FIGURE 3

(continued on other side)

DATE _____ 19 ____

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.

FM STATION CALL LETTERS

TRANSMITTER OPERATING LOG

CHANNEL 269, — 101.7 MC — POWER 1 KW

(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 _____

VIDEO FREQUENCY _____

AUDIO FREQUENCY _____

DATE _____

CITY AND STATE _____

TIME (1)	AUDIO TRANSMITTER (I)					VIDEO TRANSMITTER			(II) REMARKS
				REFLECTOMETER			REFLECTOMETER		
	E_p	I_p	F_d	INCI.	REFL.	F_d	INCI.	REFL.	
	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	

FIGURE 5.

BASIC TV SAMPLE

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.

Supplement No. 2

to

NAB (NARTB) ENGINEERING HANDBOOK

(Fourth edition, 1949)

NARTB RECORDING AND REPRODUCING STANDARDS

(June, 1953)

INSTRUCTIONS FOR FILING

To open binder, pull up on the ring and slide the cover of the binder upwards. Lift up on the metal bar, and the posts are open for insertion of the punched Supplement.

After Page	*Remove Old Pages*	*Insert New Pages*
1-2-14	1-3-01 — 1-3-14	1-3-01 — 1-3-24

NARTB
RECORDING AND REPRODUCING
STANDARDS

FOR MECHANICAL, MAGNETIC AND OPTICAL RECORDING AND REPRODUCING
including
A GLOSSARY OF TERMS AND DEFINITIONS

The NARTB 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 NARTB 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 NARTB 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.

The NARTB Recording and Reproducing Standards Committee

Neal McNaughten, *Chairman*

K. R. Smith, Mechanical Disk Subcommittee

W. Earl Stewart, Magnetic Tape Subcommittee

THE NATIONAL ASSOCIATION OF RADIO AND TELEVISION BROADCASTERS
Department of Engineering – A. Prose Walker, *Manager*
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Washington, D. C.

June 1953

1-3-01

Section 1

MECHANICAL RECORDING AND REPRODUCING STANDARDS*

Turntable Speed (RPM)

1.05 It shall be standard that the average speed of the turntable be either 33-1/3, 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 33-1/3 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 33-1/3, 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 that of the system being measured. The response of the pickup and equalizer shall conform to the NARTB 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 intented 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 effect, 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

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*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.

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."

taken periodically for each turntable in a broadcast system, with a change in the indication reflecting a 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 3-7/8 ±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 33-1/3 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"	15-15/16"	±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 33-1/3 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.

Frequency Characteristics for Lateral Recordings[2]

1.55 It shall be standard that the recorded frequency characteristics on laterally recorded records be as shown in attached Figure 2.

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[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:

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.

Record Groove Shape[3]

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 33-1/3 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 $1.0\ ^{+0.1}_{-0.2}$ 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)[4]

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) as that produced by a 1,000-cycle tone recorded at a peak velocity of 7 cm. per second.

Signal to Noise Ratio[5]

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:

---

[3] 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.

[4] 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 standard 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 33-1/3 rpm disk. This has also been substantiated by practical experience. This standard of course applies to both lateral and vertical recording.

[5] 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. NARTB 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 NARTB standard of recorded level is used, with normal program material.

16" -- outside start --	15-1/2"	±1/16"
16" -- inside start --	15-9/16"	maximum
12" -- outside start --	11-1/2"	±0.020"
10" -- outside start --	9-1/2"	±0.020"
7" -- outside start --	6-5/8"	+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 7-1/2" in the case of 33-1/3 RPM transcriptions recorded to be reproduced with a 2.3 mils radius stylus, and not less than 4-3/4" for recordings to be reproduced with a 1 mil stylus. It shall be standard that the diameter be not less than 3-3/4" for 78.26 RPM recordings and not less than 4-1/4" for 45 RPM recordings.

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 33-1/3 RPM
c. Direction of feed (start) -- outside-in or inside-out
d. Recording frequency characteristic (Example: NARTB 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.

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 (plus a starting and stopping margin) when recording with the secondary standard magnetic tape speed.

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 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

[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.

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[2]

There are two general ways in which the surface induction[3] 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

$$\frac{\sin \frac{\pi d}{\lambda}}{\frac{\pi d}{\lambda}}$$

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.

(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 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 7.

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 rises at 1 to 2 db/octave compared with the curve of surface induction vs. frequency in air as determined by a non-magnetic reproducing device, or by a "short-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:

[2] These methods resulted from experiments undertaken by members of the NARTB Recording and Reproducing Standards Committee following the original work in CCIR Study Group X on the subject.

[3] 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.

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.

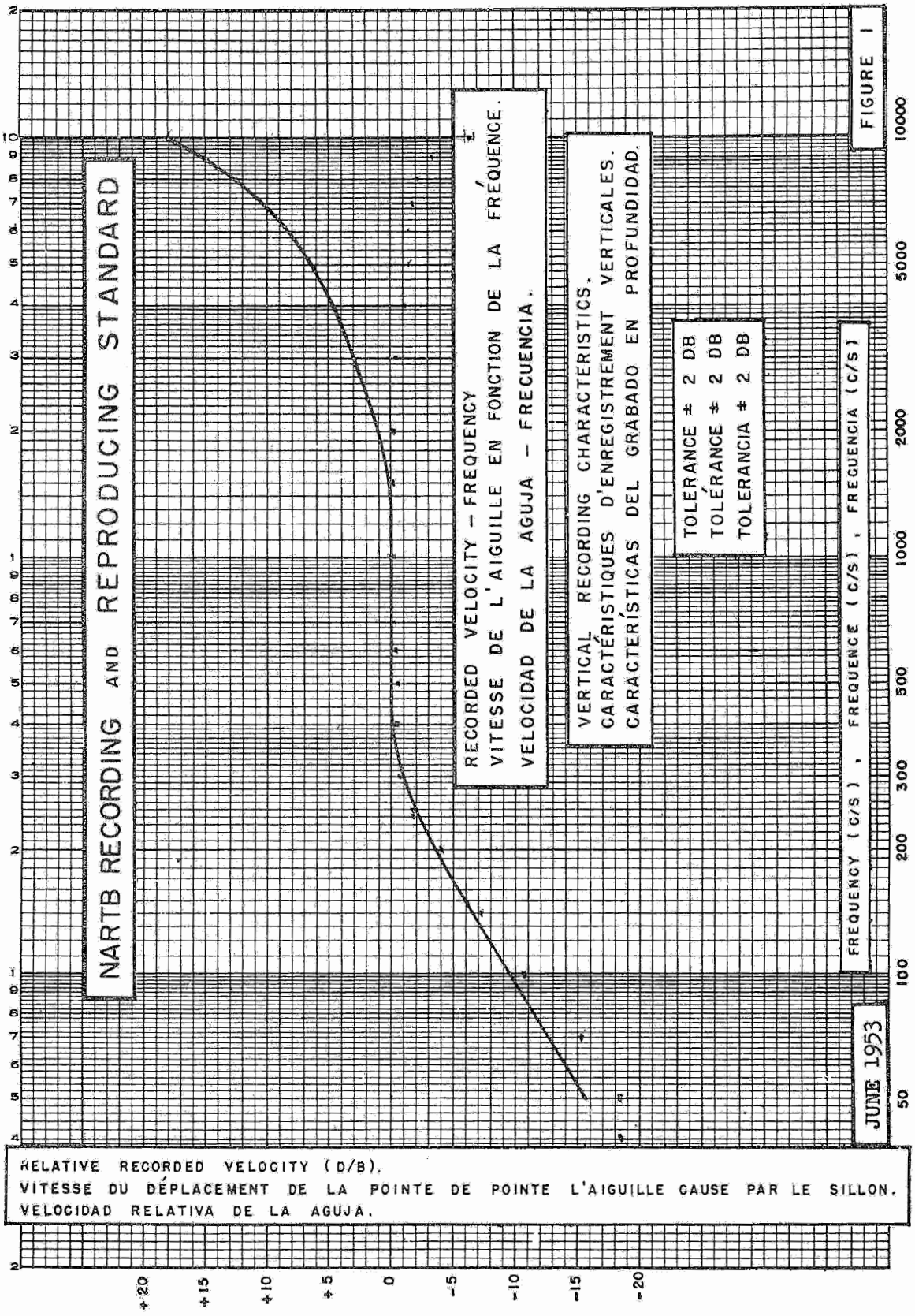
2. A "gliding tone" test tape of the audio frequencies of maximum level is then recorded with constant voltage input to the recording chain and the tape is reproduced using the long gap head. The open circuit voltage of the head around these frequencies is then plotted against frequency, and a smooth 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 overall response is obtained when using a normal reproducing head.


NARTB RECORDING AND REPRODUCING STANDARD
RECORDED VELOCITY – FREQUENCY
VITESSE DE L'AIGUILLE EN FONCTION DE LA FRÉQUENCE.
VELOCIDAD DE LA AGUJA – FRECUENCIA.
VERTICAL RECORDING CHARACTERISTICS.
CARACTÉRISTIQUES D'ENREGISTREMENT VERTICALES.
CARACTERÍSTICAS DEL GRABADO EN PROFUNDIDAD.
TOLÉRANCE ± 2 DB
TOLÉRANCE ± 2 DB
TOLERANCIA ± 2 DB
FIGURE 1
FREQUENCY (C/S), FREQUENCE (C/S), FRECUENCIA (C/S)
JUNE 1953
RELATIVE RECORDED VELOCITY (D/B).
VITESSE DU DÉPLACEMENT DE LA POINTE DE POINTE L'AIGUILLE CAUSE PAR LE SILLON.
VELOCIDAD RELATIVA DE LA AGUJA.
+20
+15
+10
+5
0
-5
-10
-15
-20
10000
5000
2000
1000
500
300
200
100
50

1-3-10

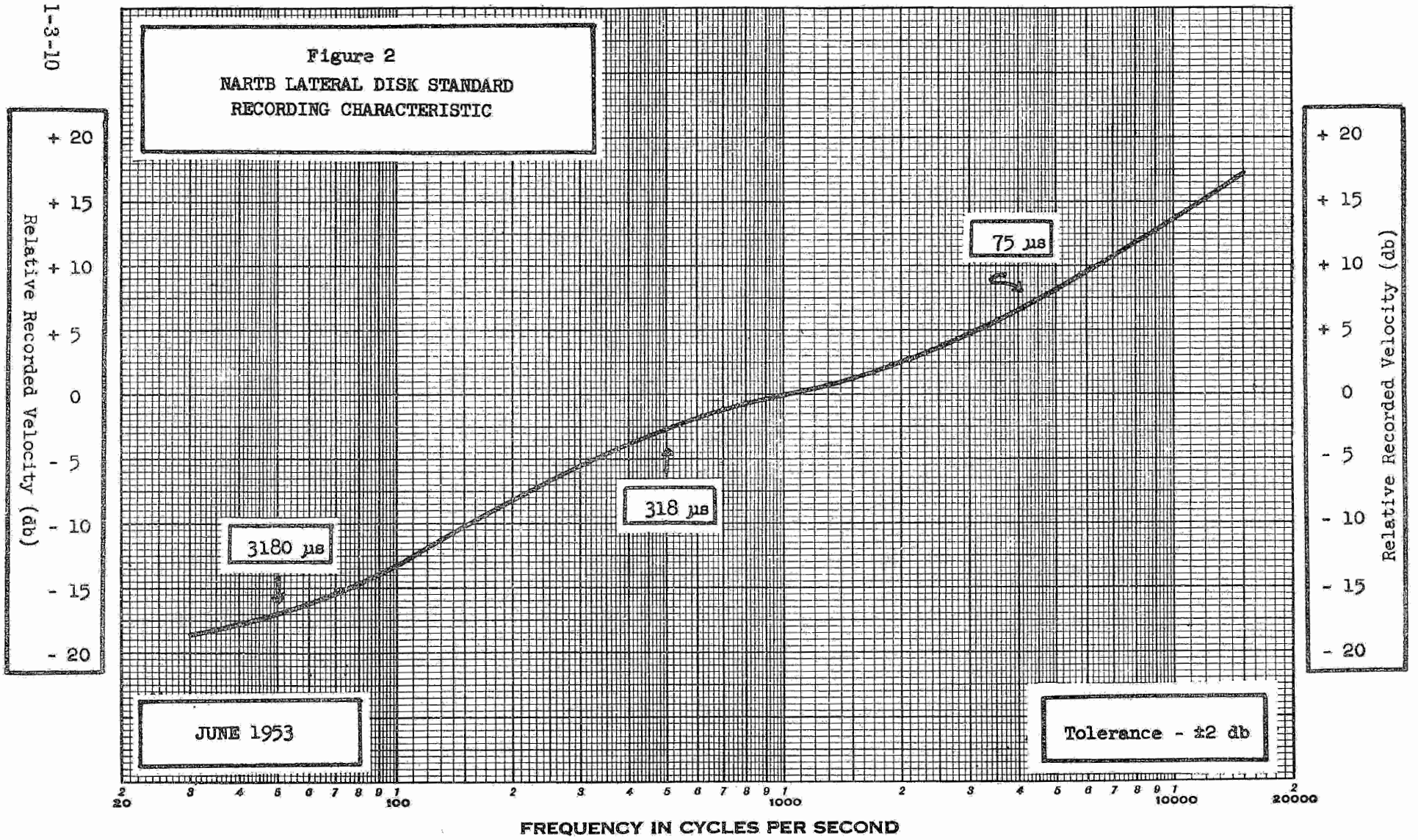
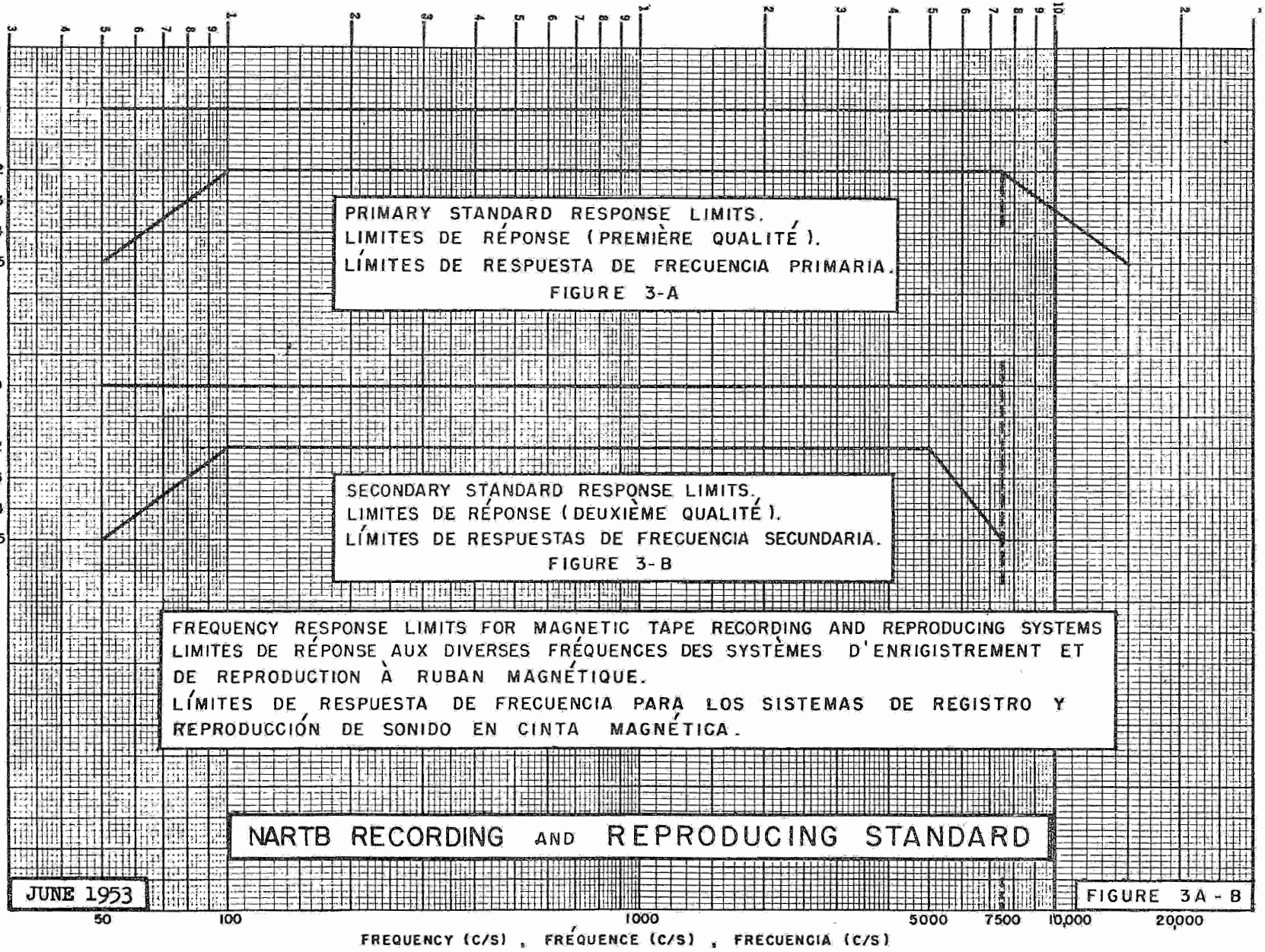
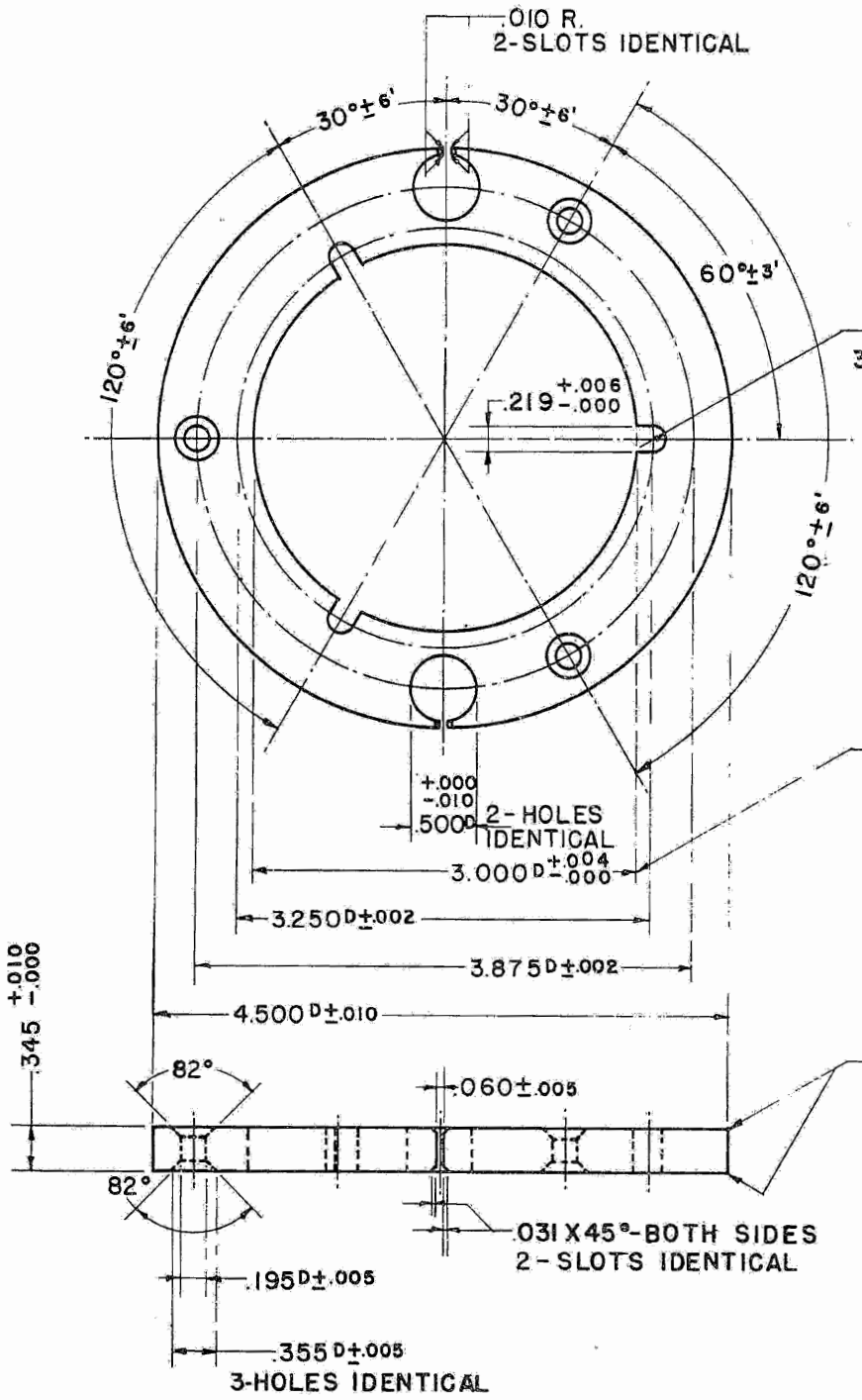


Figure 2
NARTB LATERAL DISK STANDARD
RECORDING CHARACTERISTIC
Relative Recorded Velocity (db)
+ 20
+ 15
+ 10
+ 5
0
- 5
- 10
- 15
- 20
3180 µs
318 µs
75 µs
JUNE 1953
Tolerance - ±2 db
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND


PRIMARY STANDARD RESPONSE LIMITS.
LIMITES DE RÉPONSE (PREMIÈRE QUALITÉ).
LÍMITES DE RESPUESTA DE FRECUENCIA PRIMARIA.
FIGURE 3-A
SECONDARY STANDARD RESPONSE LIMITS.
LIMITES DE RÉPONSE (DEUXIÈME QUALITÉ).
LÍMITES DE RESPUESTAS DE FRECUENCIA SECUNDARIA.
FIGURE 3-B
FREQUENCY RESPONSE LIMITS FOR MAGNETIC TAPE RECORDING AND REPRODUCING SYSTEMS
LIMITES DE RÉPONSE AUX DIVERSES FRÉQUENCES DES SYSTÈMES D'ENRIGISTREMENT ET DE REPRODUCTION À RUBAN MAGNÉTIQUE.
LÍMITES DE RESPUESTA DE FRECUENCIA PARA LOS SISTEMAS DE REGISTRO Y REPRODUCCIÓN DE SONIDO EN CINTA MAGNÉTICA.
NARTB RECORDING AND REPRODUCING STANDARD
JUNE 1953
FIGURE 3A - B
RELATIVE LEVEL (DB), NIVEAU RELATIF (DB), NIVEL RELATIVO (DB)
0
-1
-2
-3
-4
-5
50
100
1000
5000
7500
10,000
20000
FREQUENCY (C/S), FRÉQUENCE (C/S), FRECUENCIA (C/S)

NARTB STANDARD
HUB FOR MAGNETIC TAPE REEL



NOTE: ALUMINUM OR AN EQUIVALENT WEIGHT MATERIAL SHALL BE USED.

NOTE: THE 3.875, 3.250, & 3.000 DIAMETERS TO BE CONCENTRIC WITHIN .005 TOTAL INDICATOR READING.

NOTE: THIS DIAMETER SHALL NOT CHANGE MORE THAN .004 WHEN BARE HUB IS WOUND WITH 2400 FEET OF .250 X .0022 TAPE AT CONSTANT TENSION OF 5.5 OZ.

NOTE: DIAMETERS MEASURED AT THESE TWO EDGES SHALL NOT DIFFER BY MORE THAN .002.

NOTE: EXCEPT AS OTHERWISE NOTED, ALL DIMENSIONS ARE IN INCHES.

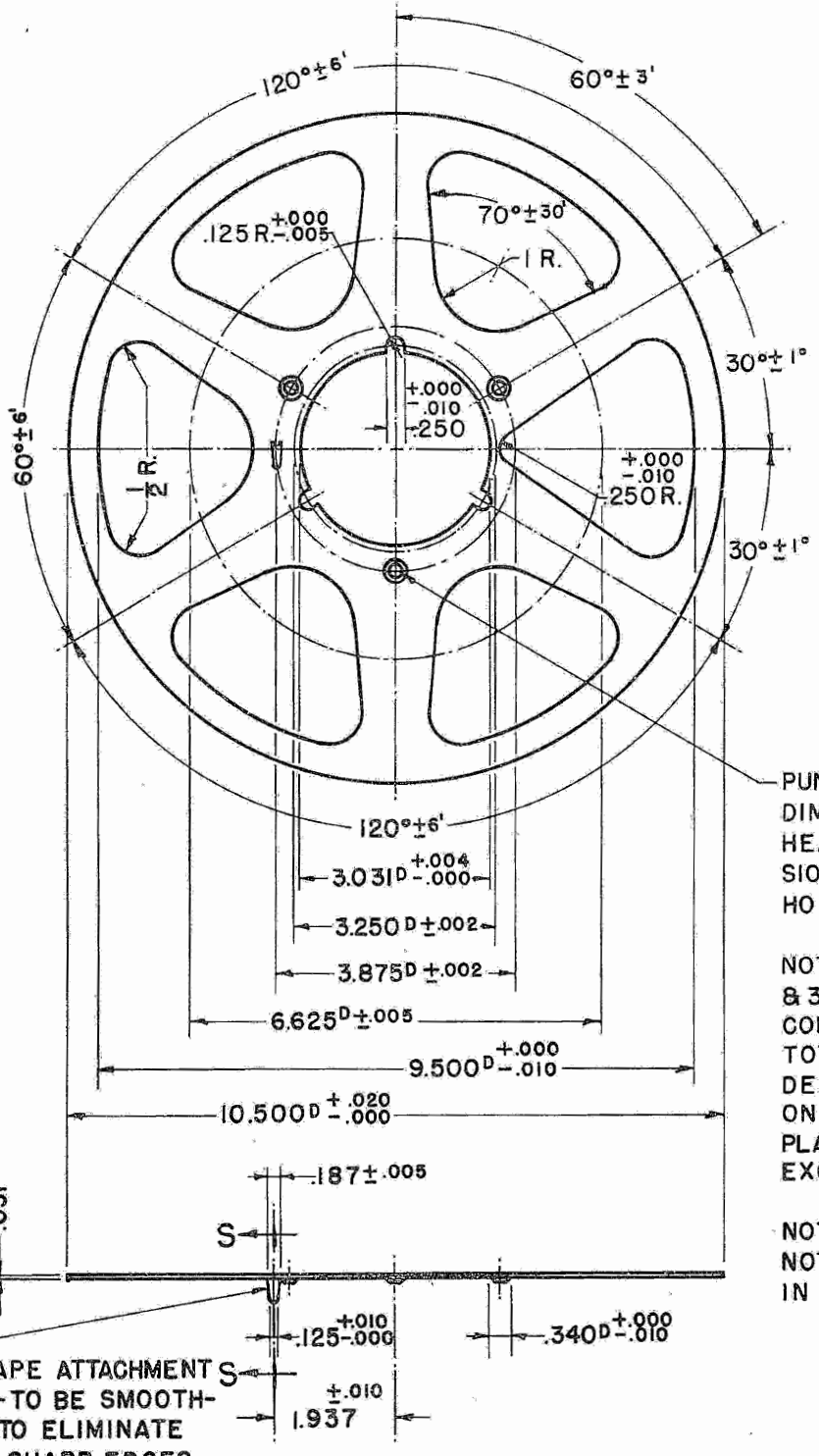
EXCEPT AS NOTED; BREAK SHARP EDGES .004 R.

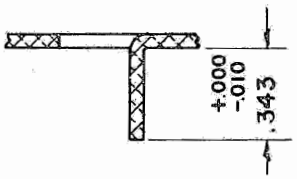
JUNE 1953

FIGURE 4

1-3-12

NARTB STANDARD
FLANGE FOR MAGNETIC TAPE REEL





SECTION S-S
ENLARGED

PUNCH (.190) DIAM. HOLE & DIMPLE FOR NO.6-32 FLAT HEAD SCREW, SEE DIMENSION IN OTHER VIEW — 3 HOLES.

NOTE: THE 10.500, 3.875, 3250, & 3.031 DIAMETERS TO BE CONCENTRIC WITHIN ± .005 TOTAL INDICATOR READING. DEPARTURE OF ANY POINT ON FLANGE FROM AVERAGE PLANE OF FLANGE NOT TO EXCEED ± .010 .

NOTE: EXCEPT AS OTHERWISE NOTED, ALL DIMENSIONS ARE IN INCHES.

.051 STANDARD MILL FINISH ALUMINUM

FIGURE 5

JUNE 1953

1-3-13

1-3-14

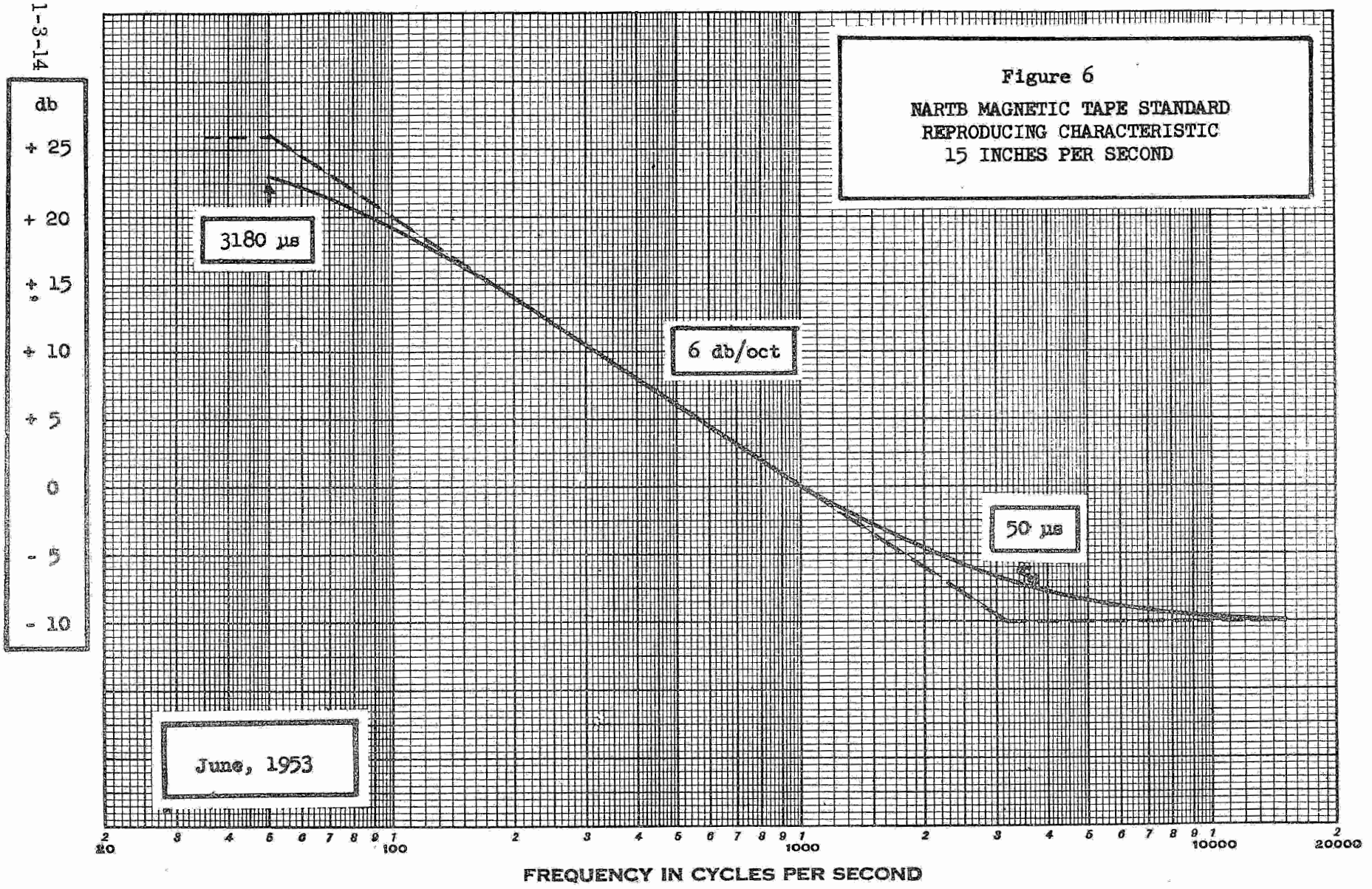
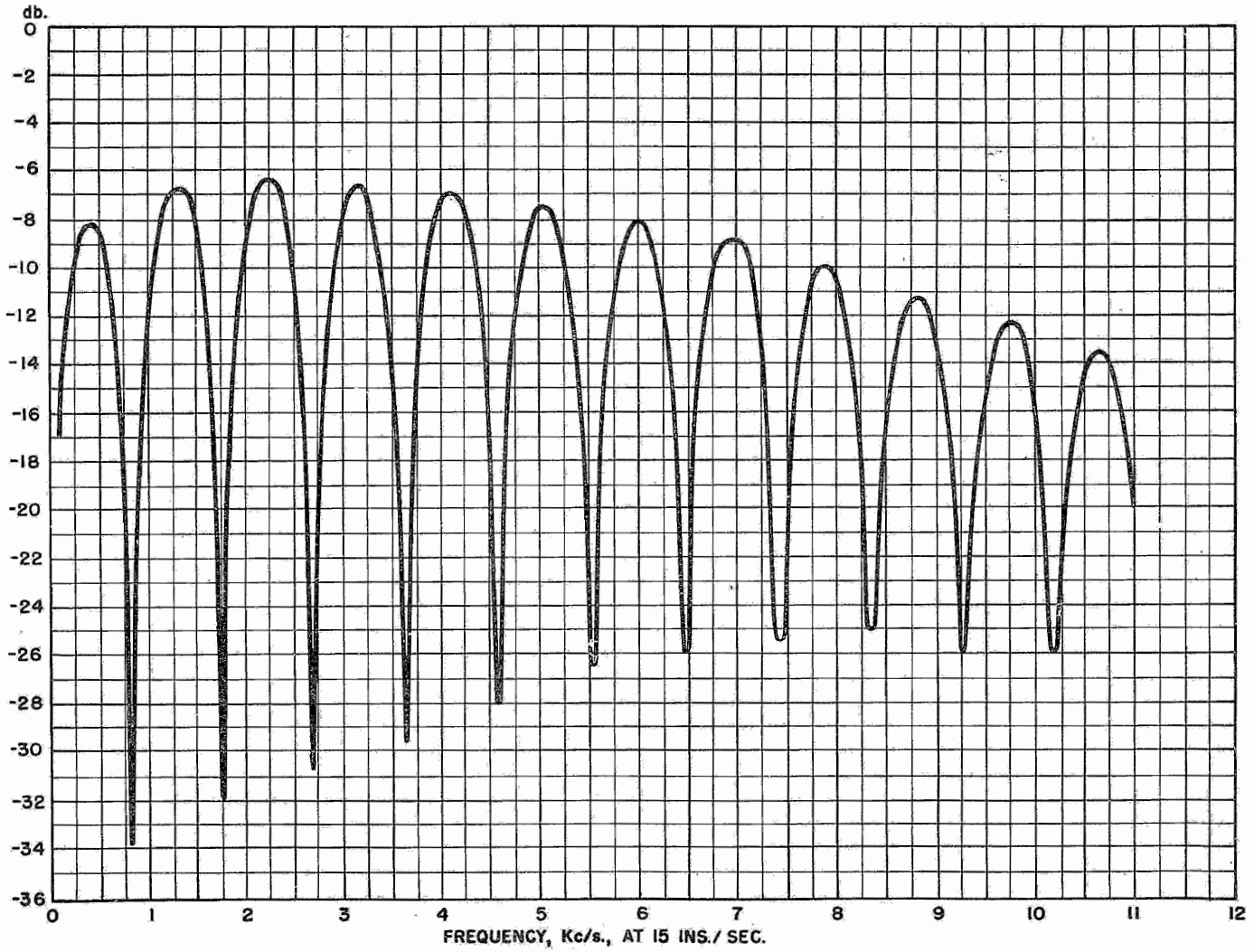


Figure 6

NARTB MAGNETIC TAPE STANDARD
REPRODUCING CHARACTERISTIC
15 INCHES PER SECOND

Figure 7

FREQUENCY CHARACTERISTIC STANDARDIZATION IN MAGNETIC RECORDING



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.

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.

* Deprecated.

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 one 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 base.

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.

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.

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* Deprecated.

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 modulations 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 Pickup, 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.

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* Deprecated.

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.

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, Throw-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 electro-forming) 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.

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* Deprecated.

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 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.

* 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.

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

* Deprecated.

American Recommended
Practice For

VOLUME MEASUREMENTS OF ELECTRICAL SPEECH AND PROGRAM WAVES*

(American Standards Association Approved November 6, 1942)

Sponsor Institute of Radio Engineers, Inc.

C16.5-1942

INTRODUCTION

Radio broadcasting, with its primary requirement of transmitting speech and program material over both wire and radio systems, has faced the problem of measuring these waves. Measurements made by different organizations with variously designed equipments have shown substantial discrepancies.

The instrument described in this recommended practice was developed specifically for broadcasting and the telephone plant which provides the interconnecting service among broadcast stations. It gives satisfactory correlation of measurements under normal conditions of operation and offers a ballistic performance which permits more rapid and accurate reading of deflection than was the case with previous types. The indicating instrument and the method of using it are covered in this document.

1. SECTIONAL COMMITTEE ON RADIO

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Harold P. Westman, Secretary

Technical Committee on Transmitters and Antennas

Haraden Pratt, Chairman
Mackay Radio and Telegraph Company
W. W. Brown
General Electric Company
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J. J. Lamb
Remington Rand
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Bell Telephone Laboratories
D. K. Gannett (Alternate)
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E. G. Ports
International Telephone and Radio Manufacturing Corporation
Harold P. Westman, Secretary
Institute of Radio Engineers

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2. GENERAL

These standards apply to the methods of and a device for measuring the strength of audio-frequency electrical waves such as speech and program waves.

The measurement of the complex and non-periodic waves encountered in electrical communication cannot be expressed in simple fashion in the ordinary electrical terms of current, voltage, or power. The concept of "volume" furnishes a practical method of great utility to the communications engineer for assigning a numerical value to the strength of electrical speech and program waves.

Volumes are read by noting the more extreme deflections of a device known as a volume indicator. Since the response of such an instrument to the rapidly varying waves is greatly dependent upon the speed of its movement, its damping, and other characteristics, an effective standard for volume measurements must include a specification of these characteristics.

It has been the custom to express the readings of volume in terms of decibels above or below some one of a number of various arbitrary reference levels. This standard uses a new term "vu" to express volume in terms of decibels above or below a particular reference level which is a part of the standard.

3. DEFINITIONS

The definitions herein cover the use of the following terms as they apply specifically to the quantities and instruments used in this field.

3.1 VOLUME

This term applies to the strength of speech and program waves. It is the indication of a device known as a volume indicator, defined in 3.2, which has specific dynamic and other characteristics and which is calibrated and read in a prescribed manner.

3.2 VOLUME INDICATOR

This is the device used for the indication of volume. A standard volume indicator must have the characteristics described in Section 4.

3.3 VU (pronounced "vee-you" and customarily written with lower-case letters).

This word is used for the numerical expression of volume. The volume in vu is numerically equal to the relative strength of the waves in question in decibels above or below "reference volume" as defined in 3.4.

The term vu should not be used to express results of measurements of complex waves made with devices having characteristics differing from those of the standard volume indicator.

3.4 REFERENCE VOLUME

This is the base of the system of measurement of volume. Reference volume is that strength of electrical speech or program waves which gives a reading of 0 vu on a volume indicator whose characteristics and methods of reading are described herein, and which is calibrated to read 0 vu on a steady 1000-cycle-per-second wave whose power is I milliwatt in 600 ohms.

3.5 REFERENCE DEFLECTION

This is the deflection to the scale point at or near which the instrument is intended normally to be read.

4. VOLUME INDICATOR

Volume is measured by means of a volume indicator. This device must conform to the following specifications and must be used in the manner described below.

4.1 COMPONENT PARTS

A volume indicator consists of at least two parts:

(a) An indicating instrument
(b) An attenuator

4.2 DYNAMIC CHARACTERISTICS

If a single-frequency sinusoidal voltage between 35 and 10,000 cycles per second, of such amplitude as to give reference deflection under steady-state conditions is suddenly applied, the instrument pointer shall reach 99 per cent of reference deflection in 0.3 second, $\pm$ 10 per cent, and shall then overswing reference deflection by at least 1.0 per cent and not more than 1.5 per cent. The time required for the instrument pointer to reach its position of rest on the removal of the sinusoidal voltage shall not be greatly different from the time of response.

4.3 RESPONSE-VERSUS-FREQUENCY CHARACTERISTIC

The sensitivity of the volume indicator shall not depart from that at 1000 cycles per second by more than 0.2 decibel between 35 and 10,000 cycles per second nor more than 0.5 decibel between 25 and 16,000 cycles per second.

4.4 RESPONSE TO COMPLEX WAVES

The response to complex waves of such amplitude as to give reference deflection when read, as described in 4.9, shall be that equivalent to the response with a direct-current instrument and a rectifier, the exponent of whose characteristic is 1.2 ± 0.2.

4.5 REVERSIBILITY

The indication must be independent of the poling of the volume indicator when measuring unsymmetrical waves. Such characteristics can be obtained by the use of a direct-current instrument in conjunction with a full-wave rectifier.

4.6 GRADUATION OF INSTRUMENT SCALE

The point of reference deflection shall be definitely indicated in some suitable manner. The remainder of the scale shall be graduated in vu above and below reference deflection. (See also 5.4.)

4.7 ATTENUATOR

The attenuator normally is of an adjustable type and shall be marked in vu.

4.8 CALIBRATION

A correctly calibrated volume indicator with its attenuator set at zero vu will give reference deflection when connected to a source of single-frequency sinusoidal voltage adjusted to develop I milliwatt in a resistance of 600 ohms, or with the attenuator set at n when the calibrating power is n decibels above I milliwatt.

4.9 METHOD OF READING VOLUME INDICATOR

The reading is determined by the greatest deflections occurring in a period of about a minute for program waves, or a shorter period (e.g., 5 to 10 seconds) for message telephone speech waves, excluding not more than one or two occasional deflections of unusual amplitude.

The volume indicator is usually connected across the circuit at a point where the impedance is 600 ohms and the attenuator is adjusted until the deflections, read as described above, just reach the scale point corresponding to reference deflection. The volume in vu is determined by the markings on the attenuator at the setting thus obtained. If for any reason the deflections reach some other scale point than that corresponding to reference deflection, the volume is given by the algebraic addition of the attenuator

setting and the actual deflection as read on the instrument scale.

When the impedance of the circuit at the point where the instrument is connected differs from 600 ohms the volume indicated must be corrected to correspond to this difference by the following relation:

Correction (to be added) in vu =

$$10 \log_{10} \frac{600}{Z}$$ where Z = actual impedance.

5. GOOD ENGINEERING PRACTICE

The following items are not fundamental to this standard but are matters of good engineering practice.

5.1 IMPEDANCE

The volume indicator is normally used as a bridging instrument and when so used its impedance must be sufficiently high so as not to influence unduly the waves in the circuit with which it is used. It is good practice to make the value of impedance not less than 7500 ohms, for use on a 600-ohm circuit.

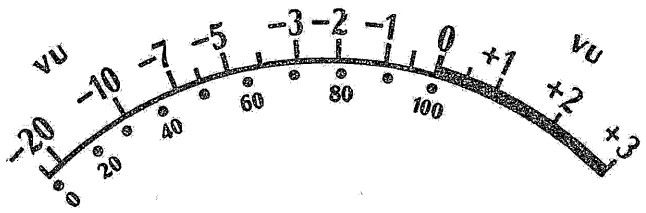

Fig. 1--This scale emphasizes the vu calibration.

5.2 HARMONIC DISTORTION

When the volume indicator is connected to a simple resistive circuit through which a sinusoidal wave, between 25 and 8000 cycles per second, is being transmitted, the root-mean-square sum of the harmonics produced should not exceed 0.2 per cent.

5.3 ABILITY TO WITHSTAND OVERLOAD

Because of the great variation in amplitude which this indicator may encounter, it should possess greater ability to stand overloads than that required for average instruments. A frequently used specification calls for an ability to withstand without injury or effect on calibration a momentary overload of ten times the voltage corresponding to reference deflection and a continuous overload of five times that voltage.

5.4 SCALE

The point of reference deflection should be located within a sector between 2/3 and 3/4 of full scale. In addition to the vu scale, it is good practice also to provide a 0-to-100 scale proportional to voltage with the 100 point coinciding with the point of reference deflection. Samples of the two types of scales in general use are shown in Figs. 1 and 2.

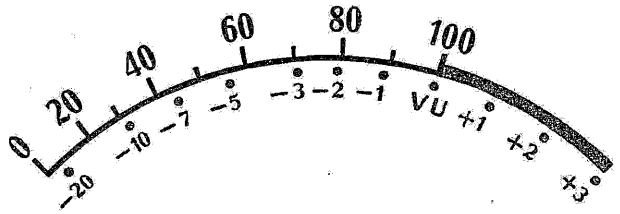

Fig. 2--This scale emphasizes the 0-100 graduations and is useful to indicate percentage utilization of facilities. It is used generally by the principal broadcast organizations.

TECHNICAL RADIO BROADCAST SERVICES,[1]
RADIO STATION WWV

The technical radio services broadcast continuously by the National Bureau of Standards, Central Radio Propagation Laboratory, include a total of eight radio frequencies, 2.5, 5, 10, 15, 20, 25, 30 and 35 Mc, which are on the air at all times, day and night. This insures reliable coverage of the United States and extensive coverage of other parts of the world.

The services are: (1) standard radio frequencies, (2) time announcements,[2] (3) standard time intervals, (4) standard audio frequencies, (5) standard musical pitch, 440 cycles per second, corresponding to A above middle C, (6) radio propagation disturbance warning notices. All of the frequencies are useful for field intensity recording by persons interested in studies of radio propagation. The three highest frequencies are broadcast particularly for this purpose. The radio frequencies and other data are given on the front and inside cover of this announcement. Vertical non-directional antennas are used.

For information on quality of reception as influenced by distance, carrier frequency, time of day, etc., see part 7 of this announcement.

The Bureau welcomes reports on reception, methods of use, or special applications of the service, particularly with reference to the higher frequencies which have been recently added. Correspondence should be addressed Central Radio Propagation Laboratory, National Bureau of Standards, Washington 25, D. C.

1. STANDARD RADIO FREQUENCY

The national standard of frequency is of value in radio, electronic, acoustic, and other measurements requiring an accurate frequency. Any desired radio frequency, including microwave frequencies, may be accurately measured in terms of the standard frequencies. This may be done by the aid of one or more auxiliary oscillators, harmonic generators, and radio receivers. The accuracy of each of the radio carrier frequencies, as transmitted, is better than a part in 50,000,000. However, if received accuracies of this order are required it is necessary to make measurements over a long interval or apply corrections for errors introduced by transmission effects in the medium (Doppler effect, etc.).

2. TIME ANNOUNCEMENTS

The audio frequencies are interrupted at precisely one minute before each hour. They are resumed precisely on the hour and each five minutes thereafter.

The beginnings of the periods, when the audio frequencies are resumed, are in agreement with the basic time service of the U.S. Naval Observatory so that they mark accurately the hour and the successive 5-minute periods.

Eastern standard time is announced in telegraphic code each five minutes. 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 4:55 PM, or 1655 EST, four figures (1, 6, 5, and 5) are broadcast in code. The code used (International Morse) is set forth as part of attached diagram sheet. The time announcement refers to the end of an announcement interval, i.e., when the audio frequencies are resumed. At the hour and half-hour the telegraph code is followed by the station announcement in voice.

3. STANDARD TIME INTERVALS

There is on each carrier frequency a pulse of 0.005-second duration which occurs at intervals of precisely one second. The pulse consists of five cycles, each of 0.001-second duration, and is heard as a faint tick when listening to the broadcast; it provides a useful standard time interval, for purposes of physical measurements, and for quick and accurate measurement or calibration of timing devices or very low frequency oscillators. It may be used as an accurate time signal. On the 59th second of every minute the pulse is omitted. The 1-minute, 4-minute, and 5-minute intervals, synchronized with the seconds pulses, are marked by the beginning or ending of the periods when the audio frequencies are off.

A time interval of one second marked by the pulse is accurate, as transmitted, to one microsecond (= 0.000 001 second). A one-minute or longer interval is accurate to a part in 50,000,000.

The one-minute interval without tone modulation is provided in order to give time and station announcements and to afford an interval for the checking of radio-frequency measurements free from the presence of the audio frequencies.

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[1] Letter circular LC886 issued Jan. 30, 1948 by the U.S. Department of Commerce, National Bureau of Standards, Central Radio Propagation Laboratory, Wash. 25, D.C.

[2] Note change in this service; see part 2.

4. STANDARD AUDIO FREQUENCIES

Two standard audio frequencies, 440 cycles per second and 4000 cycles per second, are broadcast on radio carrier frequencies as in the following table:

Mega-cycles	Power-KW	Modulation, C/S
2.5	0.7	1 and 440
5.0	8.0	1 and 440
10.0	9.0	1, 440 and 4000
15.0	9.0	1, 440 and 4000
20.0	8.5*	1, 440 and 4000
25.0	0.1	1, 440 and 4000
30.0	0.1	1 and 440
35.0	0.1	1

All broadcasts are continuous, night and day. *0.1 kw, for first 4 work days after 1st Sunday of each month.

The two standard audio frequencies are useful for accurate measurement or calibration of instruments operating in the audio or supersonic regions of the frequency spectrum. They may also be used for accurate measurement of short time intervals.

The accuracy of the audio frequencies, as transmitted, is better than a part in 50,000,000. Transmission effects in the medium (Doppler effect, etc.) may result at times in slight fluctuations in the audio frequencies as received; the average frequency received is, however, of the same order of accuracy as that transmitted.

5. STANDARD MUSICAL PITCH

The 440 cycles per second is the standard musical pitch, A above middle C. It is broadcast for four minutes and interrupted for one minute. This sequence is repeated continuously on each of the radio carrier frequencies, except on 35 Mc. This service is useful to musicians and those concerned with the manufacture or maintenance of musical instruments. For the past 23 years the standard in the music industry of the U. S. has been 440 c/s.

6. RADIO PROPAGATION DISTURBANCE WARNING NOTICE

A warning of radio propagation conditions is broadcast in code on each of the standard radio carrier frequencies at nineteen and forty-nine minutes past the hour. If a warning is in effect, a series of "W's" (in the telegraphic code) follow the time announcement; if no warning is in effect, a series of "N's" (in the telegraphic code) follow the time announcement.

A warning (W) means that radio propagation disturbance of the inosphere storm type is anticipated within 12 hours, or is in progress, with its most severe effects on radio transmission paths crossing the North Atlantic; i.e., those paths for which the control points of transmission lie in or near the northern auroral zone. This type of radio propagation disturbance is characterized by low intensities, accompanied by flutter or rapid fading on the normal frequencies used at the different times of the day, or by complete blackouts of signals. By shifting to lower than normal frequencies for that time of day it may be possible to get signals through, although with lower than normal intensity. Owing to increased auroral-zone absorption during the disturbance, however, it may be impossible to have usable transmission on any high frequency. Also, during a period of radio propagation disturbance, direction-finder observations may be unreliable. Sudden ionosphere disturbances (SID) characterized by simultaneous fadeouts in the entire high frequency spectrum, on paths in the daylight side of the world, are not covered by this warning.

If no warning (N) is in effect, satisfactory transmission should be possible on the normal frequencies for the different times of day.

The usual daily time for changing the announced warning is 2119 GMT (4:19 PM, EST). The warning is, however, issued at any hour when disturbance becomes noticeable or anticipated. The announcement is returned to normal whenever conditions seem quiet. Thus any time a radio operator questions reception of North Atlantic paths, it would be advisable to check with the WWV announcement to see whether conditions are considered by the Bureau sufficiently disturbed to make a warning desirable.

Some one of the frequencies of WWV should be receivable at every location in the United States. Only during very severe storms would reception of WWV within the continental United States be difficult. For some Canadian or other users for whom the transmission path from WWV enters into or near the northern auroral zone, it may be impossible to receive any of the WWV frequencies at usable intensities during even moderate storms. It is probable, if no WWV frequency can be heard at hours when normally audible, that a warning is in effect.

The radio disturbance warning does not apply to sudden ionosphere disturbances, which are unpredictable in detail. These occur only at times when at least part of the transmission path is in sunlight. This type of disturbance is characterized by the received intensity's dropping to zero, very rapidly, usually within a minute or so, and remaining out from a few minutes to two hours. The effect is greater on the lower high frequencies, and on paths close to the equator or whose control points are close to the noon meridian. Usually the only long distance transmission possible during a sudden ionosphere disturbance is on frequencies

below about 100 kc. About 70% of sudden ionosphere disturbances are of less than an hour's duration. The use of the highest frequency available, as long as it is below the maximum usable frequency for the path in question, may shorten the effective duration of the fadeout. During the present years of great solar activity these sudden ionosphere disturbances will occur more frequently than in the past few years. They are directly associated with eruptions on the sun, more of which are observed during the years around sunspot maximum.

7. DISTANCE RANGE OF RECEPTION

Of the radio frequencies of WWV, the lowest provides service to short distances, and the highest to great distances. Reliable reception is in general possible at all times throughout the United States and the North Atlantic Ocean, 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. For nighttime conditions over the propagation path, lower frequencies than those used during the day are usually necessary because of skip. Received intensities on usable frequencies are much greater for nighttime than for daytime conditions.

b. By making use of techniques of prediction of usable frequencies.

Although there are a great number of variables affecting radio wave propagation and distance range, techniques exist for the prediction of usable frequencies over any specific path during any future month. By means of such techniques and the Central Radio Propagation Laboratory's prediction service, it is possible for a user to prepare for his locality a graph or table showing the best frequency for any period of the day in any month, three months in advance. 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, D. C., cost $1.00 per year (12 issues) and 25 cents per copy, respectively.

For continuous 24-hour reception without a break, the use of more than one receiver and antenna is necessary. With skilled operators to anticipate times for frequency shifting and with schedules prepared as under (b) above as a guide, it may in some cases be possible to operate continuously with two receivers. For maximum certainty of reception it is necessary to employ as many receivers as there are satisfactorily receivable WWV frequencies at the location, leaving then all in operation continuously and combining their outputs. A separate and directive antenna for each radio receiver is desirable.

8. OTHER RADIO TIME SIGNAL SERVICES

The Naval Observatory, U. S. Navy Department, broadcasts time signals at regular intervals on the following frequencies:

NSS (Annapolis, Md.)	122, 4390, 9425, 12630 kc,
NPG (Mare Island, Calif.)	115, 9255, 12540 kc,
NPM (Pearl Harbor, Hawaii)	16.68, 56, 4525, 9050, 13575, 17370 kc,
NBA (Balboa, Canal Zone)	148, 5005, 11080 kc.

Detailed information may be obtained from the U. S. Naval Observatory, Washington 25, D.C.

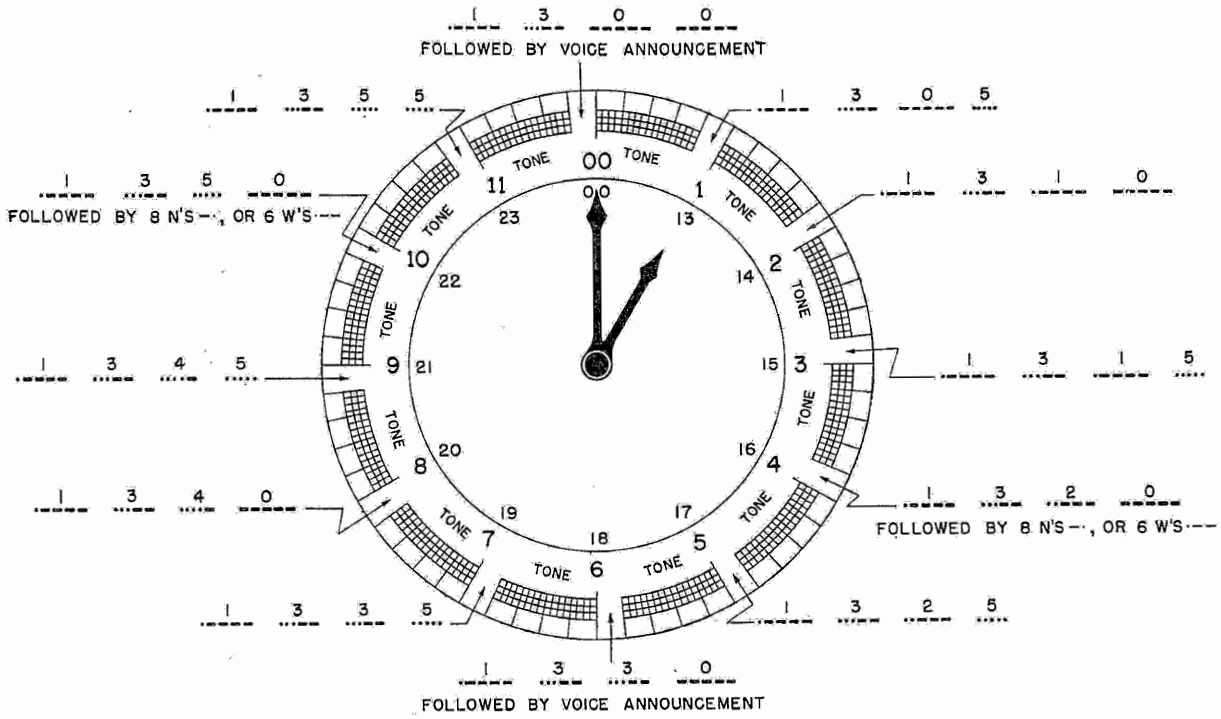
The Canadian Dominion Observatory (Ottawa) broadcasts time signals continuously over station CHU on frequencies of 3330, 7335 and 14670 kc; and at certain hours over other stations located at Ottawa, Halifax and Churchill. Information may be obtained by writing the Dominion Observatory, Ottawa, Canada.

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 $1.25.

STATION WWV TIME ANNOUNCEMENTS

THE HOUR ILLUSTRATED IS 1 TO 2 PM, OR 1300 TO 1400 IN 24 HOUR TIME

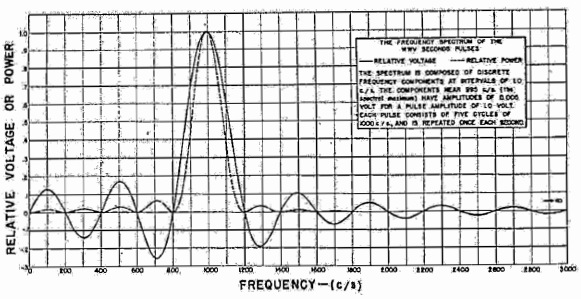
EASTERN STANDARD TIME

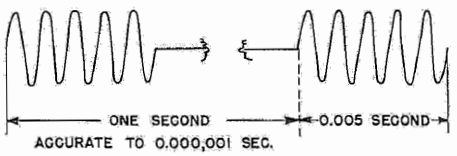


NUMERALS IN INTERNATIONAL MORSE CODE

0 -----	2 ··---	4 ····-	6 -····	8 ---··
1 ·----	3 ···--	5 ·····	7 --···	9 ----·

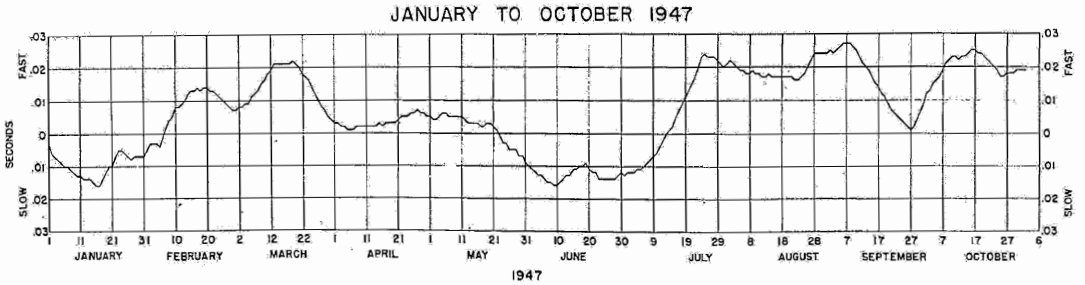
SECONDS PULSE (NO PULSE IS TRANSMITTED AT THE BEGINNING OF THE 59 th SECOND OF EACH MINUTE.)





WWV TIME SIGNALS, DEVIATIONS FROM U.S. NAVAL OBSERVATORY TIME

JANUARY TO OCTOBER 1947



PERTINENT STANDARDS OF INTEREST TO BROADCAST ENGINEERS

Standards relating to various areas of communication engineering and equipment are sponsored and developed through the efforts of many organizations. Among these are the American Standards Association, the Institute of Radio Engineers, the National Association of Broadcasters, and the Radio Manufacturers Association. In general, standards are developed by committees consisting of members representing manufacturers, consumers, technical and government agencies. Pertinent standards available from these organizations are as follows:

* * * * * * *

STANDARDS OF THE AMERICAN STANDARDS ASSOCIATION

Due to the large number of standards available from the ASA, it is suggested that those who are interested may 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 principle categories:

A--Civil Engineering and Construction
B--Mechanical Engineering
C--*Electrical Engineering*
D--Automotive
E--Transportation
G--Ferrous Materials and Metallurgy
H--Nonferrous Materials and Metallurgy
J--Rubber
K--Chemical Industry
L--Textile Industry
M--Mining
O--Wood Industry
P--Pulp and Paper Industry
Z--Miscellaneous

(Sections Z22 and Z24 are important sections to broadcasters concerned with motion pictures or acoustical terminology and sound measurements respectively.)

* * * * * * * *

INSTITUTE OF RADIO ENGINEERS CURRENT STANDARDIZATION REPORTS

(Order directly from the Institute of Radio Engineers 1 East 79th Street, New York, 21, N. Y.)

		Price
1)	Standards on Electroacoustics, 1938 Definitions of Terms, Letter and Graphical Symbols, Methods of Testing Loud Speakers. (vi + 37 pages, 6 x 9 inches).....	$0.50
2a)	Standards on Electronics: Definitions of Terms, Symbols, 1938. A Reprint (1943) of the like-named section of "Standards on Electronics, 1938." (viii + 8 pages, 8-1/2 x 11 inches)..	$0.20
2b)	Standards on Electronics: Methods of Testing Vacuum Tubes, 1938. A reprint (1943) of the like-named section of "Standards on Electronics, 1938." (viii + 8 pages, 8-1/2 x 11 inches).....	$0.50
3a)	Standards on Transmitters and Antennas: Definitions of Terms, 1938. A Reprint (1942) of the like-named section of "Standards on Transmitters and Antennas, 1938." (vi + 10 pages, 8-1/2 x 11 inches)...	$0.20
3b)	Standards on Transmitters and Antennas: Methods of Testing, 1938. A Reprint (1942) of the like-named section of "Standards on Transmitters and Antennas, 1938." (vi + 10 pages, 8-1/2 x 11 inches).....	$0.50
4a)	Standards on Radio Receivers: Definitions of Terms, 1938. A Reprint (1942) of the like-named section of "Standards on Radio Receivers, 1938." (vi + 6 pages, 8-1/2 x 11 inches.....	$0.20
4b)	Standards on Radio Receivers: Methods of Testing Broadcast Radio Receivers, 1938. A Reprint (1942) of the like-named section of "Standards on Radio Receivers, 1938." (vi + 20 pages, 8-1/2 x 11 inches).....	$0.50
4c)	Standards on Radio Receivers: Methods of Testing Frequency-Modulation Broadcast Receivers, 1947. (vi + 15 pages, 8-1/2 x 11 inches).....	$0.50
5a)	Standards on Radio Wave Propagation: Definitions of Terms, 1942. (vi + 8 pages, 8-1/2 x 11 inches)....	$0.20
5b)	Standards on Radio Wave Propagation: Measuring Methods, 1942. Methods of Measuring Radio Field Intensity, Methods of Measuring Power Radiated from an Antenna, Methods of Measuring Noise Field Intensity. (vi + 16 pages, 8-1/2 x 11 inches).....	$0.50
5c)	Standards on Radio Wave Propagation: Definitions of Terms Relating to Guided Waves, 1945. (iv + 4 pages, 8-1/2 x 11 inches).....	$0.20
6a)	Standard on Facsimile: Definitions of Terms, 1942. (vi + 6 pages, 8-1/2 x 11 inches).....	$0.20
6b)	Standards on Facsimile: Temporary Test Standards, 1943. (iv + 8 pages, 8-1/2 x 11 inches).....	$0.20
7)	Standards on Piezoelectric Crystals: Recommended Terminology, 1945. (iv + 4 pages, 8-1/2 x 11 inches)....	$0.20

8) Standards on Television: Methods of Testing Television Transmitters, 1947. (vi + 18 pages, 8-1/2 x 11 inches)..... $0.75

8b) Standards on Television: Methods of Testing Television Receivers, 1948. (vi + 40 pages, 8-1/2 x 11 inches)..... $1.00

9) Standards on Antennas, Modulation Systems, and Transmitters: Definitions of Terms, 1948. (vi + 25 pages, 8-1/2 x 11 inches)..... $0.75

ASA STANDARDS

(Sponsored by and obtainable from the I.R.E.)

ASA1) American Standard: Standard Vacuum-Tube Base and Socket Dimensions. (ASA C16.2-1939.) (8 pages 7-3/4 x 10-5/8 inches).... $0.20

ASA2) American Standard: Manufacturing Standards Applying to Broadcast Receivers. (ASA C16.3-1939.) (16 pages, 7-3/4 x 10-5/8 inches).. $0.20

ASA3) American Standard: Loudspeaker Testing. (ASA C16.4-1942.) (12 pages, 7-3/4 x 10-5/8 inches).. $0.25

ASA4) American Standard: Volume Measurements of Electrical Speech and Program Waves. (ASA C16.5-1942.) (8 pages, 7-3/4 x 10-5/8 inches)..... $0.20

Prices are net and include postage to any country. Include remittance with order.

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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 request to the NAB, Department of Engineering. These standards are set forth as Section 1-3 of this Engineering Handbook.

RECOMMENDED STANDARDS OF THE RADIO MANUFACTURERS ASSOCIATION

RMA has available and for sale Recommended Standards on Receivers, Electronic Tubes, Transmitters, and Speech Equipment. Remittances and orders should be forwarded directly to the Radio Manufacturers Association, 1317 F Street, N.W., Washington 4, D.C. Those standards available with respect to Transmitters and Speech Equipment are listed below:

			Price
TR-101-A	February 1948	Electrical Performance Standards for Standard Broadcast Transmitters.....	$0.30
TR-102	November 1947	Dry Type Power Transformers for Radio Transmitters.....	$0.25
TR-103	November 1947	Transmission Lines for FM Broadcast Transmitters (88-108 Mc/sec.).....	$0.25
TR-104	December 1947	Electrical Performance Standards for Television Broadcast Transmitters Channels 1-13 (44 Mc-216 Mc).....	$0.90
TR-105-A	May 1948	Audio Facilities for Radio Broadcasting Systems.....	$0.30
TR-106	July 1948	Electrical Performance Standards for Television Relay Facilities.....	$2.05
TR-107	March 1949	Electrical Performance Standards for FM Broadcast Transmitters 88-108 MC.....	$0.25
TR-108	February 1949	Rectangular Waveguides.....	$0.25
TR-109	March 1949	Potted Fixed Mica Dielectric Capacitors.....	$0.40
SE-101	December 1947	Amplifiers.....	$0.25
SE-102	February 1949	Panel Mounting Racks, Panels, and Associated Equipment.....	$0.25

FCC RULES GOVERNING REMOTE PICKUP BROADCAST STATIONS

INTRODUCTORY STATEMENT

Rules and Regulations of the Federal Communications Commission concerning Remote Pickup Broadcast Stations appear in Subpart D of Part 4 which is entitled "Rules Governing Experimental and Auxiliary Services." Those sections of Part 4 pertaining to Remote Pickup Broadcast Services which follow include proposed amendments in Dockets 8711, 9192, and 9363. The proposed revisions appear in italicized print. All frequency assignments to Remote Pickup Broadcast Services appearing herein were made final by the Commission as of May 3, 1949 (Dockets 8965, 8972, and 8974).

Any further action by the Commission with respect to the proposed revisions indicated in the italicized portions will be announced in NAB MEMBER SERVICE.

RULES GOVERNING EXPERIMENTAL AND AUXILIARY BROADCAST SERVICES

IN GENERAL

4.1 BROADCAST SERVICES COVERED BY PART 4 OF RULES.--The following broadcast services are covered by Part 4 of the Rules:

(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) ST Broadcast *(Subpart E)*
- (3) *Television Pickup*
- (4) *Television STL (Subpart F)*
- (5) *Television Inter-City Relay*

RULES GOVERNING ADMINISTRATIVE PROCEDURE

4.11 APPLICATIONS.--

(a) Each applicant for a construction permit or a license for a new remote pickup or ST broadcast station, or to make changes in facilities, or modification of license, or renewal of license of any such existing station shall file with the Commission in Washington, D. C., two copies of applications on the appropriate form designated by the Commission (FCC Form 313) and a like number of exhibits or other papers incorporated therein and made a part thereof. Only the original copy need be sworn to.

(b) Each applicant for a construction permit for an experimental television, experimental facsimile or developmental broadcast station, or to make changes in facilities, or modification of license, or renewal of license of any such existing station shall file with the Commission in Washington, D. C., two copies of applications on appropriate forms designated by the Commission and a like number of exhibits or other papers incorporated therein and made a part thereof. Only the original copy need be sworn to. If the application is for a construction permit for a new station or to make changes in an existing station, FCC Form 309 should be filed; for a station license, FCC Form 310 should be filed: for renewal of station license, FCC Form 311 should be filed.

4.12 FULL DISCLOSURES.--Each application shall contain full and complete disclosures with regard to the real party or parties in interest, and their legal, technical, financial, and other qualifications, and as to all matters and things required to be disclosed by the application forms.

4.13 INSTALLATION OR REMOVAL OF APPARATUS.--Applications for construction permit or modification thereof, involving removal of existing transmitting apparatus and/or installation of new transmitting apparatus, shall be filed at least 60 days prior to the contemplated removal and/or installation.

4.14 PERIOD OF CONSTRUCTION.--Each construction permit will specify a maximum of 60 days from the date of granting thereof as the time within which construction of the station shall begin, and a maximum of six months thereafter as the time within which construction shall be completed and the station ready for operation, unless otherwise determined by the Commission upon proper showing in any particular case.

4.15 FORFEITURE OF CONSTRUCTION PERMITS; EXTENSION OF TIME.--

(a) A construction permit shall be automatically forfeited if the station is not ready for operation within the time specified therein or within such further time as a Commission may have allowed for completion, and a notation of the forfeiture of any construction permit under this provision will be placed in the records of the Commission as of the expiration date.

(b) An application (Form FCC No. 701) for extension of time within which to construct a station shall be filed at least thirty days prior to the expiration date of such permit if the facts supporting such application for extension are known to the applicant in time to permit such filing. In other cases such applications will be accepted upon a showing satisfactory to the Commission of sufficient reasons for filing within less than thirty days prior to the expiration date. Such applications will be granted upon a specific and detailed showing that the failure to complete was due to causes not under the control of the grantee, or upon a specific and detailed showing of other matters sufficient to justify the extension.

4.16 EQUIPMENT 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, the permittee of any class of station listed in Part 4 may, without further authority of the Commission, operate the equipment for the purpose of ascertaining that it is in satisfactory operating condition: 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 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) 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 the construction.

4.17 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 Part 4 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 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.

4.18 LICENSE PERIOD; RENEWAL.--

(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	Date of Expiration
Experimental television broadcast station	*April 1*
Experimental facsimile broadcast station	March 1
Developmental broadcast station	May 1

(b) *Licenses for stations in the Auxiliary Broadcast Service will be issued for a period running concurrently with the licenses of the broadcast stations 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 period.

4.19 LICENSE, SIMULTANEOUS MODIFICATION AND RENEWAL.--When an application is granted by the Commission necessitating the issuance of a modified license less than 60 days prior to the expiration date of the license sought to be modified, and an application for renewal of said license is granted subsequent or prior thereto (but within 30 days of expiration of the present license) the modified license as well as the renewal license will be issued to conform to the combined action of the Commission.

4.20 RENEWAL OF LICENSE.--

(a) Unless otherwise directed by the Commission, each application for renewal of license shall be filed at least 60 days prior to the expiration date of the license sought to be renewed.

(b) Whenever the Commission regards an application for renewal of a station license for any class of broadcast station listed in 4.1 as essential to the proper conduct of a hearing or investigation, and specifically directs that it be filed by a certain date, such application shall be filed within the time thus specified. If the licensee fails to file such application within the prescribed time, the hearing or investigation shall proceed as if such renewal application had been received.

(c) A supplemental report shall be submitted with each application for renewal of license of a station licensed experimentally[1] in accordance with the regulations governing each class of station.

[1]The phrases "station licensed experimentally" and "Experimental station" are used interchangeably.

4.21 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, 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.

4.22 REPETITIOUS APPLICATIONS.--

(a) Where an applicant has been afforded an opportunity to be heard with respect to a particular application for a new auxiliary or experimental broadcast station, or for change of existing service or facilities, and the Commission has, after hearing or default, denied the application or dismissed it with prejudice, the Commission will not consider another application for a station of the same class to serve in whole or in part the same area, by the same applicant or by his successor or assignee, or on behalf of or for the benefit of the original parties in interest, until after the lapse of 12 months from the effective date of the Commission's order.

(b) Where an appeal has been taken from the action of the Commission in denying a particular application, another application for the same class of broadcast station and for the same area, in whole or in part, filed by the same applicant or by his successor as assignee, or on behalf or for the benefit of the original parties in interest, will not be considered until the final disposition of such appeal.

4.23 ASSIGNMENT OR TRANSFER OF CONTROL.--

(a) Voluntary: Application for consent to voluntary assignment of an auxiliary or experimental broadcast station construction permit or license or for consent to voluntary transfer of control of a corporation holding such a construction permit or license shall be filed with the Commission on Form FCC No. 314 (assignment of license) or Form FCC No. 315 (transfer of control) at least 60 days prior to the contemplated effective date of assignment or transfer of control.

(b) Involuntary: In the event of the death or legal disability of a permittee or licensee, or a member of a partnership, or a person directly or indirectly in control of a corporation, which is a permittee or licensee:

(1) The Commission shall be notified in writing promptly of the occurrence of such death or legal disability, and

(2) Within thirty days after the occurrence of such death or legal disability, application on Form FCC No. 314 or 315 shall be filed for consent to involuntary assignment of such station permit or license or for involuntary transfer of control of such corporation to a person or entity legally qualified to succeed to the foregoing interests under the laws of the place having jurisdiction over the estate involved.

SUBPART D--RULES GOVERNING REMOTE PICKUP BROADCAST STATIONS

DEFINITIONS AND ALLOCATION OF FREQUENCIES

4.401 DEFINITIONS.--

(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) The term "remote pickup broadcast station" as used in this part of the rules includes both of the above definitions.

4.402 FREQUENCY ASSIGNMENT.--

(a) The following groups of frequencies are allocated for assignment to remote pickup broadcast stations:[1]

(1)

Group A Kilocycles	Group B Kilocycles	Group C Kilocycles
1622	1606	1646
2058	2074[2]	2090
2150	2102	2190
2790	2758	2830

(2)

Group D Megacycles	Group E Megacycles	Group F Megacycles	Group G Megacycles	Group H Megacycles
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 Megacycles	Group J Megacycles
26.11	26.13
26.45	26.47

(4)

Group K Megacycles		
152.87[3]	153.05[3]	153.23[3]
152.93[3]	153.11[3]	153.29[3]
152.99[3]	153.17[3]	153.35[3]

(5)

Group L Megacycles	Group M Megacycles
166.25[4]	170.15[4]

Operation on the frequencies 166.25 mc and 170.15 mc is not authorized (1) within the area bounded on the west of the Mississippi River, on the north by the parallel by latitude 37° 30' N., and on the east and south by that arc of the circle with center at Springfield, Illinois, and radius equal to the airline distance between Springfield, Illinois and Montgomery, Alabama, subtended between the foregoing west and north boundaries; (2) within 150 miles of New York City, and; (3) outside the continental United States.

(6)

Group N Megacycles				
450.05	450.45	450.85	451.25	451.65
450.15	450.55	450.95	451.35	451.75
450.25	450.65	451.05	451.45	451.85
450.35	450.75	451.15	451.55	451.95

(b) For the purpose of assignment, frequencies allocated to remote pickup broadcast stations are divided into six allocations divisions designated as subparagraphs (1), (2), (3), (4), (5), and (6) of paragraph (a) above. Within each allocation division is one or more frequency groups identified by letter designation, i. e., A, B, and C in division (1): D, E, F, G, and H in division (2); I and J in division (3); K in division (4); L and M in division (5); and N in division (6). A license for a remote pickup broadcast station may authorize a frequency or frequencies in one or more allocation divisions depending upon the frequency range of equipment employed. While a licensee may have one or more remote pickup broadcast stations licensed for operation in the same area, such stations will be limited within each allocation division to the assignment of frequencies from a single group.

(c) 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 frequency 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 the rules.

RULES RELATING TO 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

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[1] *Frequencies below 25 mc are subject to change in accordance with action resulting from the proceedings in Docket No. 6651.*

[2] Subject to the condition that no interference is caused to the Industrial Radio Services.

[3] *Subject to the condition that harmful interference will not be caused to the Industrial Radio Services.*

[4] *Subject to the condition that harmful interference will not be caused to government stations present or future in the government band 162-174 mc.*

material, and related communications necessary to the accomplishment of such transmissions, to an associated broadcast station[1], 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.

[1]The term "associated broadcast station" as used herein means a broadcast station with which the remote pickup station is licensed as an auxiliary facility.

(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, and Puerto Rico 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), 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 stations will be licensed for the purpose of providing communications between the studio and the transmitter of broadcast stations which utilize an STL broadcast station for program transmission, provided that such operation shall not be conducted on frequencies other than those listed in 4.402(a)(3).

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[1] 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[1] 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[1] 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.

[1]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[1] 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, 166.25 and 170.15 mc, 60 kilocycles.

(3) For stations operating on the frequencies 450.05 to 451.95 mc, 100 kilocycles.

(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.

[1]The term "frequency swing" means the instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

RULES RELATING TO EQUIPMENT

4.451 EQUIPMENT CHANGES.--The licensee of a remote pickup broadcasting 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:*[1]

Frequency Range	Tolerance (per cent) Base Station	Mobile Station
1606 to 2830 kc:		
200 watts or less	*0.01*	*0.02*
over 200 watts[2]	*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]*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 re-assignment of these stations pursuant to the proceedings in Docket No. 6651, retain the frequency tolerance requirements of their present licenses.*

[2]*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.--*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. Each frequency for which the remote pickup broadcast station is licensed shall be measured at least once during each calendar year.*[1]

[1]*Remote pickup broadcast stations licensed for frequencies that are subject to change in accordance with the proceedings in Docket No. 6651 are required to measure only those frequencies on which they are equipped to operate.*

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 Section 4.434 the station license shall be posted in the above-described manner at the operation position.

(2) If the station is licensed for portable-mobile operation,[1] 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[1] operation, a verification card[2] 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.

[1]The term portable-mobile as here used is intended to include any type of portable or mobile operation.

[2]Form 758-F

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 Section 4.434, and in actual charge of its operation. Further provisions and restrictions concerning the operator's authority are contained in Part 13 of the Rules. 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.

THEORY AND DESIGN OF DIRECTIONAL ANTENNA SYSTEMS

By Carl E. Smith, E. E.

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NATIONAL ASSOCIATION OF BROADCASTERS

FOREWORD

The NAB Engineering Handbook, 1946 (3rd) edition, presented a section on directional antennas taken in its entirety from the book entitled "Directional Antennas" written and published by Carl E. Smith. Mr. Smith is Vice-President in Charge of Engineering, United Broadcasting Company, and President of the Cleveland Institute of Radio Electronics. The material presented to the radio engineering profession by Mr. Smith has enjoyed wide acceptance as an authoritative reference work for professional engineers concerned with the design, construction and operation of directive arrays.

The author has used as basic sources for the paper which follows, his book "Directional Antennas" and appropriate sections of the home study course on "Advanced Radio and Communication Engineering" prepared and made available to engineers, technicians and operators by the Cleveland Institute of Radio Electronics. The material which follows develops the theory and practical design of the shape and size of directional antenna systems and concludes with a section on feeder system design. As combined, amplified and edited from the two above sources, it is believed that for the first time a coordinated and complete work, authoritative in nature, is made available with respect to a practical approach in the design of directive arrays.

The NAB Department of Engineering presents this material with a twofold objective: first, that professional engineers may find in their work, with respect to directional antenna systems, a common understanding of the basic principles of design; and, second, that the broadcast engineer charged with the operation and maintenance of a directional antenna system, no matter how complex, will better understand its design and operation, which understanding in turn will pay high dividends through more efficient, economical and consistent broadcast service.

Further information with respect to Mr. Smith's book entitled "Directional Antennas" or the college-level review of the principles of radio and communication engineering as presented in the home study course "Advance Radio and Communication Engineering" may be obtained by addressing inquiries to the Cleveland Institute of Radio Electronics, 4900 Euclid Ave., Cleveland 3, Ohio.

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I. FUNDAMENTAL PROPERTIES

a. *INTRODUCTION*.--The purpose of a radio broadcasting station is to transform sound waves into radio waves that can be picked up by radio receiving sets. The utility of this service to the public depends upon. (1) *Signal Intensity*, (2) *Program Content*, and (3) *System Distortion*. Of these factors, the radio broadcasting station engineer is concerned with producing an intense signal that will override noise and undesired signals in the receiving sets being served and with minimizing distortion in the audio and radio facilities of the station.

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 polarization, and the intensity of the signals leaving the transmitting antennas. The selection of the antenna site is determined by many considerations, such as; ground constants, terrain, distance and direction to the populated areas to be served, distance and direction to the areas to be protected, and last but not least is 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 intensity 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 station involved, the only factors remaining under the engineer's control are the antenna siting and design. These factors go hand in hand when designing directional antennas for broadcasting purposes.

b. *PURPOSE*.--Directional broadcasting antennas are required for one or more of the following reasons:

(1) Protect the service area of other broadcasting stations by causing the waves to cancel in these directions.

(2) Increase the service area of a broadcasting station, particularly in the direction of densly populated areas, by causing the waves to be reinforced in these directions.

c. *CONTROL OF PATTERN SHAPE*.--The usual problem in broadcast practice is to mould the radiation pattern into the desired shape to cover the service areas and give the required protection to other radio stations. As a matter of economics, it is desirable to do the job with the minimum number of antennas. With severe requirements, the number of antennas must be increased until the radiation pattern can be made to conform to the required shape. As a general rule, two stations can be given the required protection with two towers; three stations can be completely protected with three towers in line or if the protection is not severe, it is possible many times to do the job with two towers. With four towers it is always possible to completely control the nulls toward four stations; however if the job can be done with three towers there is a saving of the cost of one tower.

In controlling the pattern shape, consideration has to first be given to fulfilling the conditions of the required protection to other radio stations in accordance with the Standards of Good Engineering Practice of the Federal Communications Commission. The FCC Standards is an excellent practical guide for allocation work. The Standards of Good Engineering Practice was compiled by FCC from extensive data collected by its Engineering Department over long periods of time. This material is under almost constant revision as the art progresses. It is recommended that in connection with any study of this article the FCC Standards contained in Section One of the NAB Engineering Handbook be referred to for details.

The next consideration is to locate the directional antenna system so that the horizontal lobes will be directed toward the population areas to be served without having too many people within the blanket area, that is, the area near the transmitter where the signal is so strong that other radio stations cannot be received without objectionable interference and still be able to serve the business district with at least 25 millivolts per meter field intensity.

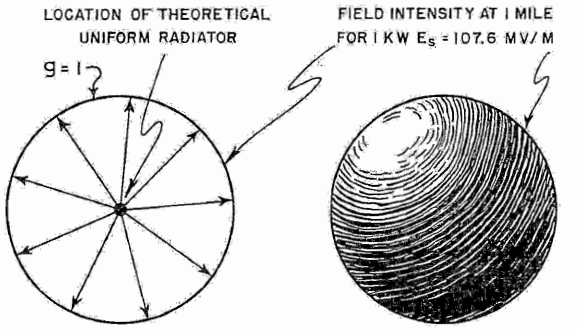
d. *DETERMINATION OF PATTERN SIZE*.--Pattern size is determined by the class of station and efficiency of the antenna system. The power for the class of station is regulated by the Federal Communications Commission as outlined in the Standards of Good Engineering Practice. In general the power ranges from; 0.25 to 50 kilowatts for stations on clear channels, 0.5 to 5 kilowatts for regional channel stations and 100 to 250 watts for local channel stations. However, local channel stations are not authorized to use directional antenna systems. The predominance of directional antenna designs are for regional stations which have to protect co-channel or adjacent channel stations in other regions of the country. Directional antennas are used by a few of the clear channel stations.

The efficiency of the antenna system depends upon the antenna design. It is always

desirable to maintain a high efficiency in order that a high percentage of the output power of the transmitter may be radiated, particularly in the horizontal plane. To do this it is sometimes necessary to use a more complicated directional antenna system to give the required degree of protection to other radio stations. In other words, a low efficiency simple antenna system might give the required protection, but would not meet the FCC minimum requirement in millivolts per meter root-mean-square unattenuated field intensity for one kilowatt at one mile in the horizontal plane.

2. GENERAL TREATMENT

a. *STANDARD REFERENCE ANTENNAS*--(1) Uniform Spherical Radiator.--The Uniform, Omnidirectional, or Isotropic radiator, in free space, is taken as THE Standard Reference Antenna because it has no directivity. Such as antenna is illustrated in Fig. 1. It is defined as a theoretical antenna which radiates waves having the same field intensity in all directions. Actually such a radiator of radio waves can not be realized, because all radio antennas have directional properties. In the case of the acoustic waves, this standard is represented by a sphere pulsating radially.



(1) CROSS-SECTION VIEW OF SPHERICAL PATTERN WHICH HAS A FIELD INTENSITY GAIN OF 1, A POWER GAIN OF 1 (g = 1) AND A DECIBEL GAIN OF ZERO

(2) SPHERICAL RADIATION PATTERN SURFACE OF A UNIFORM OR ISOTROPIC RADIATOR

PATTERN OF A UNIFORM RADIATOR WHICH IS THE THEORETICAL STANDARD REFERENCE ANTENNA

FIG. 1

For a 1 kw power source, a uniform radiator will produce a field intensity of

$$E_s = 107.6 \qquad (1)$$

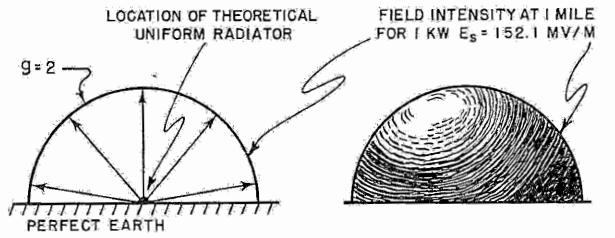
where E_s = millivolts per meter unattenuated field intensity at one mile for one kilowatt.

This standard has come into rather common use in antenna work during and since World War II. The figure of merit of all other antennas can be compared with this basic standard. Although this basic standard can not be realized in the case of electromagnetic waves, if the merit of all antennas are compared to this basic standard, then the relative figures of merit between the other antennas can be obtained immediately. Other secondary standards for free space may be selected and used as convenience demands.

(2) Uniform Hemispherical Radiator.--If a uniform radiator is placed at the surface of a perfectly conducting earth, all of the power must be radiated in the hemisphere above the surface of the earth as shown in Fig. 2. For a given power source, the power flow will have twice the intensity of a uniform radiator in free space, hence the power gain is said to be 2. For this case, the field intensity gain is $\sqrt{2}$, therefore the field intensity is $107.6\sqrt{2}$ or,

$$E_s = 152.1 \qquad (2)$$

where E_s = millivolts per meter unattenuated field intensity at one mile for one kilowatt.



(1) CROSS-SECTION VIEW OF A HEMISPHERICAL PATTERN WHICH HAS A FIELD INTENSITY GAIN OF 1.4, A POWER GAIN OF g = 2 AND A DECIBEL GAIN OF 3.01

(2) HEMISPHERICAL RADIATION PATTERN SURFACE OF A UNIFORM RADIATOR

PATTERN OF A UNIFORM RADIATOR AT THE SURFACE OF A PERFECT REFLECTING AND CONDUCTING EARTH

FIG. 2

At the present state of the art this antenna has only academic interest, however, it is a standard for antennas at the surface of the earth, such as radio broadcasting antennas. It is particularly useful in the computation of antenna gains. This type of antenna can be considered as a standard for determining the directivity of antennas located on the surface of the earth.

(3) Current Element Antenna in Free Space.--An electric current element in free space, sometimes referred to as an elementary doublet or dipole, consists of a very short conductor (mathematically of infinitesimal length) having a uniform current distribution. This infinitesimal antenna is universally used

in developing the radiation property of an antenna of any configuration. This current element antenna is a mathematical convenience only, because such an antenna in practice for a specified field intensity would require excessive transmitter power because of the high losses due to the radiation resistance being low in comparison to the loss resistance encountered in practice. The field intensity at any distant point in space as shown in Fig. 3(a) is given by:

$$E = \frac{60\pi}{d\lambda} I\,(\delta G)\cos\theta \qquad (3)$$

or

$$= \frac{60\pi f}{dc} I\,(\delta G)\cos\theta$$

where E = field intensity in volts per meter at point P

π = 3.1416

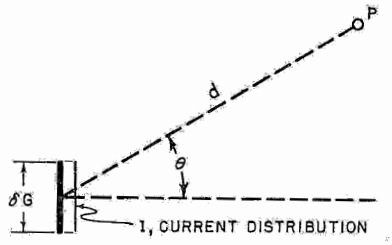
d = distance in meters from current element to the point P

λ = wave length of radiated wave in meters

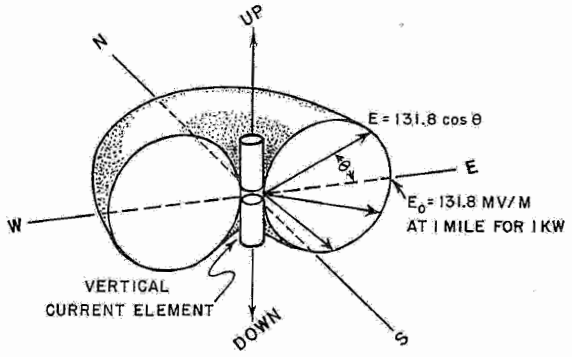
f = frequency of current in cycles per second

c = 3×10^8 meters per second, the velocity of light

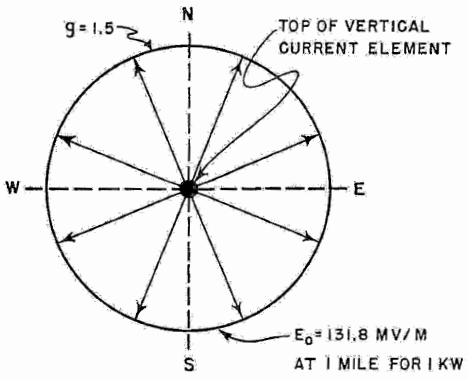
I = effective current in amperes flowing in the conductor



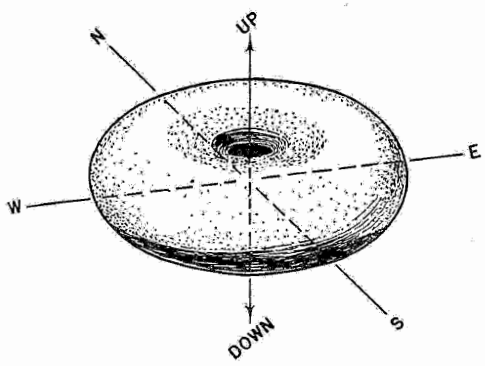
(a) ELECTRIC CURRENT ELEMENT OF LENGTH δG AND CARRYING CURRENT I



(b) SIDE CROSS-SECTION VIEW OF THE TOROIDAL RADIATION PATTERN SHOWING THE VERTICAL DIRECTIVITY.



(c) HORIZONTAL CROSS-SECTION VIEW OF TOROIDAL RADIATION PATTERN SHOWING UNIT HORIZONTAL DIRECTIVITY



(d) SURFACE PATTERN SHOWING TOROIDAL OR DOUGHNUT SHAPE

THE RADIATION PATTERN OF A VERTICAL ELECTRIC CURRENT ELEMENT IN FREE SPACE

FIG. 3

δG = elementary length (or height) of conductor measured in meters

θ = elevation angle of point P measured from a plane perpendicular to the conductor.

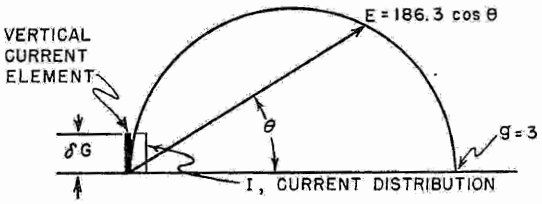
When this elementary antenna radiates one kilowatt of power the field intensity at one mile is

$$E = E_o \cos \theta \qquad (4)$$
$$= 131.8 \cos \theta$$

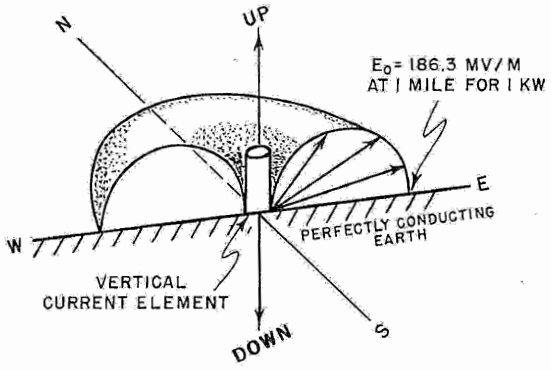
where E = millivolts per meter unattenuated field intensity at one mile for one kilowatt

E_o = millivolts per meter field intensity measured on a plane perpendicular to the conductor and in this case at the distance of one mile for one kilowatt of radiated power

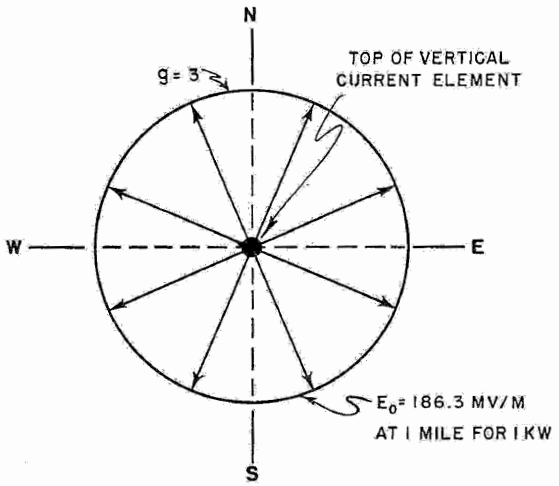
θ = elevation angle as shown in Fig. 3(a).



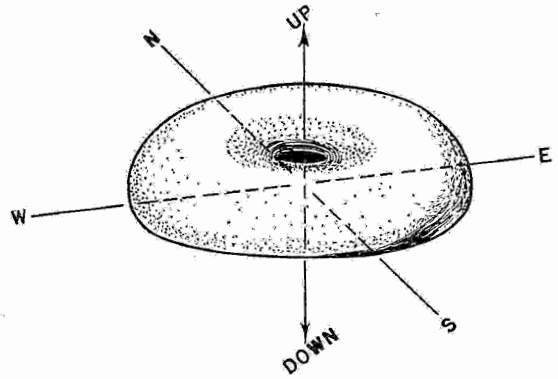
(a) VERTICAL RADIATION PATTERN



(b) SIDE CROSS-SECTION VIEW OF THE TOROIDAL HEMISPHERICAL PATTERN SHOWING THE VERTICAL DIRECTIVITY.



(c) HORIZONTAL CROSS-SECTION VIEW OF TOROIDAL HEMISPHERICAL RADIATION PATTERN SHOWING UNIT HORIZONTAL DIRECTIVITY



(d) SURFACE PATTERN SHOWING TOROIDAL HEMISPHERICAL SHAPE

THE RADIATION PATTERN OF A VERTICAL ELECTRIC CURRENT ELEMENT OVER A PERFECTLY CONDUCTING EARTH

FIG. 4

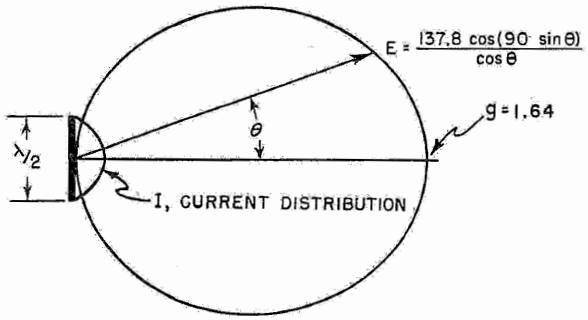
2-1-06

The value of 131.8 is the maximum field intensity and is a constant in the horizontal plane. See Fig. 3(c). This current element antenna is sometimes used as a secondary standard reference antenna.

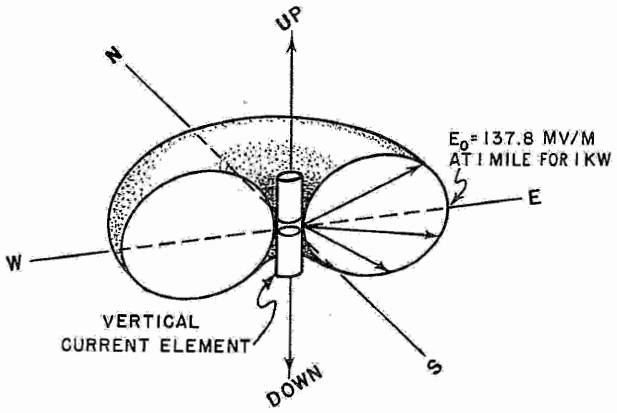
(4) Vertical Current Element Antenna Over a Perfectly Conducting Earth.--If a vertical current element antenna is located at the surface of a perfect earth, the radiation will be hemispherical as shown in Fig. 4.

When this vertical current element radiates 1 kw of power the field intensity at one mile is

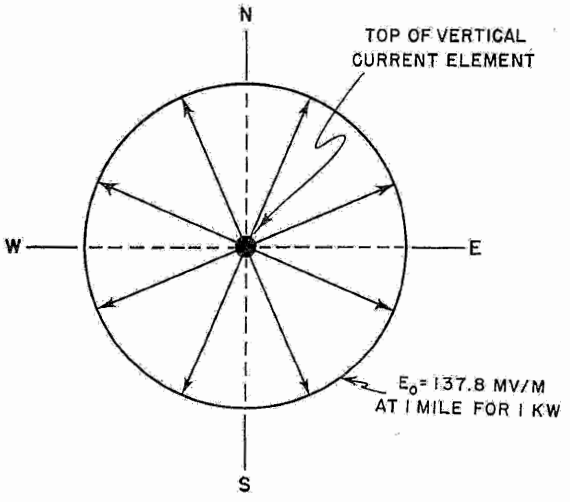
$$E = 131.8\sqrt{2}\cos\theta$$
$$= 186.3\cos\theta \qquad (5)$$



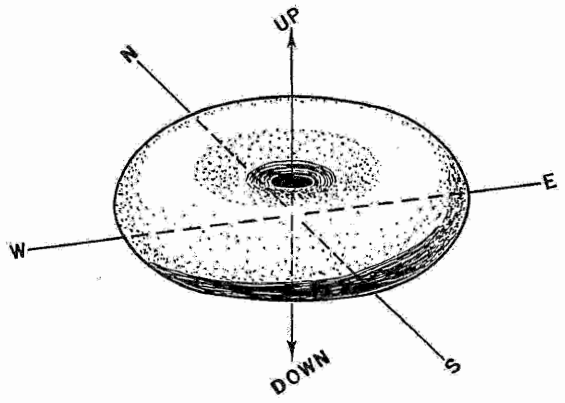
(a) VERTICAL RADIATION PATTERN



(b) SIDE CROSS-SECTION VIEW OF THE RADIATION PATTERN SHOWING THE VERTICAL DIRECTIVITY



(c) HORIZONTAL CROSS-SECTION VIEW OF RADIATION PATTERN SHOWING UNIT HORIZONTAL DIRECTIVITY



(d) SURFACE PATTERN SHOWING DOUGHNUT SHAPE

THE RADIATION PATTERN OF A VERTICAL HALF WAVE RADIATOR IN FREE SPACE

FIG. 5

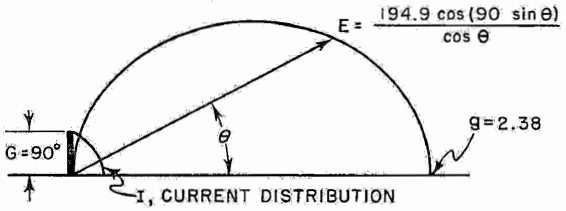
where E and θ are defined in Eq. (4) and Fig. 4(a).

This vertical current element antenna is sometimes used as secondary reference antenna. It gives the vertical pattern of a zero height antenna. See Eq. (10). While one of these infinitesimal antennas itself is of no practical value it is useful in summing up the radiation effects of antennas having practical dimensions.

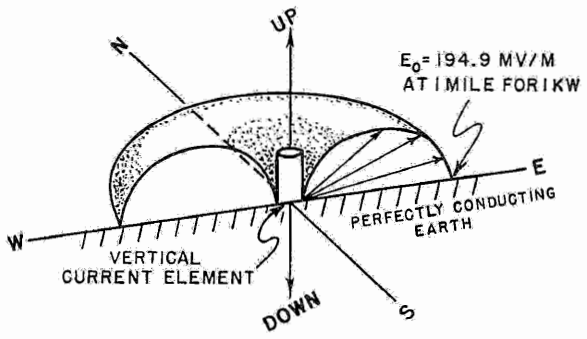
(5) Half Wave Antenna in Free Space.--A half wave antenna in free space will have essentially a sinusoidal current distribution as shown in Fig. 5(a). If the radiation effects of the current elements as given in Eq. (3) are summed up for the whole antenna the field intensity pattern is given by

$$E = \frac{137.8 \cos (90 \sin \theta)}{\cos \theta} \qquad (6)$$

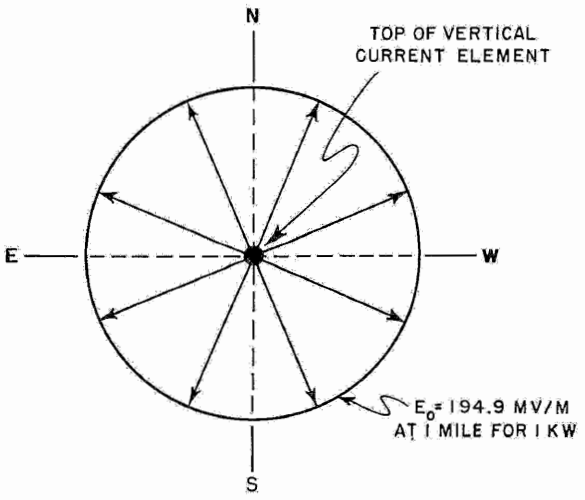
where E and θ are defined in Eq. (3) and Fig. 5(a).



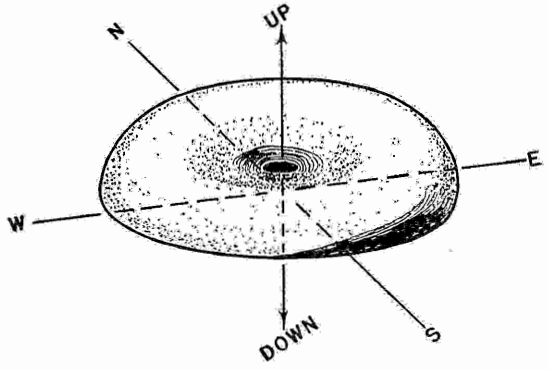
(a) VERTICAL RADIATION PATTERN



(b) SIDE CROSS-SECTION VIEW OF THE RADIATION PATTERN SHOWING THE VERTICAL DIRECTIVITY



(c) HORIZONTAL CROSS-SECTION VIEW OF RADIATION PATTERN SHOWING UNIT HORIZONTAL DIRECTIVITY



(d) SURFACE PATTERN SHOWING DOUGHNUT SHAPE

THE RADIATION PATTERN OF A VERTICAL QUARTER WAVE RADIATOR OVER A PERFECTLY CONDUCTING EARTH

FIG. 6

This type of antenna is often used as a secondary standard reference antenna because it is a practical type of antenna that is easy to set up experimentally. For example, the Federal Communications Commission uses this standard for FM and TV Broadcast Stations.

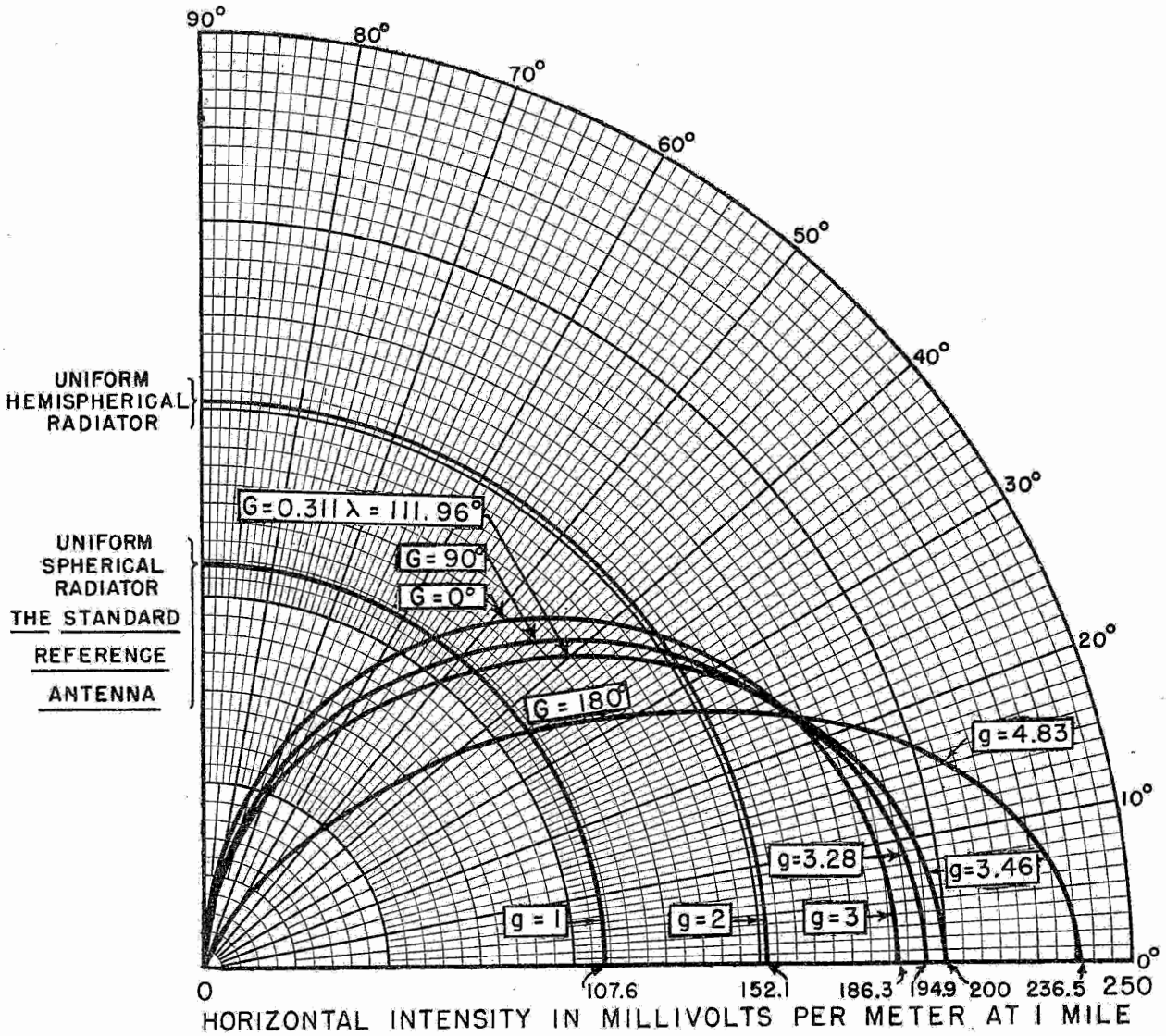
(6) Quarter-Wave Vertical Antenna over a Perfectly Conducting Earth.--This type of antenna is very common and is often used as a secondary standard reference antenna. With a sinusoidal current distribution as shown in Fig. 6(a) the radiation pattern is given by

$$E = \frac{194.9 \cos (90 \sin \theta)}{\cos \theta} \qquad (7)$$

where E and θ are defined in Eq. (3) and Fig. 6(a).

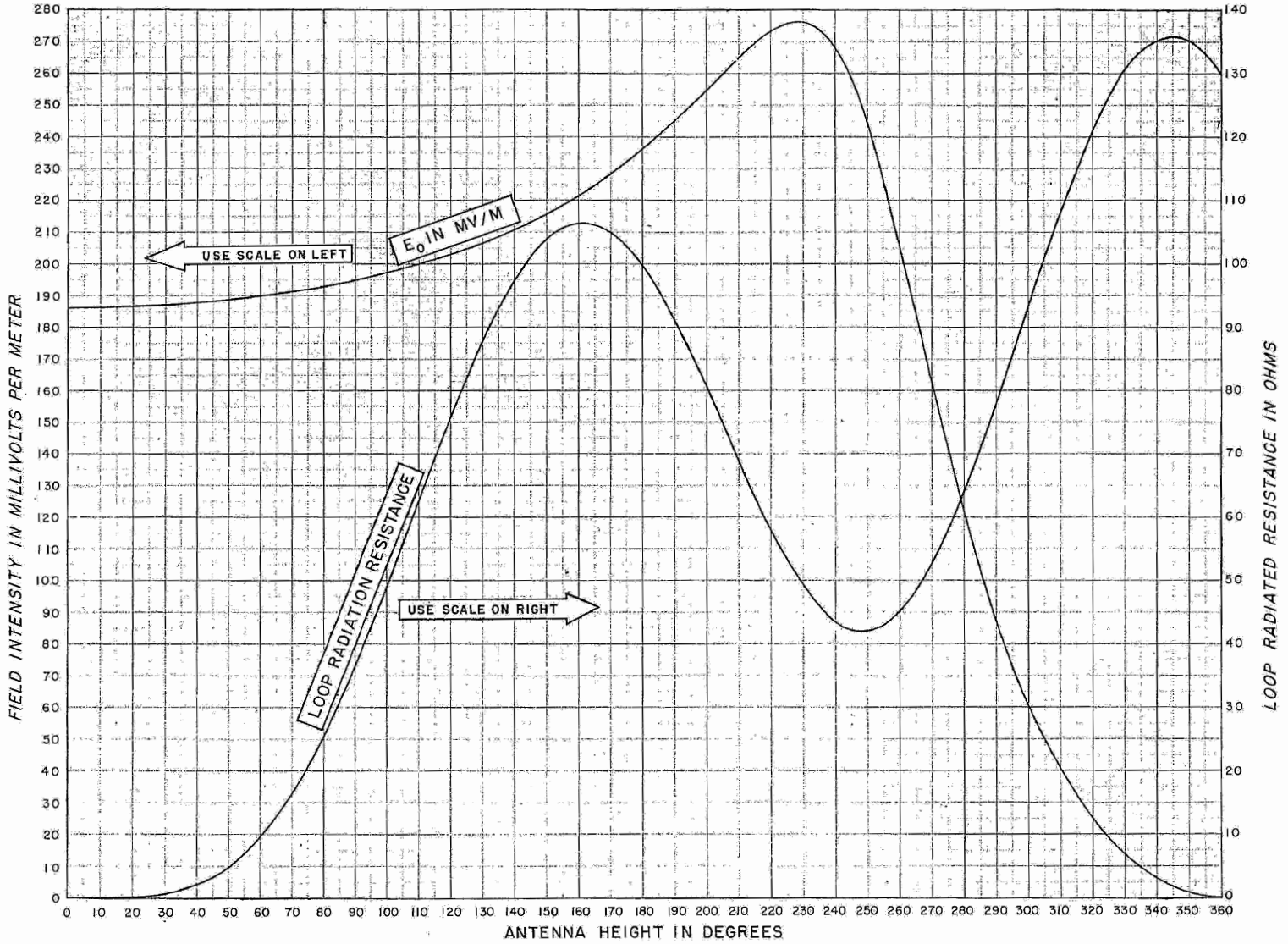
Many directional antenna arrays are designed with quarter wave elements because of the ease of making computations in design and adjustments during the proof of performance.

(7) 0.311λ Vertical Antenna Over a Perfectly Conducting Earth.--The Federal Communications Commission at the present time uses this height antenna (G = 111.96°) as their standard reference antenna. It at one time represented the average height of broadcast antennas in the United States. With sinusoidal current distribution the radiation pattern is given by



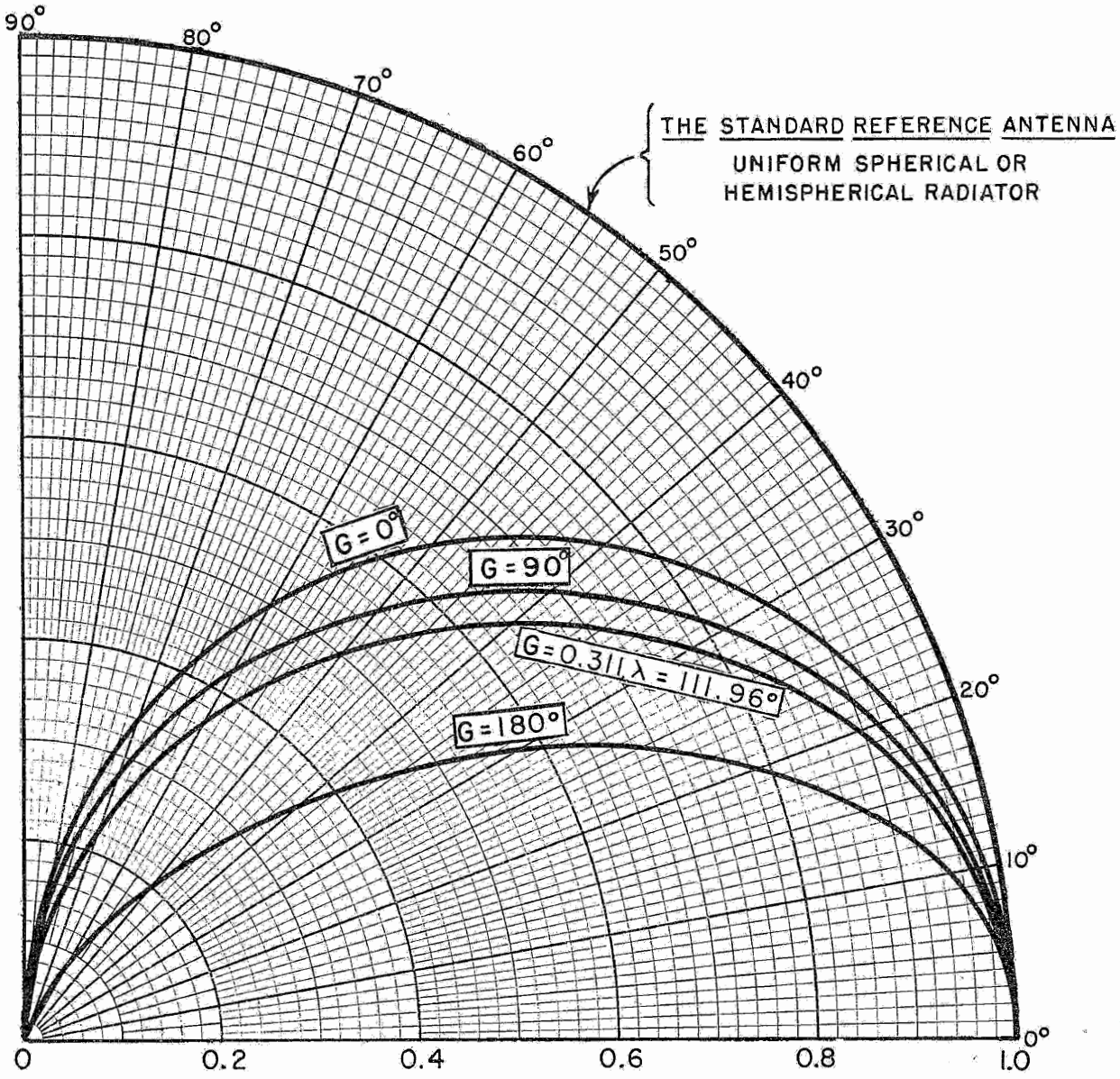
COMPARISON OF VERTICAL RADIATION PATTERN OF STANDARD REFERENCE ANTENNAS WITH A RADIATED POWER OF 1 KILOWATT

FIG. 7



UNATTENUATED FIELD INTENSITY AT ONE MILE FOR ONE KILOWATT
AND THE LOOP RADIATION RESISTANCE AS A FUNCTION OF ANTENNA HEIGHT
OVER A PERFECTLY CONDUCTING EARTH

FIG. 8



COMPARISON OF THE VERTICAL RADIATION CHARACTERISTICS FOR SEVERAL STANDARD REFERENCE ANTENNAS

FIG. 9

$$E = 200 \frac{\cos (G \sin \theta) - \cos G}{(1 - \cos G) \cos \theta} \qquad (8)$$

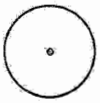
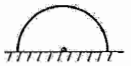
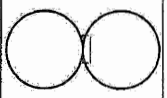
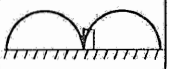
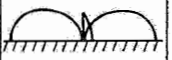
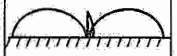
$$= 145.56 \frac{\cos (111.96 \sin \theta) + 0.3740}{\cos \theta}$$

where E and θ are defined in Eq. (3) and G = 111.96° the height of the antenna in electrical degrees.

(8) Half-Wave Vertical Antenna Over a Perfectly Conducting Earth.--For comparison purposes it is of interest to present the radiation pattern of a half-wave antenna. With sinusoidal current distribution the radiation pattern is given by

TABLE I

SUMMARY OF STANDARD REFERENCE ANTENNAS

TYPE OF ANTENNA	VERTICAL PATTERN SHAPE	MV/M FOR 1 WATT AT 1 MILE E_0	MV/M FOR 1 KW AT 1 MILE E_0	POWER GAIN g	db GAIN G	TYPE OF ANTENNA	VERTICAL PATTERN SHAPE	MV/M FOR 1 WATT AT 1 MILE E_0	MV/M FOR 1 KW AT 1 MILE E_0	POWER GAIN g	db GAIN G
UNIFORM SPHERICAL RADIATOR		3.402	107.6	1	0	UNIFORM HEMISPHERICAL RADIATOR		4.811	152.1	2	3.010
CURRENT ELEMENT		4.167	131.8	1.5	1.761	VERTICAL CURRENT ELEMENT		5.893	186.3	3	4.771
HALF WAVE ANTENNA		4.358	137.8	1.641	2.151	QUARTER WAVE VERTICAL ANTENNA		6.163	194.9	3.282	5.161
0.622 λ ANTENNA		4.472	141.4	1.728	2.375	0.311 λ VERTICAL ANTENNA		6.324	200	3.456	5.386
TWO END ON HALF WAVE IN PHASE ANTENNA		5.283	167.1	2.411	3.822	HALF WAVE VERTICAL ANTENNA		7.471	236.2	4.822	6.832

$$E = 236.5 \frac{\cos (G \sin\theta) - \cos G}{(1 - \cos G) \cos \theta} \qquad (9)$$

$$= 118.25 \frac{\cos (180 \sin \theta) + 1}{\cos \theta}$$

Where E and θ are defined in Eq. (3) and G = 180° the height of the antenna in electrical degrees.

(9) Comparison of the Vertical Radiation Patterns of Primary and Secondary Standard Reference Antennas.--Fig. 7 gives a comparison of the radiation patterns of primary and secondary standard reference antennas. The vertical patterns are expressed in millivolts per meter at one mile for one kilowatt of input power. The field intensity in millivolts per meter at one mile as a function of antenna height is given in Fig. 8.

b. *VERTICAL RADIATION CHARACTERISTICS*.--Already we have considered a number of vertical radiation patterns in Fig. 7. If these patterns are made equal to unity in the horizontal plane they are then known as vertical radiation characteristics. If this is done the curves of Fig. 9 result.

For a vertical antenna having a sinusoidal current distribution with a current node at the top, the vertical radiation characteristic takes on the form

$$f(\theta) = \frac{\cos (G \sin \theta) - \cos G}{(1 - \cos G) \cos \theta} \qquad (10)$$

where $f(\theta)$ = vertical radiation characteristic

G = electrical height of the antenna in electrical degrees

θ = elevation angle of the observation point measured up from the horizon in degrees.

The curves in Fig. 10 represent the solution of this equation over the most useful range of antenna heights. The vertical radiation characteristic is plotted as a function of elevation angle for various values of tower height. A representative set of tower heights have been selected for Fig. 10. Fig. 11 represents this same information in a different form; that is, the vertical radiation characteristic is plotted as a function of electrical tower height for various values of elevation angle. In order to prevent reversals of the lines as plotted in

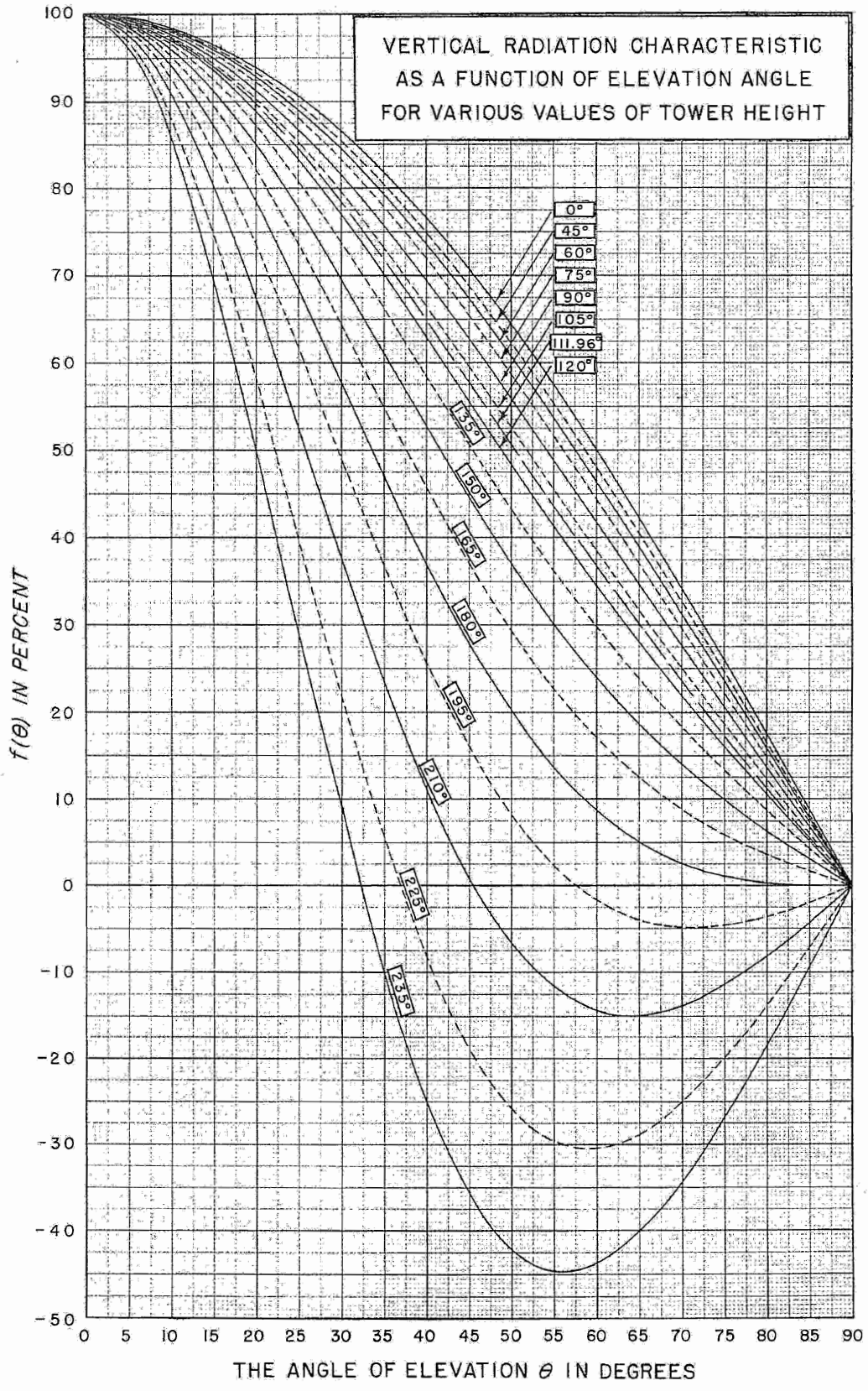

VERTICAL RADIATION CHARACTERISTIC
AS A FUNCTION OF ELEVATION ANGLE
FOR VARIOUS VALUES OF TOWER HEIGHT
0°
45°
60°
75°
90°
105°
111.96°
120°
135°
150°
165°
180°
195°
210°
225°
235°
f(θ) IN PERCENT
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
THE ANGLE OF ELEVATION θ IN DEGREES

FIG. 10

Fig. 11, the curves are extended to negative values in Fig. 10. This merely means that the high angle lobe is of opposite phase to the low angle radiation.

The vertical radiation characteristic will be used in the generalized equation for determining the shape of the directional antenna pattern. See Eq. (27). In the horizontal plane this function reduces to unity and simplifies the design equation.

c. *DIRECTIVITY DEFINITIONS.*--(1) On the Basis of Equal Powers.--*Directivity* or *directive gain* of a given antenna can be defined as the ratio of the maximum power flow intensity to the power flow intensity of a uniform radiator when the total power output of both sources are equal. In equation form,

$$g = \frac{P_m}{P_s} \quad \text{(equal powers)} \qquad (11)$$

where g = directivity or power gain

P_m = maximum power flow intensity from the directional antenna radiating 1 kw of power

P_s = uniform power flow intensity from the standard reference antenna radiating 1 kw of power.

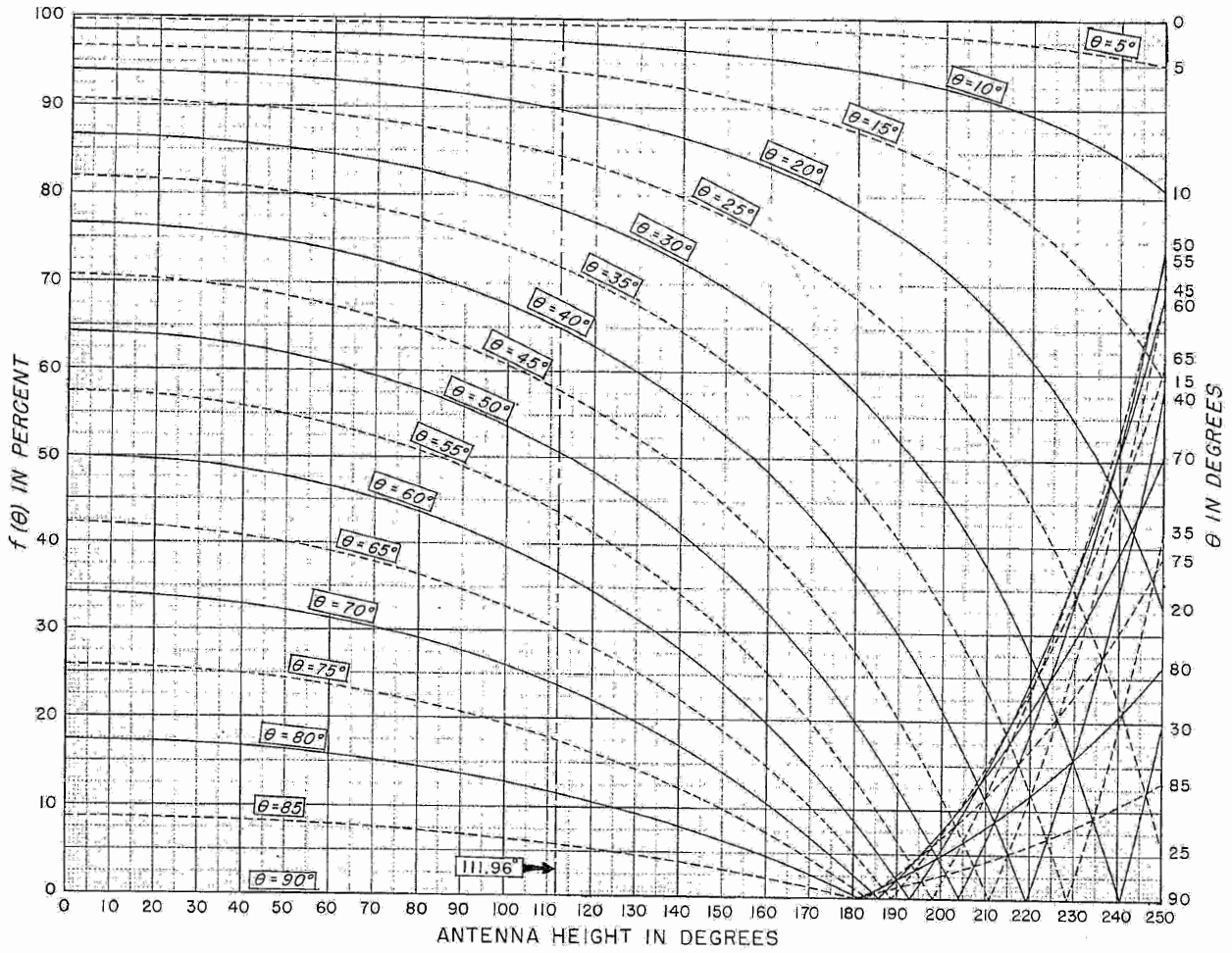
Or, in terms of field intensities power gain can be determined by the following equation,

$$g = \left[\frac{E_m}{E_s}\right]^2 \quad \text{(equal powers)} \qquad (12)$$

where g = directivity or power gain

E_m = maximum field intensity in mv/m from the directional antenna at 1 mile for 1 kw of radiated power

E_s = field intensity (107.6 mv/m) from a uniform spherical antenna at 1 mile for 1 kw of radiated power.



VERTICAL RADIATION CHARACTERISTIC AS A FUNCTION OF ELECTRICAL TOWER HEIGHT FOR VARIOUS VALUES OF ELEVATION ANGLE

FIG. 11

(2) On Basis of Equal Field Intensities.--The directivity can also be defined by taking the ratios of the power radiated when the maximum field intensity of the directional antenna is made equal to the field intensity from a uniform spherical antenna. In equation form,

$$g = \frac{P_s}{P_r} \quad \text{(equal field intensities)} \quad (13)$$

where g = directivity or power gain

P_s = power radiated (1 kw) from a uniform spherical antenna to produce a given field intensity of E_s (107.6 mv/m) at 1 mile

P_r = power radiated from the directional antenna to produce the same given maximum field intensity E_s (107.6 mv/m) at 1 mile.

To illustrate, let the field intensity of a uniform hemispherical antenna be adjusted to produce 107.6 mv/m unattenuated field intensity at 1 mile. The power radiated will be 500 watts, hence,

$$g = \frac{P_s}{P_r} = \frac{1.0 \text{ kw}}{0.5 \text{ kw}} = 2$$

the power gain of a uniform hemispherical antenna. In other words, twice the amount of power has to be supplied to the uniform spherical radiator to produce the same maximum field intensity at one mile. In the uniform spherical radiator, the additional 500 watts is used in the other hemisphere to make the radiation pattern spherical.

(3) On Basis of Decibels.--The directivity can also be computed in terms of decibels by the equation,

$$\text{decibels gain} = 10 \log g \quad (14)$$

where g = directivity or power gain.

d. *SELF BASE IMPEDANCE CHARACTERISTICS.*--The loop radiation resistance as given in Fig. 8 is not very useful because it is for a very thin conductor and the antenna is not driven at the loop point very often. Its primary application is in theoretical calculations. Since most antennas have a reasonable cross-sectional area and are driven at the base, the self base impedance equation along with the self base resistance and reactance curves will be presented. The values of self base resistance and reactance are needed in the solution of the mesh-equations of a directional antenna system.

The self resonance frequency of a tower depends upon its vertical shape as well as its cross-sectional size.[1] The first factor to be considered is the average characteristic impedance Z_o which represents the average cross-sectional size. For a cylindrical antenna

$$Z_o = 60 \left(\ln \frac{2G}{a} - 1 \right) \quad (15)$$

where Z_o = average characteristics impedance, ohms
ln = base of natural logarithms
G = antenna height, degrees or same units as a
a = antenna radius, degrees or same units as G.

EXAMPLE 1: Determine the average characteristic impedance of a 400 foot uniform cross-sectional tower that is 6.5 feet square. Use 4 feet as the equivalent radius.

SOLUTION: Substituting in Eq. (15)

$$Z_o = 60 \left(\ln \frac{2\,(400)}{4} - 1 \right)$$
$$= 60 \left(\ln 200 - 1 \right)$$
$$= 60 \, (2.303 \times 2.301 - 1)$$
$$= 60 \, (5.3 - 1) = 258 \text{ ohms} \quad \text{ANS.}$$

The second factor to be considered is the vertical shape. If the antenna is nonuniform, the first approximation is to regard it as uniform. With this assumption the error will be small for short antennas, and will become prohibitively large for really tall antennas. In practice, broadcasting antennas are not very tall in terms of wavelengths and we can treat them as transmission lines with slightly variable characteristic impedance.

Applying the theory of nonuniform transmission lines the self base impedance can be expressed by the following first order approximation,[1]

$$Z_b = Z_o \frac{H \sin G + j\,(F-N) \sin G - j\,(2Z_o - M)\cos G}{(2\,Z_o + M) \sin G + (F+N) \cos G - j\,H \cos G} \quad (16)$$

where

$Z_b = R_b + jX_b$ self base impedance, ohms
R_b = self base resistance, ohms
X_b = self base reactance, ohms
Z_o = average characteristic impedance, ohms
G = antenna height in degrees or radians
γ = 0.5772 ... Euler's constant
Si = sine integral function
Ci = cosine integral function

$$F = 60 \text{ Si } 2G + 30 \, (\text{Ci } 4G - \ln G - \gamma) \sin 2G - 30 \text{ Si } 4G \cos 2G \quad (17)$$

$$H = 60(\gamma + \ln 2G - \text{Ci } 2G) + 30 \, (\gamma + \ln G - 2 \text{ Ci} 2G + \text{Ci } 4G) \cos 2G + 30 \, (\text{Si } 4G - 2 \text{ Si } 2G) \sin 2G \quad (18)$$

$$M = 60 \, (\ln 2G - \text{Ci } 2G + \gamma - 1 + \cos 2G) \quad (19)$$

$$N = 60 \, (\text{Si } 2G - \sin 2G) \quad (20)$$

---

[1] S. A. Schelkunoff, "Theory of Antennas of Arbitrary Size and Shape", Proc. I.R.E., Vol. 29, pp. 493-521; September, 1941.

If Eq. (16), for a cylindrical vertical antenna, is solved for the base resistance and reactance the family of curves in Fig. 12 and 13 will result for the different values of average characteristic impedance indicated. If the self base impedance is needed for other antenna dimensions the solution can be obtained from Eq. (16).

EXAMPLE 2: Determine the self base input resistance and reactance of a 400 foot uniform cross-section tower that is 6.5 feet square. Use 4 feet as the equivalent radius. The operating frequency is 950 kc.

SOLUTION:

From Example 1, $Z_o = 258$ ohms.

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{950 \times 10^3} = 315.8 \text{ meters}$$

$$= 315.8 \times 3.281 = 1038 \text{ feet per wavelength}$$

$$G = \frac{400}{1038}\ 360^\circ = 139^\circ = \frac{139}{57.3} = 2.43 \text{ radians}$$

In Eq. (17)

$$F = 60\ Si\ 4.86 + 30\ (Ci\ 9.72 - \ln 2.43 - 0.5772)\sin 278^\circ - 30\ Si\ 9.72 \cos 278^\circ = 132$$

In Eq. (18)

$$H = 60(0.5772 + \ln 4.86 - Ci\ 4.86) + 30(0.5772 + \ln 2.43 - 2Ci\ 2.43 + Ci\ 4.86) \cos 278^\circ + 30(Si\ 9.72 - 2Si\ 4.86) \sin 278^\circ = 194$$

In Eq. (19)

$$M = 60(\ln 4.86 - Ci\ 4.86 + 0.5772 - 1 + \cos 278^\circ) = 89.7$$

In Eq. (20)

$$N = 60(Si\ 4.86 - \sin 278^\circ) = 154$$

Now substituting in Eq. (16)

$$Z_b = 258\ \frac{(194)(0.656) + j(132-154)(0.656) - j(516-89.7)(-0.755)}{(516+89.7)(0.656) + (132+154)(-0.755) - j(194)(-0.755)}$$

$$= 258\ \frac{127 + j308}{181 + j146} = 258\ \frac{333\,\underline{|67.5^\circ}}{233\,\underline{|38.8^\circ}} = 369\,\underline{|28.7^\circ} = 324 + j176 \qquad \text{ANS.}$$

Thus, $R_b = 324$ ohms and $X_b = 176$ ohms inductive reactance. These values can be checked on the appropriate curve of Fig. 12 and 13 respectively.

e. *MUTUAL BASE IMPEDANCE AND PHASE ANGLE CHARACTERISTICS.*--The mutual impedance between vertical antennas is needed by the designer of directional antenna feeder systems. Since, vertical antennas are usually base driven and the antennas may vary in height in the same array it is desirable to have enough mutual impedance information to handle the majority of practical cases. It is therefore desirable to have the mutual base impedance between antennas of unequal as well as equal height for all practical spacings. Sufficient design equations have been developed and presented in the literature[2,3] to solve this problem, however, only a few cases of equal and unequal height antennas for spacings up to 600 degrees has been solved.

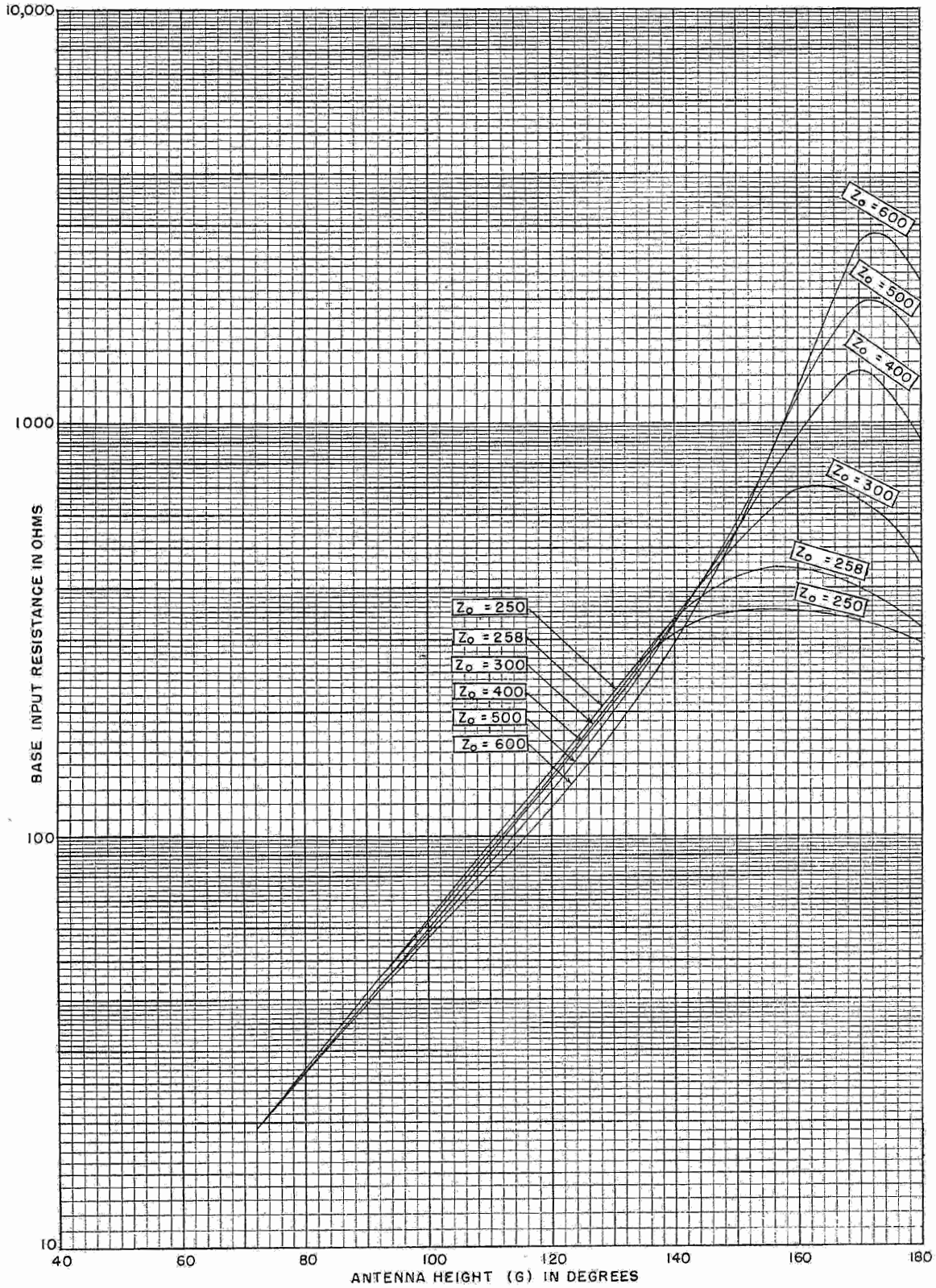
The following mutual impedance curves are presented in Appendix A:

1. Base mutual impedance curves by Chambers and Garrison.
2. Family of loop mutual impedance curves for towers of equal height by D. B. Hutton and R. H. Garrett.
3. Loop mutual impedance curves for $G_1 = G_2 = 90$ and $G_1 = G_2 = 180$ by J. F. Morrison.
4. Loop mutual impedance curves for $G_1 = 90$, $G_2 = 180$ by W. G. Hutton.

The general design equation for the mutual base resistance and reactance is given by,

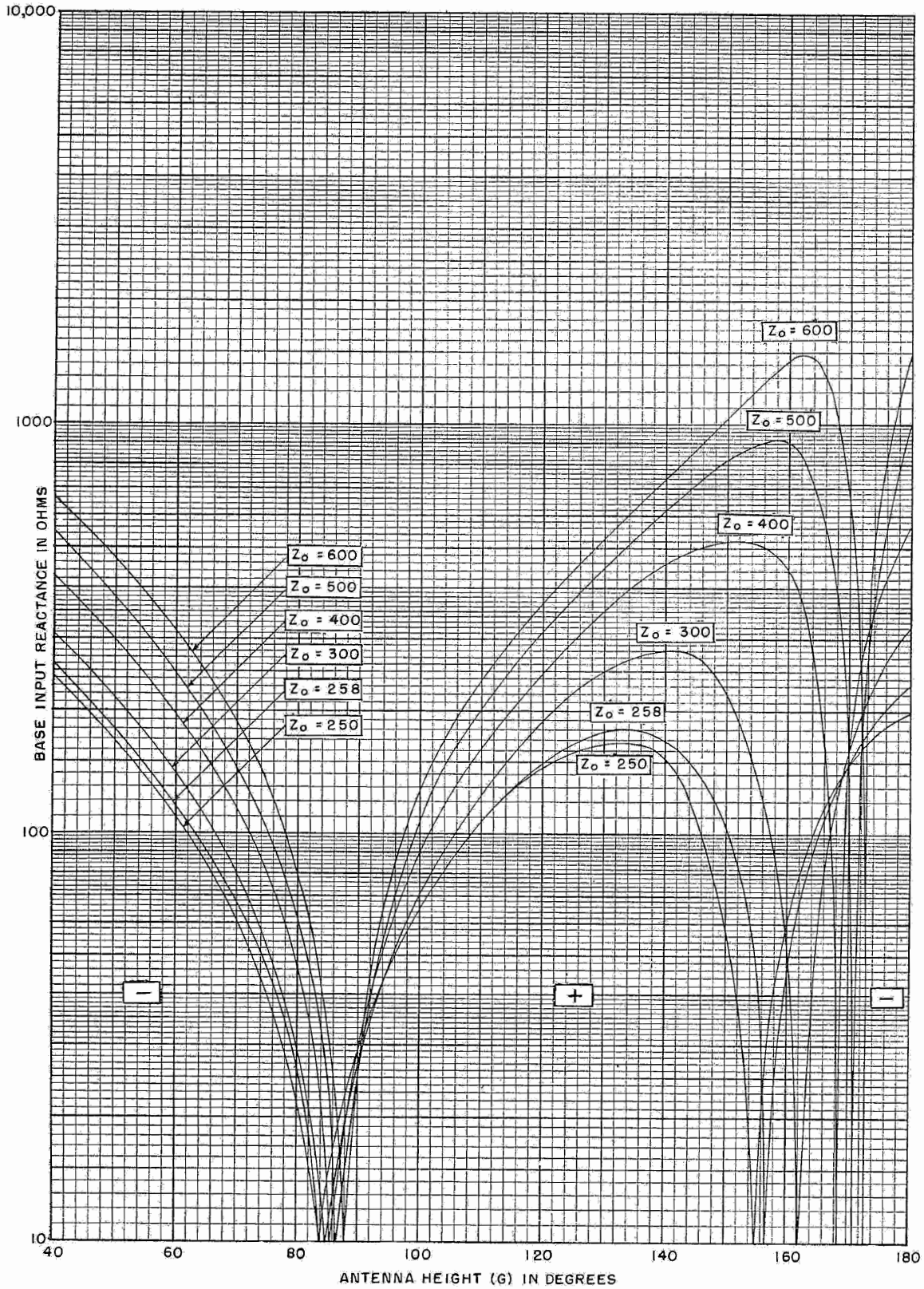
[2] G. H. Brown, "Directional Antennas," Proc. I.R.E., Vol. 25, pp. 81-145; January, 1937.

[3] C. Russell Cox, "Mutual Impedance between Vertical Antennas of Unequal Heights," Proc. I.R.E., Vol. 35, pp. 1367-1370; November, 1947.



BASE INPUT RESISTANCE OF CYLINDRICAL ANTENNAS
OVER A PERFECTLY CONDUCTING GROUND PLANE

FIG. 12



BASE INPUT REACTANCE OF CYLINDRICAL ANTENNAS
OVER A PERFECTLY CONDUCTING GROUND PLANE

FIG. 13

$$R_{12} = \frac{15}{\sin G_1 \sin G_2}\Big\{\cos(G_2 - G_1)\big[Ci\,u_1 - Ci\,u_o + Ci\,v_1 - Ci\,v_o + 2\,Ci\,y_o - Ci\,y_1 - Ci\,s_1\big] + \sin(G_2 - G_1)\big[Si\,u_1 - Si\,u_o + Si\,v_o - Si\,v_1 - Si\,y_1 + Si\,s_1\big] + \cos(G_2 + G_1)\big[Ci\,w_1 - Ci\,v_o + Ci\,x_1 - Ci\,u_o + 2\,Ci\,y_o - Ci\,y_1 - Ci\,s_1\big] + \sin(G_2 + G_1)\big[Si\,w_1 - Si\,v_o + Si\,u_o - Si\,x_1 - Si\,y_1 + Si\,s_1\big]\Big\} \quad (21)$$

$$X_{12} = \frac{15}{\sin G_1 \sin G_2}\Big\{\cos(G_2 - G_1)\big[Si\,u_o - Si\,u_1 + Si\,v_o - Si\,v_1 + Si\,y_1 - 2\,Si\,y_o + Si\,s_1\big] + \sin(G_2 - G_1)\big[Ci\,u_1 - Ci\,u_o + Ci\,v_o - Ci\,v_1 - Ci\,y_1 + Ci\,s_1\big] + \cos(G_2 + G_1)\big[Si\,v_o - Si\,w_1 + Si\,u_o - Si\,x_1 + Si\,y_1 - 2\,Si\,y_o + Si\,s_1\big] + \sin(G_2 + G_1)\big[Ci\,w_1 - Ci\,v_o + Ci\,u_o - Ci\,x_1 - Ci\,y_1 + Ci\,s_1\big]\Big\} \quad (22)$$

where

R_{12} = mutual base resistance between antennas No. 1 and No. 2, ohms

X_{12} = mutual base reactance between antennas No. 1 and No. 2, ohms

G_1 = height of No. 1 antenna, degrees

G_2 = height of No. 2 antenna, degrees

Si = sine integral function

Ci = cosine integral function

S = spacing between antennas, degrees

$u_o = \sqrt{S^2 + G_1^2} - G_1$, degrees

$u_1 = \sqrt{S^2 + (G_2 - G_1)^2} + G_2 - G_1$, degrees

$v_o = \sqrt{S^2 + G_1^2} + G_1$, degrees

$v_1 = \sqrt{S^2 + (G_2 - G_1)^2} - G_2 + G_1$, degrees

$w_o = v_o$, degrees

$w_1 = \sqrt{S^2 + (G_2 + G_1)^2} + G_2 + G_1$, degrees

$x_o = u_o$, degrees

$x_1 = \sqrt{S^2 + (G_2 + G_1)^2} - G_2 - G_1$, degrees

$y_o = S$, degrees

$y_1 = \sqrt{S^2 + G_2^2} + G_2$, degrees

$s_o = y_o = S$, degrees

$s_1 = \sqrt{S^2 + G_2^2} - G_2$, degrees.

If the mutual base impedance information needed does not appear in Appendix A then the desired solution can be obtained by solving Eq. (21) and (22).

If the antennas are of equal height ($G = G_1 = G_2$) Eq. (21) and (22) reduce to,

$$R_{12} = \frac{15}{\sin^2 G}\Big\{4\,Ci\,u_1 - 2\,Ci\,u_o - 2\,Ci\,v_o + \cos 2G\big[Ci\,w_1 - 2\,Ci\,v_o + Ci\,x_1 - 2\,Ci\,u_o + 2\,Ci\,u_1\big] + \sin 2G\big[Si\,w_1 - 2\,Si\,v_o - Si\,x_1 + 2\,Si\,u_o\big]\Big\} \quad (23)$$

$$X_{12} = \frac{15}{\sin^2 G}\Big\{-4\,Si\,u_1 + 2\,Si\,u_o + 2\,Si\,v_o + \cos 2G\big[-Si\,w_1 + 2\,Si\,v_o - Si\,x_1 + 2\,Si\,u_o - 2\,Si\,u_1\big] + \sin 2G\big[Ci\,w_1 - 2\,Ci\,v_o - Ci\,x_1 + 2\,Ci\,u_o\big]\Big\} \quad (24)$$

Now, if antenna No. 2 is 90° in height ($G_2 = 90°$) then Eq. (21) and (22) reduce to,

$$R_{12} = 15\Big\{Ci\,u_1 + Ci\,v_1 - Ci\,w_1 - Ci\,x_1 + \cot G_1\big[Si\,u_1 - Si\,v_1 - 2\,Si\,y_1 + 2\,Si\,s_1 + Si\,w_1 - Si\,x_1\big]\Big\} \quad (25)$$

$$X_{12} = 15\Big\{Si\,w_1 + Si\,x_1 - Si\,u_1 - Si\,v_1 + \cot G_1\big[Ci\,u_1 - Ci\,v_1 - 2\,Ci\,y_1 + 2\,Ci\,s_1 + Ci\,w_1 - Ci\,x_1\big]\Big\} \quad (26)$$

EXAMPLE 3: Determine the mutual base impedance between two antennas spaced at 160° with electrical heights of 120° and 90° respectively.

SOLUTION:

$G_1 = 120°$, $G_2 = 90°$ and $S = 160°$

$u_1 = \sqrt{(160)^2 + (30)^2} + 90 - 120 = 132.8°$ or 2.32 radians

$v_1 = \sqrt{(160)^2 + (30)^2} - 90 + 120 = 192.8°$ or 3.366 radians

$w_1 = \sqrt{(160)^2 + (90 + 120)^2} + 90 + 120 = 474°$ or 8.27 radians

$x_1 = \sqrt{(160)^2 + (90 + 120)^2} - 90 - 120 = 54°$ or 0.943 radians

$y_1 = \sqrt{(160)^2 + (90)^2} + 90 = 273.6°$ or 4.77 radians

$s_1 = \sqrt{(160)^2 + (90)^2} - 90 = 93.6°$ or 1.63 radians

Substituting in Eq. (25) and (26)

$$R_{12} = 15 \{ Ci\ 2.32 + Ci\ 3.366 - Ci\ 8.27 - Ci\ 0.943 + \cot 120 [Si\ 2.32 - Si\ 3.366 - 2\ Si\ 4.77 + 2\ Si\ 1.63 + Si\ 8.27 - Si\ 0.943] \}$$

$$= -2.935 \text{ ohms}$$

$$X_{12} = 15 \{ Si\ 8.27 + Si\ 0.943 - Si\ 2.32 - Si\ 3.366 + \cot 120 [Ci\ 2.32 - Ci\ 3.366 - 2\ Ci\ 4.77 + 2\ Ci\ 1.63 + 8.27 - Ci\ 0.943] \}$$

$$= -28.85 \text{ ohms}$$

Therefore the mutual base impedance is

$$Z_{12} = -2.935 - j\ 28.85 \text{ ohms} \quad \underline{\text{ANS.}}$$

EXAMPLE 4: Determine the mutual base impedance between two towers of equal height $G = 110°$ and having a spacing of $200°$.

SOLUTION: Since the tables of the Sine Integral and Cosine Integral functions are ordinarily tabulated with the arguments in radians, it has been found simpler to convert G and S to radians before substituting in the formulas.

$G_1 = G_2 = 110° = 1.9199$ radians.

$S = 200° = 3.4907$ radians.

Then

$u_o = \sqrt{3.4907^2 + 1.9199^2} - 1.9199 = 2.0639$

$u_1 = S = 3.4907$

$v_o = \sqrt{3.4907^2 + 1.9199^2} + 1.9199 = 5.9037$

$w_1 = \sqrt{3.4907^2 + (2 \times 1.9199)^2} + (2 \times 1.9199) = 9.0290$

$x_1 = \sqrt{3.4907^2 + (2 \times 1.9199)^2} - (2 \times 1.9199) = 1.3496$

$\sin^2 G = 0.9397^2 = 0.8830$

Substituting in Eq. (23) yields

$$R_{12} = \frac{15}{0.8830} \{ 4\ Ci\ (3.4907) - 2\ Ci\ (2.0639) - 2\ Ci\ (5.9037) + \cos 220° [Ci\ (9.0290) - 2\ Ci\ (5.9037) + Ci\ (1.3496) - 2\ Ci\ (2.0639) + 2\ Ci\ (3.4907)] + \sin 220° [Si\ (9.0290) - 2\ Si\ (5.9037) - Si\ (1.3496) + 2\ Si\ (2.0639)] \}$$

$$= 16.9875 \{ -0.1188 - 0.8180 + 0.1666 - 0.7660 [0.0524 + 0.1666 + 0.4549 - 0.8180 - 0.0594] - 0.6428 [1.6663 - 2.8598 - 1.2203 + 3.2672] \}$$

$$= 16.9875 \{ -0.7702 - 0.7660\ (-0.2035) - 0.6428\ (0.8534) \}$$

$$= 16.9875 \{ -0.7702 + 0.1559 - 0.5486 \}$$

$$= 16.9875\ (-1.1629) = -19.75 \text{ ohms}$$

For the reactance component of the mutual, substituting in Eq. (24) yields

$$X_{12} = 16.9875 \{ -4\ Si\ (3.4907) + 2\ Si\ (2.0639) + 2\ Si\ (5.9037) + \cos 220° [-Si\ (9.0290) + 2\ Si\ (5.9037) - Si\ (1.3496) + 2\ Si\ (2.0639) - 2\ Si\ (3.4907)] + \sin 220° [Ci\ (9.0290) - 2\ Ci\ (5.9037) - Ci\ (1.3496) + 2\ Ci\ (2.0639)] \}$$

$$= 16.9875 \{ -7.3360 + 3.2672 + 2.8598$$

$$- 0.7660 \left[-1.6663 + 2.8598 - 1.2203 + 3.2672 - 3.6680\right] - 0.6428 \left[0.0524 + 0.1666 - 0.4549 + 0.8180\right] \Big\}$$

$$= -21.33 \text{ ohms}$$

and $Z_{12} = 29.1 \angle -132.8°$ ohms. ANS.

The loop values of mutual impedance are readily obtained from the above base impedance equations if the sine terms in the denominator of the leading coefficient is omitted. Since in Eq. (25) and (26) sin G_1 does not appear in the denominator the answer can be multiplied by sin G_1 to convert from base to loop impedance.

It should be pointed out that when any of the towers are over about 120° in height, and particularly in the case of self supporting towers, the values of the base mutual impedance given by these equations are considerably in error and therefore should not be relied upon. In such cases the use of loop values of mutual and self impedance will give a better indication of the power division in the directional antenna array.

It is of cardinal importance not to mix measured and theoretical values. If reliable measured values are available they should be used, however do not use measured base self-impedance and theoretical base mutual-impedances to determine driving point base impedance and power division in the directional antenna array. It is usually feasible to measure the self-impedance of each tower with the other towers disabled and then measure the magnitude of the mutual impedance between each pair of towers. Since the mutual impedance phase angles are more difficult to measure it is quite common practice to use the theoretical phase angle since they are usually more reliable than the measured values.

3. CONTROL OF PATTERN SHAPE

a. *INTRODUCTION.*--There are two basic problems in a directional antenna design. First, it is desirable to control the pattern shape by proper selection of pattern parameters and second the size of the pattern for a given amount of power is very useful in many applications. This section will be devoted to the first problem of moulding the pattern shape. The second problem of determining the size or gain of the directional antenna will be treated in Section 4.

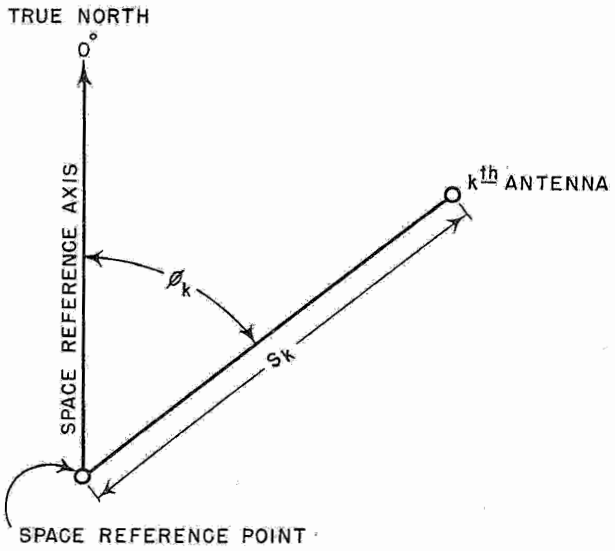
The field intensity at any given point in space is a function of the placement of the current elements along with magnitude and phase of the field intensity produced by each current element. In other words we must know the *space configuration* of the radiating elements and the *individual vectors* of the field intensities produced by these radiating elements. This information can be expressed in equation form as a vector equation or only as the magnitude of the resultant field intensity which is commonly called the pattern formula.

It is common practice to treat each tower as a radiating element over a perfectly conducting earth and select the observation point, P, far enough away from the radiating system to assume that lines joining the radiating elements and the observation point are parallel. This simplifies the mathematics and does not introduce appreciable error except when it is desired to deal with the nearby radiation field. For this case the more general equations must be employed.

b. *SPACE CONFIGURATION.*--In order to establish a system for specifying the location of each tower in such a manner that the information can be used in the design equations let us refer to Fig. 14 which gives the plan view of the space configuration of the k^{th} tower. The primary purpose of this figure is to clearly specify the position of the k^{th} tower on the ground plane. This specification contains the following:

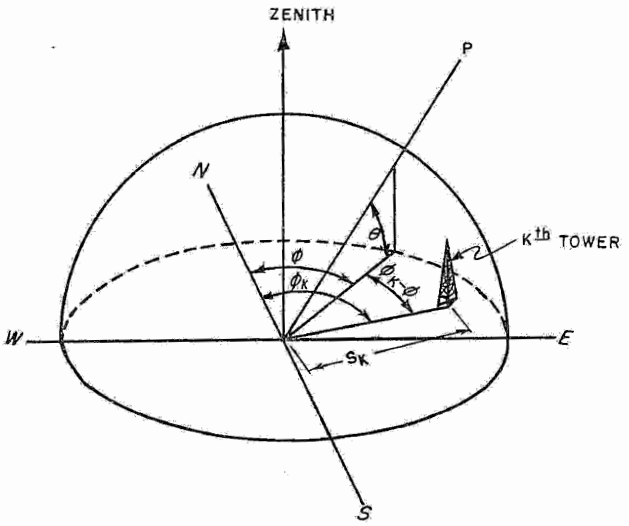
(1) Space reference point, which is the space origin or point from which all distances are measured.

(2) Space reference axis, which is a line passing through the space reference point and has a true north-south orientation. It is the reference line from which all azimuth angles are measured.



PLAN VIEW OF SPACE CONFIGURATION OF k^{th} ANTENNA

FIG. 14



SPACE VIEW OF OBSERVATION POINT P AND THE k^{th} TOWER

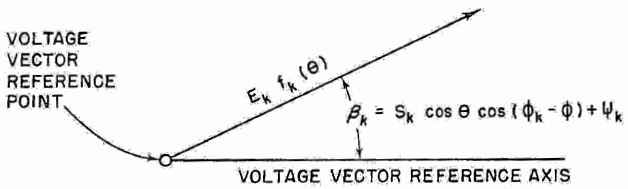
FIG. 15

(3) True azimuth of k^{th} antenna, ϕ_k, as shown in Fig. 14 is measured clockwise in degrees from the space reference axis.

(4) Spacing of k^{th} antenna, S_k, from the space reference point, is measured in electrical degrees along the horizontal plane as shown in Fig. 14.

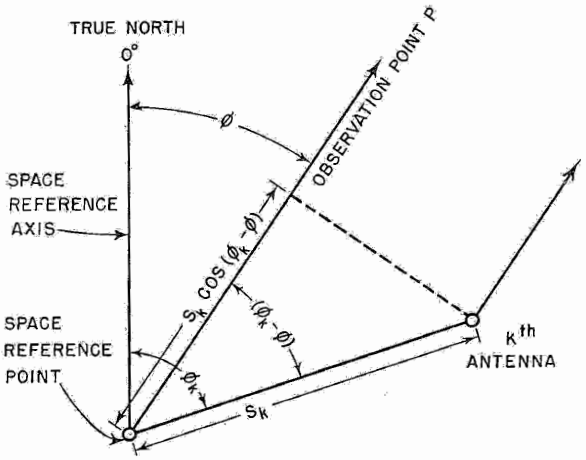
c. *VECTOR DIAGRAM.*--The field intensity at the point P in space can be expressed as the sum of the voltage vectors in the vector diagram. These vectors depend upon the space configuration, the height of the towers and the vector field intensity radiated from each tower.

For the space configuration of the k^{th} antenna as presented in Fig. 14 and 15 we have the voltage vector at the point P as shown in Fig. 16. The magnitude of this vector is simply E_k in the horizontal plane because the vertical radiation characteristic $f_k(\theta) = 1$ when $\theta = 0$. For a



VOLTAGE VECTOR DIAGRAM FOR THE k^{th} ANTENNA

FIG. 16



PLAN VIEW OF k^{th} ANTENNA SHOWING SPACE PHASING IN THE HORIZONTAL PLANE

FIG. 17

tower with sinusoidal current distribution the vertical radiation characteristic is given by Eq. (10).

The vector for the k^{th} tower makes an angle β_k with respect to the voltage vector reference axis which is along the positive x-axis according to the usual mathematical convention. The angle β_k is a function of space phasing and time phasing. The space phasing is represented by

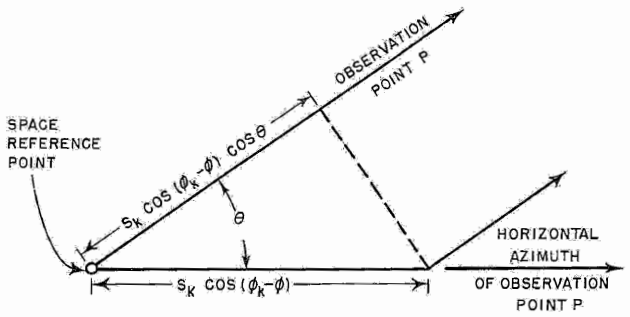
$$S_k \cos\theta \cos(\phi_k - \phi)$$

while the time phase is simply ψ_k.

For illustration, if the tower is placed at the space reference point as shown in Fig. 14 the spacing S_k becomes zero hence the space phasing also is zero. In this case only the time phase ψ_k is involved. For this case the voltage vector in Fig. 16 would make an angle ψ_k with respect to the voltage reference axis. This angle remains constant for all positions of point P.

In many directional antennas one tower is placed at the space reference point and all voltage vectors are referred to this tower. For this elementary case the voltage vector will lie along the voltage vector reference axis as shown in Fig. 16. The other voltage vectors are then referred to this vector which is in the same position as the voltage vector reference axis.

In the space phasing portion of β_k the term $\cos\theta$ reduces to unity in the horizontal plane. In this plane the space phasing is simply the difference in distance from the observation point P to the k^{th} antenna and the space reference point as shown in Fig. 17.



ELEVATION ANGLE θ SHORTENS THE SPACING S_k TO THE VALUE $S_k \cos\theta$

FIG. 18

Dropping a perpendicular from the k^{th} antenna to the straight line connecting the observation point P and the space reference point creates a right triangle the side of which is $S_k \cos(\phi_k - \phi)$. This space phasing quantity is the required difference distance since the observation point P is assumed to be at a great distance and it holds true for any direction in the horizontal plane.

When the observation point is at some elevation angle θ the k^{th} antenna will appear to be closer to the space reference point by the multiplying factor $\cos\theta$. Referring to Fig. 18, it is seen that a right triangle can be formed by dropping a perpendicular to the line connecting the space reference point and the observation point P.

The k^{th} antenna then appears to have space phasing of $S_k \cos\theta \cos(\phi_k - \phi)$ from the space reference point. This is the complete expression for the space phasing of any antenna in the system and for any observation point P in the hemisphere.

Now, if the field intensity vectors of all the towers are added in series the resultant field intensity at the observation point P can be obtained. Such a vector diagram is illustrated in Fig. 19.

d. *GENERALIZED EQUATION.*--The vector equation to express the vectors of Fig. 19 is the generalized equation that can be used to express the pattern shape for a directional antenna array with n towers. The equation in condensed form is,

$$E = \sum_{k=1}^{k=n} E_k f_k(\theta) \angle \beta_k \qquad (27)$$

where:

E = the total effective field intensity vector at unit distance (P) for the antenna array with respect to the voltage vector reference axis. This vector makes the angle β with respect to this axis as shown in Fig. 19.

k = the k^{th} tower in the directional antenna system.

n = the total number of towers in the directional antenna array.

E_k = the magnitude of the field intensity at unit distance in the horizontal plane produced by the k^{th} tower acting alone.

$f_k(\theta)$ = vertical radiation characteristic of the k^{th} antenna as given in Eq. (10).

θ = elevation angle of the observation point P measured up from the horizon in degrees.

$$\beta_k = S_k \cos\theta \cos(\phi_k - \phi) + \Psi_k \qquad (28)$$

= phase relation of the field intensity at the observation point P for the k^{th} tower taken with respect to the voltage vector reference axis $S_k \cos(\phi_k - \phi) \cos\theta$ = space phasing portion of β_k due to the location of the k^{th} tower.

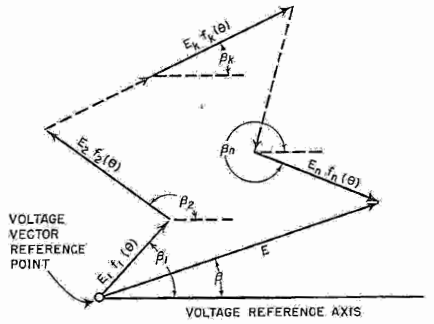
S_k = electrical length of spacing of the k^{th} tower in the horizontal plane from the space reference point.

ϕ_k = true horizontal azimuth, orientation of k^{th} tower with respect to the space reference axis.

ϕ = true horizontal azimuth angle of the direction to the observation point P (measured clockwise from true north).

Ψ_k = time phasing portion of β_k due to the electrical phase angle of the voltage (or current) in the k^{th} tower taken with respect to the voltage vector reference axis.

The shape of any directional antenna pattern can be computed by applying the above equations, however, many directional antenna arrays can be designed by simplified versions of this equation. The treatment that is to follow will show how to apply some simplified versions of the above equations.



SUMMATION OF FIELD INTENSITY VECTORS FOR n ANTENNAS IN THE DIRECTIONAL ANTENNA ARRAY

FIG. 19

EXAMPLE 5: The following parameters are furnished. Write the design equation.

PATTERN PARAMETERS

Tower No.	Electrical Height G°	True Tower Orientation ϕ°	Spacing S°	Phasing Ψ°	Horizontal field $E_{mv/m}$
1	45	78.68	185.70	133.3	154.5
2	45	108.97	195.54	226.7	163.8
3	90	178.38	50.00	226.7	327.5
4	90	257.99	178.08	226.7	163.8
5	138	289.58	187.79	133.3	154.5
6	52	358.38	50.00	133.3	309.0

SOLUTION: From Eq. (10), (27) and (28) the design equation is,

$$E = 154.5 \frac{\cos(45 \sin\theta) - \cos 45}{(1 - \cos 45)\cos\theta} \Big| 185.70 \cos\theta \cos(78.68 - \phi) + 133.3$$

$$+ 163.8 \frac{\cos(45 \sin\theta) - \cos 45}{(1 - \cos 45)\cos\theta} \Big| 195.54 \cos\theta \cos(108.97 - \phi) + 266.7$$

$$+ 327.5 \frac{\cos(90 \sin\theta) - \cos 90}{(1 - \cos 90)\cos\theta} \Big| 50.00 \cos\theta \cos(178.38 - \phi) + 266.7$$

$$+ 163.8 \frac{\cos(90 \sin\theta) - \cos 90}{(1 - \cos 90)\cos\theta} \Big| 178.08 \cos\theta \cos(257.99 - \phi) + 266.7$$

$$+ 154.5 \frac{\cos(138 \sin\theta) - \cos 138}{(1 - \cos 138)\cos\theta} \Big| 187.79 \cos\theta \cos(289.58 - \phi) + 133.3$$

$$+ 309.0 \frac{\cos(52 \sin\theta) - \cos 52}{(1 - \cos 52)\cos\theta} \Big| 50 \cos\theta \cos(358.38 - \phi) + 133.3 \quad \text{ANS.}$$

e. *DIRECTIONAL ANTENNA PARAMETERS.*--The symbols needed to describe a directional antenna array must include antenna height, true orientation, tower spacing, electric current or electric field phasing, electric field intensity at unit distance and elevation angle. For convenience it is desirable to add a symbol to express the vertical radiation characteristic and the ratio of field intensities.

The symbols chosen are those most widely used, with a few exceptions. The exceptions are necessary in order to make the system consistent in itself and not cause undue conflict with other usages of the terms. The choice of terms and their use was also influenced to a great extent by the present practice of FCC. For example, the true azimuth angle is expressed by ϕ and is measured clockwise from true north. This practice differs from mathematics where angles are measured counterclockwise from the positive x-axis. It also differs from electrical engineering where the symbol ϕ is used to measure phase angle. In another case θ is used to express elevation angle instead of zenith angle as is the usual case in mathematical treatments involving space geometry. On the other hand some consultants in the past have chosen to express the vertical angle or elevation angle by the symbol V.

Another difference of opinion revolved about the symbol to use for electrical height. The letter h or H is descriptive but the letter G was selected because of its rather general usage. Since the symbol ϕ was used for azimuth the symbol Ψ was selected to express phase angle.

Considerable discussion has revolved around the selection of a term to express field intensity ratio. The term r for ratio had been used but caused confusion because of its common use to express resistance. The term M had been used to express current ratio, but since this is often different from the field ratio, it was decided to retain M to express current ratio. The term F is selected to express field ratio, hence it can no longer be used to express field intensity interchangeably with the term E.

f. *HORIZONTAL PATTERN SHEET.*--To illustrate the use of the foregoing nomenclature a directional antenna array has been quite completely specified in Fig. 20 using the parameters of Example 5.

In preparing the pattern data, the following factors were considered:

Horizontal plane pattern plot with asimuth angles measured clockwise from true north.

Direction and distance to each protected station, with the azimuth sector indicated if an area is to be protected.

Pattern plotted to the largest scale possible on polar coordinate paper having 10 or 15 major radial divisions, using divisions and subdivisions having values of 1, 2, 5 or 10^x.

Minimum values, where possible, plotted on a 10 x expanded scale.

MEOV (maximum expected operating value) plotted and designated on the expanded scales and on the regular scales where the expanded scales do not apply.

Horizontal *rms* field intensity circle, E_o, drawn on the pattern sheet.

Tower placement sketch showing the location and number of each tower with true north at the top of the diagram, along with dimensions useful in special design equations if such are used to make the pattern computations.

Symbol definitions are as follows:

G the electrical height, should be the value used in the vertical radiation characteristic function,

$$f(\theta) = \frac{\cos\ (G \sin\theta)\ -\cos G}{(1\ -\ \cos G)\cos\theta}. \qquad (10)$$

If this is not the case, then the correct vertical radiation characteristic should be furnished.

ϕ true orientation of observation point measured in degrees.

ϕ with a subscript, as ϕ_2 for No. 2 tower, describes the true orientation of each tower in the system.

S with a subscript, as S_2 for No. 2 tower, describes the spacing of each tower from the space reference point measured in degrees.

Ψ with a subscript, as Ψ_2 for No. 2 tower, describes the phase of the electric field with respect to the voltage reference axis.

E the total field intensity at the angle ϕ and θ.

E with a subscript, as E_2 for No. 2 tower, describes the magnitude of the horizontal field intensity of each tower in the system. It is convenient to express this value in millivolts per meter unattenuated field intensity at one mile.

F the ratio of the horizontal field intensities. Double subscripts can be used if the value is to be expressed outside the table, thus

$$F_{21} = \frac{E_2}{E_1}$$

M tower current ratios which may be considerably different than the field ratios. With subscripts it is written,

$$M_{12} = \frac{I_1}{I_2}$$

This symbol is not needed in the systematization on this sheet

θ elevation angle from the space reference point measured in degrees.

E_θ the magnitude of the *rms* field intensity circle at the elevation angle θ. Subscripts are used, such as E_o at zero degrees elevation and E_{40} at 40° elevation, to denote the elevation angle of the *rms* field intensity. It is convenient to express this value in millivolts per meter unattenuated field intensity at one mile.

E_s the field intensity of an equivalent standard hemispherical uniform radiator. For 1 kw of radiated power this standard hemispherical uniform radiator will give 152.1 mv/m unattenuated field intensity at one mile.

P_r the amount of radiated power from the proposed directional antenna.

Station data tabulation, with station call letters entered on the first line of station data; if the call letters have not been assigned, line remains blank or the word *new* inserted. The proposed operating frequency in kc and the proposed operating power in kw inserted. Time of operation designated by one of the following:

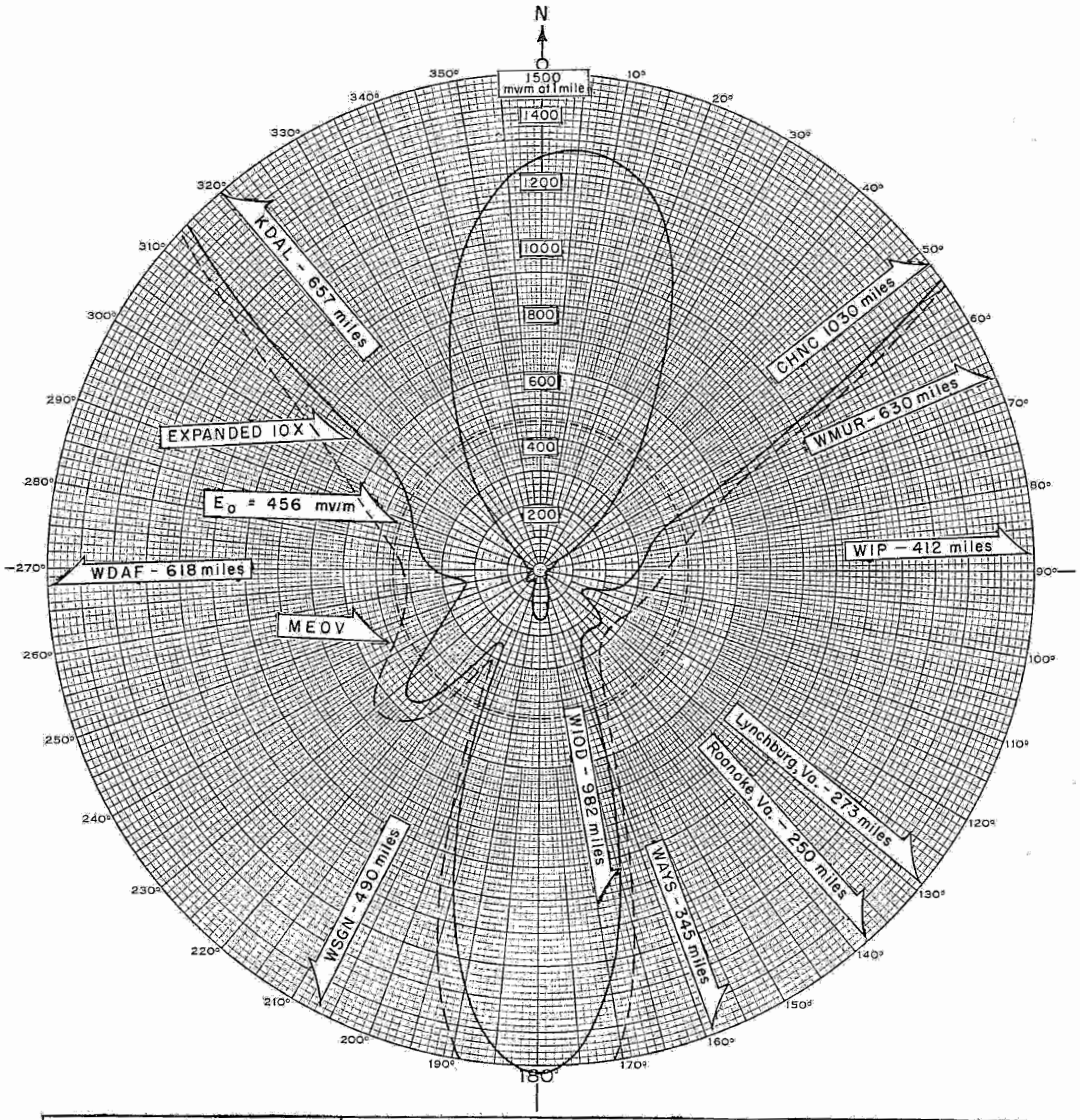
U unlimited.
D daytime.
N night time.
ST shares time.
L limited time with dominant station.
LS local sunset.
SH specified hours.
SA special authorization.

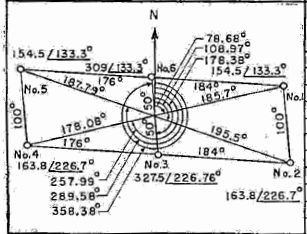
Type of operation specified by one of the following:

DA-N directional antenna night time.
DA-D directional antenna day time.
DA-1 directional antenna with same power and same pattern day and night.
DA-2 directional antenna with different power and/or different pattern day and night.

Ground system briefly described by the number of radials per tower, the length of these radials and the dimension of the ground screen if used.

Latitude and longitude given for the space reference point of the directional antenna system. Supersedes refers to the previous design pattern, if any. This number can be given as year in two digits, month in two digits, and day in two digits. Pattern number refers to the proposed



TOWER PLACEMENT SKETCH	PATTERN PARAMETERS									STATION DATA	
	TOWER No.	ELECTRICAL HEIGHT $G°$	TRUE TOWER ORIENTATION $\theta°$	SPACING $S°$	PHASING $\psi°$	HORIZONTAL FIELD mv/m E	FIELD RATIO F	ELEV. ANGLE $\theta°$	ELEVATION RMS FIELD mv/m E_θ	CALL	WHKC
	1	45	78.68	185.70	133.3	154.5	1.00	0	456	FREQUENCY	510 kc
	2	45	108.97	195.53	226.7	163.8	1.06	10	416	POWER	5 kw
	3	90	178.38	50.00	226.7	327.5	2.12	20	401	TIME OF OPERATION	U
	4	90	257.99	178.08	226.7	163.8	1.06	30	343	TYPE OF OPERATION	DA-N
	5	138	289.58	187.79	133.3	154.5	1.00	40	300	DAYTIME TOWERS	No. 5
	6	52	358.38	50.00	133.3	309.0	2.00	50	260	NIGHTTIME TOWERS	1,2,3,4,5,6
	7							60	186	No. RADIALS PER TOWER	120
	8							70	100	LENGTH OF RADIALS	90* 400 ft.
	9							80	21	GROUND SCREEN DIMENSION	
	10							E_θ*	340 mv/m	LAT.	39° 52' 26.2"
	DAYTIME OPERATION ☐ NIGHTTIME OPERATION ☑							P_r*	5 kw	LONG.	82° 58' 36.1"
										SUPERSEDES	470423
										PATTERN No.	470919

ENGINEERING STAFF
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UNITED BROADCASTING COMPANY
TERMINAL TOWER
CLEVELAND 13, OHIO

HORIZONTAL PLANE PATTERN

USING 15 MAJOR CIRCLE POLAR COORDINATE PAPER

FIG. 20

2-1-26

pattern and is given as year in two digits, month in two digits and day in two digits.

The horizontal plane pattern graph paper, as shown in Fig. 20, has a circle diameter of 10" and is printed on standard 11" x 17" sheets which can be reduced to 8.5" x 11" for record purposes. However, the 11" x 17" sheet size should be presented to FCC in order to meet their requirements.[4]

g. *BROADCAST ANTENNA REQUIREMENTS.*--The design of a broadcast antenna system is somewhat more complex than that of the so-called "beam" directional antennas used extensively for transmission in the short and ultra-short wave regions. The latter antenna systems almost invariably are designed to have a more or less concentrated beam of energy in one direction with energy in all other directions suppressed to a greater or less degree, depending upon the gain of the array. These short wave arrays often consist of numbers of stacked elements arranged symmetrically and fed with in-phase currents which can be distributed and phased throughout the array by means of transmission line sections. Either horizontal or vertical elements may be used, as sky wave or direct wave transmission is employed and the ground acts as a reflector rather than an absorber of the incident energy.

Other long-wire arrays of the rhombic or V type are also found in use at the higher frequencies, and operate on a traveling wave principle, in which the fields from each segment of the wires add up in one direction to give a sharp beam.

Broadcast antenna arrays present a rather different problem. They must usually be designed to produce a unique non-symmetrical pattern, as each directional antenna design must fulfill the peculiar requirements imposed upon the station by the proximity, direction and powers of other stations on the same or adjacent channels. Vertical radiating elements are universally used, as most of the useful transmission is by means of the surface wave, which suffers tremendous attenuation when horizontally polarized transmission is employed.

An excellent visualization of the problem involved in broadcast directional antenna design is afforded in Fig. 21, showing a typical regional broadcast channel in the United States. It will be noted that the pattern of each station is arranged so that a minimum amount of energy is directed towards other stations on the same channel. In addition the arrays are located in a position with respect to their primary service area so that the main lobe of energy covers this primary area as completely as possible.

For a complete discussion of skywave interference ratio and selection of the proper range of vertical angles for sky wave transmission reference is made to the FCC Standards of Good Engineer Practice for Standard Broadcasting Stations, issued by the Federal Communications Commission. Here the generally accepted ratio of desired to undesired co-channel signal of 20 to 1 is mentioned, and methods of calculating the interference presented to one station by another, in the primary service area of the first station, are described.

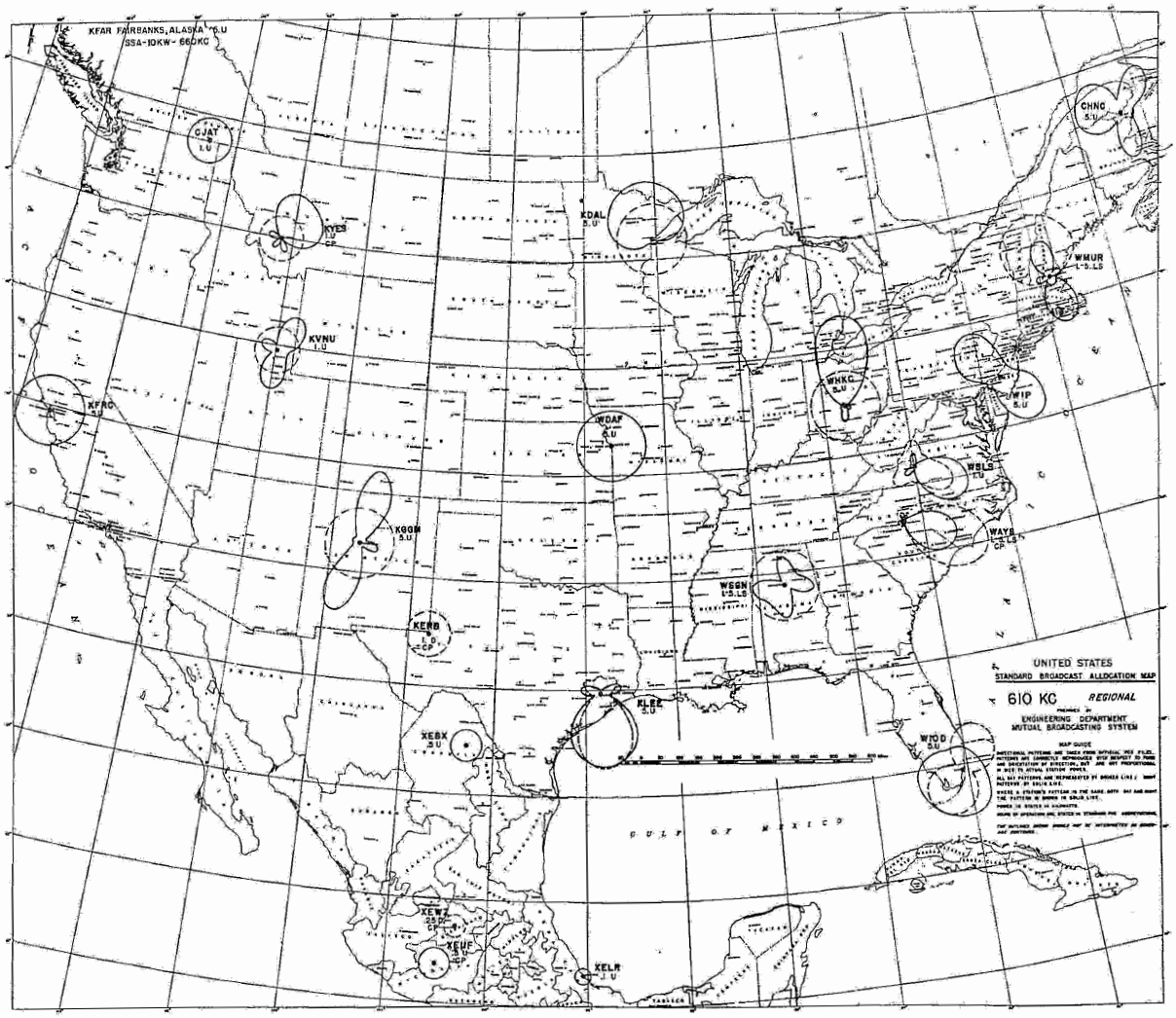
Sky wave interference, for allocation purposes, is determined by use of certain curves in the standards. These curves were prepared after exhaustive tests and surveys had been made of ground and skywave propagation characteristics at broadcast frequencies. However, changing ionospheric conditions indicate that a wholly realistic picture of interference conditions cannot be obtained solely from the curves. Actual measurements with field strength recorders are often necessary to determine absolute existing signal strengths at the points where the interference ratio is to be determined. Equipment is available for measuring the interference ratio while several stations are operating simultaneously on the same frequency.

The protection requirements will impose upon the pattern nulls and minima, at various elevation angles, the number being determined by the number of stations to be protected. The designer strives to provide the required protection with the minimum of towers, as a matter of simple economics. Several different arrangements may be tried out on paper in an attempt to find the optimum solution to the problem.

After the pattern shape has been determined, by methods such as outlined in this section, then the pattern size should be determined by methods such as outlined in the next section. With this information at hand the driving-point impedance of each tower in the array can be determined. Then it is possible to design the directional antenna feeder system which will consist of impedance matching networks between each tower and its respective transmission line, computation of phase shift in the transmission lines, provision of adequate phase shifting networks and a power dividing network at the input to the directional antenna system, which is usually at the output of the transmitter. A typical directional antenna feeder system block diagram is shown in Fig. 22.

After the construction has been completed, in accordance with the construction permit issued

[4] Two types of polar coordinate paper have been prepared by the author, with 50 and 75 complete circles. The paper is available in heavy or light weight 11" x 17" sheets. By using these two types of polar coordinate paper and reasonable scales the pattern can be drawn to at least 67 percent of full scale value.



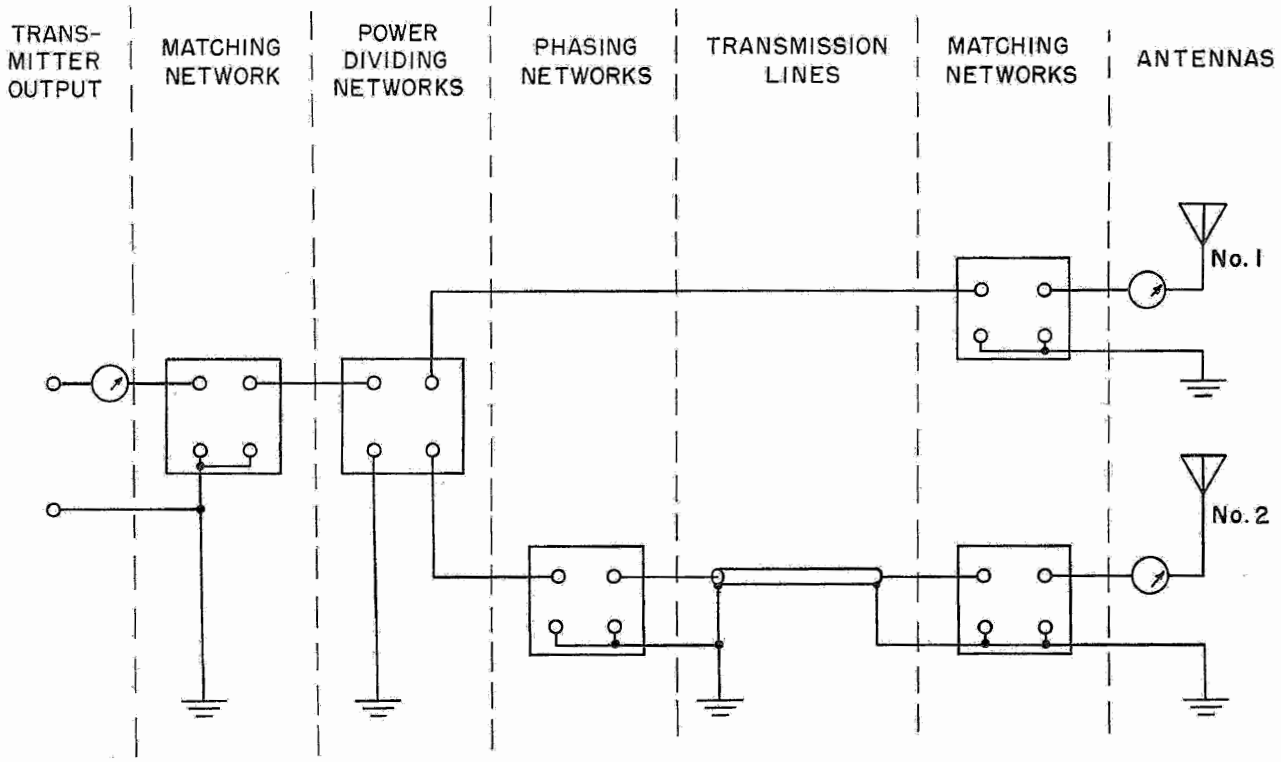
BROADCAST CHANNEL ALLOCATION MAP
SHOWING DIRECTIONAL ANTENNA PATTERNS USED BY STATIONS
TO PROTECT EACH OTHER (COURTESY MUTUAL BROADCASTING SYSTEM)

FIG. 21

by the FCC, equipment test authority is requested of FCC. Operating with this authority the networks are adjusted to meet the design requirements. Actual measurements must be made in the field to confirm that the operating parameters and field intensities are in accordance with the specifications in the construction permit. A report is then prepared and filed with the application for station license with FCC. Concurrently with the filing of this application, program test authority can be requested of FCC, thus permitting the station to go on the air before FCC has an opportunity to grant the station license.

Finally the operation of the antenna is kept under constant surveillance by means of amplitude and phase monitoring of the tower currents and by periodically checking the field strength at selected monitoring points placed in critical directions from the antenna system.

It should be realized that directional antenna design is a most exacting task, fraught with difficulties and not always culminating in unqualified success. Some large arrays for broadcasting stations have actually been designed and placed into operation, after which it was found impossible to tune them up to operate in accordance with FCC efficiency requirements. These design failures were due to neglect to consider high losses caused by excessive circulating currents in the array - another factor which must be carefully evaluated, as the FCC



BLOCK DIAGRAM OF A DIRECTIONAL ANTENNA FEEDER SYSTEM

FIG. 22

requires that a directional antenna produce at least a minimum unattenuated r-m-s field intensity at one mile. For specific details see the FCC Standards in Section One of the NAB Engineering Handbook. Some leeway for losses is afforded by the stipulation that the actual measured common driving point resistance may be multiplied by the factor 0.925 (5 kw and under) or the factor 0.95 (over 5 kw power) to obtain the operating power resistance which, times current squared, equals the licensed radiated power of the station.

h. *TWO TOWER PATTERN USING THE ADDITION FORM*--Perhaps the *simplest* directional antenna design equation is found in the two tower addition form. We will now proceed to develop this equation in considerable detail. Referring to Fig. 23(a) No. 1 tower is initially placed at the space reference point and No. 2 tower is placed directly north on the space reference axis. By substituting in the generalized Eq. (27) and (28) the horizontal pattern equation can be written,

$$E = E_1 \angle 0° + E_2 \angle S_2 \cos \phi + \Psi_2 \qquad (29)$$

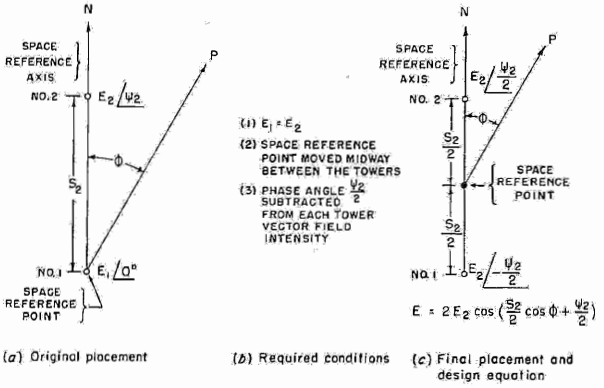
where the values are defined following Eq. (27). The vector diagram for this equation is shown in Fig. 24(a). The problem is to convert this vector equation into the simplest possible pattern formula. This can be done if E_1 is made equal to E_2, the space reference point is moved to a position midway between the two towers, and the phase angle $\Psi_2/2$ is subtracted from the phase angle of the vector field intensity of each tower. The resulting space configuration is shown in Fig. 23(c) and the resulting vector diagram is shown in Fig. 24(b).

The purpose of making this change is to remove the imaginary or j component, from the design equation. In Eq. (29) E_1 lays along the voltage vector reference axis, hence does not have a j component, however the position of E_2 will rotate with respect to E_1 and will therefore have a j component for all phase relations, β, other than 0° and 180°.

If the new parameters, as shown in Fig. 23 (c) are substituted in the general Eq. (27) and (28) we have,

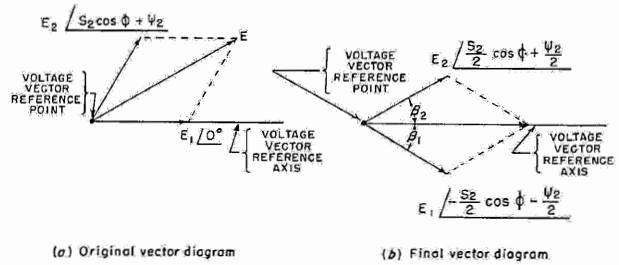
$$E = E_2 \angle \frac{S_2}{2} \cos \phi + \frac{\Psi_2}{2} + E_2 \angle -\frac{S_2}{2} \cos \phi - \frac{\Psi_2}{2} \qquad (30)$$

where the values are defined following Eq. (27).



SPACE CONFIGURATION FOR ADDITION METHOD

FIG. 23



VECTOR DIAGRAM FOR ADDITION METHOD

FIG. 24

Converting these vectors from polar to rectangular form gives,

$$E = E_2\left[\cos\left(\frac{S_2}{2}\cos\phi + \frac{\Psi_2}{2}\right) + j\sin\left(\frac{S_2}{2}\cos\phi + \frac{\Psi_2}{2}\right)\right] + E_2\left[\cos\left(-\frac{S_2}{2}\cos\phi - \frac{\Psi_2}{2}\right) + j\sin\left(-\frac{S_2}{2}\cos\phi - \frac{\Psi_2}{2}\right)\right]$$

In this equation the j sine terms cancel and the cosine terms add giving the desired answer

$$E = 2E_2\cos\left(\frac{S_2}{2}\cos\phi + \frac{\Psi_2}{2}\right) \qquad (31)$$

where

E = unattenuated horizontal field intensity from the directional antenna, mv/m

E_2 = unattenuated horizontal field intensity from each tower acting alone, mv/m

$S_2/2$ = spacing from the space reference point to each tower, degrees

ϕ = true azimuth angle toward observation point, P, degrees

$\Psi_2/2$ = time phase of No. 2 tower and the negative of the time phase of No. 1 tower, degrees.

The reason this design equation is so simple is that the j components cancel out. This can be seen quite clearly by reference to Fig. 24(b). The space reference point and time phase have been chosen such that the vector E_2 makes a positive angle β_2 that is equal to the negative of β_1 that the vector E_1 makes with the voltage vector reference axis. Since $E_1 = E_2$ the j components are always equal and opposite hence cancel each other leaving the real terms to add along the voltage vector reference axis.

When the space phase plus the time phase, $\left(\frac{S_2}{2}\cos\phi + \frac{\Psi_2}{2}\right)$, equals zero the cosine term becomes unity and the maximum field intensity is $2E_2$ in Eq. (31). For this condition the vectors E_1 and E_2 lie along the positive x-axis as shown in Fig. 25(a). For illustration if $S_2 = 180°$ and $\Psi_2 = +180°$ then when $\phi = 180°$ we have the maximum positive value due south in the pattern of Fig. 25(b). From Eq. (31) we have,

$$E = 2E_2\cos(90\cos\phi + 90)$$

as the pattern equation.

As the azimuth angle ϕ of the observation point P for the above illustration is moved counter clockwise from true south the first vector term in Eq. (30) which represents the No. 2 tower takes on a positive angle as shown in Fig. 24(b) while the second vector term in Eq. (30) which represents No. 1 tower takes on an equal negative angle. The resultant E still lies along the positive x-axis as illustrated in Fig. 24(b) and Fig. 25(a). The magnitude of this resultant decreases as the azimuth angle decreases up to 90° at which point the resultant becomes zero because the vectors E_2 and E_1 point in opposite directions as shown in Fig. 25(a). Then as the value of ϕ decreases from 90° to 0° the resultant becomes negative and increases in value until it reaches a maximum negative value as shown in Fig. 25(a) and (b).

It is of interest to note that one lobe is positive because the resultant vector E takes on positive values as it moves back and forth along the positive x-axis while the other lobe is negative because the vector E moves back and forth along the negative x-axis.

In this type of design equation the vector E always lies along the x-axis in the vector diagram. However, in order to plot the pattern in polar coordinates the magnitude of E is plotted in a polar fashion as a function of the true azimuth angle ϕ. Both ways of representing E are shown in Fig. 25.

If it is desired to fill both nulls an equal amount the field ratio can be made other than unity. In fact with a two tower array both nulls will naturally be filled an equal amount for a given field ratio. The amount of fill increases as the field ratio is increased. When the field ratio becomes infinite all of the radiation is from one tower and the pattern becomes non-directional or circular in the horizontal plane.

EXAMPLE 6: Write the equation of a cardioid pattern having a maximum field of 200 mv/m, to the north, using 90° spacing and the addition method.

SOLUTION: For this condition $S_2 = 90°$ and if the cardioid pattern is to point north then the cosine term of Eq. (31) must be unity when $\phi = 0$. For this condition the parenthesis term in Eq. (31) must be zero, thus

$$\frac{S_2}{2} \cos \phi + \frac{\psi_2}{2} = 0$$

Substituting, $$\frac{90}{2} \cos 0 + \frac{\psi_2}{2} = 0$$

Solving, $$\psi_2 = -90° \text{ or } 270°$$

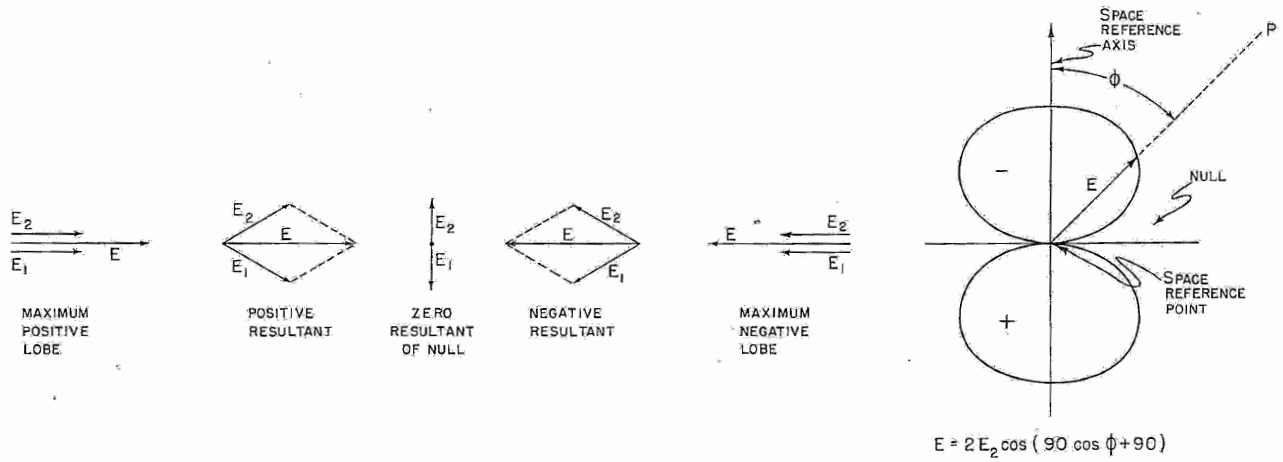
Therefore, the complete design equation can be written, by substituting in Eq. (31),

$$E = 2(100) \cos \left(\frac{90}{2} \cos \phi - \frac{90}{2}\right)$$

$$= 200 \cos (45 \cos \phi - 45) \qquad \text{ANS.}$$

For this pattern the values of E always lie along the positive x-axis, thus the whole pattern is a positive lobe pointing north with a null due south.

If we had used $\psi_2 = 270°$ instead of $\psi_2 = -90°$ then E would always lie along the negative x-axis, thus the whole pattern would be a negative lobe pointing north with a null due south.

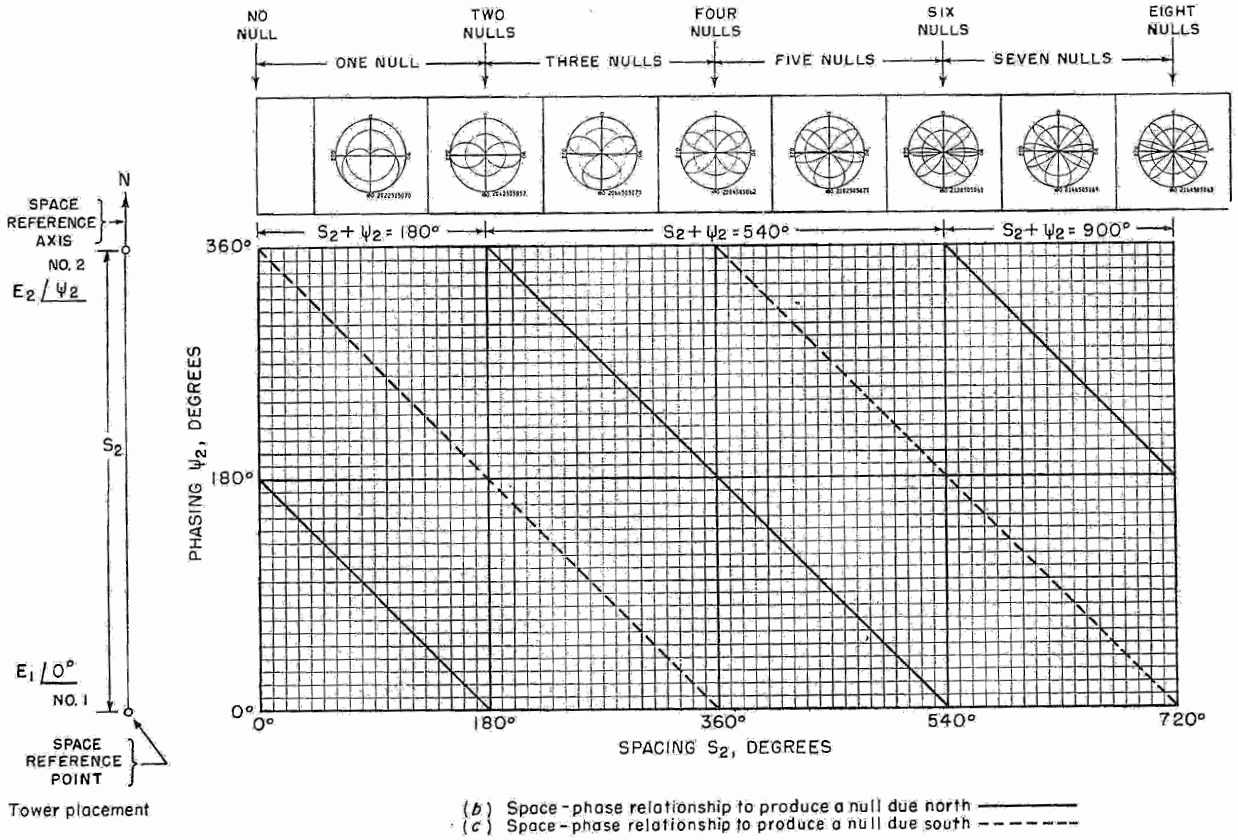


(a) TYPICAL VECTOR DIAGRAMS

(b) TYPICAL PATTERN

VECTOR DIAGRAMS AND PATTERN FOR TWO TOWER ADDITION FORM

FIG. 25



TWO TOWER SPACE-PHASE RELATIONSHIP TO PRODUCE A NULL DUE NORTH

FIG. 26

i. *SYSTEMATIZATION OF TWO TOWER PATTERNS.*--Since two tower patterns are so useful, a systematization of 568 patterns is presented in Appendix B. 256 of these patterns are general patterns with spacings out to four wavelengths, while 312 are detailed patterns for spacings out to one wavelength. The general patterns are for spacings in steps of 45 degrees and phasings in steps of 45 degrees. The detailed patterns are for spacings in steps of 15 degrees and phasings in steps of 15 degrees. The phasings are only presented from 0 to 180 degrees since the same patterns, oriented 180 degrees, result for phasings from 180 degrees to 360 degrees. This is readily observed by inspecting the general patterns which present all the phasings.

j. *DIRECTION OF HORIZONTAL NULLS FOR TWO TOWER PATTERNS.*--Whenever the parenthesis term $(\frac{S_2}{2} \cos \phi + \frac{\Psi_2}{2})$ in Eq. (31) becomes 90° or 270° the total field intensity vector E becomes zero and produces a null. If only one null is desired it must be either due north or due south since this is in the line of the towers. *A two tower pattern is always symmetrical around the line of towers,* therefore if the null is not in line with the towers there must be at least two nulls. Of course it is possible but not necessary to have two nulls in the line of the towers (due north and due south).

Let us consider the special case of a null due north. Let $\phi = 0$, then the parenthesis term in Eq. (31) must be equal to 90° for spacings up to 180°, hence

$$S_2 + \Psi_2 = 180° \qquad (32)$$

From this equation it is seen that for every spacing S_2 there is one possible phasing Ψ_2 that will produce a null due north. When the spacing goes beyond 180° then the phase angle becomes negative unless 360° is added to the spacing. Referring to Fig. 26(b) the solid diagonal lines graphically gives the relationship between S_2 and Ψ_2 to produce a null due north. The patterns, for illustration at the top of the figure, it will be noted, have been lifted from the general systematization of two tower patterns. It should be observed that for zero spacing no null can exist, for spacings from 0° to 180° only one null can exist and it will be due north for

this special case. At a spacing of 180° two nulls will exist, one due north and the other due south. From 180° to 360° spacing three nulls will exist, one of which will be due north and the others will be symmetrically located from due south in the third and fourth quadrants. At 360° spacing four nulls will exist in the exact direction of north, east, south, and west. This process of increasing the number of nulls will continue to increase, in a similar fashion, as shown in Fig. 26(b). A study of the general systematization of two tower patterns will also reveal this relationship.

EXAMPLE 7: Two towers on a North-South line have a spacing of 110°. Determine the phasing required to produce a null directly north.

SOLUTION: Substituting in Eq. (32)

$$110° + \Psi_2 = 180°$$
$$\Psi_2 = 70° \quad \text{ANS.}$$

A similar special relationship exists for a null due south. The *dashed line* in Fig. 26(b) gives the relationship between S_2 and Ψ_2 for this condition. This relationship is also illustrated in the general systematization of two tower patterns.

For the more general condition of producing a null in the direction ϕ_N, the azimuth angle of the null from the line of towers, we can apply the equation,

$$S_2 \cos \phi_N + \Psi_2 = \pm 180° \qquad (33)$$

where ϕ_N = azimuth angle of the nulls from the line of the towers, degrees
= azimuth angle clockwise and counterclockwise from true north to the nulls, if the towers are on a north-south space reference axis, degrees

Ψ_2 = total phasing of the No. 2 (north tower) with respect to the No. 1 (south tower), degrees

S_2 = total spacing between the towers, degrees.

This equation has been used to prepare the chart in Fig. 27.

EXAMPLE 8: Number 2 tower is spaced 140° from No. 1 tower on a true bearing of 40°. Determine the phasing that will produce a null at 110°. In what direction is the other null?

SOLUTION: Substituting in Eq. (33)

$$140° \text{ Cos } 70° + \Psi_2 = 180°$$
$$140° \times 0.342 + \Psi_2 = 180°$$
$$\Psi_2 = 132.1° \quad \text{ANS.}$$

The two tower pattern being symmetrical around the line of towers the other null will be at 40° - 70° = -30° or 330° from true north. ANS.

A careful inspection of this chart will reveal a number of interesting facts about two tower directional antennas. In general, spacing up to 180° will produce two symmetrical nulls for any given phasing. Of course when the null is at $\phi_N = 0°$ or $\phi_N = 180°$ there is only one null for spacings up to 180°. The positive sign in Eq. (33) is used for this case when $\phi_N = 90°$ the phasing $\Psi = 180°$ for all spacings. In other words, when the towers are exactly out of phase a null is always produced exactly broadside to the array regardless of the spacing.

For spacings from 180° to 360° there are in general two or four symmetrical nulls. The positive and negative sign in Eq. (33) must be used to determine both sets of nulls. Of course two of these nulls degenerate into a single null when $\phi_N = 0°$ or $\phi_N = 180°$ and for this condition there will be three nulls. If the spacing is increased from this value four nulls will exist while if the spacing is decreased only two nulls will exist. When there is a condition of three nulls the phasing can be increased or decreased as shown in the chart to produce either two or four nulls. When there are two nulls there may be one or two other minimums depending upon the pattern parameters. This can be visualized by observing the systematization of two tower directional antenna patterns.

EXAMPLE 9: Determine the phase and spacing to produce one pair of nulls at 80 and 280 degrees, and another pair at 150 and 210 degrees for a two tower directional antenna.

SOLUTION: Referring to Fig. 27 the specified null angles are satisfied for a spacing of approximately 346 degrees and a phasing of approximately 120 degrees. ANS.

If an exact solution is desired Eq. (33) can be applied to give the following simultaneous equations,

$$S_2 \cos 80 + \Psi_2 = +180$$
$$S_2 \cos 150 + \Psi_2 = +180$$

Substituting for the cosine values and subtracting

$$0.1736\ S_2 + 0.8660\ S_2 = 0° \text{ or add } 360°$$
$$S_2 = 346.3° \text{ spacing} \quad \text{ANS.}$$

Substituting this value of spacing in the first equation

$$\Psi_2 = 180 - (346.3)(0.1736) = 119.9° \quad \text{ANS.}$$

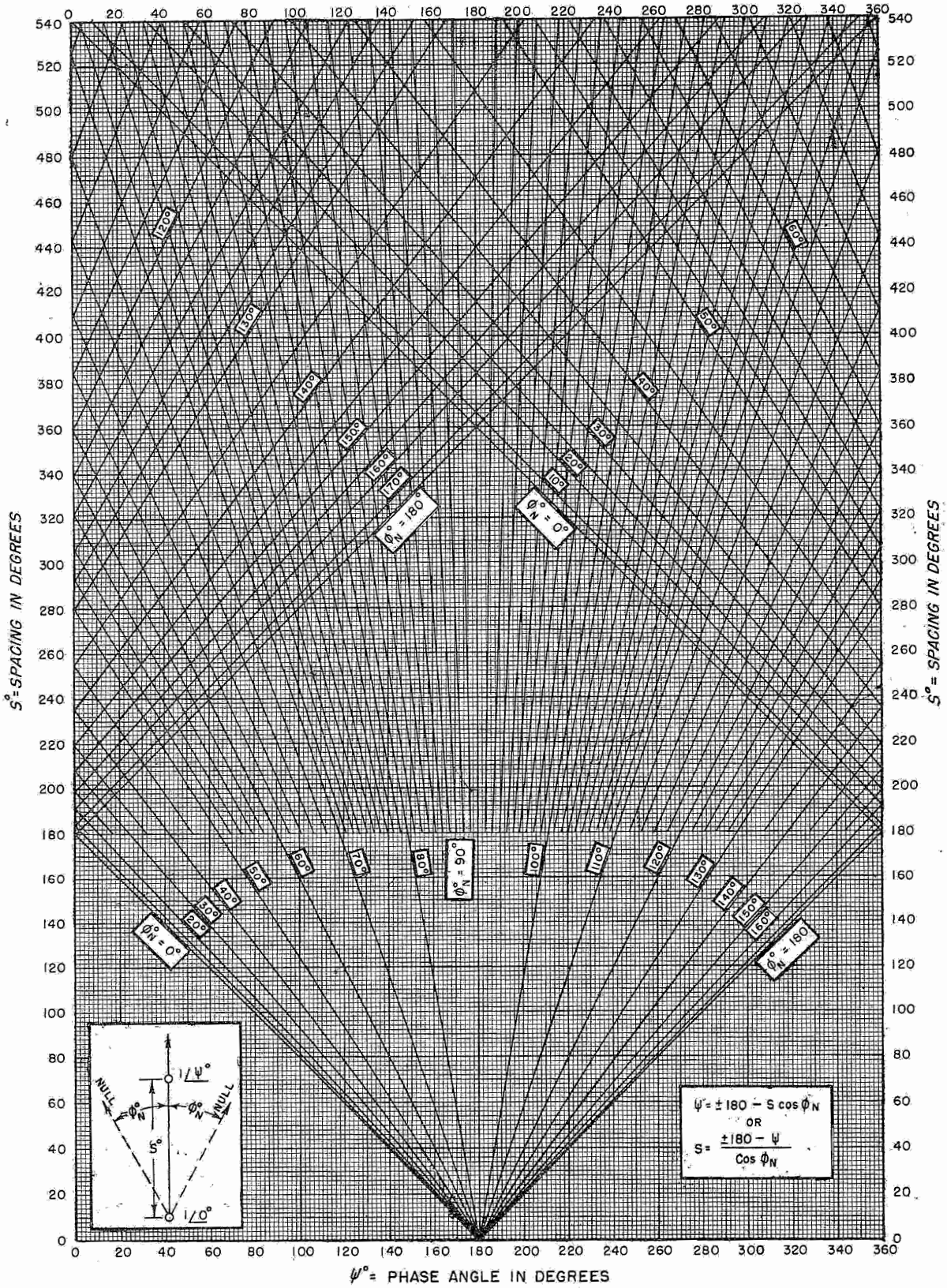


CHART FOR DETERMINING NULL DIRECTIONS OF TWO TOWER ARRAYS

FIG. 27

k. *TWO TOWER PATTERNS USING THE COSINE LAW FORM.*--Consider the generalized equation for two towers in a directional antenna array,

$$E = E_1 f_1(\theta) \angle \beta_1 + E_2 f_2(\theta) \angle \beta_2 \tag{34}$$

The terms in this equation are defined in Eq. (27) and (28), and illustrated in Fig. 29. These vectors can be resolved into components along the x-axis and y-axis and by taking the square root of the sum of the squares, the magnitude of the resultant is obtained, thus,

$$|E| = \sqrt{\begin{matrix}\left[E_1 f_1(\theta) \cos\beta_1 + E_2 f_2(\theta) \cos\beta_2\right]^2 \\ +\left[E_1 f_1(\theta) \sin\beta_1 + E_2 f_2(\theta) \sin\beta_2\right]^2\end{matrix}} \tag{35}$$

Expanding terms under the radical gives,

$$|E| = \sqrt{\begin{matrix}\left[E_1 f_1(\theta)\right]^2 \cos^2\beta_1 + \left[E_2 f_2(\theta)\right]^2 \cos^2\beta_2 + 2E_1 f_1(\theta)\, E_2 f_2(\theta) \cos\beta_1 \cos\beta_2 \\ +\left[E_1 f_1(\theta)\right]^2 \sin^2\beta_1 + \left[E_2 f_2(\theta)\right]^2 \sin^2\beta_2 + 2E_1 f_1(\theta)\, E_2 f_2(\theta) \sin\beta_1 \sin\beta_2\end{matrix}} \tag{36}$$

Since $\sin^2\beta + \cos^2\beta = 1$ and $\cos\beta_1 \cos\beta_2 + \sin\beta_1 \sin\beta_2 = \cos(\beta_2 - \beta_1)$ the above equation can be reduced to

$$|E| = \sqrt{\left[E_1 f_1(\theta)\right]^2 + \left[E_2 f_2(\theta)\right]^2 + 2\, E_1 f_1(\theta)\, E_2 f_2(\theta) \cos(\beta_2 - \beta_1)} \tag{37}$$

This is the cosine law form of a two tower pattern equation. To illustrate, consider the application of the cosine law to the triangles of Fig. 28.

If we write: $a = E_1 f_1(\theta)$, $b = E_2 f_2(\theta)$, $c = |E|$, and $C = 180 - (\beta_2 - \beta_1)$. Making these substitutions in the cosine law equation of Fig. 28 results in Eq. (37) the cosine law design equation.

Now if the field intensity ratios are defined by

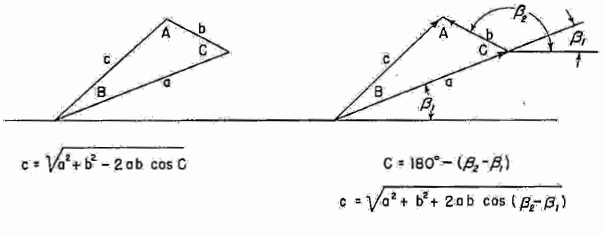
$$F_{21} = \frac{E_2 f_2(\theta)}{E_1 f_1(\theta)} \tag{38}$$

then the quantity $E_1 f_1(\theta)$ can be removed from under the radical in Eq. (37) and the equation can be written,

$$|E| = E_1 f_1(\theta) \sqrt{1 + F_{21}^2 + 2F_{21} \cos(\beta_2 - \beta_1)} \tag{39}$$

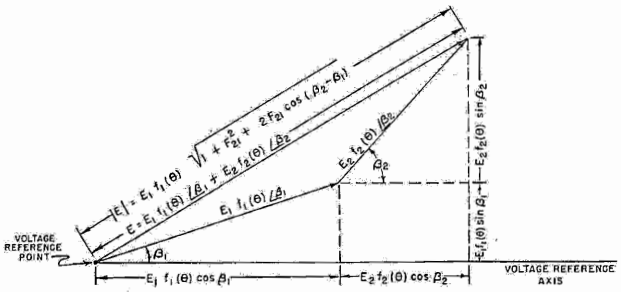
This is the cosine law equation expressed in ratio form. For some types of antenna designs this is a useful form of pattern equation. This equation is shown in Fig. 29.

EXAMPLE 10: If the towers in Example 8 have horizontal field intensities of 120 mv/m and 170 mv/m for No. 1 and No. 2 towers respectively, write the horizontal pattern equation using the cosine law form.



COSINE LAW EQUATION APPLIED TO A TRIANGLE

FIG. 28



VOLTAGE VECTOR DIAGRAM FOR TWO TOWER PATTERN

FIG. 29

SOLUTION: Substituting in Eq. (28)

$\beta_1 = 0$ since No. 1 tower is at the space reference point

$\beta_2 = 140^\circ \times \cos 0^\circ \times \cos(40^\circ - \phi) + 132.1^\circ$

Substituting in Eq. (38)

$F_{21} = \frac{170}{120} = 1.416$

Substituting in Eq. (39)

$$|E| = 120\sqrt{1+1.416^2+2 \times 1.416 \cos 140^\circ \cos (40^\circ - \phi)+132.1^\circ}$$ ANS.

1. *TWO TOWER PATTERNS USING THE MULTIPLICATION FORM.*--It is a simple matter to convert Eq. (39) to the multiplication form. Let No. 1 tower be located at the space reference point then E_1 will lay along the voltage reference axis. Now if the terms under the radical are divided by 2 F_{21} the equation can be written,

$$|E| = E_1 f_1(\theta)\sqrt{2 F_2}\sqrt{\frac{1 + F_2^2}{2 F_2} + \cos (S_2 \cos\theta\cos\phi + \Psi_2)} \quad (40)$$

where F_2 is the same as F_{21} defined in Eq. (38). The double subscript is dropped because all towers are referred to the reference tower.

For the special case of equal field intensities this equation reduces to

$$|E| = 2 F_1 f_1(\theta) \cos\left[\frac{S_2}{2} \cos\theta \cos\phi + \frac{\Psi_2}{2}\right] \quad (41)$$

EXAMPLE 11: For the directional antenna in Example 10 express the horizontal pattern equation in the multiplication form.

SOLUTION: Substituting in Eq. (38)

$F_{21} = \frac{170}{120} = 1.416$

Substituting in Eq. (40)

$$|E| = 120\sqrt{2}\sqrt{1.416}\sqrt{\frac{1+1.416^2}{2 \times 1.416} + \cos (140^\circ \cos 0^\circ \cos\phi + 132.1^\circ)}$$

$$= 202\sqrt{1.068 + \cos(140^\circ \cos\phi + 132.1^\circ)}$$ ANS.

EXAMPLE 12: Prove the two tower multiplication equation, that is, show the transition from Eq. (40) to (41).

SOLUTION: Equation (41) is for the special case of equal field intensities.

First, for Eq. (40) we have

$$E = E_1 f_1(\theta)\sqrt{2F_2}\sqrt{\frac{1 + F_2^2}{2F_2} + \cos (S_2 \cos\theta \cos\phi + \Psi_2)}$$

And for equal field strengths this first reduces to

$$E = E_1\sqrt{2} f_1(\theta) \sqrt{1 + \cos (S_2 \cos\theta \cos\phi + \Psi_2)}$$

A basic trigonometric formula is

$$\cos^2\alpha = \frac{1}{2}(1 + \cos 2\alpha)$$

$$2\cos^2\alpha = 1 + \cos 2\alpha$$

$$\sqrt{2}\cos\alpha = \sqrt{1 + \cos 2\alpha}$$

Then letting

$$2\alpha = S_2 \cos\theta \cos\phi + \Psi_2$$

$$\alpha = \frac{S_2}{2} \cos\theta \cos\phi + \frac{\Psi_2}{2}$$

And

$$E = E_1\sqrt{2}\ f_1(\theta)\ \sqrt{2}\cos\left(\frac{S_2}{2}\cos\theta\cos\phi + \frac{\Psi_2}{2}\right)$$

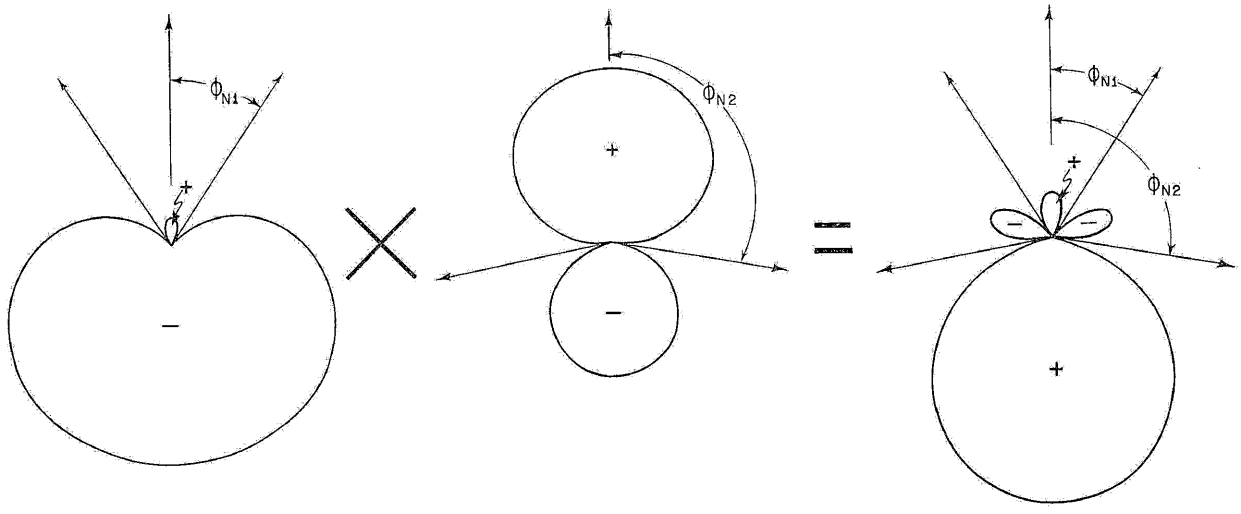
$$E = 2E_1 f_1(\theta) \cos\left(\frac{S_2}{2}\cos\theta\cos\phi + \frac{\Psi_2}{2}\right) \qquad \text{ANS.}$$

m. *THREE TOWER IN LINE PATTERNS USING THE MULTIPLICATION FORM.*--If Eq. (40) is used to express pattern No. 1 in Fig. 30 then pattern No. 2 can be expressed by,

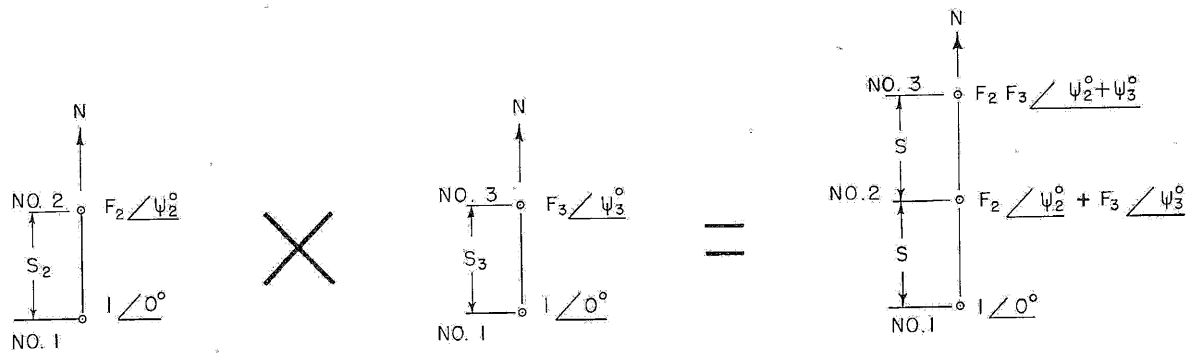
$$|E| = E_1 f_1(\theta)\sqrt{2F_3}\sqrt{\frac{1+F_3^2}{2F_3} + \cos(S_3\cos\theta\cos\phi + \Psi_3)} \qquad (42)$$

Now if the radical terms of Eq. (40) and Eq. (42) are multiplied together the multiplied pattern No. 3 of Fig. 30 results, thus,

$$|E| = 2E_1 f_1(\theta)\sqrt{F_2F_3}\sqrt{\left[\frac{1+F_2^2}{2F_2} + \cos(S_2\cos\theta\cos\phi + \Psi_2)\right]\left[\frac{1+F_3^2}{2F_3} + \cos(S_3\cos\theta\cos\phi + \Psi_3)\right]} \qquad (43)$$



(a) PATTERN NO. 1 (b) PATTERN NO. 2 (c) PATTERN NO. 3



MULTIPLICATION OF PATTERNS TO PRODUCE A THREE TOWER IN LINE ARRAY

FIG. 30

This multiplication involved all but the field intensity $E_1 f_1(\theta)$ from the reference tower. $E_1 f_1(\theta)$ is not squared because the shape factors only are multiplied. It will be noted in Fig. 30 that the field intensity of the reference tower is taken as unity, therefore, after performing the pattern multiplication it is necessary to control the pattern size by the field intensity term $E_1 f_1(\theta)$. For the multiplication in Eq. (43) the spacing $S = S_2 = S_3$. Also, it will be noted that the tower numbers have been arranged 1, 2, 3 in Fig. 30(c). This does not mean that tower Nos. 2 and 3 from Fig. 30(a) and (b) are literally moved into these new positions. In the three tower pattern No. 1 tower is the reference tower while towers No. 2 and No. 3 result from the multiplication. Tower No. 2 of the three tower array must produce a field that is the sum of the vector fields of towers No. 2 and No. 3 of the multiplied patterns, while tower No. 3 of the three tower array must produce a field that is the product of the vector fields of towers No. 2 and No. 3 of the multiplied patterns.

EXAMPLE 13: With a three tower in line array having spacings of 90° between towers it is desired to protect radio stations with true azimuth angles of 33.4°, 99.6° and 326.6°. If the field intensity from an end tower is 382 mv/m determine the equation for each pair of towers and then multiply the two patterns to arrive at the final design equation. Plot the pattern for each pair of towers acting alone and then plot the final pattern.

SOLUTION: If the azimuth angle is split between 33.4° and 326.6° it is found that the pair of towers to produce nulls in these azimuth directions must have a true north south bearing. Therefore, the final three tower array will also have this bearing.

Now, from Eq. (33) the phase angle for the first pair of towers is determined as follows,

$$S_2 \cos \phi_N + \psi_2 = \pm 180$$

$$90 \cos 33.4 + \psi_2 = \pm 180$$

$$\psi_2 = 105° \text{ when } \phi_N \text{ is measured from true north}$$

And from Eq. (40) the pattern equation for towers No. 1 and 2 is,

$$E_{12} = E_1 \sqrt{2} \sqrt{1 + \cos (S_2 \cos \phi + \psi_2)}$$

$$= 540 \sqrt{1 + \cos (90 \cos \phi + 105)} \quad \text{ANS}$$

Similarly, from Eq. (33) the phase angle for the second pair of towers is determined as follows,

$$90 \cos 99.6 + \psi_3 = \pm 180$$

$$\psi_3 = 195° \text{ when } \phi_N \text{ is measured from true north}$$

And from Eq. (42) the pattern equation for towers No. 1 and 3 is,

$$E_{13} = E_1 \sqrt{2} \sqrt{1 + \cos (S_3 \cos \phi + \psi_3)}$$

$$= 540 \sqrt{1 + \cos (90 \cos \phi + 195)}$$

Now, if the pattern No. 1 is multiplied by pattern No. 2, only the radical terms are multiplied as shown in Eq. (43) to give the final horizontal pattern equation,

$$E = E_1 \, 2 \sqrt{\left[1 + \cos (S_2 \cos \phi + \psi_2)\right] \times \left[1 + \cos (90 \cos \phi + \psi_3)\right]}$$

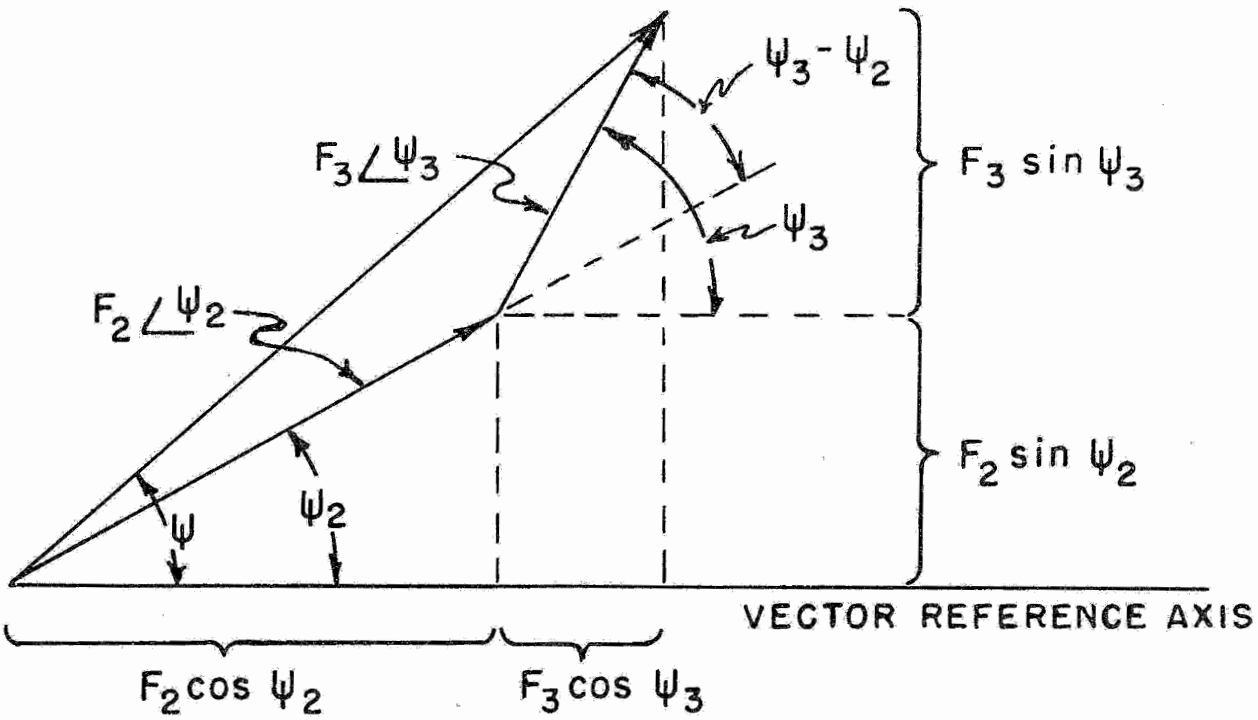
$$= 764 \sqrt{\left[1 + \cos (90 \cos \phi + 105)\right] \times \left[1 + \cos (90 \cos \phi + 195)\right]} \quad \text{ANS}$$

The pattern for each pair of towers and the final pattern are plotted in Fig. 30. ANS

The sum of the vector field intensities radiated from tower No. 2 can be expressed as a magnitude at an angle. Using the geometry of Fig. 31 we can write,

$$F_2 \angle \psi_2 + F_3 \angle \psi_3 = \sqrt{2F_2F_3} \sqrt{\frac{F_2^2 + F_3^2}{2F_2F_3} + \cos (\psi_3 - \psi_2)} \angle \psi \qquad (44)$$

This equation makes it possible to write out the magnitude and phase for No. 2 tower, thus all three field intensity vectors can be expressed as shown in Fig. 32(a). Since the cosine of a positive angle equals the cosine of a negative angle we can write $\cos(\psi_2 - \psi_3) = \cos(\psi_3 - \psi_2)$ hence the expression for No. 2 tower is correct in Fig. 32(a).



SUM OF VECTOR FIELDS FROM TOWER No. 2

FIG. 31

EXAMPLE 14: Prove Eq. (44).

SOLUTION: Referring to Fig. 31 the vector sum can be written

$$F_2 \angle \psi_2 + F_3 \angle \psi_3 = \sqrt{(F_2 \cos\psi_2 + F_3 \cos\psi_3)^2 + (F_2 \sin\psi_2 + F_3 \sin\psi_3)^2} \; \Big/ \tan^{-1} \frac{F_2 \sin\psi_2 + F_3 \sin\psi_3}{F_2 \cos\psi_2 + F_3 \cos\psi_3}$$

Expanding under the radical

$$F_2 \angle \psi_2 + F_3 \angle \psi_3 = \sqrt{F_2^2 \cos^2\psi_2 + 2F_2F_3 \cos\psi_2 \cos\psi_3 + F_3^2 \cos^2\psi_3 + F_2^2 \sin^2\psi_2 + 2F_2F_3 \sin\psi_2 \sin\psi_3 + F_3 \sin^2\psi_3} \; \Big/ \psi$$

Since $\cos^2\psi_2 + \sin^2\psi_2 = 1$ and $\cos\psi_2\cos\psi_3 + \sin\psi_2\sin\psi_3 = \cos(\psi_3 - \psi_2)$ the above equation becomes

$$F_2 \angle \psi_2 + F_3 \angle \psi_3 = \sqrt{F_2^2 + F_3^2 + 2F_2F_3 \cos(\psi_3 - \psi_2)} \; \Big/ \psi$$

$$= \sqrt{2F_2F_3} \sqrt{\frac{F_2^2 + F_3^2}{2F_2F_3} + \cos(\psi_3 - \psi_2)} \; \Big/ \psi \qquad \text{ANS.}$$

where

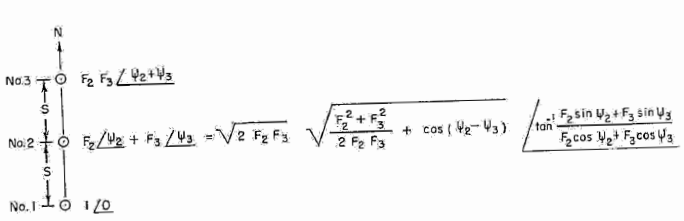
$$\Psi = \tan^{-1} \frac{F_2 \sin \Psi_2 + F_3 \sin \Psi_3}{F_2 \cos \Psi_2 + F_3 \cos \Psi_3} \qquad \text{ANS.}$$

Equation (43) is the general equation for multiplying patterns for a three tower in line array. If the field intensity ratios F_2 and F_3 are made unity a special case of interest results as shown in Fig. 32(b). For this special case Eq. (43) simplifies to read,

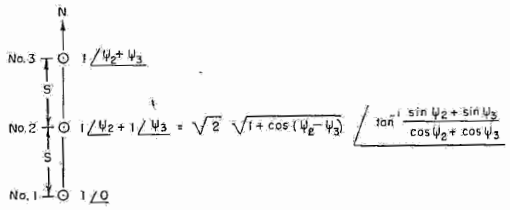
$$\left| F \right| = 2E_1 f_1(\theta) \sqrt{\left[1 + \cos(S \cos\theta \cos\phi + \Psi_2)\right] \left[1 + \cos(S \cos\theta \cos\phi + \Psi_3)\right]} \qquad (45)$$

where all three towers are of the same height.

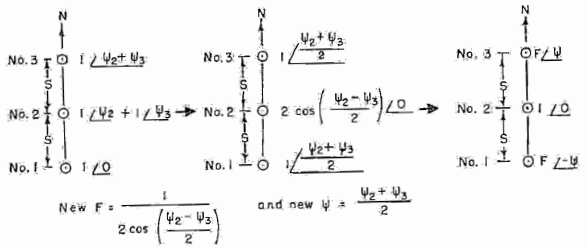
For this special case it is convenient to change the reference tower to the center of the array as shown in Fig. 32(c). This was accomplished by subtracting the phase angle $\frac{\Psi_2 + \Psi_3}{2}$ from each tower field intensity vector. The pattern is not altered by performing this operation with the result that the center tower is now the reference tower with zero phase angle. Design Eq. (44) is still valid.



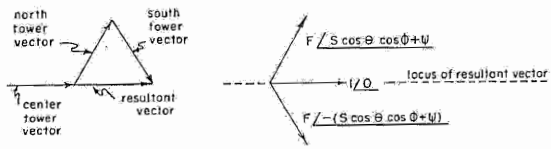
(a) GENERAL CASE



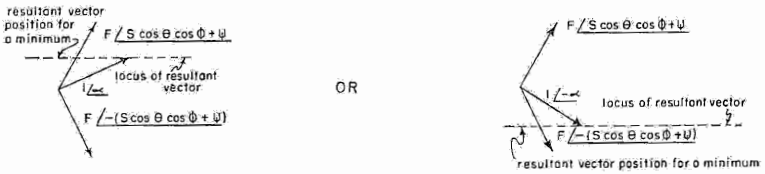
(b) SPECIAL CASE WHEN $F_2 = F_3 = 1$



(c) SPECIAL CASE WITH REFERENCE TOWER CHANGED TO CENTER OF ARRAY



(d) VECTOR DIAGRAMS FOR SPECIAL CASE WITH CENTER REFERENCE TOWER



(e) VECTOR DIAGRAMS TO FILL ALL NULLS AN EQUAL AMOUNT

VECTOR FIELDS FOR THREE TOWER IN LINE ARRAYS USING THE MULTIPLICATION FORM

FIG. 32

Another simplification can be made by changing all of the field magnitudes such that the center tower will have a unit field intensity magnitude. For this condition design Eq. (43) can be simplified to read,

$$\left|E\right| = 2FEf(\theta) \left[\frac{1}{2F} + \cos(S \cos\theta \cos\phi + \Psi)\right] \tag{46}$$

where the tower arrangement and parameters are shown in Fig. 32(c). This equation is for towers of equal height. The center tower field intensity is E $f(\theta)$. The reason this design equation is so simple is that the resultant vector always lies along the voltage reference axis. Fig. 32(d) shows how the three vectors add to produce this resultant.

EXAMPLE 15: A three tower in line array has a spacing of 135° between each tower and the array has a true north-south bearing. Write the horizontal pattern equation if stations are to be protected at azimuth angles of 10 and 30 degrees and the field from No. 1 tower is 197 mv/m.

SOLUTION: From Eq. (33) the phasing for a null at 10 degrees is

$$\Psi_2 = +180 - 135 \cos 10 = 47°$$

and at 30°

$$\Psi_3 = +180 - 135 \cos 30 = 63°$$

Applying the formulas for the special case as illustrated in Fig. 32(c),

$$F = \frac{1}{2\cos\left(\frac{\Psi_2 - \Psi_3}{2}\right)} = \frac{1}{2\cos\left(\frac{47 - 63}{2}\right)} = 0.505$$

$$\Psi = \frac{\Psi_2 + \Psi_3}{2} = \frac{47 + 63}{2} = 55$$

The horizontal pattern equation by substituting in Eq. (46) is,

$$\left|E\right| = (2)(0.505)(197) \left[\frac{1}{(2)(0.505)} + \cos(135 \cos\phi + 55)\right]$$

$$= 199 \left[0.99 + \cos(135 \cos\phi + 55)\right] \quad \text{ANS.}$$

n. *NULL FILLING USING THE MULTIPLICATION FORM.*--If it is desired to fill all nulls an equal amount the phase of the center tower can be shifted from 0° by the angle α as shown in Fig. 32(e). When the reference vector phase is shifted in this manner the resultant vector traverses a locus parallel to the reference vector axis and thus the resultant vector magnitude will never drop to zero. The magnitude of the minimums is proportional to sin α. The minimums will occur when the resultant vector is at right angles to the vector reference axis. For this condition the magnitude of the minimums can be written,

$$\left|E\right|_{min} = E_2 f(\theta) \sin\alpha \tag{47}$$

where

α = the phase angle of the center tower reference vector, and the other values are as defined above.

E_2 = the field of the center tower, mv/m.

When it is desired to fill only one set of nulls, say $\pm\phi_{N1}$ in Fig. 30, then the field ratio F_2 must be made different than unity in the design Eq. (43). If at the same time it is desired to retain nulls $\pm\phi_{N2}$ then the field ratio F_3 must be made unity. If the field intensity does not drop to zero the value is called a minimum rather than a null. Strictly speaking a null is a zero value only and a minimum is a low value that approaches a null value.

EXAMPLE 16: It is desired to fill the horizontal nulls to a minimum of 20 mv/m in a three tower in line array where, $E_1 = 197\angle 0°$, $E_2 = 390\ \angle 55°$ and $E_3 = 197\angle 110°$ and the spacing between consecutive towers is 135°.

Determine α and give the approximate and exact design equations.

SOLUTION: From Eq. (47) and for the horizontal plane we have,

$$/E/_{min} = E_2 \, f(\theta) \sin \alpha$$

$$20 = 390 \, (1) \sin \alpha$$

$$\sin \alpha = \frac{20}{390} = 0.05128$$

$$\alpha = 2.94^\circ \qquad \text{ANS}$$

Making the center tower No. 2 the reference tower, by Eq. (46) with complete nulls we have,

$$/E/ = 199 \left[0.99 + \cos (135 \cos \phi + 55) \right]$$

Now if the phase of the center tower is shifted $\pm\alpha = \pm 2.94^\circ$ we can write approximately

$$E = 199 \left[0.99 + \cos (135 \cos \phi + 55) \right] + j \, 20 \quad \text{ANS}$$

The approximation is that $\pm j \, 20$ is added to $/E_2/ = 390$ making $E_2 = 390 \pm j \, 20$ rather than the exact solution which is

$$E_2 = 390 \, \varepsilon^{\pm j\alpha} = 390 \angle \pm j\alpha$$

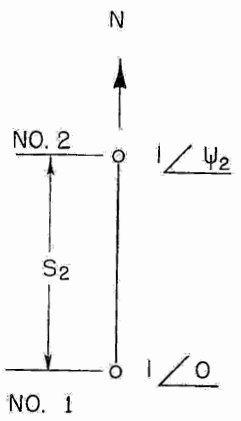
$$= 389.49 \pm j \, 20$$

which would give an exact solution of

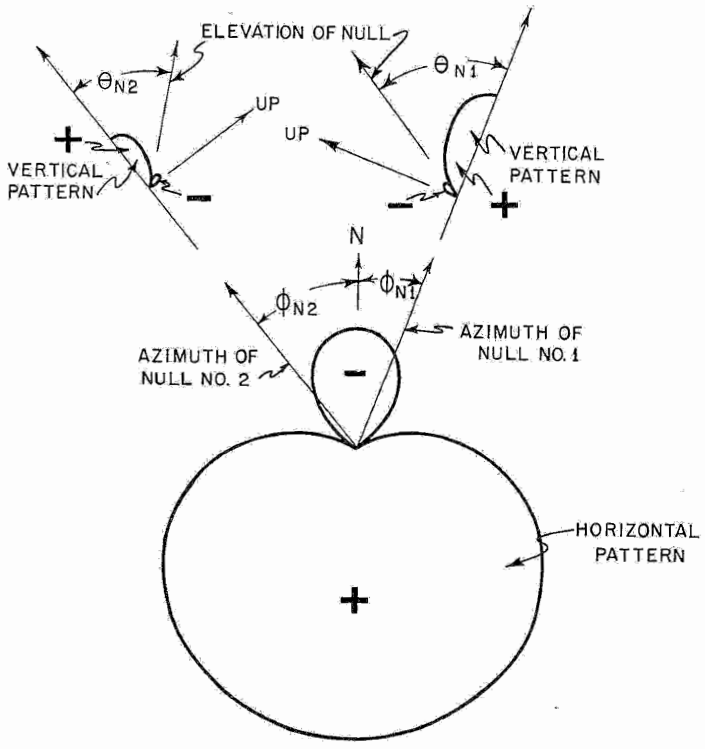
$$E = 199 \left[0.99 + \cos (135 \cos \phi + 55) \right] - 0.51 + j20 \qquad \text{ANS}$$

o. *DIRECTION OF VERTICAL NULLS FOR TWO TOWER PATTERNS.*--If a null is to be produced in the vertical plane then the space phasing term must also include the elevation angle. In equation form we can write for null No. 1

$$S_2 \cos \phi_{N1} \cos \phi_{N1} + \Psi_2 = \pm 180 \qquad (48)$$



(a) TOWER PLACEMENT



(b) HORIZONTAL AND VERTICAL PATTERNS

AZIMUTH AND ELEVATION ANGLES TO LOCATE VERTICAL NULLS

FIG. 33

where S_2 = spacing from No. 1 to No. 2 tower, degrees

ϕ_{N1} = azimuth angle of null No. 1 from line of towers, degrees

θ_{N1} = elevation angle of null No. 1, degrees

Ψ_2 = phase of No. 2 tower with respect to No. 1 tower, degrees

In a similar fashion the equation for null No. 2 can be written

$$S_2 \cos \phi_{N2} \cos \theta_{N2} + \Psi_2 = \pm 180 \tag{49}$$

where the terms are similar to those in Eq. (48) except that the values are for vertical null No. 2.

EXAMPLE 17: A two tower directional antenna array has the following parameters:

No	G°	Ø°	S°	ψ°	E	F
1	90	0	0	0	200	1
2	90	0	90	135	200	1

Determine the azimuth angles of the horizontal nulls, the elevation angle of the vertical nulls for azimuth angles of 20° and 320°. Also, plot the horizontal pattern and vertical patterns for the above azimuth angles of 20° and 320°.

SOLUTION: By Eq. (48), in the horizontal plane

$$S_2 \cos \phi_{N1} \cos \theta_{N1} + \Psi_2 = \pm 180$$

$$90 \cos \phi_{N1} + 135 = \pm 180$$

$$\phi_{N1} = 60° \text{ (using the + sign)} \quad \text{ANS}$$

$$= 300° \text{ (using the - sign)} \quad \text{ANS}$$

For an azimuth angle of 20° the vertical null is determined by Eq. (48), thus,

$$90 \cos 20 \cos \theta_{N1} + 135 = \pm 180$$

$$\theta_{N1} = 58° \quad \text{(using the + sign)} \quad \text{ANS}$$

For an azimuth angle of 300° the vertical null is determined by Eq. (49), thus,

$$90 \cos 300 \cos \theta_{N2} + 135 = \pm 180$$

$$\theta_{N2} = 49° \quad \text{(using the + sign)} \quad \text{ANS}$$

The desired horizontal and vertical patterns are plotted in Fig. 33. ANS

It is sometimes desirable to specify two vertical nulls at different bearings when using a two tower array. For illustration it may be desired to protect two stations having an azimuth angle ϕ_{12} between the two stations. For this case the azimuth angle of the two vertical nulls must add to give this angle as shown in Fig. 33, thus

$$\phi_{12} = \phi_{N1} + \phi_{N2} \tag{50}$$

Since the distance to the stations to be protected determines the elevation angle the values θ_1 and θ_2 can be specified. Of course it may be necessary to give protection over a vertical and also a horizontal angle. In such cases an estimate is made and the pattern fit is determined. If the pattern does not quite fit then the misfit will usually indicate what to try next.

If for example + signs are used in Eq. (48) and (49) then by subtracting Eq. (49) from Eq. (48) the spacing, phase, and constant 180° can be eliminated to get

$$\cos \phi_{N1} \cos \theta_{N1} = \cos \phi_{N2} \cos \theta_{N2}$$

Substituting for ϕ_{N2} from Eq. (24) we can write

$$\cos \phi_{N1} = \cos (\phi_{12} - \phi_{N1}) \frac{\cos \theta_{N2}}{\cos \theta_{N1}}$$

This equation can be rearranged to give

$$\tan \phi_{N1} = \frac{\cos \theta_{N1} - \cos \theta_{N2} \cos \phi_{12}}{\cos \theta_{N2} \sin \phi_{12}} \tag{51}$$

where

ϕ_{N1} = azimuth angle from line of towers to null No. 1, which is the value to be determined,

and the other values, as defined above are known. This design equation makes it possible to determine the true azimuth of the line of towers when two radio stations are to be protected in vertical nulls.

When this method is used to fix vertical nulls for two towers it is possible to use the multiplication method and protect other stations with another two towers, the pattern of which is to be multiplied by the first pattern. Since the multiplication method is being used a null with one set of towers will not be altered if the pattern is multiplied by the pattern of another set of towers. This is true because a null or zero value multiplied by some value is still a null or zero value. This fact makes the multiplication method very attractive to the directional antenna design engineer.

EXAMPLE 18: The vertical elevation of a null to protect station No. 1 is 20°, the vertical elevation of a null to protect station No. 2 is 30° and the azimuth angle between the two stations is 90°. What is the azimuth angle from the line of towers toward station No. 1?

SOLUTION: Applying Eq. (51) we have

$$\tan \phi_{N1} = \frac{\cos 20 - \cos 30 \cos 90}{\cos 30 \sin 90} = 1.083$$

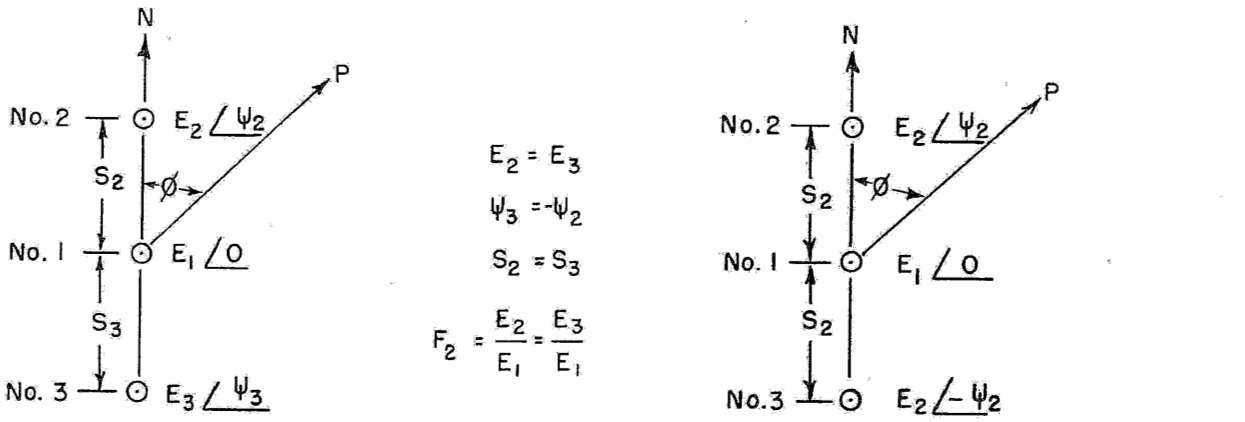
$$\phi_{N1} = 47.3^\circ \qquad \text{ANS.}$$

p. *THREE TOWER IN LINE PATTERNS USING THE ADDITION FORM.*--Referring back to Fig. 24 a three tower in line array can be obtained by placing another tower at the space reference point as shown in Fig. 34. For this special condition the design equation is

$$\left| E \right| = E_1 f_1(\theta) \left[1 + 2 F_2 \cos (S_2 \cos \theta \cos \phi + \Psi_2) \right] \tag{52}$$

where the values are as defined above and specified in Fig. 34(c).

In this case towers No. 2 and No. 3 must be of the same height. If tower No. 1 is different in height F_2 must be determined from Eq. (38). In Eq. (52) the non-directional pattern of the center tower is represented by number one the first term inside the bracket. $E_1 f_1(\theta)$ multiplied by this term gives the horizontal pattern as shown in Fig. 35(a). The second term within the bracket gives the pattern for No. 2 and No. 3 towers as shown in Fig. 32(b). This term is the same as Eq. (31)



(a) Original (b) Required equality. (c) Final values and equation.

THREE TOWER PLACEMENT FOR ADDITION METHOD

FIG. 34

except that f (θ) is multiplied by the magnitude term and the cos θ term is multiplied by the space phasing term in the angle. Also, the spacing is S_2 instead of $S_2/2$ and the phasing is Ψ_2 instead of $\Psi_2/2$. Eq. (31) is for the horizontal pattern while Eq. (52) gives the pattern for the hemisphere.

In Fig. 35 it will be noted that the vector which produces pattern No. 1 is positive and lies along the reference axis. For pattern No. 2 the sum of the two vectors for the end towers produces a positive vector which also lies along the reference axis for the positive lobe of the pattern and lies along the negative reference axis for the negative lobe of the pattern. The sum of these two pattern vectors gives the resultant addition pattern. It will be noted that both vectors lie along the vector reference axis. If it is desired to fill all nulls an equal amount the time phase of No. 1 tower can be shifted in accordance with Eq. (47).

EXAMPLE 19: When the antenna parameters in Fig. 34 are $E_1 = 63.5$ mv/m, $F_2 = F_3 = 1$, $S_2 = S_3 = 90$, and $\psi_2 = -\psi_3 = 90$ write out the horizontal pattern equation for the end towers acting alone and plot the pattern. Then add the center tower, write out the horizontal pattern equation for the 3 towers and plot the pattern.

SOLUTION: By Eq. (52) for the end towers only we have,

$$E = 63.5 \left[2 \cos (90 \cos \phi + 90)\right]$$

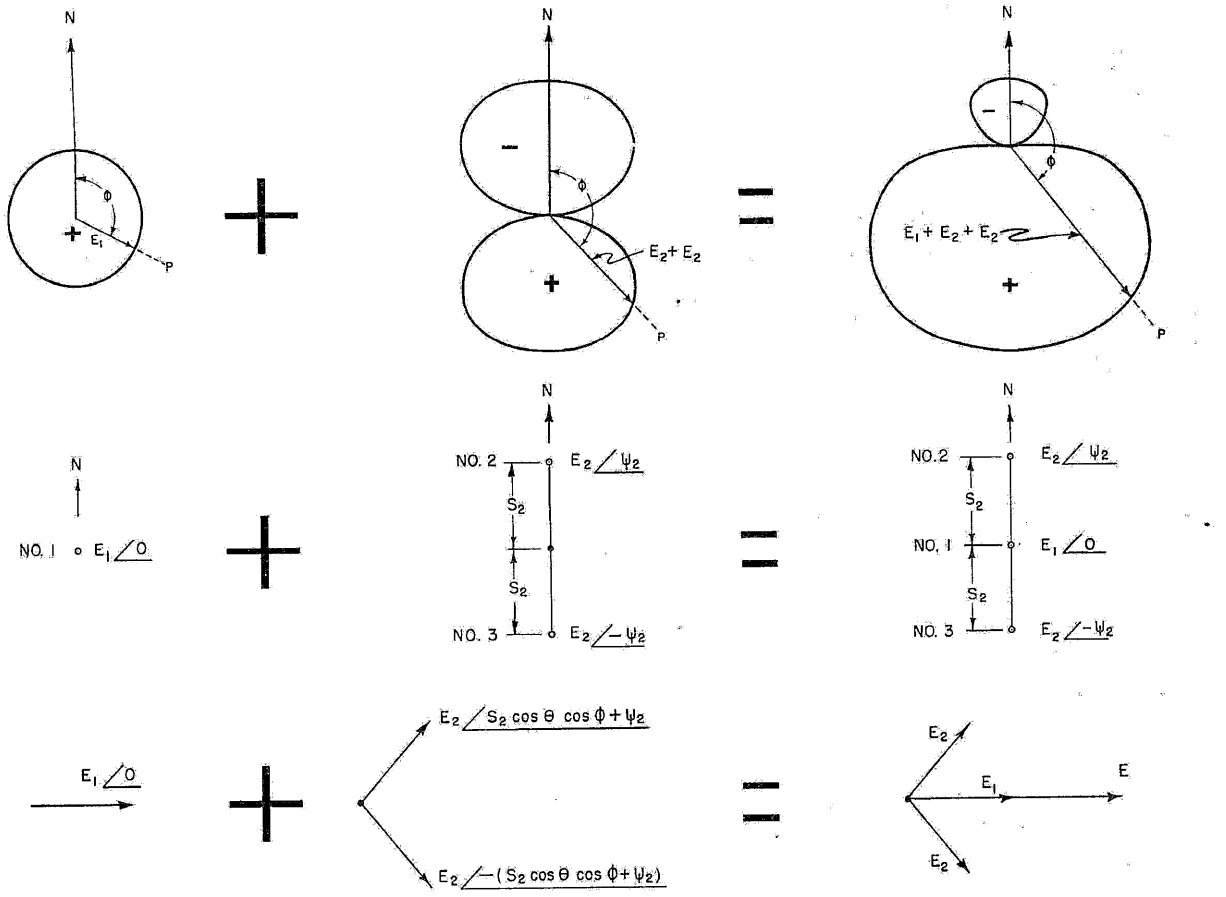
$$= 127 \cos (90 \cos \phi + 90) \quad \text{ANS}$$

This pattern is plotted in Fig. 35 (b) ANS

By Eq. (52) for all three towers we have

$$E = 63.5 \left[1 + 2 \cos (90 \cos \phi + 90)\right] \quad \text{ANS}$$

And the pattern is plotted in Fig. 35 (c) ANS



(a) PATTERN NO. 1 (b) PATTERN NO. 2 (c) ADDITION PATTERN NO. 3

ADDITION OF PATTERNS TO PRODUCE A THREE TOWER IN LINE ARRAY

FIG. 35

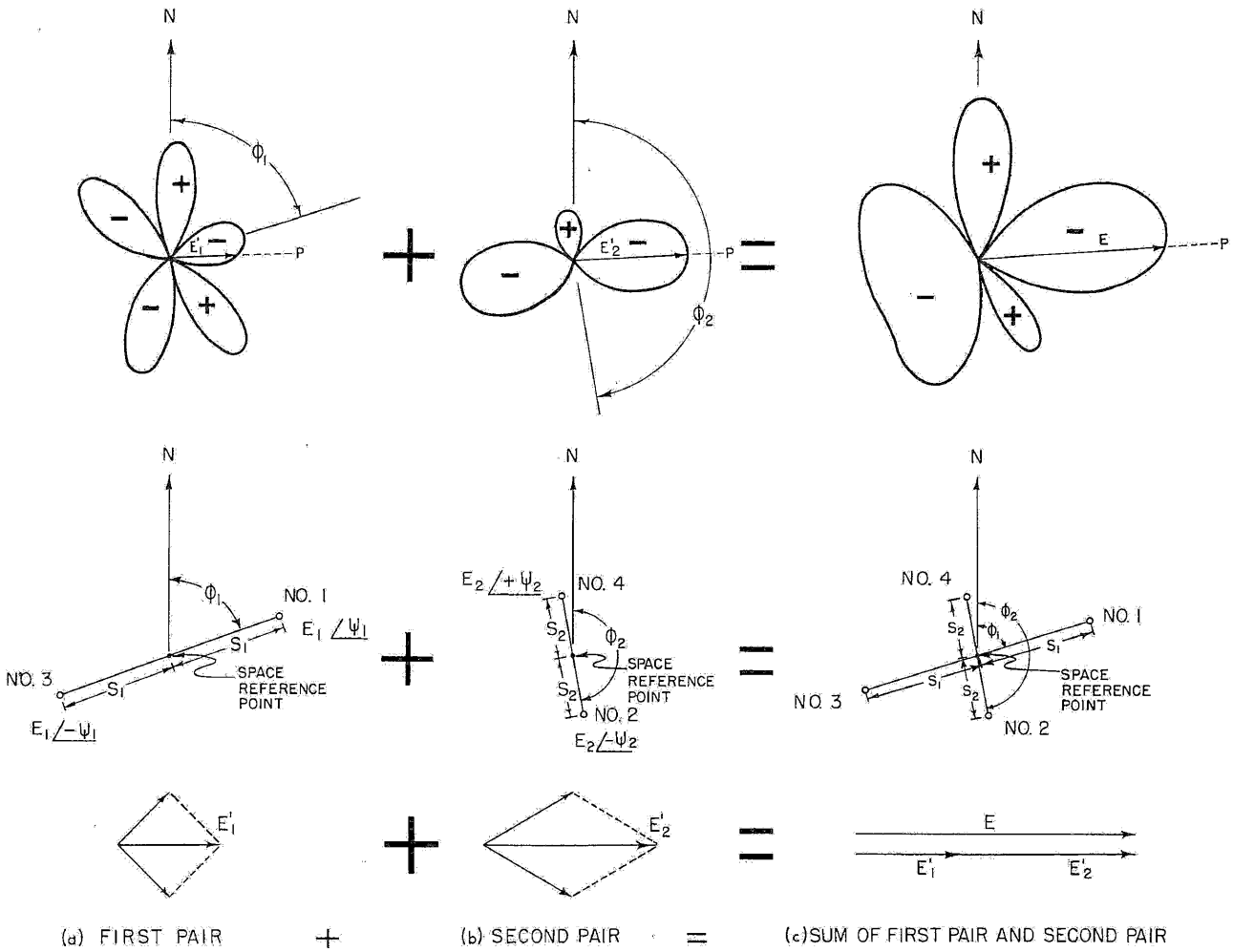
q. *FOUR TOWER PARALLELOGRAM ARRAY USING THE ADDITION FORM.*--The addition method in some respects is quite simple. With this method it is possible to lay one pattern on top of another pattern and make the required addition to produce the sum pattern. In general, to do this requires that the line of towers have different azimuth angles. Consider that towers No. 1 and No. 3 lie along a line making an angle ϕ_1 with respect to the reference axis as shown in Fig. 36(a). Similarly, place towers No. 2 and No. 4 along a line making an angle ϕ_2 with respect to the reference axis as shown in Fig. 36(b).

For the first pair of towers in Fig. 36(a) we can write,

$$E_1' = 2E_1 f_1(\theta) \cos\left[S_1 \cos\theta \cos(\phi_1 - \phi) + \Psi_1\right] \tag{53}$$

and for the second pair of towers in Fig. 36(b) we can write,

$$E_2' = 2E_2 f_2(\theta) \cos\left[S_2 \cos\theta \cos(\phi_2 - \phi) + \Psi_2\right] \tag{54}$$



ADDITION OF PATTERNS TO PRODUCE A FOUR TOWER PARALLELOGRAM ARRAY

FIG. 36

where

ϕ_1 = the azimuth orientation of the first pair of towers with respect to true north

ϕ_2 = the azimuth orientation of the second pair of towers with respect to true north

E_1' = field intensity from first pair of towers

E_2' = field intensity from second pair of towers

and the other values are as specified in Fig. 36. The total field intensity from the parallelogram array is then the *sum*,

$$\begin{aligned} E &= E_1' + E_2' \\ &= 2E_1 f_1(\theta) \cos \left[S_1 \cos\theta \cos(\phi_1 - \phi) + \Psi_1 \right] \\ &\quad + 2E_2 f_2(\theta) \cos \left[S_2 \cos\theta \cos(\phi_2 - \phi) + \Psi_2 \right] \end{aligned} \tag{55}$$

In this equation towers No. 1 and No. 3 must have the same height and towers No. 2 and No. 4 must have the same height because of the required symmetry to make the resultant vectors traverse the x-axis or reference axis. Since the resultant vectors of each pair is simply a positive or negative quantity the sum vector E must also be a simple positive or negative quantity.

EXAMPLE 20: A pair of towers having a spacing of 404° are arranged such that No. 1 tower has a true orientation of 73° with respect to No. 3 tower and a time phasing of -140° with respect to No. 3 tower. Another pair of towers are spaced 210° and arranged such that No. 2 tower has a true orientation of 170° with respect to No. 4 tower and a time phasing of 340° with respect to No. 4 tower. If the field intensity from each tower is unity, write out the addition form of the horizontal pattern design equation for each pair of towers acting alone and then give the design equation when the patterns are added together. Plot the pattern for each pair of towers acting alone and finally the pattern of the total field intensity of all four towers acting together. Also, show the arrangement for each pair of towers and the final arrangement of the four towers.

SOLUTION: From Eq. (53) the design equation for the first pair of towers No. 1 and No. 3 is

$$E_1' = 2 \cos \left[\frac{404}{2} \cos (73-\phi) - \frac{140}{2} \right]$$

$$= 2 \cos \left[202 \cos (73-\phi) - 70 \right] \quad \text{ANS}$$

And from Eq. (54) the design equation for the second pair of towers No. 2 and No. 4 is

$$E_2' = 2 \cos \left[\frac{210}{2} \cos (170-\phi) + \frac{340}{2} \right]$$

$$= 2 \cos \left[105 \cos (170-\phi) + 170 \right] \quad \text{ANS}$$

Finally, the design equation for the four tower array by Eq. (55) is

$$\begin{aligned} E &= E_1' + E_2' \\ &\quad 2 \cos \left[202 \cos (73-\phi) - 70 \right] \\ &\quad + 2 \cos \left[105 \cos (170-\phi) + 170 \right] \end{aligned} \quad \text{ANS}$$

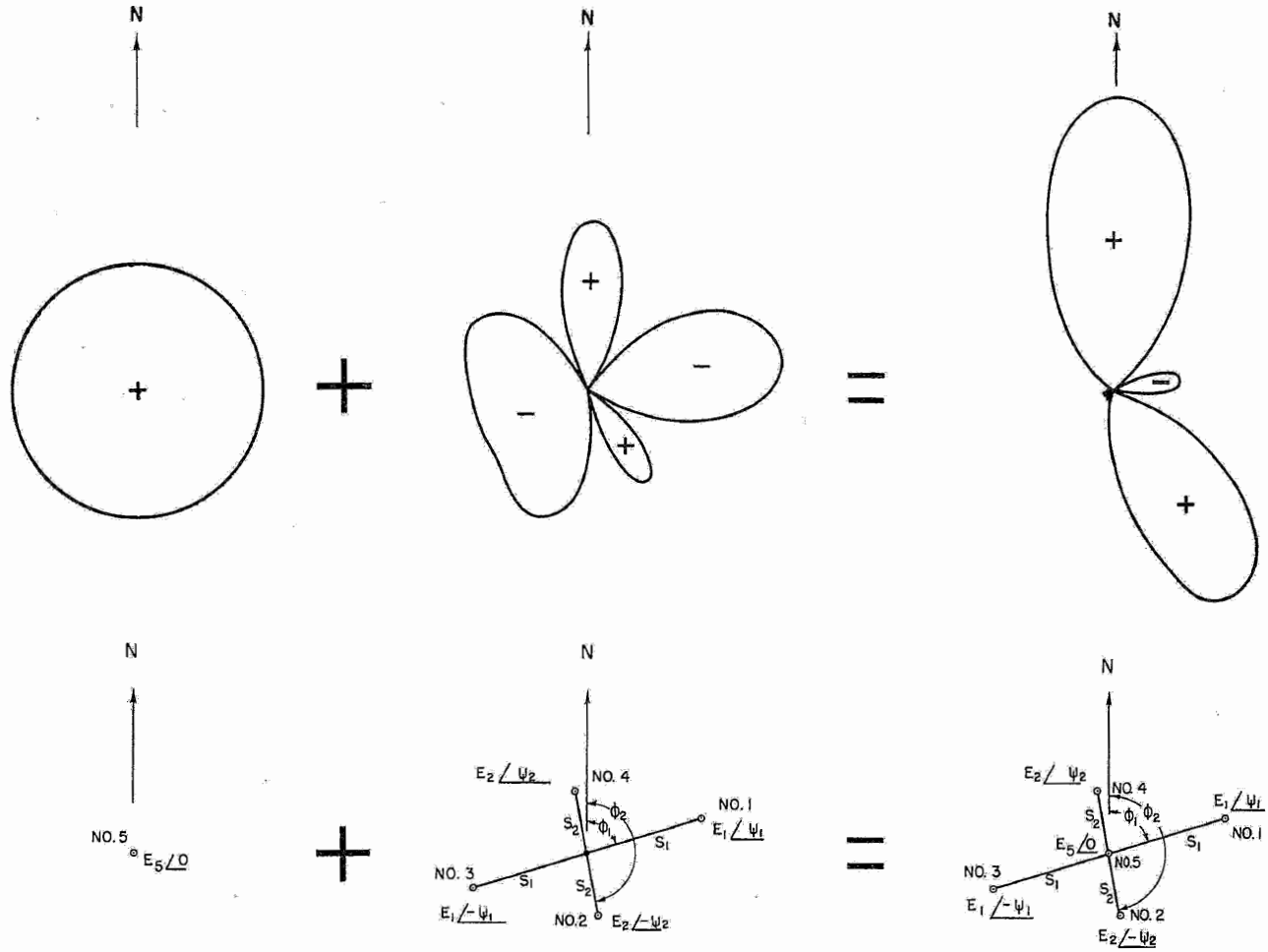
The required patterns along with the tower arrangements are shown in Fig. 36. ANS

r. *MULTI-TOWER ARRAYS USING THE ADDITION FORM.*--First let us consider a five tower array consisting of a parallelogram of four towers and a fifth tower at the space reference point. For this condition we can immediately write down the design equation which is the sum of the field from the center tower plus the sum of the fields from the other two pairs of towers, thus

$$\begin{aligned} E &= E_5 f_5(\theta) \\ &\quad + 2\, E_1 f_1(\theta) \cos \left[S_1 \cos\theta \cos(\phi_1 - \phi) + \Psi_1 \right] \\ &\quad + 2\, E_2 f_2(\theta) \cos \left[S_2 \cos\theta \cos(\phi_2 - \phi) + \Psi_2 \right] \end{aligned} \tag{56}$$

where the terms are defined as shown in Fig. 37

From the inductive steps taken in dealing with the addition form it should now be evident that more pairs of towers can be added by increasing the terms in Eq. (56).



ADDITION OF PATTERNS TO PRODUCE A FIVE TOWER DIRECTIONAL ARRAY

FIG. 37

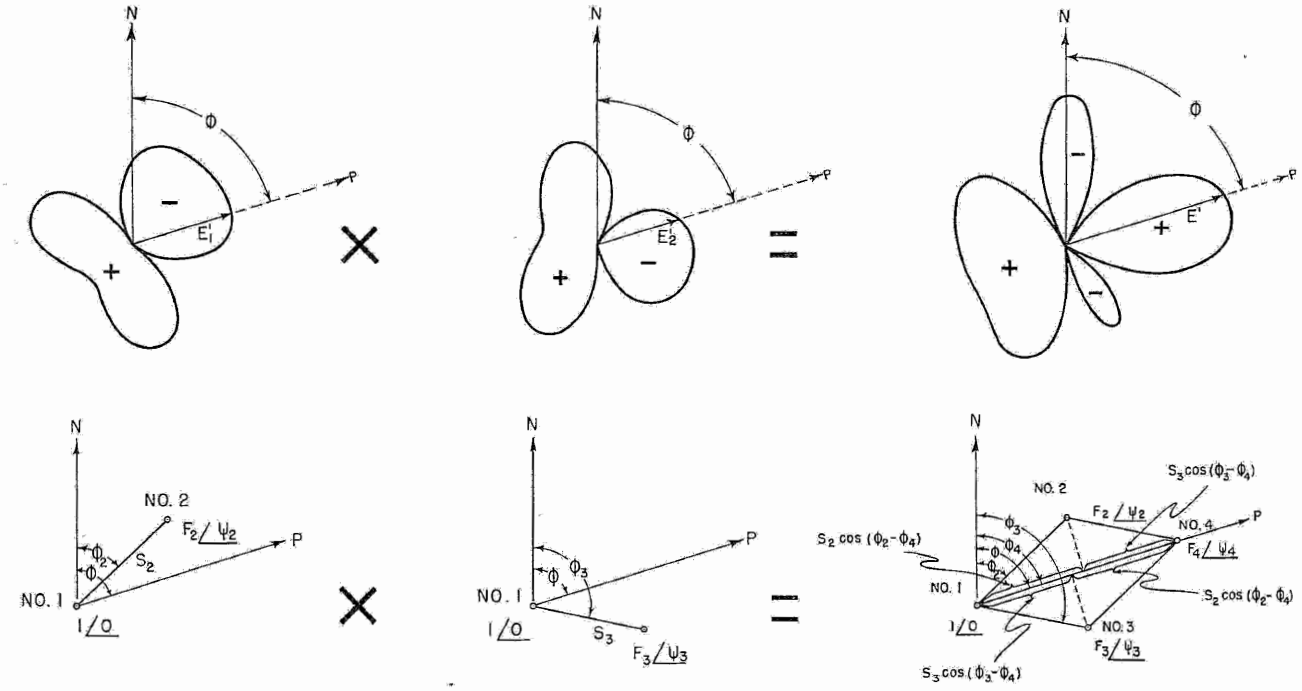
EXAMPLE 21: To the four tower array of Example 20 add a fifth tower at the space reference point which has a magnitude of 2.1 and zero time phasing. Write out the horizontal pattern design equation. Plot the single tower pattern, the four tower pattern and the five tower pattern. Show the tower arrangement.

SOLUTION: From Eq. (56) and the answer in Example (20) we can write,

$$E = 2.1 + 2\cos\left[202\cos(73-\phi) - 70\right] + 2\cos\left[105\cos(170-\phi) + 170\right] \quad \text{ANS}$$

The required patterns and tower arrangement are shown in Fig. 37 ANS

s. *FOUR TOWER PARALLELOGRAM ARRAY USING THE MULTIPLICATION FORM.*--The multiplication of two patterns which results in a four tower parallelogram array is one of the most useful tools in designing a directional antenna which must afford protection to a number of radio stations. The three tower in line array is actually a special case of the four tower parallelogram array. When the spacings are made equal and the azimuth angles of the tower pairs are identical the four tower parallelogram becomes a three tower in line array. In this case the center tower performs the function of two towers.



(a) 1ST PAIR OF TOWERS (b) 2ND PAIR OF TOWERS (c) 4 TOWER PARALLELOGRAM ARRAY

MULTIPLICATION OF PATTERNS TO PRODUCE A FOUR TOWER PARALLELOGRAM ARRAY

FIG. 38

In order to better understand the parallelogram array consider the multiplication applied to two pairs of towers as shown in Fig. 38. The normalized field (reference tower has unity as its field intensity) for the first pair of towers can be written,

$$E_1' = 1\angle 0 + F_2\angle\beta_2 \tag{57}$$

And the normalized field for the second pair of towers can be written

$$E_2' = 1\angle 0 + F_3\angle\beta_3 \tag{58}$$

By multiplying these two patterns together we get the total normalized field

$$\begin{aligned} E' &= E_1' E_2' = 1\angle 0 + F_2\angle\beta_2 + F_3\angle\beta_3 + F_2F_3\angle\beta_2 + \beta_3 \\ &= 1\angle 0 + F_2\angle\beta_2 + F_3\angle\beta_3 + F_4\angle\beta_4 \end{aligned} \tag{59}$$

where $F_2F_3 = F_4$ and $\beta_2 + \beta_3 = \beta_4$

This multiplication shows that the multiplication of two pairs of towers results in a four tower array. No. 1 tower is located at the space reference point, No. 2 tower is located where No. 2 tower of the first pair of towers is located with respect to the reference tower, No. 3 tower is located where No. 3 tower of the second pair of towers is located with respect to the reference tower of that pair, and the location of No. 4 tower is yet to be determined. Its location is controlled by the space phasing terms in β_4 which in turn is equal to the sum of the space phasing and time phasing terms of β_2 and β_3. This means that the sum of the space phasing terms No. 2 and No. 3 towers must equal the space phasing term of No. 4 tower, that is,

$$S_2\cos(\phi_2 - \phi) + S_3\cos(\phi_3 - \phi) = S_4\cos(\phi_4 - \phi) \tag{60}$$

as shown in Fig. 39 and the sum of the time phasing terms of towers No. 2 and No. 3 must equal the time phasing term of tower No. 4, thus

$$\psi_2 + \psi_3 = \psi_4 \tag{61}$$

If the multiplication of the patterns is to hold, tower No. 4 must be placed such that Eq. (60) is satisfied. Consider one case by making $\phi = \phi_4$ and place No. 4 tower at a point to complete the parallelogram. For these conditions we have Eq. (60) reduce to

$$S_2 \cos(\phi_2 - \phi_4) + S_3 \cos(\phi_3 - \phi_4) = S_4 \tag{62}$$

An inspection of the parallelogram in Fig. 38(c) reveals that this equation is true if the perpendicular lines are drawn from towers No. 2 and No. 3 to the line joining No. 1 and No. 4 towers.

Although this is not as rigorous a proof as could be furnished it is hoped that the geometrical picture makes the results more realistic.

Equation (43) can be generalized for the parallelogram array by simply orienting each pair of towers appropriately, thus,

$$E = 2E_1 f_1(\theta)\sqrt{F_2 F_3}\sqrt{\left[\frac{1+F_2^2}{2F_2} + \cos\left\{S_2 \cos\theta \cos(\phi_2 - \phi) + \Psi_2\right\}\right] \times \left[\frac{1+F_3^2}{2F_3} + \cos\left\{S_3 \cos\theta \cos(\phi_3 - \phi) + \Psi_3\right\}\right]} \tag{63}$$

where

E = magnitude of the resultant field, mv/m
$E_1 f_1(\theta)$ = field intensity from reference tower, mv/m
$F_2 = \frac{E_2}{E_1}$ ratio of field intensities of No. 2 and No. 1 towers
$F_3 = \frac{E_3}{E_1}$ ratio of field intensities of No. 3 and No. 1 towers
S_2 = spacing of No. 2 tower from No. 1 tower, degrees
θ = elevation angle of observation point, degrees
ϕ_2 = azimuth angle of tower No. 2 with respect to tower No. 1 degrees
ϕ = azimuth angle of observation point, degrees
Ψ_2 = time phase of No. 2 tower with respect to No. 1 tower, degrees
S_3 = spacing of No. 3 tower from No. 1 tower, degrees
ϕ_3 = azimuth angle of No. 3 tower with respect to No. 1 tower, degrees
Ψ_3 = time phase of No. 3 tower with respect to No. 1 tower, degrees

Although this equation does not specify No. 4 tower it is necessary to have No. 4 tower placed such that it will complete the parallelogram. Its field must be equal to

$$E_4 = E_1 F_2 F_3 \tag{64}$$

and its time phase must be

$$\Psi_4 = \Psi_2 + \Psi_3 \tag{65}$$

For the special case of equal field intensities from each tower Eq. (63) reduces to

$$E = 4E_1 f_1(\theta) \cos\left\{\frac{S_2}{2} \cos\theta \cos(\phi_2 - \phi) + \frac{\Psi_2}{2}\right\} \cos\left\{\frac{S_3}{2} \cos\theta \cos(\phi_3 - \phi) + \frac{\Psi_3}{2}\right\} \tag{66}$$

EXAMPLE 22: The first pair of towers No. 1 and No. 2 have the parameters, $\emptyset_2 = 47.10°$, $S_2 = 238.74°$ and $\psi_2 = 240°$. The second pair of towers No. 1 and No. 3 have the parameters, $\emptyset_2 = 101.8°$, $S_3 = 216.01°$ and $\psi_3 = 100°$. Tower No. 1 is at the space reference point for both pairs of towers. For unity field intensity give the design equation for each pair of towers acting alone and then give the design equation for the multiplied patterns. Finally, plot the patterns for each pair of towers acting alone and then plot the pattern for the four tower multiplied pattern. Also show the tower placement plans.

SOLUTION: Substituting in Eq. (40), after modification for the orientation of the array, for the first pair of towers results in

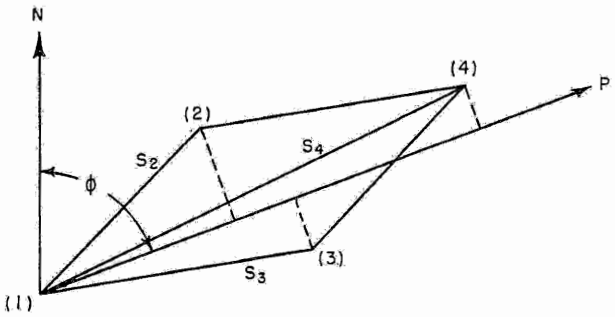


DIAGRAM TO ILLUSTRATE Eq. (60)

FIG. 39

$$E_{12} = E_1 \, f_1(\theta)\sqrt{2 F_2}$$

$$\times \sqrt{\frac{1 + F_2^2}{2 F_2} + \cos S_2 \cos \theta \cos (\phi_2 - \phi) + \psi_2}$$

For the horizontal pattern

$$E_{12} = E_1 \sqrt{2}$$

$$\times \sqrt{1 + \cos \left[S_2 \cos (\phi_2 - \phi) + \psi_2\right]}$$

$$= 2 E_1 \cos \left[\frac{S_2}{2} \cos (\phi_2 - \phi) + \frac{\psi_2}{2}\right]$$

And for the parameters specified

$$E_{12} = 2 \cos \left[119.37^\circ \cos (47.1^\circ - \phi) + 60^\circ\right] \quad \text{ANS}$$

In a similar fashion by Eq. (42) for the second pair of towers

$$E_{13} = 2 \cos \left[108^\circ \cos (101.8^\circ - \phi) + 50^\circ\right] \quad \text{ANS}$$

The design equation for the multiplied pattern by Eq. (66) is,

$$E = E_{12} \times E_{13}$$

$$= 4 \cos \left[119.37^\circ \cos (47.1^\circ - \phi) + 120^\circ\right]$$

$$\times \cos \left[108^\circ \cos (101.8^\circ - \phi) + 50^\circ\right] \quad \text{ANS}$$

The required patterns and tower placement plans are shown in Fig. 38 ANS

t. *SIX TOWER PARALLELOGRAM ARRAY USING THE MULTIPLICATION FORM*.--When simpler designs will not afford the required protections it is often possible to apply a six tower design to get the desired result. If the six towers are arranged in a parallelogram array the pattern is the result of multiplying three two-tower patterns. Two of the patterns must be the result of a three tower in line array with equal spacings between the towers. Often this type of array is referred to as a two by three tower multiplication.

If the three towers are located at an angle ϕ_2 with respect to the space reference axis and the two tower pair make an angle of ϕ_4 with respect to the space reference axis as shown in Fig. 40(a) the design equation can be written,

$$F = E_1 f_1(\theta) \sqrt{8F_2F_3F_4} \left\{\left[\frac{1 + F_2^2}{2F_2} + \cos\left\{S_2 \cos\theta \cos(\phi_2 - \phi) + \psi_2\right\}\right]\right.$$
$$\times \left[\frac{1 + F_3^2}{2F_3} + \cos\left\{S_2 \cos\theta \cos(\phi_2 - \phi) + \psi_3\right\}\right]$$
$$\left.\times \left[\frac{1 + F_4^2}{2F_4} + \cos\left\{S_4 \cos\theta \cos(\phi_4 - \phi) + \psi_4\right\}\right]\right\}^{\frac{1}{2}} \qquad (67)$$

In this equation it will be noted that the multiplication consists of three patterns two of which have a spacing of S_2 and an orientation of ϕ_2 since three of the towers are equally spaced and are in line.

For this design equation the nulls can be specified in the horizontal and elevation angles by the following equations in terms of phase angle and spacing, thus

$$\psi_2 = \pm 180 - S_2 \cos(\phi_2 \pm \phi_{N2}) \cos\theta_{N2}$$

where

ψ_2 = phase angle to use in Eq. (67)

S_2 = spacing to use in Eq. (67).

ϕ_2 = orientation of No. 2 and No. 3 towers. (68)

$\pm \phi_{N2}$ = orientation of nulls in horizontal plane with respect to the line of the 3 towers.

$\phi_2 \pm \phi_{N2}$ = orientation of nulls in horizontal plane of the two or more nulls for one pair of towers in the three tower lineup.

θ_{N2} = elevation angle of the nulls of the two or more nulls for one pair of towers in the three tower lineup.

The directional antenna parameters for the second pair of towers in the three tower lineup can be specified in terms of the orientation angle ϕ_{N3} and elevation angles θ_{N3} thus,

$$\Psi_3 = \pm 180 - S_2 \cos(\phi_2 \pm \phi_{N3}) \cos \theta_{N3} \tag{69}$$

and the other terms are similar to those defined in Eq. (68).

In a similar fashion the nulls for the third pair of towers can be written,

$$\Psi_4 = \pm 180 - S_4 \cos(\phi_4 \pm \phi_{N4}) \cos \theta_{N4} \tag{70}$$

With these last three equations it is possible to specify at least 6 nulls, two with each equation. If the spacing is greater than 180 degrees then more than 2 nulls can be specified for each pair of towers, or each equation.

For unity field ratios Eq. (67) reduces to the following simple form,

$$E = 8 E_1 f_1(\theta) \cos\left[\frac{S_2}{2} \cos\theta \cos(\phi_2 - \phi) + \frac{\Psi_2}{2}\right] \cos\left[\frac{S_2}{2} \cos\theta \cos(\phi_2 - \phi) + \frac{\Psi_3}{2}\right] \times \cos\left[\frac{S_4}{2} \cos\theta \cos(\phi_4 - \phi) + \frac{\Psi_4}{2}\right] \tag{71}$$

For the horizontal plane pattern this equation reduces to

$$E = 8 E_1 \cos\left[\frac{S_2}{2} \cos(\phi_2 - \phi) + \frac{\Psi_2}{2}\right] \cos\left[\frac{S_2}{2} \cos(\phi_2 - \phi) + \frac{\Psi_3}{2}\right] \times \cos\left[\frac{S_4}{2} \cos(\phi_4 - \phi) + \frac{\Psi_4}{2}\right] \tag{72}$$

This short form is very useful in locating nulls in the horizontal plane. After making this computation Eq. (41) or (45) can be used to determine the vertical radiation patterns.

EXAMPLE 23: By inductive reasoning write out the general design equation for a 9 tower array and sketch the tower layout.

SOLUTION: By referring to Eq. (63) and (67) it should be apparent that the required 9 tower array pattern design equation is,

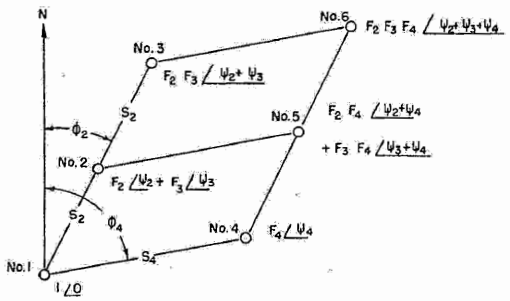
$$E = 4E_1 f_1(\phi) \sqrt{F_2 F_3 F_4 F_7} \times \left\{\left[\frac{1+F_2^2}{2 F_2} + \cos\{S_2 \cos\theta \cos(\phi_2 - \phi) + \psi_2\}\right] \times \left[\frac{1+F_3^2}{2 F_3} + \cos\{S_2 \cos\theta \cos(\phi_2 - \phi) + \psi_3\}\right] \times \left[\frac{1+F_4^2}{2 F_4} + \cos\{S_4 \cos\theta \cos(\phi_4 - \phi) + \psi_4\}\right] \times \left[\frac{1+F_7^2}{2 F_7} + \cos\{S_4 \cos\theta \cos(\phi_4 - \phi) + \psi_7\}\right]\right\}^{1/2}$$ ANS

And the tower layout sketch is shown in Fig. 40 (b) ANS

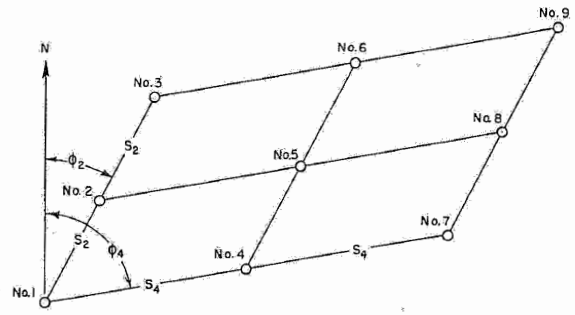
u. *FOUR TOWER IN LINE ARRAY USING THE MULTIPLICATION FORM.*--A special case of the 6 tower array which results in a 4 tower in line array is very useful because it gives the flexibility of multiplying three patterns. This design is limited to the same azimuth angle for all pairs of towers so in some cases a null may go to waste by giving protection where it is not needed.

In Eq. (67) if we let $S = S_2 = S_4$ and $\phi_2 = \phi_4$ the 6 tower array can be represented by 4 towers since tower No. 2 and No. 4 of Fig. (40(a) are the same and towers No. 3 and No. 5 are the same The resulting four tower array is given in Fig. 41(a) and the design equation is,

$$E = E_1 f_1(\theta)\sqrt{8F_2F_3F_4}\left\{\left[\frac{1+F_2^2}{2F_2}+\cos\left\{S\cos\theta\cos(\phi_2-\phi)+\psi_2\right\}\right]\right.$$
$$\times\left[\frac{1+F_3^2}{2F_3}+\cos\left\{S\cos\theta\cos(\phi_2-\phi)+\psi_3\right\}\right]$$
$$\left.\times\left[\frac{1+F_4^2}{2F_4}+\cos\left\{S\cos\theta\cos(\phi_2-\phi)+\psi_4\right\}\right]\right\}^{\frac{1}{2}} \qquad (73)$$



(a) SIX TOWER ARRAY



(b) NINE TOWER ARRAY

SIX AND NINE TOWER PARALLELOGRAM ARRAYS

FIG. 40

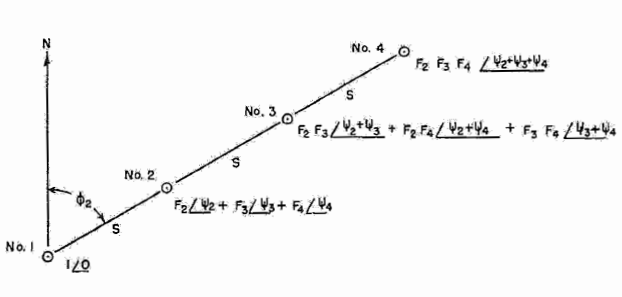
This equation, for unity field ratios, reduces to

$$E = 8E_1 f_1(\theta)\cos\left[\frac{S}{2}\cos\theta\cos(\phi_2-\phi)+\frac{\psi_2}{2}\right]\cos\left[\frac{S}{2}\cos\theta\cos(\phi_2-\phi)+\frac{\psi_3}{2}\right]$$
$$\times\cos\left[\frac{S}{2}\cos\theta\cos(\phi_2-\phi)+\frac{\psi_4}{2}\right] \qquad (74)$$

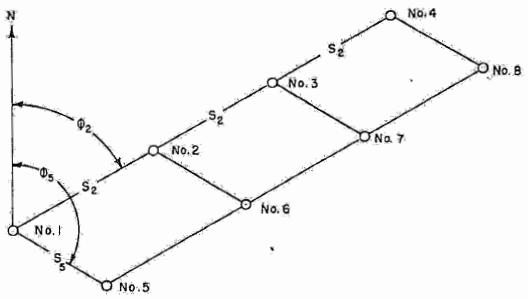
and for the horizontal pattern is further simplified to give

$$E = 8E_1\cos\left[\frac{S}{2}\cos(\phi_2-\phi)+\frac{\psi_2}{2}\right]\cos\left[\frac{S}{2}\cos(\phi_2-\phi)+\frac{\psi_3}{2}\right]$$
$$\times\cos\left[\frac{S}{2}\cos(\phi_2-\phi)+\frac{\psi_4}{2}\right] \qquad (75)$$

This short form is very simple considering that this equation actually represents an 8 tower array. This can be visualized by inspecting the array in Fig. 41(a). No. 1 and No. 4 towers represent single vectors. $1\angle 0$ and $F_2F_3F_4\angle\psi_2+\psi_3+\psi_4$ respectively while No. 2 and No. 3 towers represent three vectors each making a total of 8 vectors or 8 towers for the complete array.



(a) FOUR TOWER IN LINE ARRAY



(b) EIGHT TOWER PARALLELOGRAM ARRAY

(a) FOUR AND EIGHT TOWER ARRAYS

FIG. 41

EXAMPLE 24: By inductive reasoning write out the general design equation for an 8 tower array and sketch the tower layout.

SOLUTION: By referring to Eq. (67) and (73) it should be apparant that the required 8 tower array pattern design equation is,

$$E = 4\ E_1\ f_1(\phi) \quad \sqrt{F_2\ F_3\ F_4\ F_5}$$

$$\times \left\{ \left[\frac{1+F_2^2}{2\ F_2} + \cos \left\{ S_2 \cos\theta \cos(\phi_2 - \phi) + \psi_2 \right\} \right] \right.$$

$$\times \left[\frac{1+F_3^2}{2\ F_3} + \cos \left\{ S_2 \cos\theta \cos(\phi_2 - \phi) + \psi_3 \right\} \right]$$

$$\times \left[\frac{1+F_4^2}{2\ F_4} + \cos \left\{ S_2 \cos\theta \cos(\phi_2 - \phi) + \psi_4 \right\} \right]$$

$$\left. \times \left[\frac{1+F_5^2}{2\ F_5} + \cos \left\{ S_5 \cos\theta \cos(\phi_5 - \phi) + \psi_5 \right\} \right] \right\}^{1/2} \quad \underline{\text{ANS}}$$

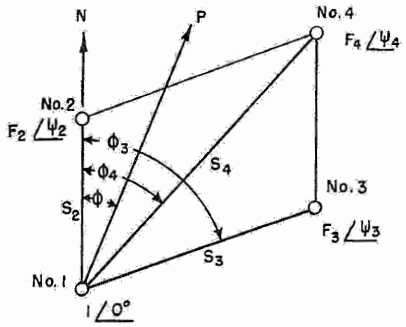
And the tower layout sketch is shown in Fig. 41 (b) ANS

v. *PROOF OF THREE AND FOUR TOWER MULTIPLICATION EQUATIONS.*--The multiplication Eq. (43) and (63) for three and four tower patterns must, by basic definition, be derived from the fundamental pattern formula, which by Eq. (27) is as follows

$$E = \sum_{k=1}^{k=n} E_k\ f_k(\theta) \quad \underline{|\beta_k}$$

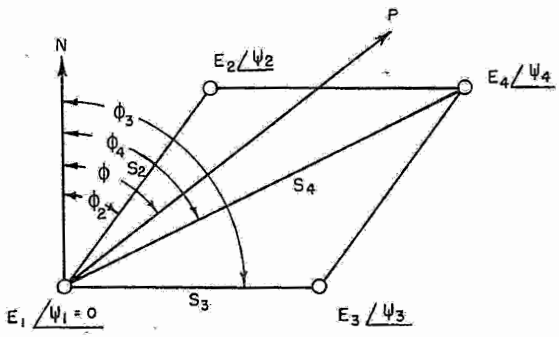
For those interested in a more rigorous proof of this fact the following development made by D. B. Hutton should be carefully studied, in order that the validity of the multiplication equation may be seen.

First of all for the four tower array shown in Fig. 42 the general pattern formula is



SIMPLIFIED FOUR TOWER PARALLELOGRAM ARRAY

FIG. 43



GENERAL FOUR TOWER CONFIGURATION

FIG. 42

$$E = E_1 f_1(\theta) \angle 0° + E_2 f_2(\theta) \angle \beta_2 + E_3 f_3(\theta) \angle \beta_3 + E_4 f_4(\theta) \angle \beta_4$$

which, expanded for the horizontal plane pattern, becomes

$$E = E_1 \angle 0° + E_2 \angle S_2 \cos(\phi_2 - \phi) + \Psi_2 + E_3 \angle S_3 \cos(\phi_3 - \phi) + \Psi_3 + E_4 \angle S_4 \cos(\phi_4 - \phi) + \Psi_4$$

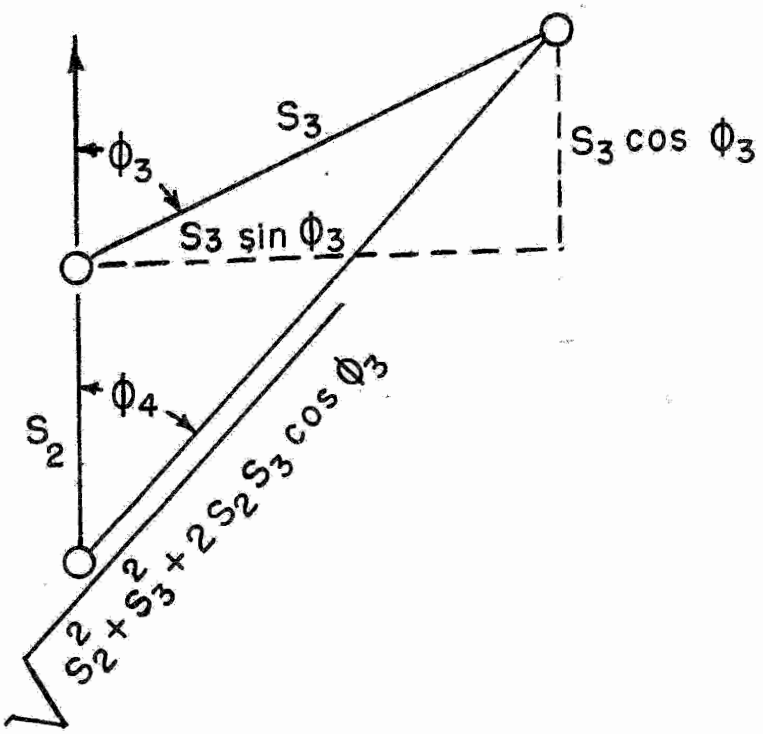
This expression can be simplified by placing No. 2 tower north of the reference point, making $\phi_2 = 0$, and by using field strength ratios giving

$$E = E_1 \left[1 + F_2 \angle S_2 \cos \phi + \Psi_2 + F_3 \angle S_3 \cos(\phi_3 - \phi) + \Psi_3 + F_4 \angle S_4 \cos(\phi_4 - \phi) + \Psi_4 \right.$$

The appearance of the array is now as in Fig. 43. Making use of identity of Eq. (37) the length of S_4 is given by the cosine law equation, and is

$$S_4 = \sqrt{S_2^2 + S_3^2 + 2S_2S_3 \cos \phi_3}$$

By constructing Fig. 44, below, the value of ϕ_4 can be determined in terms of the other parameters as shown.



DETERMINATION OF VALUE OF ϕ_4

FIG. 44

2-1-55

Therefore,

$$\tan \phi_4 = \frac{S_3 \sin \phi_3}{S_2 + S_3 \cos \phi_3}$$

$$\cos \phi_4 = \frac{S_2 + S_3 \cos \phi_3}{\sqrt{S_2^2 + S_3^2 + 2S_2S_3 \cos \phi_3}}$$

$$\sin \phi_4 = \frac{S_3 \sin \phi_3}{\sqrt{S_2^2 + S_3^2 + 2S_2S_3 \cos \phi_3}}$$

returning to the basic pattern formula on page 2-1-54 the angle $S_4 \cos(\phi_4 - \phi) + \Psi_4$ can now be rewritten as

$$\sqrt{S_2^2 + S_3^2 + 2S_2S_3 \cos \phi_3} \quad \cos(\phi_4 - \phi) + \Psi_4$$

inserting the terms above, and employing the identity

$$\cos(\alpha - \beta) = \cos \alpha \cos \beta + \sin \alpha \sin \beta$$

we have for the above angle

$$\sqrt{S_2^2 + S_3^2 + 2S_2S_3 \cos \phi_3} \left[\frac{S_2 + S_3 \cos \phi_3}{\sqrt{S_2^2 + S_3^2 + 2S_2S_3 \cos \phi_3}} \cos \phi \right.$$

$$\left. + \frac{S_3 \sin \phi_3 \cos \phi}{\sqrt{S_2^2 + S_3^2 + 2S_2S_3 \cos \phi_3}} \right] + \Psi_4.$$

$$= S_2 \cos \phi + \left[S_3 \cos \phi_3 \cos \phi + S_3 \sin \phi_3 \sin \phi \right] + \Psi_4$$

and returning the terms in brackets to the form given above the angle is

$$S_2 \cos \phi + S_3 \cos(\phi_3 - \phi) + \Psi_4$$

A vector diagram for the array of Fig. 43 then appears as in Fig. 45.

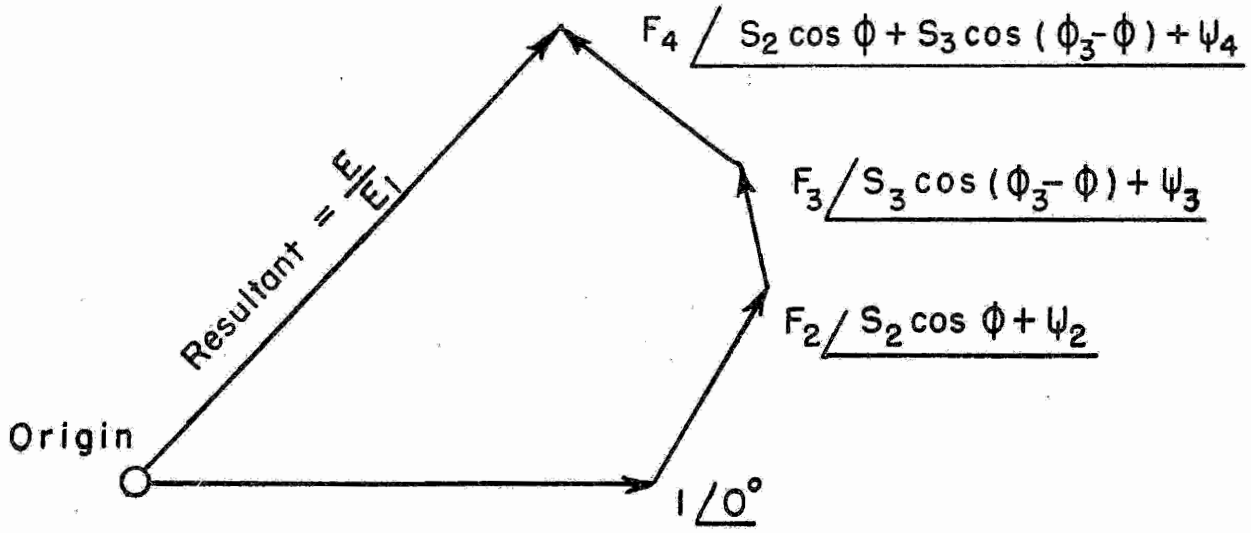
To simplify the angles above let

$$\beta_2 = S_2 \cos \phi + \Psi_2$$

$$\beta_3 = S_3 \cos(\phi_3 - \phi) + \Psi_3$$

So that

$$S_2 \cos \phi + S_3 \cos(\phi_3 - \phi) + \Psi_4 = \beta_2 + \beta_3 + \Psi_4 - \Psi_2 - \Psi_3 = \beta_4$$



VECTOR DIAGRAM OF ARRAY

FIG. 45

The vector diagram above can be resolved into its horizontal and vertical components and the resultant found by use of the expression

$$E = E_1 \sqrt{\left[1 + F_2 \cos\beta_2 + F_3 \cos\beta_3 + F_4 \cos\beta_4\right]^2 + \left[F_2 \sin\beta_2 + F_3 \sin\beta_3 + F_4 \sin\beta_4\right]^2}$$

The terms under the radical can be expanded by squaring and the resulting expression is then simplified by use of the trigonometric formulas

$$\sin^2\beta + \cos^2\beta = 1$$

$$\cos\beta_1 \cos\beta_2 = \frac{1}{2}\left[\cos(\beta_1 + \beta_2) + \cos(\beta_1 - \beta_2)\right]$$

$$\sin\beta_1 \sin\beta_2 = \frac{1}{2}\left[-\cos(\beta_1 + \beta_2) + \cos(\beta_1 - \beta_2)\right]$$

After making use of the above formulas to reduce terms in the expanded equation the field strength is written as

$$E = E_1 \left[1 + F_2^2 + F_3^2 + F_4^2 + 2F_2\cos\beta_2 + 2F_3\cos\beta_3 + 2F_4\cos\beta_4 + 2F_2F_4\cos(\beta_2 - \beta_4) + 2F_2F_3\cos(\beta_2 - \beta_3) + 2F_3F_4\cos(\beta_4 - \beta_3)\right]^{\frac{1}{2}}$$

In the next step F_4 is placed equal to F_2F_3 and ψ_4 is made equal to $\psi_2 + \psi_3$, whereupon $\beta_4 = \beta_2 + \beta_3$. Moreover, by making use of the trigonometric formula

$$\cos(\beta_1 + \beta_2) + \cos(\beta_1 - \beta_2) = 2\cos\beta_1 \cos\beta_2$$

the field strength can be written

$$E = E_1 \left[1 + F_2^2 + F_3^2 + F_2^2 F_3^2 + 2F_2 \cos \beta_2 + 2F_3 \cos \beta_3 + 4F_2F_3 \cos \beta_2 \cos \beta_3 + 2F_2^2 F_3 \cos \beta_3 + 2F_2F_3^2 \cos \beta_2 \right]^{\frac{1}{2}}$$

This, it can readily be demonstrated, is the expansion of the equation

$$E = E_1 \left[(1 + F_2^2 + 2F_2 \cos \beta_2)(1 + F_3^2 + 2F_3 \cos \beta_3) \right]^{\frac{1}{2}}$$

or, dividing by F_2 and F_3

$$E = 2E_1 \sqrt{F_2F_3} \left[\left(\frac{1 + F_2^2}{F_2} + \cos \beta_2 \right) \left(\frac{1 + F_3^2}{F_3} + \cos \beta_3 \right) \right]^{\frac{1}{2}},$$

And, as a final step, the values of β_2 and β_3 which have been given above, are substituted in the equation, giving the design Eq. (63) (also returning f (θ) and cos θ to the equation)

$$E = 2E_1 f_1(\theta) \sqrt{F_2F_3} \sqrt{\left[\frac{1 + F_2^2}{2F_2} + \cos \left\{ S_2 \cos \theta \cos (\phi_2 - \phi) + \Psi_2 \right\} \right] \times \left[\frac{1 + F_3^2}{2F_3} + \cos \left\{ S_3 \cos \theta \cos (\phi_3 - \phi) + \Psi_3 \right\} \right]}$$

And for the three tower in-line array on a north-south axis this equation reduces to that of Eq. (43).

$$E = 2E_1 f_1(\theta) \sqrt{F_2F_3} \sqrt{\left[\frac{1 + F_2^2}{2F_2} + \cos (S_2 \cos \theta \cos \phi + \Psi_2) \right] \times \left[\frac{1 + F_3}{2F_3} + \cos (S_3 \cos \theta \cos \phi + \Psi_3) \right]}$$

4. CONTROL OF PATTERN SIZE

a. *GENERAL DESIGN EQUATIONS FOR POWER FLOW INTEGRATION METHOD.*--(1) General Treatment--The total power radiated from a directional antenna array can be computed by integrating the energy flow outward through an imaginary spherical surface surrounding the directional antenna array. This method does not give information regarding the distribution of power to various towers of the directional antenna array, however, it is very useful for making comparisons of pattern size.

The rate of energy flow in watts per square meter at a given point P in space can be expressed by Poyntings vector, thus

$$= E \times H \qquad (76)$$

where p = watts per square meter energy flow
E = volts per meter electric field intensity
X = cross product sign
H = ampere-turns per meter magnetic field intensity

Out in free space the vectors E and H are orthogonal and have the following magnitude relationship,

$$H = \sqrt{\frac{\epsilon_o}{\mu_o}} E \qquad (77)$$

where $\mu_o = 4\pi 10^{-7}$ henries per meter the permeability of free space

$\epsilon_o = \frac{1}{\mu_o c^2}$ farads per meter the permittivity of free space

$c = 2.99776 \times 10^8$ meters per second the velocity of light.[5]

From these values the characteristic resistance of free space can be determined. The characteristic resistance of free space has a value of resistance such that no energy will be reflected. In other words, energy leaving the directional antenna array and flowing into free space will never return. In equation form

$$R_c = \mu_o c = \sqrt{\frac{\mu_o}{\epsilon_o}} \qquad (78)$$

where $R_c = 376.710$ ohms the characteristic resistance of free space.

Substituting Eq. (77) and (78) in Eq. (76) the power flow can be expressed

$$p = \frac{E^2}{R_c} \qquad (79)$$

If this power flow is integrated over an imaginary spherical surface surrounding the directional antenna array the total power radiated is

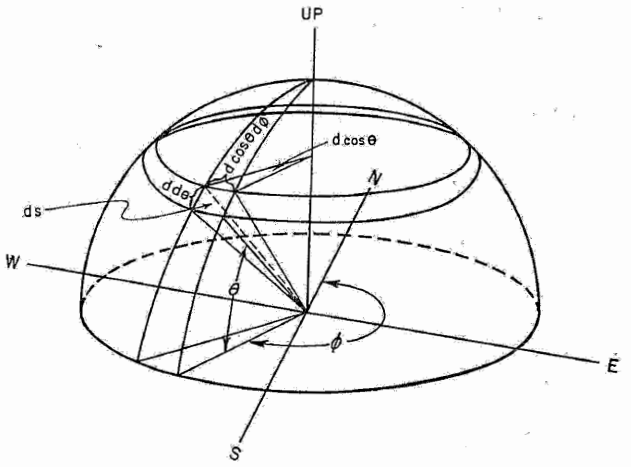
$$P_r = \int_{\text{spherical surface}} p \, dS = \frac{1}{R_c} \int_{\text{spherical surface}} E^2 \, dS \qquad (80)$$

where P_r = watts, total power radiated
R_c = 376.7 ohms the characteristic resistance of free space
E = volts per meter, total field intensity at the surface of the sphere
dS = square meters in the element of area on the surface of the sphere.

If the energy flow outward through the surface of the sphere is integrated as illustrated in Fig. 46 we can write

$$dS = d^2 \cos\theta \, d\theta \, d\phi \qquad (81)$$

where d = meters, radius of spherical surface and the other values are defined above. Substituting this value of dS in Eq. (80) gives



SPHERICAL SURFACE INTEGRATION

FIG. 46

$$P_r = \frac{1}{R_c} \int_0^{2\pi} \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} E^2 \, d^2 \cos\theta \, d\theta \, d\phi \qquad (82)$$

= total power radiated from an antenna system in free space.

(2) Field Intensity From a Standard Reference Antenna Which Has a Uniform Spherical Pattern.--If the field intensity is the same in all directions the E in Eq. (82) can be replaced by the constant E_s. Moving the constant E_s and d^2 outside of the integral signs and performing the indicated integrations gives

$$P_r = \frac{E_s^2 \, d^2}{R_c} \int_0^{2\pi} \int_{-\pi/2}^{+\pi/2} \cos\theta \, d\theta \, d\phi$$

$$= \frac{2 E_s^2 \, d^2}{R_c} \int_0^{2\pi} d\phi = \frac{4\pi E_s^2 \, d^2}{R_c} \qquad (83)$$

Solving this equation for the solid rms field intensity of a uniform spherical radiator

$$E_s = \sqrt{\frac{P_r \, R_c}{4\pi \, d^2}} \qquad (84)$$

For one kilowatt of radiated power the field intensity at one mile is

$$E_s = \sqrt{\frac{(1000)\ (376.710)}{4(3.14159)\ (1609.347)^2}}$$

$$= 107.584 \qquad (85)$$

[5] This figure $c = (2.99776 + 0.00004)10^{10}$ cm. sec^{-1} is from Raymond T. Birge, University of California published in Review of Modern Physics, Vol. 14, No. 4, p. 233, October 1941.

$\doteq$ 107.6 mv/m the field intensity at one mile for 1 kw from The Standard Reference Spherical Radiator.

(3) Field Intensity From a Standard Reference Antenna Which Has a Uniform Hemispherical Pattern.--In Eq. (82) the integration of θ is from 0 to $\pi/2$, that is, from zero elevation to straight up, therefore,

$$P_r = \frac{1}{R_c} \int_0^{2\pi} \int_0^{+\pi/2} E^2 \, d^2 \cos\theta \, d\theta \, d\phi \qquad (86)$$

Substituting the constant E_s for E and solving for E_s in a fashion similar to the procedure in Eq. (83) and (84) results in,

$$E_s = \sqrt{\frac{P_r \, R_c}{2\pi \, d^2}} \qquad (87)$$

For one kilowatt of radiated power the field intensity at one mile is,

$$E_s = 152.147 \qquad (88)$$

= 152.1 mv/m the field intensity at one mile for 1 kw from a standard reference hemispherical radiator.

This value can also be obtained by multiplying

$$107.584 \sqrt{2} = 152.147$$

(4) Maximum Field Intensity From a Current Element Antenna in Free Space.--For a current element in free space it is of academic interest to determine the maximum field intensity at one mile when one kilowatt of power is radiated. As given in Eq. (4) the field intensity pattern is a cosine function which if substituted in Eq. (82) gives

$$P_r = \frac{1}{R_c} \int_0^{2\pi} \int_{-\pi/2}^{+\pi/2} (E_o \cos\theta)^2 \, d^2 \cos\theta \, d\theta \, d\phi$$

$$= \frac{2\pi \, E_o^2 \, d^2}{R_c} \int_{-\pi/2}^{+\pi/2} \cos^3\theta \, d\theta = \frac{8\pi \, E_o^2 \, d^2}{3R_c} \qquad (89)$$

Solving for the maximum field intensity for one kilowatt of radiated power at a distance of one mile

$$E_o = \sqrt{\frac{3 \, P_r \, R_c}{8\pi \, d^2}} = 131.763 \qquad (90)$$

$\doteq$ 131.8 mv/m the maximum field intensity at one mile for 1 kw from a current element antenna in free space.

(5) Horizontal Field Intensity For a Vertical Current Element at the Surface of a Perfect Earth.--Substituting the cosine functions of Eq. (4) into Eq. (86) results in,

$$P_r = \frac{1}{R_c} \int_0^{2\pi} \int_0^{\pi/2} (E_o \cos\theta)^2 \, d^2 \cos\theta \, d\theta \cos\phi \, d\phi$$

$$= \frac{4\pi \, E_o^2 \, d^2}{3R_c} \qquad (91)$$

Solving for E_o the horizontal field intensity for one kilowatt of power radiated at a distance of one mile

$$E_o = \sqrt{\frac{3 \, P_r \, R_c}{4\pi \, d^2}} = 186.341 \qquad (92)$$

$\doteq$ 186.3 mv/m the maximum field intensity at one mile for one kilowatt from a vertical current element at the surface of a perfect earth.

(6) Field Intensity From a Center Fed Conductor of Length 2G in Free Space.--With a sinusoidal current distribution on the conductor as shown in Fig. 47, the field intensity at any angle from a plane passing through the center and perpendicular to the conductor is

$$E = E_o \, f(\theta) = E_o \frac{\cos(G \sin\theta) - \cos G}{(1-\cos G)\cos\theta} \qquad (93)$$

Substituting this value of E in Eq. (82) and integrating with respect to ϕ gives,

$$P_r = \frac{2\pi \, d^2 \, E_o^2}{R_c \, (1-\cos G)^2} \int_{-\pi/2}^{\pi/2} \frac{[\cos(G \sin\theta) - \cos G]^2}{\cos\theta} d\theta \qquad (94)$$

Performing the indicated integration[6],

$$P_r = \frac{2\pi \, d^2 \, E_o^2}{R_c \, (1-\cos G)^2} \left[(\gamma + \ln 2G - Ci \, 2G) \right.$$

$$\left. + 1/2 \sin 2G(Si \, 4G - 2 \, Si \, 2G) \right.$$

[6] See page 434 Ramo and Whinnery "Fields and Waves in Modern Radio," John Wiley and Sons - 1944.

$$+ 1/2 \text{ Cos } 2G(\gamma + \ln G - 2 \text{ Ci } 2G + \text{Ci } 4G) \;] \tag{95}$$

Solving this equation for E_o results in,

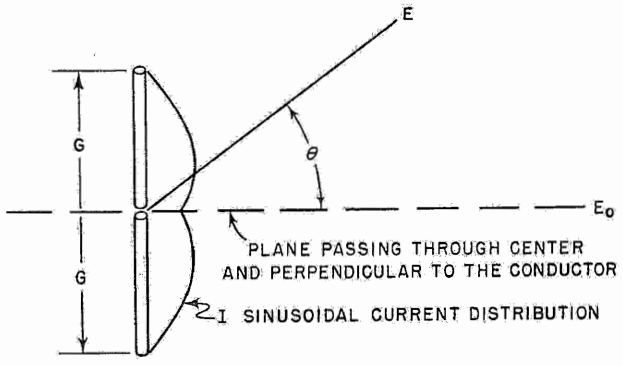
$$E_o = \frac{(1-\cos G)\sqrt{\frac{P_r R_c}{2\pi d^2}}}{\sqrt{\begin{array}{l}(\gamma + \ln 2G - \text{Ci } 2G) \\ + 1/2\ (\text{Si } 4G - 2 \text{ Si } 2G) \sin 2G \\ + 1/2\ (\gamma + \ln G - 2 \text{ Ci } 2G + \text{Ci } 4G) \cos 2G\end{array}}} \tag{96}$$

where E_o = volts per meter, the field intensity on a plane passing through the center and perpendicular to the conductor
P_r = watts, total power radiated
R_c = 376.710 ohms, the characteristic resistance of free space.
d = meters from the antenna
= 1609.347 meters in one mile
γ = 0.57721566 Euler's Constant
ln = natural logarithm to base $\epsilon = 2.71828$
Ci = cosine integral
Si = sine integral
2G = radians or degrees length of the conductor.

Substituting Eq. (96) in Eq. (93) gives the field intensity at any point in space, thus,

$$E = \frac{\dfrac{\cos(G \sin\theta) - \cos G}{\cos\theta}\sqrt{\frac{P_r R_c}{2\pi d^2}}}{\sqrt{\begin{array}{l}(\gamma + \ln 2G - \text{Ci } 2G) \\ + 1/2\ (\text{Si } 4G - 2 \text{ Si } 2G) \sin 2G \\ + 1/2\ (\gamma + \ln G - 2 \text{ Ci } 2G + \text{Ci } 4G) \cos 2G\end{array}}} \tag{97}$$

where θ = the elevation angle from the plane and the other terms are defined following Eq. (96)



CONDUCTOR OF LENGTH 2G IN FREE SPACE

FIG. 47

(7) Field Intensity From a Half Wave Antenna in Free Space.--For a half wave antenna radiating one kilowatt of power the field intensity at one mile, by substituting in Eq. (97) is

$$E = \frac{152.147\ \dfrac{\cos(90 \sin\theta)}{\cos\theta}}{\sqrt{1.21884}} = 137.813\ \frac{\cos(90 \sin\theta)}{\cos\theta} \text{ mv/m} \tag{98}$$

The space pattern resulting from this equation is shown in Fig. 5.

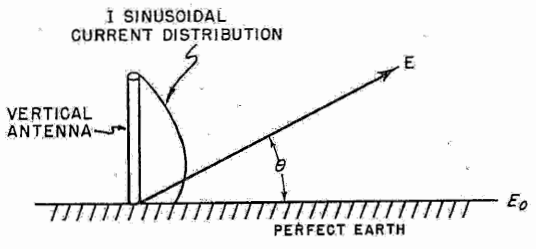
(8) Field Intensity From a Vertical Antenna of Height G Over a Perfectly Reflecting Earth.--Assuming sinusoidal current distribution the limits of integration in Eq. (94) are changed to cover the hemisphere above the surface of the earth, thus

$$P_r = \frac{2\pi d^2 E_o^2}{R_c (1-\cos G)^2} \; X \int_0^{\pi/2} \frac{\left[\cos(G \sin\theta) - \cos G\right]^2}{\cos\theta} d\theta \tag{99}$$

Performing the indicated integration and solving for E results in,

$$E = \frac{\dfrac{\cos(G \sin\theta) - \cos G}{\cos\theta}\sqrt{\frac{P_r R_c}{\pi d^2}}}{\sqrt{\begin{array}{l}(\gamma + \ln 2G - \text{Ci } 2G) \\ + 1/2\ (\text{Si } 4G - 2 \text{ Si } 2G) \sin 2G \\ + 1/2\ (\gamma + \ln G - 2 \text{ Ci } 2G + \text{Ci } 4G) \cos 2G\end{array}}} \tag{100}$$

where the terms are defined in Eq. (96) and (97) except E_o is the horizontal field intensity, G is the height of the antenna and θ is the elevation angle as shown in Fig. 48.



VERTICAL ANTENNA OF HEIGHT G OVER A PERFECT EARTH

FIG. 48

Along the horizontal plane Eq. (100) reduces to

$$E_o = \frac{(1-\cos G)\sqrt{\frac{P_r R_c}{\pi d^2}}}{\sqrt{\begin{array}{l}(\gamma + \ln 2G - Ci\ 2G) \\ + 1/2\ (Si\ 4G - 2\ Si\ 2G)\ \sin 2G \\ + 1/2\ (\gamma + \ln G - 2\ Ci\ 2G \\ + Ci\ 4G)\ \cos 2G\end{array}}} \quad (101)$$

If this theoretical field intensity E_o is plotted as a function of antenna height for one kilowatt of power at a distance of one mile the curve of Fig. 8 results.

As a matter of interest the loop radiation resistance for a thin vertical conductor is,

$$R_r = 29.99776 \left[\begin{array}{l}(\gamma + \ln 2G - Ci\ 2G) \\ + 1/2\ (Si\ 4G - 2\ Si\ 2G)\ \sin 2G \\ + 1/2\ (\gamma + \ln G - 2\ Ci\ 2G \\ + Ci\ 4G)\ \cos 2G \end{array} \right] \quad (102)$$

where R_r = ohms, loop radiation resistance of a thin vertical conductor over a perfectly conducting earth. This curve has also been plotted in Fig. 8.

For a vertical quarter wave antenna the loop radiation resistance is

$$R_r = (29.9978)\ (1.21884) = 36.5626 \text{ ohms}$$

The base resistance can be determined from the approximate equation,

$$R_b \doteq \frac{R_r}{\sin^2 G} \quad (103)$$

base resistance, ohms.

(9) Field Intensity From a Vertical Quarter Wave Antenna Over a Perfect Earth.--Substituting for $G = 90° = \pi/2$ radians in Eq. (100) when the power is one kilowatt and the distance is one mile the field intensity is,

$$E = 194.897 \frac{\cos(90 \sin\theta)}{\cos\theta} \quad \text{mv/m} \quad (104)$$

The vertical pattern resulting from this equation is shown in Fig. 7.

The field intensity along the surface of the earth from Eq. (104) is,

$E_o = 194.897$
$= 194.9$ mv/m the theoretical horizontal field intensity at one mile for one mile for one kw of power.

(10) Application of Power Flow Integration Method to Directional Antennas.--Thus far the power flow integration method has been applied to standard reference antennas, secondary standard reference antennas, and to the size of pattern produced by sinusoidal current distribution on a conductor in free space or a vertical radiator of various heights. The method is not confined to these special cases but can be applied to any directional antenna system so long as the field distribution is known from the individual elements that make up the system.

Considerable space has been devoted to determining the pattern size on a non-directional antenna, that is, an antenna which produces a constant field intensity at all azimuth angles in the horizontal plane and at any given elevation angle the field intensity is constant for all azimuth angles. The reason for this approach is that any directional antenna can be transformed to its equivalent non-directional antenna pattern. This can be accomplished by determining the root-mean-square of the pattern at each elevation angle, then it is only necessary to integrate this equivalent non-directional pattern with respect to the elevation angle since the determination of the rms values is the result of integrating the pattern with respect to the azimuth angle.

In order to develop this method consider the horizontal field intensity from two towers, one at the origin and one at the spacing S_2 due north. The total vector field is then

$$E = E_1 \underline{\lfloor o} + E_2 \underline{\lfloor S_2 \cos\phi + \Psi_2} \quad (105)$$

changing to rectangular form,

$$E = E_1 + E_2 \cos(S_2 \cos\phi + \Psi_2) + j\ E_2 \sin(S_2 \cos\phi + \Psi_2)$$

The magnitude of E squared is

$$\begin{aligned} E^2 &= E_1^2 + E_2^2 \cos^2(S_2 \cos\phi + \Psi_2) \\ &\quad + E_2^2 \sin^2(S_2 \cos\phi + \Psi_2) \\ &\quad + 2E_1 E_2 \cos(S_2 \cos\phi + \Psi_2) \\ &= E_1^2 + E_2^2 + 2E_1 E_2 \cos(S_2 \cos\phi + \Psi_2) \end{aligned} \quad (106)$$

From Eq. (86) performing the azimuth integration, we substitute the value of E^2 from Eq. (106) to get

$$\int_0^{2\pi} E^2\, d\phi = \int_0^{2\pi} \left[E_1^2 + E_2^2 \right.$$

$$+ 2E_1 E_2 \cos (S_2 \cos \phi + \Psi_2) \Big] \, d\phi$$

$$= 2\pi \left\{ E_1^2 + E_2^2 + 2E_1 E_2 \frac{1}{2\pi} \right.$$

$$\times \int_0^{2\pi} \Big[\cos (S_2 \cos \phi) \cos \Psi_2$$

$$\left. - \sin (S_2 \cos \phi) \sin \Psi_2 \Big] \, d\phi \right\}$$

The second term in the integral is zero as can be demonstrated by plotting the function. Therefore,

$$\int_0^{2\pi} E^2 \, d\phi = 2\pi \Big[E_1^2 + E_2^2$$

$$+ 2E_1 E_2 \cos \Psi_2 \frac{1}{2\pi} \int_0^{2\pi} \cos (S_2 \cos \phi) \, d\phi \Big]$$

$$= 2\pi \Big[E_1^2 + E_2^2 + 2E_1 E_2 \cos \Psi_2 J_o(S_2) \Big]$$

where $J_o(S_2)$ = a Bessel function of the first kind of a zero order. In this equation the phase Ψ and spacing S is between elements 1 and 2 hence a more general form is to write

Ψ_{12} = difference in electrical phase angle of the field from the 1st and the 2nd antenna,
S_{12} = electrical length of spacing between the 1st and 2nd antenna.

With this change in nomenclature the above equation becomes

$$\int_0^{2\pi} E^2 \, d\phi = 2\pi \Big[E_1^2 + E_2^2$$

$$+ 2E_1 E_2 \cos \Psi_{12} J_o(S_{12}) \Big] \qquad (107)$$

In this equation the integration is performed for only two antennas in the horizontal plane. This equation can be generalized to account for any elevation angle θ if the field intensities are multiplied by $f(\theta)$ and the spacing is multiplied by $\cos \theta$. Making these modifications Eq. (107) can be written,

$$E_\theta^2 = \frac{1}{2\pi} \int E^2 \, d\phi = E_1^2 f_1(\theta)^2 + E_2^2 f_2(\theta)^2$$

$$+ 2E_1 f_1(\theta) E_2 f_2(\theta) \cos \Psi_{12} J_o(S_{12} \cos \theta) \qquad (108)$$

where E_θ = root-mean-square field intensity radiated at the elevation angle θ. (In this case for only 2 antennas.)

If Eq. (108) is generalized for any number of elements in the directional antenna array the r-m-s field intensity at the elevation angle θ can be written

$$E_\theta = \sqrt{\sum_{p=1}^{p=n} \sum_{q=1}^{q=n} E_p f_p(\theta) E_q f_q(\theta) \times \cos \Psi_{pq} J_o(S_{pq} \cos \theta)} \qquad (109)$$

where E_θ = root-mean-square effective field intensity at the elevation angle θ.
p = p^{th} antenna in the system.
q = q^{th} antenna in the system.
n = number of elements in the complete directional antenna array.
E_p = horizontal magnitude of the field intensity produced by the p^{th} antenna.
$f_p(\theta)$ = vertical radiation characteristic of the p^{th} antenna.
E_q = horizontal magnitude of the field intensity produced by the q^{th} antenna.
$f_q(\theta)$ = vertical radiation characteristic of the q^{th} antenna
Ψ_{pq} = difference in electrical phase angle of the voltage (or current) between the p^{th} and q^{th} antennas in the directional antenna array.
S_{pq} = spacing in degrees or radians between the p^{th} and q^{th} antennas.
$J_o(S_{pq} \cos \theta)$ = Bessel function of the first kind and zero order of the apparent spacing between the p^{th} and the q^{th} antennas.

Analyzing Eq. (109) for a two element directional antenna reveals how Eq. (108) is deducted. When $p = 1$ and $q = 1$ we have the term $E_1 f_1(\theta) E_1 f_1(\theta) \cos \Psi_{11} J_0(S_{11} \cos \theta)$. Since $\Psi_{11} = 0$, $\cos \Psi_{11} = 1$ and since $S_{11} = 0$, $J_o(S_{11} \cos \theta) = 1$, thus resulting in the first term of Eq. (108) that is $E_1^2 f_1(\theta)^2$. In a similar fashion the second term of Eq. (108) results when $p = 2$ and $q = 2$, that is $E_2^2 f_2(\theta)^2$. When $p = 1$ and $q = 2$ we have the term $E_1 f_1(\theta) E_2 f_2(\theta) \cos \Psi_{12} J_o(S_{12} \cos \theta)$ which is one half of the third term in Eq. (108). For the condition $p = 2$ and $q = 1$ we have $E_2 f_2(\theta) E_1 f_1(\theta) \cos \Psi_{21} J_o(S_{21} \cos \theta)$. Since Ψ_{21} is the negative of Ψ_{12} and the cosine of a given positive or negative angle is the same, we can write $\cos \Psi_{12} = \cos \Psi_{21}$. The magnitude of $S_{12} = S_{21}$ because the distances are measured between the same two points. Therefore, when $p = 2$ and $q = 1$ the same value is obtained as when $p = 1$ and $q = 2$. The sum of these two terms results in the last term of Eq. (108) that is $2 E_1 f_1(\theta) E_2 f_2(\theta) \cos \Psi_{12} J_o(S_{12} \cos \theta)$. Since $n = 2$ in this case, all of the terms in the summation have been accounted for in the results given by Eq. (108).

To clarify the application of Eq. (109) consider a 3 element directional antenna system. In this case n = 3 and the equation can be written.

$$E_\theta = \sqrt{\begin{array}{l} E_1^2 f_1(\theta)^2 + E_2^2 f_2(\theta)^2 + E_3^2 f_3(\theta)^2 \\ +2 E_1 f_1(\theta)\, E_2 f_2(\theta) \cos \psi_{12} J_o(S_{12} \cos \theta) \\ +2 E_1 f_1(\theta)\, E_3 f_3(\theta) \cos \psi_{13} J_o(S_{13} \cos \theta) \\ +2 E_2 f_2(\theta)\, E_3 f_3(\theta) \cos \psi_{23} J_o(S_{23} \cos \theta) \end{array}} \qquad (110)$$

For a directional antenna with more elements the number of terms will increase. It will be noted that the general equation results in the following terms under the radical; first, the square of all the individual antenna field intensities and second, the terms written as twice the product of the field intensity of each individual antenna multiplied by the field intensity of each other individual antenna in the system and then multiplied by the cosine of the phasing of the currents between the antennas and the Bessel function of the apparent spacing between the antennas.

For the horizontal plane $\theta = 0$, $\cos \theta = 1$, $f_1(\theta) = 1$ and $f_2(\theta) = 1$ with the result that Eq. (109) can be reduced to

$$E_o = \sqrt{\sum_{p=1}^{p=n} \sum_{q=1}^{q=n} E_p E_q \cos \psi_{pq} J_o(S_{pq})} \qquad (111)$$

where E_o = root-mean-square effective field intensity in the horizontal plane, and the other values are defined in Eq. (109).

In terms of E_θ^2 as given in Eq. (108) it is possible to rewrite Eq. (86) as follows:

$$P_r = \frac{1}{R_c} \int_0^{2\pi} \int_0^{\pi/2} E^2 d^2 \cos \theta \, d\theta \, d\phi$$

$$= \frac{2\pi d^2}{R_c} \int_0^{\pi/2} E_\theta^2 \cos \theta \, d\theta \, d\phi \qquad (112)$$

The standard hemispherical field intensity produced by the directional antenna system can be obtained by substituting Eq. (112) in Eq. (87), thus,

$$E_s = \sqrt{\int_0^{\pi/2} E_\theta^2 \cos \theta \, d\theta} \qquad (113)$$

This is the *exact* formula for determining the size of the directional antenna pattern, however, to perform the integration for the general case would be quite tedious.

A practical and very useful solution is to determine the value of E_θ at a number of elevation angles and to replace the integral with the summation, thus, for intervals of 10 degrees of elevation the approximate equation by application of the trapezoidal rule[7] can be written

$$E_s \doteq \sqrt{\frac{\pi}{18} \left[\frac{E_o^2}{2} + \sum_{n=1}^{n=8} E_{10n}^2 \cos 10n \right]} \qquad (114)$$

where E_s = the standard hemispherical field intensity produced by the directional antenna system. (152.1 mv/m for 1 kw at 1 mile).

E_o = root-mean-square effective field intensity in horizontal plane.

E_{10n} = root-mean-square effective field intensity at the specified elevation angle.

n = integers from 1 to 8, which multiplied by 10 gives the elevation angle θ in degrees.

EXAMPLE 25: A four tower directional antenna system has the following parameters:

No.	G°	∅°	S°	ψ°	F
1	90	0	0	0	1.0
2	90	274.22	176	2	0.786
3	90	302.34	211.3	275	0.841
4	90	358.38	100	260	0.786

Determine the values of horizontal field intensity from each tower for 5 kw operation assuming the system loss is 405 watts according to FCC standards. What is the value of r-m-s field intensity for each 10° elevation angle?

SOLUTION: Initially solving for E_θ at every 10° elevation angle by Eq. (109) in terms of field ratios F results in column 2 of the following table

θ°	E_θ for $E_1 = 1$	E_θ for $E_1 = 275$
0	1.435	395
10	1.432	394
20	1.382	380
30	1.313	361
40	1.212	333
50	1.087	299
60	0.899	247
70	0.657	181
80	0.031	86

[7] Page 192, Smith's Applied Mathematics, published by McGraw-Hill Book Co. - 1945.

Now, by Eq. (114) we have,

$$E_s \doteq 1.236 \qquad \text{for } E_1 = 1$$

For 5 kw radiated the standard hemispherical field intensity will be

$$E_s = 152.1\sqrt{5} = 340 \text{ mv/m}$$

Therefore, the required values of field intensity are:

$E_1 = 340/1.236 = 275$ mv/m ANS

$E_2 = 275(0.786) = 216$ mv/m ANS

$E_3 = 275(0.841) = 231$ mv/m ANS

$E_4 = 275(0.786) = 216$ mv/m ANS

The final r-m-s field intensity for each 10° elevation angle is tabulated in column 3 of the above table. ANS

The input power for this problem according to FCC standards is 5,405 watts and the radiated power is 5 kw.

The solution of this problem is quite tedious by the method followed in this example, however with the help of a directional antenna pattern calculator which is capable of drawing the patterns at the various elevation angles the r-m-s values can be quickly measured from these patterns to get the required values of E_θ to use in Eq. (114).

b. *MUTUAL RESISTANCE METHOD OF DETERMINING PATTERN SIZE.*--(1) General Statement.--The power flow integration method can be used to determine the self and mutual resistance components of the elements in the directional antenna system. Since this method does not give information in regard to the reactance components it is not useful in determining the driving point impendance; however, because of its simplicity it is believed to be a very practical and useful method for determining pattern size. This method can be considered as an extension and simplification of the power flow integration method for some purposes.

(2) Relation of Field Intensity to Antenna Current.--First, let us write the equation for the field intensity E caused by a current I flowing in a single vertical conductor of height G over a perfect earth, thus,

$$E = \frac{R_c\, I \left[\cos(G \sin\theta) - \cos G\right]}{2\pi d \qquad \cos\theta} \tag{115}$$

where E = field intensity, volts per meter
R_c = 376.710 the characteristic resistance of free space, ohms
I = current at antenna current loop, amp.
d = distance from the antenna, meters
G = electrical height of antenna, degrees
θ = elevation angle, degrees.

If we define

$$h = \frac{\cos(G \sin\theta) - \cos G}{\sqrt{\cos\theta}} \tag{116}$$

later expressions can be simplified and Eq. (115) can be written.

$$E = \frac{R_c\, I}{2\pi d} \quad \frac{h}{\sqrt{\cos\theta}} \tag{117}$$

In the horizontal plane $\theta = 0$ and this equation reduces to

$$E = \frac{R_c\, I\,(1 - \cos G)}{2\pi d}. \tag{118}$$

(3) Self and Mutual Power Flow due to Self and Mutual Radiation Resistance Respectively.--By Eq. (79) the power flow vector in the direction of azimuth angle ϕ and elevation angle θ is

$$p = \frac{E^2}{R_c} \tag{79}$$

If the total vector field intensity E is the result of the two antennas with No. 1 antenna at the origin we can write

$$E = E_1\, f_1(\theta) \Big| 0 + E_2\, f_2(\theta) \Big| S_2 \cos(\phi_2 - \phi)\cos\theta + \Psi_2 \tag{119}$$

Changing to rectangular form

$$E = E_1\, f_1(\theta) + E_2\, f_2(\theta) \cos\left[S_2 \cos(\phi_2 - \phi)\cos\theta + \Psi_2\right] + j\, E_2\, f_2(\theta) \sin\left[S_2 \cos(\phi_2 - \phi)\cos\theta + \Psi_2\right] \tag{120}$$

The magnitude of E squared is

$$E^2 = E_1^2\, f_1(\theta)^2 + E_1\, f_1(\theta)\, E_2\, f_2(\theta) \cos\left[S_2 \cos(\phi_2 - \phi)\cos\theta + \Psi_2\right] + E_2\, f_2(\theta)\, E_1\, f_1(\theta) \cos\left[S_2 \cos(\phi_2 - \phi)\cos\theta + \Psi_2\right] + E_2^2\, f_2(\theta)^2 \tag{121}$$

Making this substitution in Eq. (79) gives

$$p = p_{11} + p_{12} + p_{21} + p_{22} \qquad (122)$$

where $p_{11} = \dfrac{E_1^2 \, f_1(\theta)^2}{R_c}$ (123)

= the self power flow due to the self resistance of antenna No. 1.

$$p_{12} = p_{21} = \frac{E_1 \, f_1(\theta) \, E_2 \, f_2(\theta) \cos \left[S_2 \cos (\phi_2 - \phi) \cos \theta + \Psi_2 \right]}{R_c} \qquad (124)$$

= one half of the mutual power flow due to the mutual resistance between antennas No. 1 and No. 2.

$$p_{22} = \frac{E_2^2 \, f_2(\theta)^2}{R_c} \qquad (125)$$

= the self power flow due to the self resistance of antenna No. 2.

The total power radiated by integrating the power flow of p over the hemisphere is

$$P_r = \int_{\text{hemispherical surface}} p \, dS = \int_{\text{hemispherical surface}} (p_{11} + 2p_{12} + p_{22}) \, dS \qquad (126)$$

(4) Integration of Power Flow to Determine the Self and Mutual Radiation Resistance.--Performing the integration on p_{11} by applying Eq. (86) results in the self-resistance radiated power from antenna No. 1.

$$P_{11} = \int_{\text{hemispherical surface}} \frac{E_1^2 \, f_1(\theta)^2}{R_c} \, dS$$

$$= \frac{E_1^2 d^2}{R_c} \int_0^{2\pi} \int_0^{\pi/2} f_1(\theta)^2 \cos \theta \, d\theta \, d\phi$$

$$= \frac{2\pi E_1^2 \, d^2}{R_c} \times$$

$$\int_0^{\pi/2} \left[\frac{\cos (G_1 \sin \theta) - \cos G_1}{(1 - \cos G_1) \cos \theta} \right]^2 \cos \theta \, d\theta$$

$$= \frac{2\pi E_1^2 \, d^2}{R_c (1 - \cos G_1)^2} \times$$

$$\int_0^{\pi/2} \frac{\left[\cos (G_1 \sin \theta) - \cos G_1 \right]^2}{\cos \theta} \, d\theta$$

$$= \frac{2\pi E_1^2 \, d^2}{R_c (1 - \cos G_1)^2} \int_0^{\pi/2} h_1^2 \, d\theta \qquad (127)$$

where h is defined in Eq. (116).

Now by Eq. (115) in the horizontal plane,

$$E_1^2 = \frac{R_c^2 \, I_1^2 \, (1 - \cos G)^2}{4\pi^2 \, d^2} \qquad (128)$$

which if substituted in Eq. (127) gives

$$P_{11} = I_1^2 \, R_{11} = I_1^2 \, \frac{R_c}{2\pi} \int_0^{\pi/2} h_1^2 \, d\theta \qquad (129)$$

$$R_{11} = \frac{R_c}{2\pi} \int_0^{\pi/2} h_1^2 \, d\theta \qquad (130)$$

= the self-loop radiation resistance of antenna No. 1.

In a similar fashion the self-resistance radiated power from antenna No. 2 is

$$P_{22} = I_2^2 \, R_{22} = I_2^2 \frac{R_c}{2\pi} \int_0^{\pi/2} h_2^2 \, d\theta \qquad (131)$$

where $R_{22} = \dfrac{R_c}{2\pi} \displaystyle\int_0^{\pi/2} h_2^2 \, d\theta$ (132)

= the self-loop radiation resistance of antenna No. 2.

Performing the integration on p_{12} by applying Eq. (86) results in one half of the mutual-resistance radiated power, thus,

$$P_{12} = \int_{\text{hemispherical surface}} \frac{E_1 \, f_1(\theta) \, E_2 f_2(\theta) \cos \left[S_2 \cos (\phi_2 - \phi) \cos \theta + \Psi_2 \right]}{R_c} \, dS$$

$$= \frac{E_1 \, E_2 \, d^2}{R_c} \times \int_0^{2\pi} \int_0^{\pi/2} f_1(\theta) \, f_2(\theta) \cos \left[S_2 \cos (\phi_2 - \phi) \cos \theta + \Psi_2 \right] \cos \theta \, d\theta \, d\phi$$

$$= \frac{2\pi E_1 E_2 d^2}{R_c(1 - \cos G_1)(1 - \cos G_2)} \cos \Psi_2$$

$$\times \int_0^{\pi/2} h_1 h_2 J_o(S_2 \cos \theta) \, d\theta \qquad (133)$$

Substituting for E_1 and E_2 in the horizontal plane by applying Eq. (118) gives

$$E_1 E_2 = \frac{R_c^2 I_1 I_2 (1 - \cos G_1)(1 - \cos G_2)}{4\pi^2 d^2} \qquad (134)$$

Substituting Eq. (134) in Eq. (133) yields

$$P_{12} = I_1 I_2 \cos \Psi_2 R_{12}$$

$$= I_1 I_2 \cos \Psi_2 \frac{R_c}{2\pi}$$

$$\int_0^{\pi/2} h_1 h_2 J_o(S_2 \cos \theta) \, d\theta \qquad (135)$$

where $$R_{12} = \frac{R_c}{2\pi} \int_0^{\pi/2} h_1 h_2 J_o(S_2 \cos \theta) \, d\theta \qquad (136)$$

= the mutual loop radiation resistance between antennas No. 1 and No. 2.

The self and mutual resistance terms can be determined quite readily by the following graphical method developed by Edgar F. Vandivere. Referring to Eq. (136) the following approximate equation can be written

$$R_{12} = \frac{R_c}{2\pi} \int_0^{\pi/2} h_1 h_2 J_o(S_{12} \cos \theta) \, d\theta$$

$$\doteq \frac{R_c}{36} \left[\frac{(1 - \cos G_1)(1 - \cos G_2) J_o(S_{12})}{2} \right.$$

$$\left. + \sum_{n=1}^{n=8} (h_1)_{\theta = 10n} (h_2)_{\theta = 10n} J_o(S_{12} \cos 10n) \right] \qquad (137)$$

By using curves of these three functions as drawn in Fig. 49 and Fig. 50 it is possible to determine the mutual resistance values in a relatively short time. This equation is valuable in that it will give the mutual resistance between towers of different heights.

EXAMPLE 26: Determine the mutual loop and base resistances between towers having heights of 90° and 120° when S = 200°

SOLUTION: Values of the height function h and the Bessel function J_o (S cos θ) are tabulated for various elevation angles.

n	θ	h_1 for G_1 = 90°	h_2 for G_2 = 120°	J_o(S cos θ) for S = 200°	$h_1 h_2 J_0$(S cos θ)
0	0			-0.38	
1	10	0.97	1.45	-0.37	-0.52
2	20	0.89	1.30	-0.34	-0.39
3	30	0.76	1.07	-0.27	-0.22
4	40	0.61	0.83	-0.13	-0.07
5	50	0.45	0.58	0.09	0.02
6	60	0.29	0.57	0.37	0.06
7	70	0.16	0.19	0.68	0.02
8	80	0.06	0.07	0.91	0.003

Substituting in Eq. (137) the mutual loop resistance is

$$R_{12} \doteq \frac{376.7}{36} \left[\frac{(1-\cos 90°)(1-\cos 120°)(-0.38)}{2} - 1.1 \right]$$

$$\doteq 10.46 \, (-0.285 - 1.1) = -14.5 \text{ ohms} \qquad \text{ANS}$$

The mutual base resistance is obtained by dividing by (sin G_1 sin G_2), thus,

$$R_{12} \doteq \frac{-14.5}{(1.0)(0.866)} = -16.75 \text{ ohms} \qquad \text{ANS}$$

This approximate value can be compared with -17 ohms as obtained from the mutual base impedance curves in Appendix A.

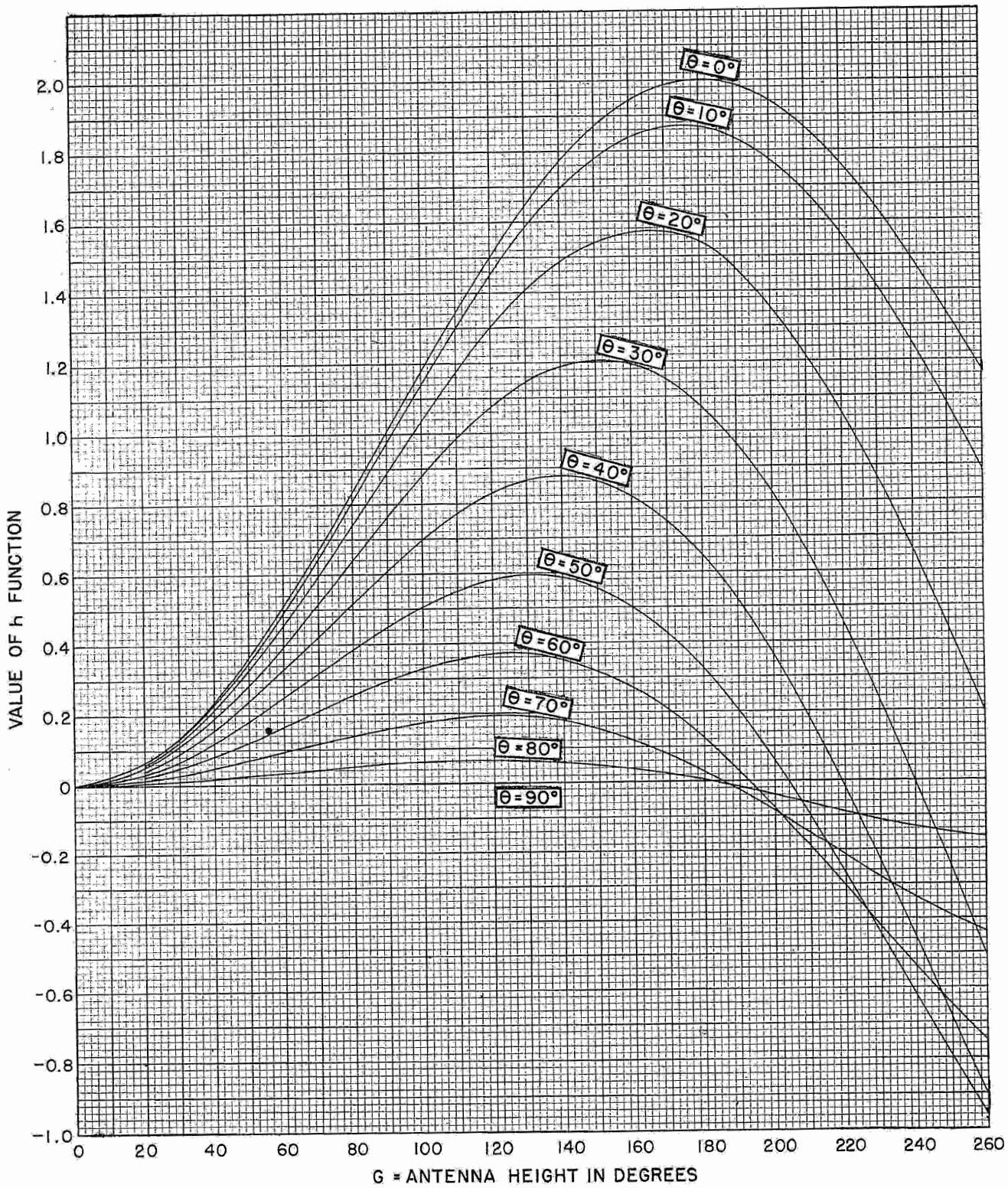
The total radiated power from the 2 element directional antenna system by Eq. (126), (129), (131), and (135) can be written

$$P_r = I_1^2 R_{11} + I_1 I_2 \cos \Psi_2 R_{12} + I_2 I_1 \cos \Psi_2 R_{21} + I_2^2 R_{22} \qquad (138)$$

or generalizing for any number of elements in the directional antenna system we can write

$$P_r = I_1^2 R_{11} + I_2^2 R_{22} + I_3^2 R_{33} + \cdots + 2I_1 I_2 \cos \psi_{12} R_{12} + 2I_1 I_3 \cos \psi_{13} R_{13} + 2 I_2 I_3 \cos \psi_{23} R_{23} + \cdots$$

$$= \sum_{p=1}^{p=n} \sum_{q=1}^{q=n} I_p I_q \cos \psi_{pq} R_{pq} \qquad (139)$$



VALUE OF h FUNCTION PLOTTED FOR VARIOUS VALUES OF ELEVATION ANGLE θ AS A FUNCTION OF ANTENNA HEIGHT G

FIG. 49

2-1-68

where $p = p^{th}$ antenna in the system
$q = q^{th}$ antenna in the system
n = number of elements in the complete directional antenna array
R_{pq} = the self-loop radiation resistance if $p = q$ and if $p \neq q$ the mutual-loop radiation resistance is expressed, ohms
I_p = loop current in the p^{th} antenna, amp.
I_q = loop current in the q^{th} antenna, amp.
ψ_{pq} = difference in electrical phase angle of the voltage (or current) between the p^{th} and q^{th} antennas in the directional antenna array, degrees.

(5) Expression for Determining Pattern Size and Resulting Horizontal rms Field Intensity.--The standard hemispherical field intensity E_s produced by the directional antenna system can be obtained by substituting Eq. (139) in Eq. (87), thus,

$$E_s = \sqrt{\frac{P_r R_c}{2\pi d^2}}$$

$$= \sqrt{\frac{R_c}{2\pi d^2} \sum_{p=1}^{p=n} \sum_{q=1}^{p=n} I_p I_q \cos \psi_{pq} R_{pq}} \qquad (140)$$

This is an *exact* formula for determining the size of the directional antenna pattern. It gives the same results as Eq. (113) but with the application of a summation instead of an integration. The integration of terms in Eq. (113) results in the mutual and self resistance terms R_{pq} of Eq. (140).

It is now desired to express the horizontal rms field intensity E_o as a function of the antenna heights, radiated power, field intensity ratios, phasings of the antenna currents, spacing, mutual and self resistances. For the purpose of this development let us consider only 2-elements in the directional antenna array.

By Eq. (111) the rms field intensity in the horizontal plane is

$$E_o = \sqrt{E_1^2 + E_2^2 + 2 E_1 E_2 \cos \psi_{12} J_o(S_{12})}$$

$$= E_1 \sqrt{1 + \left(\frac{E_2}{E_1}\right)^2 + 2 \left(\frac{E_2}{E_1}\right) \cos \psi_{12} J_o (S_{12})}.$$

Solving for E_1 we have

$$E_1 = \frac{E_o}{\sqrt{1 + \left(\frac{E_2}{E_1}\right)^2 + 2 \left(\frac{E_2}{E_1}\right) \cos \psi_{12} J_o(S_{12})}}. \qquad (141)$$

Solving for I_1 in Eq. (138) results in

$$I_1 = \frac{\sqrt{P_r}}{\sqrt{R_{11} \left[1 + \left(\frac{I_2}{I_1}\right)^2 \frac{R_{22}}{R_{11}} + 2 \left(\frac{I_2}{I_1}\right) \cos \psi_{12} \frac{R_{12}}{R_{11}} \right]}}$$

For equal height antennas $R_{11} = R_{22}$ and by Eq. (118) the current ratios can be replaced by field intensity ratios and I_1 can be replaced by E_1, thus the above equation becomes

$$E_1 = \frac{R_c (1 - \cos G)}{2\pi d \sqrt{R_{11}}} \sqrt{\frac{P_r}{1 + \left(\frac{E_2}{E_1}\right)^2 + 2 \left(\frac{E_2}{E_1}\right) \cos \psi_{12} \frac{R_{12}}{R_{11}}}} \qquad (142)$$

Equating the right hand members of Eq. (141) and (142) and solving for the horizontal rms field intensity results in

$$E_o = \frac{R_c (1 - \cos G)}{2\pi d} \sqrt{\frac{P_r}{R_{11}}} \times \sqrt{\frac{1 + \left(\frac{E_2}{E_1}\right)^2 + 2 \left(\frac{E_2}{E_1}\right) \cos \psi_{12} J_o(S_{12})}{1 + \left(\frac{E_2}{E_1}\right)^2 + 2 \left(\frac{E_2}{E_1}\right) \cos \psi_{12} \frac{R_{12}}{R_{11}}}} \qquad (143)$$

Or by applying Eq. (118) again and in doing so if the field intensity is called E_{1s} and defined as the horizontal field intensity from antenna No. 1 acting alone as a secondary reference antenna and radiating P_r then I_{1s} is the current in antenna No. 1 when the power is P_r. By making this substitution in Eq. (143) the first radical reduces to unity thus,

$$E_o = E_{1s}\sqrt{\frac{P_r}{I_{1s}^2 R_{11}}} \times \sqrt{\frac{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1}\cos\psi_{12}\, J_o(S_{12})}{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1}\cos\psi_{12}\frac{R_{12}}{R_{11}}}} = E_{1s}\sqrt{\frac{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1}\cos\psi_{12}\, J_o(S_{12})}{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1}\cos\psi_{12}\frac{R_{12}}{R_{11}}}} \qquad (144)$$

In Eq. (143) the horizontal rms field intensity for a 2-element directional antenna array with towers of equal height is expressed in terms of the independent directional antenna parameters; G, P_r, voltage (or current) ratio $\frac{E_2}{E_1}$, ψ_{12}, S_{12}, R_{12} and R_{11}. Eq. (144) expresses this same value in terms of E_{1s} instead of P_r.

It is interesting to note that the second radical in both Eq. (143) and (144) have numerators and denominators that are very similar, the only difference being that the numerator contains the Bessel function $J_o(S_{12})$ and the denominator contains the resistance ratio $\frac{R_{12}}{R_{11}}$.

Generalizing in Eq. (143) and (144) for any number of antennas, when the towers have the same height, results in the following very useful equations.

$$E_o \doteq \frac{R_c(1 - \cos G)}{2\pi d}\sqrt{\frac{P_r}{R_{11}}} \times \sqrt{\frac{\sum_{p=1}^{p=n}\sum_{q=1}^{q=n} E_p E_q \cos\psi_{pq} J_o(S_{pq})}{\sum_{p=1}^{p=n}\sum_{q=1}^{q=n} E_p E_q \cos\psi_{pq}\frac{R_{pq}}{R_{11}}}} \qquad (145)$$

$$E_o = E_{1s}\sqrt{\frac{\sum_{p=1}^{p=n}\sum_{q=1}^{q=n} E_p E_q \cos\psi_{pq} J_o(S_{pq})}{\sum_{p=1}^{p=n}\sum_{q=1}^{q=n} E_p E_q \cos\psi_{pq}\frac{R_{pq}}{R_{11}}}} \qquad (146)$$

where E_o = horizontal rms field intensity millivolts per meters.
R_c = 376.71 ohms the characteristic resistance of free space.
G = electrical height of each antenna, degrees.
d = radial distance of the observation point from the directional antenna system, meters.
P_r = total power radiated from the directional antenna system, watts.
R_{11} = self-loop radiation resistance, ohms, of each antenna since they are all of the same height.
E_{1s} = horizontal field intensity from antenna No. 1 acting alone as a secondary standard reference antenna and radiating P_r, millivolts per meter.
n = number of antennas in the system.
E_p = field intensity from the p^{th} antennas, millivolts per meter.
E_q = field intensity from the q^{th} antennas, millivolts per meter.
ψ_{pq} = difference in electrical phase angle of the voltage (or current) between the p^{th} and q^{th} antennas, electrical degrees.
S_{pq} = electrical length of the spacing between the p^{th} and q^{th} antennas, electrical degrees.
R_{pq} = mutual loop resistance between the p^{th} and q^{th} antennas, ohms.

As an illustration let us substitute in Eq. (145) and (146) to express the horizontal rms field intensity for a three tower directional antenna system.

For this case

$$E_o = \frac{R_c(1-\cos G)}{2\pi d}\sqrt{\frac{P_r}{R_{11}}} \sqrt{\frac{E_1^2 + E_2^2 + E_3^2 + 2E_1E_2\cos\Psi_{12}\, J_o(S_{12}) + 2E_1E_3\cos\psi_{13}\, J_o(S_{13}) + 2E_2E_3\cos\Psi_{23}\, J_o(S_{23})}{E_1^2 + E_2^2 + E_3^2 + 2E_1E_2\cos\Psi_{12}\frac{R_{12}}{R_{11}} + 2E_1E_3\cos\psi_{13}\frac{R_{13}}{R_{11}} + 2E_2E_3\cos\Psi_{23}\frac{R_{23}}{R_{11}}}} \qquad (147)$$

Or in terms of E_{1s}

$$E_o = E_{1s} \sqrt{\frac{\begin{array}{l} E_1^2 + E_2^2 + E_3^2 \\ + 2E_1E_2 \cos \psi_{12} J_o(S_{12}) \\ + 2E_1E_3 \cos \psi_{13} J_o(S_{13}) \\ + 2E_2E_3 \cos \psi_{23} J_o(S_{23}) \end{array}}{\begin{array}{l} E_1^2 + E_2^2 + E_3^2 \\ + 2E_1E_2 \cos \psi_{12} \frac{R_{12}}{R_{11}} \\ + 2E_1E_3 \cos \psi_{13} \frac{R_{13}}{R_{11}} \\ + 2E_2E_3 \cos \psi_{23} \frac{R_{23}}{R_{11}} \end{array}}} \quad (148)$$

where the terms are defined following Eq. (146).

EXAMPLE 27: A three tower directional antenna system has the following parameters:

No	G°	∅°	S°	ψ°	F
1	90	0	0	4	1.00
2	90	0	287	-49	0.56
3	90	180	287	49	0.56

Determine the theoretical value of E_0, E_1, E_2 and E_3 when the radiated power is 1 kw.

SOLUTION: Eq. (148) if expressed in terms of field intensity ratios can be re-written,

$$E_0 = E_{1s} \sqrt{\frac{\begin{array}{l} 1 + F_2^2 + F_3^2 \\ + 2F_2 \cos \psi_{12} J_0(S_{12}) \\ + 2F_3 \cos \psi_{13} J_0(S_{13}) \\ + 2F_2F_3 \cos \psi_{23} J_0(S_{23}) \end{array}}{\begin{array}{l} 1 + F_2^2 + F_3^2 \\ + 2F_2 \cos \psi_{12} \frac{R_{12}}{R_{11}} \\ + 2F_3 \cos \psi_{13} \frac{R_{13}}{R_{11}} \\ + 2F_2F_3 \cos \psi_{23} \frac{R_{23}}{R_{11}} \end{array}}}$$

where: $E_{1s} = 194.9$ mv/m by Eq. (104)

$F_2 = 0.56$, $F_2^2 = 0.3136$

$F_3 = 0.56$, $F_3^2 = 0.3136$

$F_2F_3 = 0.3136$

$\cos \psi_{12} = \cos(-53°) = 0.6018$

$\cos \psi_{13} = \cos 45° = 0.7071$

$\cos \psi_{23} = \cos 98° = -0.1392$

$J_0(S_{12}) = J_0(S_{13}) = J_0(287°) = -0.1776$

$J_0(S_{23}) = J_0(574°) = -0.2460$

$R_{11} = R_{22} = R_{33} = 36.56$ ohms by Fig. 8 or Eq. (102)

$R_{12} = R_{13} = -9.5$ ohms by Appendix A

$R_{23} = -3.68$ ohms by Eq. (25)

Substituting in the above equation

$$E_0 = 194.9 \sqrt{\frac{\begin{array}{l} 1 + 0.3136 + 0.3136 \\ + 2(0.56)(0.6018)(-0.1743) \\ + 2(0.56)(0.7071)(-0.1743) \\ + 2(0.3136)(-0.1392)(-0.2467) \end{array}}{\begin{array}{l} 1 + 0.3136 + 0.3136 \\ + 2(0.56)(0.6018)(-0.26) \\ + 2(0.56)(0.7071)(-0.26) \\ + 2(0.3136)(-0.1392)(-0.101) \end{array}}}$$

$$= 194.9 \sqrt{\frac{1.6272 - 0.1172 - 0.1381 + 0.0215}{1.6272 - 0.1752 - 0.2059 + 0.0087}}$$

$$= 194.9 \sqrt{\frac{1.3934}{1.2548}} = 194.9 \sqrt{1.111} = 194.9(1.055)$$

$$= 205.6 \text{ mv/m} \quad \text{ANS}$$

By Eq. (110) for E_1 when $\theta = 0$ we have

$$E_1 = \frac{E_0}{\sqrt{\begin{array}{l} 1 + F_2^2 + F_3^2 \\ + 2 F_2 \cos \psi_{12} J_0(S_{12}) \\ + 2 F_3 \cos \psi_{13} J_0(S_{13}) \\ + 2 F_2F_3 \cos \psi_{23} J_0(S_{23}) \end{array}}}$$

$$E_1 = \frac{205.6}{\sqrt{1.3934}} = 174 \text{ mv/m} \quad \underline{\text{ANS}}$$

$$E_2 = E_1 F_2 = 174\ (0.56) = 97.5 \text{ mv/m} \quad \underline{\text{ANS}}$$

$$E_3 = E_1 F_3 = 174\ (0.56) = 97.5 \text{ mv/m} \quad \underline{\text{ANS}}$$

c. *DRIVING POINT IMPEDANCE METHOD OF DETERMINING PATTERN SIZE.*--(1) Derivation of Driving Point Impedance.--The total power radiated from a directional antenna system is the sum of the radiation power fed to the respective antennas. If the driving point resistance and input current to each antenna is known, the total radiated power is given by

$$P_r = \sum_{k=1}^{k=n} I_k^2 R_k$$

$$= I_1^2 R_1 + I_2^2 R_2 + \cdots + I_k^2 R_k + \cdots + I_n^2 R_n \qquad (149)$$

where P_r = total power radiated from the directional antenna, watts.
I_k = effective current at the input terminals of the k^{th} antenna amp.
R_k = driving point or radiation resistance at the input terminals of the k^{th} antenna, ohms.
n = number of antennas in the directional antenna array.

The driving point or radiation resistance R_k is the resistance component of the driving point reactance Z_k of the k^{th} antenna. The driving point impedance can be determined by using mesh circuit equations when the self-impedance of each antenna, mutual impedance between each pair of antennas and current input to each antenna is known. To properly solve the mesh circuit equations, all quantities must be handled as vectors. The mesh circuit equations for n antennas in the directional antenna system is given by

$$\begin{aligned}
V_1 &= I_1 Z_{11} + I_2 Z_{12} + \cdots + I_k Z_{1k} + \cdots + I_n Z_{1n} \\
V_2 &= I_1 Z_{21} + I_2 Z_{22} + \cdots + I_k Z_{2k} + \cdots + I_n Z_{2n} \\
&\vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \\
V_k &= I_1 Z_{k1} + I_2 Z_{k2} + \cdots + I_k Z_{kk} + \cdots + I_n Z_{kn} \\
&\vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \\
V_n &= I_1 Z_{n1} + I_2 Z_{n2} + \cdots + I_k Z_{nk} + \cdots + I_n Z_{nn}
\end{aligned} \qquad (150)$$

where V_k = vector effective voltage at the input terminals of the k^{th} antenna, volts.
I_k = vector effective current, at the input terminals of the k^{th} antenna, amp.
Z_{kk} = self impedance of the k^{th} antenna, ohms.
Z_{kn} = mutual impedance between the k^{th} and n^{th} antennas, ohms.

All of the values given in Eq. (150) refer to the antenna terminals specified by the subscripts. If all of the currents and impedances are known then all of the input voltages can be determined by solving the set of simultaneous equations given in Eq. (150).

From this set of simultaneous equations it is possible to define the driving point of impedance of the k^{th} antenna as follows

$$\begin{aligned}
Z_k &= \frac{V_k}{I_k} \\
&= \frac{I_1}{I_k} Z_{k1} + \frac{I_2}{I_k} Z_{k2} + \cdots + Z_{kk} + \cdots + \frac{I_n}{I_k} Z_{kn}
\end{aligned} \qquad (151)$$

where Z_k = ohms, driving point impedance of the k^{th} antenna and the other quantities are defined following Eq. (150). The resistance component R_k of Z_k is a pure radiation resistance only if there is no loss in the system. The directional antenna system can be calculated on this theoretical basis and then from a knowledge of the system the losses can be estimated with fair accuracy.

The problem now resolves itself to a determination of the self and mutual impedance and then with the current magnitude and phase specified for each antenna, Eq. (150) and (151) can be used to determine the respective driving point impedances. Since Eq. (151) will yield both the resistance and reactance components of the driving point impedance it is useful in designing the impedance matching networks between the respective transmission lines and antennas in the directional antenna array.

To determine the driving point resistance of the k^{th} antenna, the real part of Eq. (151) can be written

$$\begin{aligned}
R_k = &\left|\frac{I_1}{I_k}\right| \left|Z_{1k}\right| \cos\left(\psi_{1k} + \gamma_{1k}\right) \\
&+ \left|\frac{I_2}{I_k}\right| \left|Z_{2k}\right| \cos\left(\psi_{2k} + \gamma_{2k}\right) \\
&+ \cdots + \left|Z_{kk}\right| \cos \gamma_{kk} \\
&+ \cdots + \left|\frac{I_n}{I_k}\right| \left|Z_{nk}\right| \cos\left(\psi_{nk} + \gamma_{nk}\right)
\end{aligned} \qquad (152)$$

where R_k = driving point resistance (or radiation resistance; if the system has no loss) at the input terminals of the k^{th} antenna, ohms

$\left|\frac{I_1}{I_k}\right| \left|Z_{1k}\right| \cos(\psi_{1k} + \gamma_{1k})$ = resistance at the input terminals of the k^{th} antenna due to the effect of antenna No. 1, ohms.

$\left|\frac{I_1}{I_k}\right| \angle \psi_{1k} = \frac{I_1}{I_k}$, the vector value of the current ratio for the current at the input terminals of No. 1 and the k^{th} antenna

$\left|Z_{1k}\right| \angle \gamma_{1k} = Z_{1k}$, the vector value of the mutual impedance between the No. 1 and the k^{th} antenna, ohms.

$\left|Z_{kk}\right| \cos \gamma_{kk} = R_{kk}$, self resistance at the input terminals of the k^{th} antenna, ohms

$\left|Z_{kk}\right| \angle \gamma_{kk} = Z_{kk}$, the vector value of the self impedance of the k^{th} antenna, ohms.

In a similar fashion, the reactance component is

$$X_k = \left|\frac{I_1}{I_k}\right|\left|Z_{1k}\right| \sin(\psi_{1k} + \gamma_{1k}) + \left|\frac{I_2}{I_k}\right|\left|Z_{2k}\right| \sin(\psi_{2k} + \gamma_{2k}) + \cdots + \left|Z_{kk}\right| \sin \gamma_{kk} + \cdots + \left|\frac{I_n}{I_k}\right|\left|Z_{nk}\right| \sin(\psi_{nk} + \gamma_{nk}) \quad (153)$$

where X_k = driving point reactance at the input terminals of the k^{th} antenna, ohms, and the other values are defined following Eq. (152).

EXAMPLE 28: Determine the driving point impedance for the directional antenna in Example 27 by Eqs. (151), (152) and (153).

SOLUTION: Using the mutual impedance curves or Eq. (25) and (26) we can write,

$$Z_{12} = Z_{13} = -9.5 + j6.0 = 11.24 \angle 147.72° \text{ ohms}$$

$$Z_{23} = -3.675 - j4.8 = 6.045 \angle 232.56° \text{ ohms}$$

and the self impedance can be written,

$$Z_{11} = Z_{22} = Z_{33} = 36.56 + j21 = 42.18 \angle 29.87° \text{ ohms}$$

since the towers are all the same height the current ratios can be replaced by field intensity ratios in Eq. (151) thus,

$$Z_1 = \frac{I_1}{I_1} Z_{11} + \frac{I_2}{I_1} Z_{21} + \frac{I_3}{I_1} Z_{31}$$

$$= Z_{11} + F_2 Z_{21} + F_3 Z_{31}$$

$$= 42.18 \angle 29.87° + 0.56 \angle -53° \;\; 11.24 \angle 147.72° + 0.56 \angle 45° \;\; 11.24 \angle 147.72°$$

$$= 42.18 \angle 29.87° + 6.294 \angle 94.72° + 6.294 \angle 192.72°$$

$$= 36.56 + j21 - 0.5178 + j6.272 - 6.1394 - j1.386$$

$$= 29.903 + j25.886 = 39.59 \angle 40.88° \text{ ohms} \quad \text{ANS}$$

$$Z_2 = \frac{I_1}{I_2} Z_{12} + \frac{I_2}{I_2} Z_{22} + \frac{I_3}{I_2} Z_{32}$$

$$= \frac{Z_{12}}{F_2} + Z_{22} + \frac{F_3}{F_2} Z_{32}$$

$$= \frac{11.24 \angle 147.72°}{0.56 \angle -0.53°} + 6.045 \angle 232.56° + \frac{0.56 \angle 45° \;\; 6.045 \angle 232.56°}{0.56 \angle -0.53°}$$

$$= 20.071 \angle 200.72° + 42.18 \angle 29.87° + 6.045 \angle 330.56°$$

$$Z_2 = -18.772 - j7.101 + 36.56 + j21 + 5.264 - j2.971$$

$$= 23.052 + j10.928 = 25.52 \angle 25.36° \text{ ohms} \quad \text{ANS}$$

$$Z_3 = \frac{I_1}{I_3} Z_{13} + \frac{I_2}{I_3} Z_{23} + \frac{I_3}{I_3} Z_{33}$$

$$= \frac{Z_{13}}{F_3} + \frac{F_2}{F_3} Z_{23} + Z_{33}$$

$$= \frac{11.24 \angle 147.72°}{0.56 \angle 45°} + \frac{0.56 \angle -53° \;\; 6.045 \angle 232.56°}{0.56 \angle 45°} + 42.18 \angle 29.87°$$

$$= 20.071 \angle 102.72° + 6.045 \angle 134.56° = 42.18 \angle 29.87°$$

$$= -4.419 + j19.578 - 4.241 + j43.071 + 36.56 + j21$$

$$= 27.90 + j83.649 = 88.25 \angle 71.56° \text{ ohms} \quad \text{ANS}$$

By Eq. (152)

$$R_1 = |Z_{11}| \cos \gamma_{11} + \left|\frac{I_2}{I_1}\right| |Z_{21}| \cos (\psi_{21} + \gamma_{21}) + \left|\frac{I_3}{I_1}\right| |Z_{31}| \cos (\psi_{31} + \gamma_{31})$$

$$= 42.18 \cos (29.87) + (0.56)(11.24) \cos (-53 + 147.72) + (0.56)(11.24) \cos (45 + 147.72)$$

$$= 36.56 - 0.5178 - 6.1394 = 29.903 \text{ ohms} \quad \underline{\text{ANS}}$$

$$R_2 = \left|\frac{I_1}{I_2}\right| |Z_{12}| \cos(\psi_{12} + \gamma_{12}) + |Z_{22}| \cos \gamma_{22} + \left|\frac{I_3}{I_2}\right| |Z_{32}| \cos(\psi_{32} + \gamma_{32})$$

$$= \frac{11.24}{0.56} \cos (53 + 147.72) + 42.18 \cos (29.87) + \frac{(0.56)(6.045)}{(0.56)} \cos (45 + 53 + 232.56)$$

$$= -18.772 + 36.56 + 5.264 = 23.05 \text{ ohms} \quad \underline{\text{ANS}}$$

$$R_3 = \left|\frac{I_1}{I_3}\right| |Z_{13}| \cos(\psi_{13} + \gamma_{13}) + \left|\frac{I_2}{I_3}\right| |Z_{23}| \cos (\psi_{23} + \gamma_{23}) + |Z_{33}| \cos \gamma_{33}$$

$$= \frac{11.24}{0.56} \cos(-45 + 147.72 + \frac{(0.56)(6.045)}{(0.56)} \cos(-53-45 + 232.56) + 42.18 \cos(29.87)$$

$$= -4.419 - 4.241 + 36.56 = 27.90 \text{ ohms} \quad \underline{\text{ANS}}$$

By Eq. (153)

$$X_1 = |Z_{11}| \sin \gamma_{11} + \left|\frac{I_2}{I_1}\right| |Z_{21}| \sin(\psi_{21} + \gamma_{21}) + \left|\frac{I_3}{I_1}\right| |Z_{31}| \sin (\psi_{31} + \gamma_{31})$$

$$= 42.18 \sin (29.87) + (0.56)(11.24) \sin (-53 + 147.72) + (0.56)(11.24) \sin (45 + 147.72)$$

$$= 21 + 6.272 - 1.386 = 25.886 \text{ ohms} \quad \underline{\text{ANS}}$$

$$X_2 = \left|\frac{I_1}{I_2}\right| |Z_{12}| \sin(\psi_{12} + \gamma_{12}) + |Z_{22}| \sin \gamma_{22} + \left|\frac{I_3}{I_2}\right| |Z_{32}| \sin(\psi_{32} + \gamma_{32})$$

$$= \frac{11.24}{0.56} \sin(53 + 147.72) + 42.18 \sin(29.87) + \frac{(0.56)(6.045)}{0.56} \sin(45 + 53 + 232.56)$$

$$= -7.101 + 21 - 2.971 = 10.928 \text{ ohms} \quad \underline{\text{ANS}}$$

$$X_3 = \left|\frac{I_1}{I_3}\right| |Z_{13}| \sin (\psi_{13} + \gamma_{13}) + \left|\frac{I_2}{I_3}\right| |Z_{23}| \sin (\psi_{23} + \gamma_{23}) + |Z_{33}| \sin \gamma_{33}$$

$$= \frac{11.24}{0.56} \sin (-45 + 147.72) + \frac{(0.56)(6.045)}{(0.56)} \sin (-53-45 + 232.56) + 42.18 \sin (29.87)$$

$$= 19.578 + 43.071 + 21 = 83.649 \text{ ohms}$$

(2) Coupled Field Intensity From Reference Antenna.--For the purpose of development, let us consider only two antennas. By Eq. (149) the power radiated is

$$P_r = I_1^2 R_1 + I_2^2 R_2.$$

Solving the equation for I_1, gives

$$I_1 = \sqrt{\frac{P_r}{R_1 + (\frac{I_2}{I_1})^2 R_2}} \qquad (154)$$

Now by Eq. (118) we know that the field intensity from an antenna is proportional to the current in the antenna. This equation is true, regardless of whether the antenna is in a directional antenna system or not. Therefore the following ratios can be equated

$$\frac{E_{1s}}{I_{1s}} = \frac{E_1}{I_1} \tag{155}$$

where E_{1s} = horizontal field intensity from antenna No. 1 acting alone as a secondary standard reference antenna, millivolts per meter.

I_{1s} = loop current of antenna No. 1 acting alone as a secondary standard reference antenna, amp.

E_1 = horizontal field intensity from antenna No. 1 operating in the directional antenna array, millivolts per meter.

I_1 = loop current of antenna No. 1 operating in the directional antenna array, amp.

Solving Eq. (155) for E_1, and substituting for the value of I_1 from Eq. (154) results in

$$E_1 = \frac{E_{1s}}{I_{1s}} \quad I_1 = \frac{E_{1s}}{I_{1s}} \sqrt{\frac{P_r}{R_1 + (\frac{I_2}{I_1})^2 \; R_2}} \tag{156}$$

If E_{1s} and I_{1s} are for the same amount of power as radiated from the directional antenna, then

$$\frac{P_r}{I_{1s}^2} = R_{11} \tag{157}$$

the self loop radiation resistance of antenna No. 1. Making this substitution in Eq. (156) yields

$$E_1 = E_{1s} \sqrt{\frac{R_{11}}{R_1 + (\frac{I_2}{I_1})^2 \; R_2}} \tag{158}$$

This equation says that the coupled field intensity E_1 from the reference antenna is equal to the non-directional field intensity E_{1s} from this antenna, when it is radiating P_r, the power radiated from the directional antenna multiplied by the square root of the ratio of the self-loop radiation resistance of antenna No. 1 to the quantity made up of the driving point resistance of antenna No. 1 plus the square of the current ratio between antenna No. 2 and antenna No. 1, multiplied by the driving point radiation resistance of antenna No. 2. In other words, by this equation it is possible to determine the coupled field intensity E_1 from antenna No. 1 in terms of the secondary standard reference field intensity E_{1s} from antenna No. 1 when it is radiating P_r, the self-loop radiation resistance R_{11} of antenna No. 1, the driving point radiation resistances of all the antennas in the array and the current ratios. This means that with a specified radiated power from the directional antenna system, the field intensity from antenna No. 1 can be calculated directly. If the resistance values are due solely to radiation, then the resulting field intensity from antenna No. 1 is theoretically the field that would result if the system had no loss. The value of this field intensity can be reduced to a reasonable practical value by inserting appropriate loss resistances in series with the driving point resistances for each antenna. This method has some merit in that the losses for a given tower and ground system can be taken care of at the driving point, thus, if one of the towers has a high driving point current, the loss power will be proportional to the square of the current in that tower. This method, however, does not take into account losses in the rest of the feeder system which usually is quite low.

If Eq. (158) is generalized for any number of elements in the directional antenna system we can write

$$E_1 = E_{1s} \sqrt{\frac{R_{11}}{R_1 + (\frac{I_2}{I_1})^2 \; R_2 + \cdots + (\frac{I_k}{I_1})^2 \; R_k + \cdots + (\frac{I_n}{I_1})^2 \; R_n}}$$

$$= \frac{E_{1s} \; I_1 \sqrt{R_{11}}}{\sqrt{\sum_{k=1}^{k=n} I_k^2 \; R_k}} \tag{159}$$

where E_1 = horizontal field intensity from antenna No. 1 operating in the directional antenna array, mv/m.

E_{1s} = horizontal field intensity from antenna No. 1 acting alone as a secondary standard reference antenna and radiating P_r, mv/m.

R_{11} = self-loop radiation resistance of antenna No. 1, ohms.

R_k = driving point resistance at the input terminals of the k^{th} antenna. If these values are pure radiation resistance, E_1 will be theoretical, however, if they contain loss, E_1 can be made to approach actual operating conditions, ohms.
I_k = loop current of the k^{th} antenna, amp.
I_1 = loop current of antenna No. 1, amp.

EXAMPLE 29: Determine the theoretical horizontal field intensity of No. 1 tower of the three tower directional antenna of Example 27 using the driving point impedance method when the radiated power is 1 kw.

SOLUTION: For 1 kw operation $E_{1s} = 194.9$ mv/m. Using the values of driving point resistances in Example 28 substituted in Eq. (159) gives,

$$E_1 = E_{1s}\sqrt{\frac{R_{11}}{R_1 + F_2^2 R_2 + F_3^2 R_3}}$$

$$= 194.9\sqrt{\frac{36.56}{29.9 + (0.3136)(23.05) + (0.3136)(27.9)}}$$

$$= 194.9\sqrt{\frac{36.56}{29.9 + 7.23 + 8.75}}$$

$$= 194.9\sqrt{\frac{36.56}{45.88}}$$

$$= 194.9\sqrt{0.7968} = (194.9)(0.894)$$

$$= 174 \text{ mv/m} \qquad \text{ANS}$$

It should be noted that the driving point impedance method solution is in agreement with the mutual resistance method solution of Example 27.

It is also of interest to determine the horizontal rms field intensity in terms of the driving point and self resistances rather than in terms of the mutual and self resistances as given in Eq. (145) and Eq. (109). For only two elements,

$$E_o = \sqrt{E_1^2 + E_2^2 + 2 E_1 E_2 \cos\psi_{12} J_o(S_{12})}$$

$$= E_1\sqrt{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1}\cos\psi_{12} J_o(S_{12})} \qquad (160)$$

Substituting for the value of E_1 from Eq. (158) results in

$$E_o = E_{1s}\sqrt{\frac{R_{11}}{R_1 + \left(\frac{I_2}{I_1}\right)^2 R_2}}$$

$$\times \sqrt{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1}\cos\psi_{12} J_o(S_{12})}$$

$$= E_{1s}\frac{\sqrt{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1}\cos\psi_{12} J_o(S_{12})}}{\sqrt{\frac{R_1}{R_{11}} + \left(\frac{I_2}{I_1}\right)^2 \frac{R_2}{R_{11}}}}$$

$$= E_{1s}\sqrt{\frac{R_{11}}{R_1}}$$

$$\times \sqrt{\frac{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1}\cos\psi_{12} J_o(S_{12})}{1 + \left(\frac{I_2}{I_1}\right)^2 \frac{R_2}{R_1}}}$$

$$= \frac{E_{1s} I_1 \sqrt{R_{11}}}{E_1}$$

$$\times \sqrt{\frac{E_1^2 + E_2^2 + 2 E_1 E_2 \cos\psi_{12} J_o(S_{12})}{R_1 I_1^2 + R_2 I_2^2}} \qquad (161)$$

Generalizing this equation for any number of antennas

$$E_o = \frac{E_{1s} I_1 \sqrt{R_{11}}}{E_1}$$

$$\times \sqrt{\frac{\sum_{p=1}^{p=n}\sum_{q=1}^{q=n} E_p E_q \cos\psi_{pq} J_o(S_{pq})}{\sum_{k=1}^{k=n} I_k^2 R_k}} \qquad (162)$$

where E_o = horizontal rms field intensity from the directional antenna array, mv/m.
E_{1s} = horizontal field intensity antenna No. 1 acting alone as a secondary standard reference antenna and radiating P_r, mv/m.

I_1 = loop driving point current in antenna No. 1, amp.
R_{11} = self loop radiation resistance of antenna No. 1, ohms.
E_1 = horizontal field intensity of antenna No. 1 operating in the directional antenna array, mv/m.
E_p = horizontal field intensity of antenna No. p operating in the directional antenna array, mv/m.
E_q = horizontal field intensity of antenna No. q operating in the directional antenna array, mv/m,
ψ_{pq} = difference in phase angle of the voltage (or current) between the p^{th} and the q^{th} antenna, electrical degrees.
S_{pq} = length of the spacing between the p^{th} and the q^{th} antennas, electrical degrees.
I_k = loop driving point current in the k^{th} antenna, amp.
R_k = loop driving point resistance of the k^{th} antenna, ohms.

For the special case of equal height elements the current ratios can be replaced by the corresponding field intensity ratios, resulting in

$$E_o = E_{1s} \sqrt{R_{11}} \times \sqrt{\frac{\sum_{p=1}^{p=n} \sum_{q=1}^{q=n} E_p E_q \cos \psi_{pq} J_o(S_{pq})}{\sum_{k=1}^{k=n} E_k^2 R_k}} \quad (163)$$

where the values are as defined for Eq. (162). This equation corresponds to Eq. (146) with the exception that driving point resistance values are used in place of mutual resistance values.

(3) Mutual Impedance Curves.--In order to use the driving point impedance method for determining pattern size it is necessary to know the values of mutual impedance, which includes both the resistance and reactance components or expressed in polar form as a magnitude at an angle. A number of mutual impedance curves are presented in Appendix A. (See page 2-1-16.) Values for these curves can be substituted in Eq. (152) for determining the driving point resistance which in turn is used in Eq. (162) to determine the horizontal rms field intensity.

d. *HORIZONTAL RMS POWER GAIN OF A DIRECTIONAL ANTENNA ARRAY.*--The coverage of a radio broadcasting station can be increased if for the same power input the horizontal field intensity is increased. It is therefore worth while to investigate the conditions in a directional antenna system that controls the suppression of high angle radiation and increases the low angle radiation along the ground. The merit of a directional antenna in terms of improving the coverage can be expressed in terms of horizontal rms power gain. This horizontal rms power gain is a comparison of the horizontal rms field intensity for the directional antenna array with the horizontal field intensity from the reference element in the array on the basis of equal radiated powers.

Mathematically, the horizontal rms power gain of a directional antenna by Eq. (12) can be defined

$$g_o = \left[\frac{E_o}{E_{1s}}\right]^2 \quad \text{(equal powers)} \quad (164)$$

where g_o = horizontal rms power gain of a directional antenna array
E_o = the horizontal field intensity when the directional antenna is radiating P_r watts, mv/m.
E_{1s} = the horizontal field intensity from No. 1 antenna acting as a secondary reference antenna and is radiating P_r watts, mv/m.

The horizontal rms power gain for a two element directional antenna array, by Eq. (144) and (161) is given by

$$g_o = \frac{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1} \cos \psi_{12} J_o(S_{12})}{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1} \cos \psi_{12} \frac{R_{12}}{R_{11}}}$$

$$= I_1^2 R_{11} \frac{1 + \left(\frac{E_2}{E_1}\right)^2 + 2\frac{E_2}{E_1} \cos \psi_{12} J_o(S_{12})}{I_1^2 R_1 + I_2^2 R_2} \quad (165)$$

By applying Eq. (146) and (162) this equation can be generalized for any number of antennas, thus

$$g_o = \frac{\sum_{p=1}^{p=n} \sum_{q=1}^{q=n} E_p E_q \cos \psi_{pq} J_o(S_{pq})}{\sum_{p=1}^{p=n} \sum_{q=1}^{q=n} E_p E_q \cos \psi_{pq} \frac{R_{pq}}{R_{11}}}$$

$$= \frac{I_1^2 R_{11}}{E_1^2} \frac{\sum_{p=1}^{p=n} \sum_{q=1}^{q=n} E_p E_q \cos \psi_{pq} J_o(S_{pq})}{\sum_{k=1}^{k=n} I_k^2 R_k} \quad (166)$$

EXAMPLE 30: Determine the horizontal r-m-s power gain of the directional antenna in Example 27.

SOLUTION: Using the first form of Eq. (166) the terms under the radical in Example 27 can be written,

$$g_o = \frac{1.3934}{1.2548} = 1.111 \text{ the horizontal r-m-s power gain.} \quad \text{ANS}$$

e. *EFFICIENCY OF DIRECTIONAL ANTENNAS*--(1) Definitions.--The horizontal rms field intensity of a directional antenna system will depend upon the amount of high angle radiation as compared to the horizontal radiation. For a directional antenna system with no loss this value can be expressed,

$$E_o = E_{1s}\sqrt{g_o} \tag{167}$$

where E_o = horizontal rms field intensity without loss, mv/m
E_{1s} = horizontal field intensity of antenna No. 1 acting alone as a secondary standard reference antenna and radiating P_r, mv/m
g_o = Horizontal rms power gain of directional antenna system compared to the secondary standard reference antenna as defined in Eq. (164).

It is to be noted that the power gain g_o is defined, in Eq. (164), with no loss in either the directional antenna array or the secondary reference standard antenna. Therefore, the horizontal r-m-s field gain, $\sqrt{g_o}$, represents the inherent property of the directional antenna array as to whether it is a gainer or losser of horizontal r-m-s field intensity when compared with the secondary standard reference antenna.

Now, if the directional antenna system has loss the horizontal rms field intensity must be multiplied by the square root of the power efficiency, thus

$$E_{oL} = E_o\sqrt{\eta} = E_{1s}\sqrt{g_o}\ \sqrt{\eta} \tag{168}$$

where E_{oL} = horizontal rms field intensity with loss, mv/m and the power efficiency of the directional antenna system can be defined by,

$$\eta = \frac{P_r}{P_r + P_L} \tag{169}$$

where η = power efficiency of directional antenna system (Multiply by 100 to get efficiency in percent)
P_r = power radiated from directional antenna system, watts
P_L = power lost in directional antenna system, watts.

(2) Two Tower Case.--For a two tower directional antenna system Eq. (138) can be rewritten,

$$P_r = I_1^2 R_{11}\left(1 + M_2^2\ \frac{R_{22}}{R_{11}} + 2 M_2 \cos\psi_2\ \frac{R_{12}}{R_{11}}\right) \tag{170}$$

where P_r = power radiated from directional antenna system, watts
I_1 = base current magnitude in antenna No. 1, amp
$M_2 = I_2/I_1$, ratio of base current magnitudes
R_{11} = base self resistance of antenna No. 1, ohms
R_{22} = base self resistance of antenna No. 2, ohms
ψ_2 = time phase of voltage (or current) in antenna No. 2 with respect to antenna No. 1, degrees
R_{12} = base mutual resistance between antenna No. 1 and antenna No. 2, ohms.

And since the power lost in the directional antenna system[8] can be assumed to be in series with the base impedance of each tower it can be written,

$$P_L = I_1^2 R_{L1} + I_2^2 R_{L2} = I_1^2 R_{11}\left(\frac{R_{L1}}{R_{11}} + M_2^2\ \frac{R_{L2}}{R_{11}}\right) \tag{171}$$

where P_L = power lost in directional antenna system, watts
R_{L1} = series base loss resistance of antenna No. 1, ohms
R_{L2} = series base loss resistance of antenna No. 2, ohms
I_1 = base current magnitude in antenna No. 1, amp
I_2 = base current magnitude in antenna No. 2, amp.

Substituting Eq. (170) and (171) in Eq. (169) the efficiency can be written,

$$\eta = \frac{1}{1 + \dfrac{\dfrac{R_{L1}}{R_{11}} + M_2^2\ \dfrac{R_{L2}}{R_{11}}}{1 + M_2^2\ \dfrac{R_{22}}{R_{11}} + 2M_2 \cos\psi_2\ \dfrac{R_{12}}{R_{11}}}} \tag{172}$$

[8] Carl E. Smith and Earl M. Johnson, "Performance of Short Antennas" Proc. I.R.E., Vol. 35, No. 10, pp 1026-1038, October, 1947.

The power gain of Eq. (165) for two towers of unequal height can be written,

$$g_o = \frac{1 + F_2^2 + 2F_2 \cos \psi_2 \, J_o (S_2)}{1 + M_2^2 \dfrac{R_{22}}{R_{11}} + 2 M_2 \cos \psi_2 \dfrac{R_{12}}{R_{11}}} \tag{173}$$

where g_o = horizontal rms power gain of directional antenna system compared to the secondary standard reference antenna

$F_2 = E_2/E_1$, ratio of field intensity magnitudes

S_2 = space phase of antenna No. 2 with respect to antenna No. 1, degrees

and the other terms are defined as following Eq. (170).

Substituting Eq. (172) and (173) in Eq. (168) results in,

$$E_{0L} = E_{1s} \sqrt{\frac{1 + F_2^2 + 2F_2 \cos \psi_2 \, J_o (S_2)}{1 + M_2^2 \dfrac{R_{22}}{R_{11}} + 2M_2 \cos \psi_2 \dfrac{R_{12}}{R_{11}} + \dfrac{R_{L1}}{R_{11}} + M_2^2 \dfrac{R_{L2}}{R_{11}}}} \tag{174}$$

Now if $R_{L1} = R_{L2} = 0$ the *no loss case* results, thus

$$E_o = E_{1s} \sqrt{\frac{1 + F_2^2 + 2F_2 \cos \psi_2 \, J_o (S_2)}{1 + M_2^2 \dfrac{R_{22}}{R_{11}} + 2M_2 \, \text{Cos} \, \psi_2 \dfrac{R_{12}}{R_{11}}}} \tag{175}$$

For the special case of equal height towers $R_{11} = R_{22}$, $R_{L1} = R_{L2} = R_L$ and the current ratios M_2 can be replaced by field ratios F_2, thus Eq. (172) for the efficiency can be written

$$\eta = \frac{R_{11}}{R_{11} + R_L \dfrac{1 + F_2^2}{1 + F_2^2 + 2F_2 \cos \psi_2 \dfrac{R_{12}}{R_{11}}}} \tag{176}$$

EXAMPLE 31: If each tower in Example 27 has a series base loss resistance of 2 ohms determine the efficiency of the directional antenna and the horizontal r-m-s field intensity.

SOLUTION: If Eq. (176) is written for a 3-tower directional antenna we have,

$$\eta = \frac{R_{11}}{R_{11} + R_L \dfrac{1 + F_2^2 + F_3^2}{\left(1 + F_2^2 + F_3^2 + 2 F_2 \cos \psi_{12} \dfrac{R_{12}}{R_{11}} + 2 F_3 \cos \psi_{13} \dfrac{R_{13}}{R_{11}} + 2 F_2 F_3 \cos \psi_{23} \dfrac{R_{23}}{R_{11}}\right)}}$$

Now from Example 27 and the above conditions,

$$\eta = \frac{36.56}{36.56 + 2 \dfrac{1.6272}{1.2548}} = 93.4\% \text{ efficiency}$$

By Eq. (168), the solution of Example 27 and the above η the horizontal r-m-s field intensity with loss will be,

$$E_{0L} = E_{1s} \sqrt{g_o} \sqrt{\eta}$$

$$= 194.9 \sqrt{1.111} \sqrt{0.934} = 198.5 \text{ mv/m} \quad \text{ANS}$$

This field intensity is based upon an input power of 1,081 watts to the common point of the directional antenna system according to FCC standards, with 81 watts being lost in the feeder system and 66 watts being lost in the ground system. The power radiated in this case is 934 watts.

If g_o of Eq. (173) is multiplied by the fraction in the denominator of Eq. (176) we can rewrite Eq. (176) as follows after taking the square root of both sides,

$$\sqrt{\eta} = \frac{R_{11}}{R_{11} + g_o \dfrac{1 + F_2^2}{1 + F_2^2 + 2F_2 \cos \psi_2 \, J_o(S_2)} R_L} \tag{177}$$

Glenn D. Gillett has independently arrived at this form of the efficiency equation for the special case of equal height towers.

(3) Generalized case for any number of towers.--In order to generalize Eq. (174) let us replace the ratios with the original field intensity values and use double subscripts, thus for two towers,

$$E_{0L} = E_{1s} \sqrt{\frac{\frac{R_{11} I_1^2}{E_1^2}\left[E_1^2 + E_2^2 + 2E_1E_2 + 2E_1E_2 \cos \psi_{12} J_o (S_{12})\right]}{R_{11} I_1^2 + R_{22} I_2^2 + 2I_1 I_2 \cos \psi_{12} R_{12} + R_{L1} I_1^2 + R_{L2} I_2^2}} \quad (178)$$

Referring to Eq. (144), (146) and (149) the same method can be used to generalize this equation, thus

$$E_{0L} = \frac{E_{1s} I_1 \sqrt{R_{11}}}{E_1} \sqrt{\frac{\sum_{p=1}^{p=n} \sum_{q=1}^{q=n} E_p E_q \times \cos \psi_{pq} J_o (S_{pq})}{\sum_{p=1}^{p=n} \sum_{q=1}^{q=n} I_p I_q \times \cos \psi_{pq} R_{pq} + \sum_{k=1}^{k=n} I_k^2 R_{Lk}}} \quad (179)$$

where E_{0L} = horizontal rms field intensity with loss, mv/m

E_{1s} = horizontal field intensity of antenna No. 1 acting alone as a secondary standard reference antenna and radiating P_r, mv/m

I_1 = base current magnitude in antenna No. 1, amp

R_{11} = base self resistance of antenna No. 1, ohms

E_1 = horizontal magnitude field intensity from antenna No. 1 operating in the directional antenna array, mv/m

n = number of towers in the array

E_p = horizontal field intensity magnitude of p^{th} antenna, mv/m

E_q = horizontal field intensity magnitude of q^{th} antenna, mv/m

ψ_{pq} = time phase of voltage (or current) between the p^{th} and q^{th} antennas in the directional antenna array, degrees

S_{pq} = space phase between p^{th} and q^{th} antennas in degrees or radians depending on the values in the Bessel function tables.

R_{pq} = mutual base resistance between the p^{th} and q^{th} antennas, ohms

= self base resistance when $p=q$, ohms

I_p = base current magnitude in p^{th} antenna, amp

I_q = base current magnitude in q^{th} antenna, amp

I_k = base current magnitude in k^{th} antenna, amp

R_{Lk} = base series loss resistance in k^{th} antenna, amp.

The k subscripts could be replaced with either p or q subscripts without altering the final answer. The k subscript terms are the power loss terms in the directional antenna system.

EXAMPLE 32--Write out the equation for E_{0L} for a three tower array.

SOLUTION--Using general Eq. (179) we have for a three tower array.

$$\begin{aligned}\text{The Numerator} = {} & E_1 E_1 \cos \psi_{11} J_o (S_{11}) \\ & + E_2 E_1 \cos \psi_{21} J_o (S_{21}) \\ & + E_3 E_1 \cos \psi_{31} J_o (S_{31}) \\ & + E_1 E_2 \cos \psi_{12} J_o (S_{12}) \\ & + E_2 E_2 \cos \psi_{22} J_o (S_{22}) \\ & + E_3 E_2 \cos \psi_{32} J_o (S_{32}) \\ & + E_1 E_3 \cos \psi_{13} J_o (S_{13}) \\ & + E_2 E_3 \cos \psi_{23} J_o (S_{23}) \\ & + E_3 E_3 \cos \psi_{33} J_o (S_{33})\end{aligned}$$

since $\psi_{11} = \psi_{22} = \psi_{33} = 0$, $S_{11} = S_{22} = S_{33} = 0$
$\psi_{13} = -\psi_{31}$ $\psi_{21} = -\psi_{12}$, $\psi_{23} = -\psi_{32}$,
$S_{12} = S_{21}$, $S_{31} = S_{13}$ and $S_{23} = S_{32}$

With these substitutions we can write the numerator =

$$\begin{aligned}& E_1^2 + E_2^2 + E_3^2 + 2E_1 E_2 \cos \psi_{12} J_o (S_{12}) \\ & + 2E_2 E_3 \cos \psi_{23} J_o (S_{23}) \\ & + 2E_3 E_1 \cos \psi_{31} J_o (S_{31})\end{aligned}$$

Similarly, the Denominator =

$$\begin{aligned}& I_1 I_1 \cos \psi_{11} R_{11} + I_2 I_1 \cos \psi_{21} R_{21} \\ & + I_3 I_1 \cos \psi_{31} R_{31} + I_1 I_2 \cos \psi_{21} R_{12} \\ & + I_2 I_2 \cos \psi_{22} R_{22} + I_3 I_2 \cos \psi_{32} R_{32} \\ & + I_1 I_3 \cos \psi_{13} R_{13} + I_2 I_3 \cos \psi_{23} R_{23} \\ & + I_3 I_3 \cos \psi_{33} R_{33} + R_{L1} I_1^2 + R_{L2} I_2^2 \\ & + R_{L3} I_3^2\end{aligned}$$

also $R_{12} = R_{21}$, $R_{23} = R_{32}$ and $R_{31} = R_{13}$

With these substitutions we can write the denominator =

$$I_1^2 R_{11} + I_2^2 R_{22} + I_3^2 R_{33} + 2I_1I_2 \cos \psi_{12} R_{12} + 2I_2 I_3 \cos \psi_{23} R_{23} + 2I_3 I_1 \cos \psi_{31} R_{31} + I_1^2 R_{L1} + I_2^2 R_{L2} + I_3^2 R_{L3}$$

Therefore, the full equation is,

$$E_{OL} = \frac{E_{1s} I_1 \sqrt{R_{11}}}{E_1} \sqrt{\frac{E_1^2 + E_2^2 + E_3^2 + 2E_1 E_2 \cos \psi_{12} J_o (S_{12}) + 2E_2 E_3 \cos \psi_{23} J_o (S_{23}) + 2E_3 E_1 \cos \psi_{31} J_o (S_{31})}{I_1^2 R_{11} + I_2^2 R_{22} + I_3^2 R_{33} + 2I_1 I_2 \cos \psi_{12} R_{12} + 2I_2 I_3 \cos \psi_{23} R_{23} + 2I_3 I_1 \cos \psi_{31} R_{31} + I_1^2 R_{L1} + I_2^2 R_{L2} + I_3^2 R_{L3}}}$$

ANS

5. FEEDER SYSTEM DESIGN

a. *INTRODUCTION.*--A directional antenna feeder system can be designed in many ways. The problem facing the design engineer is to make a simple economical design with adequate controls having sufficient range to make the necessary adjustments. The feeder sustem must be adjusted, during the equipment test period, such that the directional antenna will produce the required pattern in accordance with the specifications of the construction permit issued by FCC.

In general a directional antenna feeder system will consist of power dividing networks, phase shifting networks, transmission lines, and impedance matching networks. A block diagram of a typical directional antenna feeder system is illustrated in Fig. 22. In this feeder system the transmitter output impedance is transformed to match the input impedance of the power divider. The power divider in turn splits the power in the proper proportion between the two antennas. Antenna No. 1 is fed directly through an impedance matching network while antenna No. 2 is fed through a phase shifting network, transmission line and impedance matching network.

Before starting to design the feeder system it is necessary to have some idea about the driving point impedances. As a first approximation the theoretical design values can be used. If the towers are base fed, have a thin uniform cross-section and are not too tall this approximation should be satisfactory. If not, then more tuning range should be provided in the feeder system, particularly in the impedance matching networks at the base of the towers.

b. *GENERAL DESIGN PROCEDURE.*--One general procedure is to start with each tower and determine the possible phase shifts in all networks back to the power divider. Then various combinations of networks can be considered in view of making a simple, efficient design with adequate control.

The *first step* in following this procedure is to determine the driving point impedance and current phase at the input terminals at the base of each tower. Methods outlined in the previous section can be used to determine these values.

The *second step* is to transform the driving point impedance at the base of the tower to match the characteristic impedance of the transmission line. This can be done by means of an L-section, T or π section or an indirectly coupled circuit.

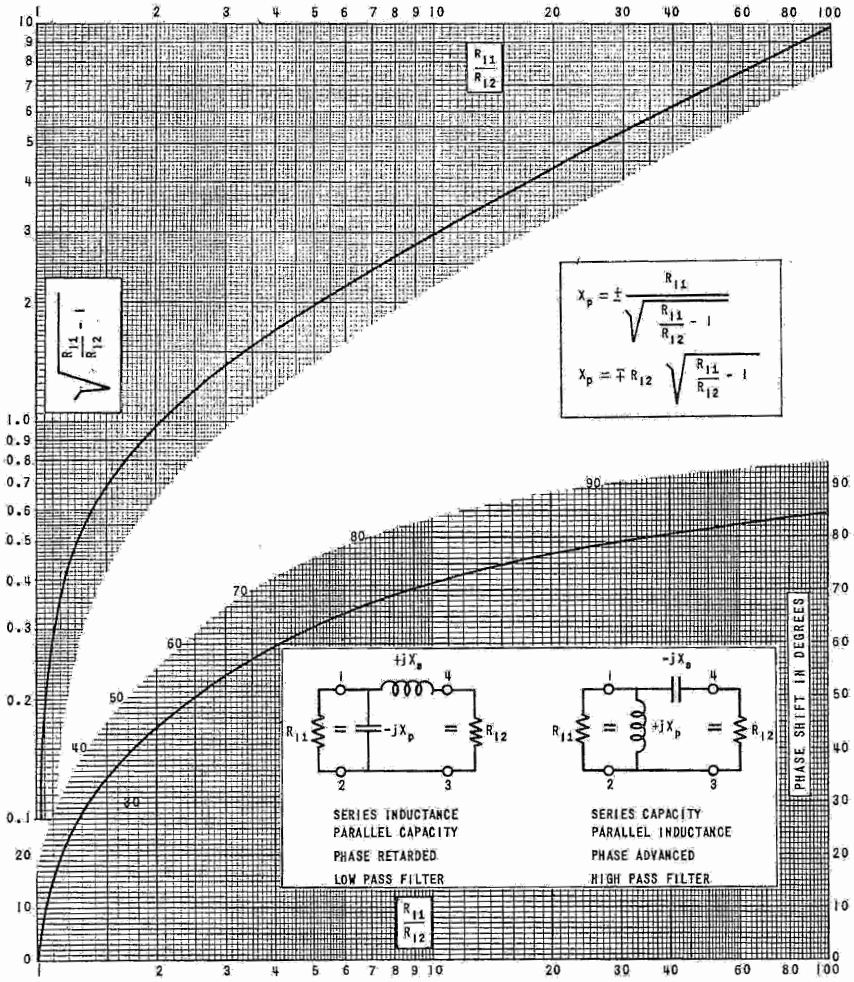
This subject has been covered thoroughly by W. L. Everitt, a brief resume of which is presented in Section 5-3 of the NAB Engineering Handbook by Arthur C. Stewart.

It is suggested that in determining the phase shifts initially an L-section with a phase advance or retard be specified wherever only impedance matching is required. An L-section has two elements and in all cases can be made to theoretically satisfy the impedance transformation requirement. The amount of phase shift is completely controlled by the resistance ratio of the terminating resistances at the end of the L-section. See Fig. 51. The phase can be advanced or retarded a given number of degrees depending on whether the L-section is a high or low pass type of filter section.

The *third step* is to determine the phase shift in the transmission lines. Usually, the physical layout of the towers and transmitter building will control the length of each transmission line. The amount of phase shift in the line will be determined by the physical length of the line, specified in degrees, and multiplied by the velocity of propagation which is usually specified by the manufacturer in percent of the free space velocity. See Section 5-1 of the NAB Engineering Handbook.

The transmission lines usually emanate from a common point either in the transmitter building or a tuning house centrally located such as to minimize the feeder system losses. At this common point, where the input impedance to the directional antenna system is measured, it is necessary to provide power dividing and phase shifting networks.

The *fourth step* is to specify 90° phase advancing or retarding networks at the common point end of each transmission line. See Section



L - SECTION REACTANCE NETWORK
FIG. 51

5-3 of the NAB Engineering Handbook. This is a widely used type of phase shifter because practically a pure phase shift without impedance transformation can be achieved by varying the series reactance elements of the T-section in unison and leaving the shunt reactance element fixed in value. The shunt reactance element controls the characteristic impedance of the network while the series elements control the phase shift. Variation of the shunt impedance value can be used to advantage in some applications as a power division control. If the series elements are inductive and the shunt element is capacitive the network will retard the phase. The network can be made to advance the phase if capacitors of suitable value are placed in series with the series variable inductors and an inductor is used as the shunt arm. The usual practice is to use variable inductors rather than variable capacitors in this particular type of application.

It is also possible to achieve the same results with an equivalent π-section that will either advance or retard the phase. In a π-section the shunt arms have practically pure phase control while the series arm will control the characteristic impedance or power division.

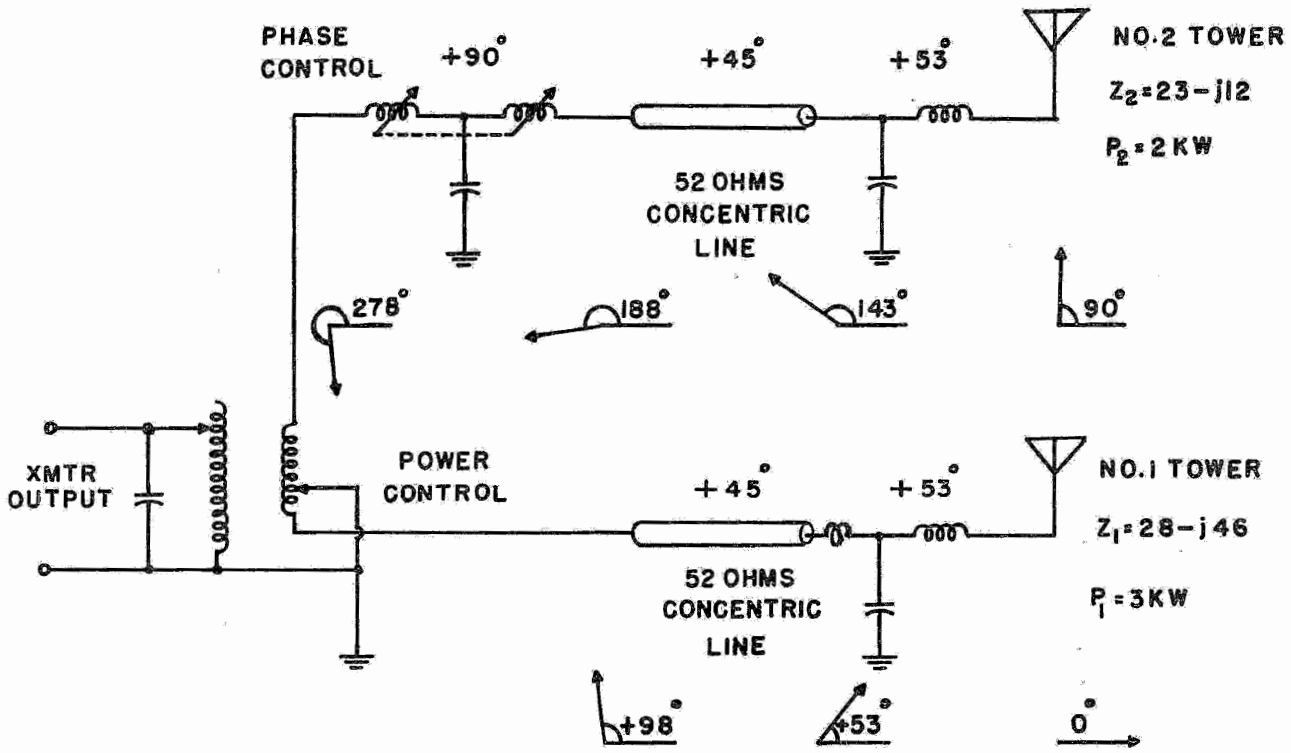
Often the feeder system can be simplified and made more efficient by making the networks as simple and direct as possible from the common point to the tower taking the most power. It is often possible to eliminate the power divider and phase shifting network in this line. For this case the impedance matching networks can be simple L-sections. Then in the feeder lines to towers requiring less power, the power division and phase shifting networks can be inserted for supplying the necessary control. If the phase shifts do not work out properly with L-sections used for impedance matching then the matching network must be expanded into T or π sections which will give the necessary phase shift to make the phase shifters operate at or near 90°.

The *fifth step* is to review the total phase shift from the power divider to each tower for various combinations of phase advancing and

retarding networks in an effort to select a combination which will give a total phase shift in each line such that all vectors are of the proper phase at the power divider. Depending upon the type of power divider to be used the phases may all be equal, 90° or 180° out of phase.

In order to minimize possible confusion in following through with this 5 step procedure it is helpful to line up the driving point impedance values and current or field vector positions along the right hand side of a work sheet as shown in Fig. 52. In this figure No. 2 tower has a driving point resistance of 23 ohms to be transformed to 52 ohms with an L-section. Referring to Fig. 51 the phase shift will be approximately ± 53°. Since the driving point current vector has a phase of +90° a lagging L-section will have an input vector of 143° = 90° + 53°. Adding the phase lag of the transmission line we have an input vector to the line with a phase of 188° = 45° + 143°. Finally, the 90° lagging phase shifter will have an imput vector phase of 278° = 90° + 183°.

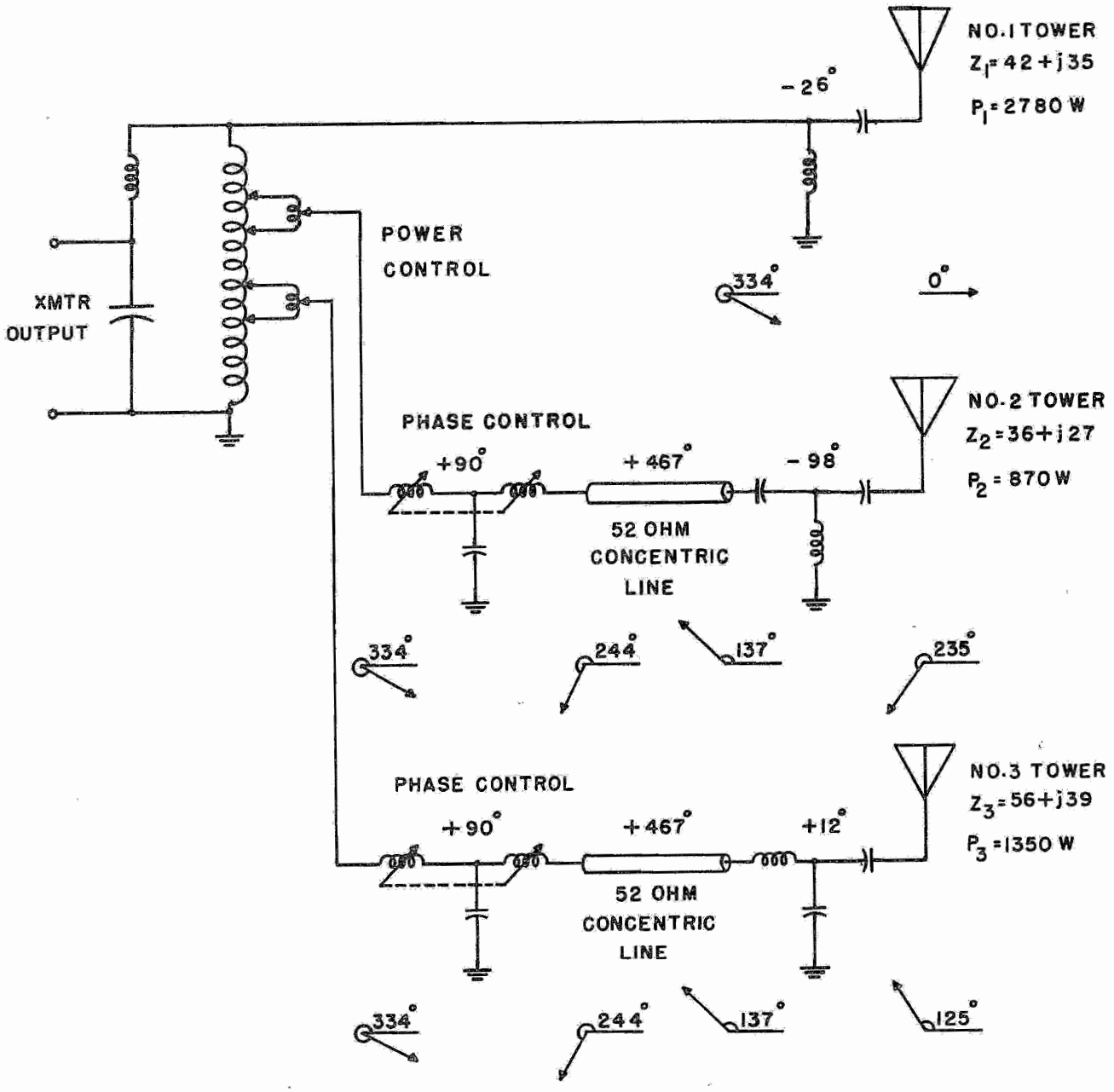
The phase shifts in the No. 1 tower feeder circuit are as follows. *First*, the driving point resistance is 28 ohms and the phase is 0°. *Second*, the phase shift in an L-section is approximately ± 48° from Fig. 52, giving an L-section input phase of 48° for a lagging network. *Third*, the input phase to No. 1 transmission line will be 93°. *Fourth*, since No. 2 tower has a phase shifter the phase of No. 2 tower can be controlled with respect to No. 1 tower hence it is desirable to feed power into this line directly from the power divider. Furthermore, this would be desirable from an efficiency standpoint since No. 1 tower takes the largest amount of power. *Fifth*, a review of the phase shifts shows that 278° the phase of the current input to No. 2 network is almost 180° out of phase with 93° the phase of the current input to No. 1 network. This phase correction can be made in the phase shifter, however, it is better practice to change one or both of the L-sections to T or π sections. If the phase lag in the matching network to No. 1 tower is increased from 48° to 53° by adding a series inductance in the arm of the T-section facing the transmission line the desired results will be obtained as shown in Fig. 52. Then a transformer type of power divider can be used



TWO TOWER NETWORK WITH LOADS 180° OUT OF PHASE

FIG. 52.

2-1-85



THREE TOWER NETWORK WITH IN PHASE LOADS

FIG. 53

with the center tap of the secondary variable and grounded while the two opposite ends which are 180° out of phase are connected to the respective loads.

Another way to correct the phasing problem in the feeder system of Fig. 52 is to add a capacitor in series with the transmission line and thus make a T-section with a smaller phase lag. Then the original L-section matching No. 1 tower to the concentric line can be used.

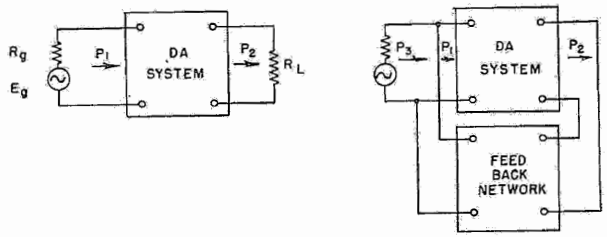
Now that the terminating impedances and phase shifts in each section is specified the only thing left to do is to determine the values of capacity and inductance needed. The usual practice is to order inductors having larger values and use a clip lead to short out turns in

the field when tuning the directional antenna system. With regard to the capacitors a common practice is to place a small coil in series with the capacitor such that the combination will give the required value of capacity at the operating frequency. This makes it easy to make trimming adjustments in the field when the directional antenna system is being tuned up.

Another feeder system, this time for three towers, is illustrated in Fig. 53. In this case the No. 1 tower is located near the common feed point hence no transmission line is needed to this tower. The L-section matches the antenna to 52 ohms. Actually, this L-section could be replaced with a -j35 ohm series capacitor and eliminate the shunt inductor. This would cause No. 1 tower to present 42 ohms of pure resistance to the power divider and would require 26° change in phase shift in the matching networks to the other two towers.

The power divider in this case is of the auto-transformer type with vernier controls to make small changes in the power division. The taps on the main control are for making large initial adjustments. It will be noted that the output phase of current is the same in this type of power divider for every feeder line. This type of power divider is attractive in many installations because it is not limited as to the number of towers that can be fed from the same transformer.

c. *TOWERS WITH NEGATIVE RESISTANCE*.--In many directional antenna systems one or more of the towers have a negative resistance when operated to produce the correct directional antenna pattern. This means that power must be removed from the antenna terminals of the negative resistance tower. In other words the resistance component of the driving point impedance is negative. While the initial adjustments are made this power can be dissipated but for the final operation this power must be fed back into the system in order to maintain high efficiency.



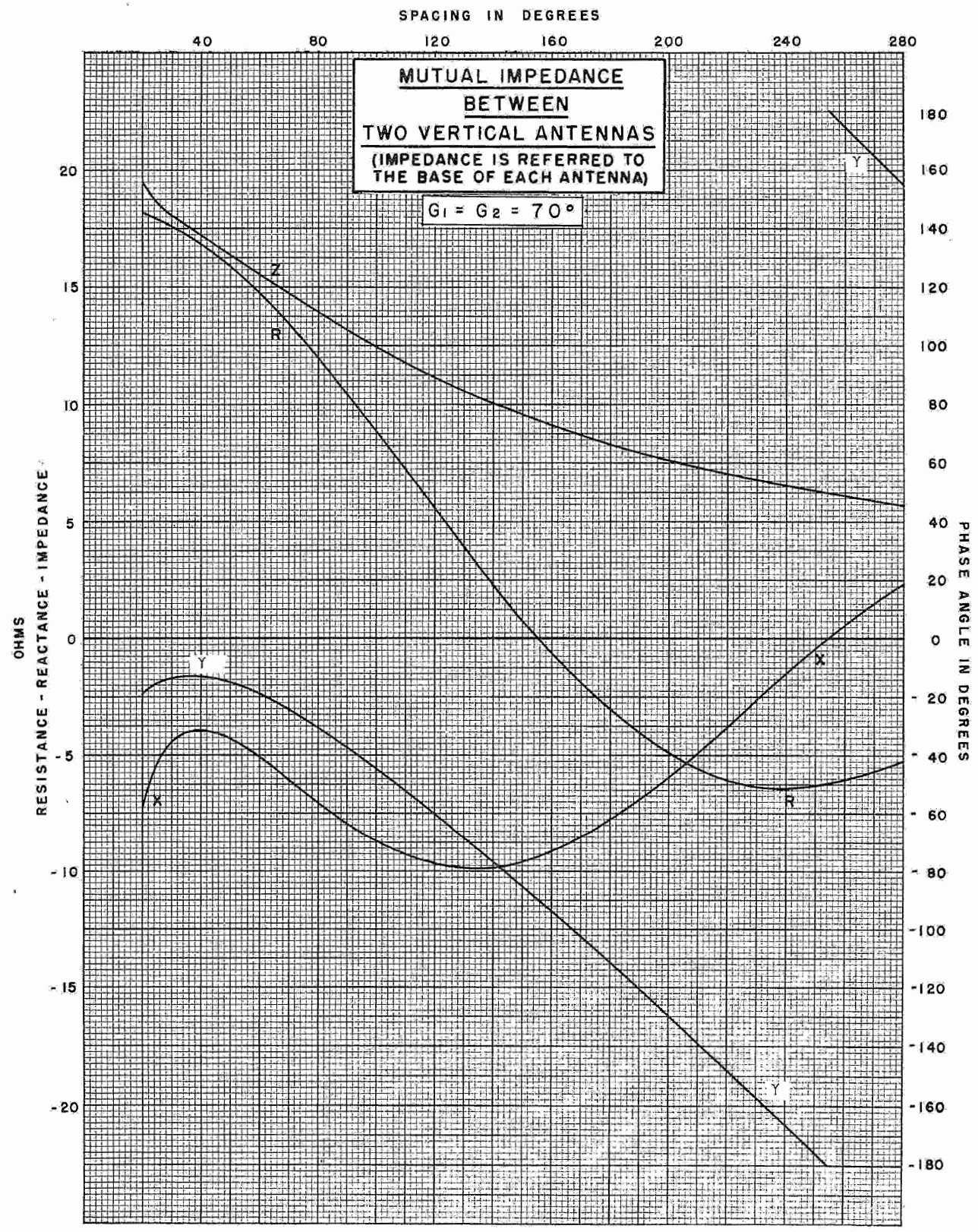
(a) Negative tower connected to dissipative load R_L

(b) Negative tower power fed back into system

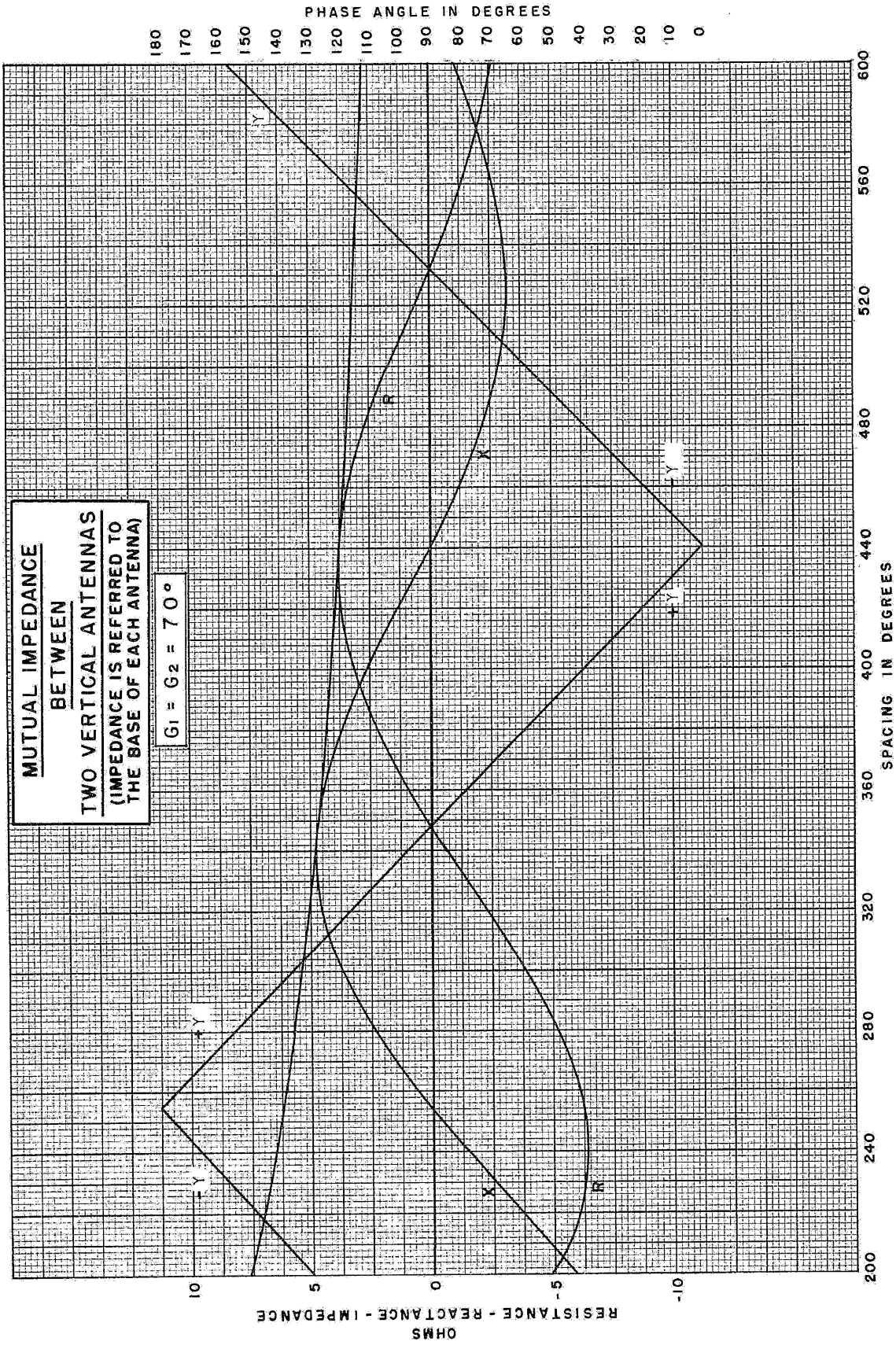
ADDITION OF POWER IN DIRECTIONAL ANTENNA SYSTEM

FIG. 54

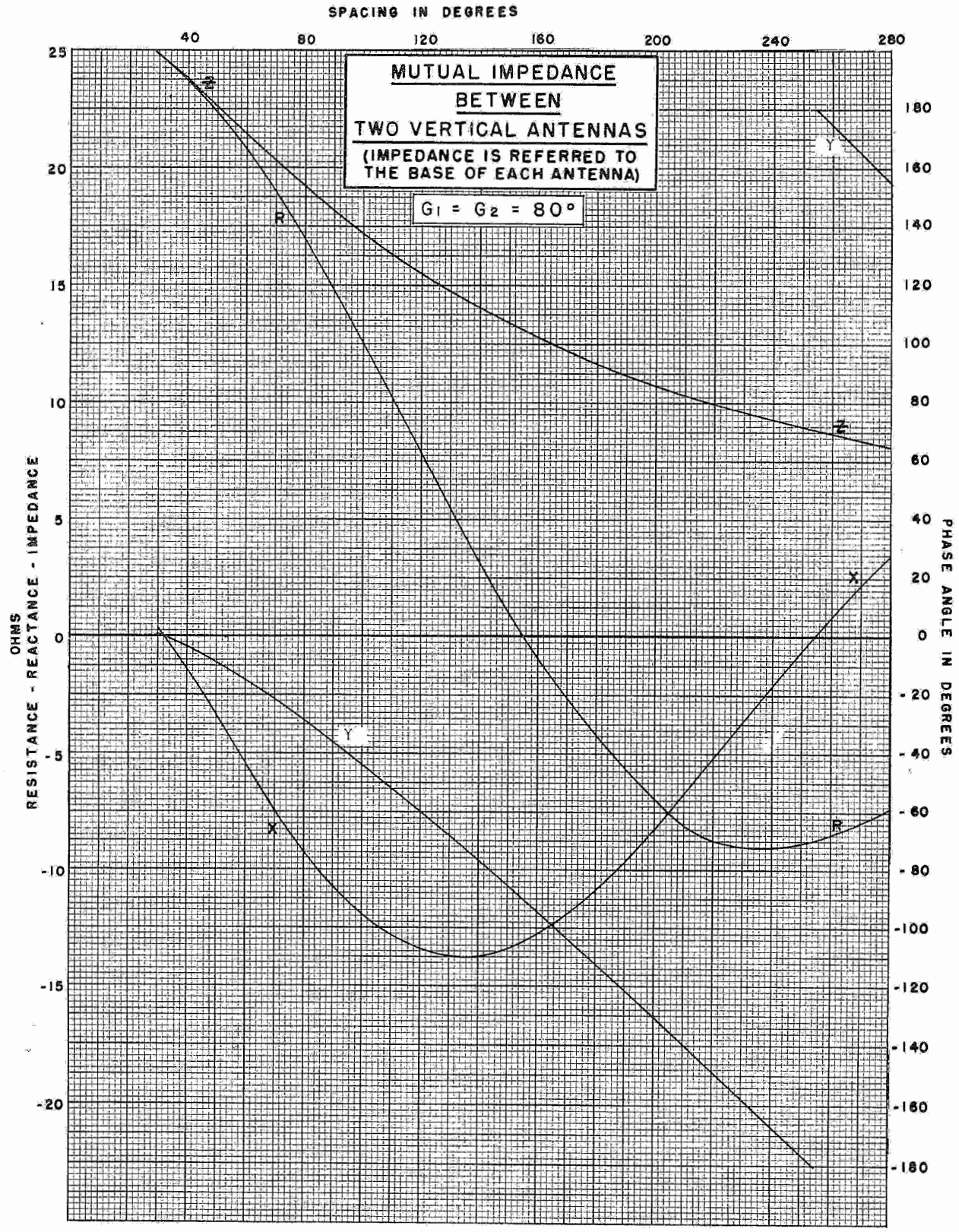
In Fig. 54(a) we have a directional antenna system properly adjusted to give the required pattern but the power from a negative tower is being dissipated in R_L. If the impedance of the negative tower is matched into a transmission line this power can be carried back to the common point input junction. Now if the phase and magnitude of the feedback voltage is properly adjusted it can be made to correspond with the phase and magnitude of the input voltage. With this condition the two circuits can be connected in parallel as shown in Fig. 54(b). The feedback network is used to adjust the phase and magnitude of the feedback voltage. Then when the feedback network is connected across the input terminals the input resistance will increase because a negative resistance in parallel with a positive resistance will have a resistance value larger than the positive resistance value alone. After the system adjustment is completed the input power will change from P_1 to $P_3 = P_1 - P_2$ where P_2 is the power fed back as shown in Fig. 54(b). Since the input resistance will increase for this condition it may be necessary to re-match the output circuit of the transmitter to the new common point impedance where the input power to the directional antenna system is measured.


SPACING IN DEGREES
40
80
120
160
200
240
280
MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = G2 = 70°
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
PHASE ANGLE IN DEGREES
20
15
10
5
0
-5
-10
-15
-20
180
160
140
120
100
80
60
40
20
0
- 20
- 40
- 60
- 80
-100
-120
-140
-160
-180
Z
R
Y
Y
X
Y
X
R

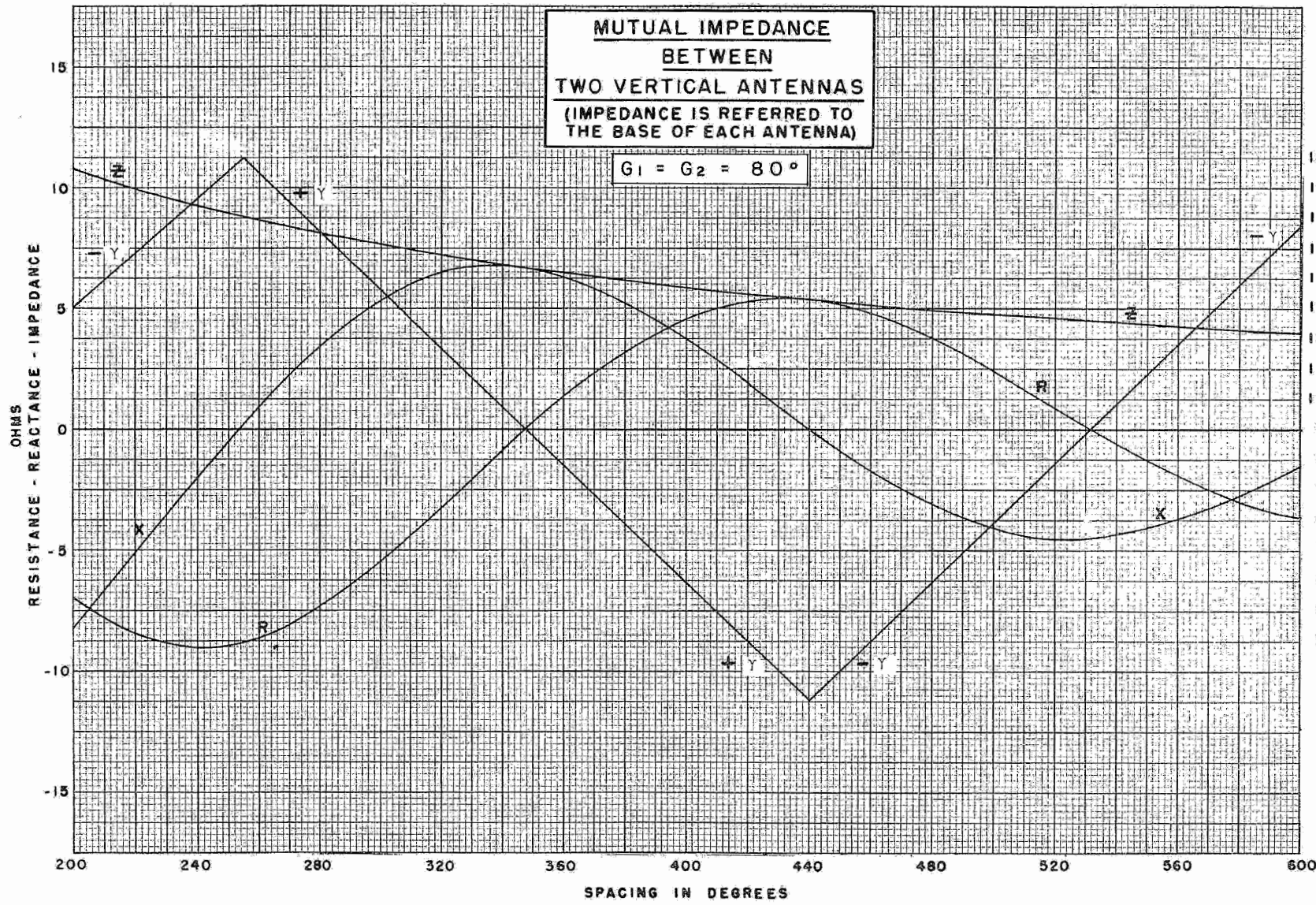
Appendix A-1

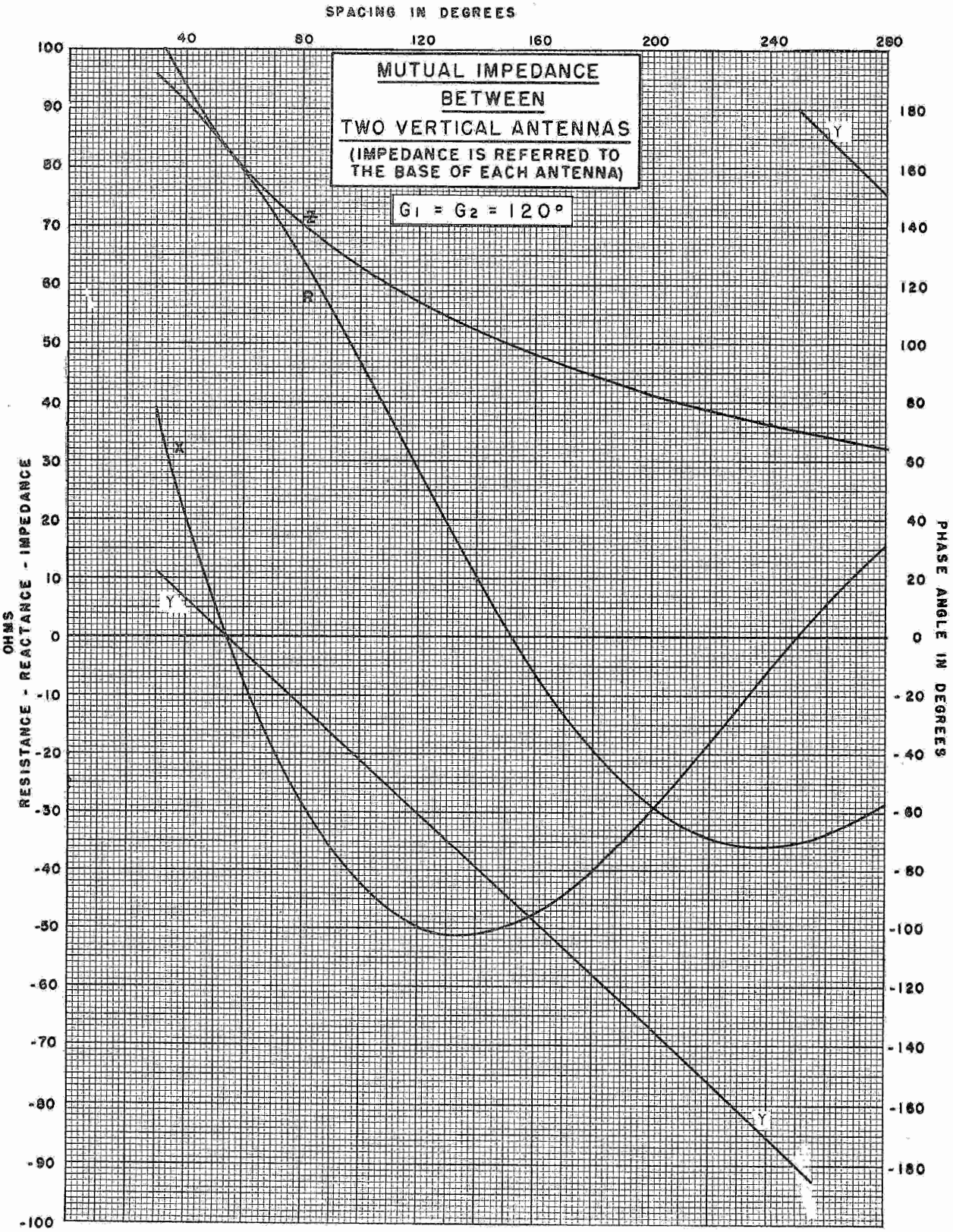

MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = G2 = 70°
PHASE ANGLE IN DEGREES
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
SPACING IN DEGREES
600 560 520 480 440 400 360 320 280 240 200
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
10 5 0 -5 -10
R
X
+Y
-Y

Appendix A-2

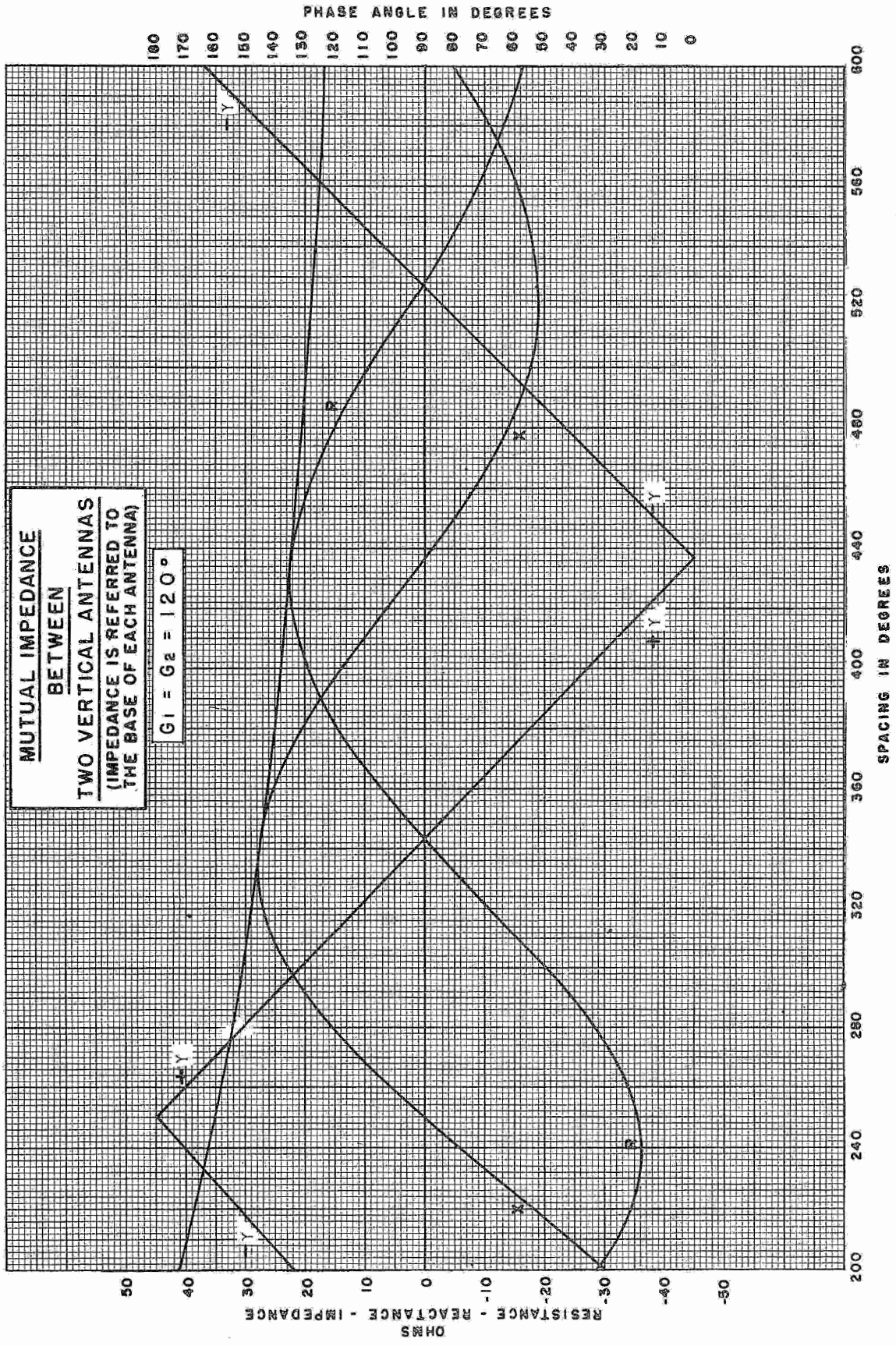

SPACING IN DEGREES
40
80
120
160
200
240
280
MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO
THE BASE OF EACH ANTENNA)
G1 = G2 = 80°
Z12
R
Y
Z
X
Y
X
R
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
PHASE ANGLE IN DEGREES
25
20
15
10
5
0
-5
-10
-15
-20
180
160
140
120
100
80
60
40
20
0
- 20
- 40
- 60
- 80
-100
-120
-140
-160
-180

Appendix A-3

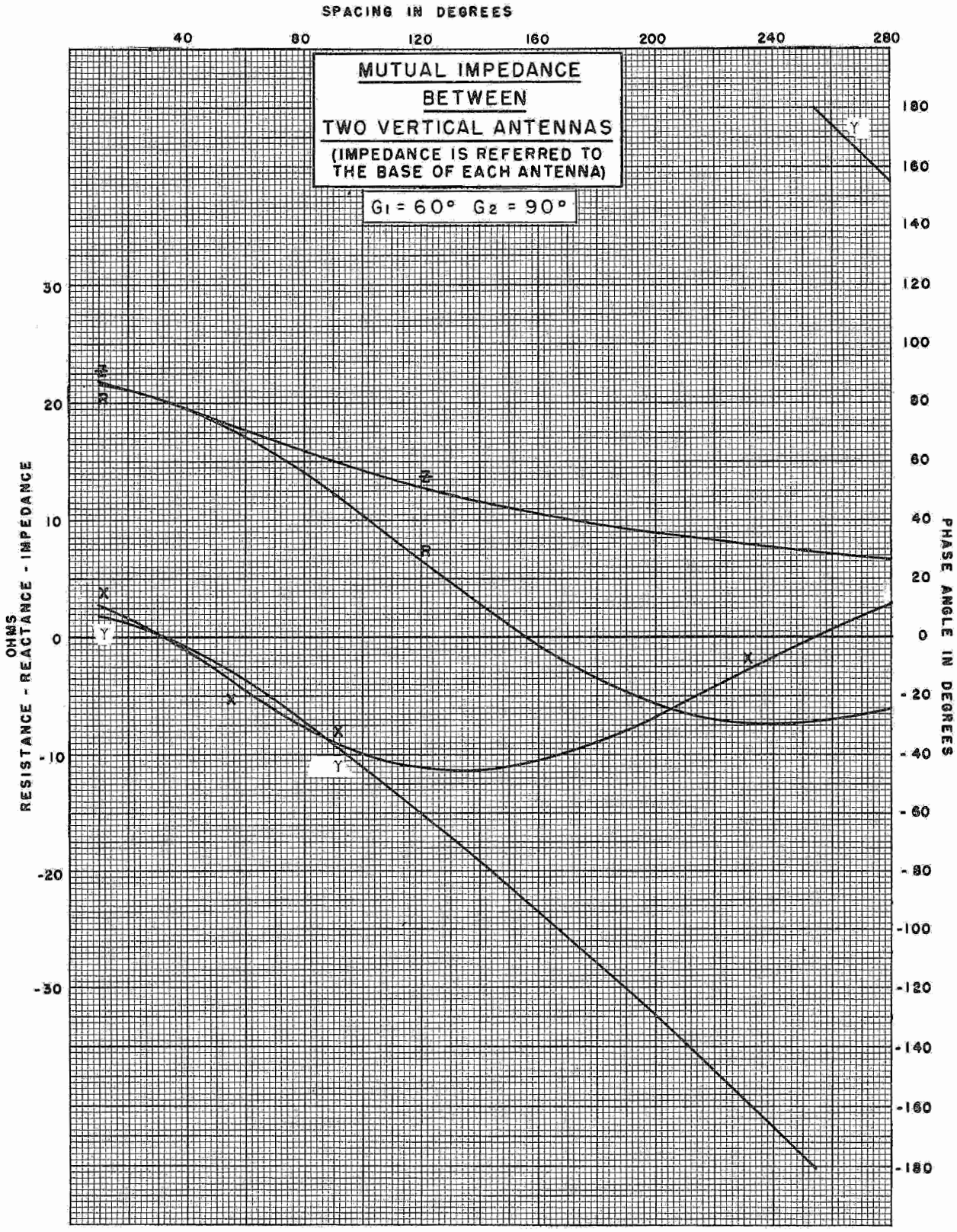

MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = G2 = 80°
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
PHASE ANGLE IN DEGREES
SPACING IN DEGREES
15
10
5
0
-5
-10
-15
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
200
240
280
320
360
400
440
480
520
560
600
R
X
Z
+Y
-Y

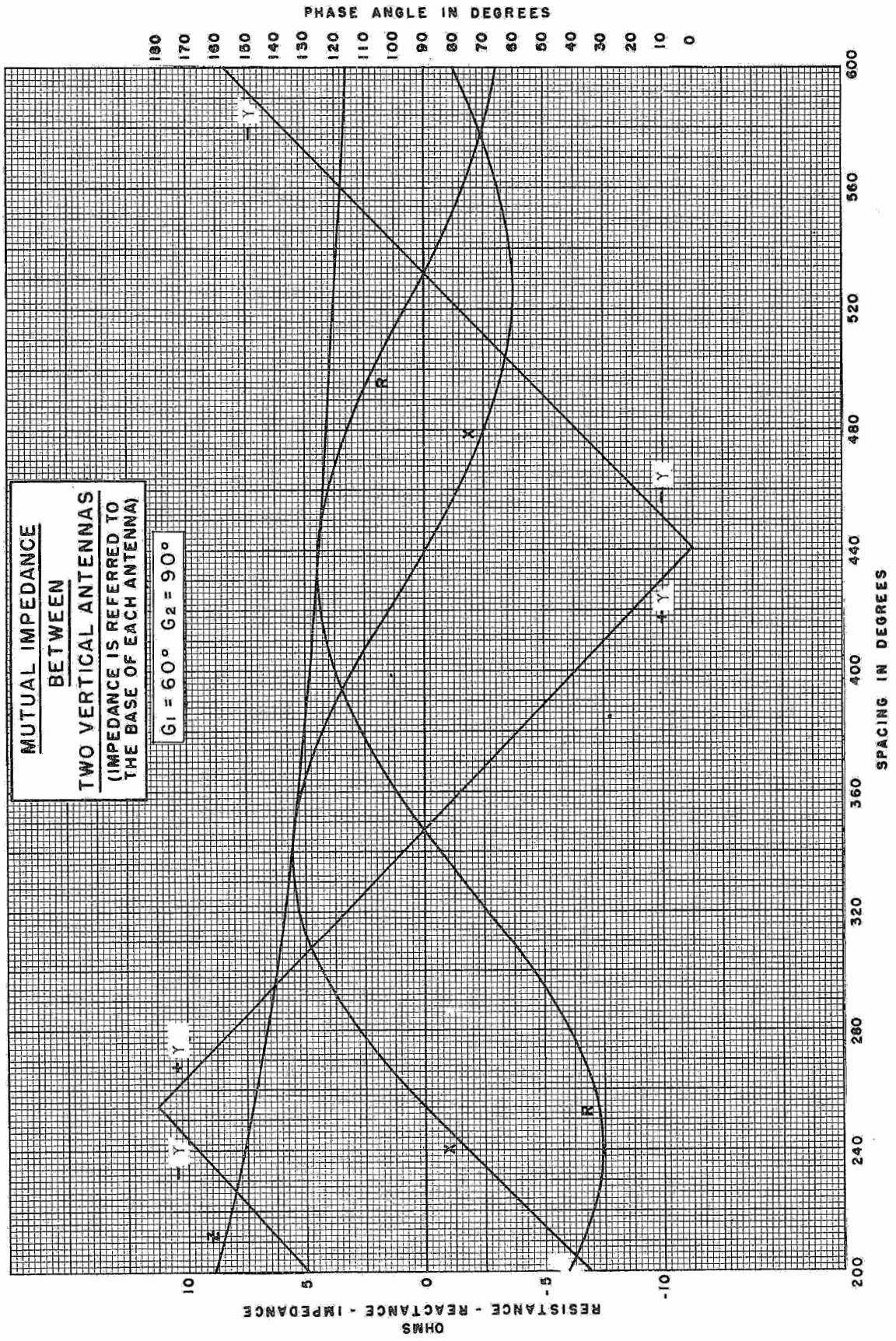

SPACING IN DEGREES
40
80
120
160
200
240
280
MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO
THE BASE OF EACH ANTENNA)
G1 = G2 = 120°
R
X
Y
Y
Y
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
PHASE ANGLE IN DEGREES
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180

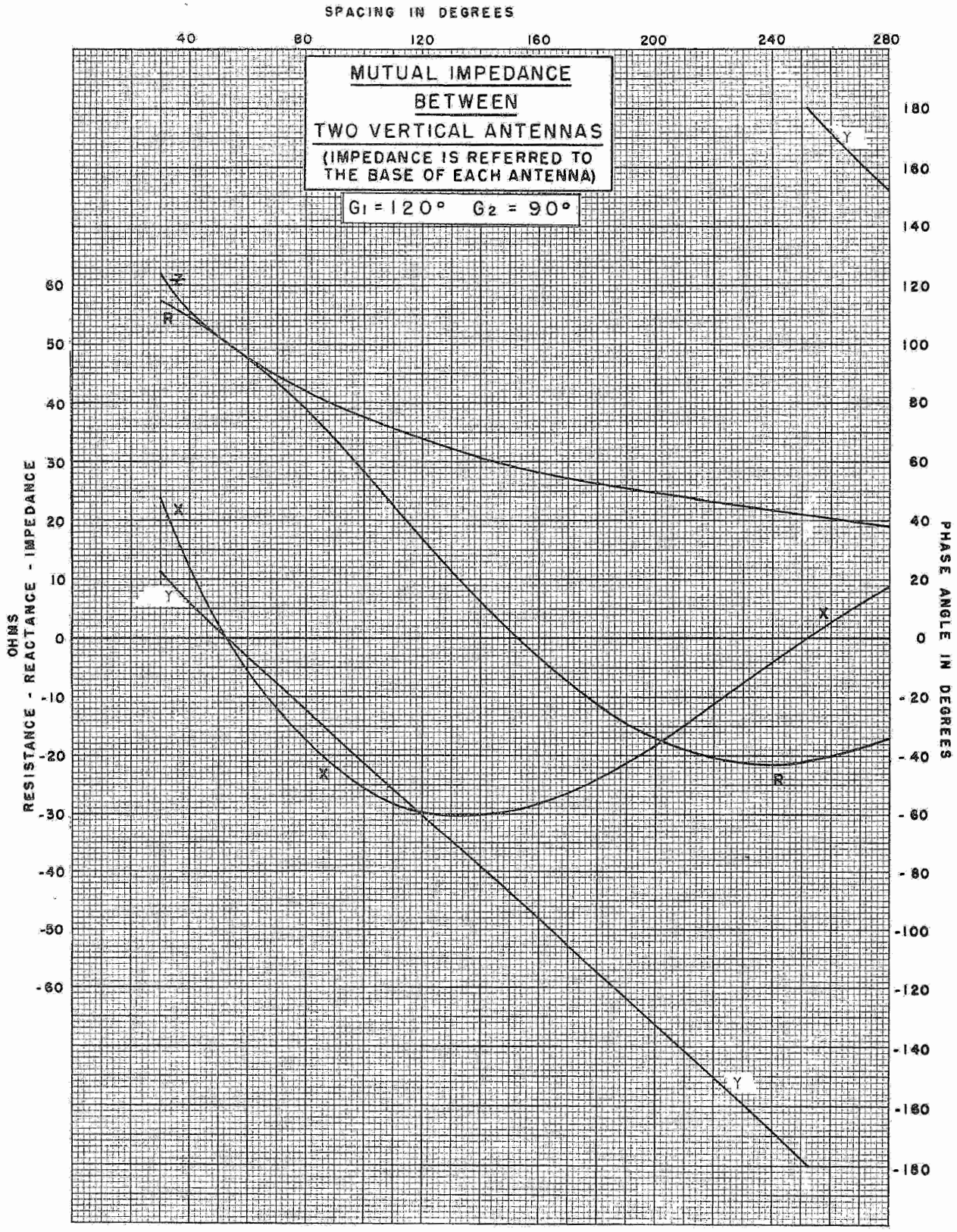
Appendix A-7

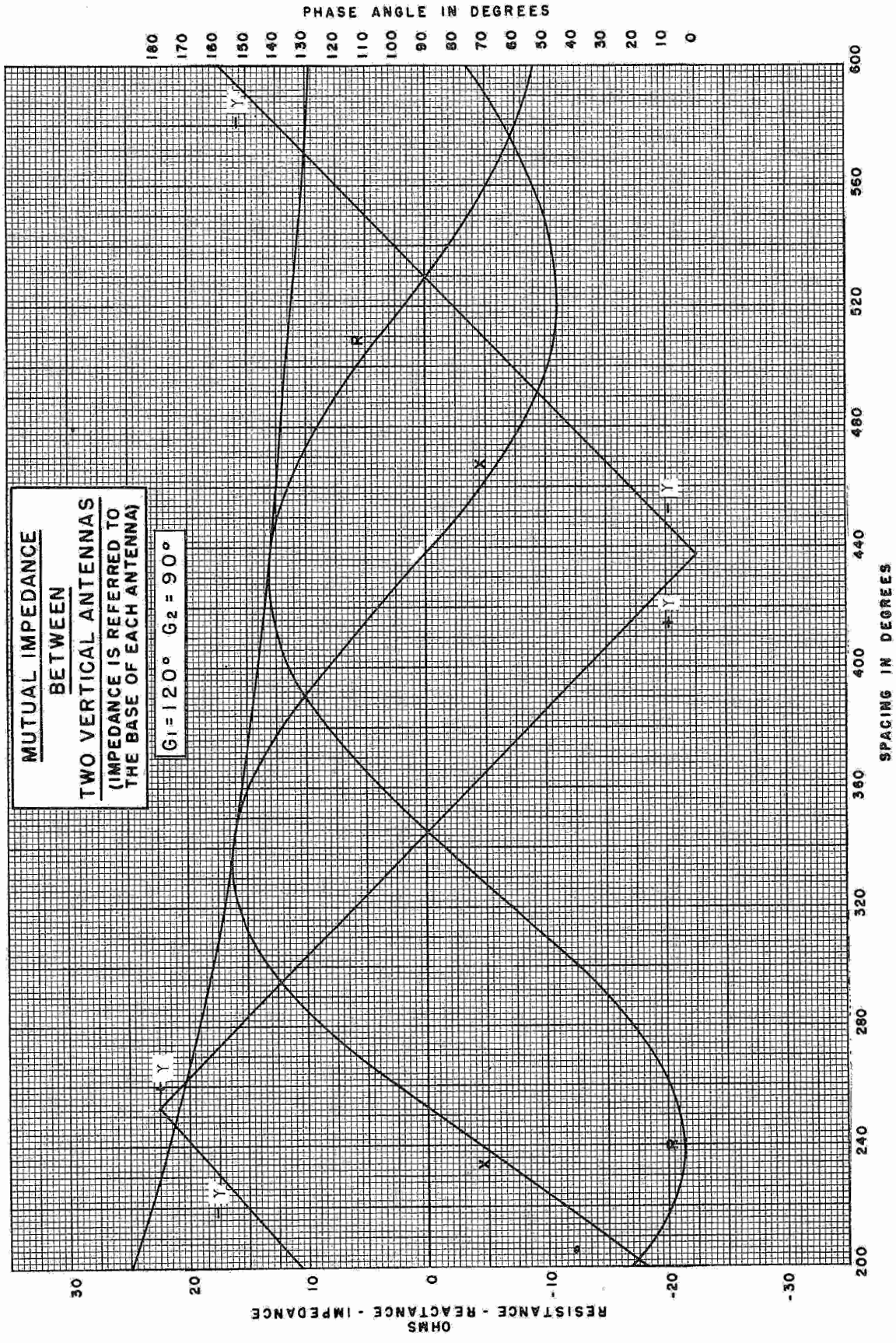

MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = G2 = 120°
PHASE ANGLE IN DEGREES
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
SPACING IN DEGREES
200 240 280 320 360 400 440 480 520 560 600
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
50 40 30 20 10 0 -10 -20 -30 -40 -50
R
X
Z
Y

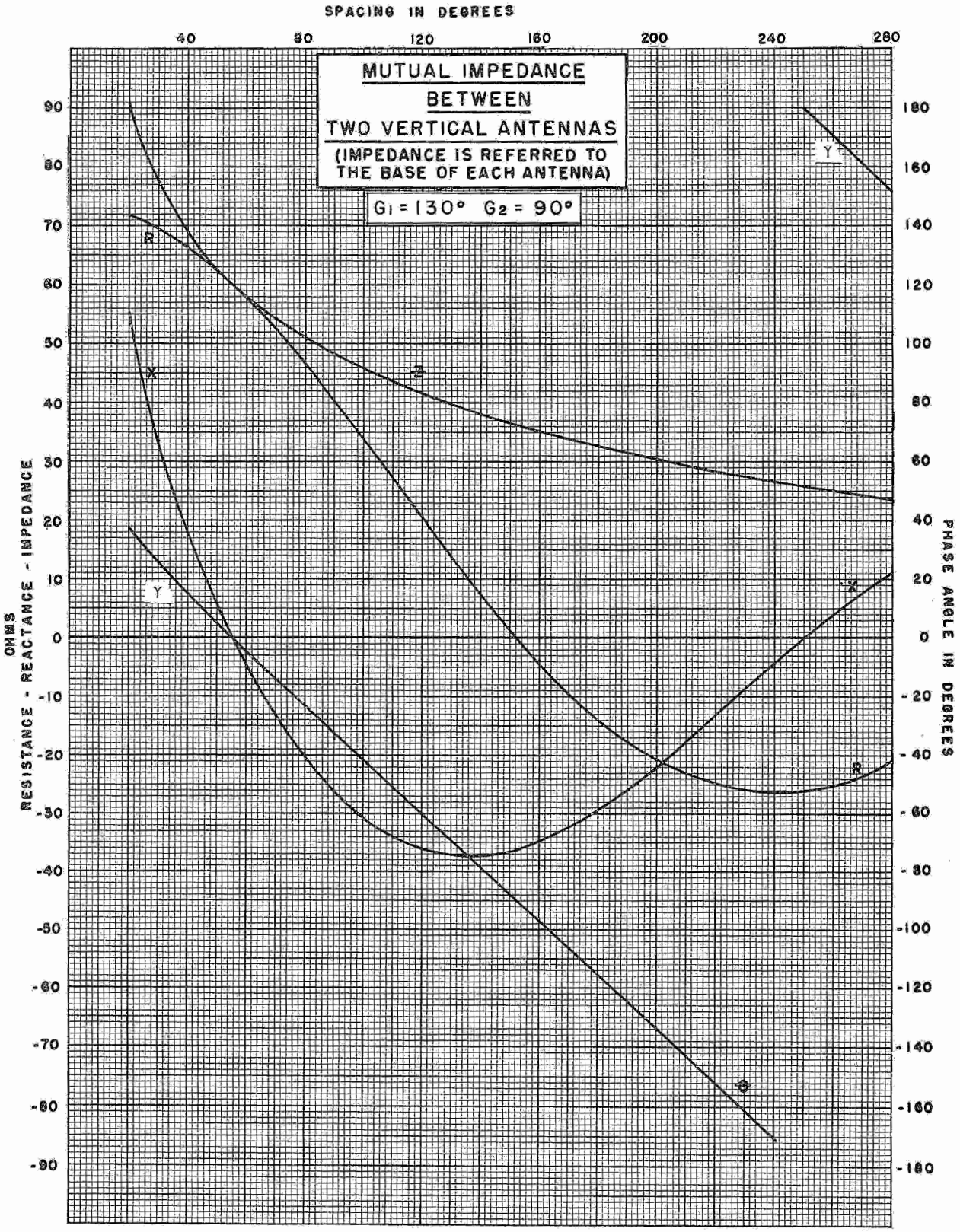
Appendix A-8


SPACING IN DEGREES
40
80
120
160
200
240
280
MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = 60° G2 = 90°
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
PHASE ANGLE IN DEGREES
30
20
10
0
-10
-20
-30
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
R
X
Y

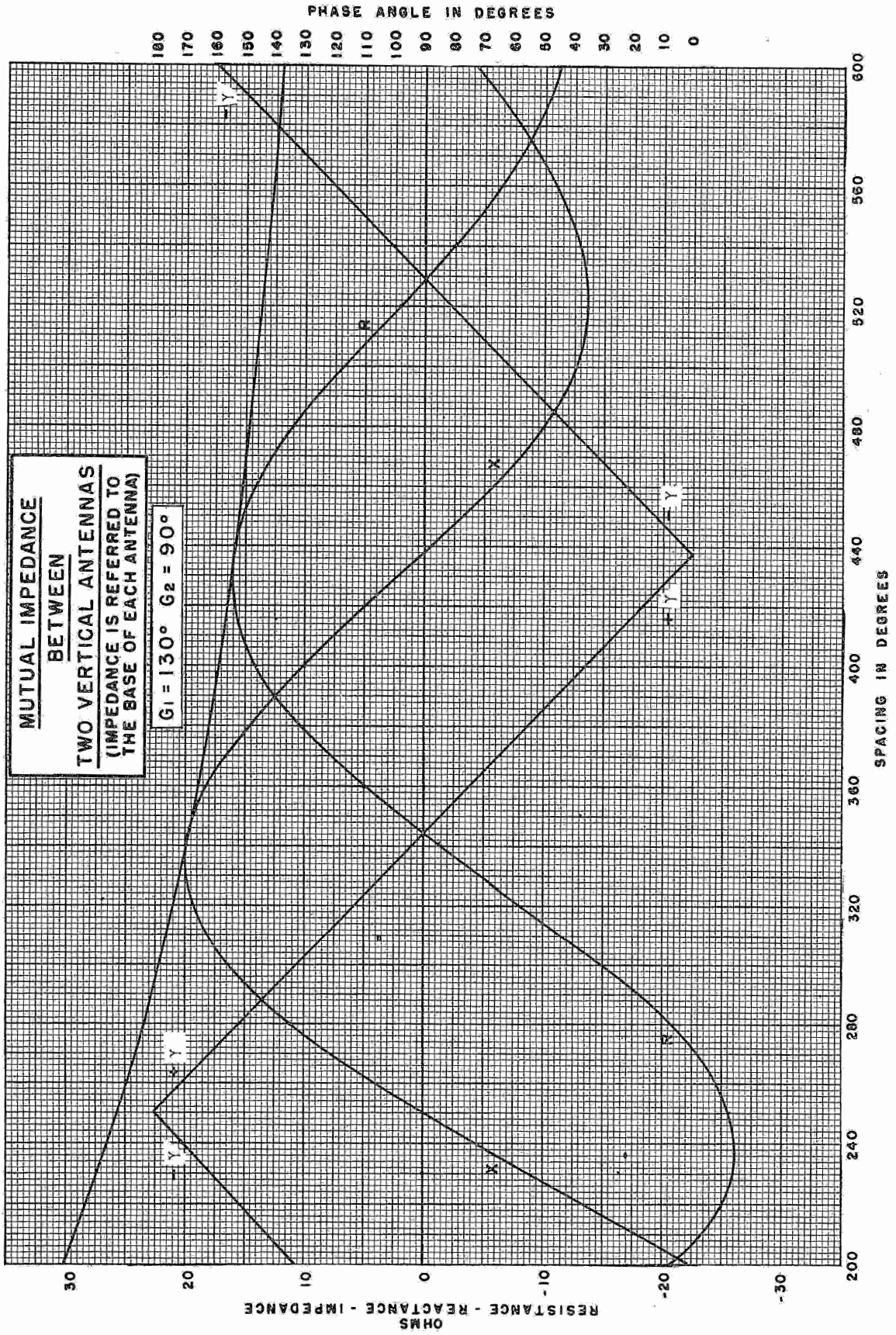

MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = 60° G2 = 90°
PHASE ANGLE IN DEGREES
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
SPACING IN DEGREES
200 240 280 320 360 400 440 480 520 560 600
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
10 5 0 -5 -10
R
X
Z
-Y
+Y

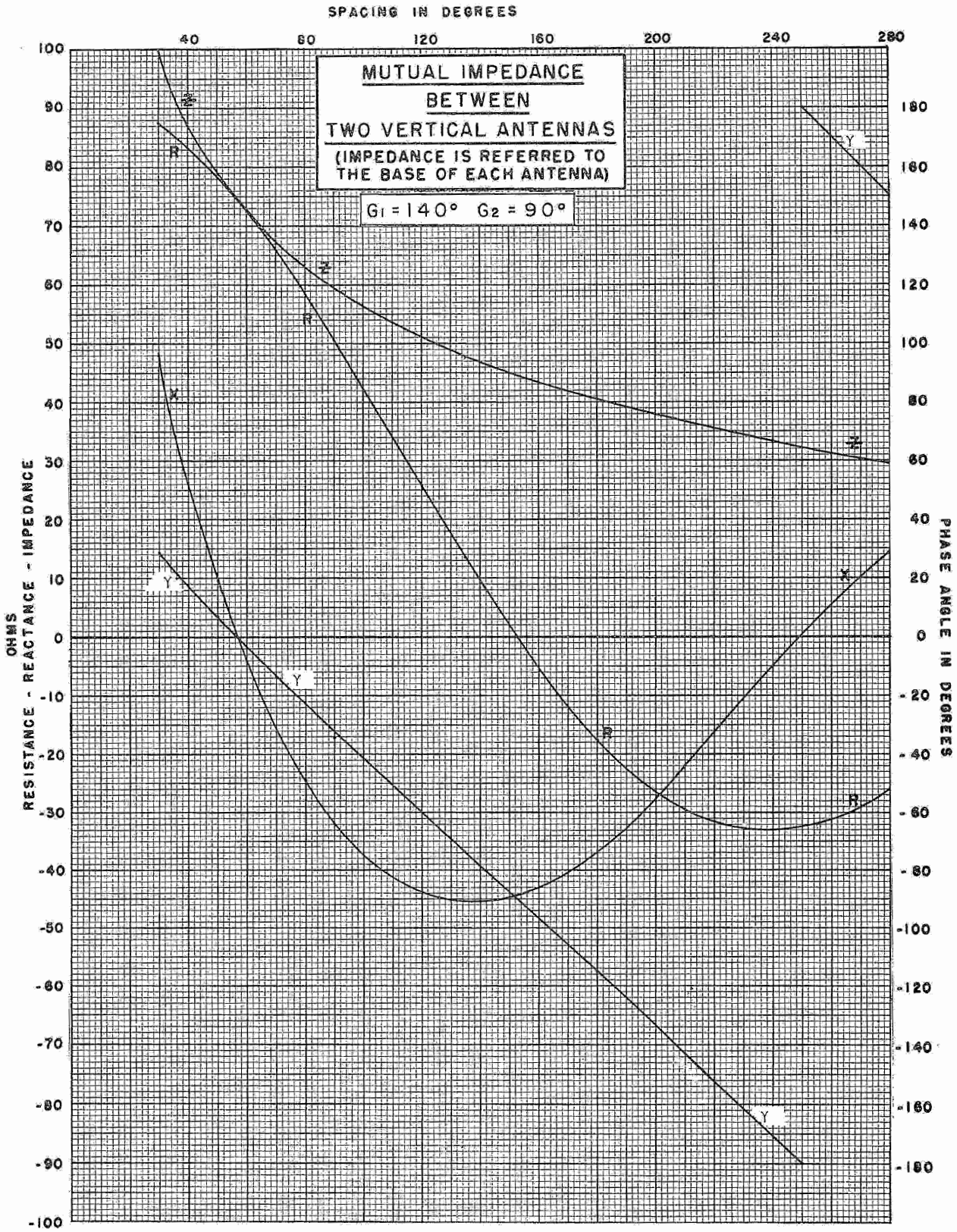

SPACING IN DEGREES
40
80
120
160
200
240
280
MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = 120° G2 = 90°
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
PHASE ANGLE IN DEGREES
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
R
X
Y

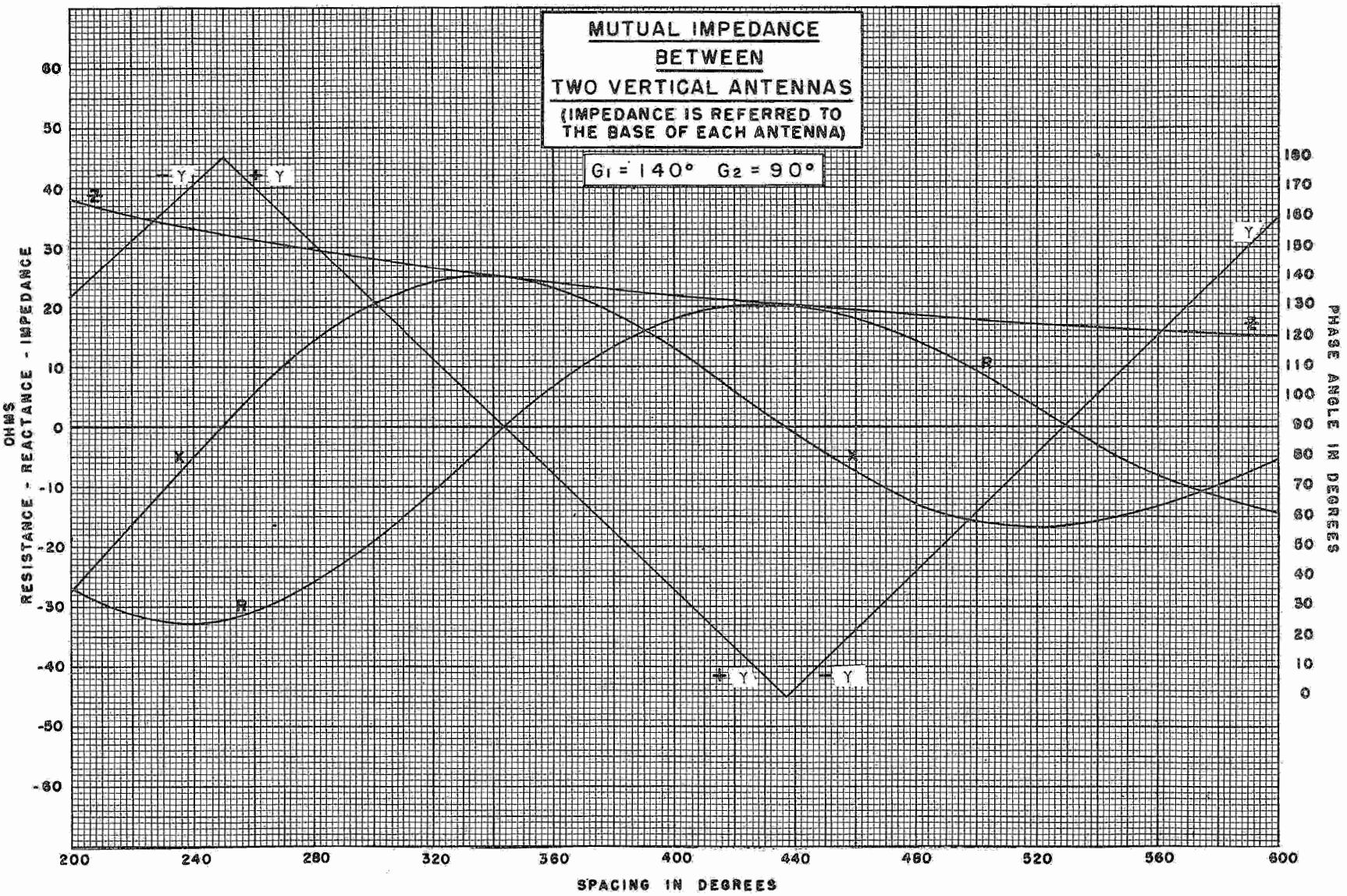

MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = 120° G2 = 90°
PHASE ANGLE IN DEGREES
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
SPACING IN DEGREES
600 560 520 480 440 400 360 320 280 240 200
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
30 20 10 0 -10 -20 -30
R
X
Z
+ Y
- Y

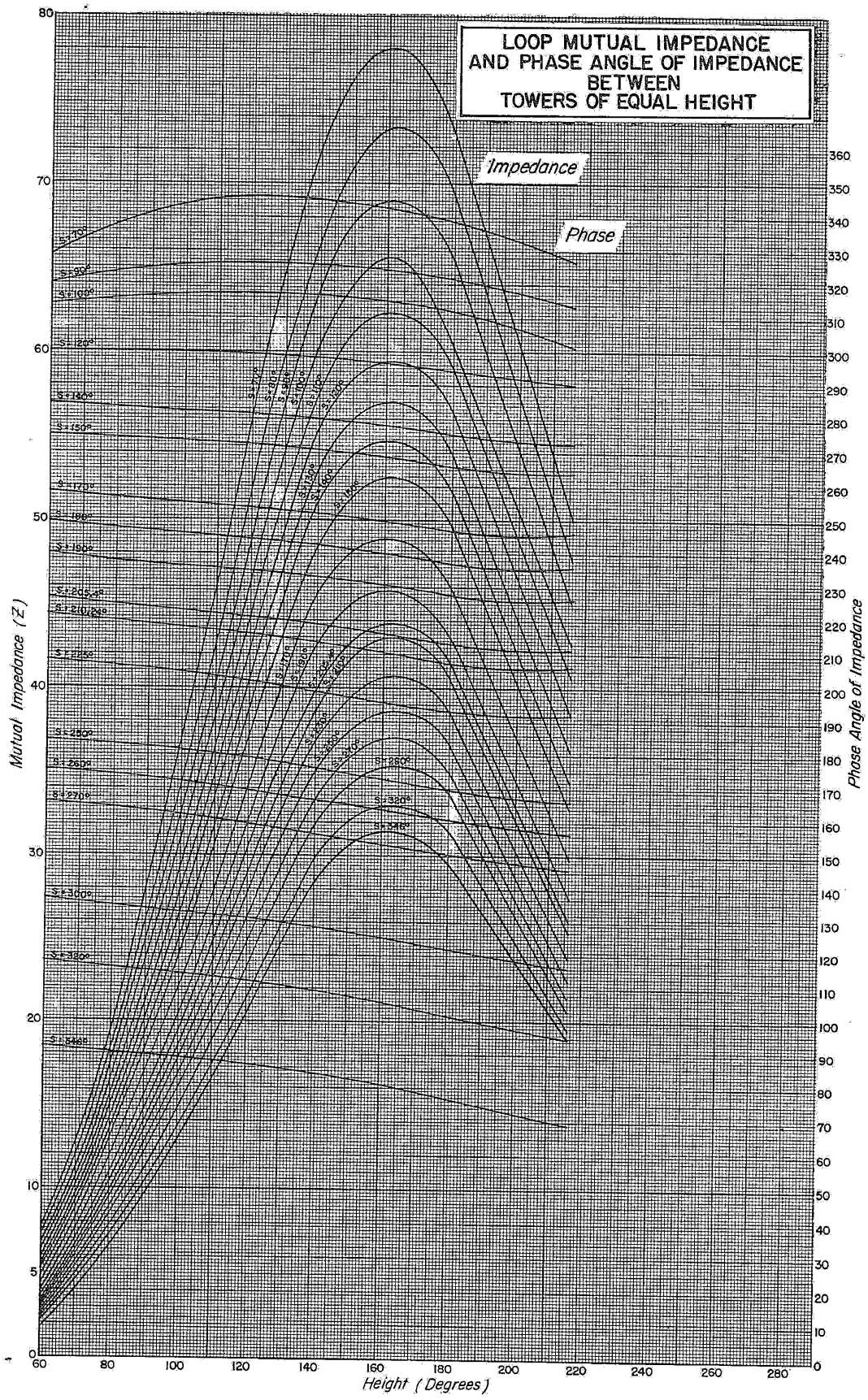


Appendix A-13


MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = 130° G2 = 90°
PHASE ANGLE IN DEGREES
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
SPACING IN DEGREES
200 240 280 320 360 400 440 480 520 560 600
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
30 20 10 0 -10 -20 -30
R
X
Z
+Y
-Y


SPACING IN DEGREES
40
80
120
160
200
240
280
MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = 140° G2 = 90°
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
PHASE ANGLE IN DEGREES
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
R
Z
X
Y

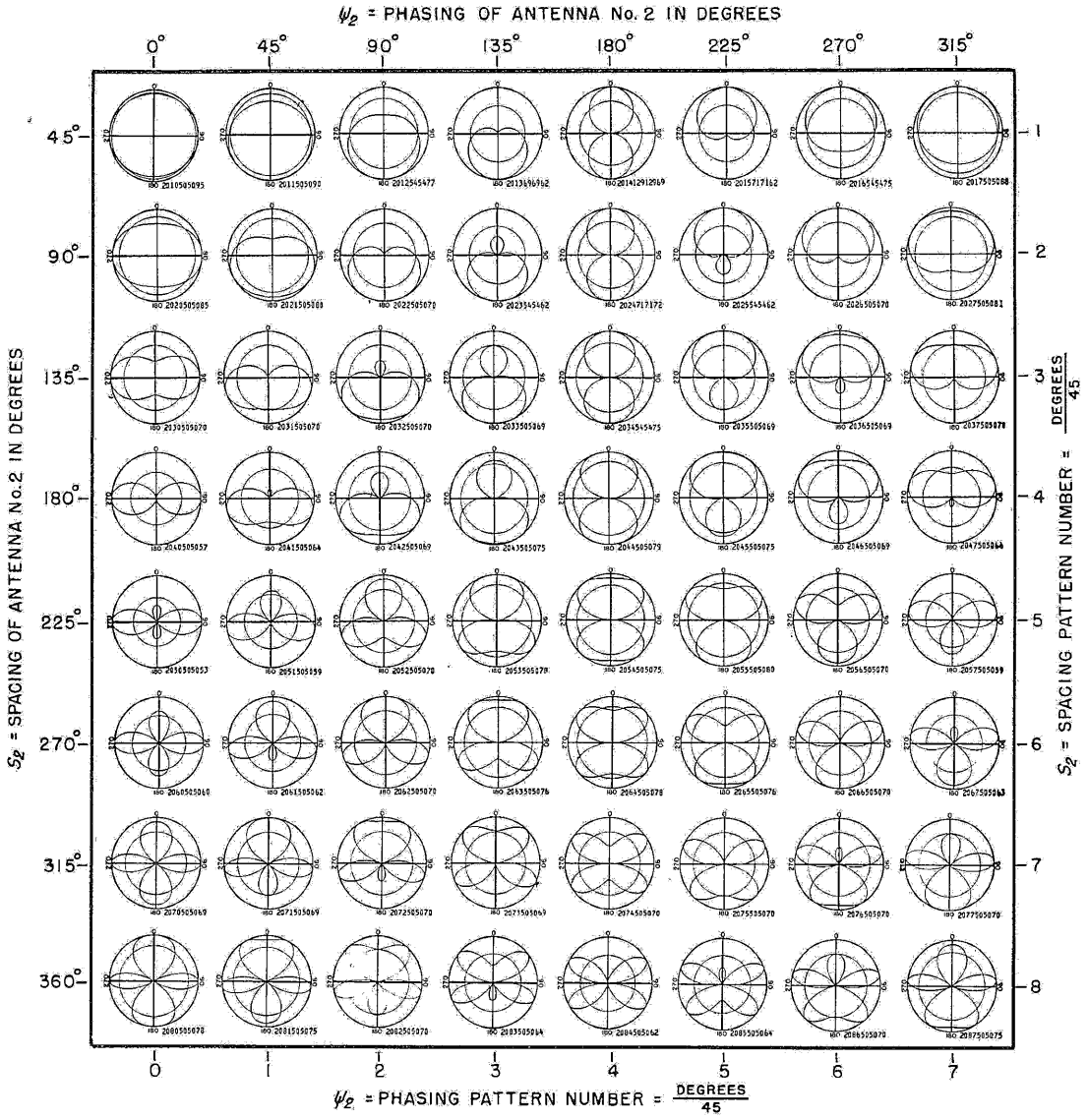

MUTUAL IMPEDANCE
BETWEEN
TWO VERTICAL ANTENNAS
(IMPEDANCE IS REFERRED TO THE BASE OF EACH ANTENNA)
G1 = 140° G2 = 90°
OHMS
RESISTANCE - REACTANCE - IMPEDANCE
PHASE ANGLE IN DEGREES
SPACING IN DEGREES
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
200
240
280
320
360
400
440
480
520
560
600
R
X
Z
Y

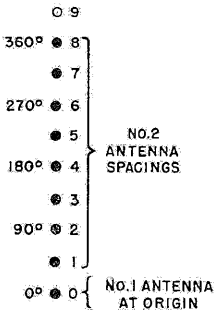

LOOP MUTUAL IMPEDANCE
AND PHASE ANGLE OF IMPEDANCE
BETWEEN
TOWERS OF EQUAL HEIGHT
Impedance
Phase
Mutual Impedance (Z)
Phase Angle of Impedance
Height (Degrees)

MUTUAL, LOOP CURRENT, IMPEDANCE
BETWEEN QUARTER WAVE VERTICAL ANTENNAS
AT THE SURFACE OF A PERFECT EARTH
PHASING IN DEGREES
180
160
140
120
100
80
60
40
20
0
-ψ = PHASE
USE SCALE ON RIGHT
ψ = PHASE
R = RESISTANCE
Z = IMPEDANCE
USE SCALE ON LEFT
X = REACTANCE
-ψ = PHASE
USE SCALE ON LEFT
USE SCALE ON LEFT
ψ = PHASE
70
60
50
40
30
20
10
0
-10
-20
-30
-OHMS-
RESISTANCE – REACTANCE – IMPEDANCE
520
480
440
400
360
320
280
240
200
160
120
80
40
SPACING IN DEGREES

MUTUAL, LOOP CURRENT, IMPEDANCE
BETWEEN HALF WAVE VERTICAL ANTENNAS
AT THE SURFACE OF A PERFECT EARTH
PHASING IN DEGREES
SPACING IN DEGREES
RESISTANCE – REACTANCE – IMPEDANCE
-OHMS-
USE SCALE ON RIGHT
USE SCALE ON LEFT
USE SCALE ON LEFT
USE SCALE ON LEFT
USE SCALE ON LEFT
R = RESISTANCE
X = REACTANCE
Z = IMPEDANCE
γ = PHASE
γ = PHASE
-γ = PHASE
-γ = PHASE

MUTUAL, LOOP CURRENT, IMPEDANCE
BETWEEN A QUARTER WAVE
AND A HALF WAVE VERTICAL ANTENNA
AT THE SURFACE OF A PERFECT EARTH
PHASING IN DEGREES
180
160
140
120
100
80
60
40
20
0
γ = PHASE
USE SCALE ON RIGHT
γ = PHASE
Z = IMPEDANCE
USE SCALE ON LEFT
$-\gamma$ = PHASE
R = RESISTANCE
X = REACTANCE
USE SCALE ON LEFT
USE SCALE ON LEFT
γ = PHASE
70
60
50
40
30
20
10
0
−10
−20
−30
RESISTANCE – REACTANCE – IMPEDANCE
– OHMS –
40
80
120
160
200
240
280
320
360
400
440
480
520
SPACING IN DEGREES

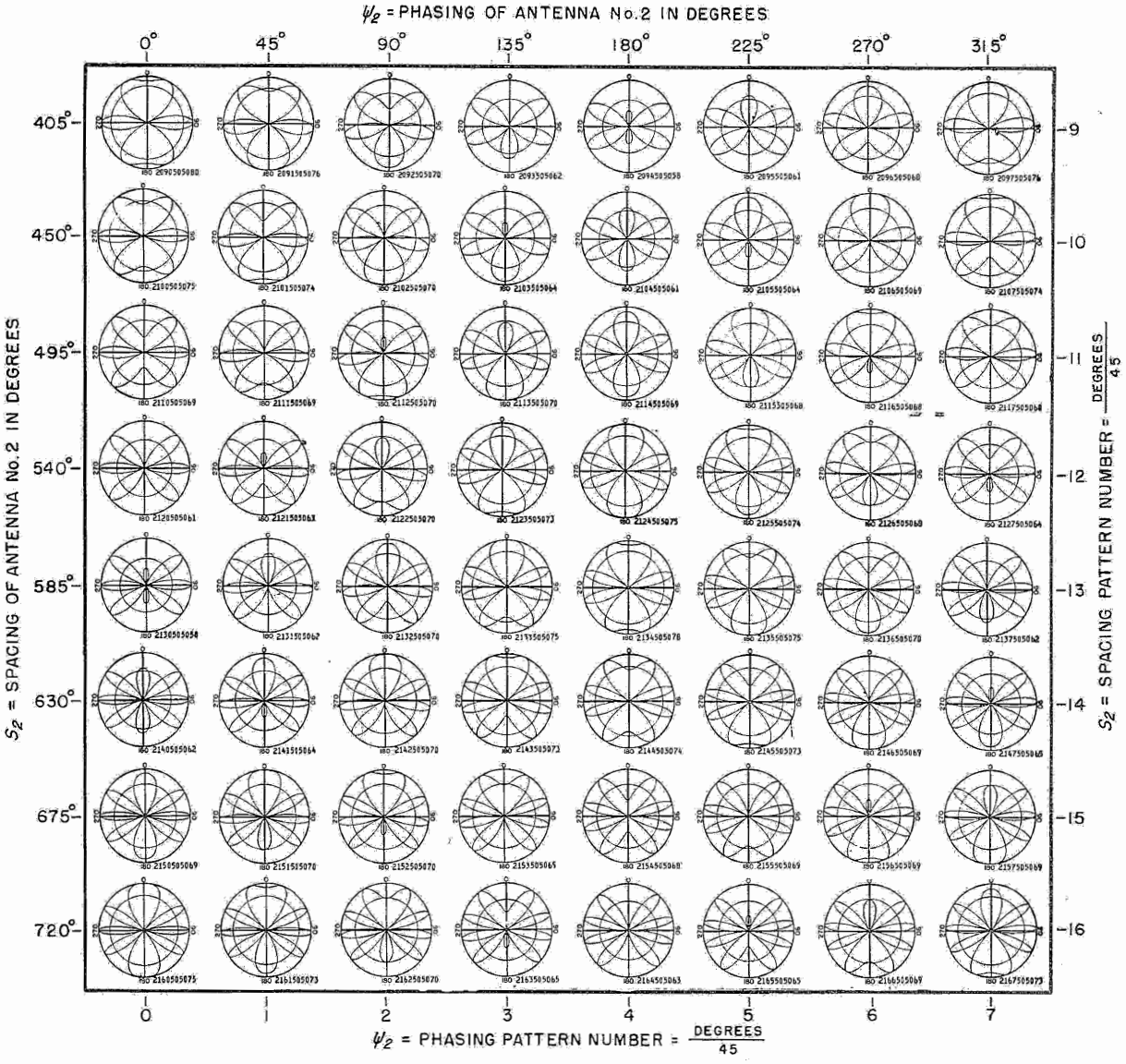




SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS.

NUMBER OF ANTENNAS IN THE SYSTEM.	SPACING OF No. 2 ANTENNA = $\frac{\text{DEGREES}}{45}$	PHASING OF No. 2 ANTENNA = $\frac{\text{DEGREES}}{45}$	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 1 ANTENNA.	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO.2 ANTENNA.	% R.M.S FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM.
No.	S_2	ψ_2	E_1	E_2	E_0
2	01	0	50	50	95

PATTERN NOMENCLATURE



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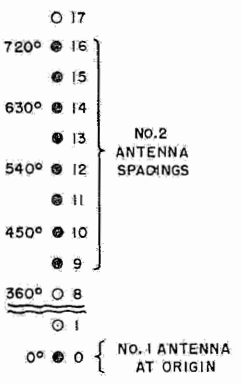
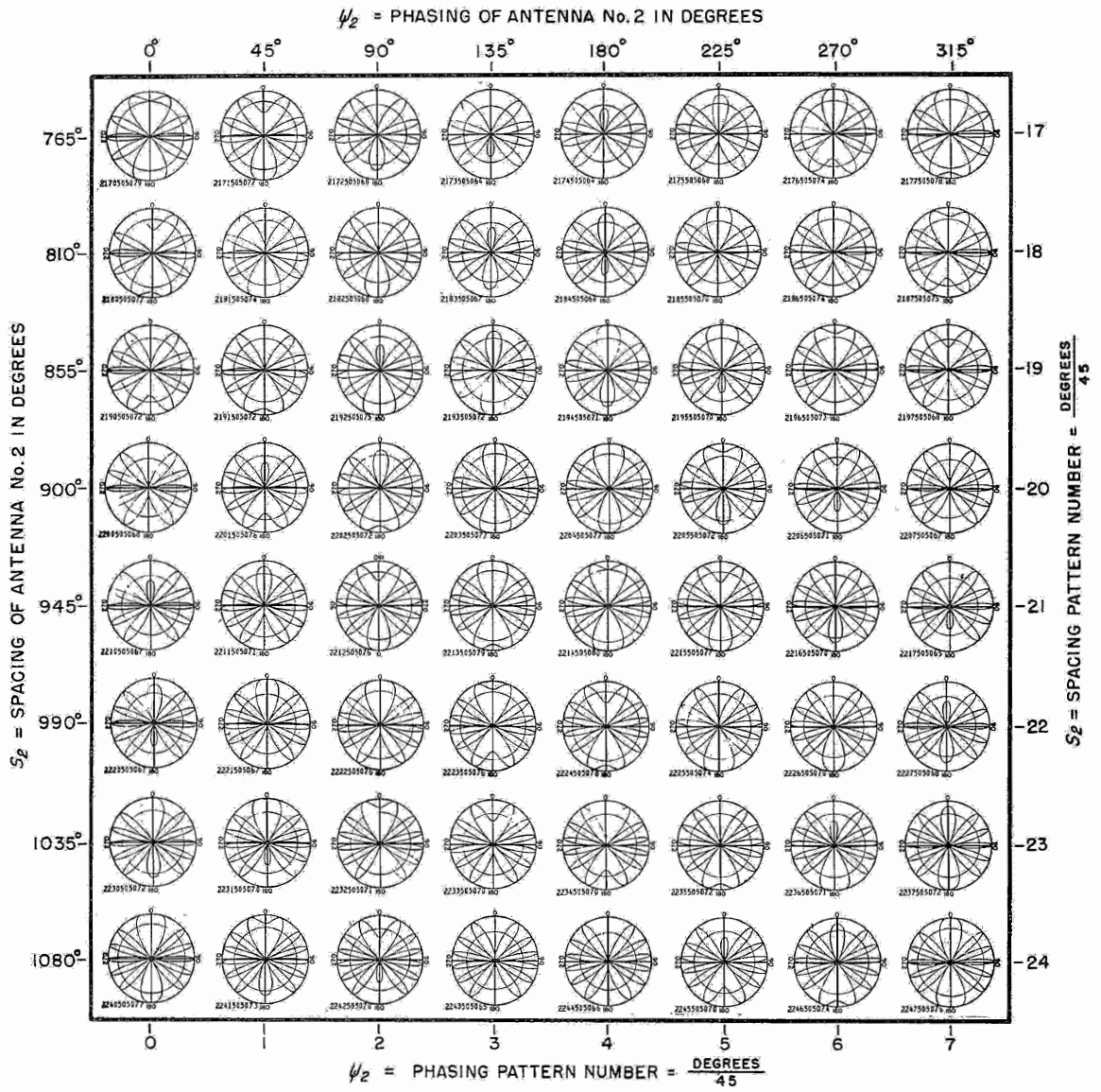
TERMINAL TOWER, CLEVELAND 18, OHIO.

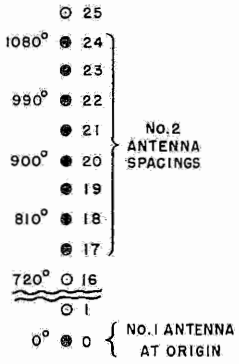


SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS.

PATTERN NOMENCLATURE

NUMBER OF ANTENNAS IN THE SYSTEM.	SPACING OF NO. 2 ANTENNA = DEGREES / 45	PHASING OF NO. 2 ANTENNA = DEGREES / 45	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 1 ANTENNA.	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 2 ANTENNA.	% RMS FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM.
No.	S_2	ψ_2	E_1	E_2	E_0
2	09	0	50	50	80





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	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 1 ANTENNA.	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 2 ANTENNA.	% RMS FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM.
No.	S_2	ψ_2	E_1	E_2	E_0
2	17	0	50	50	79

PATTERN NOMENCLATURE

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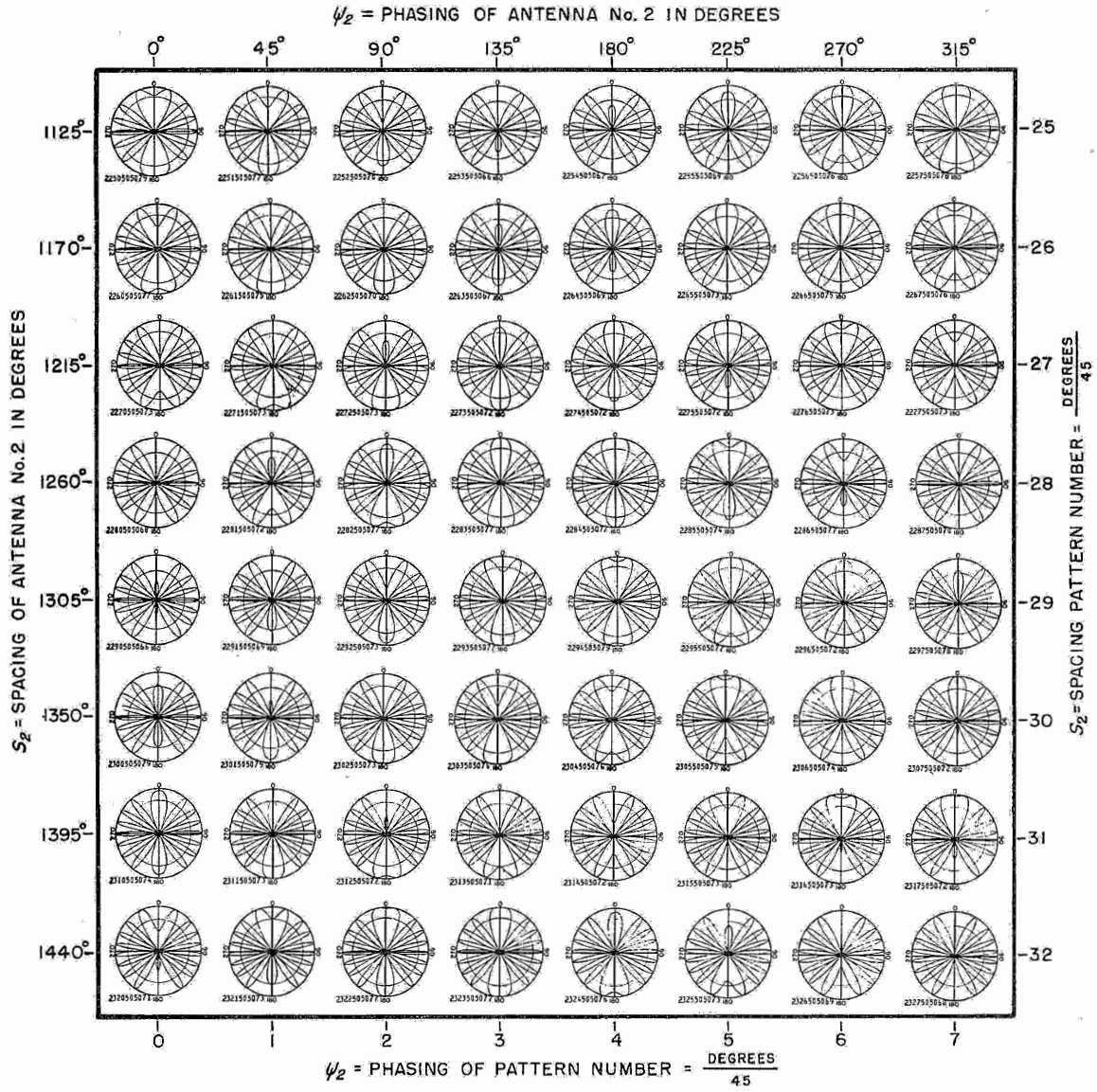
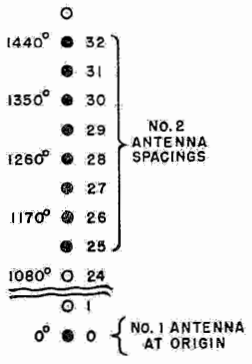
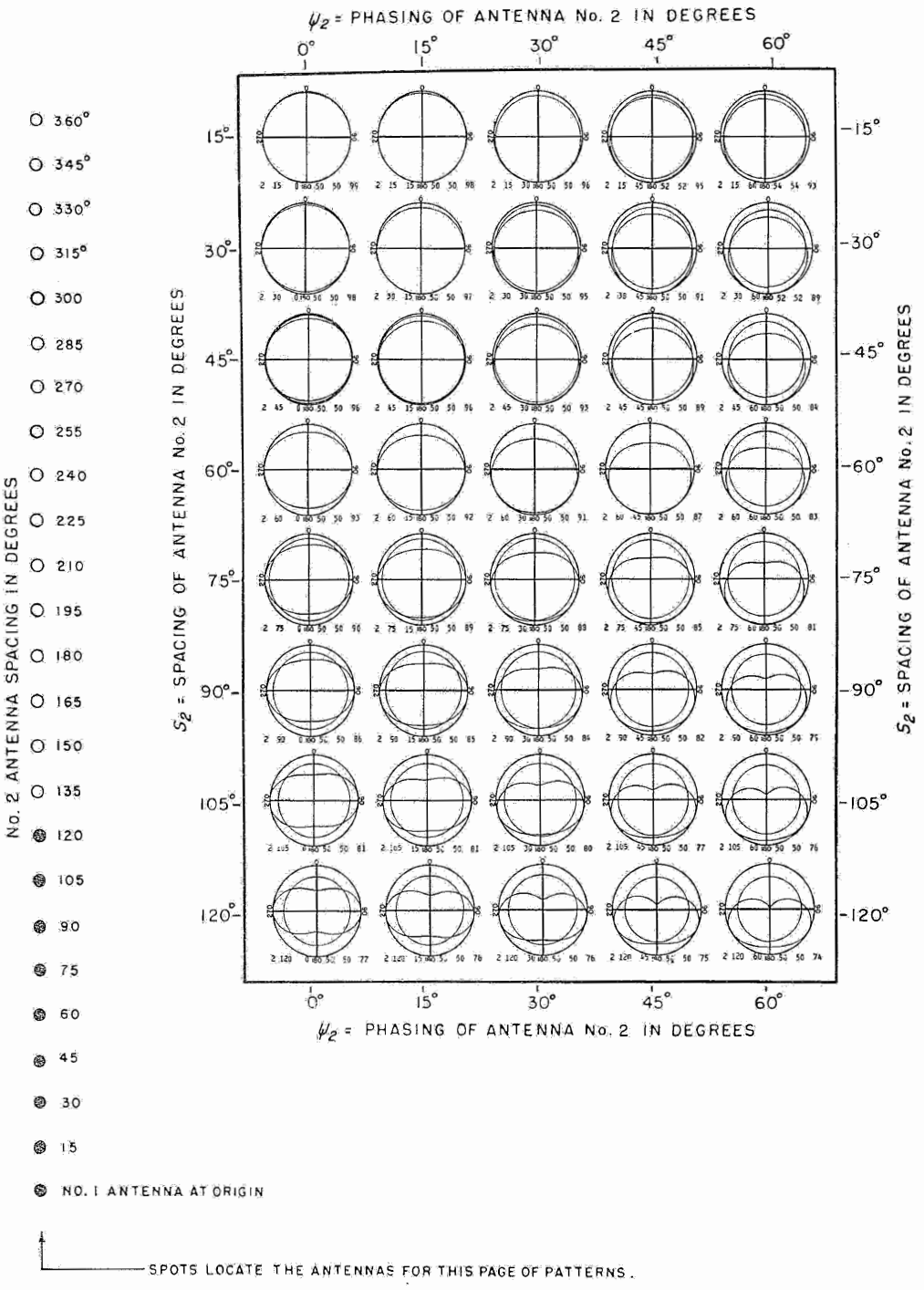




SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS.

PATTERN NOMENCLATURE

NUMBER OF ANTENNAS IN THE SYSTEM.	SPACING OF NO. 2 ANTENNA = DEGREES / 45	PHASING OF NO. 2 ANTENNA = DEGREES / 45	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 1 ANTENNA.	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 2 ANTENNA.	% RMS FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM.
No.	S_2	ψ_2	E_1	E_2	E_0
2	25	0	50	50	79


ψ_2 = PHASING OF ANTENNA No. 2 IN DEGREES
0°
15°
30°
45°
60°
S_2 = SPACING OF ANTENNA No. 2 IN DEGREES
15°
30°
45°
60°
75°
90°
105°
120°
-15°
-30°
-45°
-60°
-75°
-90°
-105°
-120°
No. 2 ANTENNA SPACING IN DEGREES
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.

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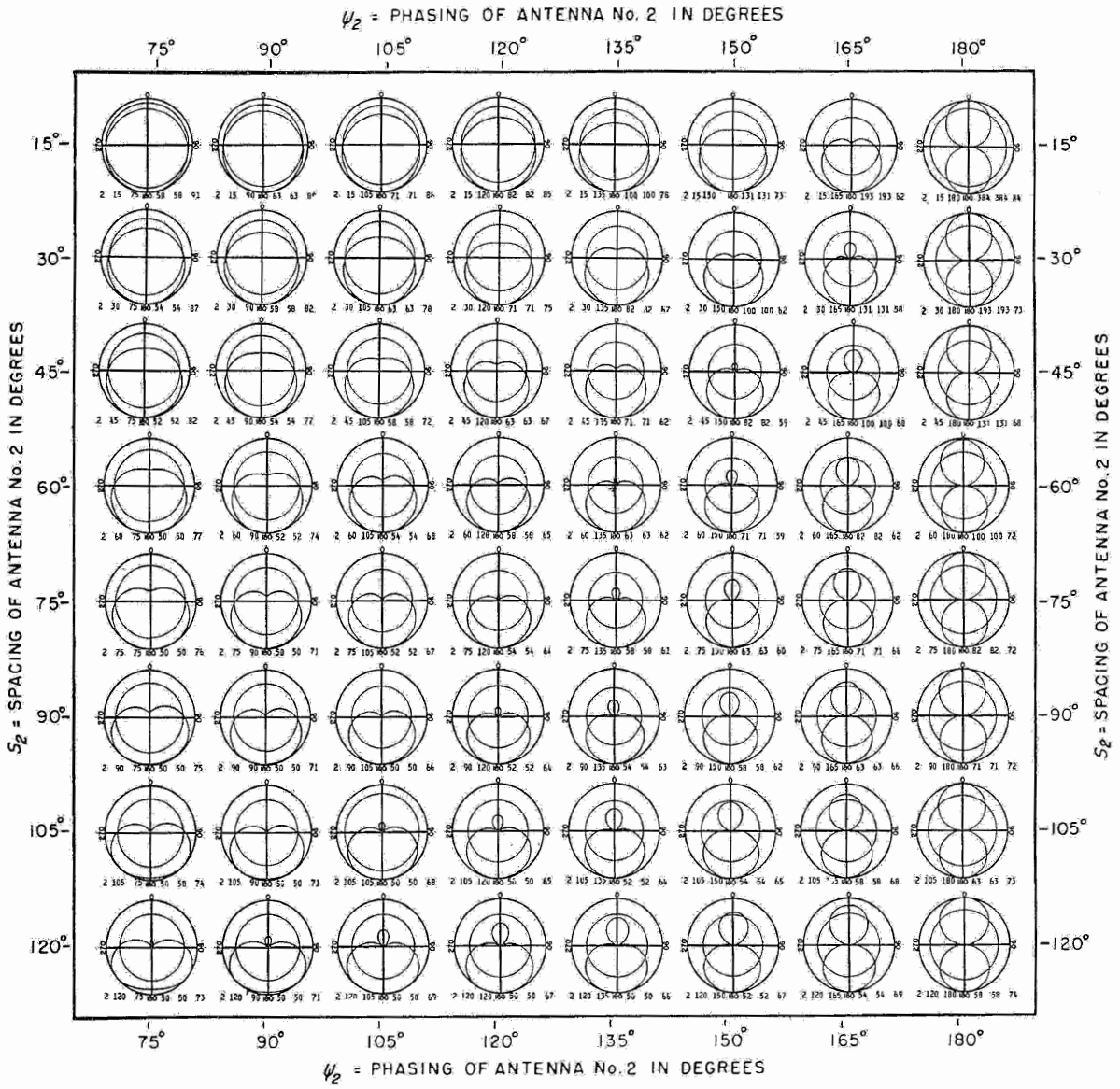
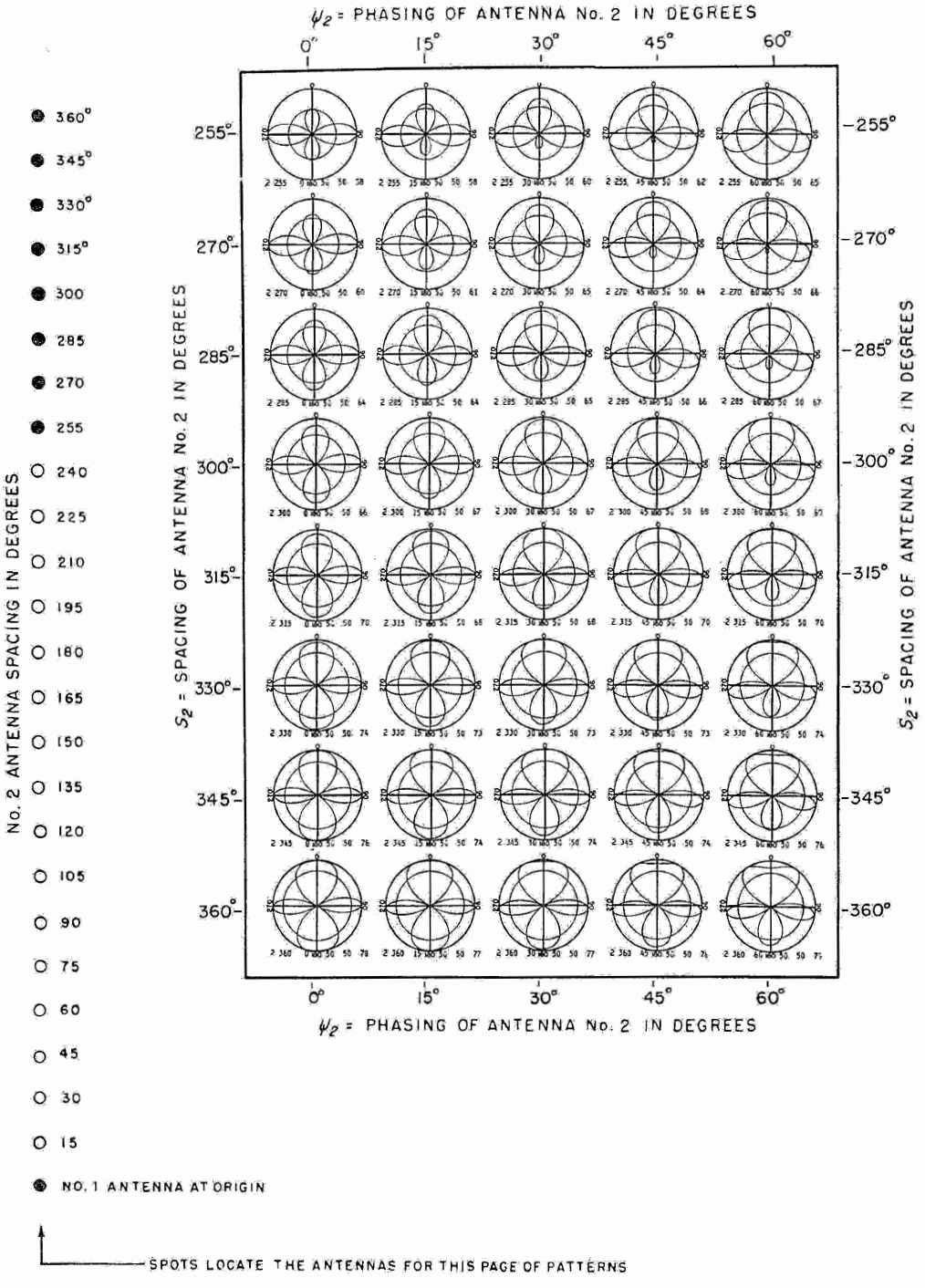
CLEVELAND INSTITUTE OF RADIO ELECTRONICS
TERMINAL TOWER, CLEVELAND 13, OHIO.



PATTERN NOMENCLATURE

NUMBER OF ANTENNAS IN THE SYSTEM	SPACING OF NO. 2 ANTENNA IN DEGREES	PHASING OF NO. 2 ANTENNA IN DEGREES	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 1 ANTENNA	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 2 ANTENNA	% RMS FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM
No.	S_2	ψ_2	E_1	E_2	E_0
2	15	75	58	58	91


ψ_2 = PHASING OF ANTENNA No. 2 IN DEGREES
0°
15°
30°
45°
60°
255°
270°
285°
300°
315°
330°
345°
360°
S_2 = SPACING OF ANTENNA No. 2 IN DEGREES
No. 2 ANTENNA SPACING IN DEGREES
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

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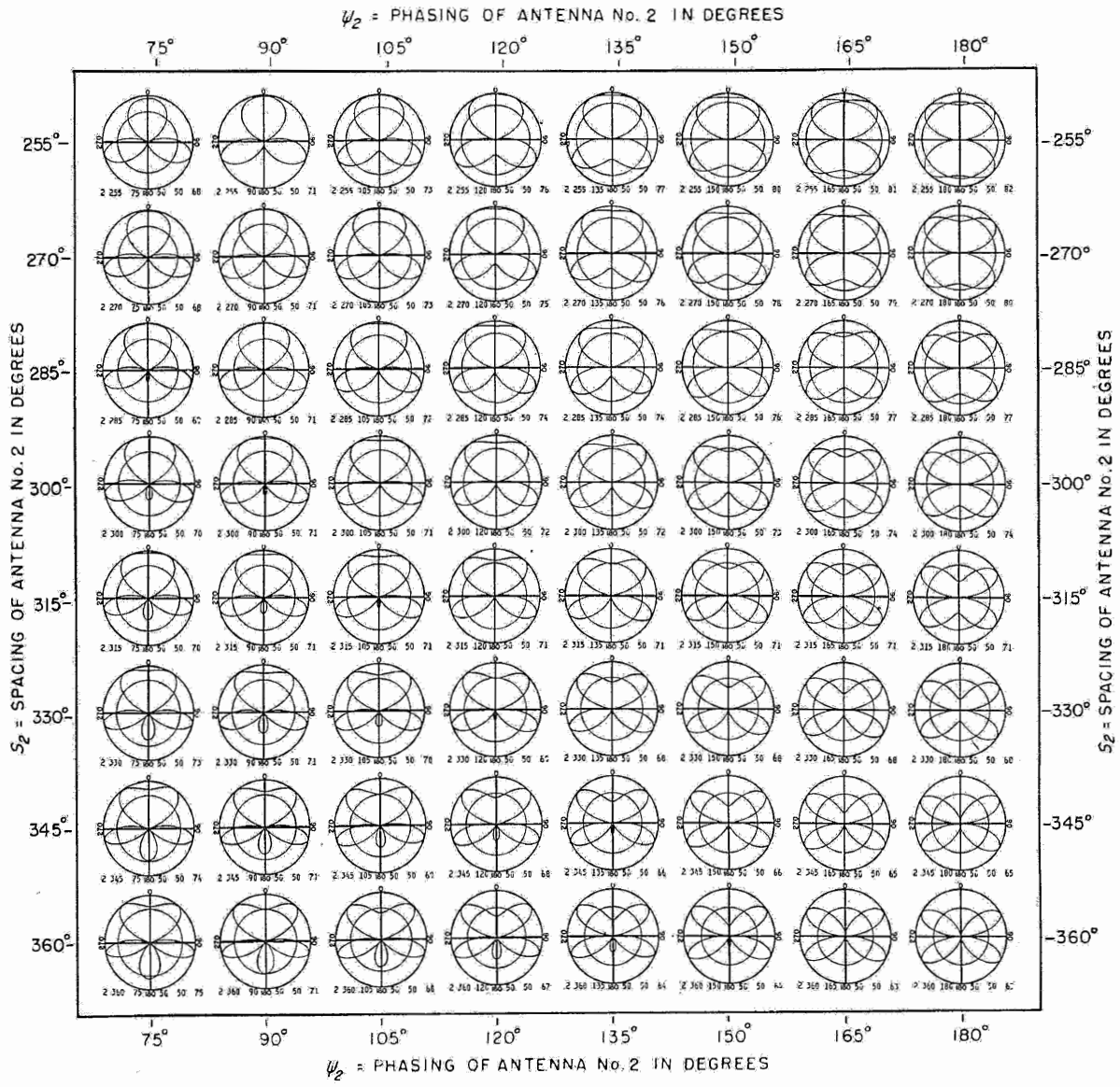


NUMBER OF ANTENNAS IN THE SYSTEM	SPACING OF NO. 2 ANTENNA IN DEGREES	PHASING OF NO. 2 ANTENNA IN DEGREES	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 1 ANTENNA	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 2 ANTENNA	% RMS FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM
No.	S_2	ψ_2	E_1	E_2	E_r
2	255	75	50	50	68

PATTERN NOMENCLATURE

DIRECTIONAL ANTENNAS - THEIR CARE AND MAINTENANCE

By Dixie B. McKey
Consulting Radio Engineer, Washington, D. C.

Standard band broadcast stations employing complex multi-element arrays, present a series of maintenance problems for the station engineering personnel. The handling of these problems by established scheduled routine tests will pay dividends in many forms. The radio engineer in attempting to plan methods whereby his plant will operate in as orderly a manner as possible, very definitely has the job of applying science to a practical business and in fulfilling it, shoulders the responsibility of bringing the results of technical achievement and business together.

Regular scheduled operating maintenance routines are a well established practice in a number of larger broadcast stations. These routines vary considerably, from a visual equipment inspection after cleaning, to elaborate tests designed to furnish recorded data that would permit the station engineer to anticipate failures and remove questionable equipment. These routines produce results in two ways; first, they reduce lost program time due to equipment failure, to a minimum, and, secondly, they familiarize the operating personnel with the location and functions of the individual apparatus units, which they would have been unable to acquire during the regular operating period.

The worth of such routines is not debatable and the long record of uninterrupted program operation of radio broadcast stations using these routine maintenance practices represents a dollar value far in excess of the small maintenance costs.

Any directional antenna system is dependent for satisfactory operation on a large number of individual component parts, carefully related and adjusted to produce a specified radiation pattern; electrical or mechanical failure of individual units will result in maladjustment of the array.

A large number of standard broadcast stations are operating full time or night directional antenna arrays that, due to the station's location with respect to other co-channel stations, must radiate low values of field strength in the direction of the co-channel stations. An array of this type as originally installed and adjusted will meet the values specified in the construction permit with an allowable tolerance for small day to day or seasonal variations providing the equipment is maintained properly. Failure of individual components in such an array will produce serious trouble.

In a number of cases non-directional operation on a single tower with reduced power is impracticable if not impossible, due to the difficulty in reducing the transmitter output to a sufficiently low value to produce the required minimum signal toward the co-channel station to prevent any objectionable interference. Under these conditions failure of any of the directional antenna array component units means a shutdown and a serious and costly loss of program air time. Consequently, any method or procedure that will reduce such loss to a minimum can be justified on a cost basis.

While speech input equipment and transmitters are fairly well standardized as to type and methods of operation, each and every directional antenna array is a custom-built job designed and constructed to meet certain specified requirements. In view of this fact, it is not possible to set up a complete specific maintenance routine that can be directly applied to any and all arrays.

However, a general set of maintenance practices based on a typical modern antenna array system can be used as a guide for the preparation of similar routines designed to fit individual array requirements.

A set of recommended schedules and forms based on a regional station operating with a four tower in line array is used as a typical example.

Before discussing a definite maintenance routine practice, it might be well to consider briefly some of the maintenance problems which generally have a considerable bearing on the satisfactory operation of a directional antenna array and yet are of such a type that they do not fit into a specified routine. For instance, in the case of many antennas, it has been established through considerable experience that in order to maintain the array as originally adjusted, all the conditions which were present during the period of Proof of Performance Tests must be maintained as closely as possible and, while maintenance routines as later suggested will perform this function as regards the individual apparatus unit, it is these factors which are not readily adaptable to a routine and yet may have a considerable bearing on the successful operation of your system. One of the most important factors in the holding of array adjustments is the maintenance of the ground system and periodic checks should be made at regular intervals by the supervisor or the chief engineer.

These checks should consist of an examination of the ground screens, radials, and the bonding for a loose or bad connection and corrosion. This is of particular importance in some locations where heavy corrosion due to the particular soil content has caused a considerable shift in the array pattern in a period of six months to a year after installation. The area immediately adjacent to the towers should be kept free of high grass and weeds and where the installation is in rolling terrain the entire ground system area should be planted with a soil holding type of grass or crop, in order to prevent erosion due to heavy rainfall. The latter is particularly important in installations where a fill has been necessary at either the tower locations or within the ground system area.

Another factor which enters into the matter of maintaining proper adjustment of an array is lightning hits, which, in many locations, are responsible for the largest percentage of lost program time. These hits or surges will cause not only carrier interruption but in some cases destruction of the component equipment parts. In the majority of cases, multiple vertical radiators make very effective lightning rods and can be expected to receive several direct hits and numerous induced surges during the summer static season. In many locations this condition is not truly seasonable as a considerable amount of difficulty has been experienced due to surges that are built up by friction from rain, snow, sand, and wind. Consequently, whenever possible, protective equipment should be utilized to minimize or eliminate potential failures due to these hits or surges. A large number of our modern transmitters contain protective circuits both for the transmitter and the transmission line. However, field experience indicates that it may be necessary to provide additional protective devices and equipment in order to secure maximum protection.

This subject has received considerable treatment by a number of engineers, and particular reference is made to an article by Mr. H. V. Tollison[1] which presents a rather complete summary of a number of methods and circuits which may be employed in the solution of this problem.

The maintenance tests as outlined have been arranged so that they can be made by regular station personnel using test and measuring equipment generally found in any modern radio station, with the addition of a field intensity meter and a radio frequency bridge together with its associated oscillator and detector units. The latter test equipment becomes a necessity for any station operating a complex directional antenna array system under present day conditions.

[1]Electronic Industries, Nov. 1946.

The preparation of a station maintenance routine for a directional antenna system should be based on the Proof of Performance Report as prepared and filed at the time of the original antenna installation. This report is a part of a station's permanent Federal Communications Commission's file and contains a complete description of the array, circuit diagram, circuit components, meter readings, and the field intensity measurement data. The importance of this report cannot be overemphasized as it provides a source of information that is of greatest importance in the day to day operation of a station.

With this report as the basis for a routine maintenance the first step in the preparation of such a routine will be to prepare a combined maintenance report book or log.

This report book should be divided into three sections. The first section shown in Fig. 1 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.

The second subdivision (Fig. 2) 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.

The third subdivision (Fig. 3) 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 one mile, the obtained unattenuated field value at one mile, together with the actual received field.

The fourth and last subdivision (Fig. 4) 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. 5) equipment and operating tower impedance (Fig. 6) if a single tower is used for non-directional daytime opera-

tion. Additional pertinent information that would be of assistance to the maintenance engineer, such as, transmission line and capacitor gas pressures, etc., 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 it 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.

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 I. 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 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.

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 this 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. 7 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.

It is, of course, realized that the suggestions and recommendations described above are not the total and complete answer to all and every directional antenna. However, it is believed the need for establishing schedules similar to the suggested program is well demonstrated and may be fitted to the individual station requirements, the results of which will be of mutual benefit to both the engineering staff and management.

CIRCUIT INFORMATION

Circuit Designation	Circuit Function	Adjustment Information	Replacement Information
L1	Shunt Input Coil	20-1/2 turns	Continuously Variable Coil - Type 4224 MS4 - 26 uh.
L2	Series Input Coil	9-1/2 turns	Variable Tap Coil - Type 322-4N4 - 26 uh.
L3	No. 1 Tank Coil	8 turns	Variable Tap Coil - Type 3208NT10 - 38 uh.
L4	No. 2 Tank Coil	7 turns	Variable Tap Coil - Type 3208NT10 - 38 uh.
L5	No. 1 Line Feed Coil	1/2 turn	Continuously Variable Coil - Type 4103 - HMS5 - 7 uh.
L6	No. 2 Line Feed Coil	7-3/4 turns	Continuously Variable Coil - Type 4103 - HMS5 - 7 uh.
L7	No. 3 Line Feed Coil	7 turns	Continuously Variable Coil - Type 4103 - HMS5 - 7 uh.
L8	No. 4 Line Feed Coil	5-1/2 turns	Continuously Variable Coil - Type 4103 - HMS5 - 7 uh.
L9	No. 1 Line Series Phase Coil	13-1/4 turns	Continuously Variable Coil - Type 4224 MS4 - 26 uh.
L12)	No. 2 Line Series Phase Coil	8-1/4 turns	Continuously Variable Coil - Type 4224 MS4 - 26 uh.
L13)			
L14	No. 2 Line Shunt Phase Coil	8-1/2 turns	Variable Tap Coil - Type 4164-N5 - 16 uh.
L15)	No. 3 Line Series Phase Coil	11-1/3 turns	Continuously Variable Coil - Type 4224 MS4 - 26 uh.
L16)			
L17	No. 3 Line Shunt Phase Coil	5-3/4 turns	Variable Tap Coil - Type 4164-N5 - 16 uh.
L18)	No. 4 Line Series Phase Coil	8-1/4 turns	Continuously Variable Coil - Type 4224 MS4 - 26 uh.
L19)			
L20	No. 4 Line Shunt Phase Coil	6 turns	Variable Tap Coil - Type 4164-N5 - 16 uh.
L21	No. 1 Tower Series Input Coil	11 turns	Variable Tap Coil - Type 3164-N5 - 16 uh.
L22	No. 1 Tower Series Output Coil (D)	7 turns	Variable Tap Coil - Type 4165-N5 - 22 uh.
L23	No. 1 Tower Shunt Coil	D10 turns ND 3-1/2 turns	Variable Tap Coil - Type 3106-NT12 - 10 uh.
L25	No. 2 Tower Series Input Coil	9 turns	Variable Tap Coil - Type 4165-N5 - 22 uh.
L26	No. 2 Tower Series Output Coil	4-1/2 turns	Variable Tap Coil - Type 4105-N5 - 12 uh.
L27	No. 2 Tower Shunt Coil	10 turns	Variable Tap Coil - Type 4164-N5 - 16 uh.
L29	No. 3 Tower Series Input Coil	1 turn	Variable Tap Coil - Type 4143-N5 - 8 uh.
L30	No. 3 Tower Series Output Coil	4 turns	Variable Tap Coil - Type 4165-N5 - 22 uh.
L31	No. 3 Tower Shunt Coil	11 turns	Variable Tap Coil - Type 4164-N5 - 16 uh.
L33	No. 1 Tower Series Output Coil (ND)	10-3/4 turns	Variable Tap Coil - Type 4165-N5 - 22 uh.
L34	No. 4 Tower Series Input Coil	11-1/4 turns	Variable Tap Coil - Type 3164-N5 - 16 uh.
L35	No. 4 Tower Series Output Coil	5-1/2 turns	Variable Tap Coil - Type 3165-N5 - 22 uh.
L36	No. 4 Tower Shunt Coil	12 turns	Variable Tap Coil - Type 3164-N5 - 16 uh.
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 uuf.
CA	Series Input Capacity		Type 1000 FBA90 - 1000 uuf.
C2	No. 1 Tank Tuning Capacity	45	Type 750FVSP250 - 750 uuf.
C3	No. 2 Tank Tuning Capacity	85	Type 750FVSP250 - 750 uuf.
C4	No. 1 Line Series Phase Capacity		Type 1500 FBA90 - 1500 uuf.
C5	No. 2 Line Shunt Phase Capacity		Type 1000 FBA90 - 1000 uuf.
C6	No. 3 Line Shunt Phase Capacity		Type 1000 FBA90 - 1000 uuf.
C7	No. 4 Line Shunt Phase Capacity		Type 1000 FBA90 - 1000 uuf.
C8	No. 1 Tower Series Output Capacity		Type 1000 FBA90 - 1000 uuf.
C9	No. 1 Tower Shunt Capacity		Type 1250FD150 - 1200 uuf.
C11	No. 2 Tower Series Output Capacity		Type 1000 FBA90 - 1000 uuf.
C12	No. 2 Tower Shunt Capacity		Type 1000 FBA90 - 1000 uuf.
C14	No. 3 Tower Shunt Output Capacity		Type 1000 FBA90 - 1000 uuf.
C16	No. 4 Tower Shunt Capacity		Type 1000 FBA90 - 1000 uuf.
C17	No. 3 Tower Series Output Capacity		Type 1000 FBA90 - 1000 uuf.
C19	No. 4 Tower Series Output Capacity		Type 1000 FBA90 - 1000 uuf.
C20	No. 1 Tower Series Output Capacity (D)		Type 1000 FBA90 - 1000 uuf.
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

Figure 1

METER INFORMATION

Meter	Range	Model	No.	Current D	Current 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 No. 1
M3	0-8	640	2835	3.9	-	Transmission Line Current - Tower No. 2
M4	0-8	640	2820	3.8	-	Transmission Line Current - Tower No. 3
M5	0-8	640	2830	2.5	-	Transmission Line Current - Tower No. 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 Figure 4 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°

Figure 2

MONITOR POINTS AND FIELD INTENSITY INFORMATION

Point No. 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 No. 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 No. 25

Azimuth Angle	Distance (Miles)	MV/M 1 Mile Specified	MV/M 1 Mile Obtained	MV/M Measured
63°	1.33	70	25	8.55

Insert Location of Measuring Point as Described in Proof of Performance

Point No. 62

Azimuth Angle	Distance (Miles)	MV/M 1 Mile Specified	MV/M 1 Mile Obtained	MV/M Measured
181°	1.36	72	40	10.75

Insert Location of Measuring Point as Described in Proof of Performance

Point No. 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 No. 104

Azimuth Angle	Distance (Miles)	MV/M 1 Mile Specified	MV/M 1 Mile Obtained	MV/M Measured
302°	.86	40	17	7.6

Insert Location of Measuring Point as Described in Proof of Performance

Point No. 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

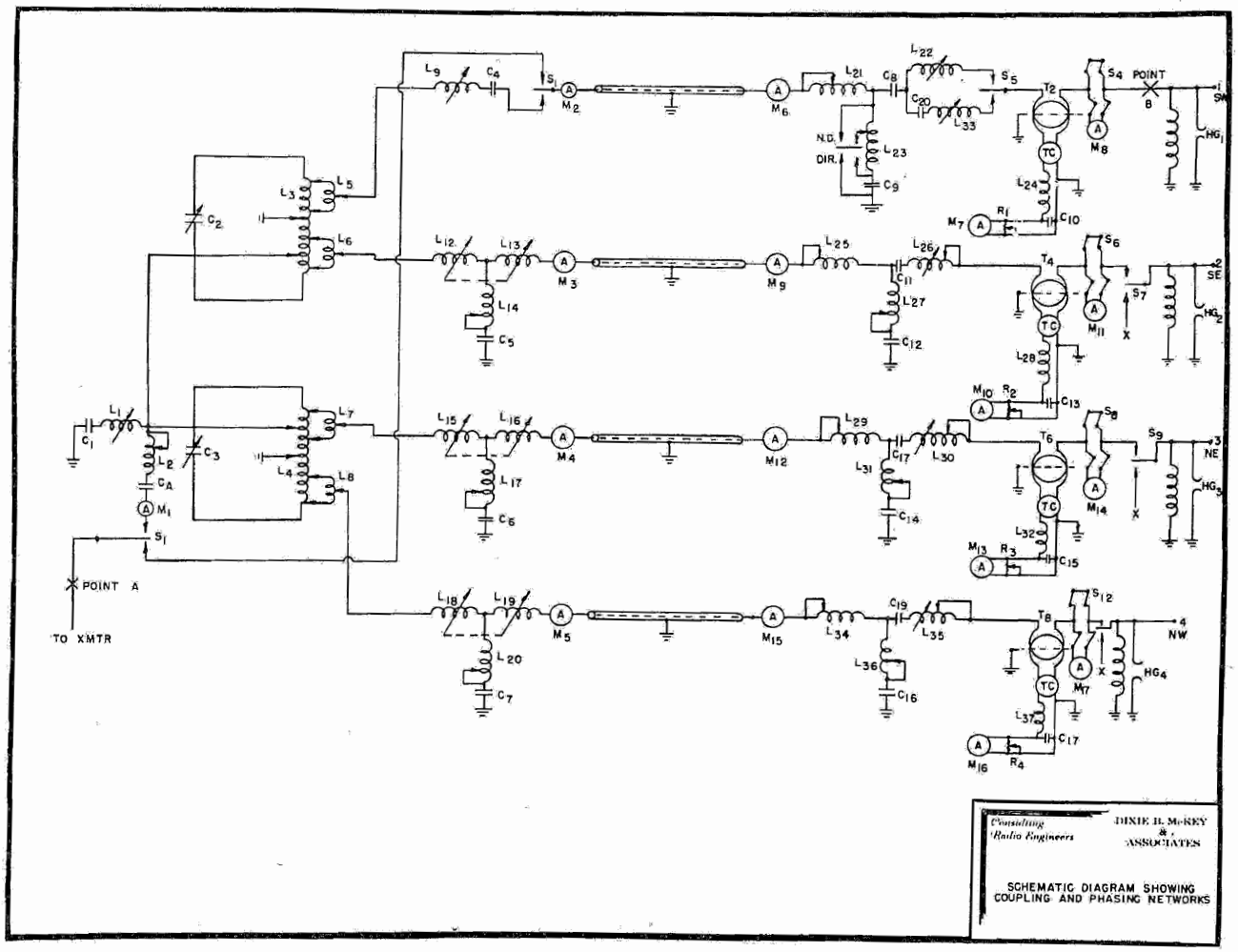


Figure 4

TABLE I

MAINTENANCE SCHEDULES

Sunday

1. Transfer all towers and antenna phasing units to emergency transmission lines and operate at full power for five minutes.
2. Restore all equipment to regular transmission lines. Check operation under full power.
3. Clean and check all connections, remote meter, phase monitor, meter panels, and phase monitor.
4. Check all phase monitor tubes with tube check. Check all transmission line protective circuits.
5. Check and record all transmission line gas pressures.

Monday

1. Check all condensers and other equipment in antenna phasing unit immediately after sign-off for over heating.
2. Clean and check all transmission line end seals.
3. Clean interior all sections antenna phasing units.
4. Clean contacts and check alignment antenna transfer relay.
5. Check and tighten all connections in antenna phasing unit.
6. Check gas filled condenser 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 non-directional 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 all antenna and remote antenna meters. Make any necessary adjustments.

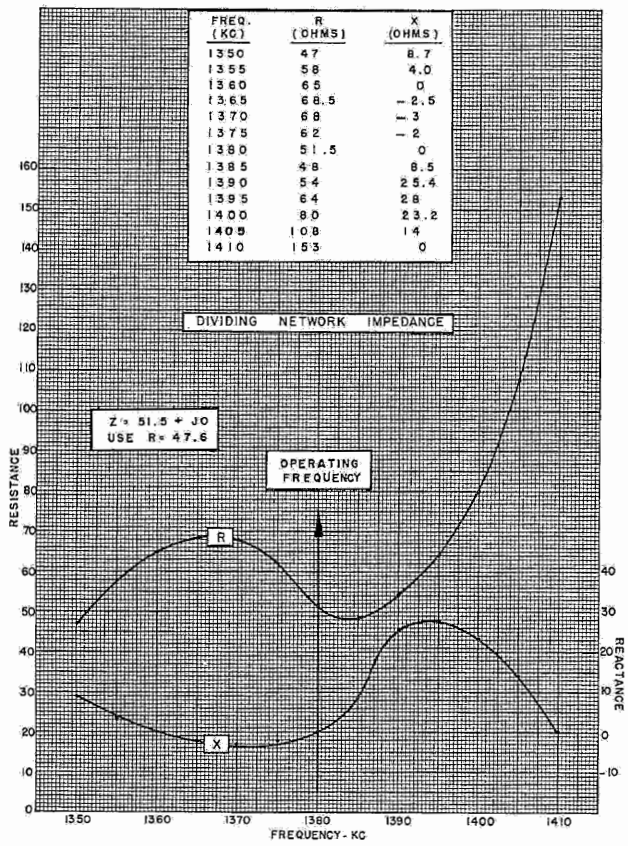


Figure 5

4. Make complete set field intensity readings at indicated monitor points. (Second and Fourth Tuesdays)

5. Check and record all transmission line gas pressures.

Wednesday

Antenna Coupling Unit No. 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 antenna relay.

6. Clean contacts and check alignment 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 No. 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 antenna relay.

6. Clean contacts and check alignment 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 No. 3

1. Check all condensers and equipment in coupling house for overheating immediately after sign-off.

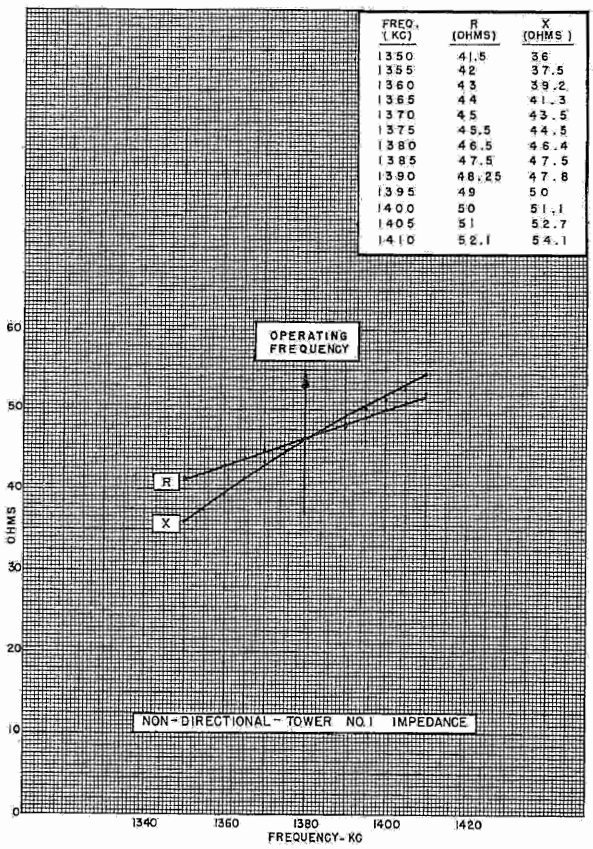


Figure 6

WEEKLY MAINTENANCE REPORT

Month			Sun.		Mon.		Tues.		Wed.		Thur.		Fri.		Sat.		Remarks				Eng.			
Date																								
Weather																								
Temperature																								
M1 - Dir.																								
M2 - Non-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																								
EMG 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. #101																								
FS Mon. Pt. #118																								
Overall Dir. Test																								
#1 Coupling Unit																								
#2 Coupling Unit																								
#3 Coupling Unit																								
#4 Coupling Unit																								

E-207-A (7-61)

2-2-09

Figure 7

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 antenna relay.

6. Clean contacts and check alignment 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 No. 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 antenna relay.

6. Clean contacts and check alignment 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.

NOTES ON TELEVISION ANTENNA EQUIPMENT

Reprinted from the RCA Manual for Television Technical Training Program through courtesy of the Radio Corporation of America

The following notes are a summary of lectures on antenna equipment for television systems. They present, in outline form, the various pieces of equipment required in the television station beyond the transmitter. Each piece is discussed as to its purpose, requirements, basic principles, construction, and performance.

SUMMARY OF ITEMS OF ANTENNA EQUIPMENT

NAME	LOCATION	FUNCTION
Balun (BALanced to UNbalanced)	Part of transmitter	Converts double-ended line to single-ended line and maintains bandwidth.
Vestigial Sideband Filter (VSBF)	Station, behind transmitter	Reduces energy in portion of lower sideband (portion outside channel) in accordance with FCC requirements.
Diplexer	Station, behind transmitter	Permits simultaneous use of a same antenna for visual and aural transmission.
Triplexer	Station, behind transmitter	Permits simultaneous use of a same antenna for FM broadcasting in the 88-108 mc band.
Antennas (Standard Types)	Top of tower	Radiates visual and aural signals as well as FM signal, if triplexing is used.
Antennas (Special Types)	Top of tower	Same as above, except fulfills special requirements as higher gain, simultaneous use of one site for several television stations, directional effects, etc.
Antennas (Combination Types)	Top of tower	Allows FM broadcasting by use of Pylon.
Transmission Line	In station and between station and antenna	Transmits power with minimum reflection and loss.

GENERAL PRINCIPLES

TRANSMISSION LINES

THE INFINITE LINE is a uniform line of infinite length. For practical purposes, a line terminated in its characteristic impedance (also called surge impedance) behaves like an infinite line because there are then no reflections from the far end of the line.

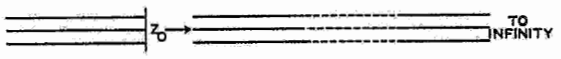


Figure 7-1 - Infinite Line and Surge Impedance

SURGE IMPEDANCE - The surge (or characteristic) impedance of a uniform line is the impedance which terminates any length of the line without causing any reflections.

STANDING WAVES - Standing waves on a transmission line are caused by reflections from a mis-

termination at the far end or by discontinuities on the line itself. The reflected wave is alternately in phase and out of phase with the incident wave. Voltage at a point on the line measures less than the incident wave if the reflected wave is out of phase with the incident wave; it measures more than the incident wave if the reflected wave is in phase with the incident wave.

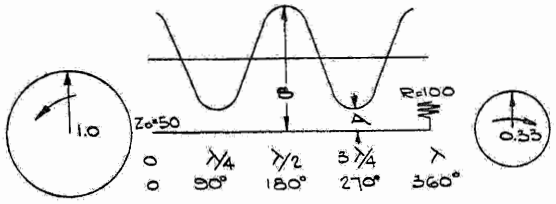


Figure 7-2 - Standing Waves on Transmission Line

VOLTAGE STANDING WAVE RATIO (VSWR) - The VSWR is defined as the ratio of maximum-to-minimum volts appearing along the transmission line. These voltage maxima and minima are the resultants of the addition and subtraction, respectively, of the incident and reflected waves. The surge impedance of the line being designated by Z_0 and the terminating impedance being called Z, the voltage reflection coefficient K is

$$K = \frac{Z - Z_0}{Z_0 - Z}$$

Thus for Z_0 = 50 ohms and Z = 100 ohms we have K = 0.33.

If A and B are the minimum and maximum voltages along the line, respectively, then

$$VSWR = \frac{B}{A} = \frac{1 + |K|}{1 - |K|} \quad (= 2 \text{ for } K = 0.33).$$

From experimental data it is found that the VSWR of the antenna system should be 1.1 or better over the band, to avoid the appearance of echoes or multiple images in the picture.

BANDWIDTH - The bandwidth is the frequency range over which the VSWR is within certain defined limits.

General Principles of Maintaining Bandwidth.

a. *Constant-impedance Network* - This is a parallel-resonant circuit having resistive components in each branch. When

$$R_C = R_L = \sqrt{L/C}$$

the circuit has constant resistance at all frequencies. Such a circuit is used in modulator and sideband filters.

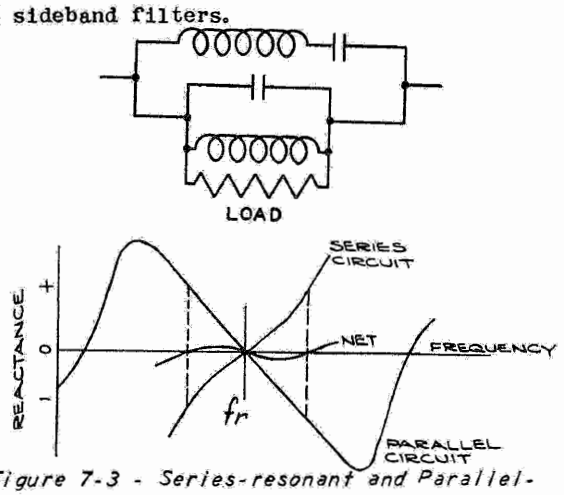


Figure 7-3 - Series-resonant and Parallel-resonant Circuit Combination

b Series-resonant circuits, used in conjunction with parallel-resonant circuits, provide complementary reactances off resonance frequency. This principle is applied in the balun, diplexer, and antenna. It is illustrated in Figure 7-3, which shows the circuit arrangement as well as the series-circuit and parallel-circuit reactances as functions of frequency The overall, or net, reactance is the difference of the series-circuit and parallel-circuit reactances. This net reactance is seen to be nearly zero within the range of frequencies (marked off in dotted lines on the diagram) which defines the bandwidth of the system.

BALUN

This name is derived from the words "BALanced to UNbalanced" which define the purpose and function of the device, namely, to convert the output of the 8D21 tube to a single 72-ohm line, on both aural and visual sides.

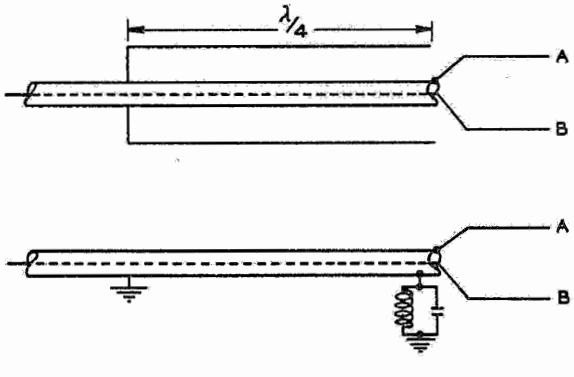


Figure 7-4 - Quarter-wave Transformer

The principle is illustrated in the first diagram of Figure 7-4. This shows a coaxial line, the end of which is surrounded by a quarter-wave sleeve connected to the outer conductor. The equivalent circuit of this "quarter-wave transformer" is shown in the second diagram of Figure 7-4 as a parallel-resonant circuit connected between the outer conductor *A* and ground, but not across the inner conductor *B*.

As a remedy to this unsymmetrical arrangement, the device of Figure 7-5 is used; it is here shown with its equivalent circuit. This is an application of the second principle discussed previously for broadbanding (see paragraph b under the heading BANDWIDTH). The actual circuit shown in Figure 7-5 has been used in the diplexer. For the balun unit, the loads and generator should be interchanged.

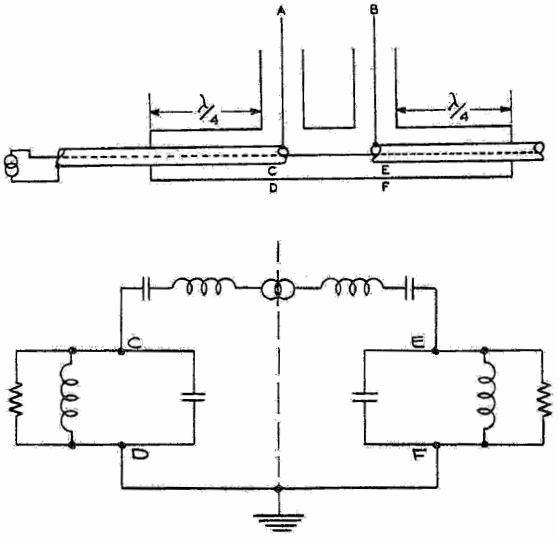


Figure 7-5 - Principle of Diplexer and Balun Units

VESTIGIAL SIDEBAND FILTER

PURPOSE - The vestigial sideband filter reduces the energy in the lower sideband in accordance with FCC requirements, while still presenting constant resistance to the transmitter over the required band.

REQUIREMENTS

(1) 20 db in addition to the average 40 db inherent in typical picture.
(2) Attenuation occurs in 1/2 mc.
(3) Constant VSWR of 1.1, or better, over the band.
(4) Small power absorption.

Typical characteristics of the vestigial sideband filter are shown by the curves of Figure 7-6.

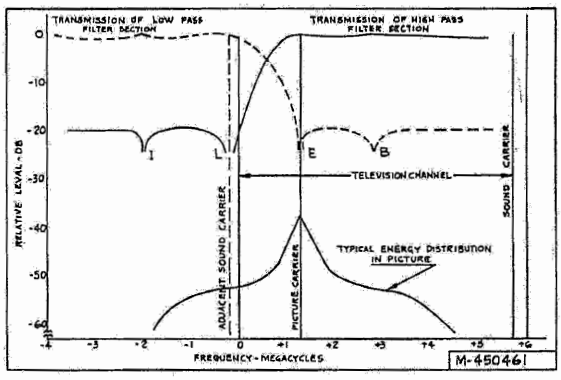


Figure 7-6 - Characteristics of Vestigial Sideband Filter

PRINCIPLE - A simple filter circuit is shown in Figure 7-7. This filter, however, does not satisfy the second of the requirements listed in the preceding paragraph. It is thus necessary to use a four-leg filter network, such as the

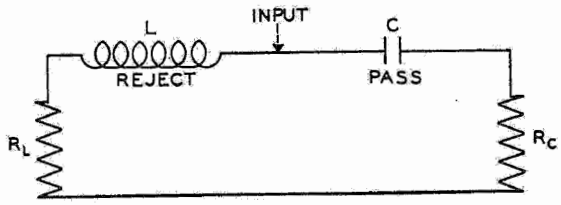


Figure 7-7 - Elementary Filter Circuit ($R_L = R_C = \sqrt{L/C}$)

one shown in the upper diagram of Figure 7-8. Depending on the frequency considered, this network appears with a low-pass or a high-pass characteristic, and is equivalent to the circuits shown in the lower diagram of Figure 7-8.

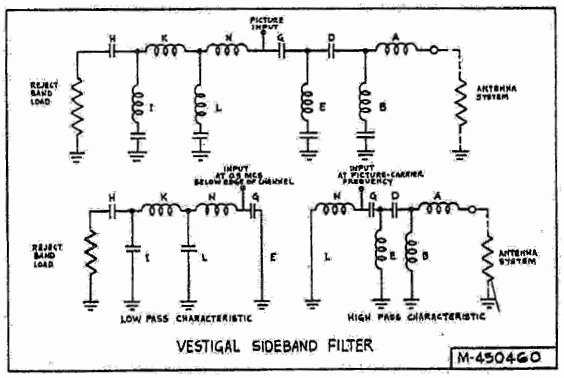
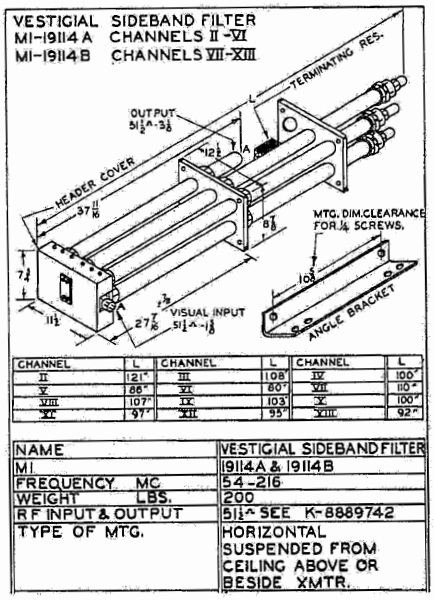


Figure 7-8 - Vestigial Sideband Filter Circuit

CONSTRUCTION - See Figure 7-9 Four shunt lines are made re-entrant to limit the length to a value of 92 to 121 inches, depending on the channel considered. Series capacitors and inductors are line sections less than one-quarter wavelength long. These sections are telescoped into the shunt sections. The entire unit is 92 to 121 inches long, 11 1/2 inches wide, and 7 3/4 inches high, and is designed for ceiling mounting.



CHANNEL	L	CHANNEL	L	CHANNEL	L
II	121"	III	108"	IV	100"
V	88"	VI	80"	VII	110"
VIII	107"	IX	103"	X	100"
XI	97"	XII	95"	XIII	92"

NAME	VESTIGIAL SIDEBAND FILTER
MI	19114A & 19114B
FREQUENCY MC	54-216
WEIGHT LBS.	200
R F INPUT & OUTPUT	51Ω SEE K-8889742
TYPE OF MTG.	HORIZONTAL SUSPENDED FROM CEILING ABOVE OR BESIDE XMTR.

Figure 7-9 - Vestigial Sideband Filter Construction

PERFORMANCE - All units are preset at the factory and require no field adjustment. The power absorbed in the load resistor never exceeds 30 watts, out of 5 kw, and then only with unusual detail energy beyond 1 1/4 mc. Normally, negligible power is absorbed in a typical picture. The unit meets all requirements outlined previously. Power absorption is 3.37% at 100 mc.

R-F LOAD AND WATTMETER

PURPOSE - The purpose of the R-F Load and Wattmeter is to determine the operating power in accordance with FCC requirements. The unit isolates the antenna system from the transmitter when shooting trouble.

REQUIREMENTS

(1) Dissipates black-level power of 3 kw.
(2) Accurately terminates output of transmitter with no reflection.

PRINCIPLE - The principle of the R-F Load is illustrated in Figure 7-10. A small resistance R_1 can be inserted at section *A*. Section *B* should then be terminated for a surge impedance of $Z_0 - R_1$, which results in a smaller diameter. The process is continued until the required surge impedance is zero. This is merely a means of using a resistor of finite size when an infinitesimally small resistor would otherwise be needed for proper termination, since this is, practically, not feasible. The shape of the outer conductor, theoretically, follows an exponential curve, but a straight line is close enough an approximation for practical cases.

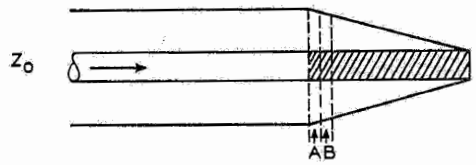


Figure 7-10 - Principle of R-F Load

The resistor is cooled by immersing it in a light grade of oil. With the unit in vertical position, the oil flows by convection to the top of the tank, where it is cooled by tap water while in use. Power is measured by measuring the voltage across the resistor, using a crystal detector for rectification.

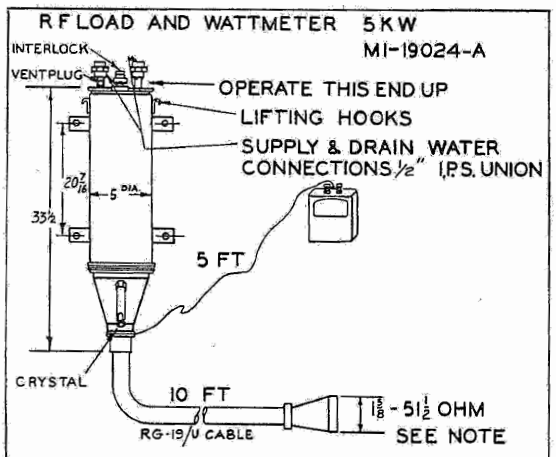
CONSTRUCTION - The load consists of a tank 5 inches in diameter and 33 1/2 inches overall in height. Connections are made to the output of the transmitter by 10-foot lengths of flexible RG-19/U cable. The unit terminates a 51.5-ohm line and, if used with the 75-ohm vestigial sideband filter, requires a quarter-wave transformer for conversion. See Figure 7-11.

DIPLEXER

PURPOSE - The diplexer permits the use of the same antenna for visual and aural transmission.

REQUIREMENTS

(1) Low cross-talk.
(2) VSWR of 1.1, or better, over the band.
(3) Minimum power absorption.



NAME	RF LOAD & WATTMETER 5 KW
MI	19024-A
FREQUENCY MC	44-216
WEIGHT LBS.	46
RF INPUT	1⅝ 51½ Ω
RF OUTPUT	
NON RF CONNECTIONS	TAP WATER 1 GALLON PER MINUTE
TYPE OF MOUNTING	VERTICAL SURFACE

Figure 7-11 - R-F Load and Wattmeter Construction

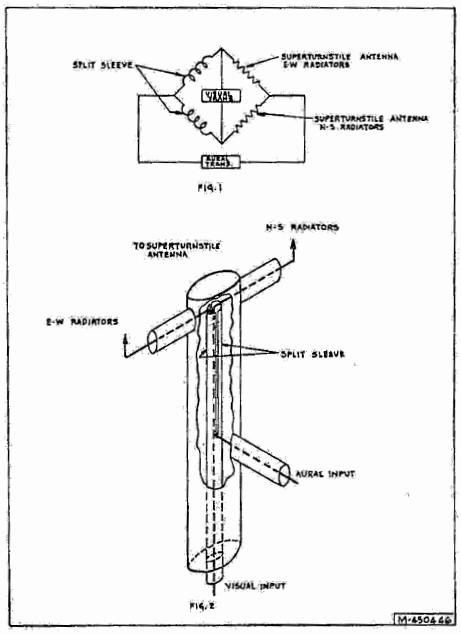


Figure 7-12 - Diplexer Schematic Diagram

PRINCIPLE - Because of the turnstiling principle, which will be discussed under the heading ANTENNAS, the antenna can be considered as two separate loads - a N-S radiator and an E-W radiator - which do not interact (see Figure 7-12). The diplexer is a bridge circuit, as shown in diagram 1 of Figure 7-12.

The visual transmitter output is single-ended and must be converted to a double-ended output. This is done with another balun unit, applying the same principle as discussed previously.

The use of a combination of sideband filter and diplexer is illustrated in Figure 7-13. The energy from the picture transmitter goes through the vestigial sideband filter, where the unwanted part of the lower sideband is suppressed. The energy to be transmitted then passes through the diplexer, where the sound energy joins in. The combined television signal (visual and aural energy) is then fed to the antenna over twin transmission lines, of which one is made one-quarter wavelength longer than the other to provide proper quadrature-phasing in the antenna. This last point is discussed in a later paragraph concerning the turnstiling principle.

CONSTRUCTION - The construction of the diplexer is apparent from Figure 7-14 and is not further described here.

PERFORMANCE

(1) No cross-talk has ever been encountered in the many checks that have been made.
(2) The VSWR is 1.1, and usually better, over the band.
(3) The power absorbed is a fraction of a decibel.

ANTENNA

REQUIREMENTS (ELECTRICAL)

(1) Horizontal polarization.
(2) Operation in 54-88 mc and 174-216 mc bands.
(3) Low VSWR over channel.
(4) Gain sufficient to provide good coverage.
(5) Pattern to be circular.

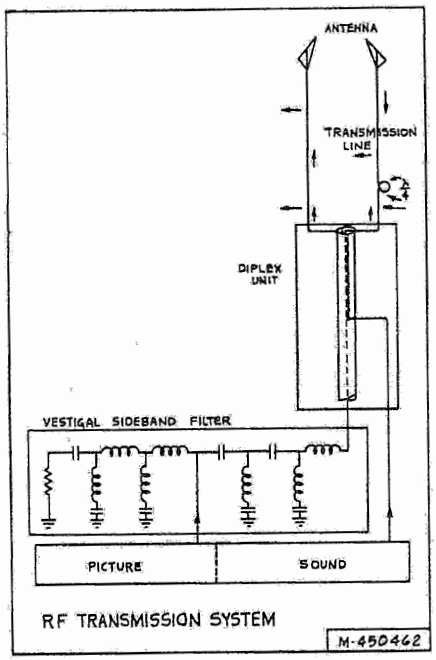
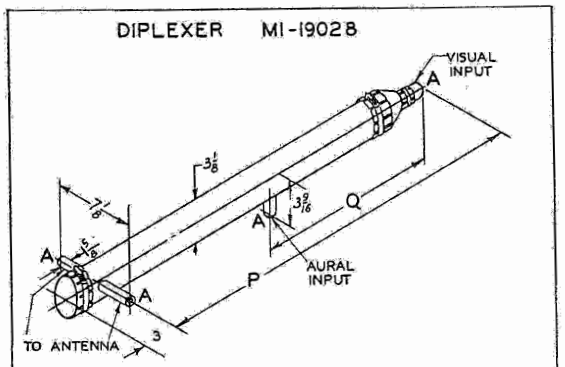


Figure 7-13 - R-F Transmission System



CHANNEL	P	Q	CHANNEL	P	Q
I	133 15/16	68 7/8	VIII	36 5/16	20 1/16
II	107 7/16	55 5/8	IX	35 5/16	19 9/16
III	97 9/16	50 1/16	X	34 5/16	19 1/16
IV	89 7/16	46 5/8	XI	33 9/16	18 11/16
V	78 9/16	41 3/16	XII	32 9/16	18 3/16
VI	73 5/16	38 9/16	XIII	31 13/16	17 13/16
VII	37 9/16	20 11/16			

NAME	DIPLEXER
MI	19028
FREQUENCY MC	54-216
WEIGHT LBS.	12 TO 30
RF INPUT AND OUTPUT	1⅝-5½ (SEE K-8889742)
TYPE OF MOUNTING	HORIZONTAL ALONG TRANSMISSION LINE (CAN BE SUSPENDED ABOVE VESTIGIAL SIDE-BAND FILTER OR TRANSMITTER.)
MAXIMUM POWER	5 KW
RF EFFICIENCY	99%

Figure 7-14 - Diplexer Construction

(6) Ability to handle visual and aural power of transmitter, and additional FM transmitter in some cases.
(7) Must lend itself to transmission of visual and aural energy from the same antenna.
(8) Transmission of FM from the same antenna is also desirable.

REQUIREMENTS (MECHANICAL)

(1) Low wind resistance.
(2) Mechanically rugged.
(3) Sleet melting provision.
(4) Minimum number of end seals.
(5) Not to be vulnerable to lightning.
(6) Easily erected.

PRINCIPLE

(1) For low VSWR response over the band (1.1 or better), use is made of the second general principle, previously discussed under the heading BANDWIDTH, of combining a parallel-resonant with a series-resonant circuit. Such a combination circuit, using lumped parameters, was shown in Figure 7-3, together with its reactance-frequency characteristic curve. The distributed-parameter equivalent, which forms an antenna, is shown in Figure 7-15a. Its reactance-frequency curve is given in Figure 7-15b.

Addition of a second stub to the arrangement of Figure 7-15a provides a second ground point and adds rigidity; see Figure 7-15c.

In general, radiators with large diameters tend to have a more constant impedance over a given band since the ratio X_L/R, and hence the "Q", is smaller. Since a large diameter is not suitable for mechanical reasons, the same advantages are obtained by using a large flat sheet. This sheet can be visualized as a series of dipoles, each carrying a current proportional to the current distributed along the two stubs. See Figure 7-15d.

By notching-in the sides, the current in the upper and lower edges of the radiator, also called "batwing", is increased, which flattens the vertical pattern and increases the gain. One radiator has the same gain as two dipoles spaced one-half wavelength apart. See Figure 7-15e.

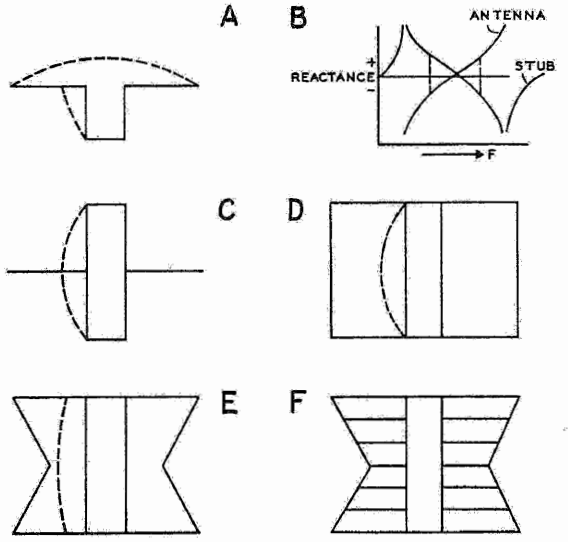


Figure 7-15 - Development of TV Antenna

By experimentally determining the minimum number of rods that can be used instead of a solid sheet, wind resistance is considerably reduced. See Figure 7-15f.

(2) *The Turnstiling Principle* - We now have a dipole with wide-band characteristics. To obtain a circular pattern, turnstiling is applied.

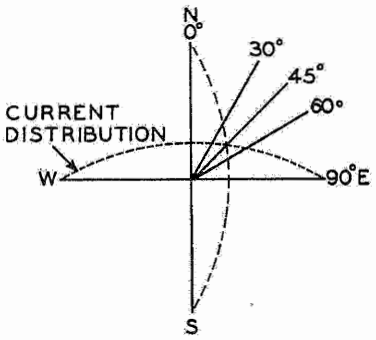


Figure 7-16 - Turnstiling Principle (Field Magnitude is Proportional to the Angle Between Direction of Radiator and Direction of Observation)

A circular radiation pattern can be obtained from cross dipoles arranged in the shape of a turnstile as follows (see Figure 7-16):

Angular Bearing	0	30°	45°	60°	90°
Field from N-S Radiator	0	0.5	0.707	0.866	1.0
Field from E-W Radiator	1.0	0.866	0.707	0.5	0
Vector Addition	1.0	1.0	1.0	1.0	1.0

To achieve this effect, the phase difference between the currents in the N-S and E-W radiators must be 90°, which is accomplished by making one of the lines 90 degrees (or one-quarter wavelength) longer than the other.

(3) *Stacking Sets of Radiators to Increase Gain* - This principle (see Figure 7-17) is an old one and has been used for years in communications antennas. If the currents in radiators *A*, *B*, *C* have the same phase (same number of wavelengths from the source) and if distances *AP*, *BP*, and *CP* are substantially alike, the field at *P* will be greater than that produced by a single radiator. Similarly, sets of batwing radiators are stacked to increase the gain. The length of the feed-line for each set, back to junction point, is kept the same. The centers of the successive radiators are spaced one wavelength apart.

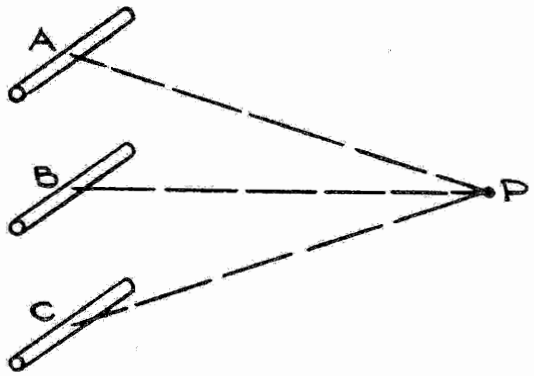


Figure 7-17 - Stacking of Antenna Radiators

CONSTRUCTION - The sets of crossed super-turnstile radiators are mounted on flag poles. The number of radiators that can be stacked is limited by the flag-pole taper and mechanical requirements.

The following types have been made:

FREQ. (MC)	STANDARD	SPECIAL
54-66	3-bay	4-bay, 5-bay
66-88	3-bay	
174-216	6-bay	

In the 3-bay antenna, each radiator has a 154.5-ohm impedance from the feed point at the center to ground. For three radiators in parallel, this becomes 51.5 ohms, which is the surge impedance of the main transmission line. Each branch line has an impedance of 154.5 ohms. For other types, transformers are used.

PERFORMANCE (ELECTRICAL)

(1) The antenna has extremely wide bandwidth. One set of radiators covers the 54-66 mc band -22%; another the 66-88 mc band -33%; and a third set covers the 174-216 mc band -25%. The pole-to-radiator spacing is varied slightly for each channel by means of pads or adjustments. An SWR of 1.1, or better, can always be achieved.

(2) The gain approaches the ideal that can be achieved and is 1.2 times the number of sections. This gain is obtained by measuring the vertical field pattern and taking into account losses in the radiators and feed system.

An exact tabulation of gain is shown:

	3-BAY		3-BAY			6-BAY						
TV Channel	2	3	4	5	6	7	8	9	10	11	12	13
Approximate Gain	3.3	3.7	3.3	3.8	4.1	6.4	6.6	6.7	6.8	6.9	7.0	7.1

(3) Theoretically the pattern is circular, but actually it departs from this slightly because the super-turnstile radiator is not a point source. This produces a square circle which, under ideal conditions, deviates by less than ±0.5 db. At no frequency within the specified TV channel will the pattern deviate by more than ±1.5 db.

(4) The antenna will handle a power of 20 kw, which is limited by the feed lines. The actual power for a 5-kw TV transmitter is 3 kw of visual power (black level) and 2 1/2 kw of aural power. This power is multiplied by the VSWR to allow for local heating at the current peaks. For TV, this is only 1.1. Hence, the total TV power is 6 kw. When triplexing is used, FM power is then limited to 14 kw divided by the maximum VSWR that may occur in the feed lines. This amounts to 10 kw for the 66-88 mc antenna, and 3 kw for the 54-66 mc antenna.

(5) By using the turnstiling principle and the bridge circuit of the diplexer, both visual and aural power can be transmitted over the same antenna. In addition, a triplexer enables the antenna, because of its response in the 88-108 mc band, also to be used to radiate FM power.

PERFORMANCE (MECHANICAL)

(1) Low wind resistance is achieved as a result of the open super-turnstile radiators.

(2) Ruggedness is achieved by:

(a) The inherent stiffness of triangular structures. Both top and bottom are firmly grounded and no weight is supported on insulators.

(b) The pole is made from Bessemer seamless steel tubing which has a U.T.S. of 60,000, and has shown as much as 70,000, 80,000, and even 120,000 on actual test. Since the material is stressed only to 20,000 lbs./square-inch, a high safety factor is obtained.

(c) Calculating 20 lbs. per square-foot of wind loading on rounds, a wind velocity of 95 miles per hour is required to stress the material to 20,000 lbs. per square-inch without ice. With 1/2 inch of radial ice, a velocity of 85 miles per hour is required to reach this same stress value.

(d) All brackets and radiator clamps are bonderized and zinc plated.

(3) De-icing is done for electrical reasons only, and not to reduce wind loading. Hence, only the section adjustment to the main pole is de-iced, which is the only portion affected by ice.

Heaters are used as follows:

ANTENNA TYPE	WATTS PER RADIATOR	KILOWATTS PER BAY
54-66	750	3
66-88	500	2
174-216	250	1

(4) Minimum end-seals are needed for feeding this antenna.

NUMBER PER BAY	ANTENNA TYPE
2	54-66 and 66-88
4	174-216
8	Dipole Construction

TOWER DESIGN - RCA has published the projected area of the antenna as well as other pertinent dimensions. From this information the tower manufacturer can design his tower. A standard

specification is now being considered by RMA committees, which will put all tower designs on the same basis.

The tower should be designed to take the standard guide flange and pole sockets provided (see Figure 7-18).

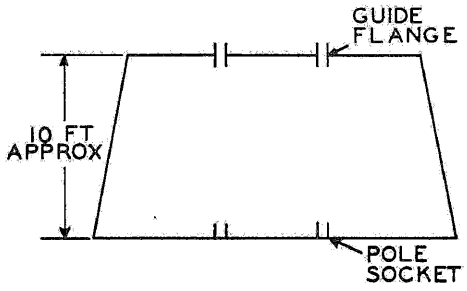


Figure 7-18 - Antenna Tower Layout

INSTALLATION

SHIPMENT - The pole can be shipped broken down as follows:

	ANTENNA	NUMBER OF POLE SECTIONS	LENGTHS - FT. AND INCHES		
3-bay	54-66	3	17'6"	23'0"	24'0"*
3-bay	66-88	2	21'6"	30'0"*	
4-bay	66-88	2	36'2"	32'6"	
5-bay	66-88	3	28'8"	31'0"	29'0"
6-bay	174-216	2	26'8"	22'1" */**	

* *For Pylon mounting, the sections listed on the right are 3 to 6 ft. shorter.*

** *On most installations to date, this antenna, because of its greater number of parts, higher frequency, and more critical assembly, has been assembled in Camden by workmen and engineers familiar with this work. The antenna has then been shipped to the customer in one piece.*

ASSEMBLY - If the antenna is assembled on the customer's premises, it should be assembled on the ground in a horizontal position, with the pole resting on saw horses. This assembly should be done under engineering supervision. The feed system should be put on the antenna. The bending tool provided should be used. Kinks and flats on the line must be avoided.

TEST ON GROUND - After assembly, the RCA Service Co. should be requested to make the following checks:

(1) Gas leaks
(2) D-C resistance
(3) Electrical leakage tests
(4) VSWR check over the band, with panoramic sweep equipment.

The RCA Service Co. has experienced men and suitable equipment, and is prepared to render this service at a reasonable cost. These tests should be made, whether the antenna is assembled in Camden or in the field. Simple corrections become extremely complex to make after the antenna is erected.

ERECTION

IN ONE PIECE - When the antenna is to be erected in one piece, the pole should be welded before assembly. Quite a number of installations have been successfully made in this way.

PARTIAL DISASSEMBLY AND REASSEMBLY - The disassembly should be done by the riggers who will reassemble the antenna. Feed lines should be carefully removed and kept in the original position. The pole need not be welded if this is done, but can be caulked after erection.

RIGGERS - It is most economical to use the same riggers who are erecting the tower. The same gin poles, donkey engines, etc., can be used. This requires close scheduling.

PAINTING - The pole and radiators are shipped with one coat of red lead only, for protection in transit and during erection. They should be painted with CAA colors after erection. All portions, except the end seals, can be painted.

SPECIAL ANTENNAS

4-BAY AND 5-BAY - These antennas have been built for the 66-88 mc band. None have been built for the 54-66 mc band, although there is

no technical reason to prevent it. It is not feasible to carry flag-pole construction to greater gains, because the pole taper causes a wider spacing between the lower radiators, resulting in a different impedance than for the upper sections.

SUPER-GAIN ANTENNAS - These antennas will take the form of a tower type. One type would consist of dipoles mounted on the four faces of a tower one-half wavelength square. Such antennas are used for three reasons:

(1) *Higher Gain* - The allocation scheme of FCC is based on 50 kw radiated power. A 5-kw transmitter, with a standard 3-bay or 6-bay antenna and nominal line loss, will radiate about 15 kw in the 54-88 band, and 25 to 30 kw in the 174-216 band.

Super-gain antennas will permit gains of 10 and 12, so that 50 kw radiated power can be achieved.

(2) *Stacked Antenna Systems* - If one site is desirable for several television stations, the lower antenna can be a tower type and the upper a standard type. Propositions have been worked up for three television stations with additional FM Pylons. Since receiving antennas are directive and generally aimed at a central cluster of stations, it is highly advisable to be in this central cluster. The use of the stacked antenna makes this possible.

(3) *Directional Antennas* - Radiators can be left off on one or two faces of the tower, to produce a directional pattern. Directional patterns are not recommended as a rule, since the total area covered is less. See Figure 7-19.

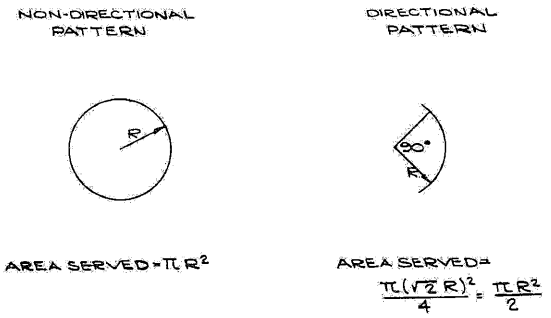


Figure 7-19 - Antenna Radiation Patterns - With the directional pattern shown, the area served is one-half the area covered with the circular pattern. Also, four times the power is concentrated in a same area. Hence, the field strength is doubled and the radius is extended by $\sqrt{2}\,R$ *(as a general approximation, the service radius varies as the fourth root of the power).*

In some cases, of course, where mountains behind the station cause serious ghosts or where protection to other stations is necessary, directional antennas must be used.

COMBINATION ANTENNAS

a. COMBINATION WITH FM BY USE OF PYLON ANTENNA

A 2- or 4-section Pylon underneath a TV antenna can be placed below any 3- or 4-bay antenna in the 54-88 band, or a 6-bay antenna in the 174-216 band.

Pylons have a gain of 1.5 per section midband and will take up to 50 kw of FM. They are 20 inches in diameter and 14 feet high. The FM feed system is inside. The TV system is mounted on the back of the pylon, opposite the slot. All FM-pylon and TV-antenna combinations have been checked for structural soundness by independent consultants.

b. COMBINATION WITH FM BY USE OF TRIPLEXING

Purpose - To use TV antennas for FM radiation.

Requirements

(1) Must keep FM out of TV and vice versa.
(2) Must not disturb VSWR of either service.
(3) Must have low insertion loss.

Principle - The TV and FM energies are kept flowing in their proper paths by suitable notch filters, as shown in Figure 7-20.

Construction - The external dimensions are the same as those of the 54-88 mc diplexer.

Performance - Installations made at stations WNBW, WEWS, WLWT, are all working satisfactorily.

Power Limitations - Because of limitations in the feed system of the super-turnstile antenna discussed previously, FM power is limited to 10 kw for the 66-88 mc antenna and 3 kw for the 54-66 antenna.

c. **USE OF TV SUPER-TURNSTILE FOR FM ONLY** - This implies that the TV installation will be made at a later date.

Principle - See Figure 7-21.

d. COMBINATION WITH AM

Purpose - Use of AM tower for TV antenna support.

Principle - TV line must be isolated from ground at AM frequency.

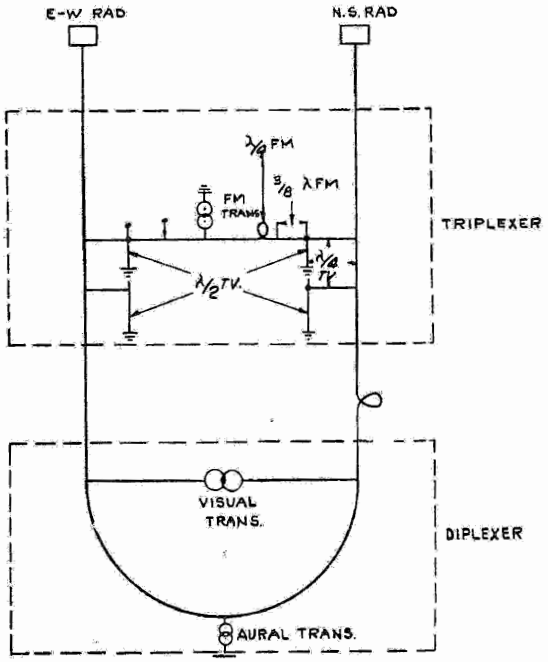


Figure 7-20 - Principle of Triplexing

As shown in Figure 7-22a, the tower acts as the outer conductor of a balun. The capacitance at the end *A* loads the balun to resonance if the tower is not high enough to furnish one-quarter wavelength at the AM frequency.

Referring to Figure 7-22b, a balun of wires is constructed around the TV line approaching the AM tower for a distance of one-quarter wavelength, or equivalent.

TRANSMISSION LINE

PRINCIPLE - Without insulators, the surge impedance is

$$Z_o = 138 \log \frac{D\ (outer)}{d\ (inner)} .$$

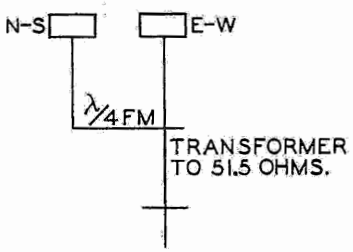


Figure 7-21 - TV Superturnstile Antenna

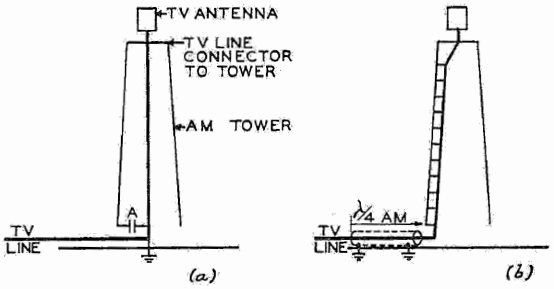


Figure 7-22 - Use of AM Tower for TV Antenna

In practice, insulators are always required. The line must then be treated as made up of recurrent T-sections, with each insulator considered as a lumped capacity. See Figure 7-23.

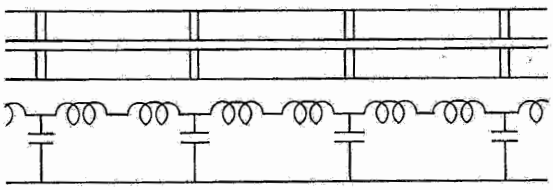


Figure 7-23 - Transmission Line Principle

This brings about two additional considerations:

(1) The line must always be cut half-way between insulators, to avoid discontinuities.

(2) The line is really a filter and has a cut-off frequency. On standard RMA line, the cut-off point is above 216 mc, due to a proper choice of insulator capacity and spacing.

RMA SIZES - Standard sizes are 7/8, 1-5/8, 3-1/8 and 6-1/8 inches. Of these, the 1-5/8- and 3-1/8-inch sizes are the most widely used for 5-kw TV installations.

SURGE IMPEDANCE - The value is 51.5 ohms for all sizes. The primary consideration in this choice was the I^2R loss, with a slight compromise on attenuation. The odd value of 51.5 ohms was chosen because this is the actual impedance of solid-dielectric line. Hence, the two types of line can be used in the same run.

POWER RATING - This is one-half the power required to raise the temperature of the outer conductor 40° C.

SIZE (IN.)	50 MC	100 MC	200 MC
7/8	4.5 kw	3 kw	2 kw
1 5/8	16	10	7
3 1/8	64	42	27
6 1/8	235	166	118

LOSS - Loss takes into account copper loss, insulation loss, and some derating due to connections. The average power transmitted at 100 mc over a 500-foot run of line is 75% for the 1-5/8-inch line and 85% for the 3-1/8-inch line. See published curves in the RCA equipment specification.

GAS - Dehydrated air, obtained from a commercial dehydrator, is probably best. Only a *small* positive pressure is needed; 5 lbs. is adequate.

CONSTRUCTION - See Figure 7-24. The primary purpose of this construction is two-fold:

(1) To prevent electrical discontinuities in the line.
(2) To make the installation as nearly foolproof as possible.

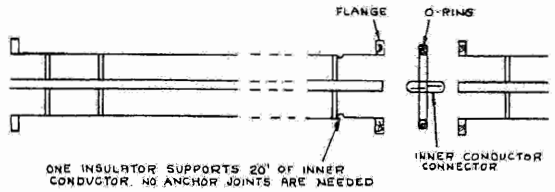


Figure 7-24 - Transmission Line Construction

No soldering or brazing is needed in the field. If a length other than 20 feet is needed, the line is cut and a flange adapter is used, which requires no brazing. Flange joints are pulled up tight and require no "feel".

FITTINGS - Fittings must be designed to prevent electrical discontinuities. This means that diameters must remain the same and insulators must continue at the same spacing. Elbows must have a wide sweep. See Figure 7-25.

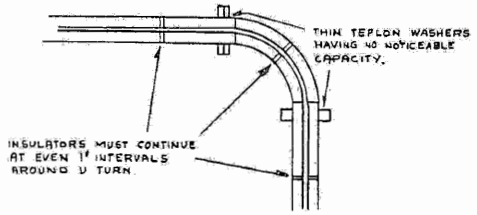


Figure 7-25 - Transmission Line Elbow Fitting

TELEVISION STANDARDS - While lines intended for TV and FM have the same approximate dimensional standards and external appearance, the surge impedance limits on TV line are tighter because the reflection problem is highly important in television. In ordering lines, be sure to specify it for TV standards, or better yet, order it through RCA.

CUTTING POINTS OTHER THAN HALF-WAY BETWEEN INSULATORS - If this is absolutely necessary, a point should be chosen further back, where the line can be cut half-way between insulators. The odd balance is then filled out with a line containing no insulators and having a diameter that will give a surge impedance of 51.5 ohms.

EXTRA QUARTER-WAVE FOR DIPLEXING - The equipment specifications (AS-5979) show several methods of introducing this at the diplexer. It also gives a table, for each channel, of the difference that should exist, taking into account the actual velocity of propagation along the line.

ATTACHING LINE TO TOWER

ELECTRICAL REQUIREMENTS - Both lines should be as identical as possible all the way down the tower. Flanges and elbows should be located in the same places from the tower top to the diplexer in the station, where the extra quarter-wave is inserted. This is because each elbow can insert a slight mismatch. If the two lines are exactly alike as to mismatch, the latter is balanced out by the extra quarter-wave section, which inverts the reactance.

MECHANICAL REQUIREMENTS - The primary requirement is to provide allowance for expansion. The following should be noted.

(1) Expansion of the inner conductor is made possible by the sliding of the spring-loaded inner-conductor connector.

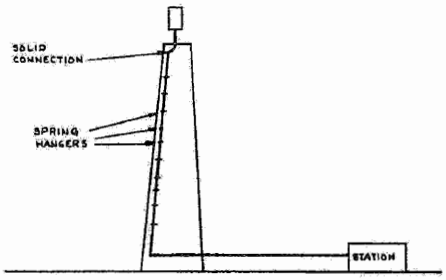


Figure 7-26 - Transmission Line Installation Layout

(2) Expansion of the outer conductor is permitted by spring hangers. The line is connected solidly at the top of the tower; and then

it is connected to the tower every 10 feet (see Figure 7-26). These hangers are pre-loaded in accordance with the temperature conditions at the time of erection. Under ordinary climatic conditions, expansions of 1 inch in 100 feet will occur, and this will be accommodated by the hangers. An elbow at the bottom of the tower should be arranged to take this movement.

If the tower is more than 500 feet high, the arrangement can follow the layout shown in Figure 7-27.

CHECKING LAYOUTS - Transmission line layouts will be checked by RCA for accuracy and completeness, if submitted.

NOTE - *Any pains taken in establishing a good transmission line and antenna installation pays enormous dividends. Here, if anywhere, a slight effort in time will prevent expensive and lengthy delays at a later date.*

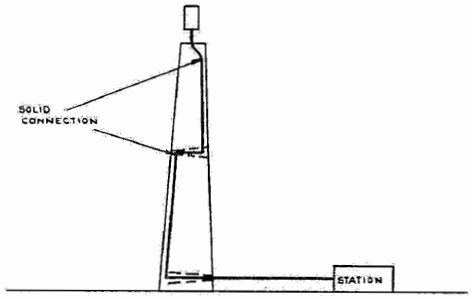


Figure 7-27 - Transmission Line Installation Layout

TRANSMITTER ADJUSTMENTS

By J. G. Sperling

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FCC Rules, Regulations, and Standards of Good Engineering Practice have required for many years that the audio frequency and radio frequency characteristics of AM broadcast transmitters shall be in accordance with certain prescribed limits. It may ordinarily be assumed that all stations operate within these limits. However, the operator of a broadcast station is quite often faced with the problem of diagnosing transmitter faults or failures which prevent operation in accordance with the standards set by FCC. The possible faults and failures, if listed, would fill many pages. Those which will be discussed here are: (1) Limited Audio Frequency Response; (2) High audio harmonic content; (3) Excessive second and/or third RF harmonic content; (4) Improper neutralization of the RF circuits; (5) Excessive hum on the carrier.

These difficulties or faults may be easily remedied as follows:

1. The use of high fidelity pre-, program, line, and modulator amplifiers will settle the question of audio fidelity in the a-f end. It should be noticed, however, that the amount of inductance of the modulation choke or other device connecting the modulator to the modulated amplifier materially determines the amount of low audio frequency response. For the response at 30 cycles to be equal to that at 1,000 cycles, it is necessary that the value of the above inductance be equal to the reflected load resistance of the class C modulated amplifier divided by at least 200, or $L = E_p/(I_p \times 200)$ where L is in henries, E_p is the plate voltage of the modulated amplifier and I_p is the plate current of the modulated amplifier.

The capacity of the plate by-pass condenser in the modulated amplifier and the following class B stages, if any, determines the amount of high a-f response. If the response at 10,000 cycles is to be the same as that at 1,000 cycles it is necessary that the capacity, in microfarads, be equal to the load resistance divided by 100, or $C = E_p/I_p \times 100$.

2. The audio harmonic content for a properly adjusted class A audio amplifier is negligible. The only precaution to watch is to see that the amplifier is not overloaded and that all the vacuum tubes are in good operating condition.

If class B audio amplifiers are used, the use of proper tubes in a correctly adjusted circuit will usually result in a third harmonic content of not over 2 per cent.

The use of a suitable KVA. to KW. ratio in the r-f amplifiers and proper adjustment of all circuits will result in audio distortion of not over 1 per cent. This is discussed more thoroughly further on.

3. The r-f harmonics present can be greatly attenuated, usually to a value around .05 per cent of the fundamental power, by the use of a suitable KVA/KW ratio and harmonic suppressing networks.

4. In spite of all that has been written regarding proper neutralization procedure, many transmitters can be found that are improperly neutralized. The easiest check for improper neutralization is as follows: Disconnect the plate voltage on the stage to be checked and all succeeding r-f stages. Note the d-c meter in the grid circuit of the stage following the stage to be checked. If there is any grid current flowing, merely adjust the neutralizing control of the preceding stage until the current drops to zero.

5. Excessive hum on carrier may be reduced by increasing the amount of filter used in all the power rectifiers, and by using properly matched r-f and rectifier tubes.

HOW THE R-F AMPLIFIER WORKS

One of the greatest problems that one encounters in transmitter adjustment is the question of how much L and C to use in the tuned circuits, and the design and adjustment of a proper coupling system for the transmission line. Before entering a discussion of the amount of L and C to use, it is necessary to see how a r-f amplifier tube works.

In Fig. 1 is seen a plot of the various voltage and current relations during an electrical cycle. A sinewave voltage, e, from the oscillator or r-f amplifier stage, is impressed on the grid of the tube along with the d-c grid bias. This bias in the case of a class C amplifier is about two times cut-off bias. For a class B stage it is just cut-off. The a-c voltage on the plate, e_p, is superimposed upon the d-c plate voltage, E_p. This e_p is 180 deg. out of phase with the voltage e_g. Grid current i_g, is drawn when the grid voltage e_g is positive. The a-c plate current i_p starts to flow when the grid voltage e_g is positive and above the theoretical cut-off bias line. This a-c plate current is not sinusoidal, as is the grid voltage, but unsymmetrical due to being operated on or past the bend of the characteristic curve.

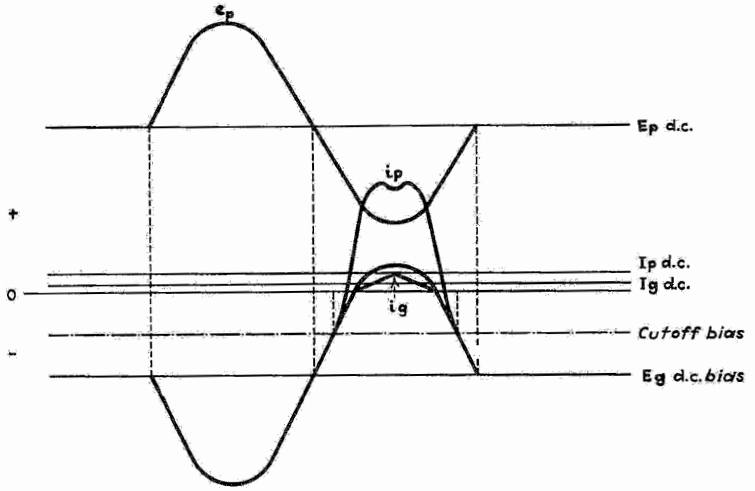


Fig. 1. Instantaneous relations between plate and grid voltages and currents in r-f amplifier

This simply means that the wave-form is replete with harmonics of the fundamental frequency. To reduce this harmonic content to a minimum, it is necessary to have a large circulating current present in the tank circuit to smooth out the wave form and transform it into something resembling a sinewave. This effect is termed the "flywheel effect." The greater the capacitance C in the tuned tank circuit, the greater the circulating current.

The fly-wheel effect operates as follows: When the a-c grid voltage e_g goes positive, the a-c plate current pulse i_p flows through the tank circuit, comprised of L and C in parallel. It produces an r-f voltage across it, charging the tank condenser C. At the moment e_g starts to go negative the condenser C discharges to L via the plate end of the tank circuit, and charges the other set of plates of C, which is the end connected to the plate supply. When the grid voltage e_g is negative no i_p flows, but the condenser C discharges in the opposite direction to which it did at first because the other set of plates of C has been charged. This completes the cycle of output r-f voltage, and explains why only one tube is necessary in a class B or C r-f amplifier for correct operation.

The ratio of KVA/KW, the ratio of volt-amperes in the tank-circuit to the d-c plate input power, $E_p \times I_p$, for maximum reduction of harmonics should be at least 12.6. It is customary to use a value between 15-25. In the preceding stages, those preceding the modulated amplifier, it is not necessary to use such a large ratio because the tank circuit is usually shielded. A value of 5 or thereabouts will do in these stages. The values of inductance and capacitance in the tuned plate circuit can be computed.

If the stage is single ended, not push-pull, the rms value of the peak plate voltage is:

$$e_{p(r.m.s.)} = \frac{2 \times E_p \times Eff}{3.14 \times .707} = 0.9 E_p \times Eff$$

As the efficiency of a class C stage is usually taken as 72 per cent,

$$e_p \text{ (r.m.s.)} = .65 E_p.$$

If push-pull is used,

$$e_p \text{ (r.m.s.)} = 1.3 E_p.$$

For a class B single stage at 63 per cent efficiency.

$$e_{p\,(r.m.s.)} = \frac{2 \times E_p \times .63}{3.14 \times .707} = 0.567 E_p$$

For a push-pull stage

$$e_p(\text{r.m.s.}) = 1.13 E_p.$$

At resonance $X_C = X_L$ and therefore the amount of circulating current through these two branches is equal.

$$I_L = I_C = \frac{\frac{KVA}{KW} \times E_p \times I_p}{e_{p\,(r.m.s.)}}$$

Therefore:

$$X_c = \frac{e_p \text{ (r.m.s.)}}{I_L}; C = \frac{1}{6.28 \times F \times X_c}$$

$$\text{and } L = \frac{X_L}{6.28 \times F.}$$

By the use of Fig. 2, all computations necessary for the derivation of C and L, other than those on the chart, are eliminated. This chart is not absolutely accurate but close enough for all adjustment purposes.

In the modulated amplifier and the Class B stages, if any, it is customary to use a KVA/KW ratio of 15-25.

TRANSMISSION LINE TROUBLES

Much trouble is encountered in the design and correct adjustment of a transmission line coupling unit. Dietsch has shown the proper method of designing such coupling devices.[1] If we wish to terminate the transmission line into a tank circuit, it is necessary to provide such values of C and L so as to provide a suitable KVA/KW ratio and at the same time offer a unity power factor or resistance load to the transmission line so there will be no reflection losses. Before proceeding with the design of the coupling units it is necessary that the characteristic impedance of the transmission line and the antenna resistance be accurately known. Any suitable measuring device may be employed for these determinations.[2]

The value of tank capacity may be derived from the following formula:

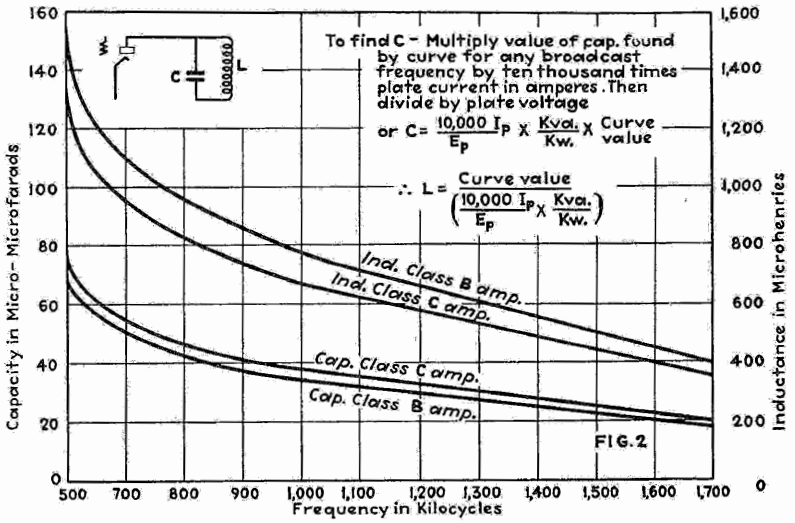
$$C_{\mu\mu f} = \frac{KVA}{KW} \cdot \frac{10^{12}}{6.28 \times F \times Z_o}$$

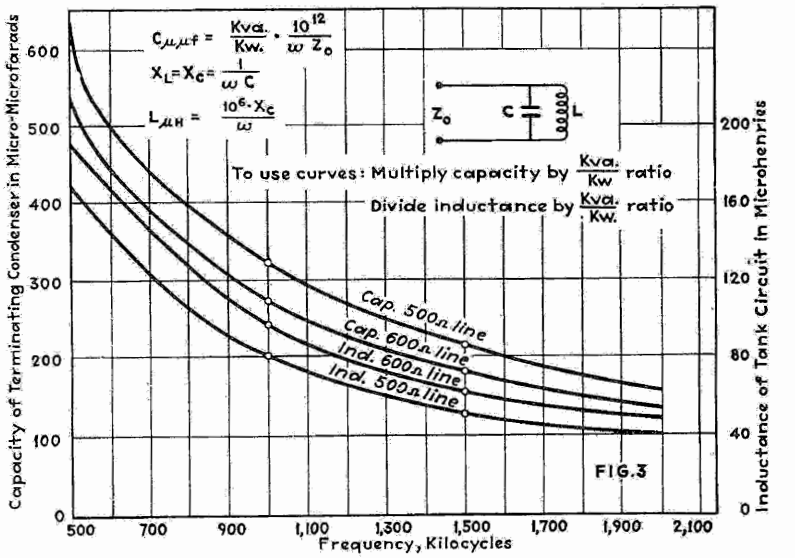
Where F = frequency in cycles and
Z_o = characteristic impedance of transmission line

Since $X_L = X_C$ at resonance, $L = X_c/6.28\ F$.

Calculations have been made for the 500 and 600 ohm. transmission lines only, because of their widespread use as compared to the low impedance concentric transmission line.

The values of C and L versus frequency for the 500 and 600 ohm. transmission lines are shown on Fig. 3.





Figs. 2 and 3. Charts for calculating capacity and inductance of radio-frequency amplifier tank circuits

The value of mutual inductance, M, between the tank coil and the antenna coupling coil can be derived from the following formula:

$$M = \frac{10^6}{6.28\ 2\pi F}\cdot X_C \sqrt{\frac{R_a}{Z_o}}$$

Where:

M = Mutual Inductance in μ
X_c = Reactance of tank capacity
R_a = Antenna resistance
Z_o = Transmission line impedance
F = Frequency in cycles

When it is merely desired to use a terminating capacity at the antenna end of the transmission line and not a tank circuit, the value of capacity necessary to provide a unity power factor load is equal to:

$$C\ (\mu_f) = \frac{10^6}{6.28 \times F \times Z_o}\sqrt{\frac{Z_o - R_a}{R_a}}$$

Where F = frequency in cycles
Z_o = transmission line impedance
R_a = antenna resistance

The antenna will be properly coupled to the transmission line, when using a tank circuit at the antenna end of the transmission line, when the antenna current, and the current in the capacitive and inductive branches of the tank circuit are the pre-calculated value.

The current in the antenna can be easily calculated.

$$P = I^2_{ant} \times R_{ant} \text{ or } I_a = \sqrt{P/R_a}$$

Where P = input to transmitter.

The current in the capacitive branch of the tank circuit may be determined as follows:

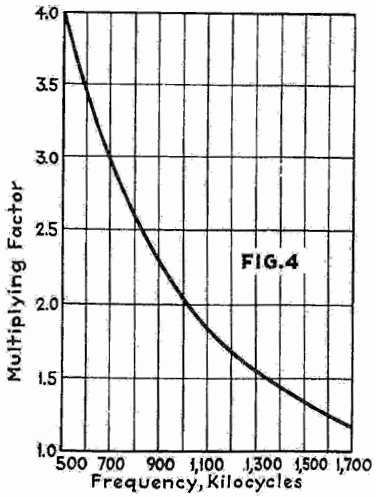


Fig. 4. Correction curve for applying Figure 5

$$E\ (\text{rms}) = \sqrt{Z_0 \times P}$$

$$\text{and } I_{cap} = \frac{KVA/KW \times P}{E_{rms}}$$

It is usually customary to use a KVA/KW ratio slightly higher than that in the final amplifier tank circuit if the antenna impedance is relatively high. This impedance can be determined from any good r-f measuring set.[2] When the antenna impedance is low, a lower KVA/KW ratio may be used.

The value of current in the inductive branch of the terminating tank circuit may be derived as follows:

$$X_L = R \times \frac{Z_o}{X_c};\ Z_o = R + \left(\frac{Z_o}{X_c}\right)^2 R;$$

$$\therefore I_L = \frac{E_{rms}}{X_L}$$

Where X_c = reactance of tank cond.
X_L = reactance of tank ind.
R = tank inductance resistance plus reflected resistance of antenna coil.

The antenna should be resonated at the transmitter frequency by means of a driver oscillator coupled to the antenna coupling coil, with the tank circuit disconnected from the transmission line. Then the tank circuit should be connected across the transmission line and the antenna coil opened. At this point tune the tank circuit to resonance. The amount of inductance in the antenna may be calculated from any of the many formulas in Bulletin 74 of the Bureau of Standards. Now reconnect the antenna and ground or counterpoise to the antenna coupling coil and put the transmitter into operation. The current readings in the antenna, and the capacitive branches of the tank circuit should indicate the values already calculated. When the antenna current and the capacitive current are both low, there is insufficient excitation from the transmitter. Increase the r-f drive. If the capacitive current is high and the antenna current is low, there is insufficient inductance in the antenna coupling coil. With the above readings reversed, the opposite is true. Whenever the antenna coil is touched the antenna must be again tuned to resonance.

It will be noticed that the current in the inductive branch is not its pre-calculated value when the other two readings are correct. It is merely necessary to vary the inductance of the tank circuit until the inductive current is correct. At this point the tank circuit offers a unity power factor or resistance load to the transmission line.

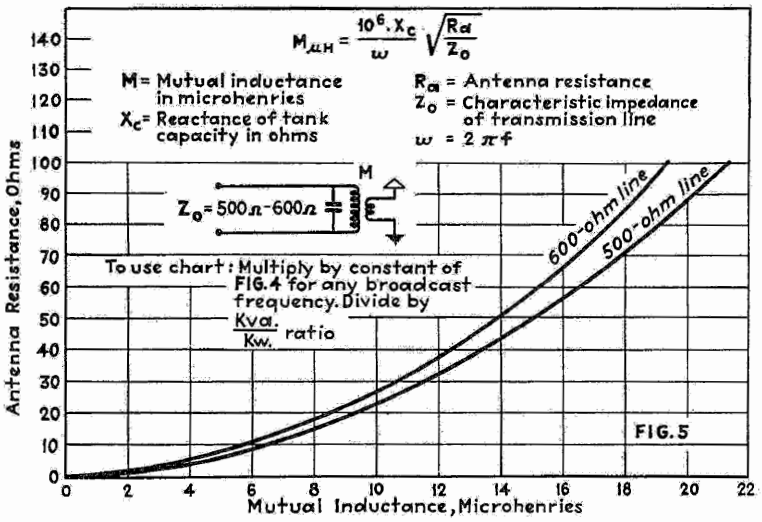


Fig. 5. Chart for computing proper mutual inductance between the tank and the antenna for two impedance values of transmission line

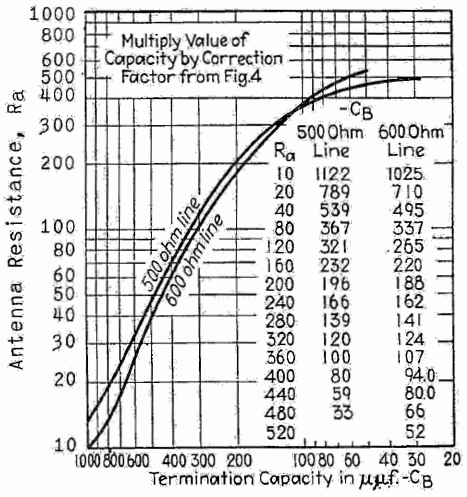


Fig. 6. Terminating capacity vs. antenna resistance for 500-600 ohm lines

It is recommended that the tank circuit be used to terminate the transmission line and not merely the capacitor as in Fig. 6, for increased harmonic reduction.

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ELIMINATING SPURIOUS RADIATIONS FROM BC TRANSMITTERS

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PRACTICAL METHODS FOR DETERMINING EXISTENCE AND EXTENT OF HARMONIC GENERATION AND OF DESIGNING AND APPLYING CORRECTIVE FILTERS

Even though commercial design of radio transmitters is such that most spurious signals are eliminated or greatly reduced, there are many cases where such radiation does not appear until the transmitter is in operation and must be corrected by the station engineer. Among the common cases of such are combination frequencies resulting from two different transmitters, and cases where a harmonic is particularly objectionable because it falls on the frequency of another service nearby.

The first requisite is an accurate diagnosis of their origin. Failure to find a successful cure has usually resulted from a hasty conclusion as to the nature of the trouble, and consequent improper corrective measures. One of the essential instruments needed is a simple resonant wavemeter used as a wave trap, with a wide, carefully calibrated frequency range. This instrument does not contain harmonics or respond to combination frequencies, as does a transmitter, receiver, heterodyne frequency meter, or any other instrument containing a vacuum tube. Any conceivably spurious response from this wavemeter is likely to be several octaves removed, and not in exact harmonic relationship with the primary response frequency.

A spurious response in a receiver from a spurious signal from the transmitter can be distinguished quickly by inserting the resonance wavemeter as a wave trap in the antenna lead of the receiver. The signal will drop when the wavemeter is tuned to the frequency at which the signal enters the receiver. If the fault lies in the receiver, this drop will be the correct frequency of the transmitter. If the fault lies in the transmitter, or at least somewhere external to the receiver, the wavemeter will indicate a spurious frequency at whatever point the receiver is tuned.

A direction finder is another desirable instrument for locating the source of an undesired signal. Cases frequently occur where a spurious frequency carries the program of one radio transmitter, but is actually generated in another transmitter, or in something completely foreign to any transmitter. When a direction finder is not available, useful results may be obtained with a portable radio receiver which has a signal strength meter.

Location Radiating Source

Such a direction finder or a signal strength indicator leads to the antenna radiating the signal. The signal itself is generated in some non-linear (or rectifying) device, and may be carried some distance by wires which serve as a transmission line, before it reaches the point of radiation. Before correction is made, it is ordinarily necessary to locate the non-linear device. The correction usually consists of adding or modifying networks adjacent to the non-linear device in such a manner that the spurious signal cannot reach the radiator, or else in such a manner that a contributing frequency necessary to produce the spurious radiation is prevented from reaching the non-linear device.

With the recent rapid increase in the number of broadcast stations, a new spurious frequency is sometimes formed by a combination of the frequencies of two (or more) stations. To produce the new frequency, energy from both of the base frequencies must flow through one non-linear device. Common devices for production of such interference are:

1——The final amplifier tube of one of the stations.
2——Any vacuum tube in an indicating instrument connected to the final amplifier, such as an inverse feedback rectifier, audio monitor rectifier, remote ammeter rectifier, or phase monitor.
3——The crystal oscillator tube or other low level rf or af tube in the transmitter or amplifier preceding the transmitter.
4——Rusty iron or corroded copper in the antenna system.
5——Man-made structures which are not part of a transmitter, possibly at some distance (a mile or more) from the transmitter. Poor electrical connections, old plumbing, and corroded metal roofs fall in this category.
6——The ionosphere (assuming that the debated "Luxemberg Effect" is accepted as a reality).
7——A vacuum tube in the radio receiver in which the interference is observed.

Combination frequencies usually are frequencies which are defined by $f = mf_a + nf_b$, where f is the spurious frequency, and f_a and f_b are the correct operating frequencies of two radio transmitters; m and n are any integers, positive, negative, or zero. The entire range of spurious frequencies expressed by all values of m and n are ordinarily produced when two

frequencies are combined and passed through a non-linear device. However, the only one which ordinarily concerns us is the one which meets three conditions:

It is initially strong, the associated networks, transmission line, and radiator convert a substantial part of it into radiation, and finally it falls on a frequency which interferes with some other service.

Harmonic Suppression

Good engineering requires suppression of all spurious radiations. This is not always attained in the design, construction, and operation of transmitters. Strong radiations of the kinds most frequently occurring (such as harmonics) are eliminated fairly well in the manufacture of the transmitters. Other spurious radiation is usually eliminated only if it is observed either by a government monitoring station, or by someone who suffers interference from it. Even after an interfering radiation is observed, it is not always possible to identify the station responsible for it and to persuade the owners or engineers to eliminate it. A few specific cases might be cited.

The FCC ordered a broadcast station to eliminate third harmonic interference at a communications receiving station about two miles distant. Field intensity measurements indicated about 10 microvolts per meter at a mile, but there was such a large fluctuation in the field that no useful intensity measurements could be made. The loop antenna of the field intensity meter gave a bearing toward the broadcast station.

It was assumed that the harmonic (which is always generated in the final amplifier of the transmitter) was being radiated and a diagnosis was first made to determine whether the radiation was from (1) the antenna, (2) power lines, audio input, or other wires leaving the transmitter, (3) direct radiation from the final tank circuit (particularly likely because of poor shielding). When the transmitter was operated into a dummy antenna, the interference disappeared, establishing the fact that the only radiation was along the transmission line to the antenna. To our surprise the normal cure (a trap circuit resonant

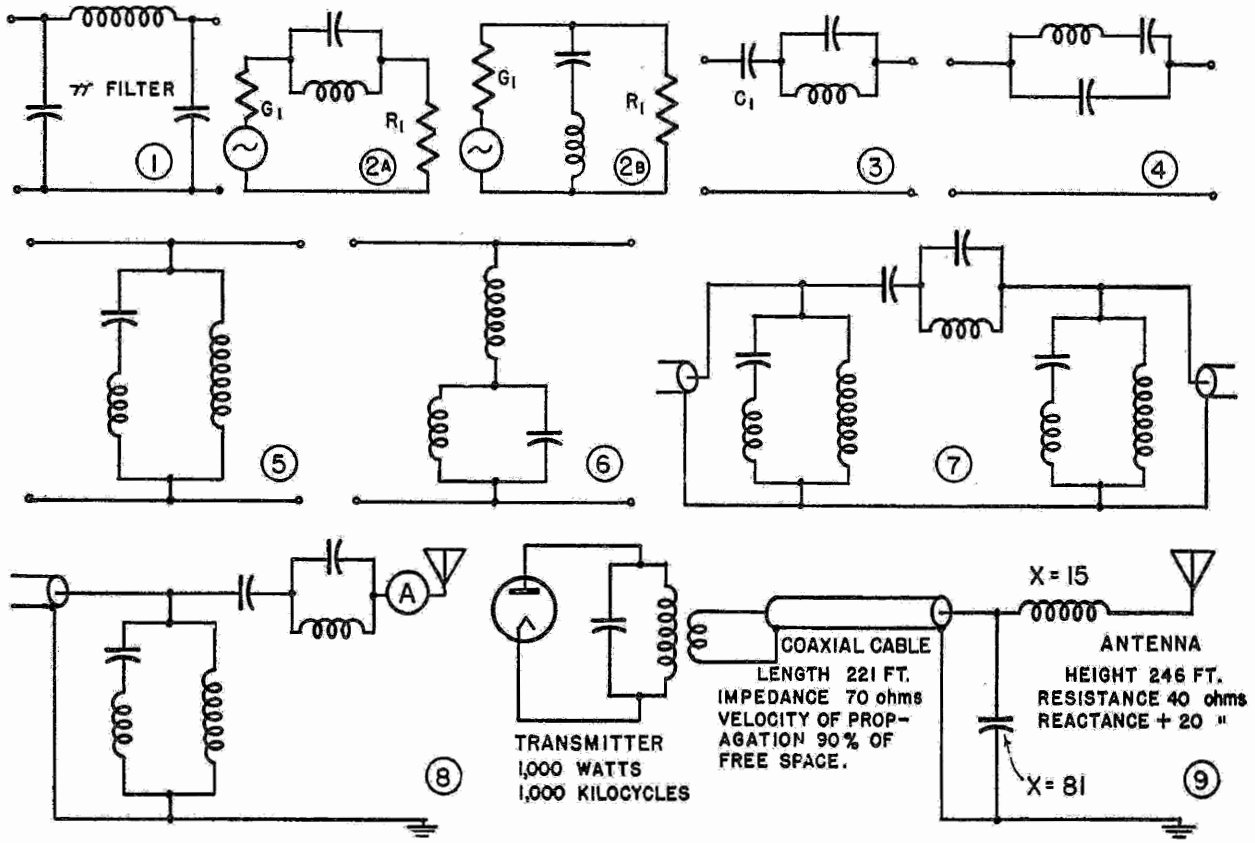

Fig. 1--Simple pi filter. 2A--Simple wave-trap filters. 3--Type A filter with reactance a pass frequency tuned out by C_1. 4--Filter with Fig. 3 characteristics. 5--Type B filter with reactance at pass frequency tuned out by an added inductance. 6--Filter with Fig. 5 characteristics. 7--A pi filter of resonant circuits. 8--L network prevents induced antenna current from nearby station from registering on antenna meter. 9--Typical filter for rejection of 1100 kc from transmission line input.

at the harmonic frequency, connected between the transmitter output and the transmission line input) was ineffective.

Trap Characteristics

The performance of the trap was proven to be good. Supplying a signal at the harmonic frequency from a signal generator established that a signal at harmonic frequency was adequately suppressed in the trap. But when the main transmitter was fed into the line, the harmonic was unaffected by tuning the trap near the harmonic frequency, and was reduced only when the trap was tuned to the fundamental frequency of the transmitter. This paradox seemed unbelievable for a time. The implication, however, was that the signal passed from the transmitter to the antenna at fundamental frequency, and was converted to third harmonic in the antenna.

The remote meter rectifier tube in the antenna turning unit was removed, but the harmonic remained. Nothing else in the antenna seemed to be capable of producing a harmonic. The field intensity meter was set up about two hundred feet from the antenna, with a long cord to the headphones, and various parts of the antenna system were disturbed while listening for any change in the harmonic.

Finally it was found that the harmonic fluttered violently when the guy wires of the antenna tower were jarred. The guys were rusty iron, apparently with poor contacts at splices or other attachment points that became generators of the harmonic. The obvious correction was replacement of the guy wires. Such problems from a little rust seem far-fetched. However, it is a matter of public record in this case that this harmonic interference on a communication frequency caused the death of an aviator.

Unusual Source

In another similar case a harmonic which did not respond to the usual wave traps was finally found to be generated in the vacuum tube rectifier at the antenna which was used for a remote antenna ammeter. This was a rectifer which produced several milliamperes dc.

There have been numerous cases recently of spurious radiations in the broadcast band at a frequency of $f = 2f_a - f_b$. For instance, where there are stations in the same city on 1000 kc and on 1100 kc, a signal is heard on 900 kc. It carries modulation of both transmitters, but much stronger modulation of the 1100 kc transmitter. On investigation it is found to be radiated from the 1000 kc station. It is produced in the final amplifier tube of the 1000 kc station, when the 1100 kc signal is received in this tube from the other station.

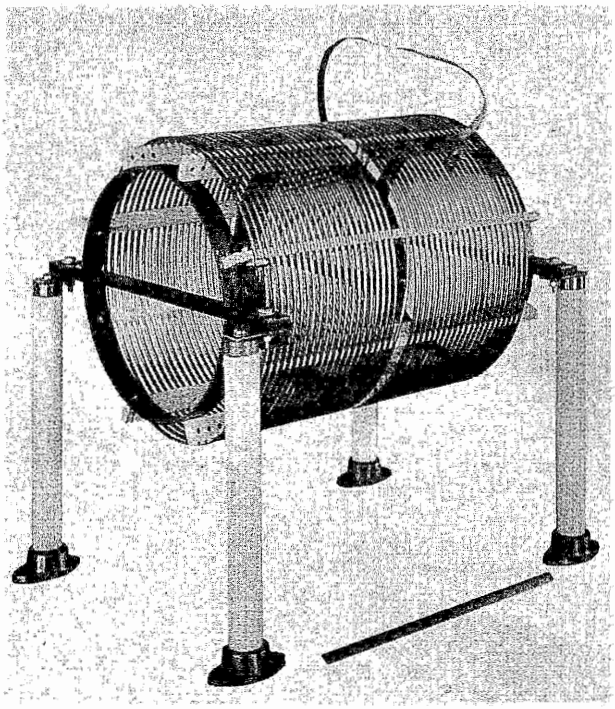

Fig. 10--Transmitting inductance well designed to give high Q factor.

Correction consists of inserting a filter somewhere between the final amplifier tube and the antenna of the 1000 kc station, and tuning the filter to reject 1100 kc. When properly tuned, the signal on 900 kc disappears. Final tuning is most easily accomplished with both transmitters in operation, and a receiver tuned to 900 kc to indicate filter adjustment. In a similar manner, the other station produces a spurious radiation on 1200 kc, and must have comparable corrective measures.

Particularly troublesome cases occur where the frequency separation is small and the distance between antennas is small. In numerous cities both 1450 and 1490 kc are assigned. The frequency separation of 2.7% is very difficult to separate with resonant circuits. In one city, stations on these frequencies have antennas only 500 ft. apart. Here an added difficulty appears: each antenna picks up so much current from the other station that the antenna current indication is inaccurate by as much as 20% when the other transmitter is operating. This trouble also has been corrected by proper filter design, but it is a severe complication to the design.

Spurious Modulation

It was found that a 250-watt broadcast station (tested without modulation) actually had a substantial modulation from the program of a higher power station several miles away, and widely different in frequency. Preliminary check

showed that this signal was not coming in on the audio lines to the new station. If this was a case of picking up the spurious signal in the antenna and rectifying it in the final amplifier, a trap in the antenna lead to reject the carrier frequency of the other station would be needed. However before building the trap, the inverse feedback rectifier tube was pulled out of its socket. The spurious modulation disappeared completely! This rectifier takes its input from a small sampling line loosely coupled to the final tank circuit of the transmitter. All that was necessary was a small resonant trap in this input circuit to the rectifier.

The trap was built out of miniature receiver components, and worked perfectly! A tank built in the main transmission line from the transmitter to the antenna would have done the job too, but it would have required large and expensive transmitter components, its adjustment would have changed the loading on the transmitter, and it would have caused some loss of transmitter power.

In a similar case spurious radiation appeared as a hash 30 kc on each side of the carrier frequency. When the transmitter was not modulated, no spurious radiation was found.

Other Interference

Here again it was found that by removing the inverse feedback rectifier tube, the spurious signal disappeared. A squeal at 30,000 kc was apparently set up in the inverse rectifier in some manner, probably by feedback completely around the circuit of this rectifier, and the transmitter audio and radio circuits. A slight reduction in the amount of feedback used was all that was necessary to eliminate the trouble.

In a communications station, where the same frequency was used for transmission and reception, when receiving, the plate voltage was turned off the transmitter, but the filaments were left on. Interference was found on the operating frequency, heavily modulated at 60 cycles. The tubes were obviously generating oscillation due to plate and grid being grounded to the center of the filament. The cure: leaving the grid bias on the final amplifier when the plate was turned off.

Police were using a frequency on the third harmonic of a broadcast station. They complained of hearing the broadcast station in their cars when near the transmitter. While examining the harmonic, we used a field intensity meter about a thousand feet from the transmitter.

It was found that the field intensity meter did not have sufficient selectivity in the input circuits, and therefore the fundamental frequency reached a tube in the receiver with sufficient amplitude to produce the harmonic in the receiver. A communications receiver with an additional wave trap at the fundamental frequency in its antenna lead disclosed the true third harmonic of the transmitter. This permitted correct tuning of the third harmonic trap in the transmission line input to reduce the interference.

The police car receivers apparently were subject to the same defect, insufficient selectivity in the input circuits, which lead to actual production of the harmonic in receiver. Correction of such difficulty cannot be accomplished at the transmitter, except by such drastic change as moving to a distant location or changing operating frequency.

We have mentioned earlier the necessity for filters where two stations have antennas near each other. In reality, where antennas must be near, the engineering problems are often simpler if only one antenna is used. Both transmitters are connected to the same antenna, with filters at the points of connection which pass the proper frequency and reject the other. There have been several installations of this type in the past, even including one where both stations used directional antennas. One tower was common to both directional systems. Other towers were not.

Monkey Chatter

The modulation sidebands of a transmitter often cause interference with reception on adjacent channels. There are two common causes: the audio frequency input to the transmitter may contain sufficient power at frequencies above 5000 cycles to cause noticeable interference on a station on the next channel. This can easily be eliminated by insertion of a 7500 cycle cutoff filter in the audio input to the transmitter.

The other cause of monkey chatter (overmodulation of the transmitter) is cured by keeping modulation down. Limiter amplifiers now in widespread use in broadcast stations have contributed greatly to correcting this difficulty.

The first filter in a transmitter output is the tank circuit. It is tuned to pass one frequency with small loss, and to offer high attenuation to other frequencies. By decreasing the ratio of inductance to capacity in the tank circuit, the attenuation of other frequencies can be improved, but at the same time the loss of power in the fundamental frequency increases.

Pi Net Suppressors

The addition of a pi or tee network in the output of a transmitter is often used for harmonic suppression. Such a network substantially attenuates all frequencies from the second harmonic upward, but is of little service where the separation between the pass frequency and the rejection frequency is small (under 30%).

Fig. 1 and Table I show design data for a pi filter suitable for harmonic suppression, for specific frequencies and load impedances. Satisfactory design for other frequencies and load impedances may be obtained by interpolation. The number of turns of inductance applies only to an inductance 6 in. in diameter, with 4 turns per inch.

Capacitances may be varied as much as 25% in order to use commercially available fixed capacitors. The currents shown for the capacitor are actual unmodulated amperes for a 250 watt transmitter. For other powers, the current varies as the square root of the transmitter power. For proper factor of safety, the capacitors should have commercial rating of at least twice the indicated values.

Filters of high selectivity such as are often required in elimination of combination frequency radiation are best constructed with one or more resonant circuits at the rejection frequency. This type of filter finds its best applications where the frequency difference between the pass and the rejection frequency is in the range from 2% to 50%.

When the frequency separation is greater than 50%, a pi filter is adequate, unless an unusually high degree of suppression is required. Where the frequency separation is less than 2%, separation usually is beyond the ability of resonant circuits. Where the frequency separation is less than 5%, it is ordinarily necessary to use a filter containing more than one resonant section.

Resonant Filters

There are two ways of connecting the resonant circuits in this kind of filter. In Type A (Fig. 2) the resonant circuit is parallel resonant, and is connected in series with the main circuit. This wave trap approximates an open circuit for the rejection frequency. The other form (Fig. 2B), a series resonant circuit connected across the main circuit, approximates a short circuit across the line at the rejection frequency.

The following formulas are useful: (1) to determine whether to use Type A or Type B filter, to evaluate its components and to compute the results which can be obtained. They contain numerous assumptions and approximations, but have sufficient accuracy for practical use in filter design.

Here the term rejection ratio refers to the ratio of the voltage passed at the rejection frequency (f_2) after insertion of the filter to voltage passed without the filter. The loss ratio is the power dissipated in the filter at the pass frequency (f_1) compared to the power delivered from the filter to the load.

$D = (f_1-f_2)/f_1$ the frequency separation.

X_2 = the reactance of the inductance (or capacitor) in Type A filter at f_2.

Y_2 = the reactance of the inductance (or capacitor) in Type B filter at f_2.

Q = the figure of merit of the inductance used in the filter. For typical transmitting inductances, Q may be assumed to be 300, if the Q of the capacitor is essentially high. In the diagrams the generator is assumed at the left, and the load at the right.

TABLE I

Operating kc	Line or antenna impedance, ohms	L-μh	Inductance turns (6" dia.)	Capacitance, μf	Capacitor Current, Amps.
600	20	5.3	4	.013	3.5
600	70	19	10	.0038	1.9
600	300	80	31	.00088	0.91
1000	20	3.2	3	.0080	3.5
1000	70	11	7	.0023	1.9
1000	300	48	20	.00053	0.91
1500	20	2.1	2	.0053	3.5
1500	70	7.4	5	.0015	1.9
1500	300	32	15	.00035	0.91

Values of components required for a pi filter for harmonic suppression for a 250 watt broadcast station.

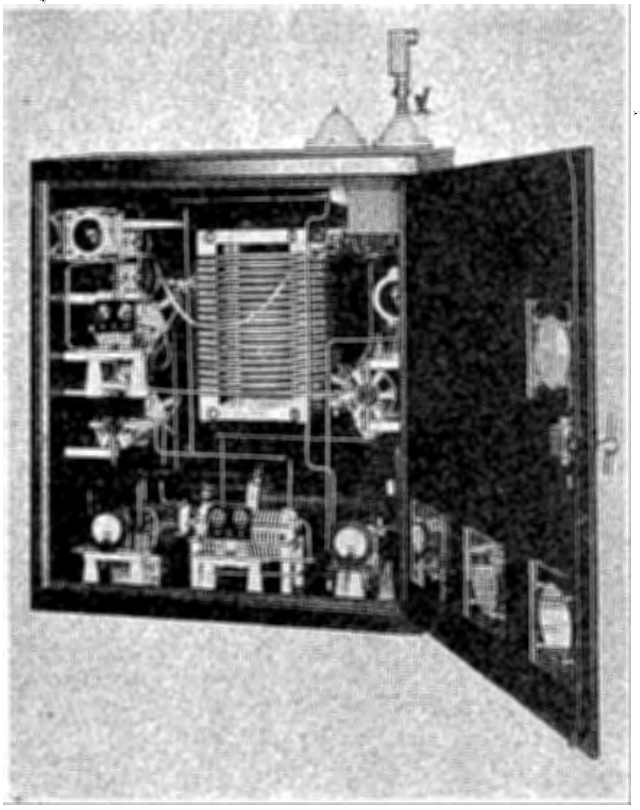

Fig. 11--Typical network incorporated in an antenna tuning unit

However, f_2 may be impressed on either left or right side of the filter, in various applications, and the filter is intended to prevent it from reaching the other side. The designation of one side as "generator" and the other side as "load" is therefore not always clear.

R_1 = the load impedance at f_1.
R_2 = the load impedance at f_2.
G_1 = the generator impedance at f_1.
(G_1 is assumed to be small compared to R_1).
G_2 = the generator impedance at f_2.

In choosing between Types A and B, the former is more effective when the impedance of the circuit is lower at f_2 than at f_1, and vice-versa. Definite formulas for selection of types are:

When R_2G_2 is less than R_1^2, use type A.
When R_2G_2 is greater than R_1^2, use type B.

Any of the following methods may be used to determine which case prevails.

(1) If all components in the circuit are known, it is possible to make calculations of the impedance at the filter point, for both f_1 and f_2. Usually the impedance at f_2 is found to be so greatly different from that at f_1, the choice is obvious.

(2) The impedances may be measured with an rf bridge.

(3) Types A and B may each be tried out, and the preferable one determined from the comparative performance of the two. If this method is followed, it is best to design the two for equal loss at f_1 (according to the formulas given hereafter), and then observe the difference in performance at f_2.

Methods (1) and (2) are applicable to determination of load impedance, and from this impedance alone, the advantage of one type of filter may be so great, or the needed performance so easily obtained, that there is no need for further analysis. These methods, however, do not readily give the generator impedance. Method (3) for this reason is sometimes the only satisfactory method.

To design a type A filter, a value of X_2 must be selected which will give satisfactory performance. Then Rejection Ratio = $(R_2+G_2)/QX_2$ = R_2/QX_2 (when $G_2 \ll R_2$).

Loss Ratio = $X_2/4D^2QR_1$.

Losses Must Be Lowered

It is seen that a larger X_2 makes the rejection ratio lower (an improvement), but also makes the loss ratio higher (a disadvantage). Since performance in both respects is improved by increasing Q, use the lowest loss inductance available, a good capacitor, make good connections between them, and see that the housing and other objects around them do not greatly reduce the Q. Also since the loss varies as D^2, performance deteriorates rapidly as the frequency separation is decreased.

In practice, it is rarely necessary to obtain either of these performance factors lower than 0.001. Where frequency separation is small, it is sometimes necessary to allow each factor to be as high as 0.1. If either factor is higher than 0.1, the filter usually is considered useless, and the project abandoned, or a more complex filter used. If we set 0.1 as the maximum limit of each factor, and assume that Q = 300 and $R_1 = R_2$, we find that this type of filter is useful only for frequency separations of 1.7% or greater.

In resonant filters, high values of current and voltage appear in both the inductance and the capacitor. Components of suitable size must be selected to prevent failure from overheating or voltage breakdown.

In Type A filters the current is ½D times the current in the load. For example, if the frequency separation is 3% the load current is 5 amperes, the current circulating in the filter inductance and capacitor is 83 amperes. This calls for rugged components and makes it clear why severe losses may occur. The voltage across these components is the current times the reactance, and is likely also to be so high that precautions must be taken to prevent corona.

Component Selection

In selecting components, the current rating of fixed capacitors should be 1.22 times that shown to allow for rise in RMS current with 100% modulation. The voltage rating of inductances and air condensers should be 2.30 times that shown in order to allow for maximum RMS voltage with 130% positive peaks of modulation. To find peak voltage, this RMS value must be multiplied again by 1.41. Furthermore, for adequate factor of safety in commercial equipment, it is well to have actual current and voltage ratings about double again the maximum values just computed.

These current and voltage calculations are for the pass frequency (f_1). In most applications, the current and voltage at the rejection frequency (f_2) is so much smaller that it may be neglected. This is so however in some cases, such as operation of two transmitters into one antenna.

For the design of Type B resonant filters the corresponding formulas are:

Rejection Ratio = $(R_2+G_2)Y_2/R_2G_2Q$
Loss Ratio = $R_1/4D^2QY_2$

Here the voltage across each component in the filter is ½D times the voltage across the load and the current is found by dividing the voltage by the reactance.

The insertion of a Type A network in series with a circuit introduces a new reactance in the circuit at f_1. This may be tuned out by an equal and opposite reactance, as shown in Fig. 3. If $f_2 > f_1$ the added reactance must be capacitive. If $f_1 > f_2$ it must be inductive.

In a different arrangement of the three components accomplishing the same end (Fig. 4), the two upper components are series resonant at the pass frequency, and therefore form a zero impedance. They have an inductive reactance at the higher rejection frequency, and a parallel capacitance of the same value of reactance forms a parallel resonant circuit, which approximates an infinite impedance at the rejection frequency.

The small difference in performance of these two circuits permits choice from ease of adjustment, and commercially available components. In the form shown in Fig. 3, the parallel resonant circuit must be tuned to (f_2) first. Then the series capacity C_1 may be tuned for (f_1) without disturbing the (f_2) adjustment. In Fig. 4, the circuit must be tuned first at (f_1), and then the (f_2) tuning does not affect the (f_1) adjustments.

Since tuning adjustment must be made to closer than 1%, construction must be used which will be stable against mechanical shocks and temperature changes. In each three-element group, at least two elements (including the third element) must be continuously variable. It is ordinarily necessary to have these variables so constructed that they can be adjusted with full power on the transmitter, and with all doors closed and other electrostatic shields in place. In any ordinary cabinet construction, opening a door will detune the inductances several percent.

The Type B filter has similar possibilities for adding a third component to neutralize the effect of the filter at (f_1). Figs. 5 and 6 correspond in principle to Figs. 3 and 4.

Where a simple resonant filter does not offer good enough performance, resonant groups may be used to replace single elements in a pi or tee network, as shown in Fig. 7. This network permits complete tuning at (f_2) first, and then tuning at (f_1) without disturbing the (f_2) adjustments. To attain this independence of adjustment, one of the things necessary is to see that stray inductive and capacitive coupling between components is kept small.

This nine-element filter is in use where stations on 1450 and on 1490 kilocycles are located within a quarter mile of each other.

In designing these filters consisting of two or more Type A and Type B groups connected in L, pi, or tee arrangement, the loss in each group must be kept low enough so the sum of these losses will not be objectionable. The rejection ratio in each group may be kept quite low, but the total rejection increases rapidly as the number of groups is increased, and so is as high as desired.

Where two antennas are so close together that the antenna ammeter of one shows an objectionable amount of current picked up from the other station, an L or tee arrangement of these groups must be used so that a Type A group is nearest the antenna and is designed to have a high enough impedance at (f_2) to reduce the antenna current to a harmless value.

For a numerical example of network design assume the previous example of a station operating on 1000 kc and another nearby on 1100 kc. A spurious signal is heard on 900 kc with the program of the 1100 kc station dominant. However, a direction finder, field strength indicator, or other means indicates that the spurious signal is being radiated from the 1000 kc station. The inverse feedback, audio monitor, remote ammeter, and any other similar rectifiers are disconnected without improving the situation. The presumption therefore is that the final amplifier of the 1000 kc station is the tube producing the spurious frequency. The correction consists of inserting a filter between this tube and the antenna which will reject the 1100 kc signal.

The constants of the station at 1000 kc are all known (Fig. 9). The antenna impedance is known to be 40+j20 at 1000 kc, and 50+j50 at 1100 kc. The L network is correct for matching the antenna impedance to the 70-ohm line at 1000 kc. By recomputing the performance of the antenna tuning network at 1100 kc, it is found that the load at the end of the transmission line is 107-j58 at 1100 kc. Then by computing the transformer effect through the transmission line, it is found that the load at the input to the transmission line (where the filter is to be inserted) is 35+j19, or an impedance of 40 ohms.

On the generator side we need not make an exact calculation, but we know that the small pickup coil offers low impedance, and is little affected by the tank circuit at this frequency which is not the resonant frequency of the tank circuit. Therefore both R_2 and G_2 are smaller than R_1, so we may be sure that we have the condition $R_2 G_2$ less than R_1^2, and the Type A filter will be most effective.

The formulas for performance, after substituting D = 0.1, Q = 300, R_1 = 70, and R_2 = 40 are: Rejection ratio = $0.13/X_2$; Loss Ratio = $0.0012X_2$.

We select a value of $X_2 = 10$. Then the rejection ratio is 0.013, or 1.3% of the objectionable frequency is passed by the filter. The loss factor is 0.012, or a power loss of 12 watts in this 1000 watt station.

Calculating shows the current in the inductance and capacitor is 5 times the current in the load, or 25 amperes. The voltage across the inductance is 250 volts. Any transmitting components will handle this voltage, plus modulation peaks.

FACSIMILE

A Brief Theory of Present Day Facsimile Prepared by the NAB Department of Engineering with the Assistance of Mr. John V. L. Hogan, President of Faximile, Inc.

Electrical transmission of pictures was conceived more than a century ago by Alexander Bain, an English Physicist, who proposed a system so basically correct that the fundamentals of the present day system of Facsimile transmission show a remarkable likeness.

The work of many brilliant men has gone into the development of Facsimile as we know it today. It was first used only on wire line circuits and many methods of transmission were tried. Finally about the time radio broadcasting was born, pictures were transmitted by radio. In fact on July 6, 1924 the first picture, termed a photoradiogram, was successfully relayed from New York to London and back to New York. Today the transmission of pictures is an accepted service, and one needs only to refer to his daily newspaper for this evidence.

The broadcaster's use of Facsimile was first authorized by the FCC in the late '20's utilizing frequencies in the range 1500 Kc to 2950 Kc. As a matter of interest two bands of frequencies were allocated to visual broadcasting which included still pictures and moving pictures (Television). In 1937 experimental use of facsimile was permitted on frequencies in the standard broadcast band from midnight to 6:00 a.m. Systems with varying standards were used for this service. In 1939 frequencies above 25 megacycles were authorized for experimental facsimile, and in 1940 the first facsimile rules were adopted by the Commission which provided for operation with FM broadcast stations.

On July 9, 1948 the FCC adopted its present Rules and Standards with respect to facsimile, permitting simplex or multiplex transmission on FM frequencies. (See Appendix I). A general and brief theory of the operation of one system operating in accordance with these rules is here outlined.

Facsimile Transmitting Equipment

The facsimile terminal equipment, for installation at the studios of an FM broadcasting station (or elsewhere, -- as for example in the editorial rooms of a newspaper) should comprise two complete transmitting scanners and their associated accessories including monitor recorders, scanner amplifiers and limiter line amplifiers. Two scanners are needed for the same reason that two turntables are required in a transcription studio. A single scanner necessarily causes some waste space (as well as delay) between successive pages, while the scanner is being reloaded and adjusted. The alternate use of two scanners permits a continuous, unbroken flow of facsimile copy.

A lamp, optical system, phototube and amplifier tube are mounted in the movable scanner head or carriage. The lamp illuminates a spot on the copy. The phototube receives reflected light from the illuminated spot through an optical system. The phototube current or output is controlled by the optical density of the desired portion of the original copy. For each revolution of the copy drum, the carriage advances along the drum, so that the copy is scanned in a spiral. The scanner produces electrical signals representative of the optical density of the copy scanned and feeds these signals to the scanner amplifier.

The scanner amplifier supplies power to the scanner, and uses the signals from the scanner to amplitude modulate a subcarrier which is developed in the scanner amplifier. The modulated subcarrier is amplified and fed into the limiter line amplifier which has two inputs. Signals applied to one of these inputs are amplified linearly. Signals applied to the other input are fed through an adjustable preset limiting stage whose output is either zero (or no signal), or equivalent to a full marking density. This limiting channel is useful for transmitting poorly prepared copy. The limiter line amplifier has a common output which operates with balanced circuits. This output of the limiter line amplifier may be fed directly into an FM transmitter for simplex facsimile broadcasting, or into the facsimile input channel of a transmitting multiplexer unit for multiplex operation.

Single scanner operation requires one of each of the following units: Scanner, Scanner Amplifier and Modulator, Limiter Line Amplifier, and a Pulse and Page Separation Signal Generator. (See Figure 1-A)

Dual scanner operation requires two each of the Scanner, Scanner Amplifier, and Limiter Line Amplifier units; one Pulse and Page Separation Signal Generator; plus control and output switching equipment. (See Figure 1-B)

The output of the facsimile input equipment may be fed directly into an FM transmitter, or relayed from the scanner location.

Synchronizing of broadcast facsimile transmitting and receiving equipment is accomplished by using identical or interconnected power sources. In areas where power line synchronization is not possible, automatic synchronizing amplifiers may be provided for receiving sets.

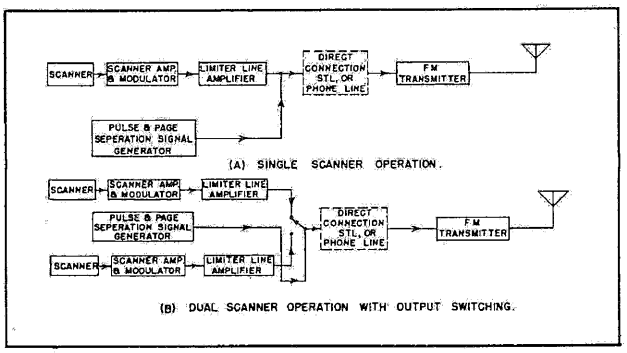

Figure 1--Input equipment used in Simplex Facsimile Broadcast Operation

The service area of an FM transmitter is affected in no way by the change from sound modulation to facsimile modulation. A good FM receiving antenna should be considered standard practice in most receiver installations.

A simplex facsimile broadcast operation can be advanced to a Multiplex FM sound and facsimile operation by feeding the two programs into a Multiplexer unit located at the FM transmitter. The mixed sound and facsimile output is then used to modulate the FM transmitter. (See Figure 2)

When planning a Multiplex aural and facsimile operation it should be noted that two program transmission lines are usually required to feed the two input channels of the Multiplexer unit. This may dictate the use of dual STL systems, dual telephone lines, or any acceptable combination. It is not necessary for the sound and facsimile programs to originate at the same place.

Various combinations of units may be used to form a mobile or portable facsimile input equipment. Basically, a Scanner, Scanner Amplifier, and Limiter Line Amplifier, are needed together with the Pulse and Page Separation Signal Generator.

Power source for portable or mobile operation must be synchronous or interconnected with that at the location of the broadcast station's fixed facsimile input equipment. It is suggested that, whenever possible, operations combining fixed, portable, and mobile facsimile input equipments be consistent in using the same phase of the normal three phase 115 volt 60 cycle AC power.

Facsimile Receiving Equipment

The signals needed to operate the facsimile recording equipment are taken directly from the output of the discriminator of an FM receiver. If the receiver is limiting excellent copy can be expected. (See Fig. 3 for simplex reception; Fig. 4 for multiplex.)

The discriminator output signal is applied to a recorder amplifier which amplifies the signal, rectifies it, and supplies current corresponding to the signal to mark the moist electrolytic recording paper in the recorder.

The recorder amplifier supplies all power to the facsimile recorder, including power to the synchronous recorder motor. A relay in the recorder amplifier interrupts the motor power when necessary to phase or "frame" the recorder.

The recorder has a humidor compartment which stores the moist electrolytic recording paper. Feed rollers advance the paper between the marking electrodes which consist of a printer blade and helix drum. After the paper is marked it passes over a heater which dries the paper and completes the marking process.

Marking the recording paper is nominally a constant current, low voltage process. In broadcast recording equipment 250 milliamperes of direct current are needed for full density marking. The voltage in recording may reach a maximum of about 50 volts depending on the amount of moisture in the paper. As the recording current passes through the paper from printer blade to helix, iron from the blade is deposited in the paper in proportion to the amount of current. The marking process gradually consumes the printer blade which is replaced along with the roll of recording paper.

Rotation speeds of recorder helix drum and scanner copy drum are 360 rpm. Paper feed in the recorder corresponds to scanner carriage advance rate of 3.43 lineal inches per minute. The recorder delivers approximately 28 square inches of copy in a minute. A fifteen minute broadcast program interval will result in four pages of recorded copy, 8.2 by 11.5 inches, in size, together with the required page separation signals.

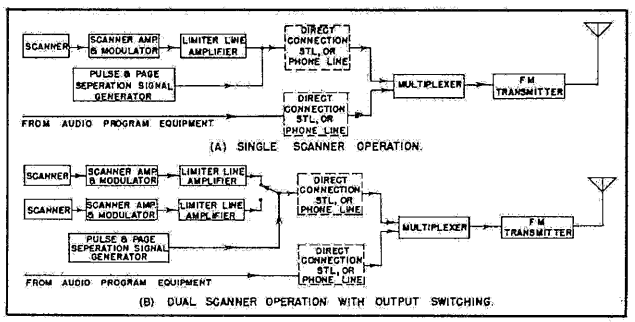

Figure 2--Input equipment used in Multiplex Facsimile Broadcast Operation

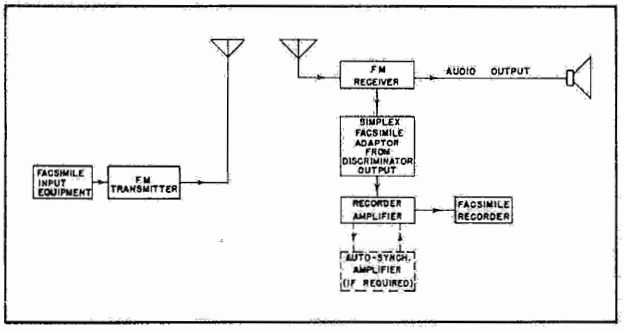

Figure 3--Equipment used in Simplex FM-Facsimile Broadcast Operation

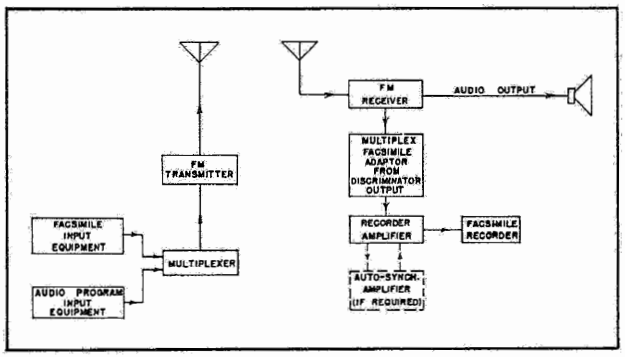

Figure 4--Equipment used in Multiplex FM-Facsimile Broadcast Operation

Discussion of FCC Standards

Standard (1) calls for straight line scanning from left to right and progressing from the top to the bottom of the page. This was selected, of course, so that the received copy can be comfortably read as it is being recorded.

Standard (2) states that the Index of Cooperation shall be 984. This is the number that defines the amount of intelligence that can be carried by a single facsimile page. It takes account of the lines per inch and the length of the scanning line. As usually applied, an Index of 984 results in a scanner whose effective line length, across the page, is 8.2 inches, whose line use ratio is 7/8 and whose definition is 105 lines per inch. The copy may be reproduced on recorders having the same dimensions or the recorders may deliver reduced or enlarged copy. The aspect ratio and the amount of intelligence will be the same in all cases, so long as the Index number remains approximately 984.

Standard (3) states the number of scanning lines per minute as 360. This standard is essential for synchronization, and determines the speed of transmission of copy having any particular definition or number of lines per inch. With the standard Index of 984 applied to an 8.2 inch scanning line, the standard drum speed of 360 r.p.m. results in a copy speed of 3-3/7 lineal inches, or 28.1 square inches, per minute. This produces four pages, each about a foot long, in each fifteen-minute period of broadcasting.

The remaining standards from (4) to (10) are principally important from the point of view of providing inherent interchangeability or compatibility between all transmitters and all receivers. They define the line use ratio as 7/8, describe the phasing and synchronization pulse which is to be transmitted during the 1/8 of the scanning cycle not used for copy, and prescribe a page separation interval, the use of subcarrier amplitude modulation (and the laws which it is to follow) and finally specify sub-carrier noise level as at least 30 d. b. below maximum picture modulation. Noise levels may be higher in facsimile broadcasting than in sound broadcasting without causing comparable interference effects; with a 30 d. b. ratio, or even less, no signs of noise can be detected on facsimile copy.

APPENDIX I

FCC Rules and Regulations

S 3.266 Facsimile Broadcasting and Multiplex Transmission

(a) FM broadcast stations may transmit simplex facsimile in accordance with transmission standards set forth in the Standards of Good Engineering Practice Concerning FM Broadcast Stations during periods not devoted to FM aural broadcasting. However, 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 Section 3.261.

(b) FM broadcast stations may, upon securing authorization from the Commission, transmit multiplex facsimile and aural broadcast programs for a maximum of three hours between the hours of 7 A. M. and midnight (no limit for the hours between midnight and 7 A. M.) in accordance with transmission standards set forth in the Standards of Good Engineering Practice Concerning FM Broadcast Stations provided that the transmission of facsimile does not impair the quality of the aural program below 10,000 cycles per second, and that a filter or other additional equipment is not required for receivers not equipped to receive facsimile.

FCC Standards

Sections 1 and 8 of the Standards of Good Engineering Practice Concerning FM Broadcast Stations are amended by adding the following:

1 - DEFINITIONS

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 x 8.2 x 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.

8 - TRANSMITTERS AND ASSOCIATED EQUIPMENT

H. Facsimile-Engineering Standards.

The following standards apply to facsimile broadcasting under Section 3.266 of the Rules and Regulations.

1. Rectilinear scanning shall be employed, with scanning spot progressing from left to right and scanned lines progressing from top to bottom of subject copy.

2. The standard index of cooperation shall be 984.

3. The number of scanning lines per minute shall be 360.

4. The line-use ratio shall be 7/8, or 315° of the full scanning cycle.

5. The 1/8 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.

6. 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.

7. Amplitude modulation of subcarrier shall be used.

8. Subcarrier modulation shall normally vary approximately linearly with the optical density of the subject copy.

9. Negative modulation shall be used, i.e., maximum subcarrier amplitude and maximum radio frequency swing on black.

10. Subcarrier noise level shall be maintained at least 30 d.b. below maximum (black) picture modulation level, at the radio transmitter input.

THE ECONOMICAL OPERATION AND MAINTENANCE OF POWER TUBES*
NAB

OPERATION

Longer tube life means lower tube costs. Find a way to increase the useful life of tubes in your equipment and the unit cost per hour of operation drops accordingly.

Vacuum tube replacements constitute one of the three major cost items of operating a broadcast transmitting station. Because of this, and because of the importance of maintaining the best possible continuity of service, proper maintenance and operation of all tubes and in particular of the water-cooled and air-cooled power tubes used in the transmitter contribute to the efficiency of station operation. This is a subject deserving close attention on the part of the station engineer.

Many factors enter into the life of tubes. Of these the following are the most apparent:

1. Filament Voltage
2. Plate Voltage
3. Operating Temperature
4. Amount and nature of residual gas in tube
5. Number of times current is turned on and off
6. Fatigue of metal parts

Bright Tungsten Filament Tubes

The first mentioned factor, that of filament voltage, if carefully controlled will pay economic and operational dividends. As illustrated in Fig. 1, an extremely small change in filament voltage results in a considerable change in filament life. The possibility of increasing tube life by reducing filament voltage and consequently filament temperature is the result of the fact that bright-tungsten-filaments (water-cooled tubes) may be operated at complete saturation. In other words peak currents amounting in value to the total emission available may be drawn continuously without damage to the filaments. Obviously, Fig. 1 shows theoretical filament life based on normal evaporation of filaments and applies to bright tungsten filaments such as are generally used in water cooled tubes. While they may not hold for every installation the ratios or relationships may be considered an average for a large number of tubes.

Note that the increase in life obtainable is considerable even at slightly reduced filament voltages. For the same reason a correspondingly larger reduction in life results from even slightly increased filament voltages.

Bright tungsten filament tubes used both in amplifiers and rectifiers, should be operated at the lowest possible filament voltage consistent with satisfactory operation; i.e., power output, tolerable distortion, hum, and carrier shift. All broadcast transmitters should be operated in accordance with good engineering practice. However, it is not necessarily good engineering or good economy to adjust the transmitter in such a way as to reduce harmonic distortion from, let us say, 3% to 1% if in so doing it becomes necessary to operate the water-cooled tubes at a 5% higher filament voltage. The application of the cold eye of logic in arriving at a compromise in this regard will pay dividends and should not result in distortion of an objectionable nature. Class B modulator stages should be watched carefully in this connection.

Tubes are designed to provide a certain amount of emission at certain input voltages. Obviously, if the whole amount of emission designed into the tube is not required it becomes possible for the user to obtain more than the life expectancy provided for in the design of the filament.

For the same reason as shown in Fig. 1 an increase in tube life resulting from a decrease in filament voltage must be accompanied by a decrease in the available emission. The relationship of emission and theoretical filament life appears in the curves. It is important to note that reductions in filament voltages, therefore, are recommended only in conjunction with reliable distortion measurements because of the possible flattening of positive peaks.

Knowing the operating conditions of the tube, it is readily possible to estimate in advance the approximate amount of filament voltage reduction that can be made. The peak emission current requirements for the usual types of operation will run approximately as follows:

TYPE OF OPERATION	REQUIRED PEAK EMISSION
Class B Audio	3-1/2 times d-c plate current
Class B Radio Freq.	8 times d-c plate current
Class C Telephony	9 times d-c plate current

Curves of filament voltage versus emission are published for many tubes, and are usually

*Source Material: (1) Operation and Maintenance of Transmitter Power Tubes (from the engineering notes of the Columbia Broadcasting System), 2nd Edition of the NAB Engineering Handbook; (2) FTR Handbook of Tube Operations issued by Federal Telephone and Radio Corporation; (3) A Simple Test for Defects or Damage to Vacuum Tubes, 2nd Edition of NAB Engineering Handbook; (4) Engineering notices of the National Broadcasting Company.

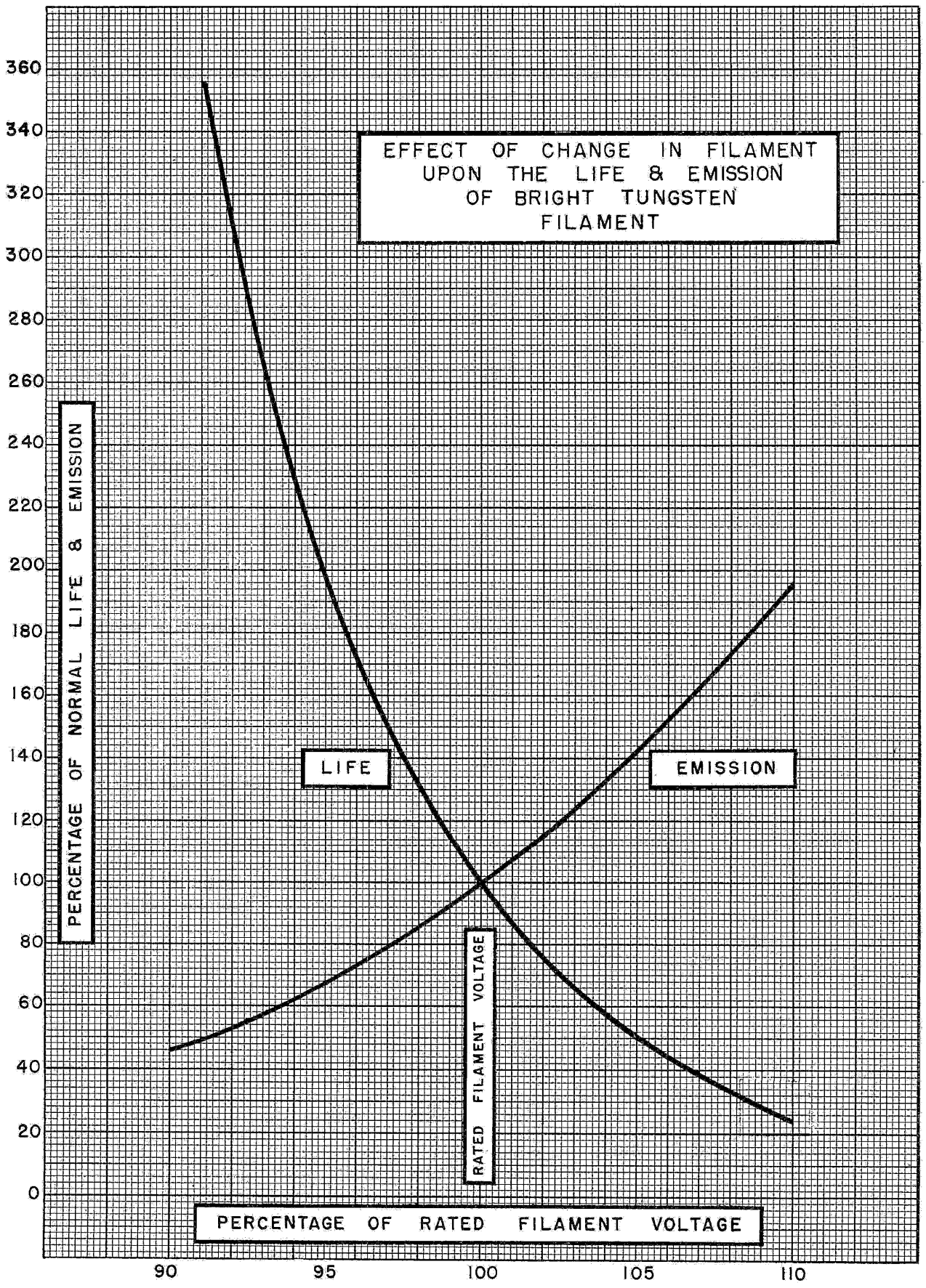

Figure 1 (Courtesy FTR)

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available from the supplier. In the absence of these curves, an approximation of normal emission can be made by assuming 7.5 ma. emission per watt of rated filament power. Knowing the peak emission requirement and the total emission at rated filament voltage, it is possible to estimate from Fig. 1 a reduced voltage which will satisfy the peak requirements.

That filament voltage which fully satisfies the emission requirement can be applied with no sacrifice in transmitter performance. It may be advisable to determine if it is possible to reduce the filament voltage still further. Probably the best way to determine the proper voltage for a broadcast transmitter is to take a curve of distortion versus filament voltage at a high percentage of positive modulation. Limited emission of a class C tube causes a limiting and rounding off of the positive modulation peaks. Limited emission of a class B modulator tubes will cause a limiting and rounding off of both positive and negative peaks. If the filaments are heated by alternating current, some increase in hum level may result from a decrease in filament voltage. It is extremely important that filament volt meters be accurate and indicate the voltage at the tube and not at the source.

The following tabulation taken from Fig. 1 will indicate the relationship between filament voltage, total hours of useful life and unit cost per hour:

Filament Voltage		Total Hours of Useful Life		Unit Cost per Hour
90%		400%		25%
95%		194%		52%
100%	Normal	100%	Normal	100%
105%		50%		200%
110%		26%		415

Let us take a typical example. Suppose a tube has a rated filament voltage of 20 volts and theoretical average life expectancy of 3000 hours. Let us assume further that the tube costs the station $600.00. If the tube were operated with 20 volts on the filament the life expectancy would be 3000 hours and the cost of operation would be twenty cents per hour. Now let us assume that this same tube could be operated at 95% of the rated filament voltage. The theoretical average life expectancy would be increased to 5820 hours and the unit cost of operation would be reduced to about ten cents per hour.

Aside from the above discussion the following suggestions will also aid in prolonging the life of your tungsten-filament tubes:

1. Minimize anode dissipation by careful tuning of the transmitter
2. Be sure there is plenty of water flowing on the water-cooled anodes and plenty of air on air cooled anodes to prevent hot-spotting and gassing.
3. Keep plenty of air on the glass bulb--particularly on the seals where glass joins metal or leads go through--to reduce electrolysis and gas evolution from glass.
4. Switch leads every 500 hours, preferably once a week, when filaments operate on d.c.
5. During starting cycle be sure the instantaneous current does not exceed 150 percent of normal current.
6. Raise plate voltage in easy steps when starting.
7. Prevent damage caused by overloading the plate circuit. Use protective devices such as a fuse or relay.
8. Hard water (over 10 grains per gallon) should not be used for water cooling. Distilled water will reduce scale formation on anode.

Thoriated Tungsten And Oxide Coated Filaments

Thoriated tungsten and oxide-coated filaments used in intermediate sized air-cooled amplifier tubes and mercury vapor rectifier tubes must be operated within the rather critical filament voltage range specified by the manufacturer. Short life usually results and may be expected from the operation of such tubes much below or above (within approximately 5%) rated filament voltage.

It is very important that the filament voltmeters used be accurate and that the meters be connected in the circuit to indicate the voltage at the filament terminals--not, as is sometimes done, at a point beyond which there is an appreciable voltage drop in the filament supply bus. It is recommended that these instruments be calibrated periodically.

Thoriated tungsten filaments are operated at temperatures of such degree that evaporation is negligible. This means that the life of the tube is not controlled by the reduction of the tungsten wire and can not be extended by operation at reduced voltage as in the case of the water-cooled tubes.

In thoriated tungsten filaments the source of emission is a layer of thorium on the filament surface. During operation the thorium in this layer is constantly being removed by evaporation and bombardment and is constantly being replenished from within the wire. In order to maintain the balance between the loss and replacement of an active layer of thorium, therefore, an operation is required within a comparatively narrow range of temperature. This is evidenced by the fact that a reduction of only 1% in filament voltage may cause a loss of approximately 5% in emission.

Unlike bright-tungsten-filaments, dull emitter thoriated tungsten type filaments should never be operated at or near saturation. In other words, the peak currents drawn should not exceed more than one half of the maximum of which the filament is capable of emitting. These filaments are, therefore, designed to provide at least double the emission that would be needed in any normal class of operation.

Often thoriated filaments, due to momentary overloads or operation at improper voltages, provide low emission. A process generally known, but which is worth repeating, can often reactivate tubes subjected to the above strains. This process is merely that of flashing the filaments with 120% of normal filament voltage for about one minute, followed by ten minutes at normal voltage. No grid or plate voltage should be applied during these periods.

Concerning factors which enter into the life of tubes, number 5 is that number of times the current is turned on and off. It is always preferable to avoid intermittent operation of any filament. With tubes of 250 watt plate dissipation rating, or higher, it is suggested that filaments be turned off for standby periods of more than about two hours. For periods of less than two hours, the filaments may be reduced to 80% of the normal voltage. With tubes of less than 250 watt rating, the filament voltage should be removed for standby periods of more than 15 minutes.

Here are a few suggestions not discussed above which will help in extending the life of your thoriated tungsten filament tubes:

1. Don't overload the tubes. Use adequate protective devices such as fuse or relay. Heavy overloads are apt to evaporate the thorium surface from the filament, and permanently damage the tube.
2. Normal operating temperature for thoriated-tungsten-filament tubes is obtained by operating them at the rated filament voltage. Care should be taken to operate them at this voltage (except for standbys and when reactivating). Occasionally, under or over-loading will give longer life, but such operation should only be carried out after first consulting the tube manufacturer.
3. Increase the filament voltage progressively (only a small percentage at a time) when a tube no longer responds to reactivation. New filament transformers may be necessary for this operation.
4. Keep tubes well ventilated--with fans or blowers, if necessary.
5. Run at lowest possible anode current and voltage.
6. Minimize plate dissipation by careful tuning of the transmitter.

POWER TUBE MAINTENANCE

Inasmuch as broadcasting stations are required by the FCC to maintain a specified stock of spare tubes, some tubes may deteriorate on the shelf before being placed in service. This deterioration was at one time a serious problem to the users of large vacuum tubes. However, improvements in the methods of manufacturing tubes in the past few years have greatly improved this situation. For those users of large water-cooled tubes who may wish to either check new tubes upon receipt or who may wish to improve initial operation of tubes which have been kept on the shelf for extended periods the following checking on conditioning treatment is set forth for consideration.

Tests for Defects or Damage

Users of large vacuum tubes may save considerable time and money by utilizing a simple H. F. coil to rough-check all tubes before placing in service. The coil is a high-frequency 15 to 25 kilovolt source, operated from a 110 volt a.c. plug, and for this purpose may be small or of the type suggested below for conditioning. In use, the tip of the coil is placed against the external bulb surface of the tube far enough away from all external metal parts so that no arc can be struck externally. Any glow observed with the tube (glow may range from light pink to deep purple) indicates a poor vacuum and the tube should not be placed in service. If the tube is completely "down to air" (i.e. the internal and external atmospheres are alike), no color will be observed. However, to test this possibility, the coil tip should be placed against the bulb, completely clear of any external metal surfaces, but within an inch or less of some internal metal part. If the tube is nearly "down to air" an arc (usually a deep purple line) will appear, within the tube, between the metal part and the point of contact of the coil. A properly evacuated tube will show no glow or arc of any kind. (In rare cases when internal and external pressures are equal, no arc glow will be apparent.) Occasionally, however, the high frequency source will cause certain constituents of the glass or deposits thereon to fluoresce. This condition appears as a surface effect on the bulb and is readily distinguished from a glow within the tube.

This procedure, when used in conjunction with a continuity meter to check for open filaments or shorts between elements, provides a simple and adequate test to check shipment damage or manufacturing effects. Great care should, of course, always be exercised in handling vacuum tubes, since to damage one tube beyond any further use may negate operational savings built up over a period of months.

The above procedure to test the degree of evacuation does not apply to mercury vapor tubes since the results may be misleading with the presence of mercury in vapor form.

Conditioning Large Water-cooled Tubes

Before a tube that has stood for several months in storage is put into operation, it may be placed in an insulated mounting without the filament being lighted. The output from a high voltage, high impedance transformer, such as the Thordarson Type 2479[1], 1 kw, 110 - 25,000 volts, should be connected directly across from the anode to the filament and grid terminals tied together with the magnetic shunt adjusted for minimum voltage. The primary voltage should be applied until no arcing takes place over the transformer protective gap. The magnetic shunt is gradually pulled out until the maximum voltage is applied. This voltage should be left on for about ten minutes or longer if arcing takes place over the transformer protective gap.

If the tube envelope shows a hazy type of discharge on the first application of voltage, the tube may be gassy as a result of a small leak. The ten-minute treatment recommended above should clean up this haze condition unless the tube has developed a leak sufficiently large to cause trouble when put in service.

A second treatment consists of filament aging at the normal operating filament voltage without plate voltage and under normal water-cooling conditions, for several hours. This tends to clean up residual gases and cleans off both the filament and grid surfaces. It has been found that the above treatments are effective in cutting down initial flashing during operation, even though the tube is returned to the spare shelf for a week prior to being installed for regular service.

Tubes held as spares may be conditioned periodically to insure continuity of service when the tubes are inserted for use.

[1]This transformer is fairly large but may be used on the work bench. It is currently available from Thordarson on special order at approximately $165.00.

High vacuum rectifier tubes may be conditioned in the same manner as water-cooled tubes.

Mercury Vapor Rectifiers

Mercury vapor rectifiers should be preheated and tested under standard operating conditions as recommended by the manufacturer to determine that there is no vacuum leak and that all the mercury splashed on the tube elements during shipment and handling has been evaporated to the lower and cooler part of the envelope. After the initial acceptance test the tubes should always be handled and stored vertically to insure that excess mercury does not splash on the electrodes.

If a tube fails to rectify without arc backs after the recommended preheating time, another treatment has been found to be useful. This treatment consists of inserting approximately 1 megohm, such as 20 - 20 watt resistance units, connected in series with the anode of the tube which has shown arc-backs.

Using the maximum available voltage in the transmitter, the inserted resistance prevents excess currents from flowing through the tube which tends to arc back. The voltage should be left on for at least one hour, or until all visible mercury is removed from the anode. Room temperature air should be blown on the lower end of the envelope during this treatment. Then the tube may be operated under standard conditions without the resistance and put back into the spare tube cabinet for future use. Periodic tests during off hours will insure that spare tubes have not developed vacuum leaks.

Air Cooled Tubes

Air-cooled amplifier tubes should be placed in service as soon as received and then used alternately with other tubes of the same type. This will keep all the tubes "conditioned" and tend to decrease the possibility of a tube developing slow leaks. When placed in service the filaments should be operated at normal rated voltage for several hours in order to clean up residual gas and to activate fully the filament.

TELEVISION TRANSMITTER THEORY

Reprinted from the RCA Manual for Television Technical Training Program, through courtesy of the Radio Corporation of America.

FCC REGULATIONS - Specifications of Performance:

a. Twelve channels are provided, from 54 to 216 mc.

b. The width of the standard television broadcast channel shall be 6 mc.

c. It shall be standard to locate the visual carrier 4.5 mc lower in frequency than the unmodulated aural carrier.

d. "Vestigial sideband" transmission shall be used with the idealized amplitude characteristic shown in Figure 5.1.

e. It shall be standard that a decrease in initial light intensity cause an increase in radiated power (negative transmission).

f. It shall be standard that the black level be represented by a definite carrier level, independent of the light and shade in the picture; that is, the "d-c component" must be transmitted.

g. It shall be standard to transmit the black level at 75% ±2.5% of the peak carrier amplitude.

h. It shall be standard to rate the transmitter in terms of its peak power when transmitting the standard television signal. This represents peak of "sync" power. "Carrier power" has no significance when the d-c component is transmitted.

i. Amplitude modulation shall be standard in the visual transmitter, and the radio-frequency amplitude shall be reduced to 15%, or less, of the peak amplitude for maximum white.

FURTHER CRITERIA FOR TRANSMITTER PERFORMANCE have been specified by RMA:

a. The carrier frequency of the visual transmitter shall be held to within ±0.002%.

b. The peak-to-peak variation of transmitter output within one frame of the video signal due to all causes, including hum, noise, and low-frequency response, measured at both sync peak and pedestal level, shall not exceed 5% of the average overall sync peak signal amplitude. Thus all effects of hum and poor low-frequency response must be 25 db down.

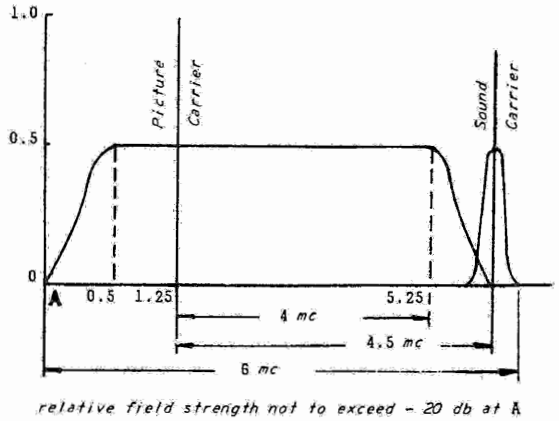

Figure 5-1 - Vestigial Sideband Amplitude Characteristic

c. The RMA recommended that, for normal transmission, the characteristic of transmitter output voltage versus brightness of subject be substantially logarithmic.

These regulations define, in general terms, the performance specifications of the visual transmitter. We see that we must operate in the medium- to semi-high-frequency part of the spectrum, radiating sidebands from dc out to 4.5 mc, using vestigial sideband transmission with amplitude modulation. The minimum depth of modulation must be 15 percent, and black in the picture must represent increased power. The carrier stability is defined, and the total of hum, noise, and low-frequency response on the carrier must be at least 26 db down. The specifications on amplitude linearity, as it concerns the transmitter only, are covered up by the logarithmic character of the camera output, and will be discussed later.

IDEALIZED TRANSMISSION CHARACTERISTIC

THE IDEALIZED TRANSMISSION CHARACTERISTIC of the FCC governs transmitter design in several respects. First of all, this vestigial sideband characteristic lops off part of the lower sideband, and ideally transmits out to 4.5 mc for the upper sideband and 1.25 mc for the lower. This

is basically to save channel space, but it is also a receiver problem. In any vestigial or single-sideband transmission and reception system, we deliberately throw away an amount of information, quantitatively in direct relation to the percent of one sideband which is attenuated, since one sideband only yields 50 percent modulation. As long as one sideband is unaltered, the quality and resolution do not suffer. In the receiver, the i-f systems can be built with only half as much bandwidth, and the loss of signal is regained by adding a stage of video without any net increase in receiver cost.

BANDWIDTH

THE BANDWIDTH required to transmit a picture is basically a function of the number of picture elements which must be reproduced, and the speed at which an element must be scanned. In terms of picture constants, bandwidth is given by the relation

$$f_{max.} = \frac{w}{h} \frac{kfn^2}{2}$$

where w/h is the aspect ratio (4/3), k the utilization ratio (0.75), f the frame repetition rate, and n the total number of lines. The expression is for equal vertical and horizontal resolution. Thus for a 525-line, 30-frame picture, $f_{max.}$ equals 4.15 mc. For double-sideband transmission, a total bandwidth of 8.3 mc would be required.

There are several ways of thus squeezing a 525-line picture into a 6-mc channel. The most important are known as the RA, or Receiver Attenuation system, and tha TA, or Transmitter Attenuation system. The RA system is the one authorized by the FCC, and the frequency response through such a system is shown in the accompanying graphs, Figure 5-2. These curves are typical only of a high-level modulated-type of transmitter.

It is important to note the curtailment of high-frequency response in the receiver output, as compared to the response of the transmitter input. Studio equipment (and also the transmitter, to a lesser degree) is intentionally designed for greater response in the high end, to avoid any picture degradation, other than that actually imposed by the basic limitations of channel width. Since the receiver must adhere strictly to channel requirements, its reproduced picture will not contain as much detail as that actually transmitted. This factor should be taken into account when analyzing system performance.

The essence of proper vestigial sideband system operation is the fact, that, in the region of carrier out to 1.25 mc, the transmitter and receiver must have complementary phase and amplitude characteristics, as shown in (d) and (e), Figure 5-2. The transmitted signal has double amplitude response in the low-frequency end, which poses a monitoring problem, since a simple diode will not suffice.

Two other rather important matters arise in connection with sideband energy distribution. The first relates to the points designated as "a" in the FCC idealized characteristic. The regulations state that, at 1.25 mc below the visual carrier and at 4.5 mc above the carrier, the relative field strength shall not exceed 0.0005 to prevent adjacent channel interference. This value representa an attenuation of 60 db with respect to the 0.5-value of normal sideband amplitude. This appears rather severe, particularly at the point 1.25 mc below the carrier. However, Kell, Brown of RCA, and Keister and associates of GE, have made calculations and measurements which show that, for an average picture, the voltage components of sidebands in the vicinity of carrier ±1.25 mc are at least 40 db down. The transmitting equipment, then, must furnish the other 20 db. The RTPB has taken cognizance of this relationship, and has recommended to the FCC that equipment performance be judged on the basis of -20 db being satisfactory.

SIDEBAND ATTENUATION

SIDEBAND ATTENUATION may be obtained by two basic methods, which, for want of better terminology, may be referred to as the GE method and RCA method. The GE method uses low-level modulation followed by a multiplicity of broadband, linear r-f amplifiers, with each stage carefully tuned off-center so that the overall response gives the desired pass-band and attenuation. The RCA system uses high-level modulation, though not necessarily in the last stage, and then inserts a filter system between the PA stage and the antenna. In medium-power transmitters, *i.e.*, around 5-kw peak output, it is technically and economically feasible to build a video system with good frequency characteristic and a voltage output sufficient to modulate the grid of the final stage. If, however, we consider modulating the grid of a 40- or 50-kw output stage, we find that (1) the increased requirements of voltage necessitates water-cooled tubes; (2) water-cooled tubes with good modulator characteristics are not available; (3) overall cost is greater; and (4) we can get about the same power output by operating the 40-kw stage as a class B linear amplifier.

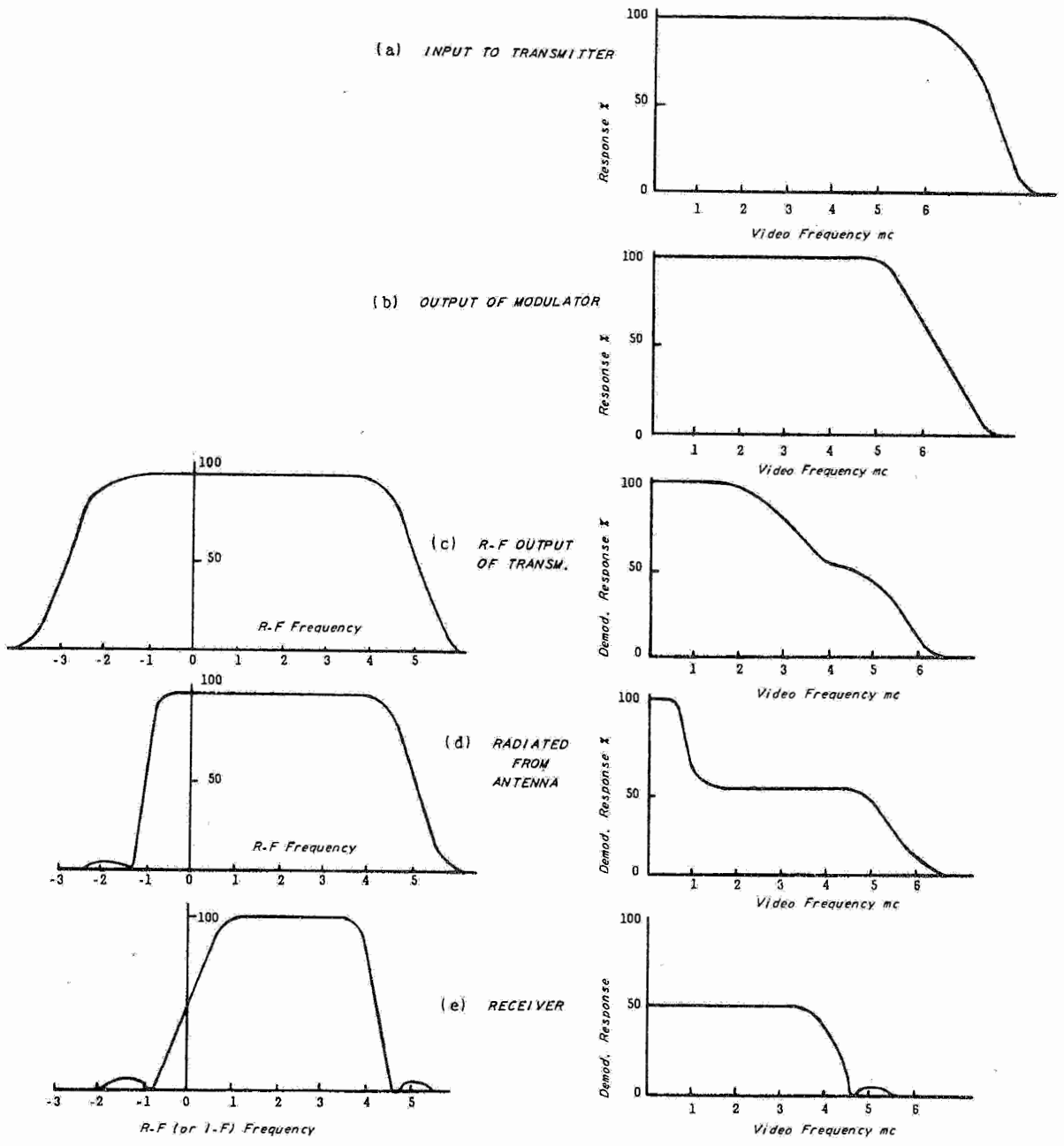

Figure 5-2 - Frequency Response Through a Television Transmitter System

The RCA system, as used in the FT-5A transmitter, modulates the final stage of a medium-power transmitter and the next-to-the-final stage of a high-power transmitter. In either case, there are tuned tank circuits between the points of modulation and the transmission line; and the response characteristic, which of course must be broadband, can be set with respect to the carrier frequency in such a way as to aid in the attenuation at the points "a". This not only provides a safety factor for the vestigial sideband filter, but, what is more pertinent, such adjustment allows the PA to work into a higher impedance, since the pass band is smaller, and hence to be capable of putting out more power.

NEGATIVE TRANSMISSION

NEGATIVE TRANSMISSION means that the transmitter power decreases as the light intensity into the camera increases. In England and pre-war Europe, positive transmission was used, *i.e.*, increased power with increased light. The reasons for standardizing on negative transmission in this country are based on two facts: (1) Noise produces areas of lack of light, or black spots, which are considered to be less bothersome to the eye than bright spots, and (2) a much simpler receiver AVC system can be built if the blacks go in the increased-power direction. Since the blanking pedestal must represent black, the combined pedestal and sync pulse must modulate the transmitter in the "up" direction. Herein lies a disadvantage of negative transmission. To obtain increased output from a PA during the sync pulse interval, its grid must be driven into the positive or grid-current region, and the tendency is to saturate sync; or to reduce the amplitude of the sync pulses with respect to the rest of the signal. This, of course, does not happen with positive modulation; but a certain percentage of saturation of the whites is probably preferable to loss of sync voltage at the receiver. However, precautions can be taken to minimize sync saturation, and these will be discussed later.

There is another important advantage in using negative transmission, which ties in with the FCC specifications stating that the black level shall be transmitted at 75 percent of the peak carrier height. Since the blacks and the sync signals modulate in upward direction, the transmitter must hold peak power only for the duration of the sync pulse. Since the pulses are relatively short, about 6 microseconds for horizontal and 75 microseconds for vertical, they do not contribute appreciably to PA anode dissipation. The voltage and power relations are as shown in Figure 5-3.

The voltage curve shows the relationships of black level to sync tips as specified by the FCC, on the basis of sync tip height equal to unity. If we now re-plot this curve in terms of power, still using the sync tips as unity, it is seen that black level represents $(0.75)^2$, or 0.56, of peak power. Now, the sync pulses contribute additional power in proportion to their total duration and repetition rate. If a complete signal is analyzed, including both horizontal and vertical sync pulses, it is found that their total duration is equal to 0.1 of the repetitive time interval; therefore, the power they contribute is 0.1 (1.00 - 0.56) = 0.044, or a total of 0.56 + 0.044 = 0.604, or 60% of peak of sync power. Anode dissipation is proportional to power output (assuming constant plate efficiency). Therefore, for a given tube complement with a given anode dissipation, the output can be increased 40%. If positive modulation were used, the output stage would have to be capable of handling continuous power equal to the peak power whenever a white picture came along.

In addition to the stipulation that the black level be 75% of the peak r-f amplitude, it is also specified that this black level represents a definite power level independent of changes in the picture itself. This means that the peaks of sync also represent a certain power level, since the ratio between black level and sync peaks is fixed. The picture transmitter could thus be rated (in power output) in terms

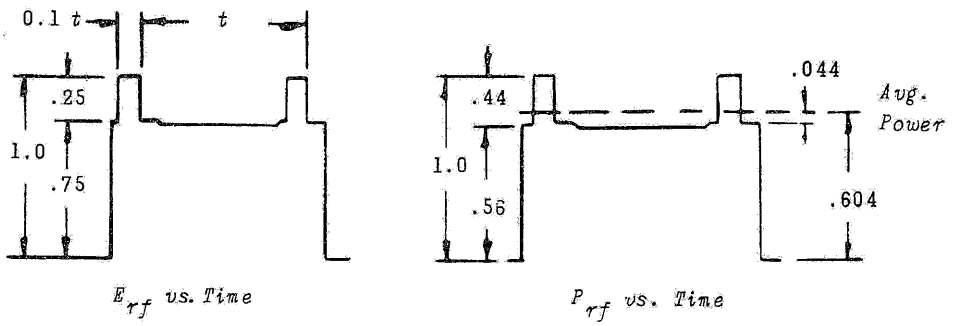

Figure 5-3 - Voltage and Power Relations for Negative Transmission

of either black level or sync peaks. The sync peak level was chosen because, at the time the old NTSC considered this matter, there was considerable discussion on what percentage of the signal should be devoted to synchronizing, and hence what percentage of the signal would be black level. So to avoid any possible confusion in the future, in case the percent of sync was changed, the peak of sync level was chosen.

To appreciate the significance of maintaining the sync peak at a certain fixed power or voltage level, it is necessary to look briefly at the d-c component of the signal; how it is obtained, and how it is handled. The discussion must start with the studio camera, and end with the receiver kinescope. It is in the output of the camera tube itself that the composition of the picture signal must be recognized and handled properly. In any picture scene which is to be transferred to electrical wave form, the signal can be said to contain two generalized components: One, the detailed information, which is the a-c component; and the other, the background, or d-c component. The background is simply the average illumination of the whole scene, taken over the interval of one complete picture frame. The image orthicon and the Farnsworth dissector tube are direct-coupled devices and automatically supply both components. The iconoscope, depending as it does, on a multiplicity of sensitized, capacity-coupled cells, puts out only the a-c component, referred to some arbitrary axis. The scene must therefore be viewed with an auxiliary light-sensitive device such as a photocell, whose output, suitably amplified, controls the bias of an appropriate tube in the unit in which the camera signal is combined with the sync signals (see Figure 5-4).

Thus, it is apparent that true d-c insertion is accomplished at the camera, and that fundamentally this consists of properly locating the camera a-c output voltage wave form with respect to the blanking pedestal or black level.

To preserve the background component, each amplifier between the camera and the kinescope could be d-c coupled. However, it is neither desirable nor necessary to go to these extremes. When a video signal passes through a capacity-coupled amplifier stage, the signal orients itself around a reference axis which is the average of the entire wave form. Thus, in the output of such a stage, black is no longer black in the sense that it represents a given voltage level, since that level will vary as the symmetry of the wave form varies. However, the relationship between the a-c wave form and the blanking pedestal has not been lost. In fact, the only thing that is lacking is the establishment of the black level to represent a given voltage or power output, as the case may be. Through relatively simple circuits, the black level may be re-established at any desired point in the television system. Not many years ago, before the value of establishing the black level in the transmitter was recognized, re-insertion was not applied until the signal reached the grid of the kinescope. At this point, a simple diode was connected across the grid resistor, and the desired reproduction was obtained.

LIMITING WAVE FORMS

Before pointing out the advantages of establishing the black level in the transmitter, let us look briefly at the *limiting wave forms* encountered in video signals, as illustrated in Figure 5-5.

The all-white and the all-black (with a white line) pictures represent the extreme cases, and typify the nature of the departure from symmetry which we nearly always encounter in video signals. The significance of this phenomenon

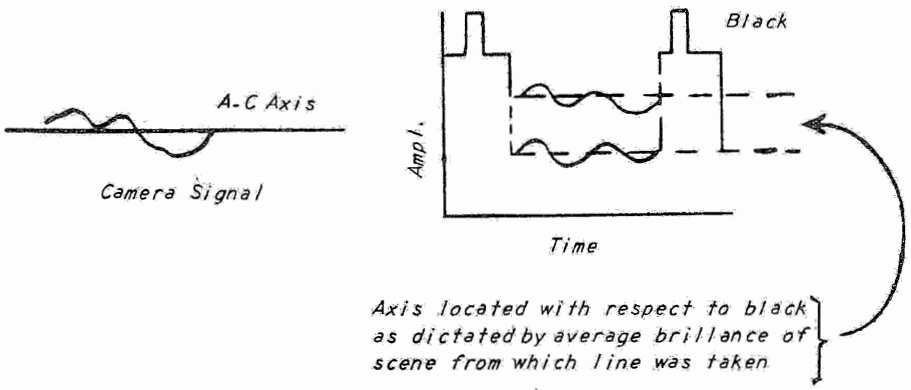

Figure 5-4 - Picture Signal Showing D-C Component

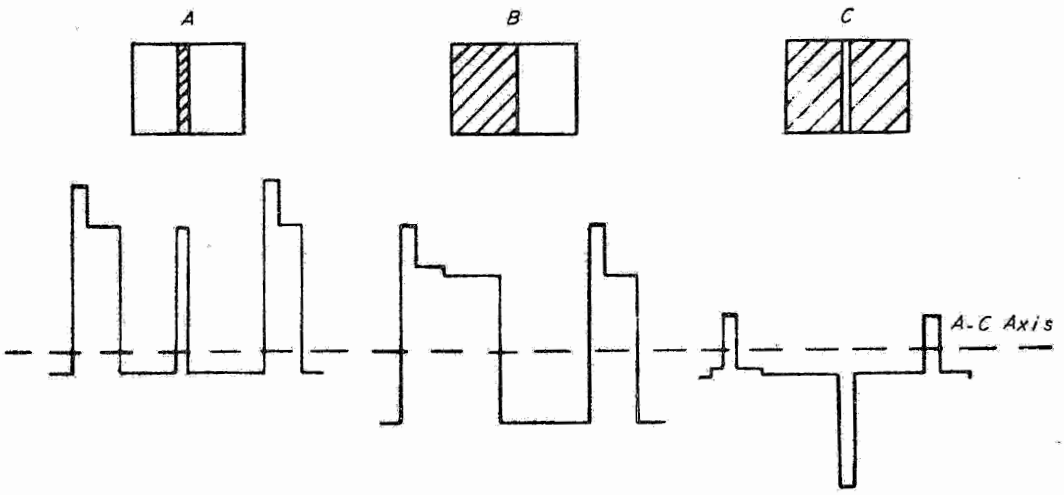

Figure 5-5 - Limiting Wave Forms in Video Signal

is seen when we think of these unsymmetrical wave forms in terms of voltage swings on the tube characteristic. The important fact, for transmitter design, is that a given tube will handle appreciably greater output with d-c re-insertion, although the actual voltage gain remains the same. Kell has shown, after analyzing the areas above and below the axis for the two extreme wave forms, that there is a ratio of 1.5 to 1 for the two cases.

D-C re-insertion allows 50 percent more intelligence to be transmitted in the sidebands, without increasing the carrier power, and hence without increasing the interference range of the transmitter. From the foregoing, it is seen that it is particularly advantageous to re-insert the d-c component in high-level stages, both video and r-f, where voltage-swing limitations are encountered. In present designs, this practice is followed, in that the d-c component is re-inserted in the grid of the last video or modulator stage, and preserved on the grid of the modulated stage by d-c coupling.

MODULATION

The last point in our standard specifications for television transmitter concerns modulation. Amplitude modulation for the video signal is specified and *grid modulation* appears to be the preferred method for the very-broad-band systems, and for systems requiring transmission of the d-c component. A similar analysis for narrow-band sound transmission will probably yield the opposite answer, and one of the deciding factors, in this comparison, would be distortion. High-output grid-modulated stages yield such high distortion as to be intolerable for high-fidelity transmission. In order to work on the truly linear portion of an r-f amplifier characteristic, it is necessary to stay almost entirely in the negative grid region, and thus a very considerable amount of power must be sacrificed. In television signal transmission, much greater distortion can be tolerated, and as a matter of fact the right kind of distortion is invited.

Referring to Figure 5-6, all camera tubes

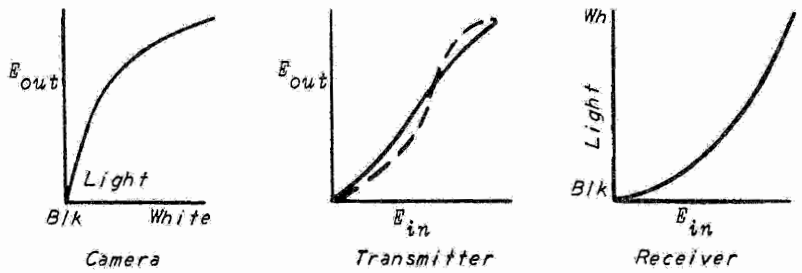

Figure 5-6 - Linearity Characteristics of TV System Elements

have an amplitude-linearity characteristic which flattens off in the white region and is expanded in the black. Camera circuits could be designed to correct this, but it so happens that the receiver kinescope has an opposite, and nearly complementary, characteristic. Thus, at the receiver the response in the black region is contracted. Because, with negative transmission, noise, and interference bursts are in the black direction, this kinescope characteristic is very desirable, since it tends to saturate off noise peaks. It is very much akin to pre-emphasis of high's in a sound transmitter, so that the receiver can de-emphasize and attenuate noise. The RTPB recognized this feature, and recommended that the amplitude linearity of the transmitted television signal be "logarithmic", and the receiver "exponential". Furthermore, the transmitter and receiver characteristics can depart considerably from being complementary without affecting anything except the relative shades of black and white in the picture, the optimum value of which changes from one scene to another. It is apparent then, that the characteristic of the transmitter proper can be allowed to vary considerably from linearity, particularly in the white region, without appreciably changing the desired systems characteristic. It is important, however, to watch closely the linearity in the black region, since the sync signal must be held to + 0, - 2 percent of specified amplitude.

TERMINAL EQUIPMENT THEORY
THE TELEVISION SYSTEM

Reprinted from the RCA Manual for Television Technical Training Program through courtesy of the Radio Corporation of America

PART I

A REVIEW OF THE BASIC CONCEPTS OF THE SYSTEM AND THEIR EFFECT ON THE DESIGN OF STUDIO EQUIPMENT

INTRODUCTION

The problems which arise in the design of television equipment involve a branch of electronics which is strange to many technicians entering the field for the first time. This is especially true of those who have long experience in the field of sound broadcasting and reproduction, but whose education and experience antedate the post-war television boom as well as the war-time period, during which were developed so many of the techniques of electronic pulsing circuits. Basically the art involves the generation and reproduction of high-speed transient phenomena at both regular and irregular intervals and the consequent need for understanding circuits used for amplifying and transmitting wide bands of frequencies. Not only are the techniques new, but a whole new language has been developed to aid in their expression. It is hoped to provide here at least a brief glimpse of this new field and its language, thus helping the beginner to a firmer grasp of the tools he must now employ.

LIMITATIONS

No true appreciation of any system can be realized without some understanding of its basic limitations, and a discussion of the television system should therefore begin by reviewing these. The most serious limitation of a television system, as in the case of an aural system, is "noise." The same phenomena that cause hum, crackle, and hiss in the background of a sound broadcast, cause bar-like shadows, random blotches, and "snow storms" in the background of a television picture. The word, noise, has been carried over from aural terminology into television terminology with the same connotation; thus, any spurious elements in a television picture are generally called noise. In reading the following discussions, it will be helpful to remember that much of the reasoning behind the methods used in the television system is based on the need to minimize the effects of noise.

Spurious noise components in the signal arise from three general sources, (a) shot noise and thermal agitation in vacuum tubes and other circuit elements, (b) pickup from associated or remote electrical apparatus, and (c) microphonics. The best means for minimizing noise is to maintain a high signal-to-noise ratio in all parts of the system; but where this is impossible, special circuits are a distinct aid in extending the useful range of operation.

Noise limits, among other things, the ability of the system to resolve fine detail. However, a more direct limitation on the resolving power of the system is the frequency bandwidth available in the transmission system. This limitation has commercial aspects of more significance than the technical aspects because of the limited room available in the radio spectrum. As a result, the decisions of the Federal Communications Commission effectively determine the limits of resolution within the noise-free service area of any station. Long years of field testing have shown that a six-megacycle channel will provide adequate resolution and at the same time will yield a reasonable number of channels.

Other factors which limit overall performance are the fineness of scanning apertures*, the degree of accuracy with which tonal gradations

* *The use of the word aperture in television probably arose from the use of scanning disks where the light passed through small holes which traversed the projected area of the scene. Small holes traversing closely spaced lines in the area were capable of greater resolution than larger holes traversing more widely spaced lines. Though scanning disks are no longer used, the term aperture is still applied to the scanning device in a general sense. In electronic television, the diameter of the "aperture" is simply the diameter of the scanning beam of electrons in the plane of the scanned image. Similarly the term aperture correction is applied to means (usually the use of special circuits) for compensating the picture signal for loss of resolution caused by finite size of the beam and by non-uniform distribution of electrons over the cross-sectional area of the beam.*

are reproduced, and the brightness range of which the reproducing device is capable. However, if it can be assumed that the transmission system between the pickup and reproducing devices is reasonably linear, then the problems arising from these particular limitations are confined largely to the pickup and reproducing devices themselves, and do not affect system considerations to the same extent as limitations described in the preceding paragraphs, and as certain economic factors do.

Economic factors usually limit the degree to which technological development is used to improve the quality of performance. Methods may be known by which some of the physical limitations of the system can be overcome, but sometimes such methods are not used for a long time after their discovery because means for applying them economically are not developed simultaneously. In other words, their use increases the cost of equipment excessively. This is especially true in the case of receiving equipment which must be produced in large quantities at low unit cost.

Such methods often do find their way into transmitting equipment, where low unit cost is not so important and where quality of performance is paramount. Quality is stressed in transmitting equipment to provide reliability and to reduce the need for including in the receivers complicated and expensive corrective circuits. Examples are circuits for automatic correction of scanning linearity, and clamp circuits for accurate re-establishment of black level, or d-c restoration, as it is often called.

STANDARDS

During the decade preceding the entrance of the United States into World War II, Radio Corporation of America carried on an extensive program of research and development in television which has been largely responsible for the formulation of the standards governing our present black-and-white system. The earliest work on standards was done through the medium of the Radio Manufacturers' Association. Much more extensive work on standards was carried on later by the National Television System Committee and the Radio Technical Planning Board, the former body being set up to deal exclusively with television standardizing problems and to bring about agreement among the several interested groups on suitable standards for recommendation to the FCC. With the approach of commercial broadcast service, the FCC adopted the recommendations of these bodies as the basis for tentative standards of good operating practice. Activity of the RMA has continued on television and its recommendations have been extended to cover much of the detail of studio and transmitter operation, and of receiver design. While a considerable portion of this material still exists only in the form of recommendations to the FCC, it will undoubtedly constitute the major part of the final standards.

One of the most important standards recommended is the one which describes the waveshape of the picture signal. This standard is outlined in detail in a drawing which is reproduced in Figure 3-5. Reference will be made to this drawing from time to time in discussing the system, and an attempt will be made to clarify the reasoning involved in establishing many of the specifications included in it.

SCANNING SYSTEM

The standard system of scanning in television is one in which the scene or image is traversed by the aperture in lines which are essentially horizontal, from left to right, and progressively from top to bottom. The aim is to have the aperture move at constant velocity both horizontally and vertically during actual scanning periods because this type of motion is simple to duplicate in the reproducing aperture and because it provides a uniform light source in the reproducer. At the end of each line the aperture, or scanning beam, moves back to the start of the next line very rapidly. The time occupied by doing this is called the *fly-back* or *retrace* period. In a similar way, the beam moves from the bottom back to the top after the end of each picture scan. Motion during retrace periods need not be linear. The complete traversal of the scene is repeated at a rate high enough to avoid the sensation of flicker. This rate has been set at 60 times per second because most of the power systems in the United States are 60-cycle systems, and synchronism with the power system minimizes the effects of hum and simplifies the problem of synchronizing rotating machinery in the television studio (film projectors) with the scanning.

It has appeared rather recently that the choice of 60 cycles for the vertical scanning frequency was a fortunate one for another reason. The progress of the art has included means for obtaining brightness levels in the reproduced pictures which are appreciably greater than those used in motion picture theatres. It is well known that the threshold of flicker increases as the brightness increases. Thus, 48- or 50-cycle flicker would be noticeable to some observers at modern brightness levels in television receivers. Persistence of vision varies in different people, and those whose persistence characteristics are short are conscious of the 60-cycle flicker in the bright pictures

on some present-day receivers. Therefore it appears that a still higher vertical frequency would be desirable if other factors would permit. Needless to say, the interline flicker, mentioned later in connection with interlacing, is also less objectionable with the higher scaning rate.

Another important factor affecting flicker is the persistence characteristic of the screen material in the receiver. This can be made long enough to overcome any appearance of flicker, even with scanning rates less than 50 cycles per second, but, if carried too far, such long persistence causes ghost-like trailing after moving objects in the scene. Judicious choice of screen persistence is a great aid in reducing flicker.

Obviously the scanning apertures in the pickup and reproducing parts of the system must be in exact synchronism with each other at every instant. To accomplish this, synchronizing information is provided in the form of electrical pulses in the retrace intervals between successive lines and between successive pictures. The retrace intervals are useless in reproducing picture information, hence are kept as short as circuit considerations permit, but are useful places in which to insert the synchronizing pulses. These pulses are generated at the studio in the same equipment that controls the timing of the scanning of the pickup tube, and they become part of the complete composite signal which is radiated to the receiver. Thus scanning operations in both ends of the system are always in step with each other. Synchronizing is discussed in more detail in a later section.

The number of scanning lines is the principal factor determining the ability of the system to resolve fine detail in the vertical direction. The number of scanning lines is also related to the resolving power in the horizontal direction because it is desirable to have the same resolution in both directions. Thus, as the number of lines increases, the bandwidth of the system must also increase to accommodate the greater resolution required in the horizontal direction. The present system employs 525 lines, a number arrived at after thorough consideration of the related questions of channel width and resolution by the N.T.S.C. and the R.T.P.B.

INTERLACING

One of the most interesting features of the television scanning system is the interlacing of the scanning lines, a scheme which is used to conserve bandwidth without sacrificing freedom from flicker. The sensation of flicker in a television image is related to the frequency of the illumination of the entire scene. It has no relation to the number of scanning lines nor to the frequency of the lines themselves. Therefore a system which causes the entire area of the scene to be illuminated at a higher frequency, even though the same lines are not scanned during successive cycles of illumination, results in greater freedom from flicker. Interlacing does just this by scanning part of the lines, uniformly distributed over the entire picture area, during one vertical scan, and the

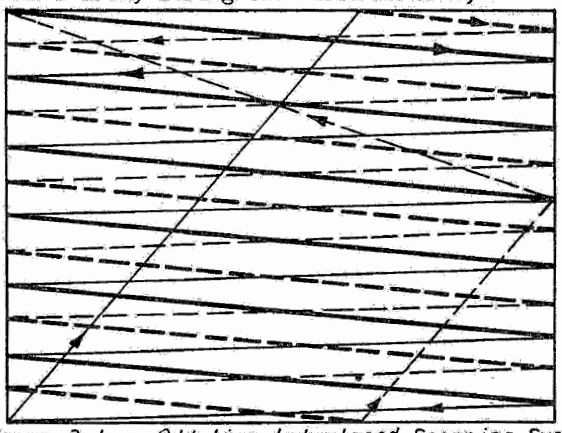

Figure 3-1 - Odd-line Interlaced Scanning System with 13 Lines. Consecutive Fields are Indicated by Solid and Dotted Lines, Respectively.

remaining part or parts during succeeding scans. Thus, without changing the velocity of the scanning beam in the horizontal direction, it is possible to obtain the effect of increased frequency of picture illumination.

In the standard two-to-one interlaced system, alternate lines are scanned consecutively from top to bottom, after which the remaining lines, that fall in between those included in the first operation, are likewise scanned consecutively from top to bottom. (Figures 3-1 and 3-2 il-

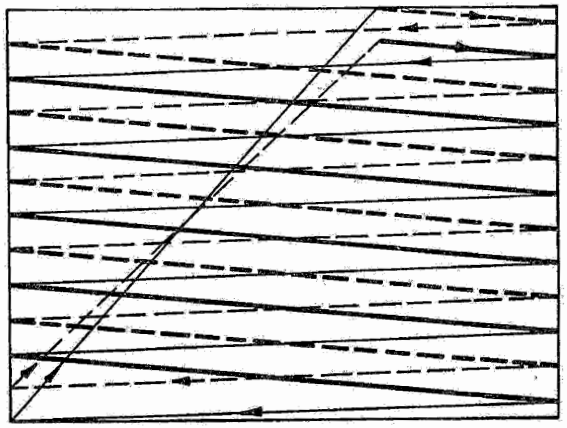

Figure 3-2 - Even line Interlaced Scanning System with 12 lines.

lustrate this principle). In the 525-line system, each of these groups, called a *field*, consists of 262-1/2 lines. Two consecutive fields constitute a *frame*, or complete picture, of 525 lines. Each field is completed in 1/60 of a second and each pair of fields or frame, in 1/30 of a second. The effect on the observer's eye, from the standpoint of flicker, is that of repetition of screen illumination every 1/60 of a second, yet the complete picture is spread out over 1/30 of a second.

The important result of interlacing is a reduction in the bandwidth of the frequencies generated in the picture signal, for a given value of limiting resolution, as compared to the bandwidth produced in a system using sequential scanning. This may be understood as follows. In either system, interlaced or sequential, the vertical scanning frequency must be the same and must be high enough to avoid the sensation of flicker. In the standard television system this frequency is 60 cycles per second. In a sequential system, *all* of the scanning lines must be traversed in the basic vertical scanning period. However, in the two-to-one interlaced system, only *half* of the scanning lines are traversed in the same period. Thus, obviously, the horizontal velocity of motion of the aperture in the interlaced system is only half of the velocity in the sequential system, and likewise the signal frequencies are reduced by the same factor.

Interlaced scanning has certain inherent faults among which are interline flicker, and horizontal break-up when objects in the scene move in the horizontal direction.

Interline flicker results from the fact that adjacent scanning lines are separated in time by 1/60 of a second, and that each line is repeated only at intervals of 1/30 of a second, It is apparent in any part of a scene where some detail of the scene is largely reproduced by a few adjacent scanning lines, and where the contrast in the detail is high. For example, the top edge of a wall which is oriented in the scene so as to be nearly parallel to the scanning lines might be reproduced by only two or three adjacent lines. The 30-cycle flickering of the line segments forming the edge of the wall would be quite noticeable. In the limiting condition, where the wall is exactly parallel to the scanning lines, the edge would be reproduced by only one line repeated at intervals of 1/30 of a second. This is probably the worst possible condition, but one which is encountered rather infrequently. The top and bottom edges of the raster nearly always produce objectionable interline flicker because they are nearly parallel to the scanning lines. Interline flicker, like any other type of flicker, is most objectionable in scenes where the highlights are very bright and the contrast is high. When the brightness and contrast are low, interline flicker becomes negligible.

Break-up exists when an object in the scene moves in the horizontal direction rapidly enough so that the total motion in 1/60 of a second is equal to one or more picture elements. Then vertical edges of the object become jagged lines instead of smooth lines and there is apparent loss in horizontal resolution. This is roughly illustrated in Figure 3-3 where two rectangles

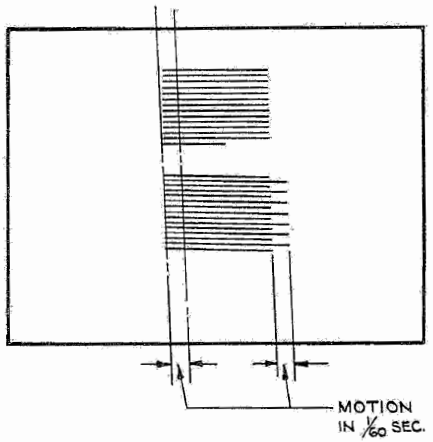

Figure 3-3 - Effect of Horizontal Motion on Resolution of Vertical Edges in 2-to-1 Interlaced System. Upper Object Stationary. Lower Object Moving to Right.

are shown, the upper one being stationary, and the lower one moving toward the right. The moving rectangle is shown as though it started moving from a position directly below the other. In the moving rectangle, signal is generated, *in both fields*, from the starting position of the left edge because of the storage of information in the pickup tube during the interval between fields. Thus the storage effect causes actual blurring of the trailing edge of a moving object. This is illustrated by the thin extensions of the scanning lines in the second field at the left side. The leading edge of the moving object may have a more definite jagged appearance because the storage effect in the pickup tube cannot fill in the spaces. In non-storage pickup devices, both edges will appear jagged.

The geometrical distortion, illustrated by the tendency for the moving rectangle to become rhombic, is characteristic of any scanning system, whether interlaced or sequential. It is similar to the effect produced by a focal-plane shutter in a photographic camera.

Further consideration makes it clear that higher ratios of interlacing would produce these troubles in aggravated form, which would be intolerable. Another objection to higher ratios of interlacing is an illusion of crawling of the scanning lines either up or down, depending on motion of the observer's eyes. The effect is extremely annoying and tends to distract the observer's attention from the scene.

The type of interlacing adopted for commercial television is known as *odd-line* interlacing. The total number of lines is an odd integer. Thus the number of lines in each of two equal fields is a whole number plus a half. In this system, the use of perfectly uniform vertical scanning periods (equal to half the product of the total number of lines and the period of one line) and constant vertical scanning amplitude, results in consecutive fields which are displaced in space with respect to each other by half a line, thus producing interlacing of the lines, as illustrated by the 13-line system in Figure 3-1. Specifically, as stated above, the total number of lines in the standard system is 525; the number per field is 262-1/2; the vertical scanning frequency is 60 cycles per second; the number of complete pictures (frames) per second is 30; and the horizontal scanning frequency is 60 x 262-1/2, or 15,750 cycles per second.

Interlacing may also be obtained when the total number of lines is an *even* number, but *even-line* interlacing requires that alternate fields be displaced vertically one-half line with respect to each other by the addition of a 30-cycle component to the amplitude of the vertical scanning sawtooth wave (see Figure 3-2). This frame frequency component must have a degree of accuracy that is impractical either to attain or maintain. Hence even-line interlacing is not used for commercial television.

One other factor has influenced the choice of the particular number of scanning lines. This is the need for an exact integral relationship between horizontal and vertical scanning frequencies. It has been the practice to attain this relationship by using a series of electronic counting circuits. To secure a high degree of stability, the characteristic count of each circuit was limited to a small integer less than ten. Thus the h/v frequency ratio was required to be related to the combined product of several small integers. In the RCA synchronizing generator equipment, for example, there are four such circuits counting the numbers 7, 5, 5, and 3 respectively. The combined product of these four numbers is 525, the number of lines per frame. The product of 525 and 60 is 31,500 which is the frequency of the master oscillator in the sync generator. To obtain the correct frequency for the horizontal scanning system, another counter circuit divides the master oscillator frequency by two to yield the required frequency of 15,750 cycles.

SYNTHESIS OF THE PICTURE SIGNAL

The basic part of the signal applied to the reproducer is the series of waves and pulses generated during the actual scanning lines in the pickup or camera tube. No matter what else is done in the equipment intervening between the two ends of the system, this basic part of the signal should be preserved in character with the greatest possible accuracy. However, during the retrace periods, the pickup tube may generate signals which are spurious or which at least do not contain valuable picture information. Furthermore, retrace lines in the reproducing tube itself, especially during vertical retrace, detract from the picture. It is therefore desirable to include in the picture signal, components which will eliminate spurious signals during retrace and the retrace lines themselves in the reproducer. These results may be obtained by adding synthetically some pulses known as blanking pulses.

Blanking pulses are applied to the scanning beams in both the camera tube and the kinescope in the receiver. *Camera blanking* pulses are used only in the pickup device and never appear directly in the final signal radiated to the receiver. They serve to close the scanning aperture in the camera tube during retrace periods. In orthicon tubes, the picture signal during retrace thus goes to reference black or to some level constantly related to reference black. This is a useful result to be discussed later. In iconoscopes, no such constant relationship to black exists during retrace, and the only function of camera blanking is to prevent spurious discharge of the mosaic during the retrace periods.

Kinescope blanking or *picture blanking* pulses are somewhat wider than corresponding camera blanking pulses. They become integral parts of the signal radiated to the receiver.

The function of the kinescope blanking pulses is to suppress the scanning beam in the kinescope (reproducing tube), or in other words, to close the aperture in the receiver during the retrace periods, both horizontal and vertical. They are simple rectangular pulses having duration slightly longer than the actual retrace periods in order to trim up the edges of the picture and eliminate any ragged appearance. They are produced in the sync generator from the same basic timing circuits that generate the scanning signals; hence they are accurately synchronized

with the retrace periods. Typical waveshapes of a basic camera signal and blanking pulses are illustrated in Figure 3-4, A and B respectively. Only parts of two scanning line periods are shown, and the pulse in B is therefore a single *horizontal blanking pulse*. The result of adding the signals in A and B is shown in C, where it

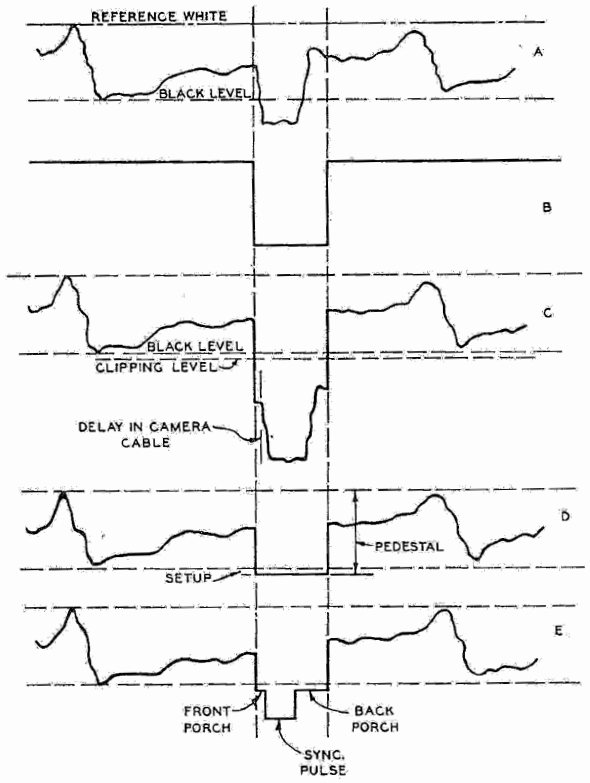

Figure 3-4 - Steps in Synthesis of Picture Signal.

may be seen that the unwanted spurious part of the camera signal has been pushed downward out of the territory of the basic picture signal. This unwanted part may now be clipped off and discarded, leaving the signal illustrated in D.

The blanking signal, shown only in part in Figure 3-4B, actually contains pulses for removing visible lines during both horizontal and vertical retrace periods. The horizontal pulses recur at intervals of 1/15,750 of a second and are only a small fraction of a line in duration; but at times corresponding to the bottom of the picture they are replaced by *vertical blanking pulses* which are just like the horizontal pulses, except that they are of much longer duration, approximately 15 scanning lines long, because the vertical retrace is much slower than the horizontal. The period of recurrence of the vertical blanking pulses is of course 1/60 of a second. Both horizontal and vertical blanking pulses, and their approximate relationship, are shown in diagrams 1 and 2 of Figure 3-5.

The picture signal shown in D of Figure 3-4 may be considered as partly natural and partly synthetic. It is important to point out here that the natural part, or basic camera signal, may contain certain noise components arising from the fact that the output of the pickup tube usually is not large compared to the noise threshold of the first picture amplifier stage or some other part of the system, such as the scanning beam in an image orthicon. On the other hand, the blanking pulses, or synthetic parts of the signal, are added at a relatively high-level part of the system and are therefore noise-free (at least in the transmitted signal). The importance of noise-free blanking pulses will become apparent in the discussions of other functions which they perform.

Details of horizontal blanking pulse shape are shown in diagram 5 of Figure 3-5. That part of the diagram below the point marked Blanking Level is a synchronizing (sync) pulse which will be considered later. The overall vertical dimension β is the maximum height of a blanking pulse. Thus the top horizontal line is Reference White Level, as indicated in diagram 3. The duration, or width, of the pulse must be sufficient to cover the horizontal retrace in the most inefficient receiver. Thus, the circuit limitations in such receivers set a minimum limit to the horizontal blanking width which was the basis for the RMA specification in Figure 3-5. This minimum is indicated by the width near the peak (lower end) of the pulse and is prescribed by the sum of two dimensions $x + y$, the value of which is 16.5% of the horizontal period, H. The impossibility of producing infinitely steep sides on the pulse is recognized in the greater maximum width (18% of H) allowed at the upper end of the pulse and in the obviously sloped sides.

Because of inevitable discrepancies at the extremes of the sides of the pulse, all measurements of pulse widths are made at levels slightly removed from the extremes of the sides. These levels are shown by dotted horizontal lines in diagram 5 of Figure 3-5, spaced 10% of β from top and bottom of the pulse.

Details of the vertical blanking pulses are shown in diagrams 1 and 3 of Figure 3-5. The width of the pulses is not limited by circuit considerations, as is the width of horizontal blanking. The limitation here is the requirement of television film projectors of the intermittent type, that the scene be projected on the pickup tube only during the vertical blanking period. The maximum period of 8% is ample for the operation of present-day film pickup systems, the criterion being that enough time must

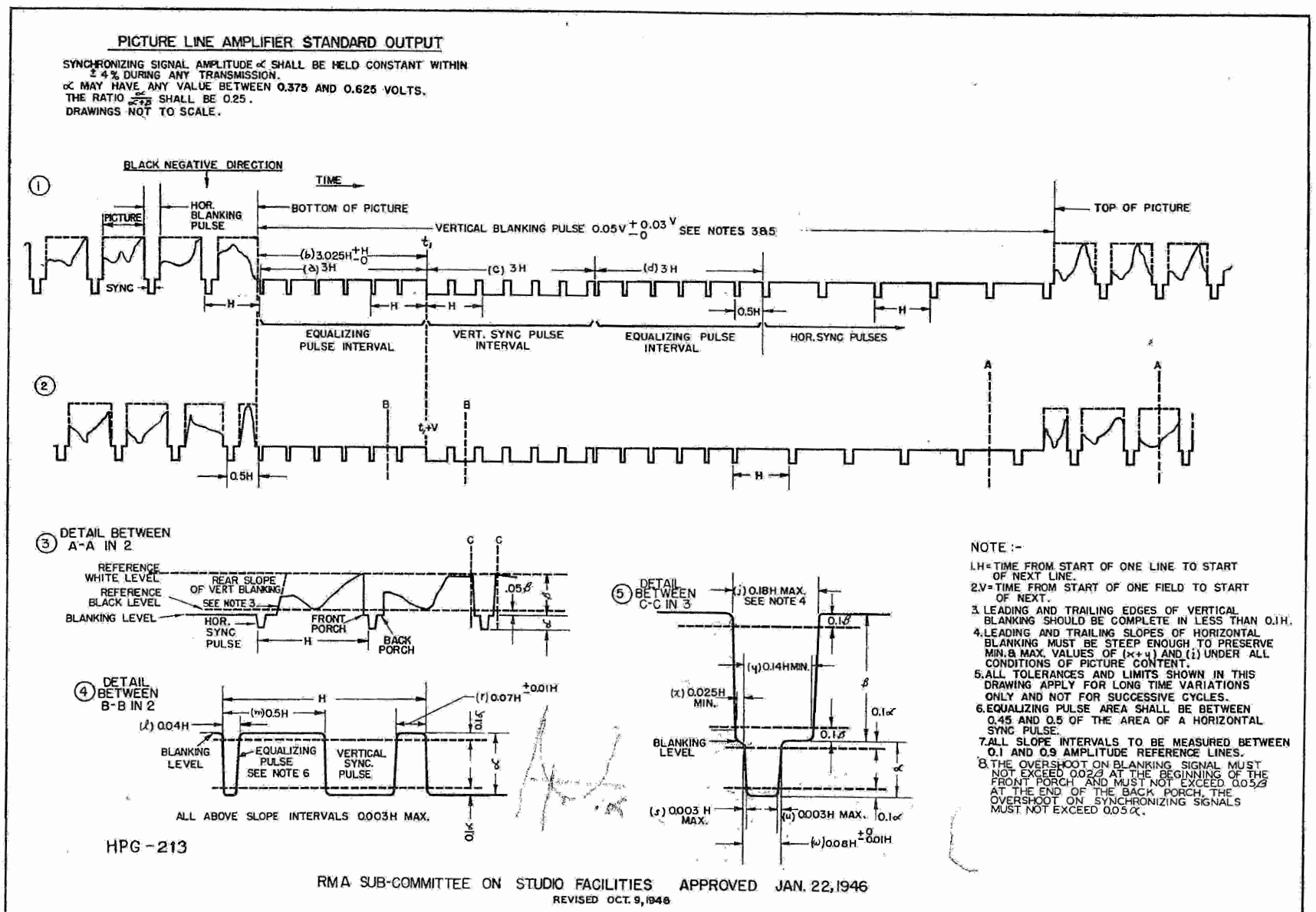

Figure 3-5 - Standard Television Signal

be allowed for projection so that there is adequate storage of photoelectric charges on the sensitive surface of the pickup tube. The minimum period of 5% is an indication of expected system improvements in the future, when it will be possible to reduce waste of picture transmission time in vertical blanking. The present usefulness of the 5% minimum is to require receiver manufacturers to maintain vertical retrace periods at less than 5% and thus avoid the need for modifying old receivers when improvements are made in the system. The problem of film projectors is discussed in a later section.

The final step in synthesizing the complete composite picture signal which goes to the modulator in the transmitter is to add the synchronizing pulses which are required for triggering the scanning circuits in the receiver. These pulses, like blanking pulses, are essentially rectangular in shape. The blanking pulses serve as bases or pedestals (inverted) for the sync pulses, as shown in E of Figure 3-4. Here is one of the most important reasons for having noise-free blanking. The synchronizing function in the receiver is a very critical one, and it is important that nothing be allowed to distort the sync pulses either in shape or timing, as noise during the blanking intervals would do. The nature of the vertical sync signal is rather complicated; it is not illustrated in Figure 3-4, but will be discussed later along with other details of synchronizing.

The sync signal is not added individually to the output of each camera, but is added at the studio output so that switching from one camera to another will not cause even momentary interruptions in the flow of synchronizing information to the receivers.

THE D-C COMPONENT OF THE PICTURE SIGNAL

The visual and aural senses differ in one important respect which places a requirement on the television transmission system which has no counterpart in the sound transmission system. The response of the ear to sound is actually a response to variations in air pressure. While the ear is very sensitive to rapid variations in pressure, it is completely unconscious of absolute values of air pressure, or of slow variations in pressure, as sound. In other words, there is a definite low limit to the frequency of pressure variations which the ear accepts as sound. Therefore there is no need, for a sound transmission system, to pass frequencies below the aural limit which is somewhere in the neighborhood of 15 cycles per second. The circuits may be a-c coupled without loss of essential information. Even the best of practical systems have a low-frequency cutoff at about 30 cycles, and most others cut off somewhere between 50 and 100 cycles.

The eye, on the other hand, is sensitive to absolute intensities of light and to slow variations of intensity. As the frequency of variation increases, the eye rapidly loses its ability to follow the changes and tends to produce a sensation which is an average of the variations. It is this averaging ability that enables the eye to interpret a rapid succession of still pictures as a portrayal of smooth motion. This phenomenon is the basis of both motion picture and television systems.

The important point, in the present discussion, is that the eye recognizes a slow change in light intensity. The period of the change may be a fraction of a second or it may be a minute, an hour, or a half-day in length. A television system must be capable of conveying these slow changes, no matter how long the period, to the receiver. The rapid scanning of the image of the scene in the camera produces a signal containing these slow changes as well as very rapid variations caused by the passage of the scanning beam over small light and dark areas of the image. The slow changes often have periods so long that they may be considered as d-c levels which simply change value occasionally. Hence, the signal is said to contain a d-c component. The television system must either pass the entire spectrum, including the d-c component, in each of its stages, or the signal must contain such information that it will be possible to restore the d-c component, which would be lost in an a-c-coupled system, when it finally arrives at the reproducer. Because of the well-known difficulties in constructing multistage d-c coupled amplifiers, it is desirable to use an a-c coupled system. It is fortunate that relatively simple means are known for d-c restoration, thus making possible the use of an a-c coupled system.

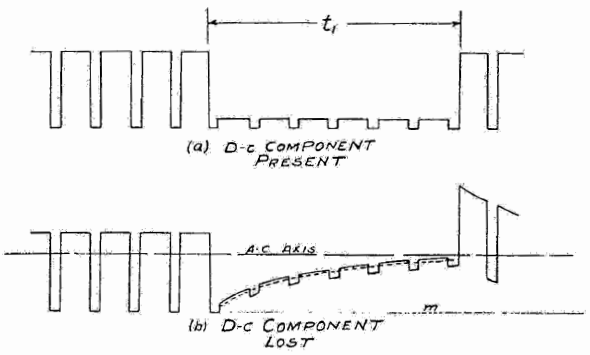

Figure 3-6 - D-C Component

Figure 3-6(a) illustrates a signal which contains a d-c component in the form of a temporary

change in the amplitude of the pulses. The period t_1 embracing the low-amplitude pulses may be of any arbitrary length. The original signal is characterized by the constant level of the negative peaks of all the pulses, regardless of amplitude. After passing through an a-c coupled system (in which the time constants of the coupling networks are short compared to the period t_1), the signal becomes distorted approximately as shown in Figure 3-6(b). Here the negative pulse peaks no longer fall on a constant level, but the signal tends to adjust itself in a consistent manner about an axis called an a-c axis.

The a-c axis of a wave is a straight line through the wave, positioned so that the area enclosed by the wave above the axis is equal to the area enclosed by the wave below the axis. The broken line marked a-c axis in Figure 3-6(b) is actually the correct axis only for a wave composed of large pulses like the first four at the left. During the transient condition following the first short pulse, the line shown is not the true a-c axis, but represents the operating point of the amplifier in the a-c coupled system. The actual a-c axis of the short pulses (shown by the dotted line) gradually adjusts itself to coincide with the operating point of the amplifier. This adjustment is shown by the exponential rise of the signal during the interval t_1, but it is interrupted before completion by the resumption of the large pulses. Thence a second transient condition takes place, leading to a gradual restoration of the signal to its original form.

The departure of the pulse peaks from the original constant level indicated by the line m, is called *loss of the d-c component* or loss of "lows". It is interesting to note that this loss causes an increase in the peak-to-peak amplitude of the signal, a condition which is undesirable, especially in high-level amplifiers.

BLACK LEVEL

An absolute system of measurement must have a fixed standard reference unit or level. This rule applies to the problem of reproducing absolute light intensities. The simplest and most obvious reference for such a system is zero light, or *black level* as it is often called. This is a reference level which can be reproduced arbitrarily at any point in the system. Now if the television signal can be synthesized in such a way that frequent short intervals have some fixed relationship to actual black in the scene, then it becomes possible to restore the d-c component by forcibly drawing the signal to a fixed arbitrary level during these intervals.

D-C INSERTION AND D-C RESTORATION

Because the blanking or retrace periods are not useful for transmitting actual picture information, they offer convenient intervals for performing special control functions such as d-c restoration as mentioned in the previous paragraph. If the peaks of the blanking pulses are coincident with black level, or differ from black level by a constant amount, then d-c restoration can be accomplished simply by restoring these peaks to an arbitrary reference level. Thus, in Figure 3-6(b), if the peak of each pulse can be restored to the line m, then the signal will appear as in (a) and the d-c component will have been restored. Small errors will remain, corresponding to the displacements in level between pulses, but these are usually negligible and in any case do not become cumulative. Hence the restoration is essentially complete.

It now becomes apparent that an extremely important step in the synthesis of the television signal is that of making the peaks of the added blanking pulses bear some fixed relationship to actual black level in the scene. It was pointed out previously that the peaks of these pulses are produced by clipping off unwanted portions of the signal, as illustrated in Figure 3-4, C and D. A second, and most important, function is performed when the clipping is controlled in such a way that the resultant peaks have the required fixed relationship to black level. This process of relating the blanking peaks to actual black level is called *d-c insertion*, or insertion of the d-c component. A subsequent process, later in the system, of bringing these peaks back to an arbitrary reference level is called *d-c restoration*. D-C restoration must be accomplished at the input of the final reproducing device (the kinescope) in order to reproduce the scene faithfully.

It is desirable to restore the d-c component at other points in the system also, because the process reduces the peak-to-peak excursions of the signal to a minimum by removing increases in amplitude caused by loss of the d-c component. In a similar way, it is possible to remove switching surges, hum, and other spurious signal components which have been introduced by pure addition to the signal. Maintaining minimum excursion of the signal is important, especially at high-level points in the system, in order to avoid saturation in amplifiers and consequent distortion of the half-tones in the scene. For a specific example, d-c restoration helps to maintain constant sync amplitude in high-level amplifiers. In other words, it makes possible economies in the power capabilities of amplifiers such as the final stage in the picture transmitter.

Diagram 3 in Figure 3-5 illustrates part of a typical picture signal including two horizontal blanking pulses. It may be seen that there is a distinct difference between actual black level and blanking level which is prescribed as 5% of maximum blanking pulse amplitude. This difference is usually called *setup* and its magnitude was set as a reasonable compromise between loss of signal amplitude range and the need for a tolerance in operating adjustment. Setup is desirable as an operating tolerance in the initial manual adjustment of the clipper in that part of the system where the d-c is *inserted*. It simply insures that no black peaks in the actual picture signal are clipped off.

The accuracy with which setup is maintained depends on characteristics of the pickup or camera tube. Some types of pickup tubes produce signals during blanked retrace periods which are the same as, or are constantly related to, black level. In systems where such tubes are used, the magnitude of setup may be held constant automatically at whatever value is determined in the initial manual adjustment of the clipper circuit. In general, pickup tubes employing low-velocity scanning, such as the image orthicon, provide this kind of basic black level information. The iconoscope differs from orthicons in this respect, because the secondary emission resulting from the high-velocity scanning produces a potential distribution on the mosaic in which black level is far from the level existing during the retrace periods when the beam is cut off. In fact, the difference between black level and blanking level varies continuously as the scene brightness changes, because the potential distribution caused by resettling of the secondaries likewise changes. Automatic maintenance of setup, or pedestal height, cannot therefore be obtained by reference to the signal during blanked retrace periods in the iconoscope, but may be obtained by reference to actual black peaks in the picture signal. Where such reference is not practical, a manual control may be readjusted from time to time to keep the setup at the required value.

SYNCHRONIZING

The horizontal and vertical scanning circuits in a receiver are two entirely independent systems, both of which require extremely accurate information to keep them in step with the corresponding scanning systems in the camera, where the signal originates. Because the duration of sync pulses may be rather short, these pulses may be added to the picture signal in such a way as to increase the overall amplitude of the final signal without increasing the average transmitted power level very much. Thus, simple amplitude discrimination can be used to separate the synchronizing information from the incoming composite signal in the receiver. It is, however, desirable that a second increase in amplitude should not be used to distinguish between horizontal and vertical sync. The reason for this is that a further increase in signal amplitude would make necessary an increase in the peak power rating of the transmitter or else would unnecessarily restrict the power available for the picture and horizontal sync portions of the signal.

A synchronizing system has therefore been chosen in which both vertical and horizontal pulses have the same amplitude, but different waveshapes. Frequency discrimination may then be used to separate them in the receiver. The shapes of these pulses and their relation to the blanking pulses are illustrated in detail in Figure 3-5. Figure 3-7 is a functional block diagram showing the steps necessary to "utilize" the sync signals.

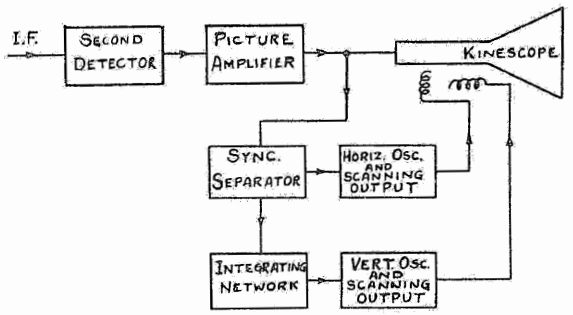

Figure 3-7 - Block Diagram of Picture-signal Amplifier and Scanning Circuits in Typical Receiver.

Diagrams 1 and 2 of Figure 3-5 illustrate a typical complete composite picture signal in the neighborhood of the vertical blanking pulse in each of two successive fields. Interlacing of the scanning lines is shown by the time displacement of the horizontal blanking pulses in one diagram with respect to those in the other diagram. This displacement is one-half of the interval of a scanning line ($H/2$).

All sync pulses appear below black level in an amplitude region which is sometimes called *blacker-than-black*; hence they can have no effect on the tonal gradation of the picture. Horizontal sync pulses are (except during the first portion of the vertical blanking interval) simple rectangular pulses, such as those appearing at the negative peaks or bases of the horizontal blanking pulses and during the last portion of the vertical blanking pulses. The duration of a horizontal sync pulse is considerably

less than that of the blanking pulse, and the leading edge of the sync pulse is delayed with respect to the leading edge of blanking, forming a step in the composite pulse which is called the *front porch*. Correspondingly, the step formed by the difference between the trailing edges of sync and blanking is called the *back porch*. The purpose in forming the front porch is to insure that the horizontal retrace in the receiver (initiated by the sync pulse) does not start until after the blanking pulse has cut off the scanning beam. It also insures that any discrepancies which may exist in the leading edge of blanking do not effect either the timing or the amplitude of sync.

The choice of the nominal width of horizontal sync (0.08 *H*, see diagram 5 in Figure 3-5 was influenced by three factors. First, the width should be as great as possible so that the energy content of the pulses will be large compared to the worst type of noise pulses which may be encountered in the transmission process, thus providing maximum immunity to noise. Second, the width should not be greater than is necessary to meet the first condition, because average power requirements of the transmitter may thereby be minimized. Modulation of the picture transmitter is such that sync pulses represent maximum carrier power; hence it is desirable to keep the duty cycle as small as possible. Third, the horizontal sync pulses should be kept as narrow as possible so as to maintain a large difference between these pulses and the segments of the vertical sync pulses described in the following paragraph. Such a large difference makes it easier to separate the vertical sync from the composite sync signal. It has also been recognized that the back porch is useful for a special type of clamping for d-c restoration. Hence it should be as wide as possible.

Vertical sync pulses are also basically rectangular in shape, but are of much greater duration than the horizontal pulses, thus providing the necessary means for frequency discrimination to distinguish between them. However, each vertical sync pulse has six *slots* cut in it, which make it appear to be a series of six wide pulses at twice horizontal frequency, *i.e.*, wide compared to horizontal sync pulses. The slots contribute nothing to its value as a vertical sync pulse but do provide means for uninterrupted information to the horizontal scanning circuit.

Before and after each vertical pulse interval are groups of six narrow pulses called *equalizing pulses*. These also are for the purpose of maintaining continuous horizontal sync information throughout the vertical sync and blanking interval. The repetition frequency of the equalizing pulses and the slots in the vertical pulses is twice the frequency of the horizontal sync pulses. This doubling of the frequency does two things. First, it provides an arrangement in which the choice of the proper alternate pulses makes available some kind of a horizontal sync pulse at the end of each scanning line in either even or odd fields. Second, it makes the vertical sync interval and both equalizing pulse intervals exactly alike in both even and odd fields. The importance of this latter result will become evident in following paragraphs. It is important to point out that the leading edge (downward stroke) of each horizontal sync pulse and of each equalizing pulse, and the trailing edge (again the downward stroke) of each slot in the vertical pulses are responsible for triggering the horizontal scanning circuit in the receiver; hence the intervals of *H* or *H/2* apply to these edges.

Perhaps the most difficult problem in synchronizing, and the one in which there is the largest number of failures, is that of maintaining accurate interlacing. Discrepancies in either timing or amplitude of the vertical scanning of alternate fields will cause displacement, in space, of the interlaced fields. The result is non-uniform spacing of the scanning lines, which reduces the vertical resolution and makes the line structure of the picture visible at normal viewing distance. The effect is usually called *pairing*. The maximum allowable error in line spacing in the kinescope, to avoid the appearance of pairing, is probably 10% or less. This means that the allowable error in timing of the vertical scanning is less than one part in 5000. This small tolerance explains why so much emphasis is placed on the accuracy of vertical synchronizing.

The presence of a very minute 30-cycle component in the *vertical* scanning invariably causes pairing. The fact that the rasters produced in alternate fields are displaced with respect to each other by half a line means that the *horizontal* sync signal has an inherent 30-cycle component. It is this situation, and the need to prevent any transfer of the 30-cycle component into the vertical deflection, which account for the introduction of the double-frequency equalizing pulses before and after the vertical sync pulses. The vertical sync pulses are separated from the composite sync signal, before being applied to the vertical scanning oscillator, by suppressing the horizontal sync pulses in an integrating network similar to that illustrated in Figure 3-8.

Most receivers employ integrating networks of three stages instead of the two illustrated.

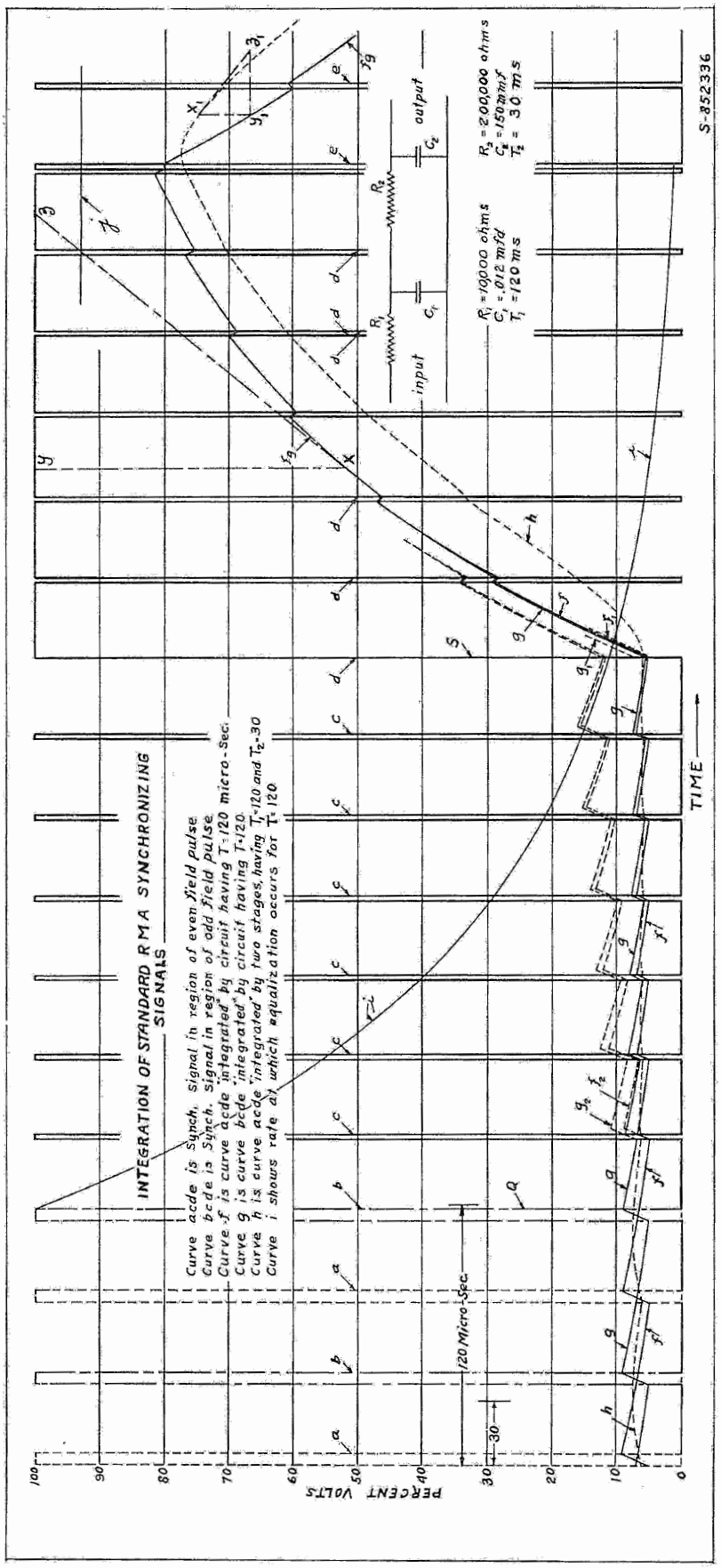

Figure 3-8 - Integration of RMA Synchronizing Signals

however, the general character of the circuit action is clearly shown by the wave-form diagrams* in Figure 3-8. In simple terms, the equalizing pulses before the vertical sync pulses cause the integrating network to "forget" the difference between alternate fields by the time the vertical sync pulses begin. This is illustrated by the gradual convergence of curves f and g during the equalizing pulse interval, as the result of integration in the first stage alone. The effect of further integration in the second stage is shown by curve h, which is typical of the pulses applied to the vertical oscillator in a receiver. Thus, the 30-cycle component is effectively eliminated, from the standpoint of accurate timing of the start of vertical retrace, by the addition of the first set of equalizing pulses and the slots in the vertical pulse itself. The second set of equalizing pulses which follow the vertical pulse affect to some extent the impedance of the circuit to which the vertical scanning oscillator is coupled, and thus affect the amplitude of its output; hence these pulses help to provide more nearly constant output of the oscillator. Both sets of equalizing pulses contribute materially to the necessary accuracy of vertical synchronizing.

The width of an equalizing pulse is half the width of a horizontal sync pulse (see diagram 4 of Figure 3-5, and Figure 3-8). This width is chosen so that the a-c axis of the sync signal does not change at the transition from the line-frequency horizontal sync pulses to the double-frequency equalizing pulses. The curves f_2 and g_2 in Figure 3-8 illustrate the undesirable effect of making the equalizing pulses the same width as the horizontal sync pulses. There is a slight rise in the integrated wave during the equalizing pulse interval, which could cause premature triggering of the vertical oscillator in the receiver if the hold control were adjusted near one end of its range. This rise in the integrated wave results from the change in the a-c axis.

The width of the slots in the vertical sync pulses is approximately equal to the width of the horizontal sync pulses. The slots are made as wide as possible so that noise pulses or other discrepancies occurring just prior to the leading edge of a slot (*i.e.*, near the end of the preceding segment of a vertical pulse) do not trigger the horizontal oscillator. Premature triggering can happen if the noise pulse is high enough and if it occurs very close in time to the normal triggering time. Increased time-separation (a wider slot) reduces likelihood of such premature action. Here again, the requirements of special clamping also are met more easily if the slots are made as wide as possible.

A further important advantage of the RMA system of separating the vertical sync by frequency discrimination is that the integrating network is a potent factor in reducing the effect of noise on vertical synchronizing. Noise signals contain mostly high-frequency components; hence they are almost completely suppressed by the integrating circuit.

Differentiation, or suppression of the low-frequency components, of the sync signal before it is applied to the horizontal scanning oscillator is done sometimes, but it is not necessary, and has not been indicated in Figure 3-7.

The methods just described for synchronizing the scanning circuits in a television receiver are complicated by the need for transmitting the complete information over a single channel. In the case of the scanning circuits in the cameras, however, the situation is very different. The cameras and the synchronizing generator are so close to each other that there is no problem in providing as many wire circuits as may be desired. Therefore it is customary to use what are called *driven* scanning circuits in cameras and sometimes in picture monitors used with the cameras. Separate pulse signals, called *driving signals*, are produced in the synchronizing generator for exclusive use in the terminal equipment. Horizontal and vertical driving signals are completely independent of each other in the RCA system and are carried on separate transmission lines to the points of application. The driving signal pulses trigger directly the sawtooth generators which produce the scanning wave forms. This method reduces interlacing errors in the terminal equipment to the errors inherent in the driving signals.

Figure 3-9 illustrates a portion of the scanning lines appearing on a kinescope as a result of the application of a television signal composed of RMA sync and blanking pulses. The group of lines shown are those occurring in the neighborhood of the vertical retrace period including a few before and a few after the vertical blanking pulse. As noted on the diagram, the triggering of the lines has been displaced both vertically and horizontally so that the shadows produced by the sync and blanking pulses appear near the center of the raster rather than

* *Diagram prepared by A. V. Bedford, RCA Laboratories, for presentation to the N.T.S.C.*

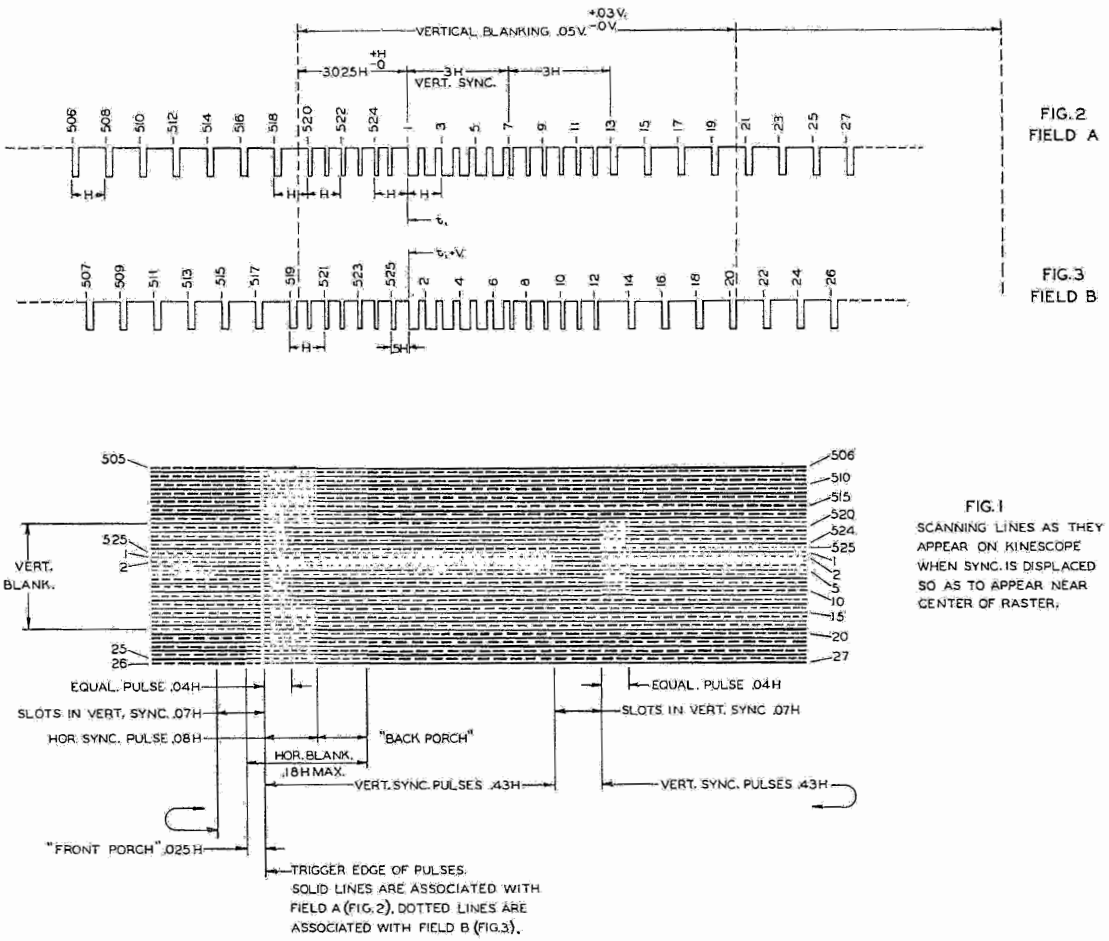

FIG. 1
SCANNING LINES AS THEY APPEAR ON KINESCOPE WHEN SYNC. IS DISPLACED SO AS TO APPEAR NEAR CENTER OF RASTER.

Figure 3-9 - Television Synchronizing Signal and Pulse Cross

in the normal positions at the edges of the raster. This displacement is brought about simply to clarify the illustration of the effect of the pulses on the raster.

The shadows produced thus are called a *pulse cross*. When expanded vertically so that individual scanning lines become easily apparent, the pulse cross becomes a ready means of checking the performance of the sync generator. The shadows produced by each different kind of pulses are indicated clearly on the diagram. With linear scanning, the horizontal dimensions of the shadows are measures of time or pulse width, and, because of the expanded scale, they provide a relatively accurate means of measuring pulse width. Furthermore, by counting appropriate lines, the numbers of equalizing pulses, slots, vertical sync pulses, etc. can be checked easily.

A useful piece of station test equipment can be made by modifying the deflection circuits in a picture monitor to provide the displacement of the lines and the extra large vertical expansion described.

AUTOMATIC FREQUENCY CONTROL OF SCANNING

The constant search for means of immunization against the effects of noise has brought about the development of automatic frequency control (afc) of the scanning circuits in television receivers. In triggered circuits, each scanning line (and each field) is initiated individually by a pulse in the incoming signal. In contrast to this, in an afc system, scanning generators are governed by stable oscillators which, in turn, are controlled by voltages obtained from phase comparison of the incoming sync pulses with the scanning signals themselves. The time-constant of the comparison circuit is usually made long, compared to the period of the scanning, so that random noise pulses have very little effect on the resulting control voltage, and correspondingly little effect on the scan-

ning frequency. The fact that such afc circuits are keyed provides a further immunization factor by eliminating the possible effect of all noise pulses except those which coincide with the short keying intervals. The use of afc scanning circuits makes possible accurate synchronizing of a receiver under such bad conditions of noise that the masking of the picture by the noise renders it completely unusuable. Thus, failure to synchronize may be largely eliminated as a limiting factor in picture reception.

AFC may be used with both vertical and horizontal scanning circuits, but so far is being used commercially for horizontal circuits only. One reason for not using afc with the vertical circuits is that the time-constant must be very long to provide a stable control voltage. As a result, the circuit will not recover from an extended interruption of the incoming signal until an intolerably long time has elapsed. The frequency of the oscillator drifts during an interruption, and may not recover for a large number of seconds after the signal returns. During the period of recovery, the raster rolls over continuously at a decreasing rate until control is restored. The time-constant of the horizontal circuit, on the other hand, may be short enough so that recovery takes place in less than one field. Triggered scanning circuits, of course, recover from signal interruptions very rapidly, but they do not have the same high immunity to noise that the afc circuits have.

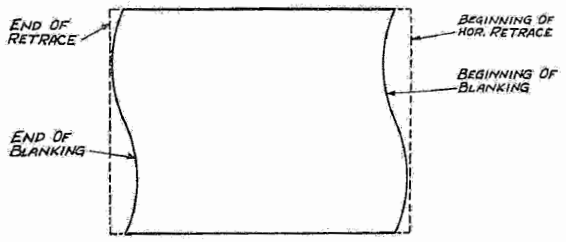

Figure 3-10 - Effect of Frequency Modulation of Horizontal Sync and Blanking on Shape of Raster in Receiver with AFC of Horizontal Scanning.

As a result of the use of afc circuits in receivers, a high degree of frequency stability is required in the horizontal sync and blanking signals. Frequency modulation of the horizontal pulses is intolerable because it causes the right- and left-hand edges of the blanked raster in the receiver, as well as vertical lines in the scene, to assume the same shape as the modulating wave. As shown in Figure 3-10, the border of the complete raster in the receiver is rectangular, but frequency modulation of the horizontal sync and blanking will distort the shape of the border produced by blanking. Frequency modulation by a 60-cycle sine wave is illustrated.

Horizontal retrace begins along a straight vertical line regardless of timing; and since this retrace is controlled by a stable oscillator in the receiver which is not responsible to short-time changes in sync timing, the presence of variations in sync timing and of corresponding changes in blanking pulse timing, will show as a displacement of the edges of the blanked raster. The frequency stability of the sync generator must therefore be at least equal to the stability of the oscillators used in afc receivers. The maximum rate of change of frequency allowable in a sync generator has been specified by RMA as 0.15% per second. This is a rather strict tolerance, as indicated by the fact that it allows a total displacement of only 1/32 of an inch (approx.) in a period of one field in a picture 10 inches wide.

FILM PROJECTION

The use of standard sound motion picture film for television program material offers a special problem which arises from the difference in the picture repetition rates use. For reasons explained previously, the rate used for television is 30 frames and 60 fields per second. The standard speed for sound film, both 16mm and 35mm, is 24 frames per second, and since each frame is projected twice, the pictune rate is 48 per second. The basic problem of reconciling the frequency difference has been met by using special projectors for television, in which alternate frames of the film are projected twice and the remainder are projected three times. In this way, 60 pictures are obtained in place of the usual 48, but the average speed of the film through the projector is unchanged; hence the sound take-off is entirely normal.

Another problem also presents itself in the use of intermittent film projectors for television. The vertical scanning period occupies from 92% to 95% of the total period. If the projected image is to be thrown on the pickup tube during the scanning period at all, it must be for the entire time so that all parts of the area will be subject to the same lighting conditions. Such an arrangement would leave only the vertical retrace period (5% to 8% of the total, or approximately one thousandth of a second) in which to pull down the film to the next frame. 35mm film will not stand up under accelerations produced by sprocket-hole pull-down in such a short period; hence some other scheme must be used. The method which has been adopted for use with intermittent projectors makes use of the storage property of certain kinds of pickup tubes, such as the iconoscope. The frame of film is projected with very intense illumination during the vertical blanking period only, while neither the pickup tube nor the receiver is being scanned. Then the light is cut off and the pickup tube is scanned in the absence of any

optical image from the film. The signal generated during this scan results from charges stored on the sensitive surface during the preceding flash of light. While the light is cut off during the scan there is ample time to pull the film down before the next flash of light, without exerting destructive forces. The pulses of light may be obtained by chopping the output of a continuous source with a rotating disk, or (with a special type of arc lamp) by pulsing the source itself by electronic means. The storage properties of pickup tubes for this purpose must be sufficiently good so that dissipation of the stored charges is negligible between light pulses. Appreciable dissipation causes loss of contrast at the bottom of the picture.

Another solution to the problem of film projection in television is the use of a continuous projector, a type which produces a stationary image from continuously moving film by means of moving mirrors or lenses. This solution has not been accepted commercially so far because of practical difficulty in making the optical system sufficiently accurate to stop motion of the image completely.

The film problem in England, Europe, and other areas where 50-cycle power systems are standard, and where the television field frequency is also 50 cycles per second, is simpler in one respect, namely that it is not necessary to use the two-three ratio for projection of alternate frames of film. Instead, the film is projected as it is in theaters where each frame is projected twice. No attempt is made to compensate for the difference between the 24 frame taking speed and the 25 frame projection speed. The results are an approximate 4% increase in the apparent speed of motion of objects in the scene (which is probably negligible) and a slight rise in the pitch of all sounds. This latter effect is the more objectionable of the two, though generally it is not noticeable in speech and many other ordinary sounds. The change in pitch is undoubtedly noticeable to the trained musician in the case of musical sounds and must produce an unpleasant mental reaction to the music. However, no easy solution to the problem is known, and the situation is accepted without serious complaint. The other aspects of the film problem are not affected by the use of 50 fields instead of 60.

REFERENCES

The preceding discussion is necessarily brief and cannot serve as much more than an outline for further reading. There are many papers dealing more comprehensively with the details and problems associated with the various parts of the television system. References to some of these are included in the following bibliography. Most of the papers referred to also include references to others which, *in toto*, comprise a comprehensive list.

One book deserves special mention as a reference covering much of the engineering background of our television system. It is entitled, "Television Standards and Practice," (McGraw-Hill Book Co., 1943), and is essentially an abridged version of the proceedings of the National Television System Committee, as edited by Donald G. Fink. It includes a statement of the standards recommended by the Committee to the Federal Communications Commission, discussion of the investigations on which the recommendations were based, and references to pertinent papers.

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PART II

FUNDAMENTAL CIRCUITS

INTRODUCTION

The foregoing discussion of basic concepts shows that television circuits use vacuum tubes and components in ways that differ significantly from audio- or radio-frequency circuit applications. Sinusoidal wave forms are the exception rather than the rule. Usually the complex wave forms observed in television circuits are rectangular pulses, sawtooth shapes, or combinations of both. Vacuum-tube grids may be driven from a point well below cut-off potential into the positive region where grid current flows. The vacuum tube may operate as a switch in which total voltage and current values are used rather than small incremental quantities. Also time becomes an important factor since certain circuits must function in a particular manner with respect to time. The following notes are concerned with some fundamental television circuits employing concepts outlined above.

OVERDRIVEN AMPLIFIER

An overdriven amplifier is one in which the grid voltage is varied from a point below the tube cut-off voltage to some value in the positive region where grid current flows. This type of amplifier may be used as a limiting or clipping device or as a pulse amplifier. A circuit diagram is shown in Figure 3-11.

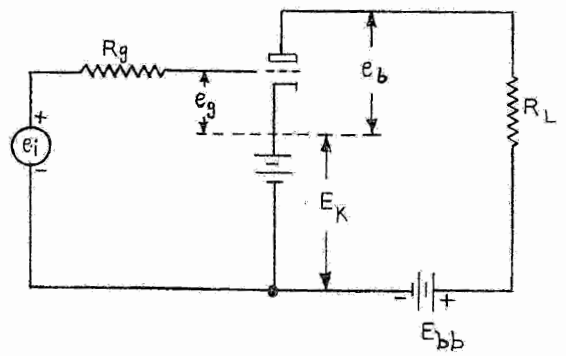

Figure 3-11 - Overdriven Amplifier

In the overdriven amplifier the following symbols apply:

$\overline{r}_p$ = d-c plate resistance = e_b/i_p. For $e_g = 0$ assume $\overline{r}_p$ constant

= 10,000 ohms approximately for 6SN7.

$\overline{r}_g$ = d-c grid resistance = e_g/i_g. Assume $\overline{r}_g$ constant for given tube

= 1,000 ohms approximately for 6SN7.

E_{co} = grid voltage for plate current cut-off

= E_{bb}/μ for triodes only.

R_g = grid limiting resistor which limits grid voltage to a value slightly positive with respect to the cathode.

Figure 3-12 shows an equivalent circuit and the resultant wave forms when a sinusoidal voltage e_i is applied to the grid. In this equivalent circuit, switches S_1 and S_2 are open when the grid voltage is below cut-off. They are closed when the grid voltage is positive with respect to the cathode.

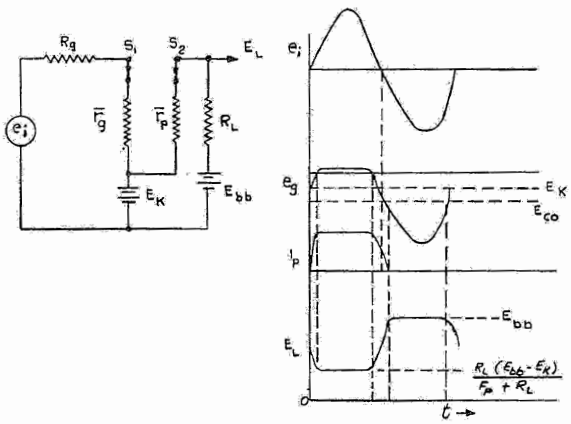

Figure 3-12 - Overdriven Amplifier, Equivalent Circuit and Wave Form.

When $e_i = 0$, the grid voltage e_g is equal to E_k. When $e_i - E_k = 0$, grid current flows and limits e_g to a slightly positive value. The grid voltage remains positive and constant, because of the drop across R_g (note that $R_g >> \overline{r}_g$), until e_i approaches the 180-degree point of the cycle. During the first half-cycle i_p rises

rapidly to a value determined by $\overline{r}_p$, R_L, E_k, and E_{bb}, and then remains constant until e_g becomes negative. When $e_i + E_k$ is equal to the cut-off voltage, i_p falls to zero and no plate current flows for the remainder of the cycle. During the time that e_g is zero or slightly positive,

$$E_L = \frac{R_L (E_{bb} - E_k)}{\overline{r}_p + R_L}$$

When plate current is cut off (S_2 open),

$$E_L = E_{bb}.$$

In this circuit the sinusoidal input voltage has been clipped at both top and bottom to give a rough square-wave output voltage.

CATHODE FOLLOWER

A linear cathode-follower stage differs from the ordinary amplifier circuit in five ways: (1) the signal polarity is not inverted, (2) the gain is less than 1, (3) the output impedance is low, (4) the input impedance is high, and (5) the input capacitance is lowered. It may be used (1) after a pulse-shaping circuit to prevent loading of the circuit, (2) to drive tubes requiring grid power without altering the waveshape, or (3) as a device to match high to low impedances. It can deliver high currents to a low-impedance load without altering the waveshape. The basic circuit and equivalent circuit are shown in Figure 3-13 for incremental quantities.

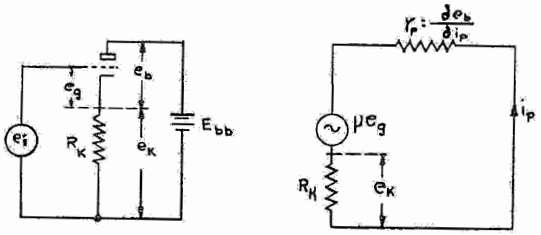

Figure 3-13 - Cathode Follower Circuit

From Figure 3-13 it may be seen that $e_g = e_i - e_k$; hence μe_g becomes $\mu(e_i - e_k)$. Then in the equivalent circuit

$$i_p = \frac{\mu(e_i - e_k)}{r_p + R_k}$$

and the output voltage e_o is

$$e_o = e_k = i_p R_k$$

$$= \frac{\mu(e_i - e_k) R_k}{r_p + R_k}$$

from which the gain A is expressed

$$A = \frac{e_k}{e_i} = \frac{\mu R_k}{r_p + (\mu + 1) R_k}$$

If the amplification factor μ is large, compared to 1, the gain A becomes

$$A = \frac{\mu R_k}{r_p + \mu R_k}$$

In another form, the gain may be expressed

$$A = \frac{\frac{\mu}{r_p} R_k}{1 + \frac{\mu}{r_p} R_k}$$

$$= \frac{g_m R_k}{1 + g_m R_k}$$

The last equation resembles the equation for the gain of an ordinary amplifier stage reduced by the factor $\frac{1}{1 + g_m R_k}$. The grid-to-cathode input capacity is reduced by the same factor, and the total input capacity becomes

$$C_i = C_{gp} + \frac{C_{gk}}{1 + g_m R_k}$$

Similarly, the output impedance is reduced to

$$Z_o = \frac{R_k}{1 + g_m R_k}$$

MULTIVIBRATORS

A multivibrator is a circuit arrangement in which two tubes operate as switching elements to control the duration of current flow in the two load resistances. It may be compared to an oscillator, in that its action can be self-sustained. Such a multivibrator is called a "free-running" multivibrator. It may be synchronized to a desired frequency by either a sine wave of the given frequency or by a pulse whose repetition rate is equal to the desired frequency. There is also a type of multivibrator known as a "flip-flop", "one-kick", or "one-shot" multivibrator. This type of multivibrator performs one cycle of operation only when triggered by an external synchronizing signal.

Figure 3-14 is a circuit diagram of an unbiased free-running multivibrator. Capacitor

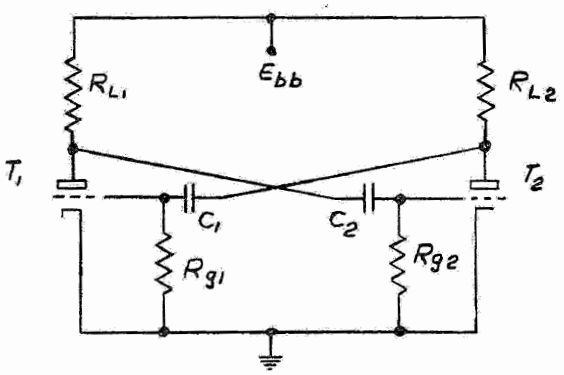

Figure 3-14 - Unbiased Free-running Multivibrator

C_1 couples the grid of T_1 to the plate of T_2. Similarly, C_2 couples the grid of T_2 to the plate of T_1. The circuit operates as follows: Suppose E_{bb} is applied when both tubes tend to conduct. Any small difference in circuit values or tube characteristics will result in one tube carrying more current than the other. Suppose more current flows in T_1. The greater voltage drop in R_{L1} is impressed on the grid of T_2, making that grid more negative and decreasing the current flow in T_2. The plate potential of T_2 rises, and this drives the grid of T_1 toward positive potential, causing T_1 to draw a still greater current. The effect is cumulative and results in T_1 carrying maximum current while T_2 is cut off.

The cycle of operation following the cut-off of T_2 is shown in Figure 3-15. The plate voltage of T_1 drops to a value equal to $\frac{\bar{r}_p}{\bar{r}_p + R_{L1}} E_{bb}$. Since the grid of T_2 is coupled to the plate of T_1 through C_2, the grid voltage of T_2 also drops below zero by an amount equal to e_{RL1}. Grid voltage e_g tends to go positive because e_{b2} rises to E_{bb} when T_2 is cut off; however, C_1 charges quickly through R_{L2} and r_{g1} and leaves e_{g1} at approximately zero potential. Capacitor C_2 begins to discharge exponentially through R_{g2} and R_{L1} and $\bar{r}_{p1}$ in parallel. The equivalent circuit, for C_2 discharging, is shown in Figure 3-16.

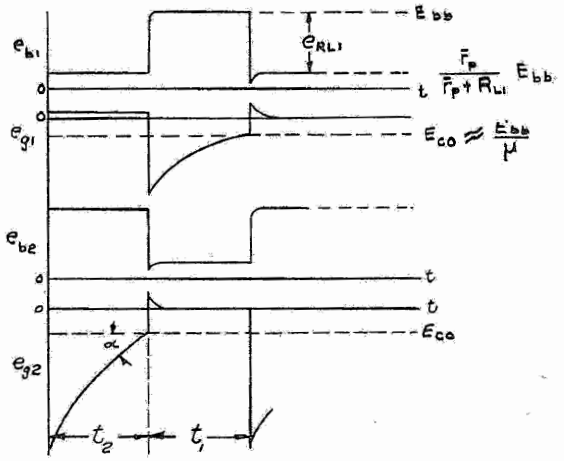

Figure 3-15 - Operating Cycle of Free-running Multivibrator

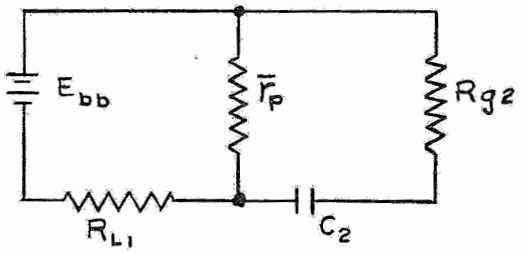

Figure 3-16 - Capacitor Discharge Circuit

The equation for the discharge of a capacitor is

$$e_c = E_o \epsilon^{-t/RC}$$

where e_c = voltage on capacitor at time t
E_o = total discharge voltage
RC = time constant of discharge circuit.

Since we are interested primarily in e_{g2}, we shall consider the voltage across R_{g2}. At the beginning of the discharge $e_{g2} = e_{RL1}$. The steady-state condition toward which e_{g2} is tending is zero volt; however, when e_{g2} reaches cut-off voltage, tube T_2 will begin to conduct, and tube T_1 will be cut off.

From Figure 3-10 it can be seen that the total resistance in the discharge path is

$$R_{g2} + \frac{\overline{r}_{p1} R_{L1}}{\overline{r}_{p1} + R_{L1}}$$

Stray capacity is neglected in the calculations, but tends to round the corners of the plate-voltage wave form as shown in Figure 3-15. From the foregoing we may write the equation for the voltage on the grid of T_2:

$$e_{g2} = e_{R_{L1}} \epsilon^{-t/RC}$$

$$E_{CO} = e_{R_{L1}} \epsilon^{-t_2/\left(R_{g2} + \frac{\overline{r}_{p1} R_{L1}}{\overline{r}_{p1} + R_{L1}}\right) C_2}$$

(specific equation to point of cut-off).

In the usual design problem all the constants are known or can be determined, with the exception of R_{g2} and C_2. The value of R_{L1} is determined by the amplitude of plate-voltage change desired. E_{CO} and $\overline{r}_{p1}$ depend upon the tube type. The time interval t_2 is known for a particular application and is the time that T_2 is not conducting. The product $R_{g2}C_2$ may be calculated from the equation for voltage across R_{g2}.

The operation of T_1 follows an identical cycle when it is cut off. The sum $t_1 + t_2$ of the cut-off periods determines the total period of the cycle. The frequency of the multivibrator may be varied by varying either or both grid resistors.

It will be noted in Figure 3-15 that e_g approaches E_{CO} at the angle α. Since this angle is small, any variation in tube characteristics or components causing a shift in E_{CO} will alter the cut-off period t because the point of intersection of e_g with E_{CO} will change. When it is essential that t remain nearly constant over a long period of operation, the grid may be returned to E_{bb} as shown in Figure 3-17.

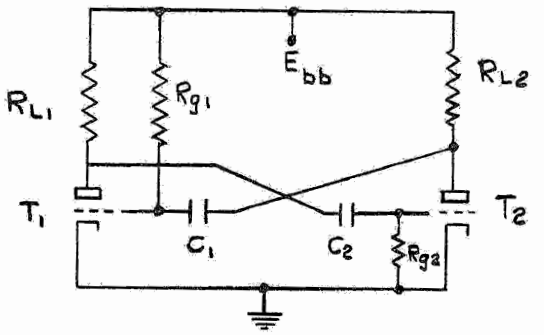

Figure 3-17 - Grid Return Circuit

The discharge wave form for e_{g1} is shown in Figure 3-13. In this example, e_{g1} is heading for E_{bb} instead of zero potential as in the previous case, and the angle α is large. Small

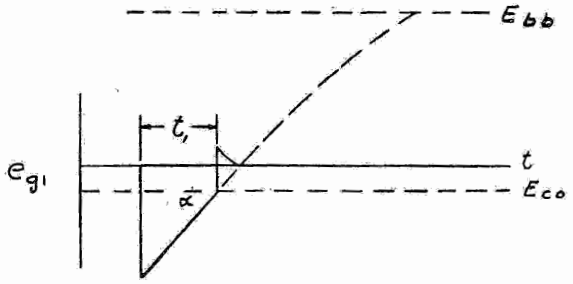

Figure 3-18 - Grid Voltage Wave Form

variations in E_{CO} will not greatly alter the intersection of e_{g1} and E_{CO}, and thus t_1 will remain very nearly constant. The equation for the discharge of C_1 becomes

$$E_{bb} + E_{co} = (e_{R_{L2}} + E_{bb}) \epsilon^{-t_1/RC}$$

An example of the so-called "flip-flop" multivibrator is shown in Figure 3-19 with the associated wave forms. Tube T_2 is normally conducting, and plate-current flow through R_k keeps T_1 cut off. When the grid of T_1 receives the trigger pulse, e_{p1} decreases and drives the grid of T_2 below cut off. T_2 remains cut off until C_2 discharges to the cut-off potential, at which

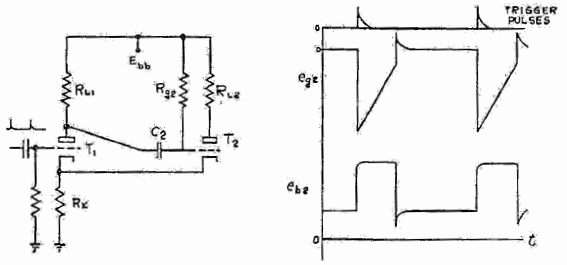

Figure 3-19 - "Flip-flop" Multivibrator

point T_2 resumes conduction until another trigger pulse is received.

CATHODE-COUPLED MULTIVIBRATORS

The multivibrators discussed thus far operate well up to pulse repetition rates of several thousand pulses per second. At higher repetition rates, stray capacity tends to cause unstable operation. To minimize stray-capacity effects and extend the stable range of operation, one can resort to cathode coupling between stages.

A cathode-coupled multivibrator is shown schematically in Figure 3-20.

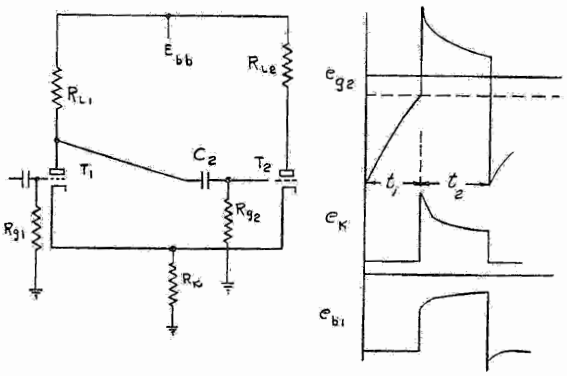

Figure 3-20 - Cathode-coupled Multivibrator

When +B voltage is applied to the circuit, plate-current flow establishes across R_k a bias voltage common to both tubes. At the same time the voltage drop across R_{L1} is impressed on the grid of T_2, reducing the plate current in T_2 and lowering the bias voltage across R_k. With lower bias voltage, T_1 carries a larger plate current, and the resulting plate-voltage drop drives the grid of T_2 more negative. The process is cumulative and rapid, so that T_2 is cut off quickly.

Capacitor C_2 discharges in normal manner until the grid reaches cut-off potential. This cycle is shown, during t_1, in Figure 3-20. Then T_2 begins to conduct. The flow of T_2 plate current through R_k reduces the plate current in T_1 because of increased bias. The plate voltage of T_1 rises as the plate current decreases, and this voltage rise is coupled to the grid of T_2 through C_2. The grid of T_2 is driven positive by this cumulative process. Heavy current in T_2 cuts off T_1.

Now C_2 begins to charge through R_{L1} and the parallel combination of r_g and R_{g2}. It charges quickly until the grid voltage is reduced to cathode potential. Then T_2 grid current ceases, and C_2 continues to charge through R_{L1} and R_{g2}. At the end of the time interval t_2 plate current in T_2 has been reduced sufficiently to allow T_1 conduction. From this point on, the cycle is repeated.

This type of multivibrator is inherently unstable because neither tube can keep the other in cut-off condition. Also, the effect of stray capacity is reduced by interstage coupling to one grid only, and the input capacity of that grid is reduced by cathode-follower action. The controlling signal is coupled between stages by a low-impedance circuit in the cathodes, in which the effect of stray capacity is lessened. A multivibrator of this type may be operated in reliable manner at a pulse repetition rate of a million pulses per second.

CLIPPING CIRCUITS

Clipping circuits are used to eliminate undesired portions of complex wave forms by limiting the amplitude excursion in either the positive or negative direction, or in both directions. Clippers or limiters are usually applied in circuits in which pulses are formed and shaped to desired specifications.

Figure 3-21 illustrates a simple peak-clipping circuit which may be used to form a square

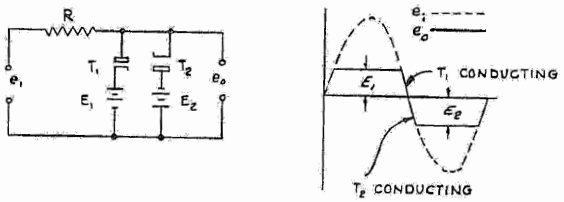

Figure 3-21 - Peak Clipping Circuit

wave from a sinusoid. Two diode elements, T_1 and T_2, are connected as shown. Bias battery E_1 keeps tube T_1 cut off until input voltage e_i increases in the positive direction to a value equal to E_1. Further increase in e_i causes conduction of T_1 and results in a voltage drop across R. As e_i increases, both the current in T_1 and the voltage drop across R increase so that the output voltage e_o is fairly constant after e_i becomes slightly greater than E_1. A similar condition holds for the negative half-cycle of the input voltage. In this, the output voltage increases in the negative direction until bias E_2 is overcome. Then conduction in T_2 limits the output voltage to a fairly constant value. Wave forms for the cycle of operation are shown in Figure 3-21.

To produce, from a sine wave, a square wave with a short rise time by using a clipper of this type, it is necessary to connect several stages in cascade, inserting amplifiers between stages.

The overdriven amplifier discussed on previous pages may also be used for performing a clipping operation. Figure 3-22 is a practical

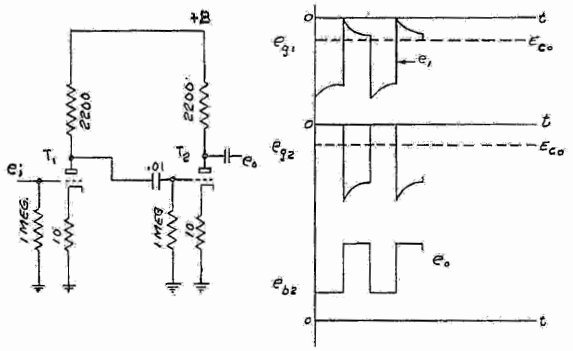

Figure 3-22 - Triode Clipper Circuit

triode clipper circuit utilizing a type 6SL7 tube. It may be desirable, for example, to remove overshoots or distortion in the tops of a square wave such as e_i in Figure 3-22. If e_i is symmetrical about the a-c axis, the grid of T_1 will assume a bias voltage, due to grid current, which will permit just the tip of the pulse to reach zero potential with respect to the cathode. If the pulse amplitude is sufficiently large, the negative excursions will drive the tube beyond cut off and eliminate the overshoot on the negative half-cycle.

The signal on the plate of T_1 consists of a square wave with overshoots eliminated in the positive half-cycle. By passing this signal through T_2, the overshoot is eliminated in the negative half-cycle, and a clean square wave is obtained in the output.

In the foregoing examples of clipping circuits, the action was symmetrical about the a-c axis. In some cases it may be desirable to clip only the tips of positive pulses, retain the tips, and eliminate the remainder of the wave form. Such a circuit and the appropriate wave forms are shown in Figure 3-23. Suppose the input voltage consists of alternate positive and

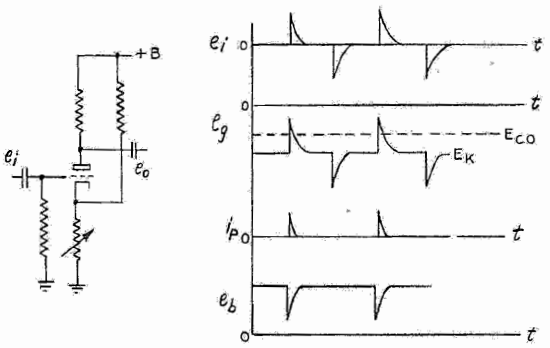

Figure 3-23 - Clipper Circuit

negative pulses obtained by differentiating a square wave. It is desired to clip the positive pulses midway between the axis and the tips. Voltage relationships are shown in Figure 3-23.

The clipping level is set by adjusting the bias in the cathode circuit so that, without signal, the tube is biased beyond cut-off. Only the positive tips of the input pulses cause plate current to flow.

In the clipping circuits described thus far, no attempt has been made to compensate for the inherent curvature near cut-off in the plate-current-cut-off type of clipper. Where the clipper is used to clip the blanking pulse and establish black level, as in Figure 3-4C, it is imperative that the slope of the grid characteristic curve remain constant to the clipping point; for this will prevent squashing of the video signal near black level and avoid change in the transfer characteristic. The linear clipper shown in Figure 3-24 accomplishes the desired result.

The linear clipper circuit includes a pentode V_1, a load resistor R_2 in series with a diode section V_2, and an additional load resistor R_1

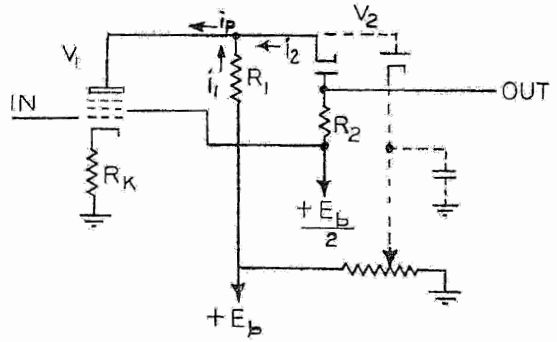

Figure 3-24 - Linear Clipper Circuit

in parallel with R_2 and V_2. The value of R_1 is approximately 20 to 30 times that of R_2. Both plate and screen supplies are regulated.

Figure 3-25 shows the characteristic curve for the linear clipper.

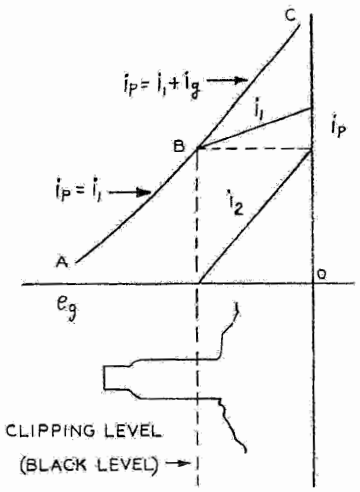

Figure 3-25 - Linear Clipper Characteristic

When V_1 is operating on the linear portion B-C, the plate current i_p is $i_1 + i_2$, and the plate voltage is less than $E_b/2$; hence V_2 conducts and causes signal current i_2 to flow in R_2. At point B the plate voltage of V_1 is equal to $E_b/2$. Between B and A the cathode voltage of V_2 is greater than $E_b/2$; therefore i_2 is zero, and there is no change in signal output voltage. Thus the blanking pulse is clipped at black level. Only the linear portion of the curve between B and C is used for the picture signal.

Cut-off in this clipper is abrupt. The use of a pentode tube permits an abrupt change in external load resistance without affecting plate current. As i_2 approaches zero, the ratio i_1/i_2 changes rapidly, resulting in a rapid change of V_2 cathode voltage in the cut-off region.

By adjusting the equivalent bias on V_1, point B can be made to coincide with black level.

A serious drawback of the linear clipper is capacity feed-through of transients. This trouble can be cured by connecting a second diode element, as shown by the dotted lines in Figure 3-24. By proper bias adjustment the second diode can be made to conduct at a potential just above cut-off of the limiter so that unwanted signals are shunted to ground when the limiter is inoperative.

BLOCKING OSCILLATORS

A blocking oscillator is a form of self-pulsed oscillator that is used as a simple means for obtaining a short pulse at some desired repetition rate. Figure 3-26 is a schematic diagram of a simplified blocking oscillator circuit. The coupling coefficient of the iron-core transformer T is very nearly unity. The connection polarities of the transformer must be as

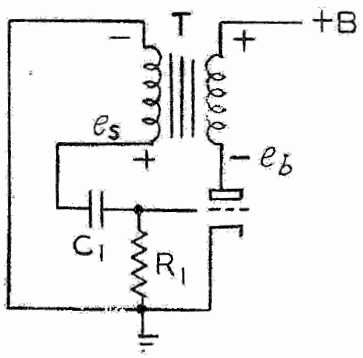

Figure 3-26 - Blocking Oscillator Circuit

shown. Wave forms for the operating cycle are given in Figure 3-27.

When $B+$ is applied and plate current starts to flow, a voltage develops in the primary winding, due to the inductance drop $L\,di/dt$. This voltage is coupled to the secondary so as to cause the grid voltage to rise in the positive direction. Thus, the plate current is further increased. The effect is cumulative and causes the grid to go positive quickly. As the grid

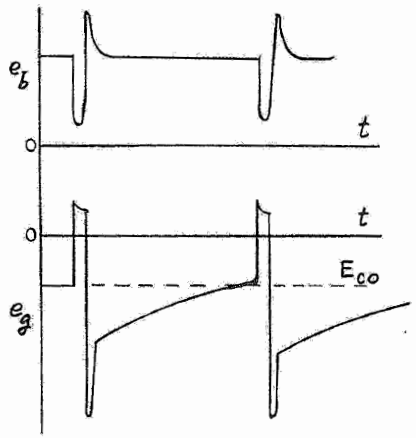

Figure 3-27 - Blocking Oscillator Operating Cycle

is driven positive, two actions occur: Grid current flows and charges C_1; and plate voltage is reduced to such a low value that further increase in grid voltage will not increase the plate current. The secondary voltage then ceases to increase, and C_1 begins to discharge. The discharge of C_1 lowers the grid voltage, causing a decrease in plate current. The induced voltage in the secondary is in the negative direction, due to the change in di_p/dt, and the grid is driven quickly below cut-off. Then C_1 is discharged through R_1 and the transformer secondary until the grid voltage is less than cut-off. When plate current starts to flow, the cycle is repeated. The unbiased blocking time is roughly 2 or 3 times C_1R_1, depending upon the transformer turns ratio, inductance values, and self-resonant frequency. The blocking oscillator frequency may be controlled by varying the bias on the grid or on the cathode, or by varying R_1.

The blocking oscillator may be synchronized by applying either a sine-wave or a pulse voltage across a resistor in the ground lead of the transformer secondary.

STEP-CHARGING CIRCUITS

A step-charging circuit is one in which the potential across a capacitor is built up in a series of steps. Its fundamental use is in a frequency-dividing system in which a blocking oscillator is triggered after a number of steps have been completed. Figure 3-28 shows a simple step-charging circuit and the resultant wave forms.

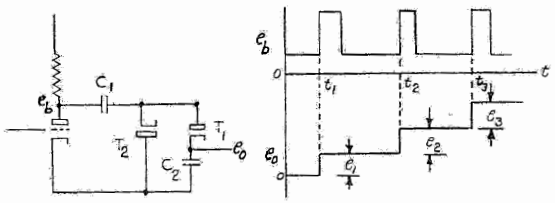

Figure 3-28 - Step-charging Circuit

Assume that the plate voltage e_b rises quickly at time t_1 and that $e_o = 0$. Diode section T_1 will conduct and charge C_1 and C_2. The voltage across C_2 is given by the equation.

$$e_1 = \frac{e_b C_1}{C_1 + C_2}$$

When e_b returns to its minimum value, diode section T_2 will conduct and discharge C_1. At time t_2 diode T_1 conducts again, charging C_1 and C_2. This time, however, the total change in e_b is not divided between C_1 and C_2 since C_2 has on it the voltage developed at time t_1. Let e_1 denote voltage to which C_2 was charged during the initial pulse. Then

$$e_2 = \frac{(e_b - e_1)\, C_1}{C_1 + C_2}$$

Each succeeding step may be calculated in the manner shown above. The voltage on C_2 during the preceding step must be subtracted from the peak-to-peak plate voltage in determining the amplitude of the next step.

At the end of a given number of steps, a blocking oscillator is triggered, C_2 is discharged, and the cycle is repeated.

NON-LINEAR MIXERS

In some television applications, specifically in the synchronizing generator, it is necessary to mix two pulses in such a manner that the resultant signal is not the algebraic sum of the two pulses. In effect, a third pulse is created

which differs in character from the original pulses. Consider the circuit in Figure 3-29. The 6L7 tube is biased at such a high value that both grids must receive positive pulses before plate current can flow. During the time that a positive pulse exists on both grids, plate current flows and gives an output voltage as shown.

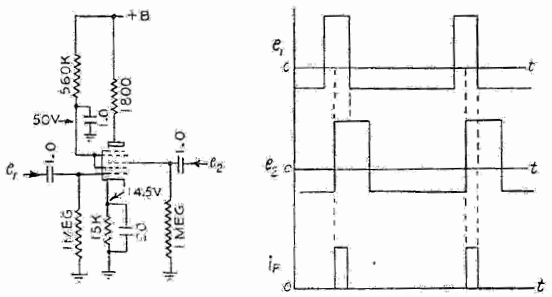

Figure 3-29 - Non-linear Mixer

Figure 3-30 is a curve taken on a type 6L7 tube for the electrode voltages shown. If the bias voltage is set at -14.5 volts as indicated, either grid potential may be reduced to zero without plate current flow.

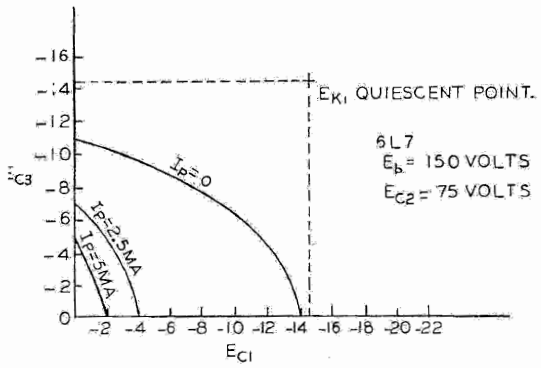

Figure 3-30 - Characteristics of Type 6L7 Tube

A-F-C DISCRIMINATOR CIRCUIT

To improve receiver performance, certain limitations have been recommended by the RMA Committee on Standards for the maximum acceleration of the synchronizing-signal frequency. Also, it is desirable to lock the frequency of the sync generator to a local 60-cycle power supply so as to simplify studio and remote operation. Since the local power-supply frequency may change by an amount exceeding RMA standards during sudden load changes, a means of delayed frequency control must be devised, in which the acceleration of frequency, in cycles per second per second, does not exceed the recommended standard. Such a circuit is the lock-in circuit shown in Figure 3-31.

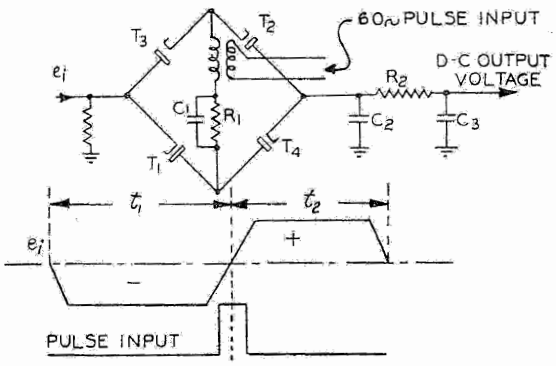

Figure 3-31 - Frequency Control Circuit

The circuit consists of four diode elements in a balanced bridge network. The sine wave of the local 60-cycle supply is clipped and applied across the bridge. A 60-cycle pulse voltage, derived from the synchronizing signal oscillator, is applied to the center leg of the bridge through a transformer. The phase of the local power supply voltage is adjusted so that the pulses occur at the zero-voltage point.

With reference to Figure 3-31 it may be seen that, normally, T_1 and T_2 would conduct during the negative half-cycle; however, a bias voltage, built up across R_1C_1, prevents conduction. Similarly, T_3 and T_4 would normally conduct during the positive half-cycle, except for the bias voltage. The pulse voltage overcomes the bias voltage when the clipped sine wave is passing through zero, and T_1 and T_2 conduct briefly during a small portion of the negative half-cycle, while T_3 and T_4 conduct momentarily during a small portion of the positive half-cycle. If the pulse voltage is in phase with the power line voltage and of the same frequency, the net charge on C_2 will remain the same.

If, however, the frequency relationship between C_1 and the pulse voltage should change, the charge on C_2 will change because the diodes will conduct more during one of the half-cycles than during the other. The time constant of R_2C_3 may be adjusted to provide for slow changes in the d-c output voltage, thus preventing erratic changes in power-line frequency from appearing in the control voltage.

The d-c output voltage is used to control a reactance tube for changing the frequency of the pulse voltage.

REACTANCE TUBE CIRCUIT

A reactance tube is used for controlling the frequency of an oscillator by varying the effective tank circuit in the plate of the oscillator. Figure 3-32 shows a typical reactance tube circuit.

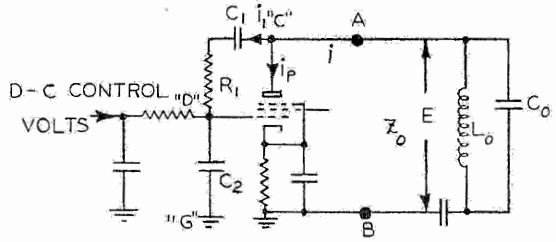

Figure 3-32 - Reactance Tube Circuit

In this circuit, $R_1 \gg 1/j\omega C_1$. Let the impedance between points "C" and "D" be $Z_1 = R_1$. The impedance from "D" to "G" is $1/j\omega C_2$, which we shall call Z_2. Then we may draw the equivalent circuit shown in Figure 3-33.

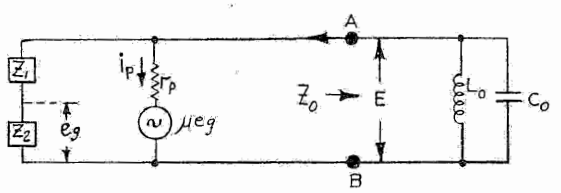

Figure 3-33 - Reactance Tube Equivalent Circuit

$$\text{If} \quad Z_1 \gg Z_2, \quad e_g = \frac{E\,Z_2}{Z_1 + Z_2} \approx \frac{E\,Z_2}{Z_1}$$

$$\text{If} \quad Z_1 + Z_2 \gg r_p, \quad i_p \approx i$$

$$\text{but} \quad i_p = g_m e_g = \frac{g_m Z_2 E}{Z_1}$$

The admittance, looking into the reactance tube plate is

$$Y_{AB} = \frac{i}{E} \approx \frac{g_m Z_2}{Z_1}$$

or

$$Y_{AB} = \frac{g_m}{j\omega C_2 R_1}$$

Thus, the admittance of the reactance is equivalent to an inductance which would vary with g_m. The vector diagram of current and voltage relationships is shown in Figure 3-34.

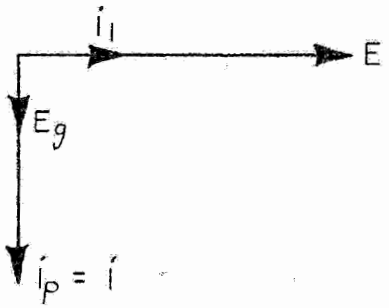

Figure 3-34 - Reactance Tube Circuit Vector Diagram

Mutual conductance of the reactance tube is varied by changing the d-c grid bias. This circuit, in conjunction with the lock-in circuit previously described, may be used to keep the frequency of an oscillator synchronized to a local power source.

SAWTOOTH GENERATORS

A sawtooth generator is a device whose output voltage has a repeating triangular wave shape of which the positive slope is constant. Thus

$$\frac{de}{dt} = \text{Constant}$$

This type of voltage is used as a time base for the scanning of cathode-ray or kinescope tubes. In view of the present television standards, we shall be concerned with sawtooth wave forms whose frequencies are 60 cycles and 15,750 cycles per second.

Figure 3-35 is a circuit diagram of a sawtooth generator commonly used in television equipment.

Assume that C is charged at the beginning of a cycle. Pulse e_i is applied to the grid

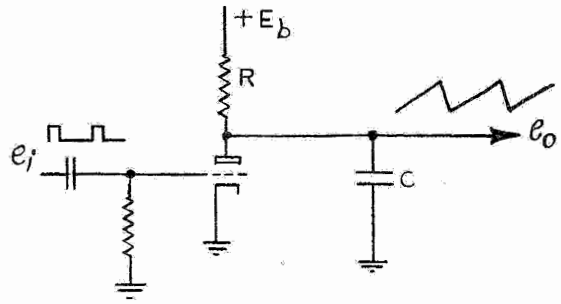

Figure 3-35 - Sawtooth Generator Circuit

with sufficient amplitude to drive the grid positive. The triode conducts heavily, discharging C. During the positive pulse interval, the flow of grid current produces a bias voltage across the grid resistor, of sufficient amplitude to cut the tube off when the pulse goes negative. Capacitor C charges exponentially through resistor R while the tube is cut off between pulses.

In the analysis of the sawtooth generator, certain assumptions will be made. First, we shall assume complete discharge of C during the pulse. Usually $\overline{r}_p \ll R$ and t_1 is long enough to permit the voltage across C to discharge to $E_b\overline{r}_p/(\overline{r}_p + R)$. With $\overline{r}_p \ll R$, we have $e_1 \approx 0$.

Now we shall define a linearity factor λ. Consider Figure 3-36 in which we have a linearly increasing voltage of constant slope de/dt. Such a voltage may be obtained by making the charging current constant, or

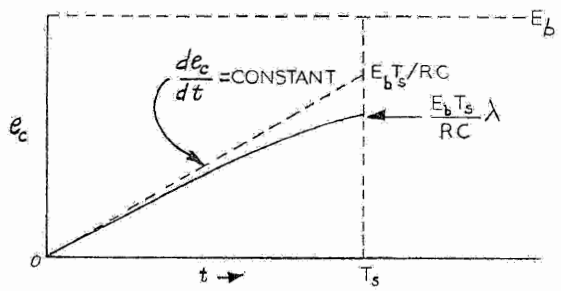

Figure 3-36 - Analysis of Sawtooth Voltage

$$e_c = \frac{1}{C}\int_0^t i\,dt$$

$$= \frac{i}{C}\,t$$

$$= \frac{E_b\,t}{RC}$$

In the ordinary sawtooth generator circuit, the charging current is not constant, but varies exponentially so that the voltage on C at the time T_s is less than the voltage for the ideal case by a factor λ, or

$$e_c = \frac{E_b\,T_s}{RC}\,\lambda$$

The linearity factor λ is thus expressed as the percentage of ideal voltage to which C charges in a simple circuit.

From the simple circuit we know that

$$e_c = E_b(1 - \epsilon^{-T_s/RC});$$

hence

$$\lambda = (1 - \epsilon^{-T_s/RC})\,\frac{RC}{T_s}$$

If we expand the exponential term about zero by means of a McLaurin's series we obtain

$$\lambda = \left[1 - \left(1 - \frac{T_s}{RC}\right) + \left(\frac{T_s}{RC}\right)^2\frac{1}{2} - \left(\frac{T_s}{RC}\right)^3\frac{1}{6} + \left(\frac{T_s}{RC}\right)^4\frac{1}{24} + \ldots\right]\frac{RC}{T_s}$$

$$= 1 - \left(\frac{T_s}{RC}\right)\frac{1}{2} + \left(\frac{T_s}{RC}\right)^2\frac{1}{6} - \left(\frac{T_s}{RC}\right)^3\frac{1}{24} + \ldots\Big]$$

Let us take the first two terms and rearrange

$$\frac{2}{\lambda} - 2 = \frac{T_s}{RC}\,\frac{1}{\lambda}$$

If we restrict the value of λ to the limits 0.75 to 1, we may write

$$\frac{T_s}{RC} \approx \frac{2}{\lambda} - 2$$

Substituting, we obtain

$$e_c \approx E_b \left(\frac{2}{\lambda} - 2\right) \lambda$$

$$\approx 2 E_b (1 - \lambda)$$

The preceding equations are useful for determining the charging time constant and output voltage for a given supply voltage and linearity requirement. The linearity factor usually varies from 0.90 to 0.95.

BLOCKING OSCILLATOR SAWTOOTH GENERATOR

The sawtooth generator described above requires a pulse driving signal of fairly good rectangular wave shape. If the driving pulse fails, no sawtooth output is obtained. A blocking oscillator can be used as a sawtooth generator to provide output voltage even though the synchronizing source may fail. Figure 3-37 is a circuit diagram of such a generator

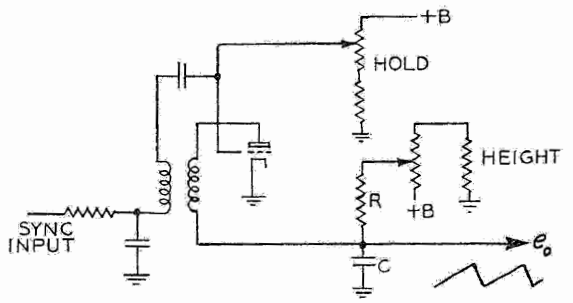

Figure 3-37 - Blocking Oscillator Sawtooth Generator

In this circuit, R and C form the sawtooth through the charging and discharging action of the tube. Assume that C is charging through R. Then the blocking oscillator conducts heavily, discharging C. When the grid is driven below cut-off, the tube ceases conduction, and C charges through R. The blocking oscillator is synchronized by a pulse signal whose wave form need not be rectangular. Frequency is adjusted to the synchronizing signal by the "hold" control. Amplitude of the sawtooth is adjusted by the "height" control.

LINEARITY

The linearity of the output voltage from the conventional sawtooth generators described above varies with the time constants used; and the voltage always is an exponential, instead of a linear, function of time. Special methods may be applied to improve the linearity of the sawtooth. One means by which linearity may be corrected is shown in Figure 3-38.

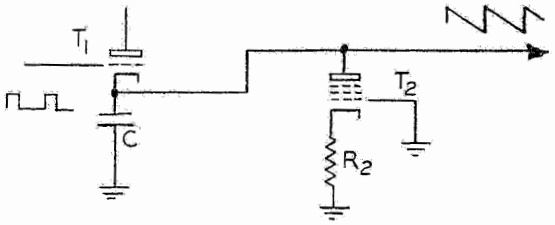

Figure 3-38 - Sawtooth Linearity Circuit

In this circuit C is charged during the input pulse and discharged through a constant-current pentode T_2. Since the discharge current is very nearly constant, the voltage on the capacitor becomes.

$$e_c = -\frac{1}{C}\int_0^t i\, dt$$

$$= \frac{Kt}{C}$$

The plate resistance of the pentode can be increased by using a large cathode resistor R_2, thus increasing the effective plate resistance by $1/(1 - g_m R_2)$

It will be noted that the output is inverted from the conventional sawtooth generator.

By the use of feedback to the pentode of Figure 3-38, a perfect sawtooth may be obtained. In Figure 3-39 a portion of the sawtooth output

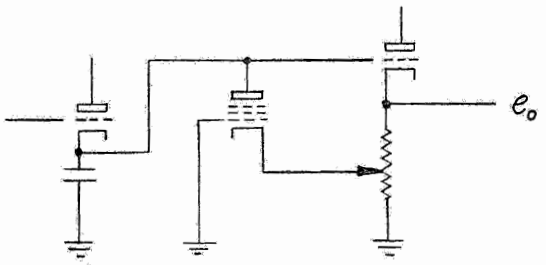

Figure 3-39 - Linearity Feedback Circuit

is fed back to the cathode of the constant-current pentode. The effective plate resistance is high as C begins to discharge, and decreases as the discharge proceeds. Not only may a linear sawtooth be obtained, but a strong overcorrection may be attained.

These, and other methods of linearity correction, are described in the December 1946 issue of "Electronics" in the paper "Linear Sweep Circuits" by Robert P. Owen.

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Brainerd, J.G., *Ultra-high Frequency Techniques*, D. Van Nostrand Company, Inc., New York, 1942.

MAGNETIC DEFLECTION

Deflection of the electron beam in kinescope and camera tubes is accomplished by a uniform magnetic field at right angles to the tube axis. When it travels through the magnetic field, the electron is subjected to a transverse force which causes it to move along an arc of a circle. On leaving the magnetic field, the electron continues along a straight line which is tangent to the arc at the field boundary, as shown in Figure 3-40. The electron emerges from

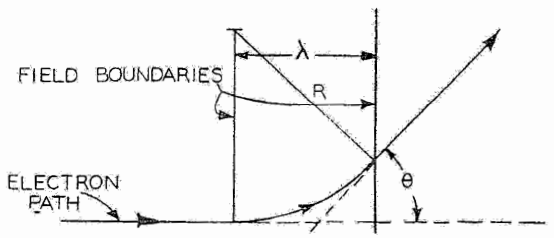

Figure 3-40 - Electron Path at Field Boundary

the field at an angle θ with respect to the original direction of motion. The total angle of deflection is 2θ. In present-day kinescope tubes, the maximum angle of deflection is 50° and is limited by inside neck diameter and length of field λ.

The magnetic field required for deflecting the electron beam in a television kinescope or pick-up tube is produced by passing a sawtooth current through a pair of series-connected coils on opposite sides of the tube neck. Formerly, the coils which make up the yoke were wound on a flat rectangular template, and then formed around a cylinder of a diameter equal to, or greater than, the tube neck. Present coils are machine-wound, and the cylindrical forming occurs during the winding process. Figure 3-41 is a rough sketch of a modern yoke winding.

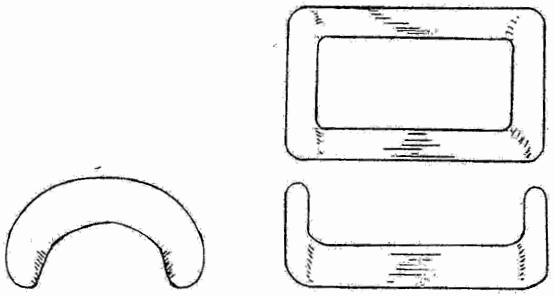

Figure 3-41 - Deflection Yoke Winding

The number of ampere-turns required to produce a given angle of deflection is calculated from

$$NI = \frac{2.68\ l_o\ \sin\theta\ \sqrt{E_a}}{\lambda}$$

where NI = ampere-turns of winding
l_o = length of air gap, inches
λ = length of magnetic field, inches
θ = 1/2 total deflection angle
E_a = accelerating potential, volts.

Note that the above value NI is for half the total deflection angle. To obtain NI for the total deflection angle, multiply by 2.

For a standard 4:3 aspect-ratio television raster, the value of the horizontal-winding ampere-turns is

$$(NI)_H = 0.8\ NI$$

while for the vertical winding it is

$$(NI)_V = 0.6\ NI.$$

VERTICAL DEFLECTION CIRCUIT

Figure 3-42 shows a vertical deflection circuit in its simplest form. The vertical yoke

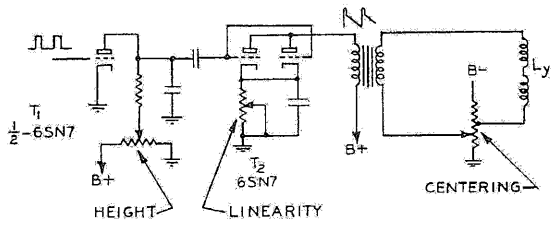

Figure 3-42 - Vertical Deflection Circuit

winding is transformer-coupled to a 6SN7 triode, T_2, with both sections parallel-connected. The driving sawtooth is generated in a conventional sawtooth generator, T_1.

Practical values for the vertical winding of the yoke are $L = 43$ millihenrys and $R = 70$ ohms. At the vertical scanning frequency the load impedance becomes

$$Z_y = 70 + j18.1$$

In the design of the transformer and driving circuit, the inductive component of the load is neglected. The problem then becomes one of designing a transformer which will match the yoke resistance to the driver tube and present sufficient primary inductance for good low-frequency response. A type 6SN7 triode provides sufficient output to deflect a 9-kv beam. The plate resistance of the 6SN7, parallel-connected, is approximately 3500 ohms. For maximum power output, the load should be $2r_p$; therefore the reflected load of the yoke should appear as 7000 ohms on the primary side. The transformer turns-ratio becomes

$$N_p/N_s = \sqrt{Z_p/Z_s} = \sqrt{7000/70} = 10/1.$$

Good low-frequency response is obtained by making the primary inductance large. In the RADIOTRON DESIGNER'S HANDBOOK the ratio of low-frequency gain to mid-band gain is given as

$$A_r = \frac{1}{\sqrt{1 + (r_p/L_p)^2}}$$

If the response at 30 cycles is to be 1 db down, A_r becomes 0.89, from which

$$L_p/r_p = 1.94.$$

For the circuit of Figure 3-42 the primary inductance should be 18 henrys. Actually, for standard vertical-deflection transformers, L_p varies from 40 to 60 henrys.

Some control of linearity may be obtained by varying the bias voltage of T_2. Usually, the sawtooth amplitude and bias are adjusted together to place the operating point in the most linear portion of the tube curves.

The picture is centered by adjusting the centering potentiometer so that a steady d-c current flows in the yoke. Current may be caused to flow in either direction to move the picture in either direction.

No external damping of the yoke winding is required, in the majority of cases, since the plate resistance of the tube is reflected to the transformer secondary. If external damping is required, a resistor of proper value may be placed across the yoke winding.

AUTOMATIC LINEARITY CONTROL

Picture linearity may be corrected by the linearity correction devices previously discussed. Additional tubes and circuit components are required, however, and if the expense is justified, an automatic control may be used.

Figure 3-43 shows an automatic linearity control circuit recently developed by the Advanced Development Section, Home Instruments Department.

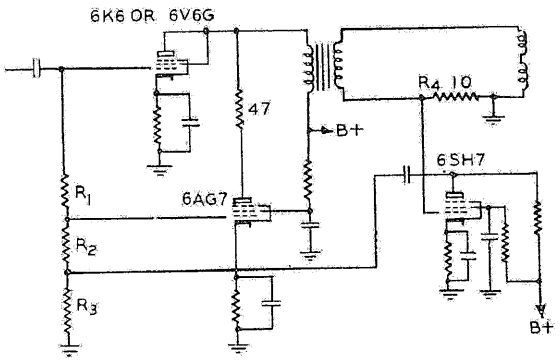

Figure 3-43 - Automatic Linearity Control Circuit

The circuit operates as follows. A pilot voltage is developed across R_4 in the yoke circuit, which is proportional to the current in the yoke. This voltage contains the distortion of the current sawtooth and is shown in Figure 3-44(a).

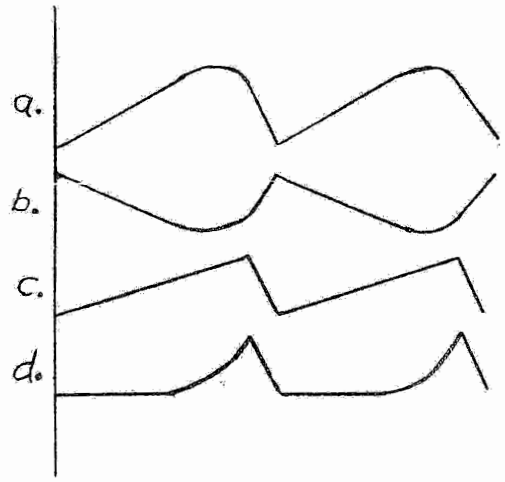

Figure 3-44 - Sawtooth Linearity Control
a. *Current Sawtooth Containing Distortion*
b. *Plate 6SH7 Sawtooth Plus Distortion*
c. *Input Sawtooth*
d. *Grid 6AG7 Distortion Only.*

The distorted sawtooth is amplified in a high-gain pentode and fed to the top of R_3. A sawtooth of good linearity is fed into the driver tube, 6K6 or 6V6, and also to R_1. In the resistance network R_1R_2 the linear sawtooth is compared to the distorted sawtooth, and the existing distortion is placed on the grid of the 6AG7. The distortion signal causes the plate of the 6AG7 to draw a current which cancels the original distortion.

In this system, picture size may be changed over wide limits with negligible vertical distortion. The values of R_1 and R_2 should be less than one-half megohm to prevent integration of the linear sawtooth.

HORIZONTAL DEFLECTION CIRCUITS

Circuit design for magnetic deflection of the electron beam at horizontal-line frequencies requires a different approach than for vertical deflection. At 15,750 cycles per second, the yoke presents a load which is almost entirely reactive. Unless means are devised to recover a portion of the power fed into the yoke during trace time, a relatively high amount of power must be expended in deflecting the beam. An ideal cyclic system such as that discussed by Otto Schade in RCA REVIEW for September, 1947, requires wattless power. This system will form the basis for study of the horizontal-deflection problem.

Consider the simple circuit of Figure 3-45, The yoke is represented by L_y, C_y, R_y. Suppose that switches S_1 and S_2 are open at the time $t = 0$. At the beginning of the deflection cycle, S_1 is closed, applying voltage E across L_y, R_y, and C_y. If it were not for R_y, the current through L_y would increase linearly with time, as expressed by the relation

$$\frac{di}{dt} = \frac{E}{L} .$$

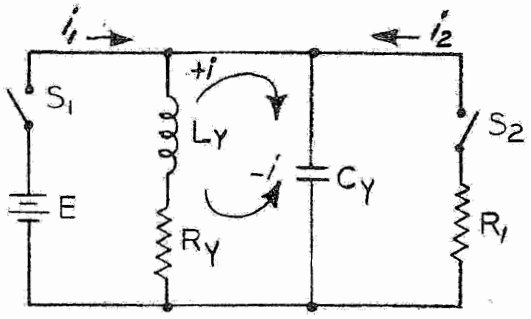

Figure 3-45 - Equivalent Horizontal Deflection Circuit

Since R_y is present, the current rises exponentially until switch S_1 is opened. At this point, the beam has been deflected to the right-hand side of the picture. The magnetic field must be reversed quickly in order to return the beam to the left-hand side of the picture, to begin another trace.

Since L_y, C_y, and R_y form a resonant circuit, the fastest means for reversing the field is to permit the winding to oscillate for approximately one-half cycle at its natural resonant frequency.

When S_1 is opened, the magnetic energy stored in the field of L_y is converted into potential energy by the flow of $+i$ into C_y, and back into magnetic energy by the flow of $-i$, resulting in an almost complete reversal of the field. Losses in the resonant circuit limit the completeness of reversal to

$$\frac{i_1}{i_2} \approx \epsilon^{-\pi/2Q}$$

Figure 3-46 indicates the current and voltage waveshapes in the yoke for a complete deflection cycle.

When the current in the yoke has reached the value $\hat{i}_2$ in the negative direction, switch S_2 is closed, which places damping resistor R_1 across

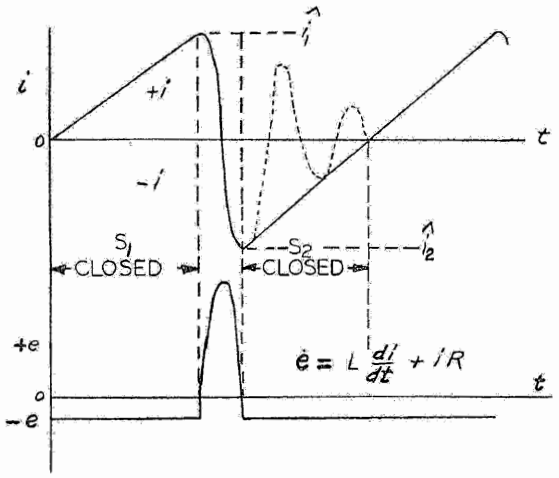

Figure 3-46 - Deflection-cycle Waveshapes

the oscillating circuit. If S_2 were not closed, the yoke would continue to oscillate, as shown by the dotted lines in Figure 3-46. Closing of S_2 causes the oscillatory circuit to be slightly overdamped, so that $-i$ decays exponentially. When $-i$ reaches zero, S_1 is closed again to begin another cycle.

Because of the presence of the iR drop in the inductance, the resultant current wave form in the yoke is exponential instead of being linear with time, as desired. If the iR drop can be canceled, the total voltage E may be applied to L_y, resulting in a linear current in the yoke. Suppose we insert a generator in series with E, whose characteristic is

$$\frac{\Delta e}{\Delta i} = -R .$$

Then a linear rise of current in L_y may be obtained. Reference to the plate-family of curves for a vacuum tube reveals that a tube may serve as such a generator and as an electronic switch to replace S_1. Also, we may use a vacuum tube to replace S_2 and add $-R$ for the oscillatory phase. Such a circuit is shown in Figure 3-47.

The operation of the tube may be plotted from its family of curves. Refer to Figure 3-48. The load line $-R$ is so drawn that it intersects the plate-voltage, or zero-current, axis at the point $E - L\ di/dt$. A plot of current-versus-time is obtained from the intersection of the $-R$ line with the grid-voltage lines. The grid-voltage waveshape e_g is obtained for the tube

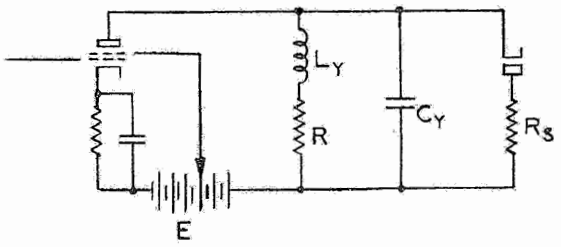

Figure 3-47 - Electronic Switch and Generator Circuit

by plotting E_{c1} against time for corresponding values of current i.

The diode characteristic is plotted in a similar manner. The voltage causing diode conduction, however, becomes $L\ di/dt$ and is equal

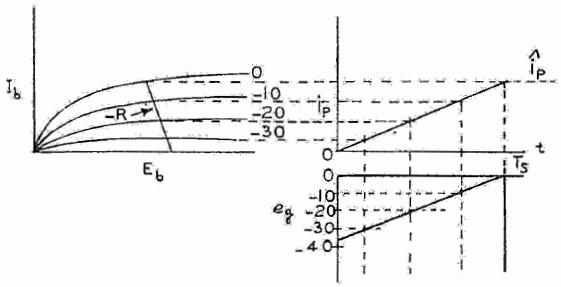

Figure 3-48 - Tube Operating Curves

to the drop across the inductance during trace time. The load line for the diode must be drawn for $r_d + R_s$, where r_d is the diode resistance. Schade states that linearity in the diode circuit occurs when

$$R_s = [E - (\hat{i}_1 R + E_d)]/\hat{i}_2 .$$

The circuit operation may be improved by replacing the diode with a controlled triode. For simplification, a transformer is added, and the circuit becomes the one shown in Figure 3-49.

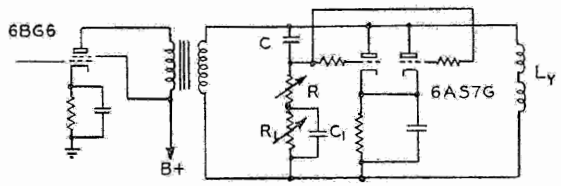

Figure 3-49 - Improved Switching Circuit

The combined characteristics of the beam tetrode and the triode are shown in Figure 3-50. Note that the characteristics resemble those of the ordinary push-pull arrangement.

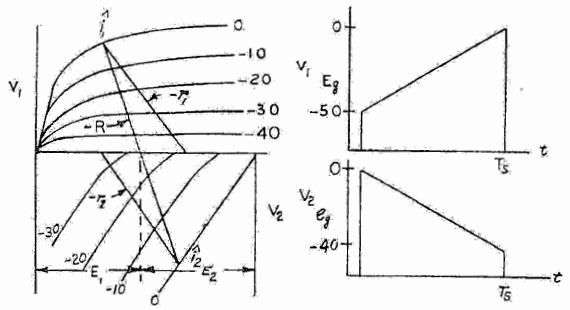

Figure 3-50 - Combined Characteristics of Beam Tetrode and Triode

In the ideal case, in which there are no losses, the 6BG6 driver tube supplies half the deflection current, and the 6AS7 triode damper supplies the remainder from the stored energy. Such utilization of current is shown in Figure 3-51. Because of losses in the actual circuit, the driver tube must supply about 60% of the total deflection current.

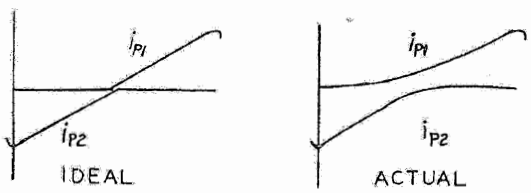

Figure 3-51 - Deflection Circuit Operation

The control-grid voltage for the triode damper is generated by differentiation of the pulse voltage across the yoke. The values of *RC* are determined by the equation

$$\frac{T_S}{R_C} \approx \frac{2}{\lambda} \cdot 2$$

where λ = linearity of voltage rise = 0.3 to 0.8.

Usually R is made variable for adjusting linearity.

The combination $R_1 C_1$ has a long time-constant and is placed in the grid circuit for establishing grid bias for the triode by the flow of grid current on the peaks of the grid voltage.

REFERENCES

Maloff, I. G., and Epstein, D. W., *Electron Optics in Television*, McGraw-Hill Book Co., Inc., New York, 1938.

Schade, O. H., *"Magnetic Deflection Circuits for Cathode-Ray Tubes,"* RCA Review, September, 1947.

VIDEO AMPLIFIERS

REQUIREMENTS - The nature of the picture signal imposes certain requirements upon the video amplifier, which must be met if fine picture detail is to be resolved. First, the bandwidth must satisfy the relation

$$f_n = A_r n \frac{10^6}{H_a \times 2}$$

where f_n = fundamental frequency for n lines
A_r = aspect ratio = 4/3
n = number of lines to be resolved
H_a = active trace time, microseconds.

Since horizontal blanking occupies 16% of the horizontal period, the active trace time, H_a, is 0.84 × 63.5 = 53.3 microseconds. To resolve 400 lines, the bandwidth must be

$$f_n = \frac{4}{3} \times \frac{400 \times 10^6}{53.3 \times 2} = 5 \text{ megacycles}$$

In practice, the output of the video transmitter is specified by standards to include all frequencies between 30 cps and 4 megacycles per second. Hence, the video amplifier must amplify, without discrimination, at least those frequencies between 30 cps and 4 megacycles per second. Usually, the video amplifier is designed with a bandwidth exceeding these limits.

Also, the video amplifier must have a minimum time-delay discrimination. This requirement is fulfilled when the phase angle between input and output voltages is proportional to frequency.

Finally, there are requirements for the video amplifier which are set by standards or practice, some of which are output-voltage levels, terminal impedances, permissible signal-to-noise ratio, etc.

FREQUENCY RESPONSE - Low-frequency response of an RC-coupled amplifier is determined by the time-constant of the coupling capacitor and grid-leak resistor. In practice, good low-frequency response is obtained by making the time-constant large or by using clamp circuits.

High-frequency response is limited by shunt capacity across the plate-load resistor. This shunt capacity includes the tube input and output capacity, wiring capacity, and stray capacity of circuit components. Good high-frequency response is obtained by utilizing the various shunt capacities as elements of a low-pass coupling filter.

Figure 3-52 is a diagram of a constant-K low-pass filter consisting of one full section and one half-section terminated in its characteristic impedance. The terminating half-section is added for impedance matching purposes. When the low-pass filter is properly designed and terminated, the characteristic impedance is constant to almost the cut-off frequency. Connection of the coupling filter to the amplifier tubes is shown in Figure 3-53. In Figure 3-53

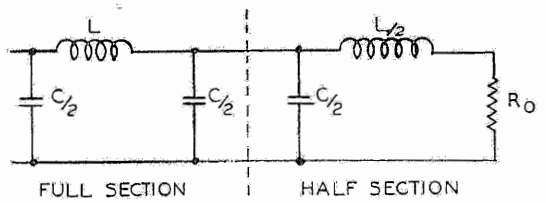

Figure 3-52 - Constant-K Low-pass Filter

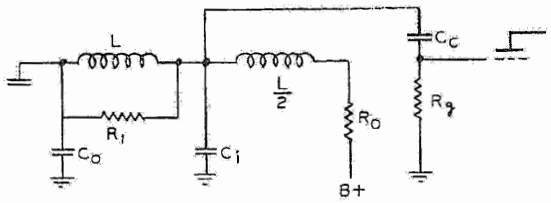

Figure 3-53 - Coupling Filter-connection

C_o and C_i are output and input capacities of the tubes. For this particular type of low-pass filter, the following equations apply:

f_c = *cut-off frequency*

$$R_o = \frac{1}{\pi f_c C_i}$$

$$L = R_0^2 C_i$$

$$C_o = \frac{C_i}{2}$$

$$R_1 = (5 \text{ to } 10) R_o$$

$$A = g_m R_o$$

The resistor R_1 is added to lower the Q-factor of the series inductance. A peak in the response curve will result prior to cut-off if the Q-factor is not optimum.

The characteristics of the constant-K low-pass filter depend upon the components being pure inductances and pure capacitances. It has been shown that distributed coil capacity converts the constant-K type into an M-derived filter, as shown in Figure 3-54.

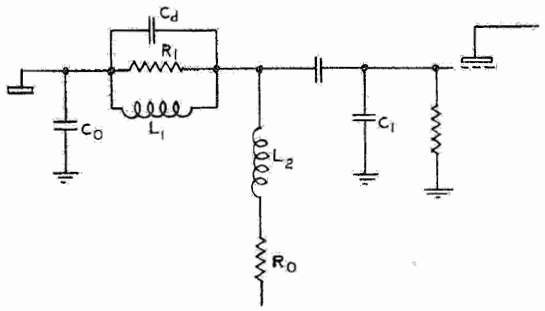

Figure 3-54 - Effect of Coil Capacity on Constant-K Filter

Equations for the M-derived filter are as follows:

$$M = \sqrt{1 + \left(\frac{C_d}{C_o}\right)^2} - \frac{C_d}{C_o}$$

$$R_o = \frac{M}{\pi f_c C_i}$$

$$L_1 = R_0^2 C_i$$

$$L_2 = 0.8 L_1 \text{ approx.}$$

$$R_1 = (5 - 10)\, R_o$$

$$A = g_m R_o$$

Practical video amplifiers use the M-derived low-pass filter as a means of coupling amplifier stages.

Diagnosis curves are given in Figures 3-55 and 3-56 to aid in the alignment of video amplifiers using low-pass filter coupling.

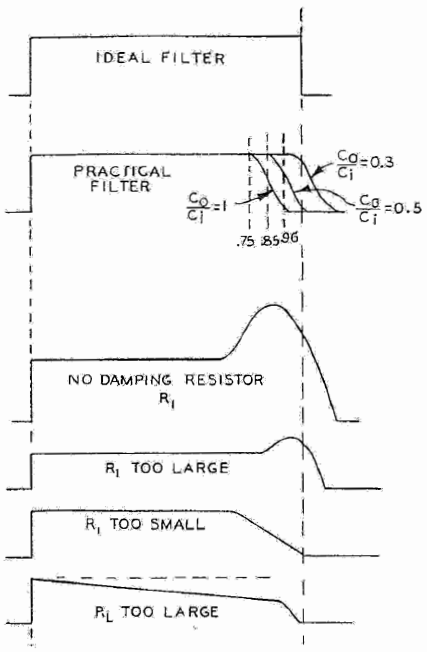

Figure 3-55 - Diagnosis Sheet #1

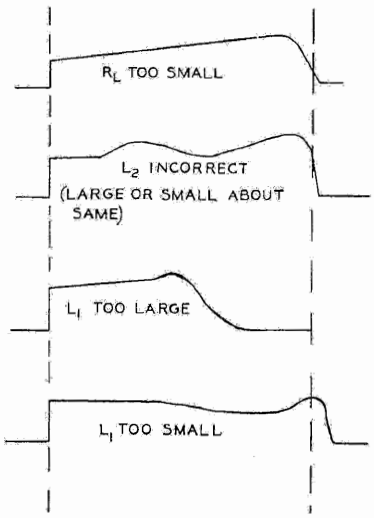

Figure 3-56 - Diagnosis Sheet #2

CLAMP CIRCUITS

The clamp circuit is often used as a "D-C Restorer"; however, it can also be used to restore low frequencies in a video amplifier. Its operation in the latter application will be described first.

Consider the video signal for a half-black, half-white picture applied to the input of a video amplifier whose frequency response is very poor below the horizontal-scanning frequency. Assume that horizontal blanking pulses are also introduced at the amplifier input, and that they are of greater amplitude than any other part of the video signal. A sketch of the picture and the corresponding video signal with horizontal blanking is shown in Figure 3-57.

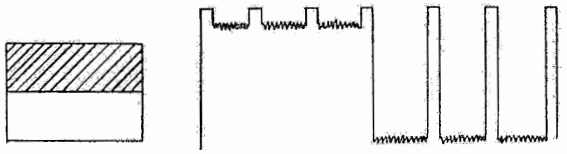

Figure 3-57 - Half-black, Half-white Picture and Video Signal

After this signal has passed through the amplifier, the low-frequency components will be missing, and the signal will distribute itself about an a-c axis as shown in Figure 3-58. Low-frequency components are, in this case, considered to be any components of less than the horizontal scanning frequency. The transitory periods immediately following the change from black to white are not shown in Figure 3-58.

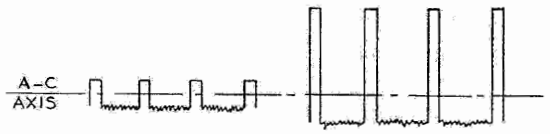

Figure 3-58 - Video Amplifier Output Signal

Note that, if we could bring the peaks of the horizontal blanking pulses that occur during the "black" portion of the picture to the same level as the peaks of those that occur during the "white" portion, the signal would again be identical to that in Figure 3-60. In other words, the low-frequency components would then be restored because the output signal would be similar in shape to the input signal.

Figure 3-59 shows a hypothetical circuit for bringing all of the blanking pulses to the same level. The time-constant of R and C must be

sufficiently small so that C is discharged before the blanking pulse is over. The switch is so controlled that it closes at the start of the blanking pulse and opens *before* the end of the pulse. Because of these conditions (grid of the tube floating during the time the switch is open, grid-side of C being always brought to ground potential during the pulse, and switch opening before the pulse is over), *the remaining portion of the pulse always falls at the same point on the tube's operating characteristic.* As explained in the preceding paragraph, this is equivalent to restoring the low-frequency components.

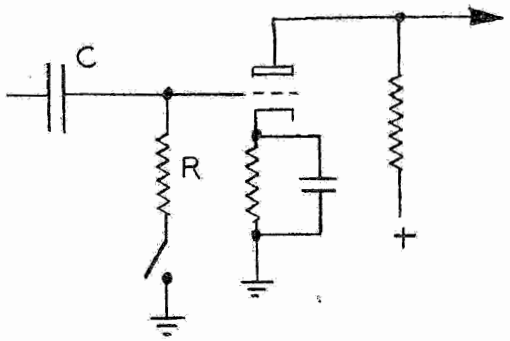

Figure 3-59 - Simplified Clamp Circuit

A clamp circuit, shown in Figure 3-60, is electrically equivalent to the arrangement of Figure 3-59. The diodes replace the switch of Figure 3-59, and the switch control is supplied by the diode keying pulses. The circuit "clamps" on the periodic pulses in the video signal, which in the given example are horizontal blanking pulses; hence its name.

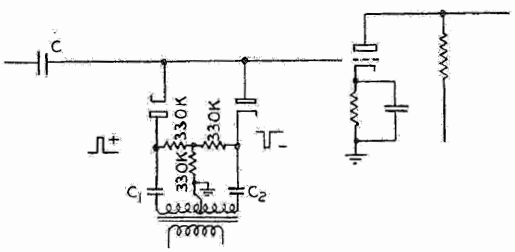

Figure 3-60 - Clamp Circuit

The keying pulses (which should not be confused with the clamp pulses) are 180 degrees out of phase, so that both diodes become conducting simultaneously. By using this balanced arrangement, the keying pulses cancel out at the grid of the amplifier tube, and are therefore not added to the desired signal. It is essential that the keying pulses end before the clamp pulses, as explained above. Horizontal synchronizing signal makes ideal keying pulses. The amplitude of the keying pulses must also be greater than the clamp pulses, so that the diodes can be made conducting during keying time. Practice has shown that the keying pulses should be one-and-a-half to two times as large as the clamp pulses.

It is important to note that pulses other than horizontal blanking can be used to clamp on. The only requirements are that they be greater in amplitude than any other part of the video signal, that their peaks represent constant amplitude in the input signal, and that their frequency be sufficiently high for the amplifier to pass them without frequency or phase distortion. Of course, they must not interfere with the desired signal. Hence, for television work, they must occur at horizontal scanning frequency, and during horizontal blanking time. Their polarity, with respect to the video signal, is unimportant.

The coupling capacitor C and the resistance between grid and ground during keying time must have a sufficiently small time-constant for C to discharge during keying time. For 15-kc clamp pulses, the value of C can be between 100 and 500 $\mu\mu f$. The coupling capacitors, C_1, and C_2, are also somewhat critical because the diodes are self-biased by them and their associated "leak" resistors. The bias developed is proportional to the amplitude of the keying pulses, in a manner similar to that of a conventional diode detector. Values for C_1 and C_2 are best determined by experiment. Values which have been used in the past lie between 0.003 μf and 0.1 μf for the leak resistances shown.

In some cases it may be desirable to return the grid of the amplifier tube to a fixed-bias source instead of to ground. The bias source is then introduced in series with the ground lead shown in Figure 3-60.

The source of the keying pulses is of importance. A center-tapped transformer is desirable because it provides balanced pulses easily, and the source-impedance is low. A tube with load resistors in both plate and cathode circuits (cathode-follower type of phase inverter) can be used to provide keying pulses. This tube should preferably operate with a negative-polarity pulse on its grid, so that the tube is cut off during keying time. Otherwise, the source-impedance will be different for the positive and negative output pulses, due to cathode-follower action. An unbalance in the source-impedance may adversely affect the operation of the clamp circuit.

The clamp circuit can be modified to advantage when only single-polarity keying pulses

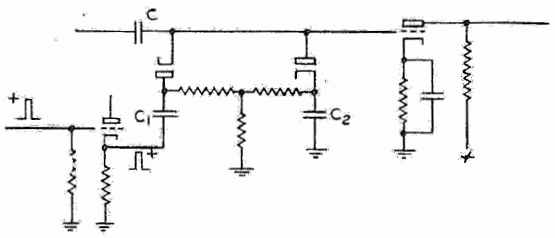

Figure 3-61 - Clamp Circuit for Single-polarity Keying Pulses

are available. This is shown in Figure 3-61. In this circuit, a single keying pulse makes both diodes conducting because they are in series, as far as the keying pulse is concerned. The disadvantage of this circuit is that a small amount of the keying pulse is super-imposed on the video signal because of the unbalance. When horizontal sync pulses are used as keying pulses, this circuit will add a small amount of sync to the video signal; this will some times be an advantage rather than a disadvantage. If vertical sync is unavoidably present along with the horizontal, the coupling capacitors C_1 and C_2 should be increased to 0.5 μf.

Another version of the clamp circuit is shown in Figure 3-62. Only single-polarity keying pulses are required. The source-impedance of the keying pulses can be high, but the circuit provides a low-impedance path between grid and ground during keying time.

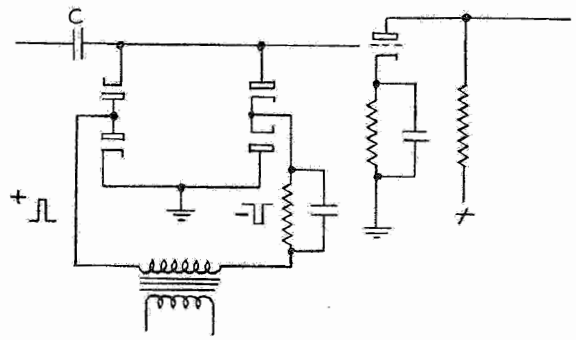

Figure 3-62 - Clamp Circuit for Single-polarity Keying Pulses

THE CLAMP CIRCUIT AS A D-C RESTORER

Since, as was just shown, the clamp circuit effectively restores low frequencies, the same reasoning can be extended to say that the clamp circuit will also restore the d-c component of the video signal. Without d-c restoration, the a-c axis of any signal will pass through the operating point of the tube characteristic to which that signal is applied. However, when the clamp circuit is used on the grid of an amplifier tube (or kinescope), the clamp pulses in the signal are always referred to the same point on the characteristic, regardless of signal amplitude or wave form. In other words, the a-c axis is shifted as the signal amplitude and wave form vary, and a shift in the a-c axis of a wave is equivalent to adding a d-c component. The clamp circuit has the advantage over the simple, single-diode type of d-c restorer in that it responds very quickly to signal changes, whether they be increasing or decreasing; whereas the simpler type has appreciable time lag when the signal suddenly decreases.

PICK-UP TUBES

TYPES - Two types of pick-up tubes are in general use today, namely, the iconoscope and the image orthicon. The iconoscope dates back to about 1923, when it was developed by Dr. V. K. Zworykin. It is still being used for motion-picture pick-up. The image orthicon has replaced the iconoscope for live-talent pick-up. Image-orthicon development was hastened by wartime requirements, and progress on the stabilization and improvement of this tube has been rapid.

ICONOSCOPE - The iconoscope pick-up tube may be used where the scene is illuminated by incident light of approximately 1500 foot-candles. Under ideal lighting conditions, the pictures obtained have excellent resolution and low noise-level. The intensity of illumination, however, limits the use of the iconoscope for outdoor events. When incandescent lighting is used in studios, the problem of removing the heat arises. At present, the iconoscope is used in film cameras only where the motion-picture projector provides ample illumination on the iconoscope mosaic.

The iconoscope contains a photo-sensitive mosaic, a collector ring, and an electron gun. A sketch of the tube is shown in Figure 3-63. The electron gun is set at an angle with the mosaic in order to clear the front of the tube, so that an optical image may be focused on the mosaic.

A uniform mica plate, 0.001 inch thick, is the basic structure upon which the mosaic is constructed. A fine coating of silver oxide is sifted upon the mica. Then, the structure is baked in an oven. The heat produces pure silver from the silver oxide. The pure silver congeals into thousands of small droplets. Then the mica plate is placed in the presence of cesium vapor and oxygen, and a glow discharge is passed through the tube. Silver oxide, cesium oxide, and pure cesium are formed. By this process,

small photo-sensitive islands are formed on the mica. The mosaic is completed by coating the back side of the mica with colloidal graphite to form the signal plate which is capacity-coupled to the photo-sensitive surface. Better color response is obtained by the process of silver sensitizing, in which a small particle of pure silver is heated in a filament while the tube is on the pumps. Silver vapor settles on the photo-sensitive islands and gives the mosaic better response toward the blue end of the visible spectrum.

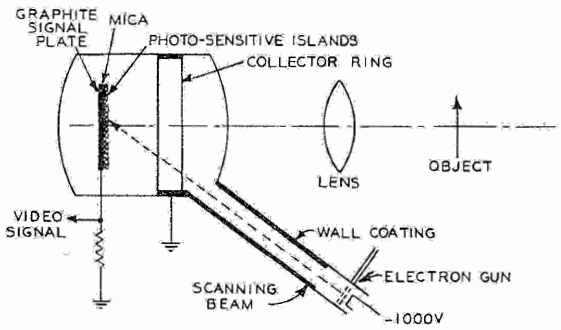

Figure 3-63 - Iconoscope Pick-up Tube

The iconoscope is a storage-type device in which the varying illumination of an optical image on the mosaic causes emission from the photo-sensitive islands. The charge on each picture element represented by the photo-sensitive element remains constant until released by the scanning beam. The operation of the iconoscope is best understood by considering first the action resulting from scanning the mosaic in darkness, *i.e.*, with no optical image or light on the mosaic.

With the collector ring grounded and the cathode potential fixed at -1000 volts, the beam acquires a kinetic energy of 1000 electron volts by the time it reaches the mosaic. On striking the mosaic, the beam causes secondary emission of electrons from the photosensitive islands, *i.e.*, each beam electron knocks several secondary electrons off the photosensitive island. The ratio of secondaries to beam electrons is 6:1 under dark conditions. The secondary electrons, for the most part, rain back on the mosaic. Enough secondaries travel to the collector ring for the collector-ring current to be equal to the beam current (since the mosaic is completely insulated, the current leaving it must equal the current arriving in the scanning beam)

Figuratively speaking, the scanning beam plows along the mosaic, causing an eruption of secondary electrons from the photo-sensitive surface. The element under the scanning beam charges up to about 2 volts, due to loss of electrons. This value represents the maximum charge which the element can attain by secondary emission and is known as the white level. As the scanning beam moves across the mosaic, part of the electron shower can fall back on the scanned area and reduce the positive charge on picture elements just scanned. At the right-hand edge of the mosaic, however, the scanning beam is turned off for retrace, and no more secondaries are generated to discharge the last part of the trace. Similarly, the beam is cut off at the bottom of the mosaic for vertical retrace; therefore, the last few scanning lines do not receive a proportionate share of the electron rain and remain partially charged. Remember that this action is occurring in complete darkness.

As the electron beam starts scanning the second frame, it encounters elements of the mosaic on the right-hand side and on the bottom that are partially charged, due to the loss of electrons. These elements appear as though they had been exposed to white light. When the beam scans them, fewer secondaries are emitted, and a signal voltage is impressed on the signal plate. This voltage has the waveshape shown in Figure 3-64 vertical and horizontal scans. It is an unwanted signal, that is due to uneven redistribution of secondary electrons, and it is called a shading signal. For eliminating shading signals, equal-amplitude opposite-phase signals are fed

Figure 3-64 - Shading Signal Waveshape

into an amplifier stage following the pick-up tube. The unwanted signal may, fortunately, be effected by a combination of parabolic and sawtooth signals which can be generated quite easily.

Now we may consider the action of the scanning beam when the mosaic is illuminated by a scene. Bright areas in the scene cause the islands to emit electrons. These electrons travel to the collector ring or redistribute themselves over the mosaic. Suppose a gray tone causes a photo-sensitive island to charge up to +1.5 volts. Then, when the scanning beam comes along, this particular element can only be charged by a differential of 0.5 volt to the white level. On the other hand, a black area

leaves the element discharged until it is scanned, at which time the element can charge to the full 2-volt white level. The video signal current in the load resistor is shown in Figure 3-65.

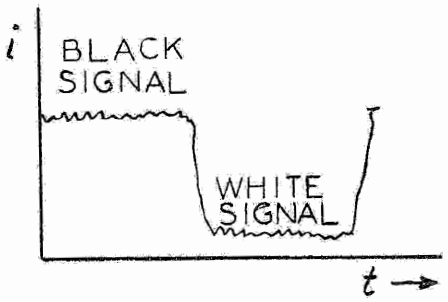

Figure 3-65 - Video Signal for Illuminated Scene

In Figure 3-63 the electron gun for the iconoscope is shown at an angle with the mosaic. This geometrical arrangement produces an effect known as keystoning. For a given angle of deflection of the scanning beam, more of the mosaic top is scanned than the bottom. If no correction were applied to the horizontal scanning generator, the resultant pattern on a monitor would appear as shown in Figure 3-66.

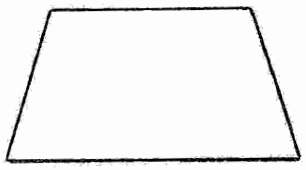

Figure 3-66 - Keystone Pattern

To correct for keystoning, the horizontal scanning generator is modulated by a 60-cycle sawtooth that increases the horizontal scanning current peak-to-peak value linearly at a 60-cycle rate, so that the angle of deflection becomes larger as the beam is deflected vertically.

IMAGE ORTHICON PICK-UP TUBE - The image orthicon is at least 100 times more sensitive than the iconoscope. Also, it is free from the annoying shading and edge-flare effects of the iconoscope. It will deliver a satisfactory picture, without readjustment, when the scene brightness changes by a factor of 100 to 1. A satisfactory picture may be obtained when the incident light on the scene is only 10 foot-candles. The sensitivity of the image orthicon makes it an ideal tube for pick-up of outdoor events.

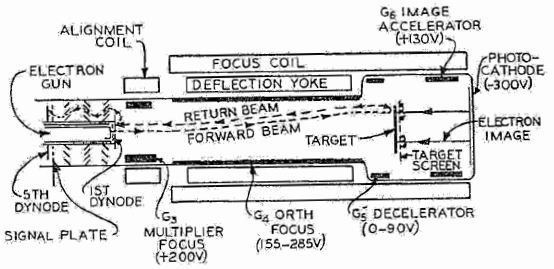

Figure 3-67 - Image Orthicon Pick-up Tube

A sketch of the image orthicon tube construction is shown in Figure 3-67. The tube contains an electron gun with a grid for controlling the current in the scanning beam. The #3 grid, sometimes called the "persuader", causes electrons from the first dynode to go to the second dynode. The #4 grid, which is the coating on the tube wall, together with the magnetic focusing field, focuses the electron beam on the target. The decelerating ring, grid #5, produces an electric field which improves corner focus.

The target is a special glass membrane stretched in a metal ring. The thickness of the glass is approximately 0.0001 inch. On the image side of the target, and at a distance of 0.001 inch, is a mesh screen having 250,000 holes per square inch.

Grid #6 is a ring placed between the target and photocathode. It aids the focusing of electrons from the photocathode on the target.

The photocathode is a transparent layer of cesium in type 2P23 tubes, antimony in type 5769 tubes, and bismuth in type C73150 tubes. The cesium tubes have high infra-red response, while the antimony and bismuth tubes have a more uniform color response in the blue regions.

IMAGE ORTHICON OPERATION - When an optical image is focused on the photocathode, electrons are emitted in proportion to the light and dark areas of the scene. Since the photocathode is at a potential of about -300 volts with respect to the ground and the target screen, the electrons are accelerated toward the target. The action of the focusing coil and the #6 grid focuses the electrons on the target. Thus the optical image is converted into an electron image which bombards the target.

Bombardment of the target causes an emission of the electrons from the glass. Secondary electrons released by the target are collected by the screen. Secondary emission leaves a positive charge pattern on the front of the target, corresponding to the electron image.

Because of the thinness of the glass target, it does not matter, for the electron beam, on which side of the glass the positive charge lies. Upon its arrival near the target rear surface, the beam deposits enough electrons to neutralize the charge. The remainder of the beam turns around and heads toward the rear of the tube. During frame time, the deposited electrons flow through the glass and unite with the positive charge.

The returning electron beam is equal to the electrons emitted by the cathode (nearly a constant number) minus those electrons deposited on the target. The returning beam, therefore, is the original beam modulated by the video signal.

An electron multiplier is located at the rear of the tube. The construction of this multiplier is shown in Figure 3-68.

It is such as to offer an almost opaque surface to the electrons entering from the front. Electrons leaving each dynode, however, find negligible resistance to their travel.

The return beam containing the video information strikes the first dynode, causing secondary emission. The secondary electrons are persuaded to the second dynode by the action of the "persuader," or multiplier focus electrode. As the beam travels from dynode to dynode, the original

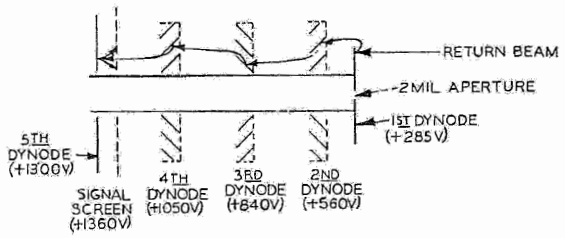

Figure 3-68 - Electron Multiplier for Image Orthicon

return beam is multiplied by secondary emission. The final signal is removed from the signal plate. The overall gain in the electron multiplier can be as high as 2000.

In tube manufacture, the electron gun may become tilted with respect to the tube axis. Electrons emitted from such a gun would enter the focus field with a transverse component of velocity. A force would be developed, which would cause the beam to travel in a radius about the tube axis. The net effect is a spiraling of the beam down the tube. To correct for misalignment of the electron gun, an alignment coil is placed just in front of the gun. It produces a transverse field which cancels the deflection of the beam due to gun tilt.

LIVENESS IN BROADCASTING

By J. P. Maxfield

Bell Telephone Laboratories

(Reprinted From Western Electric Oscillator, Through Courtesy of Western Electric Company)

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 you 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, a singer, or perhaps to someone telling you the latest news, with two ears. The binaural sense which results from the use of the two ears enables you to pay attention to the sound arriving from any desired direction and to partially exclude the sound from other directions. Similarly, you 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.[1,2]

Therefore, the situation may be summarized as follows:

(1) You have lost all ability to accentuate at will certain parts of the sound such 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 accentuated.

Any studio technique which is to reproduce life-like and realistic programs must (1) provide the studio engineer with a means of supplying the necessary accentuation lost by the failure 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 auditorium sound pick-up 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 pick-up is as much as 6 db gain in coverage at no extra expense to the sponsor or the broadcasting company.[3]

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" pick-ups. 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 space, such as a studio or auditorium, including the effect of the distances from the artists to the pick-up microphones.[4] The properties of this constant are such that the formula can be readily applied to the use of one general or "over-all"

[1,2] Superior figures refer to Bibliography

microphone in combination with the necessary additional microphones for accentuation purposes.

The liveness formula is:

$$L = \frac{1000T^2D^2}{G_p V} \qquad (1)$$

where L = Liveness
T = Reverberation Time in Seconds
D = Distance from Sound to Microphone in Feet
V = Volume of Studio in Cubic Feet
G_p = Directivity of Pick-up Microphone from source to microphone.

The value of T used for the practical application of this technique to broadcast pick-up is an average of the values over the frequency range from 500 cps, to 2000 cps. Where this average is unknown, the value at 1000 cps or even 500 cps may 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 pick-up the limits of the value of liveness selected for best monaural pick-up 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 pick-up varies materially from one type of sound to another as, for instance, from symphony orchestra to solo singing to speech. Table 1 shows the values of the monaural liveness range for several different types 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.

TABLE 1

Type of Sound	Liveness Range
Piano	4-16
Symphony Orchestra	5-20
Small Orchestra	3-12
Solo violin, cello, etc.	1- 4
Solo singing	1/2- 3
Speech	1/6-2/3

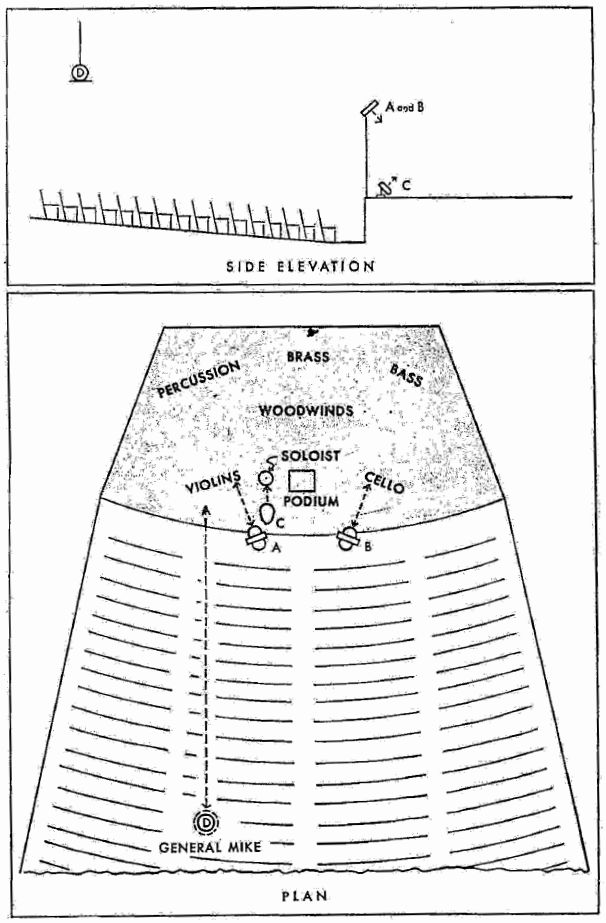

Figure 1--Large auditorium with a symphony orchestra. A and B, accentuation microphones; C, solo microphone; D, general microphone. Dotted lines show distances which can be computed as described elsewhere.

INCREASED SENSE OF REALITY

If sound is reproduced from a pick-up in which the liveness is controlled within the useful range as shown in Table 1, the subjective effect might be described as the acoustic recreation of the pick-up 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 to so 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 pick-ups 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 pick-up.

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 pick-up may 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 pick-up 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

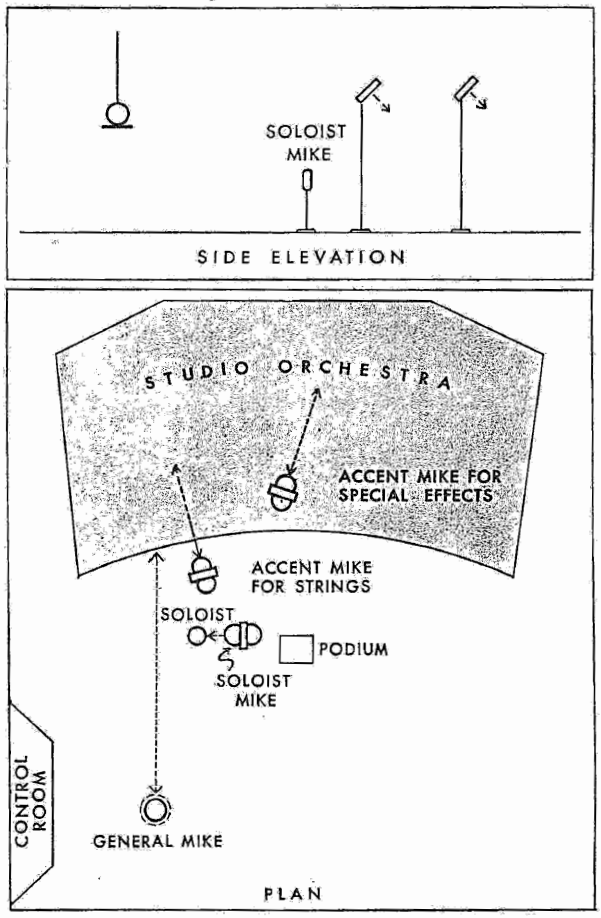

Figure 2--Plan and side elevation of normal studio, set up for orchestra with vocals. It should be noted that all of the Accentuation Microphones in this arrangement are not necessarily used at the same time.

sound pick-ups made within the useful range have an apparent volume range nearly twice that of similar reproductions from dead pick-ups.

(4) The change in quality of the monaurally reproduced sound as a function of the loudness of reproduction is materially reduced. This characteristic may 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 with the differences in the loudness contours of the Fletcher-Munson curves.[5]

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 either an average ear level 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 pick-up 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 sound and (2) one or more accentuation microphones for accenting desired portions of the orchestra, soloists, etc.[6] 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 640 AA 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 shows a qualitative arrangement for a symphonic broadcast with soloist, and some orchestral accentuation, while Figure 2 shows a typical studio set-up for orchestra with vocals. It should be realized, of course, that all of the accentuation microphones are not necessarily used simultaneously.

Arrangements such as these insure 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 pick-up unsuitable for broadcast.

(4) The arrangement is versatile and capable of rapid adjustment during rehearsal.

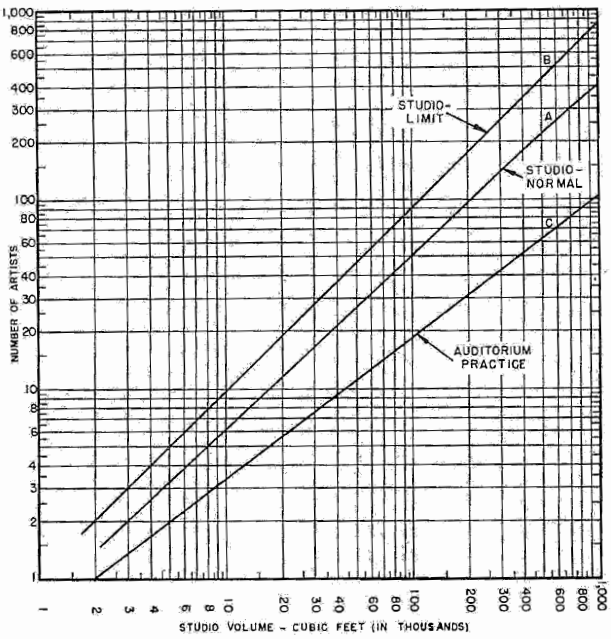

Figure 3--Relation between number of artists and studio size. A shows good studio practice; B maximum crowding without loss of realism; C, for comparison, shows auditorium conditions for symphonic music.

The employment of this technique requires studios with acoustic properties of a "pleasing" nature, i.e., studios of good acoustic properties.[7] It also requires that studios shall not be overcrowded.

Figure 3 shows the relation between the number of artists and the studio size.[8] 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 4 shows the optimum reverberation time with artists in place, as a function of studio or auditorium size.[4] 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

A. Positioning the General or Over-all Microphone.

1. Choose from Table 1 the maximum value of liveness necessary for any part of the program. For instance, for a studio pick-up 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 overall 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.

3. Determine the distance D from equation (2) below. D represents the distance of the microphones from the front of the orchestra.

Equation (1) may be solved for D and we get

$$D = \frac{\sqrt{L \times V \times G_p}}{31.6\ T} \qquad (2)$$

Where studios are in active use, a set of curves as shown in Figure 5 may 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 seconds. 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 equation (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 Figure 5) and connect them with a straight line. From this chart the distance D corresponding to any desired value of liveness may be obtained for a nondirectional microphone.

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, Figure 5. Connect these with a straight line.

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.

B. Positioning the Accentuation Microphones.

1. Choose from Table 1 the minimum liveness for the portion of the orchestra, the soloist or other source 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 = 1/2 (Solo Singing).

2. Choose a value which is two-thirds of that obtained from Table 1 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.

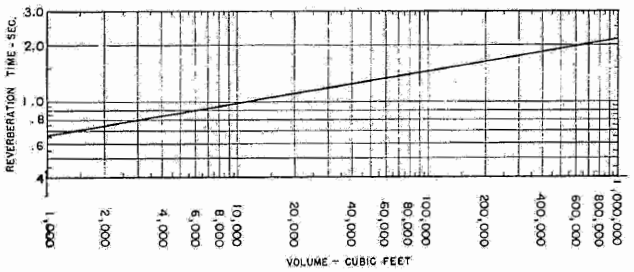

Figure 4--Curve showing optimum reverberation time with artists in place, as a function of studio or auditorium size. Any values within 30 per cent of above can be compensated for by microphone placement.

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.

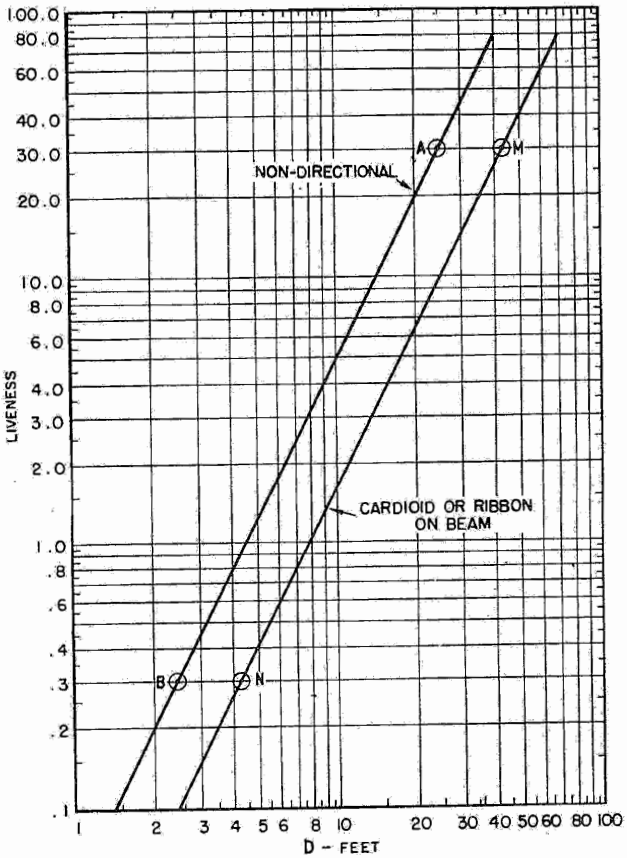

Figure 5--Typical chart used for positioning General and Accentuation Microphones in active studios.

4. Determine the distance D from Equation (2) or from the studio chart typified by Figure 5. 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.

C. 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 1. 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 pick-up, 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.

1. *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 1. 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.

Figure 1 shows the approximate arrangement of the microphones for the broadcast of the New York Philharmonic Symphony concerts by CBS on Sunday afternoons. This arrangement was arrived at in cooperation with Howard A. Chinn, CBS's Chief Audio Engineer after experimentation, with the valuable assistance of engineers and production personnel of the Columbia Broadcasting System.

Table 2 shows the liveness value for each of the three microphones and the power used, expressed in db above (+) or below (-) the power supplied by the over-all microphone D, Figure 1.

TABLE 2

Mike	L	db
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.

2. *Studio Music Programs with or without vocals.* As before, the most pleasing result is obtained when 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 1/2 to 1/3 of the orchestra value, while crooners may operate as low as 1/6 of it. These values are easily obtainable in a good studio which is not overcrowded much beyond curve B in Figure 3.

Figure 2 shows a typical studio set-up. 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, Figure 3. Therefore, the studio volume is about 22,000 cu. ft. and it should have a reverberation time of about 1.1 seconds (see Figure 4) with orchestra.

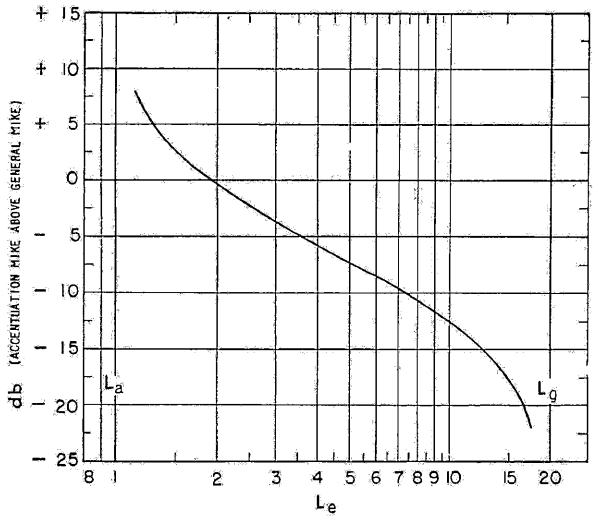

Figure 6--Chart showing effective liveness of two microphone combinations as function of relative level.

Assume

(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 non-directional characteristics.
(4) the microphone for the crooner and any accentuation microphones for parts of the orchestra have bi-directional characteristics.

Proceed as follows:

a. Set liveness of general microphone at a value 1.5 x 10 = 15.
b. Set liveness of crooner microphone at a liveness not greater than 1.6 x 2/3 = 1.0 approximately. Use 0.5 if in doubt, as slightly more flexibility is assured.
c. Set orchestral accentuation microphone at a liveness not greater than 2.0 x 2/3 = 1.3. Use 1.0.

From equation (2) you get the values in Table 3.

TABLE 3

Microphone	Type	G_p	L	Distance
General	Non-direct	1.0	15	16'--17'
Crooner	Bidirect	3.0	1/2	4'-- 6'
Accentuation	Bidirect	3.0	1.0	7'-- 9'

If the distance of 4'--6' for the crooner worries you cut it down to any value not less than 2' and mix accordingly (see Appendix 1).

3. *Speech such as announcers, newscasters, lecturers, etc.* These programs usually originate in small rooms of 1000 to 2000 cu. ft. with reverberation times of the order of 1/2 second. They get the full benefit of the extra coverage and naturalness due to liveness, for values of L greater than 1/6 to 1/4. From equation (2) the distance for a non-directional microphone for a 2000 cu. ft. studio, having a reverberation time of 1/2 second, would be 1-1/4 ft. and for a ribbon or cardioid microphone on beam would be 2 ft.

APPENDIX I

Method of Setting Relative Gain for General and Accentuation Microphones

Let L_a = liveness for the accentuation mike, and
L_g = liveness for the general mike, and
L_e = effective liveness of the combination
P_r = equal the ratio of the power contributed by the accentuation microphone to the power contributed by the general microphone; then db = 10 log P_r.

It can be shown that

$$P_r = \frac{1 - L_e/L_g}{L_e/L_a - 1} = \frac{L_a}{L_g}\,\frac{L_g - L_e}{L_e - L_a} \qquad (3)$$

and

$$L_e = \frac{L_a L_g (1 + P_r)}{L_a + P_r L_g} \qquad (4)$$

For example if $L_a = 1.0$ and $L_g = 20.0$ we may use equation (3) and compute the data shown in Table 4.

TABLE 4

L_e	P_r	db	Approx. db
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 6 shows such a plot.

In Table 4 and Figure 6, negative values of db mean that the level of the accentuation mike is below that of the general mike by the number of db shown.

Since the sensitivities of the various microphones are not equal, the following procedure must be used to determine this relative gain value.

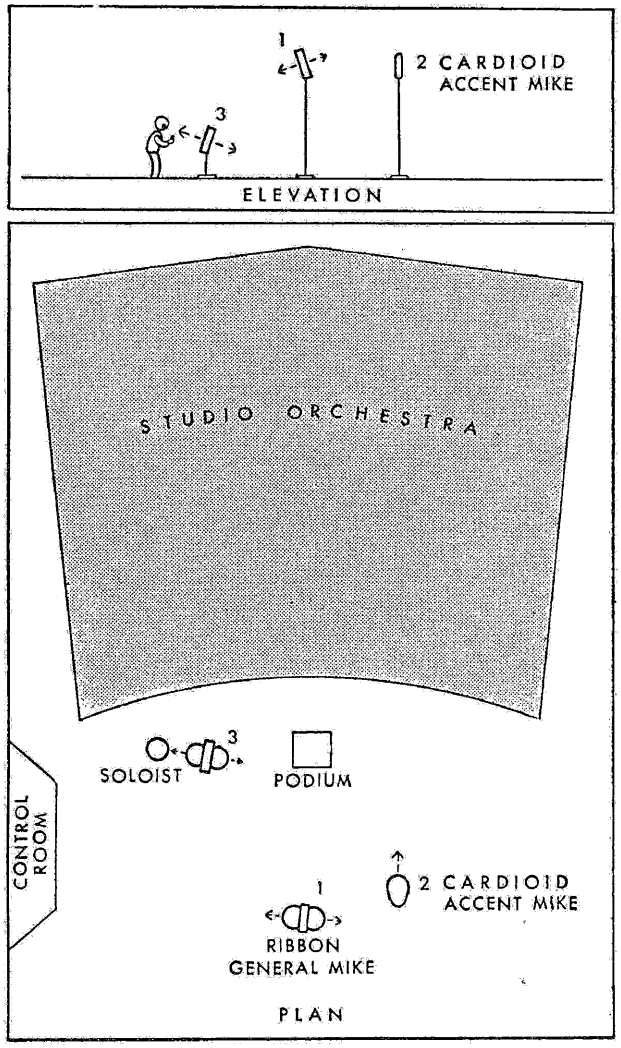

Figure 7--Plan and elevation of overcrowded studio.

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 attenuator dial setting for maximum peaks on vu meter.

Then turn off general microphone and turn up accentuation microphone, until maximum peaks have the same vu reading. Read attenuator dial for the accentuation mike. This becomes the zero of the db scale illustrated in Table 4 or in Figure 6.

For example, assume the general microphone had an attenuator dial setting 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 Figure 6 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 2

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," Figure 7, with its insensitive direction pointing toward the orchestra. In practice this microphone will act as if G_p (see Equations 1 and 2) had a value of 1/4 to 1/3.

(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 pick-up into the region below the useful liveness range. You then obtain "absence" instead of "presence".

This article has attempted to describe a semi-quantitative sound pick-up technique. If followed as a general guide, experience has shown that these methods can almost insure 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.

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HOW TO IMPROVE PROGRAM PICKUPS

STUDIO PRACTICES REQUIRED FOR FM IMPROVE AM, TOO. HERE ARE IDEAS THAT CAN BE EMPLOYED WITH FACILITIES AVAILABLE AT ANY STATION--By HAROLD E. ENNES*

(Reprinted through courtesy of FM and Television)

Make it good. Then make it better. This is the creed of radio engineers. Over a period of twenty-eight years, broadcasting has been made good. With the advent of FM, it can be made very much better. 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 co-ordinating 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 & 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 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, then 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 hodge-podge 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 lim-

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itations 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 is setting 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.

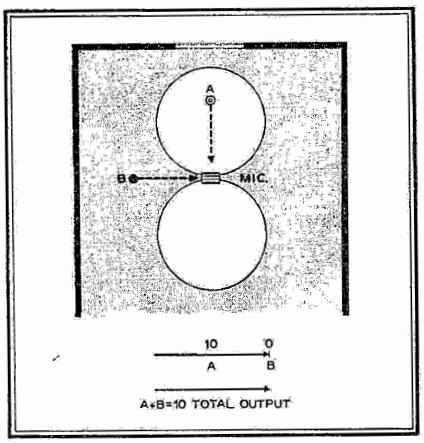


Fig. 1. Bi-directional pattern in dead room

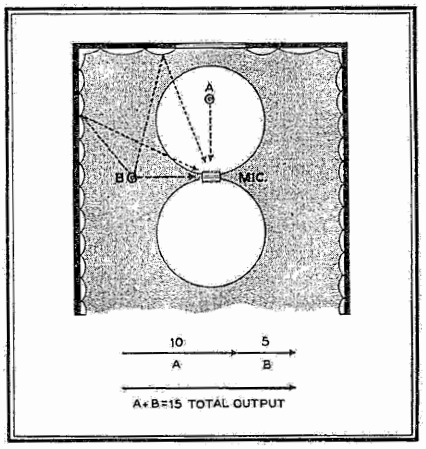


Fig. 2. Results are modified in live studio

Understanding Response Patterns:

Insofar 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 bi-directional microphone.

Fig. 1 illustrates the ideal response curve of a bi-directional mike in a completely dead room. Sound sources A and B are of the same intensity and at 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.

Fig. 2 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. Fig. 3 shows the polar response pattern of a Western Electric 639 A cardioid, 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. 3 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 zero degrees. 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:

1. If a sound source must be moved about the mike, loss of 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 bi-directional 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 bi-directional microphone has a greater deviation in angular response between high and low frequencies. Also, the cardioid or uni-directional instrument has a much wider angle of response at all frequencies than a bi-directional mike.

This is shown in Fig. 3, where the 1,000-cycle curve of an RCA 77 B uni-directional mike (solid curve) is super-imposed on the 1,000 cycle curve of an RCA 44 BX velocity (bi-directional) 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 uni-directional and bi-directional patterns.

Studio Acoustics:

The non-standard acoustical characteristics of broadcast studios are the outstanding factor that has prevented any establishment of definite

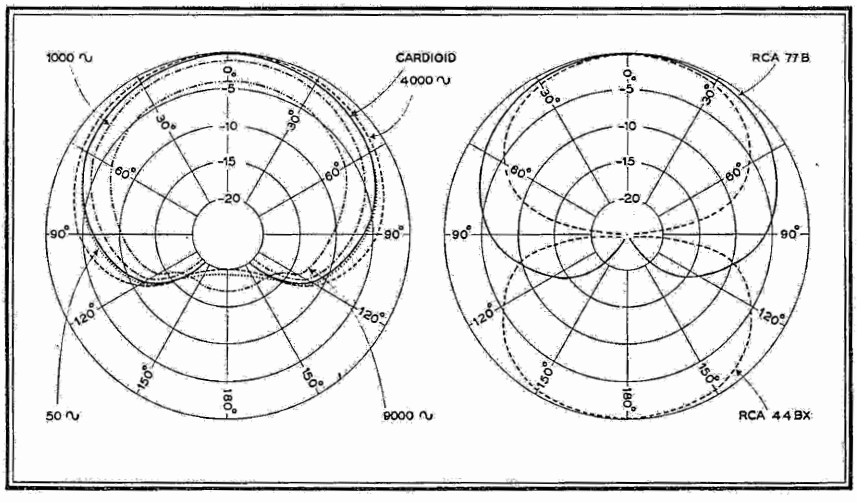


Fig. 3. Left: W. E. Cardiod. Right: Uni-directional and bi-directional RCA types

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. This is the most deplorable situation existing in broadcasting, but it is outside the influence of the average operator. All we can do is hope, and then plead, and plead some more until the station owners become cognizant of the extreme importance of modern studio design. It is a sad state of affairs that even some of the most recent FM installations, with completely new studios independent of any AM connection, are neglecting this feature. Most of the good articles appearing thus far on microphone setups have been concerned with well-designed, musically-live studios of the network centers, or the more production-conscious independent owners.

Yet how can an article of this kind be useful to the average operator wanting to do his best in studios of the same design as those built twenty years ago? Since it is the purpose of this paper to present practical information, the writer will attempt to show some definite rules that can be used to meet any acoustical conditions. High-fidelity techniques for a good, modern studio can not 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, poly-phased 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 to really 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 impedances of the control system. They are designed this way so that the electrical impulses may correspond to the thunderous crescendos of Wagner's Die Walküre 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 radio's service 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 arm rest. 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 only be used 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 ins. 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.

In small announce booths, where space is at a premium and where distance would create a barrel effect due 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 of 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. 4. 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

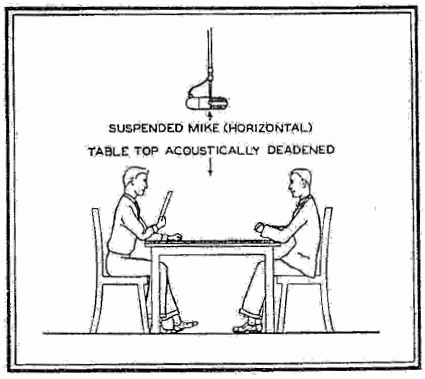


Fig. 4. Setup for interview in small room

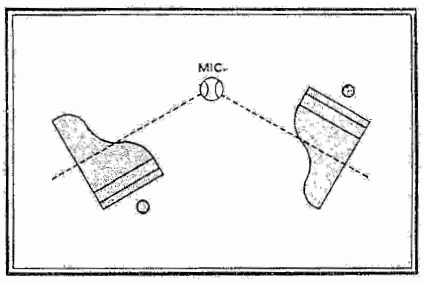


Fig. 5. Orientation for a two piano-team

the system and the lack of focusing power unless 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 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 to 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, is 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 overall 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 reverberant 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.

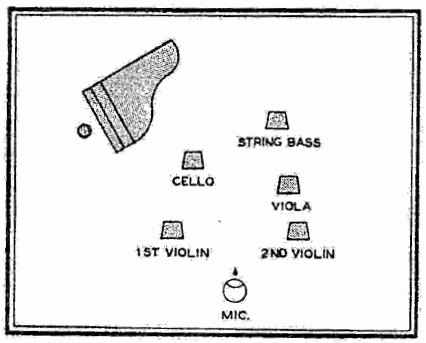


Fig. 6 Orientation for a salon orchestra

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. Fig. 5 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 bi-directional 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. Due to their comparative volume they are usually placed in that order from the microphone. Fig. 6 illustrates the general orientation of such a group with the mike.

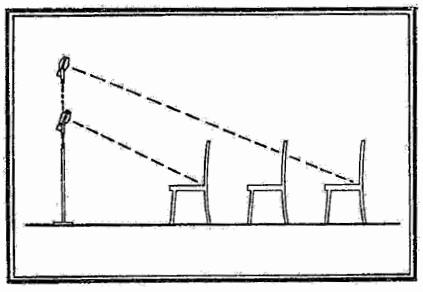


Fig. 7. Adjusting microphone for balance

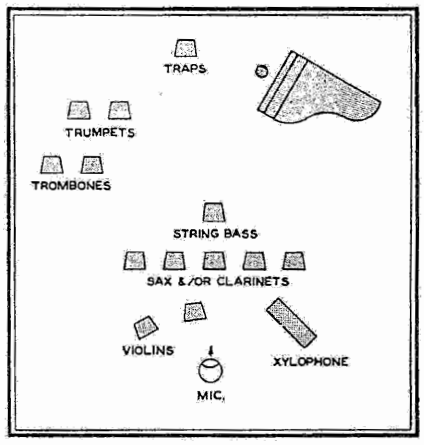


Fig. 8. Conventional one-microphone plan

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 further 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. 7. 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 over-tones are very important for wide-range pickups.

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.

Small Orchestra Setups:

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. 8. 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 is 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 they 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. 8. 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.

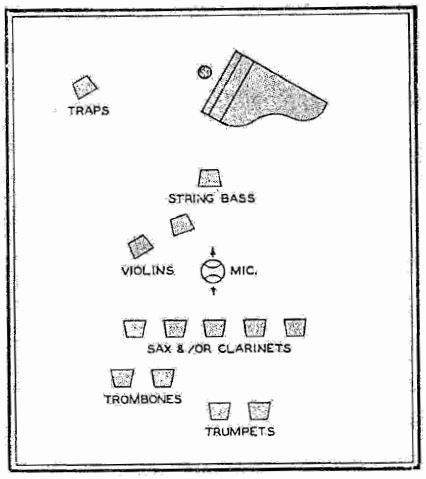


Fig. 9. Improved pickup location

In nearly every case, however, best results are obtained with one mike, and by using the setup illustrated in Fig. 9. The mike is a bi-directional ribbon type. The instruments must be more nearly on beam, due to the narrower angle of response in comparison to the uni-directional mike employed in Fig. 8 and to 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 uni-directional type, with dead side toward orchestra. This mike can be used for the announcer, also.

Symphony Orchestras:

The large symphony orchestra setup 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.

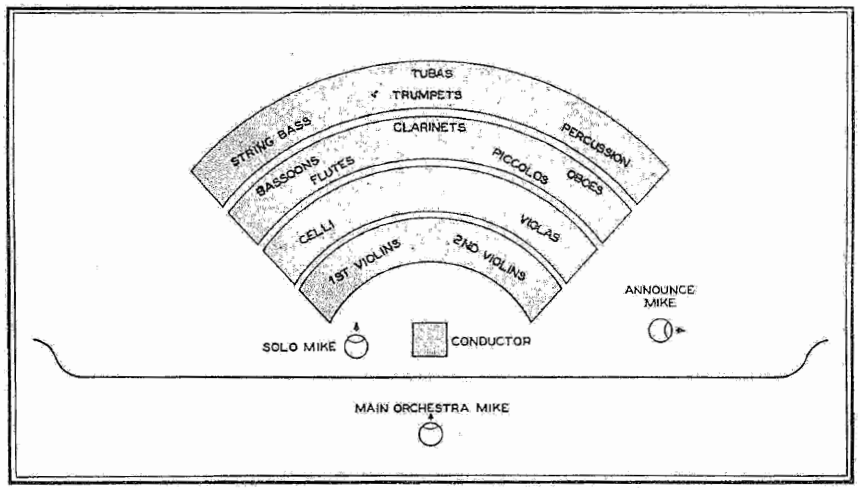


Fig. 10. Symphony orchestras may require solo and section mikes for highest fidelity

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. Fig. 10 illustrates a typical grouping of a large symphony orchestra.

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.

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 due to the spread of the total combination, in order to obtain focusing power.

Notes on Field Setups:

Field setups are an entirely different matter. The musical instruments must usually be placed more in a straight line due 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.

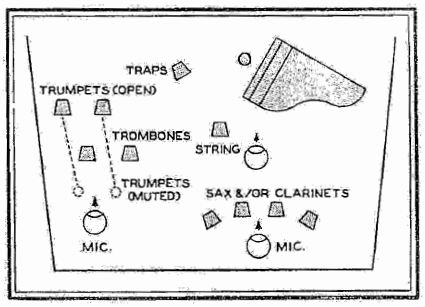


Fig. 11. Mike setup for dance orchestra

Fig. 11 illustrates a 3-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. 11, 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 paper. 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.

ROOM ACOUSTIC DESIGN

PREFACE

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 Acoustic Design." Mr. Volkmann, who is Manager, Theatre Equipment Engineering, Sound Engineering Section, RCA Victor Division, Camden, N. J., has 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 sufficient data believed, of interest in the construction of Television Studios, especially in view of the trend toward large screen television.

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 has received ever-growing attention by architect and engineer, and has 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, as follows: ". . . it is necessary that the sound should be sufficiently loud; that the simultaneous components of a complex sound should maintain their proper relative intensities; and that the successive sounds in rapidly moving articulation, either of speech or music, should be clear and distinct, free from each other and from extraneous noises. These three are the necessary as they are the entirely sufficient, conditions for good hearing." (1)

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.*

Experience in rooms with wood-paneling and sound-diffusing surfaces indicates that the manner in which the reverberant and other after-sounds 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 spherically 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 again suffer partial reflection, absorption, and transmission

*See Appendix I for definitions of acoustic terms.

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 suffer from 200-300 such reflections before its energy is completely dissipated by absorption or transmission. If we recall that sound travels 1120 feet per second it is readily seen that the duration of this prolonged after-sound, 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 due 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 due 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 room, so we have learned that an optimum size of studio exists for each type and size of orchestra. The data (2) in Table I is based on commercial practices and subjective listening tests. The column labeled "auditorium practice" shows the minimum number of orchestral instruments recommended for auditoriums, (3) 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. Several typical Hollywood scoring stages are shown in Figures 16, 17, and 18. 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 movie reproducing equipment is more than adequate for the ordinary size review room; however, in those cases where the picture is reviewed in a theatre, the reproducing equipment should meet the "Minimum Power Requirements for Theatres" established by the Academy Research Council.(4)

From the standpoint of reverberation time, minimum power requirements, air-conditioning system requirements, etc., the theatre, which is used for reviewing purposes, should be made a minimum in size compatible to 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 theatre 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 may be increased to as much as 500 cu. ft. per seat.

TABLE I

Size of Orchestra VS. Room Size

Volume of Room in Cubic Feet	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

Room Resonances--Effect of Parallel Reflecting Surfaces:

When sound is generated between two paraallel 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 cycles, 100 cycles, 150 cycles, etc. (frequency equals 1120 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 handing-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 may 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 se-

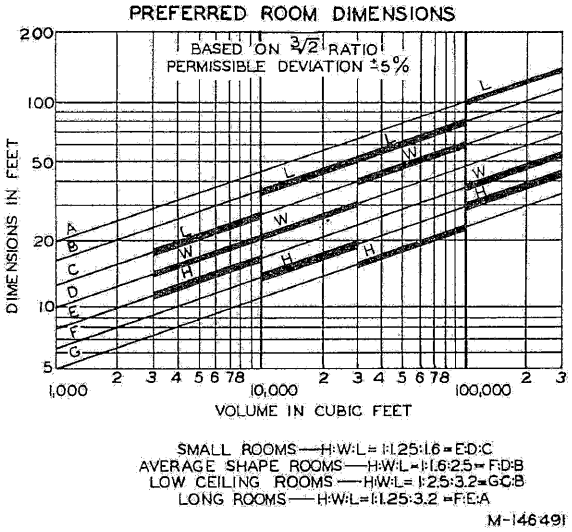


Figure 1--Preferred studio dimensions.

lective may cause it to sound too "bassy." The other two methods will be discussed under separate paragraphs later.

Structural Resonance:

The phenomena 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 due to variations in size and construction of the individual wood panels.

Shape of Studio--Preferred Proportions: (5)

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 each other. By proportioning the three major dimensions of a room in the ratio of the cube root of two (or in ratio of multiples of the cube root of two), 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 Figure 1. For the average size and shape studio the preferred dimensions should be in the ratio of 1:1.6:2.5. 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 each other, or, other ratios derived from this fundamental ratio by shifting any or all of the dimensions by one or more integral octaves may be used. Other preferred proportions for less common shaped rooms are also shown in Figure 1.

We next deal with the shape and treatment of individual surfaces.

Shape of Reflecting Surfaces--Sound Diffusion: (5)

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 distribution of the after sound in a room and may 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 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. (6)

This reradiated energy does not follow the regular law of equal angle of incidence and

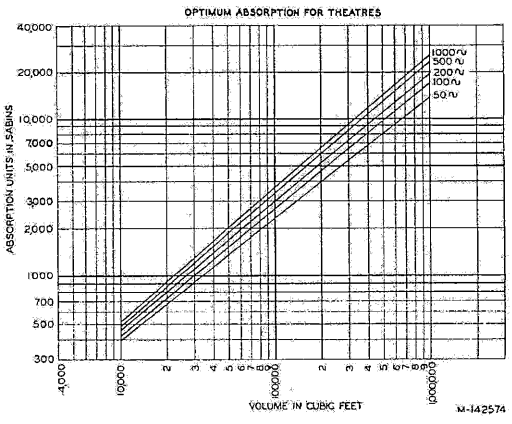


Figure 2--Optimum absorption.

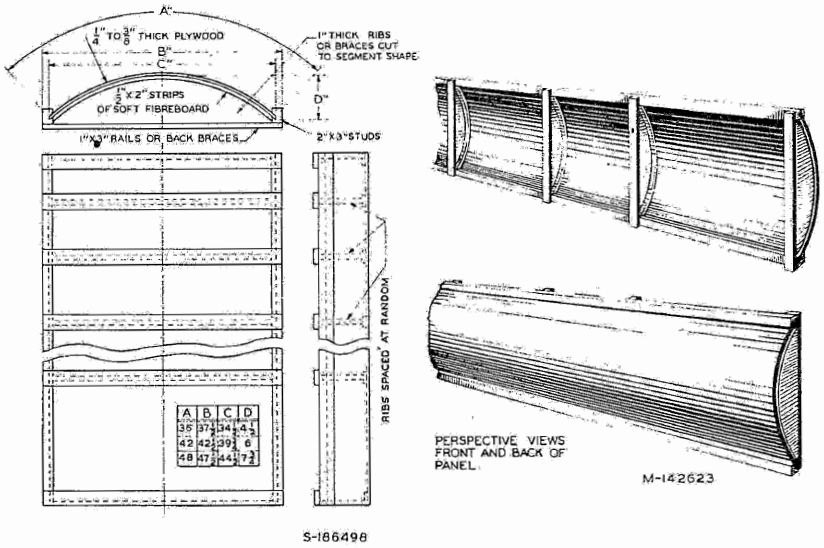


Figure 3--Convex wood panel.

reflection, but due 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 further due 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 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 Figure 1).

The optimum sound-absorption units versus frequency corresponding to the optimum reverberation times for various room volumes is shown in Figure 2.

Convex Wood Panels: (5)

Figure 3 shows a typical curved wood panel consisting of 4' x 8' plywood formed over curved segment braces and fitted at the edges with 2" x 3" strips which have been routed and held together with 1" x 3" back braces. The segment braces which must be spaced at random have strips of 1/2" 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 panel and their relation to the wavelength. Dispersion characteristics for a curved and flat panel plotted on polar coordinates are shown in Figure 5. 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.

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 to flat surfaces is shown in figure 5. 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 figure 6. 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 pick-up in allowing greater freedom of placement. For remote surfaces in large rooms a similar diffuse reflection may 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 to the wavelength radiated, the distribution will tend to be non directional. For vibrations normal to the surface, a convex cylindrical panel would tend to set up a cylindrical wave front as compared to the plane wave front 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 coefficient of the material, thickness, spacing of braces, method of mounting of the entire panel, etc. It is interesting to note that due to the added stiffness introduced by bending, a smaller panel thickness may 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 figure 7. In addition to the dispersion and radiation action, the vibration of the wood paneling aids the absorption efficiency over more rigid materials.

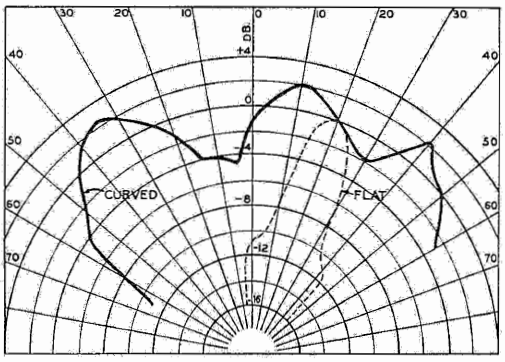


Figure 4--Polar distributions from convex and flat panels.

Preliminary data indicates 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 particularly 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, due to

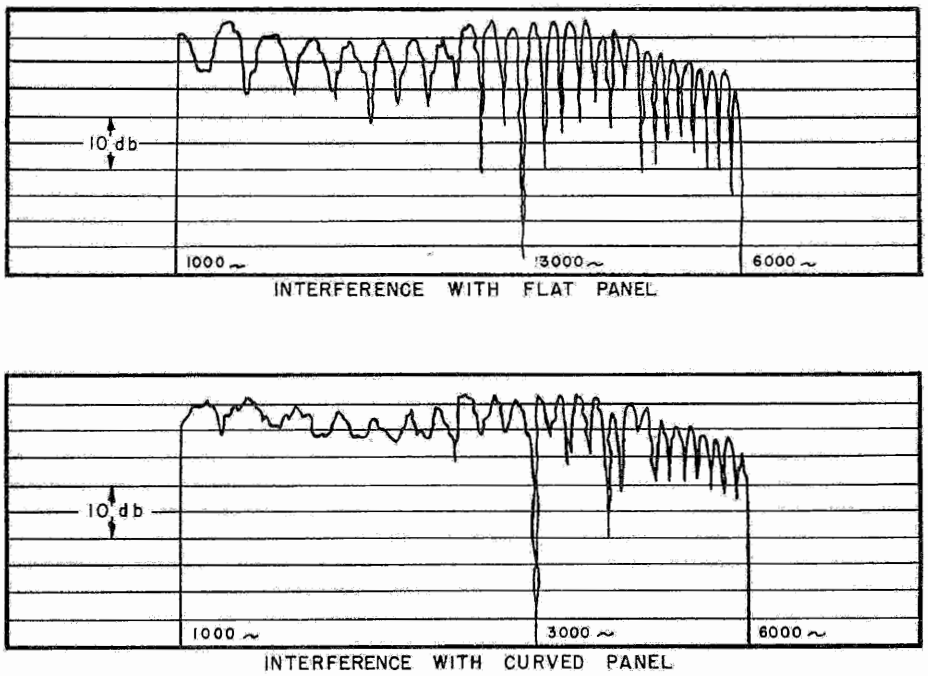
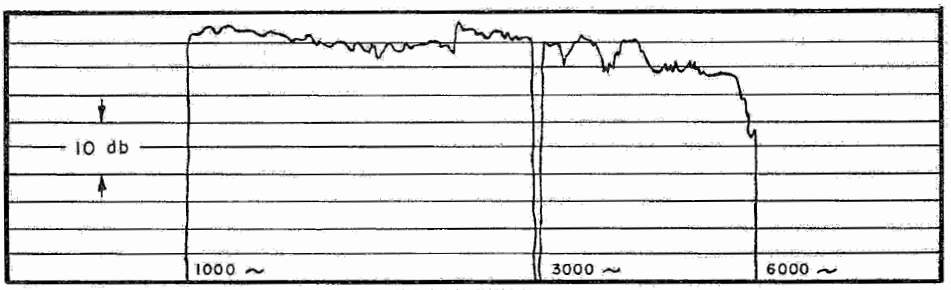
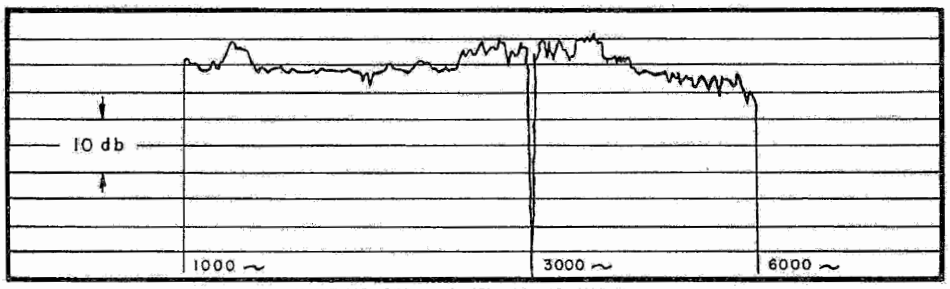


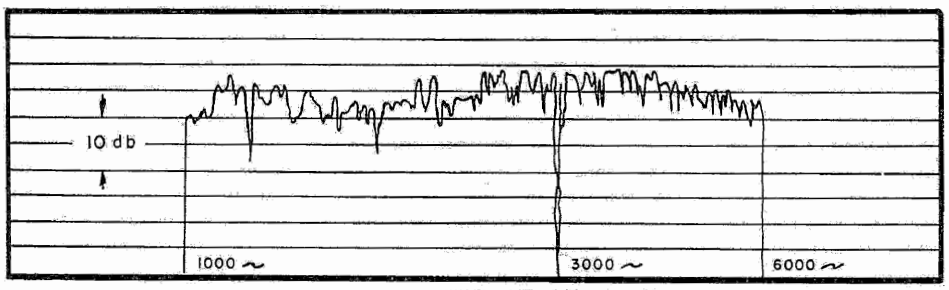
Figure 5--Interference between direct and reflected waves for convex and flat panels.



DIRECT SOUND



REFLECTION FROM FLAT PANEL



REFLECTION FROM CURVED PANEL

Figure 6--Direct and reflected response of panels used in interference measurements.

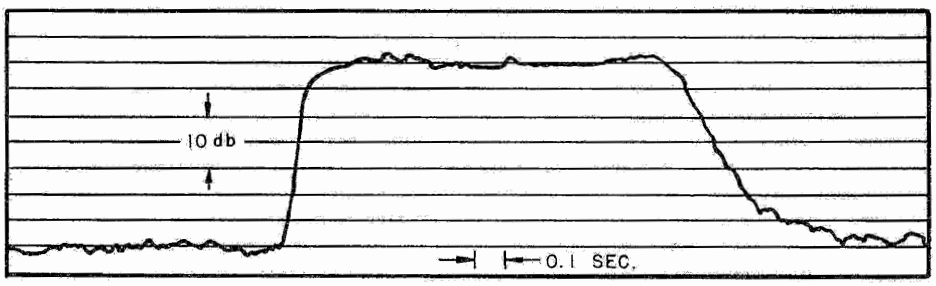


Figure 7--Growth and decay curve of vibrating convex panel.

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. Due to 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.

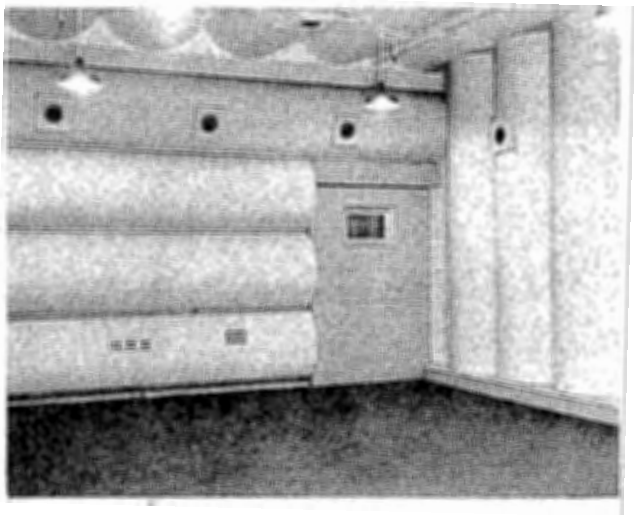


Figure 8--Polycylindrical studio.

Studio With Polycylindrical Wood Panels:

Figure 8 is a photograph of one of the studios in the RCA Sound Engineering Laboratories at Indianapolis, Indiana, used for listening purposes. In addition to the cylindrical wood diffusers already mentioned, these studios have several other features of interest in room acoustic design.

In order to obtain maximum diffusion in the three orthogonal planes, axes of the polycylindrical surfaces were placed mutually perpendicular to each other. Three different sized panels and curvatures were 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 this studio is shown in figure 9, which conforms reasonably well with published optimal times. (10)

Another feature of the studio is the choice of the major dimensions (12.5 ft. x 20 ft. x 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 c.p.s. 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.*

*See Appendix II.

Orchestra Shell:

Occasionally regular sound stages (usually treated over the entire wall area with 4" rockwool and over the entire ceiling area with 2" rockwool to eliminate all reflections) are employed for musical recordings, in which case it is necessary to "liven" the stage.

An application of polycylindrical design to an orchestra shell which was used for recordings by Leopold Stokowski on the Walt Disney Live Action Stage, and which is here reproduced through their courtesy, is shown in figure 10. The multiplicity of dispersing surfaces and resonant panels not only minimized the microphone placement problem, but gave a more pleasing reinforcement of sound to the conductor and musicians. The platforms were for elevating and reinforcing the bass instruments in the orchestra.

Exclusion of Noise: (7)

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: (a) aerial, and (b) 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 air-tight 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 floor by heavy blocks mounted on cork or Keldur is often necessary to reduce transmitted sound.

Double or triple optical glass in ports is usually used to reduce the sound conducted by the air through these ports.

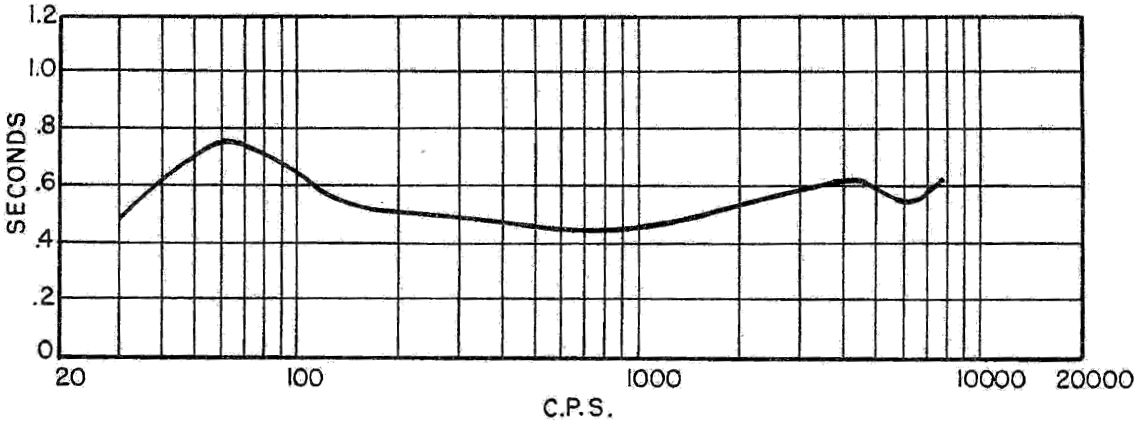


Figure 9--Reverberation time of listening studio.

The projection booth walls should be either very heavy (12" 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 11 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 12 shows a cross section of a typical sound retarding door such as the Riverbank door used by broadcasting stations and other sound studios. Figure 13 illustrates construction of a typical sound insulating wall in accordance with principles stated by Bagenal and Wood in their book "Planning for Good Acoustics." (6)

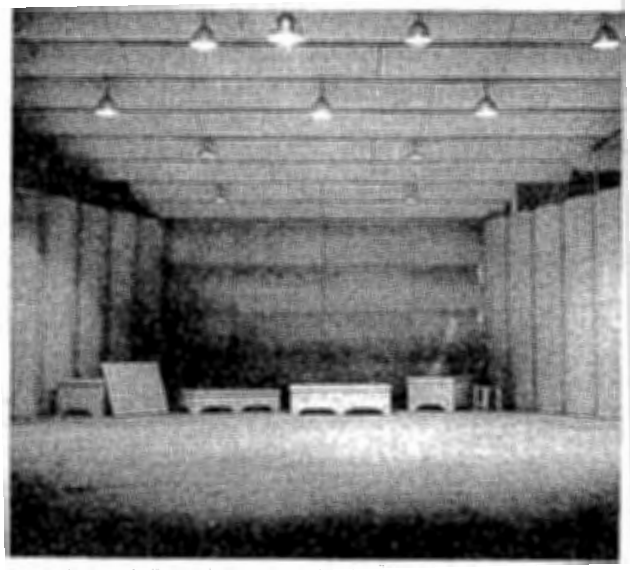


Figure 10--Polycylindrical Orchestra Shell.

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:

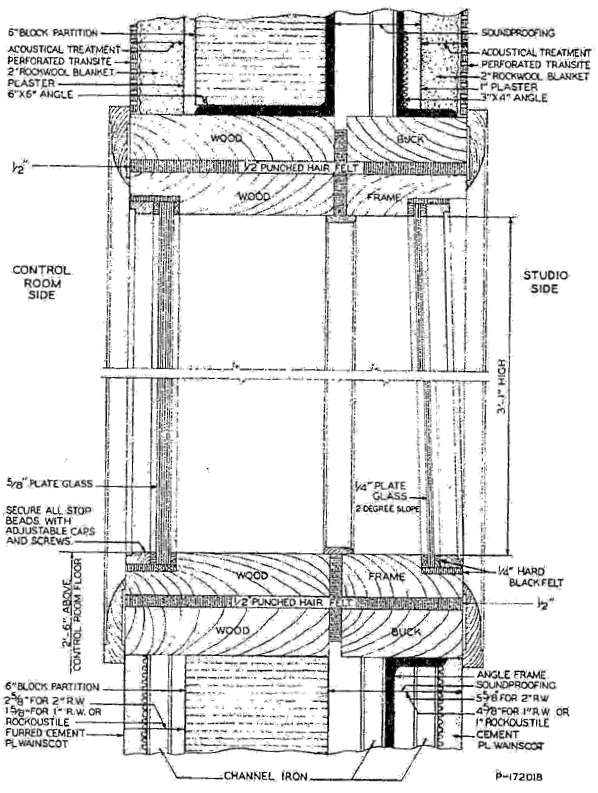


Figure 11--Sound insulated window.

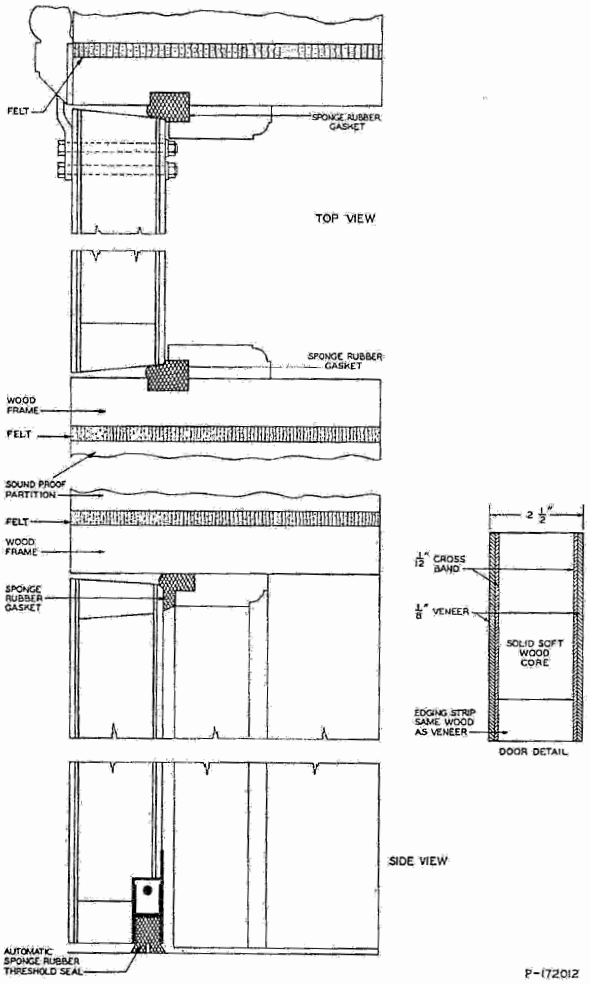


Figure 12--Sound retarding door.

1. Straight Recording (Voice or Music).
2. Pre or Post Scoring 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 figure 15.

Size and Proportions of Studio:

The studio proper shall have a minimum volume of 16,000 cubic feet and shall have its average height, width, and length proportioned in the ratio of 1: 1.6: 2.5, namely,

Height, 16 feet
Width, 25 feet
Length, 40 feet

A deviation in average dimension not greater than plus or minus 5% is permissible. (See figure 1.)

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 50-65,000 cubic feet (25'x40'x65') 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 figure 14 is recommended for this purpose.

Walls: All walls shall be treated with convex wood panels, general specifications for which are given in figure 3. The panels on the rear wall should be disposed horizontally while the front and side wall panels should be vertical an indicated in figure 14. All walls shall be

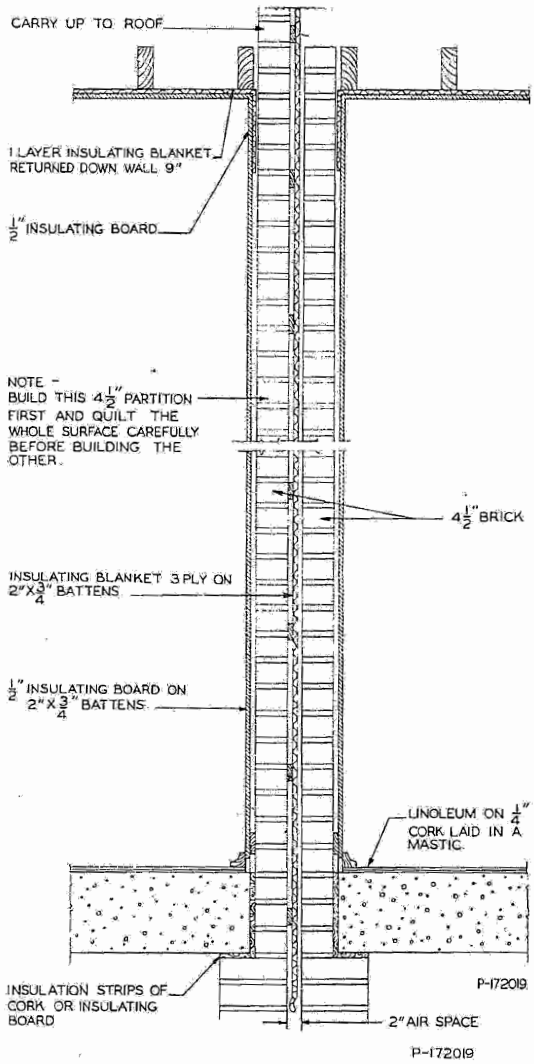


Figure 13--Sound insulating wall construction.

insulated as specified later. Double-wall construction is particularly important between the projection booth and studio. A blanket of 1" rockwool 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 figure 14. The attic side of the ceiling should receive a granulated fill of rockwool 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 bandshell 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 seal-tight chamber. The ceiling and back side of the screen wall forming the loudspeaker chamber should be lined with 4" of rockwool.

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 drapes 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 strictly essential that during erection all joints and openings between panels, etc., shall be fully caulked to give a continuous and seal-tight enclosure and further that the entire wall structure shall be floated on cork, rubber, or other suitable material, in order to completely isolate the walls 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.

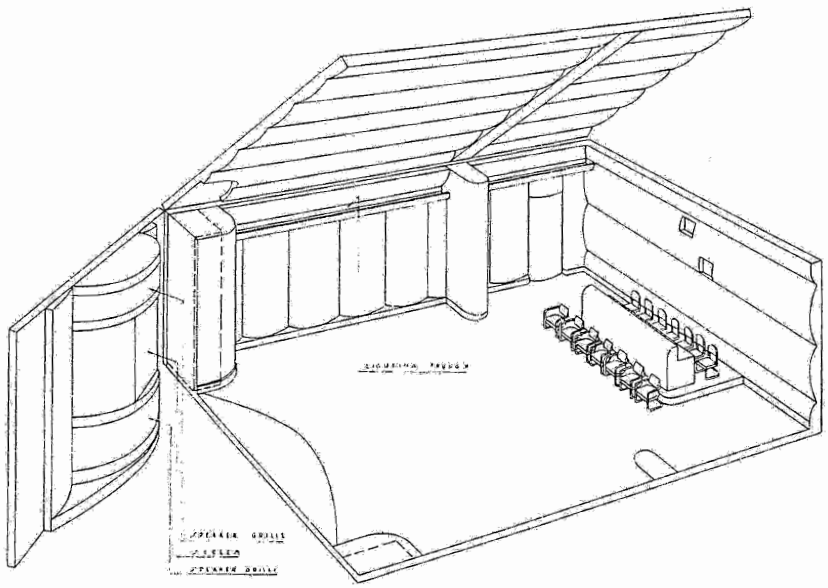


Figure 14--Proposed Design of a Small Film Recording Studio and Review Room.

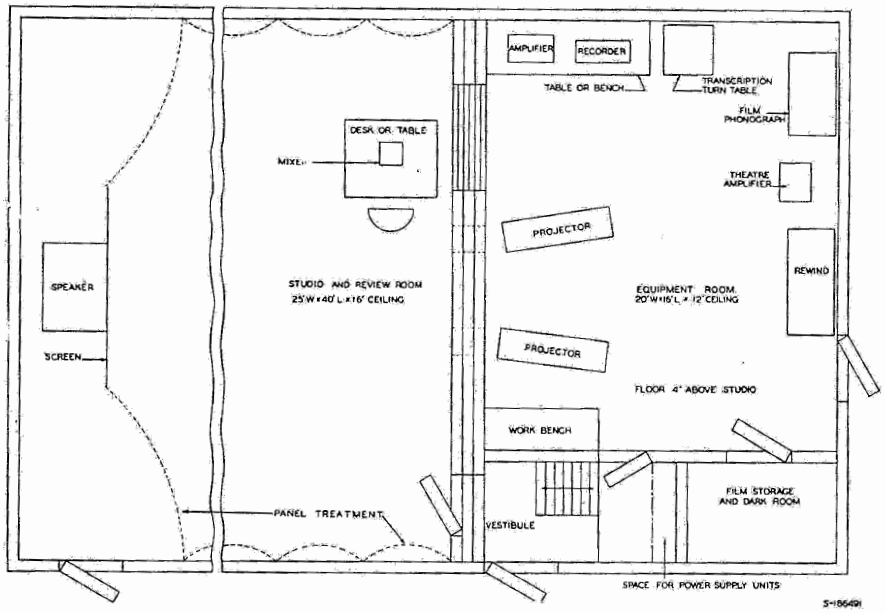


Figure 15--Proposed arrangement of a small studio.

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 watts 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 10 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 due to the canvas or other isolation coupling.

Recording and Projection Booth:

The size of the projection and recording equipment booth should be 20 ft. x 16 ft. with a 12-ft. ceiling height as indicated in the floor plan in figure 15. 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" 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 figure 12. The vestibule or sound-lock area may 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 may 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 ten-piece orchestra the minimum volume would be 16,000 cubic feet. (For orchestras of other size refer to table I.)

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 cubic feet this would represent a studio 16 ft. x 25 ft. x 40 ft.

3. Large parallel surfaces should be avoided.

4. All reflecting surfaces should be shaped, preferably convex, to give a

Figure 16--Scoring Stage of Republic Studios--Courtesy Republic Productions, Inc.

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 rockwool or other absorbing blanket.

7. The floor should be covered with a good grade of reinforced carpeting with padding underneath.

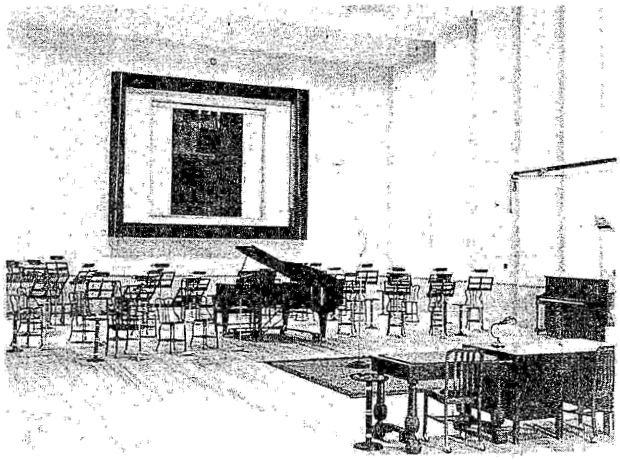


Figure 17--Scoring Stage of Columbia Studios--Courtesy Columbia Pictures, Inc.

8. Seats should be of the upholstered type.

9. Adjustable drapes 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.

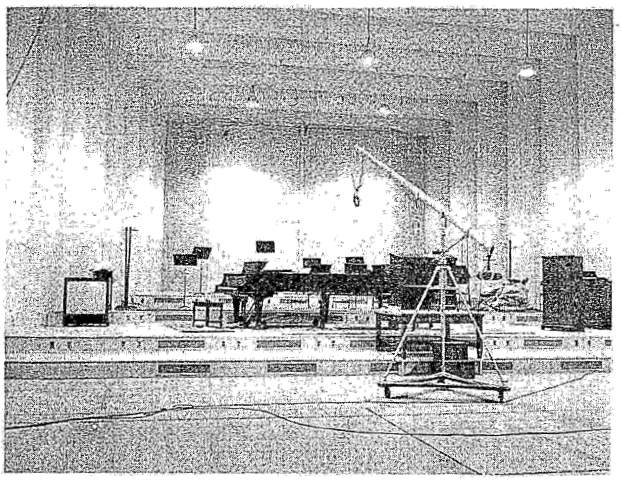


Figure 18--Walt Disney Scoring Stage--Courtesy Walt Disney Productions, Ltd.

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 may be used with similar results.

REVERBERATION CHAMBERS FOR RERECORDING*

In the recording of sound on film or wax it is frequently desirable to add a reverberatory quality to the recording after its completion. This may be accomplished by reproducing the sound in a highly reverberant room--the so-called reverberation chamber--and "mixing" the output from a microphone in this room with the original recording in a process known as "dubbing" or rerecording.

Surprisingly, when the electrical level of the reverberated signal is as much as 20 db below the electrical level of the original recording at the mixing panel, the combined reproduced signal conveys a strong impression of reverberation in every syllable of speech, and chord or passage of music.

Unlike in other means, electrical or mechanical, of adding a reverberatory note to a recording, the chamber method provides both the proper growth characteristic and the decay quality of sound in a live enclosure. Delay networks, magnetic tape recordings, and other devices for achieving synthetic reverberation usually permit only provision for the decay characteristic; no attempt is made to introduce the growth characteristic, since the latter is less essential in an approach to total reverberation.

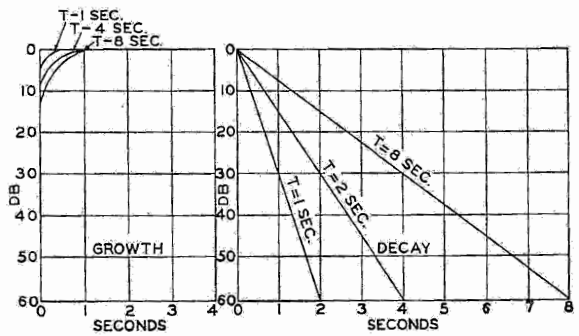


Figure 19--Curves Illustrating Growth and Decay of Sound in Different Rooms.

*Condensed from article in Journal of the Society of Motion Picture Engineers. Vol. 45, No. 5 (November, 1945), Pp. 350-357.

It is interesting to plot the growth curves of sound and the corresponding decay characteristics for a number of rooms. Figure 15 shows the sound-growth and sound-decay curves for rooms that have different reverberation times, namely 8 sec., 4 sec., and 1 sec. The curves are plotted on the assumption that the power output of the source in the different rooms is such as to provide the same value of steady-state energy-density in each enclosure.

For the addition of reverberation to recordings made on film, a room with a reverberation period of approximately 4 sec. appears adequate. A chamber of 4000 cu ft volume, with walls and ceiling made of concrete, answers this purpose very well. If the mean dimensions for the height, width, and length of the enclosure are 12.5 ft, 16 ft, and 20 ft, respectively, the total interior surface comes to approximately 1540 sq ft. Crediting concrete, 6 in. thick, with an absorptivity of 0.03 sabine at 1000 cycles, the total absorption comes to 46.2 sabines, and the reverberation time therefore to 4.33 sec. Mean dimensions are indicated because the preferred shape of the enclosure is nonrectangular, in order to avoid flutter echoes.

It is interesting to consider the decay characteristic of the sound which actuates the microphone in the chamber. The sound which was originally recorded in the recording stage is itself characterized by the reverberation of the studio. During reproduction the decay characteristic of the chamber is superimposed upon that of the stage. Thus, superimposing a reverberation period of 4 sec. upon sound recorded in a room with a reverberation period of one second has, for short initial intervals, the effect of sound decaying in a room of 8 or more sec. reverberation. This may account for the low electrical level of the reverberated signal necessary (at the mixing console) for its combination with the original recording to obtain the desired reverberatory character in the rerecording.

Another reason for the low electrical level required of the reverberated signal is the fact that the microphone represents only one ear. In binaural hearing, the ear is to some extent capable of suppressing unwanted sound, whether direct or reflected, and to concentrate only on the desired sound. This can be readily demonstrated by closing one ear in the reverberation chamber, in which case the reverberation appears considerably prolonged.

Another reason for maintaining a low electrical level for the reverberated signal is, of course, an attempt to preserve as much as possible the intelligibility of the dialogue. The ear is evidently able to judge the reverberation of a room by the audible, slow trailing-off of the sound intensity at the end of *words*.

In the case of music, where longer reverberation tends to provide a richer or more pleasing quality, the electrical level of the reverberated signal is kept higher. Still, the definition of instruments can be preserved remarkably well by this means. One may indeed consider whether this type of reproduction does not supply a superior rendition, unattainable in any other way, since both clarity of instruments and an undertone of prolonged decay exist simultaneously.

Different recordings call for the addition of different amounts of reverberation, and sometimes, *for the addition of different types*, of reverberation characteristics. The reason for this is that, in sound-on-film recordings, a large number of different sound effects have to be included. If the dialogue is recorded in a cellar, tunnel, hull of a ship, etc., but the incident sounds (footfalls, jack-hammer drives, engine noise) are not included in the original recordings, it is desirable to match the character of these effects with the "room-tone" existing in the surrounding in which the speech was recorded. Some variation in the reverberation characteristic can be effected by changing the distance between loudspeaker and microphone, since this will change the ratio of direct-to-reflected sound at the microphone.

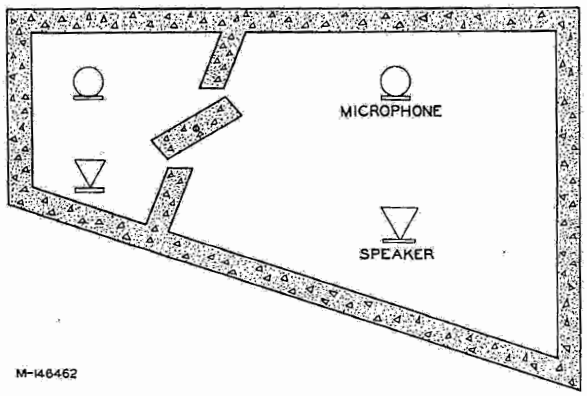


Figure 20--Double Reverberation Chambers

The character of the reverberated signal may be altered more perceptibly by dividing the chamber into a small and a large room. Since the number of normal modes and their spectral distribution is decidedly different in two such enclosures a considerable variation in the quality of the signals may be effected by using one or the other of the two rooms. If a door is provided in the partition between the two chambers, a further variation will result by placing the speaker in one of the rooms and the microphone in the other. Such a door acts like an acoustic high-pass filter, thereby making the reverberation characteristic of each room a function of the door opening.

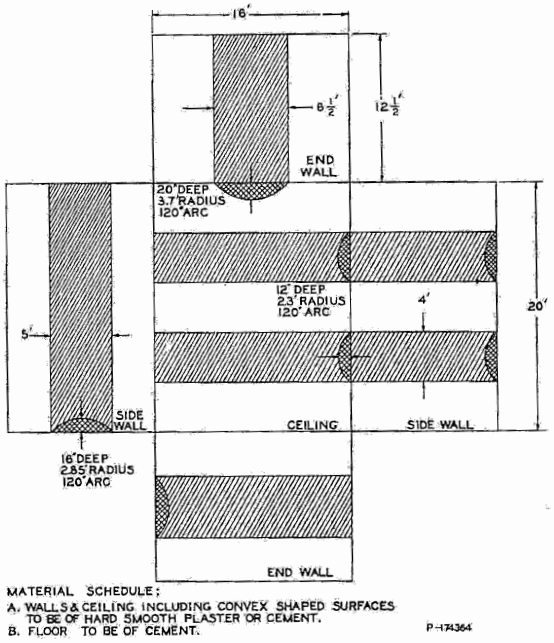


Figure 21--Developed Plan for Echo Chamber

A change in the character of the sound picked up in the chamber can, of course, also be secured by using different microphones.

Figure 20 represents the plan of a dual reverberation chamber, of which the walls as well as the ceiling and the floor were kept at a slant to avoid echoes. The dual chambers employ concrete for the material of the walls, the ceiling, and the floor. A massive door, 5 ft wide and 6 ft high, weighing approximately 450 lb, may be rotated by means of a knob located at the rerecording console; in this manner it is possible to change the reverberation characteristics of the rooms easily and quickly. Where it is not feasible to employ dual chambers and slanting walls an alternative plan for the chamber is shown in figure 21.

Figure 22 shows a block schematic of a recording channel employing a reverberation chamber.

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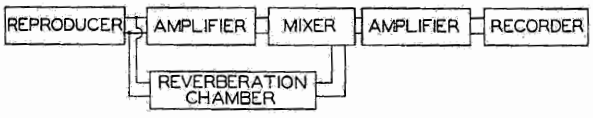

Figure 22--Block Diagram of Rerecording Channel

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APPENDIX I

Definitions in Architectural Acoustics From ASA Standards Z24.1

Acoustic Absorptivity (Absorption Coefficient)

The acoustic absorptivity of a surface is equal to one 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 to 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 ten of the ratio

of the intensity I of this sound, to the reference intensity I_o. Intensity level may 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

(a) Sound is an alteration in pressure, particle displacement or particle velocity propagated in an elastic material or the superposition of such propagated alterations.
(b) Sound is also the sensation produced through the ear by the alterations described above.
Note--In case of possible confusion, the Term "Sound Wave" may be used for concept (a), and the term "Sound Sensation" for concept (b).

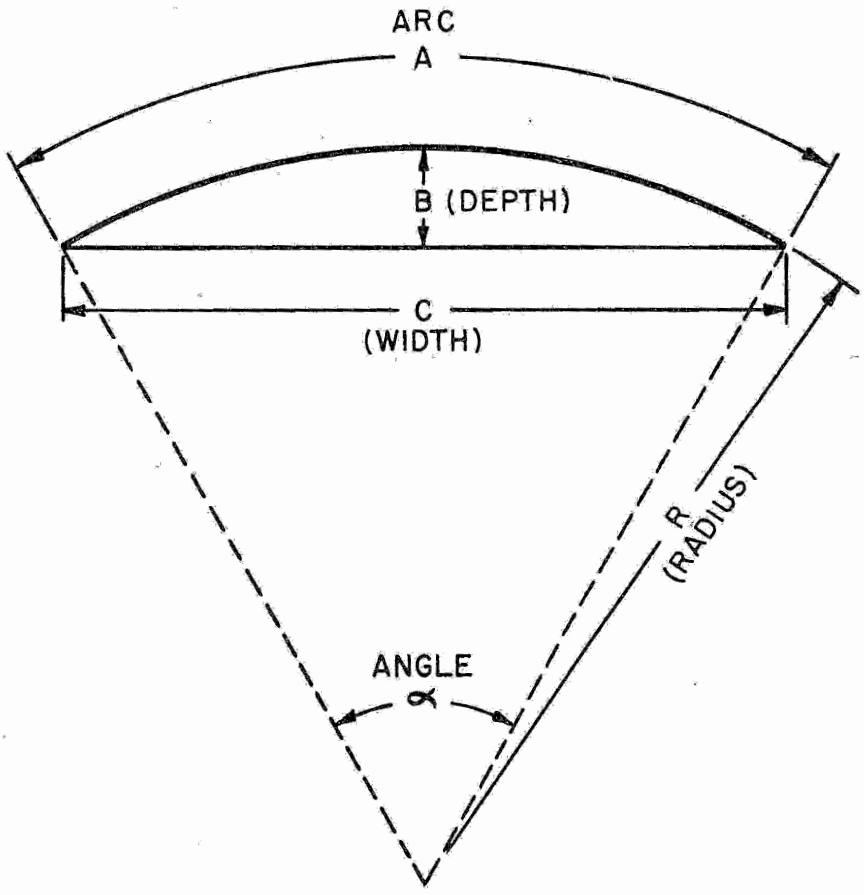
Wavelength (λ)

The wavelength of a periodic wave in an isotropic medium is the perpendicular distance between two wave fronts in which the displacements have a phase difference of one complete cycle.

APPENDIX II

Sectional Dimensions 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"	15-1/4	2	15-1/4	14-3/8	3	10-3/8	13-1/8	3-7/8	7-5/8	5-1/8
32"	30-5/8	4-1/8	30-5/8	28-3/4	6	20-3/4	26-1/4	7-5/8	15-1/4	10-1/8
48"	45-7/8	6-1/8	45-7/8	43-1/4	9	31-1/4	39-1/2	11-1/2	22-7/8	15-1/4
64"	61-1/8	8-1/4	61-1/8	57-5/8	12	41-5/8	52-5/8	15-1/4	30-1/2	20-3/8
80"	76-3/8	10-1/4	76-3/8	72	15	52	65-3/4	19-1/8	38-1/8	25-1/2
96"	91-5/8	12-1/4	91-5/8	86-3/8	18	62-3/8	78-7/8	23	45-3/4	30-1/2
112"	107	14-3/8	107	100-3/4	21	72-3/4	92-1/8	26-3/4	53-3/8	35-5/8
128"	122-1/4	16-3/8	122-1/4	115-1/4	23-7/8	83-1/4	105-1/4	30-5/8	61	40-3/4
144"	137-1/2	18-3/8	137-1/2	129-5/8	26-7/8	93-5/8	118-3/8	34-3/8	68-5/8	45-3/4



NEW CBS PROGRAM TRANSMISSION STANDARDS*

Howard A. Chinn†, Fellow, I.R.E., and Philip Eisenberg†

(Reprinted from Proceedings of the Institute of Radio Engineers, Dec. 1947)

Summary--Over a period of years, broadcast listeners have complained that the musical portions of radio programs are sometimes unpleasantly loud--that is, music is too loud compared with speech. Two surveys conducted by the Columbia Broadcasting System in 1940 and 1944 found this to be true of all broadcast stations, and established the validity of the complaints. This led to more definitive studies.

Two related listener studies in 1945 were undertaken, to (1) discover proper (pleasing-to-listener) relative levels at which music and speech should be transmitted, and (2) determine the range within which the *peak* levels of a program should fall in order to please the largest number of listeners.

A total of 224 persons, representing a cross section of the radio audience, took part in individual listener tests. In both studies the listeners, one at a time, heard a series of passages from radio programs. They were asked to adjust the volume of each passage to the most pleasant listening level. Every variable which could be anticipated was provided for, including such matters as introducing controls to account for differences in room noise levels.

The major findings of the studies were as follows:

(1) Listeners prefer to hear broadcast music and speech at about the same peak levels (as read on a standard volume indicator).

(2) The limit of the range of *peak* volume levels tolerated by the largest number of listeners is approximately 8 db (4 db above or below the average peak-volume level of the passage).

(3) Within this range (8 db) volume-level changes are less annoying when made gradually, in two or more steps.

The 8-db limit mentioned above refers to the range of *peak* or maximum volume levels, *not* to the range of minimum and maximum sound intensities or "dynamic range." It is important that this range of *peak* levels not be confused with "dynamic range."

In addition to the three principal findings, the studies uncovered data on a number of related points which obtained, irrespective of the sex, age, education, or musical taste of the individual listeners. For example:

(1) Listeners like to hear broadcast music and speech at the same *relative* levels, regardless of the *absolute* sound level that is preferred.

(2) Listeners prefer an even level, regardless of whether they are hearing variety, drama, narrative, or music.[1]

(3) The peak sound level that the average listener prefers ranges from 65 to 70 db above the acoustical reference level of 10^{-16} watts/cm^2.

This study has led to the adoption by CBS of a new set of program transmission standards, in order to make broadcasting more pleasing to the listener. The old transmission standards provided for maximum peak levels or "ceilings." The new standards retain "ceilings" (but different from past ones) and, in addition, provide minimum peak levels, or "floors," below which the level of the *main program peaks* should not fall.

I. INTRODUCTION

It is axiomatic that broadcasting programs should be written and produced in a manner that makes for pleasant listening. Aside from the content of a given program, a broadcast may be easy or difficult to listen to, depending upon the method of presentation. Tonal range, sound reproduction level, and the range of peak volume levels are three of several factors that have a bearing on ease of listening. A former study[2] has shown that both tonal range and sound intensity influence listeners' preferences, and that listeners can distinguish more readily between different sound intensities than between different tonal ranges.

Broadcast receivers can be readily designed to provide the listener with means for selecting the tonal range and the sound-reproduction level he finds most pleasant. However, the listener is not in a position to materially alter the *relative* sound levels between different parts of a program.

Radio listeners have complained that, while listening to a program, they have to make volume adjustments because some parts of the program are broadcast too loud, and others not loud enough. The complaint has been registered for many years and to essentially all radio

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†Columbia Broadcasting System, Inc., New York, N. Y.

We are going to ask you to do something different from what you do at home when you listen to a radio program. At home you are usually seated away from the radio. If the program gets too loud or too soft, sometimes you do not change the volume because it is inconvenient.

But here, the volume-control dial is right before you. It works just like the dial on your radio. We are going to play parts of radio programs, and we would like you to keep your hand on the dial while you are listening. Whenever the program gets too loud or too soft for you, even if it is only for a few seconds, change the dial to the level you like best.

After the participant indicated that the instructions were understood, a practice test was given. For this purpose, a portion of a radio program *not* used in the final test was reproduced. When it was established that the subject understood the instructions--to make an adjustment whenever the sound level became too high or too low for him--the test series was begun.

Each participant heard five samples, varying in length from 2-1/2 to 8-1/2 minutes. The samples were chosen from regular broadcasts and ranged from program excerpts with relatively small volume-level changes to those in which the volume varied considerably. A continuous, synchronized chart was automatically drawn by a moving-tape recorder of the volume control settings made by the participant.

Program Material

All test selections were recorded from broadcast programs, and were chosen to provide a wide variety. Material from five kinds of programs was used, namely, popular music, comedy quiz, comedy variety, narrative drama, and crime drama (see Table II).

Environment

The tests were conducted in a small room furnished as far as feasible like an average living room. The room measured 23 feet long, 14 feet wide, and 10 feet high. The average noise level in the room, without the loudspeaker operating, was slightly less than 29 db above the acoustical reference level.

The loudspeaker was located at one end of the room at a height approximating ear level of the listeners. The person being tested sat in an armchair, directly facing the loudspeaker and ten feet away from it. In front of the participant was a small table, on which there was a small box equipped with a dial for controlling the volume level of the selections heard.

Equipment

Uniformity in the program material presented to each listener was assured by the use of especially recorded "masters" cut on cellulose-nitrate coated disks. The recordings were made by the Columbia Recording Corporation and employed the standard electrical-transcription recording characteristics. Original master recordings were used because of the uniform response characteristic, the low nonlinear distortion, and the very low surface-noise level that this type of recording affords. As soon as any distortion or noise became detectable under the conditions of the tests, a new recording was used.

In order to simulate home listening conditions, a band-pass filter was placed in the reproducing channel. The actual over-all response of the system, including the recording

TABLE II
Program Passages

Passage Number	Type	Content	Duration
1	Popular music	Theme music, announcements (2 male, 1 female); "Just a Prayer Away," by Tobias (male and orchestra); "My Dreams Are Getting Better," by Curtis (female and orchestra)	4 minutes, 59 seconds
2	Comedy quiz	Comedy quiz (3 males, 1 female) Commercial (male announcer) Comedy music (orchestra)	7 minutes, 5 seconds
3	Drama	Opening Announcement (male) Theme music Conversation (2 males)	2 minutes, 17 seconds
4	Comedy-variety	Opening Announcement (male) Theme music Comedy (2 males) Comedy (3 males) Commercial (1 male) Comedy (2 males)	8 minutes, 31 seconds
5	Crime drama	Conversation (3 men in a car) A murder Conversation (2 men) Conversation (several men)	2 minutes, 34 seconds

and reproducing process, but excluding the loudspeaker, is shown in Fig. 1. The loudspeaker was a dual unit, employing a folded horn for the low frequencies and a multicellular horn for the high frequencies. Facilities were not available for a free-space calibration of the loudspeaker, but the manufacturers' measurements, which are believed to be reliable, indicate the system is uniform over a much wider range than was employed for this experiment.

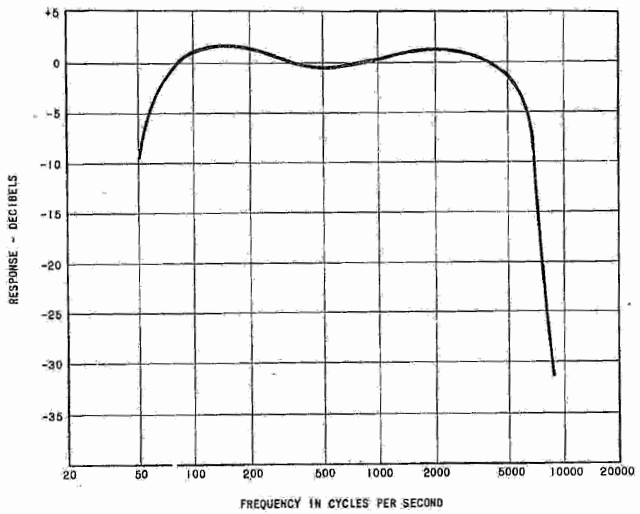

Fig. 1--Average home sound-reproduction conditions were simulated for this study by employing a band-pass filter in the test channel. The frequency-response characteristic of the channel (exclusive of the loudspeaker) is shown in this chart.

TABLE III
Composition of the Group

Number of persons = 92	
	55 per cent
Female	45
	100 per cent
Age	
Under 26 years	47 per cent
26 to 40 years	34
Over 40 years	19
	100 per cent
Education	
Grammar school	12 per cent
High school	61
College	27
	100 per cent

Although probably of secondary importance for the study undertaken, the harmonic distortion of the system was as low as it is possible to obtain with the best present-day equipment.

Subjects

The group of participants were representative of a cross section of the radio audience. They were secured by means of spot announcements over the CBS key station, WCBS, located in New York City. The exact composition of the 92 subjects, all adults, taking part in the individual listener tests, are detailed in Table III.

IV. RESULTS OF MAIN EXPERIMENT

Method of Analysis

The data were analyzed from two points of view: (1) the actual volume changes within the passages as broadcast, and (2) the listeners' reactions to these volume changes.

A unit of analysis was established by dividing each of the five passages into a number of *intervals*. A new interval started whenever any clear change in volume occurred, or when the program content changed. Intervals varied in length from 3 to 20 seconds, although most intervals were of 5 to 10 seconds duration. In all, the five program passages were divided into 390 intervals.

The average peak level of each of the 390 *intervals* was determined, using a standard volume indicator,[5] by averaging the readings of two trained observers who, incidentally, agreed very closely. These readings were expressed as differences (in db) above or below the average level of the *entire passage*. Listeners' reactions were then analyzed in terms of *direction* and *amount* made by the listener with each interval.

Direction of Change

Although listeners could turn the volume up, turn it down, or make no adjustment at all, any changes they made were significant only in relation to the actual volume changes occurring in the passage itself. Therefore, the direction of the change in the passage had to be related to the direction of the listeners' adjustments.

The adjustments made by the listeners were therefore classified as follows:

(1) Counter-adjustments, which offset the change in volume of a passage.
(2) Pro-adjustments, which accentuated the amount of change in the volume of the passage.
(3) No adjustment.

[5] H. A. Chinn, D. K. Gannett, and R. B. Morris, "The new standard volume indicator and reference level," PROC. I.R.E., vol. 28, pp. 1-17; January, 1940. Also, *Bell Sys. Tech. Jour.*, vol. 19, pp. 1-44; January, 1940.

In other words, listeners made counter-adjustments when variations in volume were too great for pleasant listening--that is, they turned the volume up or down to keep it within the range they preferred. They made pro-adjustments when they turned the volume up or down in the same direction as the volume changes occurring in the program material.

Amount of Change

Listener adjustments were also measured by amount of change. It was possible to measure the amount of change in db for each listener and for each interval. These changes were then averaged.

It is worth noting that, since a measurement was taken for each of the 92 test participants for each of the 390 intervals, a total of 35,880 individual reactions were analyzed.

Preferred Range of Peak Levels

Two typical examples of the way listeners reacted to changes in the peak levels during a program passage are shown in Fig. 2. In this figure, the line graphs show the variations in

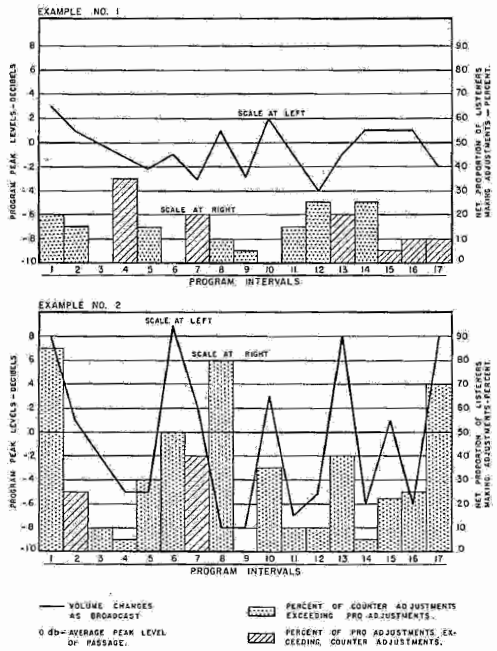

Fig. 2--The variations in peak volume levels, as shown by the line graphs in this chart, are typical of the program excerpts used in this study. In example No. 1 the range of peak levels is not very great whereas in example No. 2 the range is rather large.

The vertical bars show the extent of the reaction of the listeners to these volume changes. The bars show the difference between the proportion of listeners who made counter-adjustments and those who made pro-adjustments.

average peak levels, as broadcast, of two of the program passages listed in Table II. In the first example, the maximum variation in peak levels was only 7 db; 3 db above to 4 db below the average for the passage. In the second example, on the other hand, the variation was 17 db; 9 db above to 8 db below the average.

The vertical bars in Fig. 2 show the reaction of the listeners to these volume changes. The bars show the difference between the proportion of listeners who made counter-adjustments and those who made pro-adjustments.

In the first example the volume variations were slight, and few of the listeners found it necessary to make volume adjustments. On the other hand, the second example, containing marked volume changes, caused large numbers of listeners (in some instances more than 50 per cent) to make adjustments that offset these changes.

TABLE IV
Distribution of Program Intervals

Deviation of interval from the average level of the passage	Number of intervals
9 + db	15
8	20
7	17
6	31
5	26
4	43
3	51
2	74
1	79
0	34
Total	390

Fig. 2 presents the data for only a few typical intervals. In all the test passages, the intervals totaled 390. The distribution of these intervals, broken down according to the differences (in db) from the average levels of the passages in which they occurred, is shown in Table IV.

The proportion of listeners who made counter-adjustments and the proportion who made pro-adjustments for each of these groups of intervals is shown in Fig. 3. It is seen that when the intervals were transmitted at the average volume level of the passages (0 db), more than half of the listeners made no adjustment at all. Those who made adjustments did so to offset or to accentuate the change in roughly equal proportion (23 per cent made counter-adjustments; 18 per cent made pro-adjustments). In other words, these changes tended to cancel out.

Fig. 3 shows that the farther the average peak level of an *interval* lies from the average

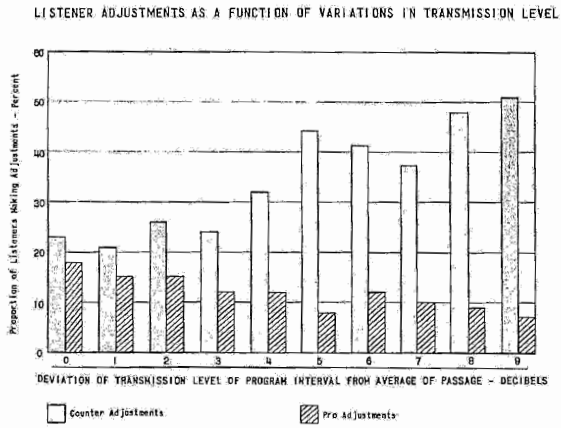

Fig. 3--This chart shows the proportion of listeners making volume adjustments as a function of the deviation of the transmission level of the program interval from the average of the complete passage. The limit beyond which listeners appear to object to large volume variations seems to occur at 4 db above or below the average of the passage.

of its *passage*, the greater is the listeners tendency to offset it--that is, to narrow the volume range down to the limit of pleasant listening. The limit beyond which listeners appear to object to large volume variations seems to occur at 4 db above or below the average of a passage. (At this point, more than 30 per cent of the listeners made counter-adjustments.)

Since listeners evidently will tolerate a variation up to 4 db above or below the average of a passage, *the range of listener tolerance for peak levels appears to be no more than 8 db.*

The foregoing analysis was made by *direction* of adjustment. It remains to analyze the *degree* of adjustment made by the listeners. These data are presented in Fig. 4 which shows by how many db the average listener who made adjustments moved the volume-control dial.

It is seen that where the deviation of the peak level of an interval is 4 db or less from the average for the passage, the amount of adjustment made by the listeners was less than 1 db. Beyond the 4-db point, however, there is an abrupt break, and for greater deviations the listeners tend to counter-adjust by 2 or more db. It is also evident that the farther a peak level lies from the average peak levels of a passage, the greater the adjustment.

Tolerable Rate of Change in Peak Levels

Thus far, the analysis has been limited to listener preferences in terms of peak sound intensity, in relation to the average peak level of passages. This does not however, take into account the complexity of volume changes as they occur in radio programs. At least two other factors are significant in influencing listener reactions: (a) the *amount* of volume change from interval to interval, and (b) the *direction* of the volume change from interval to interval.

An illustration of the effect of these factors can be seen in Fig. 2(b). Interval 10, while it is only 3 db above the average of the passage, is 11 db above the peak level of the preceding passage. A relatively large proportion of listeners reacted to this change (the difference between the percentage of listeners making counter-adjustments and the percentage making pro-adjustments was 35 per cent). This illustrates the importance of the amount of volume change from interval to interval.

Furthermore, the direction of the volume change is of some consequence. In the same example, interval 8, which is 8 db below the average, has moved 17 db, in two steps, from a preceding interval. From a peak at interval 6, the volume dropped in the *same* direction to interval 8.

On the other hand, intervals 13 through 17 illustrate the situation when volume changes zigzag back and forth; listeners' adjustments are in contrary direction. In order to unravel these complexities, it was necessary to analyze listener adjustments of intervals in terms of the two factors mentioned above.

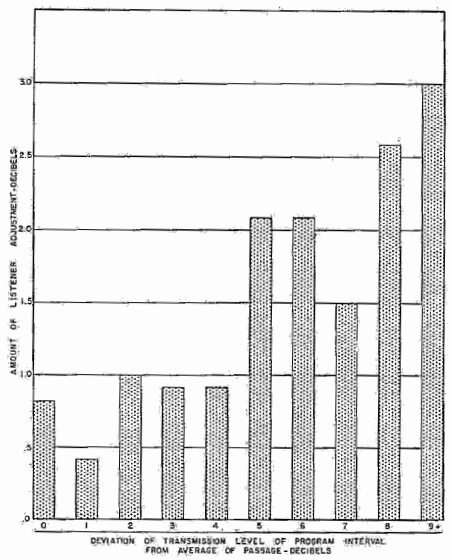

Fig. 4--The extent of the volume-level adjustments made by those listeners who made a change is shown in this chart as a function of the deviation of the transmission level of the program interval from the average of the complete passage. Again it is seen that beyond the 4-db point there is an abrupt break, and for greater deviations listeners tend to counter-adjust by larger and larger amounts.

The amount of volume change from interval to interval was divided into three categories: (1) large = more than 6 db; (2) moderate = 3 through 6 db; and (3) small = 2 or fewer db.

For *direction* of volume change, intervals were divided into those which continued in the same direction as the preceding interval and those which changed direction.

However, the analysis would not be complete unless the *distance* of peak levels from the average were also taken into account. That is, some intervals were either very high or low in volume, as compared with the average for the passage, while others were close to the average of the passage. Therefore, intervals were further subdivided into those which were a large distance from the average of a passage (4 or more db) and those which were a small distance (3 or few db).

The great mass of data resulting from the analysis of all participants' reactions to the 390 intervals involved can best be presented in chart form. Fig. 5 presents the data in terms of the proportion of listeners making adjustments. This figure shows the proportion of listeners making counter-adjustments and those making pro-adjustments where the volume change between intervals is large (more than 6 db), moderate (3 to 6 db), and small (less than 3 db). The left-hand column of bars is for those intervals where the volume level of the interval changed in the same direction as in the preceding interval. The right side of the chart is for those intervals where the volume level changed in a contrary direction to that of the preceding interval.

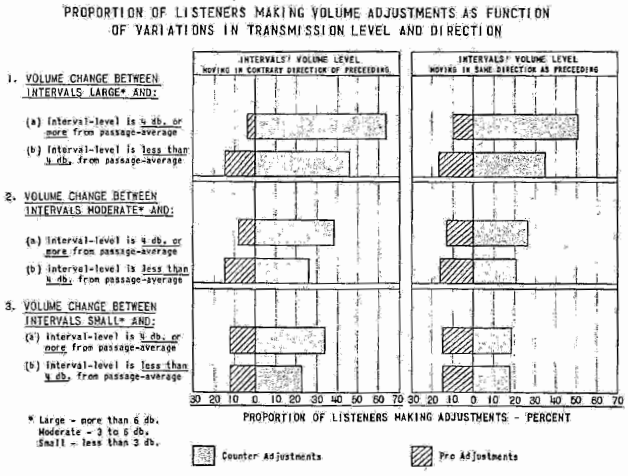

Fig. 5--Listeners' reactions to changes in volume level are complex. As this chart shows, they are influenced by (a) the direction of the volume change, (b) the degree of the volume change, and (c) the relative volume level with respect to the average of the passage.

Figure 6

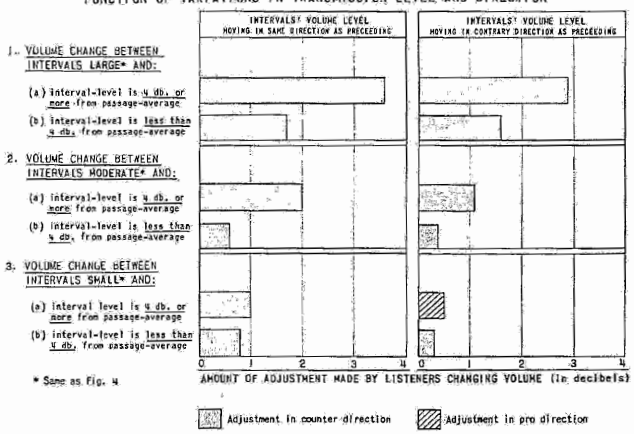

Fig. 6--From the *amount* of the volume adjustment made by listeners, it is seen that not only is a fairly narrow range of *peak* levels preferred, but, in addition, within that range large changes are not liked. Changes in the peak volume level must be made gradually for easy listening.

From these data it is seen that:

(1) The direction of volume change influences listener adjustments. A greater proportion of listeners make counter-adjustments and few make pro-adjustments when volume changes occur in the same direction as the preceding interval.

(2) The degree of volume change from interval to interval also influences listener adjustment. The larger the change, the more counter-adjustments.

(3) Distance from the average peak level of a passage influences adjustments. The greater the distance, the more counter-adjustments.

The intervals in which most listeners make counter-adjustments are those which move in the same direction as the preceding interval and which, at the same time, represent a large volume change from the preceding interval. These intervals are also farthest removed from the average level of a passage. The fewest changes are made in intervals with reverse characteristics.

The data, in terms of average db change, for those listeners who make adjustments, are given in Fig. 6. It is seen that direction of volume change, *amount* of volume change, and *distance from average level* also influence the amount of this compensation made by the listener. These data show that the listener not only prefers a fairly narrow range of peak levels (not more than 8 db) but, in addition, within that range does not like large changes. In other words, the whole range of 8 db cannot be

jumped in one step. *Volume changes must be made gradually.*

Influence of Program Content

Thus far, listener preferences have been covered only in terms of relative volume levels without regard to the program content. In general, radio programs can be broken down into three types of content, (1) speech, (2) music, and (3) laughter, applause, and sound effects (grouped together as a "special" type of content.) The test passages were therefore segregated into these three categories and the peak levels analyzed, both as originally broadcast and as adjusted by listeners during this study.

The average difference from the average peak-levels of the passages as originally broadcast was as shown in Table V.

TABLE V

Type of Program	Average Difference from Average Level of Passage
Speech	-0.6 db
Music	+0.7 db
Laughter, applause, and sound effects	+3.9 db

A survey[6] made on a wider basis scrutinized the practices of a variety of programs as broadcast by various networks, and verified that the program samples used in these experiments were typical.

The average peak level of all music intervals in these experiments was 1.3 db higher than the average of all speech intervals. This difference corresponds closely with the former standard practice, wherein music was peaked at 100 on the volume indicator and speech at 80. This corresponds to a difference of 1.8 db.

In order to relate the volume differences (as broadcast) to the adjustments which the listeners made, their reactions to each type of program content were analyzed in terms of the distance of each interval from the average of the passage. This analysis shows listeners' adjustments to music and speech intervals of the same loudness.

Fig. 7 shows the proportion of listeners making counter- and pro-adjustments for intervals of various differences from the average of all passages.

Listeners turn the volume up for below-average musical intervals in about the same proportion as they do for speech. The reaction to intervals containing laughter, applause, and sound effects is similar to the reaction to music.

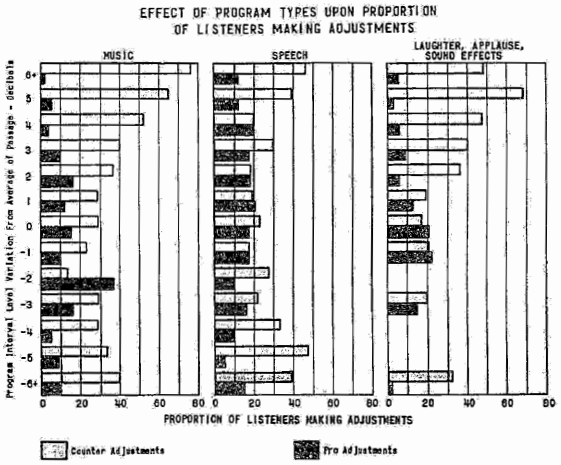

Fig. 7--The reactions of listeners to different types of program material is shown by this chart. Listeners' reactions to musical passages, speech and laughter, applause and sound effects follow the same general pattern.

The evidence of this study supports this conclusion: For radio program material (exclusive of symphonic music, which was not studied) listeners prefer a fairly even level for all types of program content.

V. DISCUSSION

The listener's preference for a limited range of peak levels differs sharply with the ideas of some radio program directors, conductors, and performers (and some scientists). They have sometimes felt that a restricted range of peak levels unduly limits the dramatic and musical effects that can be achieved. This feeling on the part of producers, conductors, and performers may be a carry-over from the stage and concert halls, in which, for reasons to be mentioned, a wide range in peak intensities probably does not irritate the listener.

Broadcasting, however, is an entirely different medium. It differs from the stage and the concert hall in at least two important respects: (1) It is intimate. The listener is in a small room and cannot tolerate shouts and loud orchestral crescendos. (The listener, moreover, frequently considers his neighbor's feelings, as well as his own.) (2) Listening to the radio is a monaural process. That is, although the listener actually hears with both ears, the sound comes from a single source and all sense of direction, and almost all sense of perspective, is lost. The listener to "real-life" sound, on the other hand, enjoys binaural listening. He can pay attention to what he

[6]Unpublished report, CBS General Engineering Department, April, 1945.

wants to hear and discriminate against undesirable sounds. The radio listener, however, must listen to all the sounds that come from the loudspeaker.

Although the reason is not yet known, monaural hearing is apparently more pleasant when the range of peak intensities is somewhat restricted. The manner in which sound is used in motion pictures supports this fact. Motion-picture sound, also monaural, is generally reproduced at a narrower range than that which is transmitted by radio.

It is essential that this monaural peculiarity of radio be taken into account. Although it calls for a restricted range of peak intensities, the desired dramatic effect may be gained in another dimension--*timbre*. Varying the distances of speaker or musical instrument from the microphone will effect the apparent loudness, even while maintaining an even level as measured on the volume indicator, because of the change in liveness of the pickup. The opportunity for such effects should be exploited to the fullest degree.

VI. CONCLUSIONS

The conclusions resulting from the two studies reported are:

(1) Listeners prefer to hear music and speech at about the same peak levels (as read on a standard volume indicator).

(2) Listeners like to hear music and speech at the same relative levels, regardless of the absolute sound-intensity level that they prefer.

(3) Listeners prefer an even level regardless of whether they are hearing variety, drama, narrative, or music.[7]

(4) The limit of the range of *peak* volume levels tolerated by the largest number of listeners is approximately 8 db (4 db above or below the *average volume* level of the passage).

(5) Within this range (8 db) it appears that volume-level changes are less annoying when made gradually--in two or more steps.

The 8-db limit mentioned above refers to the range of *peak* or maximum volume levels, *not* to the range of minimum and maximum sound intensities or "dynamic range." It is important that this range of *peak* levels not be confused with "dynamic range."

As a result of this study, CBS has adopted the following program transmission standards:[8]

CBS Program Transmission Standards

		VI Peaks
(1)	*Speech and Music*	
	Normal passages	Peaks of 100
	Low-level passages	Not less than 40
(2)	*Theme under station breaks*	Peaks of 40
(3)	*Applause and audience reaction*	Maximum peaks of 70

(4) *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.

(5) *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 must be kept to a minimum.

VII. PRACTICAL TEST

Theoretically, the adoption of new program transmission standards based upon the foregoing conclusions should remove the cause of listener's complaints arising from former practices. To check this, a practical before-and-after test was made. Three pairs of program excerpts were used in these tests. In each pair the excerpt was produced in two ways--the old way, with wide range in *peak* volume levels, and the new way, in accordance with the findings of the study. Thus, listeners were enabled to express their direct preference for one type of transmission or the other. For the test the selections used were as follows:

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[7] These findings do not necessarily apply to symphonic music, which was not analyzed in these studies.

[8] It is hardly necessary to state that the standards contained in this report may not remain static indefinitely, since they are based upon current broadcast-pickup techniques. Future operations and experience may indicate that permanent or temporary departures from them are desirable, and actual practices may, from time to time, vary from these standards. They represent, however, the conclusions which have been reached as a result of the investigation which is reported upon in this paper.

(1) A passage containing a loud, but typical orchestral bridge.

(2) A loud but typical opening followed by conversation in low tones.

(3) A passage containing a loud scream.

The preferences for the old and the new transmission standards are shown in Fig. 8. It can be seen that in two of the three cases there was an overwhelming preference for the new standards.

The third test selection emphasized still another condition which plainly contributes to the sources of complaint mentioned earlier. In this test, production rather than engineering played the major part. The director realized that some of the life-like quality of the scream would be lost if the technician held the transmission level within the prescribed limits by "fading-down" the output of the microphone. To avoid this loss of dramatic effect, the producer accepted an annoyingly loud peak in the original production of the program.

The desirable solution, which would have retained the dramatic effect and eliminated the high peak, would have been to move the performer farther from the microphone. Advantage was not taken of this technique in the third practical test; rather, the levels were simply faded-down. Even so, 60 per cent of the listeners preferred the new transmission practices to the old.

An even more practical test has been the introduction of the new transmission standards to programs originated by the Columbia Broadcasting System. This was done during 1946, and the number of listener complaints on this score has markedly decreased. Furthermore, listeners have not felt that there has been diminution of dramatic value in program production. Rather, they have experienced a more even transition between segments of program.

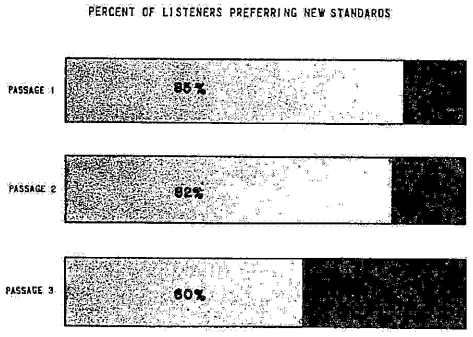

Fig. 8--The proportion of listeners favoring the new standards over the old, in a practical test involving three typical passages, is shown in this chart. In passage 3, changes in production techniques would have been required (as explained in the text) in addition to the new transmission standards in order to make the passage more acceptable.

(NAB Editor's Note: Immediately following this article will be found CBS Report No. E-611-E prepared by the CBS General Engineering Department and Research Department, outlining the direct application of the Program Transmission Standards.)

VIII. ACKNOWLEDGMENT

Studies of this type require a great deal of detailed preparation and care to insure reliable data. Without the patience, ingenuity, and skill of A. G. Peck and D. C. Battin, it would have been difficult to have successfully completed this study. The authors gratefully acknowledge their contribution.

Report No. E-611-E

December 4, 1945

CBS General Engineering Department and Research Department

CBS PROGRAM TRANSMISSION STANDARDS

The Condition Which Exists

Over a period of years, listeners have complained in writing that the musical portions of broadcasting programs are unpleasantly loud--that is, music is too loud compared with speech. These complaints are supported by comments frequently made by subjects in CBS Research Department Analyzer sessions.

This condition results partially from the practice of operating the monitoring loudspeaker in studio control rooms at abnormally loud levels (as compared to home listening practices), and partially from the program transmission practices that have been standard for some years.

The program transmission standards which are currently in use, result in the broadcasting transmitters being modulated an equal amount, by both speech and music, when the prescribed peak levels are maintained. This practice insures the maximum use of the available power. From a purely technical standpoint, the procedure is sound--however, it does not take into consideration the listener's preferences. Two surveys conducted by the CBS Research and the General Engineering Departments (October, 1940 and October, 1944) established the validity of the complaints and led to further, more definitive study.

The Studies

In order to obtain quantitative data concerning these general complaints, two related listener studies were made (January-April, 1945) designed to:

(1) discover proper (pleasing-to-listener) relative levels at which music and speech should be transmitted.

(2) determine the range within which peak levels of a program should fall in order to please the largest number of listeners.

In both studies the listeners, one at a time, heard a series of test passages from radio programs. They were asked to adjust the volume, by turning a dial, to the most pleasant level. Further information was secured by means of a questionnaire.

A total of 224 subjects, representing a cross-section of the radio audience took part in those individual listener tests.

Every variable which could be anticipated was provided for, including such things as introducing controls to account for differences in room noise levels.

The Major Findings

(1) Listeners prefer to hear music and speech at about the same peak levels (as read on a standard volume indicator).

(2) The limit of the range of peak volume levels which will be tolerated by the largest number of listeners is approximately 8 decibels (4 decibels above or below the *average volume* level of the program).

(3) Within this range (8 decibels) it appears that volume-level changes are less annoying when made gradually.

Some Further Findings

In addition to the three principal findings, the studies uncovered data on a number of related points--which obtained regardless of the sex, age, education or musical taste of the individual listener. Here are three of them:

(1) No matter how loud or how soft the individual operates his radio, he still wants to hear music and speech at the same relative levels.

(2) Listeners prefer an even level regardless of whether they are hearing variety, drama, narrative or straight music.*

(3) The average volume at which listeners set their home radios ranges from 65 to 70 decibels above the acoustical reference level.

Why?

Most professional broadcasters will perceive immediately one of the reasons why present practices are not entirely in accord with listeners' preferences. The explanation lies to a very large extent in the differences between (a) loudspeaker monitoring levels in the home and in the control room and (b) the background noise level in the average home and in the control room.

Surveys indicate that control room monitoring levels from 75 db to 95 db above the acoustical reference level. The average is 85 db and this is 20 db louder than in the home.

Furthermore, the background noise level in the average control room (aside from that created by the occupants) is some 20 db *lower* than in the home. Thus, the control room occupants may have a 40 db advantage over the average listener when it comes to hearing weak sound--not to mention the tremendous advantage of being able to see the source of the sounds and thereby being able to anticipate their nature.

In view of this situation, the home listener must bring the level of his radio up in order to hear weak sounds. But when he does this, loud sounds become excessively loud and irritating. It is for a very practical reason, therefore, that the listener indicates a preference for a range of peak volume levels of no more than 8 decibels.

Abrupt Level Changes

Although the average listener will tolerate an 8 db range in peak levels, he is annoyed if a change in levels as great as this occurs abruptly. Changes of this amount (and more) often occur under present practices in the following situations:

(a) between the end of a speech passage and the following music,

(b) between one speaker and another,

(c) between loud musical opening of a program and subsequent quiet conversation,

(d) between one musical passage and another,

(e) between the end of one program and the beginning of the next,

(f) sudden loud sound effects, screams, etc.,

(g) sudden loud applause or loud audience laughter.

*These findings do not necessarily apply to symphonic music, which was not analyzed in these studies.

Changes in peak volume levels within the 8 db limit should be made gradually--certainly no two succeeding passages should differ by more than 4 db under any circumstances.

The 8 decibel limit used throughout this report refers to the range of *peak* or maximum volume levels, not to the range of minimum and maximum sound intensities or "dynamic range." It is important that this range in *peak* levels should not be confused with "dynamic range."

The Remedy

To remedy this condition, three coordinated steps are necessary:

(a) Control room loudspeakers should be adjusted to levels more commensurate with the home listening habit.

(b) The production of shows must be undertaken with the view towards correcting the shortcomings of our present practices.

(c) New standards for program transmission levels must be adopted.

Control Room Loudspeaker Levels

In addition to the detrimental effects already mentioned (caused by operating the control room loudspeaker at abnormal levels) an even more undesirable phenomenon results from this practice.

This occurs because of the fact that the response of the human ear to sounds of different frequencies varies with the intensity level. Consequently, a program that is "balanced," in accordance with a producer's wishes, at a particular loudness level, is likely to sound completely unbalanced when reproduced at a different level. Furthermore, the effects that seem so dramatic, when reproduced at an abnormal listening level, may fall completely flat at the lower, home-listening, level. Finally, sounds that are quite audible in the relatively quiet control room where the loudspeaker is operating at a high level, are entirely inaudible in the average home with its higher noise level and lower loudspeaker volume.

The remedy in this case is obvious. Every effort should be made to operate the control room loudspeaker at a level which is comparable to that used in the *average* home.

Production

Listeners prefer an "even" volume level--regardless of the particular absolute level at which they listen. This desirable result can only be achieved by the combined efforts of both the program director and the studio technician. The transmission level standards which the studio technician must maintain necessarily require tremendous assistance production-wise if the desired result is to be obtained. Not only must the program director plan his sequences so as to avoid abrupt changes in volume level between one portion of the program and the next, but he must also aid in the control of extreme high level and low level by taking full advantage of studio acoustics and microphone distances.

It is generally conceded that the illusions of distance, intimacy and motion can neither be created nor destroyed by changes in the transmission volume. They are a product of acoustics, placement before the microphone and timbre of sound. With these facts in mind, performers should be properly spaced before the microphone(s) so that the pickup level is much the same for all. Thereafter the distances should vary with the effect desired or volume used in the studio.

When two or more people use the same microphone, they should be placed so that differences in voice levels are eliminated. This is very important on quiz programs when the master of ceremonies may insist on using one microphone for himself and for all the contestants even though the better solution would be to use two microphones.

The new transmission standards are intended to make radio more pleasing to the listener. An acoustical balance in the studio will aid tremendously in doing so.

CBS Program Transmission Standards

The inauguration of new program transmission standards will also contribute materially to the excellence of our broadcasting. The new standards reflect the results of the studies that have been made to determine listeners' preferences.

The old transmission standards provided for maximum peak levels or "ceilings." The new standards retain "ceilings" but, *in addition*, provide minimum peak levels or "floors" below which the peak volume level should not fall.

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 must be kept to a minimum.

VI Standards

Speech and Music	
Normal passages	Peaks of 100
Low level passages	Not less than 40
Theme under station breaks	Peaks of 40
Applause and Audience reaction	Maximum peaks of 70

Rewards

Application of the new standards should result in:

(1) Greater listener satisfaction and, consequently, a steadier audience.

(2) The listener hearing all the sounds and the effects that are being created for his enjoyment.

(3) An end to the protests, often violent, that the more annoyed listeners pen.

Symphonic Music

Since listeners' reactions to symphonic music were not tested, the present standards will be used until such time as study warrants a change. These *tentative* standards are:

Normal passages	Peaks of 100
Pianissimo passages	Must always move VI

Important

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.

MAGNETIC RECORDING IN BROADCASTING

*By S. J. Begun**

(As Presented at 3rd NAB Broadcast Engineering Conference, Chicago, Ill., April 7, 1949)

Mechanical disc recording has been for many years the preferred and practically only method of instantaneous recording employed by broadcast studios. Now there are definite signs that disc recording will soon have to share its place with magnetic recording.

It is one of the objects of this paper to analyze why magnetic recording has been gaining so rapidly in importance for broadcast work. An appraisal of the magnetic recording method discloses the usefulness of its unique features. To mention only a few: (1) There is easy erasability of the recording medium. (2) The practical signal to noise ratio is greater than presently obtained in any other recording method. (3) The recording is relatively permanent and its repeated reproduction without quality deterioration is only limited by the life of the recording medium. (4) An uninterrupted recording period of any desired length can be provided. (5) The making of a good recording requires no particular skill on the part of the operator. (6) A coated tape as recording medium can be easily cut and spliced.

On the other hand, the price of the recording medium for any given length of recording time is high compared to that of mechanical recording. The making of copies, if such are needed, is cumbersome and special equipment is required if it is to be done on a reasonably economic basis. The elasto-mechanical properties of the recording medium make it difficult to play a recording back within exactly the same time period within which it was recorded.

The features enumerated on the credit side of magnetic recording make this method of sound recording particularly desirable when the recording does not need to be preserved for long periods of time. Under these conditions, the erasability of the magnetic recording medium more than outweighs the somewhat lower price of disc blanks. Without any doubt, magnetic recording provides the best economical solution for time delaying of programs. Here, the repeated use of the same recording medium is only limited by the mechanical wear which eventually deteriorates the performance.

There are two other applications in which magnetic recording has already proven its value: For on-the-spot recording and for editing of program material.

No one instrument will be best suited for all these applications. For time delayed programs a sturdy rack and panel arrangement, preferably remotely controlled, will be most practical, since with such a layout all operations can be initiated by the attendant at the master control board.

For on-the-spot recording, lightweight portable equipment is needed. For this application, some compromises will have to be made. While good performance still is required, one cannot expect to obtain results which are equivalent to that from a studio installation.

Editing requires still another type of instrument. The simplicity of cutting and splicing tapes makes it extremely easy to rearrange the sequence of a program and thus provides a new tool for the program director. The console type of magnetic recorder is presently believed to be most suitable for this application. It is important in this type of instrument that provisions be made to find easily any particular part of the program.

Only a general review of the most essential requirements of these three classes of instruments will be attempted here. A detailed discussion of all the desirable features, which should be associated with each of these devices, is beyond the scope of this paper. One other point needs mentioning here. A recording made on any one of these machines must be reproducible on any other type of instrument. Furthermore, equipment for various applications may be supplied by more than one manufacturer. Interchangeability of recorded program material is a must, if full use is to be made of the potentialities of magnetic recording. This calls for standardization wherever technical developments have advanced sufficiently to make agreement among the interested parties feasible.

A bird's-eye view of the present status of the art at this point might be profitable. There are four main criteria which determine the performance of sound recording equipment:

(1) The signal to noise ratio
(2) The response versus frequency
(3) The nonlinear distortions
(4) Flutter and wow

In regard to the first three points, magnetic recording is at least equal to the best of the optical and mechanical recording methods. Presently available experience indicates that a signal to noise ratio in the order of 60 db might be considered as normal. Of course, this does not

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*Dr. Begun is Vice President in charge of Engineering for The Brush Development Company, Chairman of the NAB Committee on Magnetic Recording and Author of "Magnetic Recording" available from Murray Hill Books, Inc., New York.

necessarily mean that all magnetic recorders will have such a high signal to noise ratio, since only careful design can assure it. Permanent magnetization of the playback head must be avoided since a d-c magnetic field component can increase the background noise of the medium from 10 to 20 db. Permanent magnetization of the recording head will also adversely affect the signal to noise ratio of the system. Furthermore, the erasing and biasing current should be free of harmonics. Only under these conditions will the recording medium be left, in the absence of a signal, in a state of complete magnetic neutralization, which is so essential for noise-free operation.

Proper shielding of the playback head, which should preferably be of hum-bucking construction, is essential. Even small extraneous magnetic fields can do much damage if they are permitted to induce a voltage in the coil of the playback head.

Response versus frequency is associated with the speed of the medium and also depends upon the magnetic properties of the recording medium. In addition, it is a function of the playback head gap length and the choice of the value of the biasing current. Proper adjustment of the recording and playback head are imperative since the response at the high frequency end of the spectrum suffers if the recording head gap is tilted with respect to the playback head gap. Maintenance of intimate contact between the recording medium and the pole pieces of the recording and playback head is another necessary condition.

Experience has shown that with available coated tapes, a flat response can be obtained, with proper equalization, until a frequency is reached which is equivalent to a wavelength of .001". In other words, with a speed of 15" per second, the response versus frequency can be made to be essentially flat up to 15,000 cycles per second. A suitable tape is one which has a coercivity between 200 to 300 oersteds and a remanence between 600 to 900 gausses.

Distortion can be kept to a minimum by proper adjustment of the value of the biasing current. With the biasing current too low, the transfer characteristic is nonlinear; with the biasing current too high, the response at high frequencies deteriorates. The biasing frequency should be at least four to five times higher than the highest audio frequency to be recorded. It is, of course, unnecessary to state that the recording current associated with the maximum signal must not exceed a given value since otherwise overloading occurs.

The amount of distortion is also a function of the magnetic properties of the recording medium and of the dispersion of the magnetic powder in the binder. Each medium must be carefully tested. In general, for a signal to noise ratio of 60 db, not more than 2 to 3% harmonic distortions need be tolerated.

With regard to flutter and wow, no better performance than obtainable with other methods should be expected. Well designed disc, film, and magnetic recording equipment can be made to meet the specified requirements.

But let nobody be fooled into thinking that a high quality magnetic recorder of the studio type can be built less expensively than instruments for other recording methods. If price is an important factor, the purchaser of magnetic recording equipment will have to make concessions in one or in another respect. In many cases where high performance standards are mandatory, it will prove to be worth-while to pay a high price for the proper equipment.

In the course of this paper, reference has been made from time to time to disc recording. It is of particular importance to the broadcast engineer to appreciate where mechanical recording falls short of magnetic recording. The advent of the cellulose nitrate record blank brought about the era where the recordist thought that the crest of performance had been reached. But only most careful attention during the cutting process gives good results. After the disc has been cut, most meticulous protection against dust particles is required to insure the maximum signal to noise ratio of the system. An excessive stylus force coupled with a high mechanical impedance of the moving elements of the pickup cartridge tends to destroy the modulated groove in many cases after the first playing. The eternal problem of translation loss adds an additional difficulty. But worst of all, the tracing distortions are of considerable magnitude, particularly when the recorded wavelength approaches the stylus tip dimension of the reproducing device. Mechanical recording also suffers from the fact that the mechanical vibrations, always present during the recording and reproduction, lead often to an unwanted relative motion between the recording medium and the recording and reproducing stylus causing modulations which are reproduced as rumbling noises.

In contrast, magnetic recording is free of most of these difficulties. While there is a gap length effect in magnetic recording which in some respects might be compared with the tracing problem in disc recording, the gap length effect does not cause nonlinear distortion even if the wavelength approaches the gap length of the reproducing head. Only the frequency response is affected by short wavelengths of the recorded signal.

All this is not meant to imply that magnetic recording is the wonder elixir which solves all

problems. In fact, magnetic recording introduces difficulties of its own. The recording medium, particularly when it is a coated tape, is usually extremely elastic and stretches during operation. Its dimensions are also changed by the effect of humidity and temperature. Expansion and contraction of the medium will lengthen or shorten the playback period compared to that of the recording time, if no special provisions are made to decrease or increase the speed of the drive mechanism to compensate for the variations of the length dimension of the tape. The use of sprocket holes has been suggested, but appears to be impractical, since it would require considerable strengthening of the base material resulting in bigger reels for accommodating a given recording period.

The amount of magnetic energy which can be stored on the thin layer of magnetic material is relatively small. Therefore, the impressed signals can only develop weak magnetic fields which must generate the useful voltages in the playback head. To design a highly sensitive amplifier which is responsive to these small signals with the necessary signal to noise ratio, challenges the ingenuity of electronic engineers. The small fields generated by the recording medium are sometimes comparable to the magnitude of external fields. Thus, it is difficult to reduce hum to an appropriate low level. But even though problems are still to be solved, there is good reason to believe that they do not represent unsurmountable barriers in future developments.

Some question might be raised with regard to modulation noise. Modulation noise is a noise which exists only in the presence of a signal and its magnitude depends upon the strength of the recorded signal. The modulation noise is a phenomenon which is not unique with magnetic recording since it is at least to some extent found in mechanical recording and particularly is present in film recording. Because of the other outstanding performance characteristics of magnetic recording, modulation noise is now looked upon as the one factor which limits the ultimate capabilities of this sound-recording method. It causes fuzziness in reproduction with a corresponding annoyance to the listener. Various statements have been made regarding the order of magnitude of the modulation noise for different types of magnetic recording mediums. Values of 30 to 40 db have been reported but it is doubtful whether great significance can be assigned to these figures. No specific measurement procedure has been agreed upon as yet.

Level variations are another objectionable deficiency in magnetic recording. They occur in the playback process, being particularly pronounced in the reproduction of the higher frequencies of the spectrum. Such level variations are usually brought about by contact variations between the recording medium and the pole pieces of the recording and playback head and are received by the listener as noise and fuzziness. Careful design of the equipment, cleanliness of the heads, smoothness of the recording medium surface and of the pole pieces will all tend to reduce level variations to a minimum.

The need for standardization has already been stressed. Various technical organizations and societies have established committees to review the available information and to see whether an agreement could be reached with regard to certain design features so that interchangeability of such elements could be accomplished which need to be interchangeable for the benefit of the user of magnetic recording equipment. The NAB Magnetic Recording Committee has drawn its membership from industry active in the field of magnetic recording and from broadcasting organizations interested in employing magnetic recording. Thus, there is assurance that the designer's and consumer's viewpoints are properly considered.[1]

A brief review of some of the problems with which the committee was and still is confronted will underline the magnitude of its task. First of all, there must be agreement on the speed and on the physical dimensions of the recording medium. This requirement is so basic that no further explanation is needed here. Secondly, signals must be so recorded that the remanent magnetic induction in the recording medium for any frequency within the specified spectrum should have a definite relationship to the remanent induction of any other frequency. Only under such conditions is it possible to obtain the desired response versus frequency with one setting of post equalization independent of equipment on which the recording has been made. Furthermore, tape reels must be so designed that they can easily be attached to any instrument.

Very definite progress has been made in establishing standards for the physical dimensions and for the speed of the recording medium. After considerable deliberation, 3 tape speeds have been chosen:

(1) *15" per second (primary standard):* Where high fidelity performance is required.

A magnetic recorder operating at 15" per second shall provide a response which should lie between two limits; the upper limit is represented by an equal level line from 50 to 15,000 cycles per second. The lower limit is an equal level line from 100 to 10,000 cycles per second but 2 db down with respect to the upper limit. From 100 to 50 and from 10,000 to 15,000 cycles per second the lower limit is permitted to drop uniforml and progressively an additional 3 db.

[1]Refer to NAB Recording and Reproducing Standards in Section 1 of this Handbook.

(2) *7.5" per second (secondary standard):* Where limited performance, as far as frequency range is concerned, can be tolerated.

Response versus frequency of a magnetic recorder employing a tape speed of 7.5" per second shall have a response in character similar to that of 15" per second equipment, only that in this case, the 2 db allowable level variations are restricted to the band from 100 to 5000 cycles and that beyond 5000 cycles per second to 7500 cycles per second the response can drop an additional 3 db. The requirements from 100 to 50 cycles per second for 15" and 7.5" per second recorders are the same.

(3) *30" per second (supplementary standard):* Wherever special requirements make an increase in speed desirable.

A few explanatory words seem to be in order here. These 3 speeds have been chosen since their ratio is 1 to 2 to 4. Should it at any later time become desirable to provide markings on the tape for speed correction to compensate for elongation or contraction, such ratios which are based on multiples will greatly simplify the problem. Furthermore, speeds of 7 1/2" and 30" per second had already wide use prior to the final proposal made by the NAB Committee.

With regard to the physical dimensions of coated tape, its thickness shall not exceed .002" and its width shall not exceed .250" nor shall it be less than .0244". Only an upper value has been set for the thickness of the tape. There is no objection to the use of a thinner tape, as long as its mechanical strength is high enough to withstand operational stresses and as long as the coating permits sufficient storage of magnetic energy. The maximum permissible thickness of the tape determines the dimensions of the reels for any given recording time and thus controls certain important dimensions of magnetic recording equipment.

The work on standardizing reels has not been completed. This problem is aggravated by the fact that there are instruments in use which require different reel designs for proper operation. After many months of deliberation it seems that the committee can now propose a reel which will be acceptable to all.

Much more work has still to be done in setting standards for remanent induction values versus frequency. There are so many factors which tend to change conditions that only careful consideration can bring about a satisfactory agreement.

BROADCAST STATION AUDIO AND CONTROL CIRCUITS*

Warren E. McDowell

Radio Station WCFM, Washington, D. C.

Summary

The author describes the audio frequency control circuits for a typical local station operation utilizing one control room and two studios. The general layout of circuits is shown together with detailed descriptions of various parts of the system. It is not the author's intention to furnish detailed instructions covering the installation of such a system, but rather to provide ideas which experienced engineers might find helpful in designing their own studio circuit arrangements. Those who have not had adequate training and experience in the design and operation of high quality audio circuits are cautioned against assuming that this paper includes complete instructions for making such an installation.

In broadcasting, ease of operation and simplification of equipment maintenance is highly desirable and will pay dividends in the form of improved program production. With a flexible system, the station engineer is able quickly to solve unusual setup problems and system testing. It is much easier to install a flexible design originally than to add a bit at a time after the basic system is on the air. In many stations, lack of time and personnel often prohibit working on equipment once it is placed in service. Hasty modifications usually result in "haywire." Thus it becomes highly desirable to have a certain measure of planning in the original construction.

The Mixer System

There are nine faders in the mixing system, handling normally two microphones from each studio, one microphone from the control room, two transcription turntables, one network line and one remote line. Wiring of key switches and faders is shown on DWG 5 and the values of R shown on DWG 3, FIGS. 2 and 5. Also on DWG 3 is shown a variation of the regular mixing system, three outputs being utilized instead of two. This latter might be used in a small master control position.

As tape recorders are now coming into quite common use it may be necessary to expand the mixer system by one or two more faders. Some of the present day tape recorders deliver at least zero level and may be brought in on the remote key. Since most of these recorders are complete with record and playback amplifiers as well as gain controls all operation and control can take place where the units are mounted.

The regular mixing system has two outputs, one for feeding programs to the transmitter and the other for auditioning a second program simultaneously. The mixer is so designed that the throwing of a key switch makes no noticeable change in level either in the program or audition channels.

The use of different colored knobs, or section paneling, is desirable since a row of nine faders may be confusing.

DWG 1 shows all inputs to channels going to the relay arms, and the inputs of the faders to front contacts. In a channel where talk-back or cue circuits do not exist, the relay may be turned around and the fader input connected to the arm. This will make available an extra input to the fader when the channel is in the "OFF" position.

Transcription Cue and Talk-back Circuits

Transcription cueing systems in current use are many and varied and are at times quite inconvenient. The system described here is entirely automatic and is successfully installed in a number of stations.

Many of the smaller stations begin their operations with a stock model console. Most of these consoles have keys for channel control without any room for addition of pushbuttons for relay control. These keys may be wired to turn on a turntable motor relay to start the table from the console position. Placing the key in either "ON AIR" or "AUDITION" will start the table and take the preamp off the cueing circuit and returning it to "OFF" will place the output of the preamp back in the cueing position. A simple switch in the relay control circuit will de-energize the relays and the tables can be operated in the normal manner, that is, one hand on the fader and the other on the table.

By the relay method, provision is made for cueing by automatically setting up a monitoring channel. This means that there is no key switch to throw when cueing a record or listening for checking. A control pushbotton operates relays starting the turntable motor and placing the channel "ON AIR." When the channel relay is released, the output of the pickup preamplifier connects automatically to the cueing amplifier through a back contact of the relay. This is shown in detail on DWG 5. Relays for channels six and seven are

* Revised 1949

wired similarly to channel one. A separate toggle switch on the turntable console may be employed to operate the turntable motor when desiring to listen to a transcription with the system in cueing position.

The talk-back circuit makes the output of a microphone preamplifier available for talk-back purposes when the channel relay is not in the "ON AIR" position. Channel relays are directly ahead of faders in the mixing system, being controlled from the announcing position as well as in the control room. Speaker cutout relays prevent feedback when the studio is "ON AIR", but, when talk-back is used, both the microphone and speaker are on, with the gain of the talk-back amplifier set below the feed-back point.

Talk-back relays are controlled by push-buttons at the three microphone positions. This is a simple circuit using a push-to-make button to apply power to the relay coil. DWG 4 shows the audio wiring in a one-line diagram. It may be desirable to use a separate speaker in the studio so that the regular reproducer will not be subject to interruption at a critical point in the program being monitored.

Remotes

The remote channel, number nine, may be set up to handle two remotes, one following the other. Interlocking prevents putting both on the air at the same time. Details will be found on DWGS 2, 4 and 5.

Several ways of sending cue to a remote operator are indicated. If the microphone talk-back circuit is used, the telephone may be omitted. Usually, the remote operator can make use of a regular microphone and headphones for pre-program communication with the studio. It has been suggested that, by incorporating a switching arrangement in the remote amplifier, crystal headphones can be used for talking and listening.

Relay eleven can be made to operate an indicating device in the control room when the operator arrives at the remote and plugs in his equipment. The center-tap of the remote amplifier output transformer has to be grounded to make R11 operate. This ground, as a rule, effects a reduction in hum level and should be made to a nearby water-pipe. For convenience, the remote line and the ground wire should be connected to a socket. Further, an output plug should be built into the remote amplifier paralleling or replacing the usual terminal strip. A flexible cord connects this plug with the remote line-ground socket, as well as completing the studio call-in circuit. This procedure also facilitates the quick setting up of a remote.

Relay twelve can be used for signalling after the remote has been patched up. This circuit of battery, PB1, R12 and repeat coil is duplicated in the remote setup. The relay at the remote point may be controlled to turn on an unattended amplifier.

Relay Controls

Relay control wiring detail is shown on DWG 2, FIG 1. Relay catalogs will give all information for ordering units with coils of proper resistance for the voltage chosen. Telephone type indicator lights rated at 14 volts will give long service when operating on 12 volts. Should any other voltage be used, the rating of the lamps should be approximately ten percent above the supply voltage for maximum life with satisfactory brilliance.

The D.C. power supply for relays and lamps should be well filtered; an electrolytic condenser of 1000 mfd capacity probably will suffice. A selenium type rectifier supplying 12 volts is a satisfactory source of power. Current requirements should be calculated after relays and lamps have been chosen. Voltage regulation of the power supply should be capable of handling all variations in the load that will occur during operation.

Some trouble may be expected from clicks when relays are operated; a little experimenting will correct this. A resistor or resistor-condenser combination across the "OFF" push-button contacts will minimize interference. Relay and power wiring should be isolated completely from audio circuits, and it is recommended that such control circuits be shielded in conduit or braid. Any contact that breaks a current is a potential source of trouble and should be investigated if clicks persist.

FIG 2 on DWG 2 shows a variation of wiring for the relays in any one channel. This change causes the speaker relay to operate first, thus cutting off the speaker before the microphone is turned on. Also, if used in the transcription channel, it allows the turntable to start before cutting in the channel. In some cases, the bending of relay contacts will produce the desired operation.

Wiring

Audio wiring is carried in shielded pair with two wires for each circuit even though one side is common. Present day practice calls for twisted pair, third wire bare, copper braid shield and cloth braid over-all. The bare wire is used to carry the ground so that the point of grounding a run can be controlled, thus eliminating a "ground loop" and reducing noise in low level circuits. All common wires should be tied together at one point in the mixer console.

An external GROUND is also brought in at this point. Low level circuits can be run in mike cable to permit the grounding of the shield at one point only.

If a noise level of 60 DB below reference is to be obtained extreme care must be taken with all wiring. Keep low and high level circuits well separated.

Wiring from jacks and units in a rack may be brought down to a terminal strip and cross-connected both to one another and to other racks. This will simplify any later changes that may be necessary. Jacks can be numbered in order as they appear in the rack and this number carried to the main block diagram. A sample of this numbering is shown on DWG 5. Jack numbers should also be put on the terminal boards within the cabinets. This makes for rapid tracing of circuits and aids in making special setups.

Conclusion

The manufacturer of equipment or components is not specified since each engineer will have his own preference. Satisfactory operation will depend, of course, upon the care with which the selection is made. This choice of high quality relays, pushbuttons and key switches will more than repay the cost in good operation.

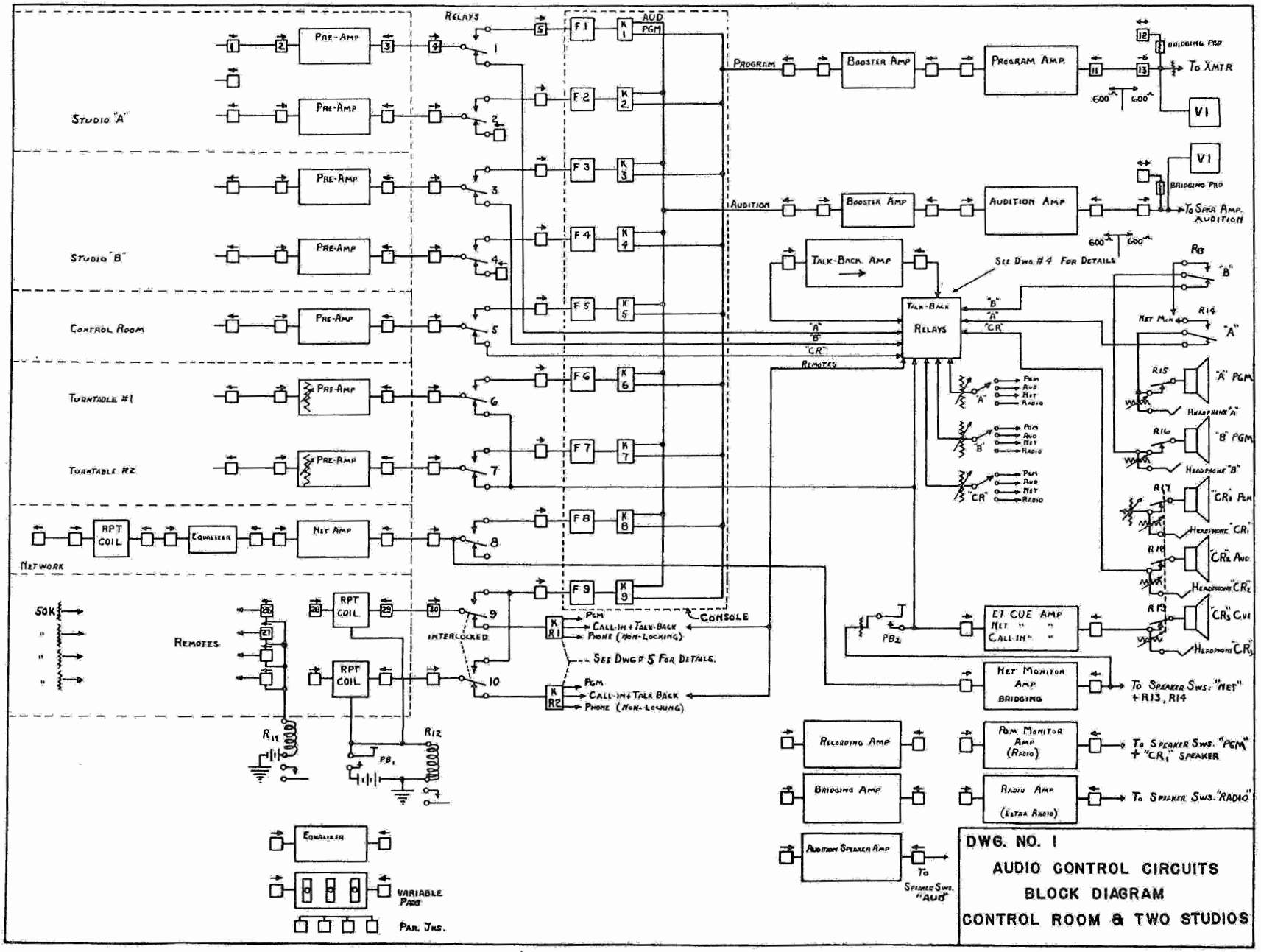
Auxiliary amplifiers are shown for use as indicated, rather than providing one amplifier for many functions. Program and audition channels are identical, with the level set the same to make quick interchange, in the program channel, possible in the case of trouble. Lay-out and design of the mixing console can take many forms and is left to the individual engineer.

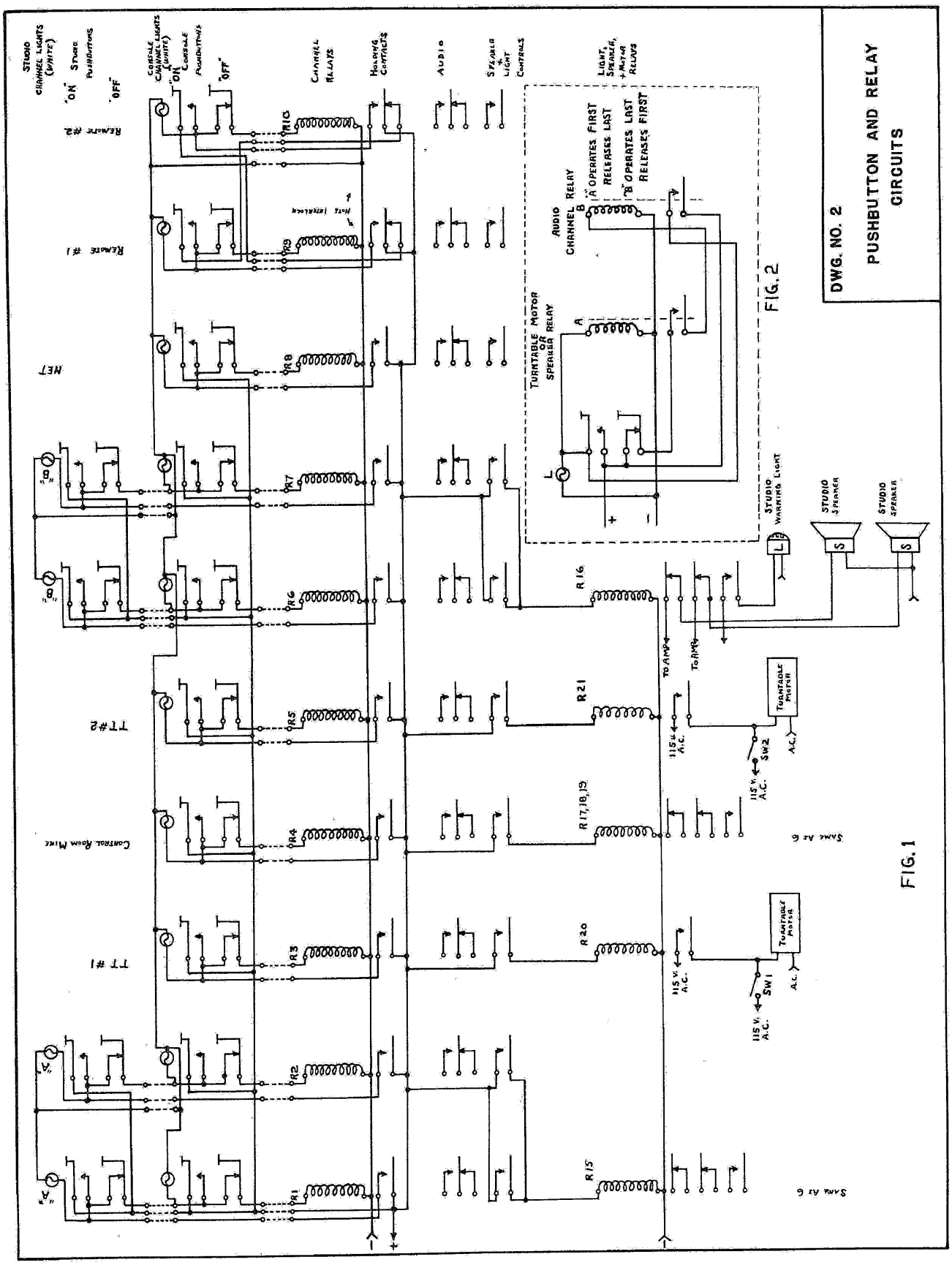
Stations operating full time with records and transcriptions should give serious consideration to the use of a third turntable to accommodate spot announcements, leaving the other two tables for programs. A complete and dependable recording installation, separate from the playback turntables, is a necessity for many stations. It is expected that this system will not fulfill all demands but, once the operating requirements are determined, a minimum number of changes will effect the desired setup.

The present day trend toward tape recording points towards the need for two console mounted machines in the control room and one for portable use. In addition, an editing playback unit should be available for those who have to make short programs out of long ones. This editing can become very tedious and should be done in a room away from everyone else.

The author acknowledges the assistance in the development of these circuits from the following: David W. Jefferies, Radio Station WESB, Bradford, Pennsylvania; Otis L. Atherton, Radio Station WHDL, Olean, New York; John T. Dowdell, Radio Station WIBX, Utica, New York.

3-7-04


RELAYS
AUD PGM
STUDIO "A"
PRE-AMP
STUDIO "B"
CONTROL ROOM
TURNTABLE #1
TURNTABLE #2
RPT COIL
EQUALIZER
NET AMP
NETWORK
50K
REMOTES
INTERLOCKED
CONSOLE
PGM
CALL-IN + TALK-BACK
PHONE (NON-LOCKING)
SEE DWG # 5 FOR DETAILS.
PROGRAM
BOOSTER AMP
PROGRAM AMP.
BRIDGING PAD
TO XMTR
600Ω
V1
AUDITION
AUDITION AMP
TO SPKR AMP. AUDITION
TALK-BACK AMP
SEE DWG. # 4 FOR DETAILS
TALK-BACK RELAYS
REMOTES
NET MON
"A" PGM
HEADPHONE "A"
"B" PGM
HEADPHONE "B"
"CR1" PGM
HEADPHONE "CR1"
"CR2" AUD
HEADPHONE "CR2"
"CR3" CUE
HEADPHONE "CR3"
ET CUE AMP
NET " "
CALL-IN " "
PB2
NET MONITOR AMP BRIDGING
TO SPEAKER SWS. "NET" + R13, R14
RECORDING AMP
BRIDGING AMP
AUDITION SPEAKER AMP
TO SPEAKER SWS. "AUD"
PGM MONITOR AMP (RADIO)
TO SPEAKER SWS. "PGM" + "CR1" SPEAKER
RADIO AMP (EXTRA RADIO)
TO SPEAKER SWS. "RADIO"
EQUALIZER
VARIABLE PADS
PAR. JKS.
PB1
DWG. NO. 1
AUDIO CONTROL CIRCUITS
BLOCK DIAGRAM
CONTROL ROOM & TWO STUDIOS


DWG. NO. 2
PUSHBUTTON AND RELAY CIRCUITS
FIG. 1
FIG. 2
STUDIO CHANNEL LIGHTS (WHITE)
"ON" STUDIO PUSHBUTTONS
"OFF"
CONSOLE CHANNEL LIGHTS (WHITE)
"ON" CONSOLE PUSHBUTTONS
"OFF"
CHANNEL RELAYS
HOLDING CONTACTS
AUDIO
SPEAKER & LIGHT CONTROLS
LIGHT, SPEAKER, & MOTOR RELAYS
REMOTE #2
REMOTE #1
NET
TT#2
TT#1
CONTROL ROOM MIKE
TURNTABLE MOTOR OR SPEAKER RELAY
AUDIO CHANNEL RELAY
"A" OPERATES FIRST RELEASES LAST
"B" OPERATES LAST RELEASES FIRST
STUDIO WARNING LIGHT
STUDIO SPEAKER
STUDIO SPEAKER
TO AMPS
TO AMPS
TURNTABLE MOTOR
TURNTABLE MOTOR
115 V. A.C.
SW2
SW1
SAME AS 6
SAME AS 6
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R15
R16
R17,18,19
R20
R21

3-7-05

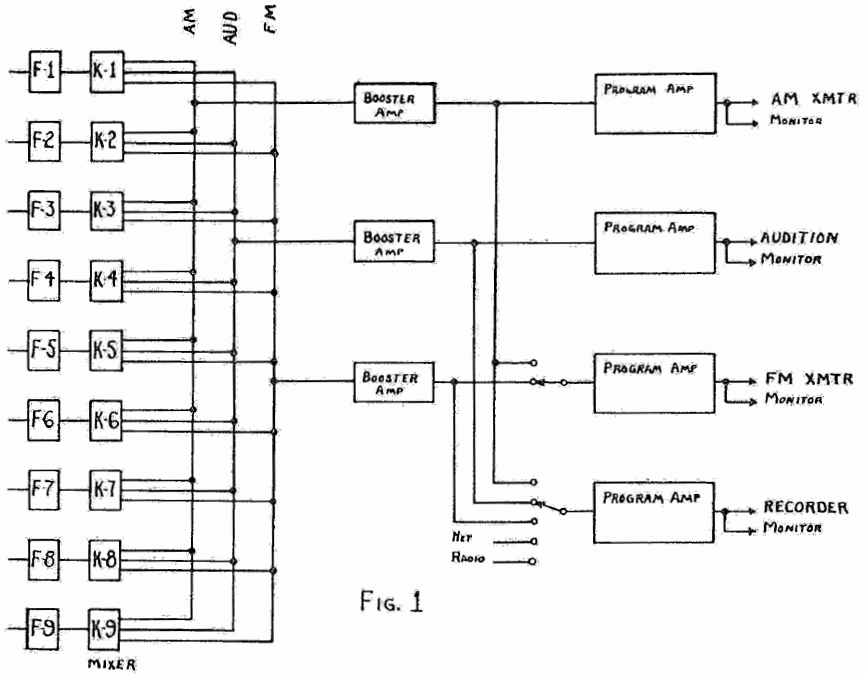
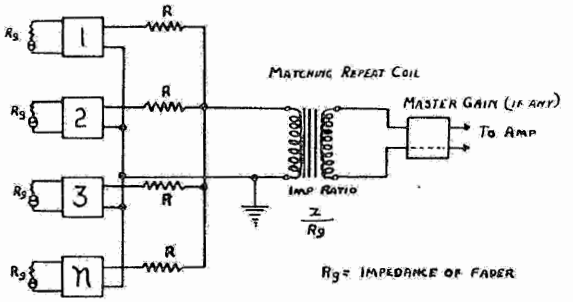
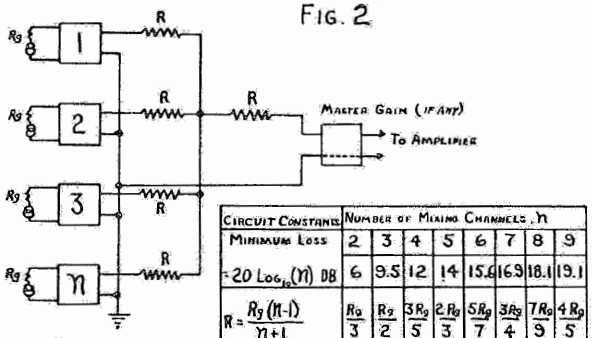


FIG. 1



CIRCUIT CONSTANTS	NUMBER OF MIXING CHANNELS, n							
MINIMUM LOSS	2	3	4	5	6	7	8	9
$= 10\log_{10}(2n-1)$ DB	4.8	7	8.4	9.5	10.4	11.1	11.8	12.3
$R = \frac{R_g(n-1)}{n}$	$\frac{R_g}{2}$	$\frac{2R_g}{3}$	$\frac{3R_g}{4}$	$\frac{4R_g}{5}$	$\frac{5R_g}{6}$	$\frac{6R_g}{7}$	$\frac{7R_g}{8}$	$\frac{8R_g}{9}$
REPEAT COIL PRIMARY IMPEDANCE $= \frac{R_g(2n-1)}{n^2}$	$\frac{3R_g}{4}$	$\frac{5R_g}{9}$	$\frac{7R_g}{16}$	$\frac{9R_g}{25}$	$\frac{11R_g}{36}$	$\frac{13R_g}{49}$	$\frac{15R_g}{64}$	$\frac{17R_g}{81}$

FIG. 2



CIRCUIT CONSTANTS	NUMBER OF MIXING CHANNELS, n							
MINIMUM LOSS	2	3	4	5	6	7	8	9
$= 20\log_{10}(n)$ DB	6	9.5	12	14	15.6	16.9	18.1	19.1
$R = \frac{R_g(n-1)}{n+1}$	$\frac{R_g}{3}$	$\frac{R_g}{2}$	$\frac{3R_g}{5}$	$\frac{2R_g}{3}$	$\frac{5R_g}{7}$	$\frac{3R_g}{4}$	$\frac{7R_g}{9}$	$\frac{4R_g}{5}$

FIG. 5

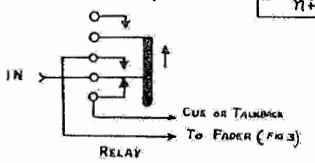


FIG. 4

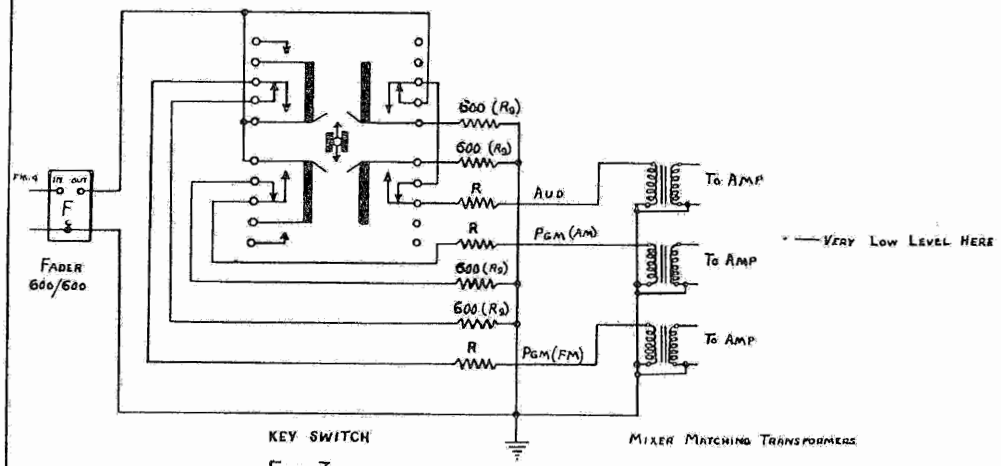
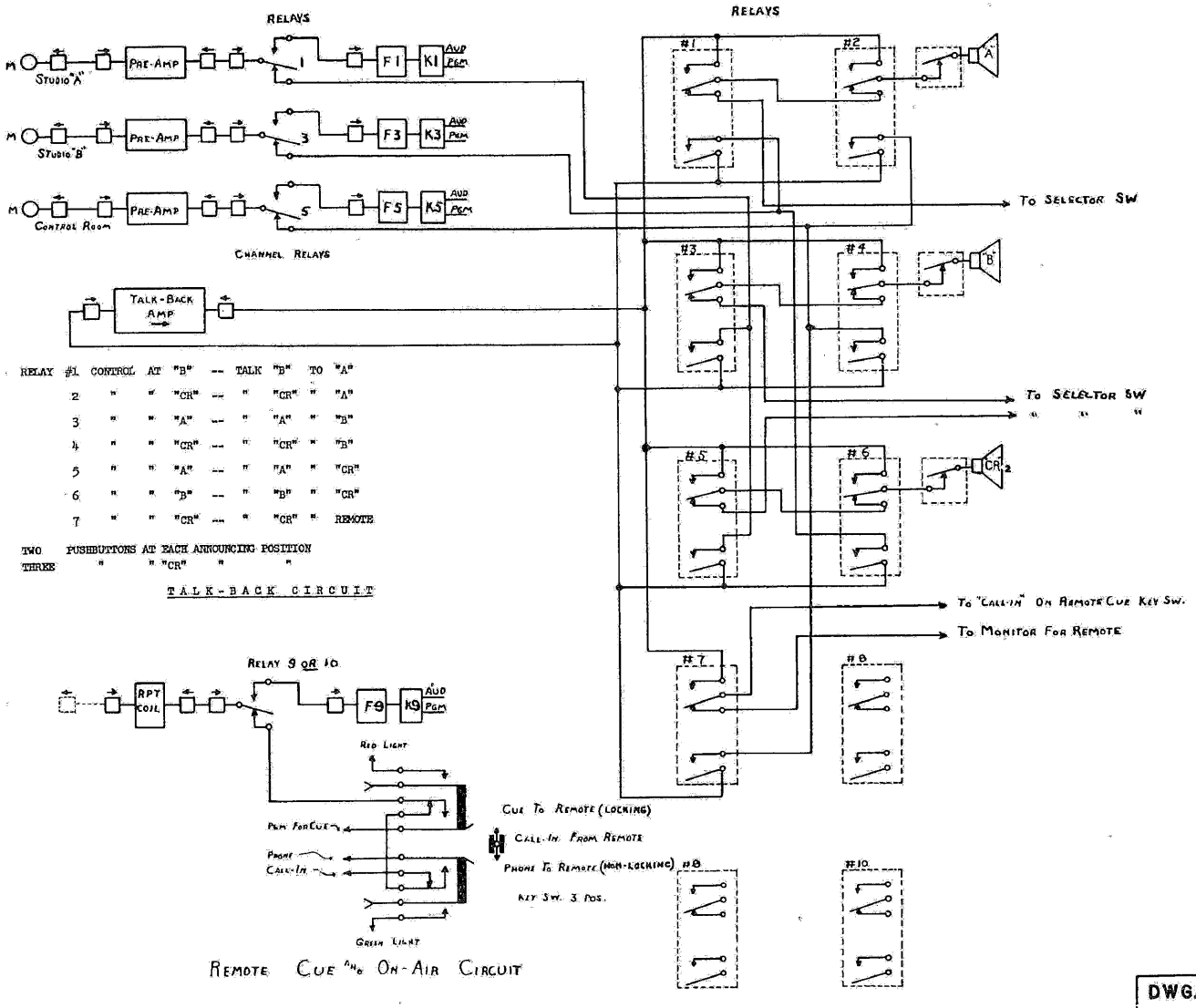


FIG. 3

DWG. NO. 3

MIXER SYSTEMS

"PICKUPS" 9-37

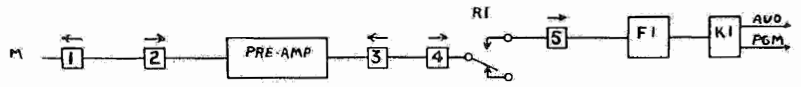


DWG. NO. 4

REMOTE CUE CIRCUIT

TALK-BACK CIRCUIT

3-7-07



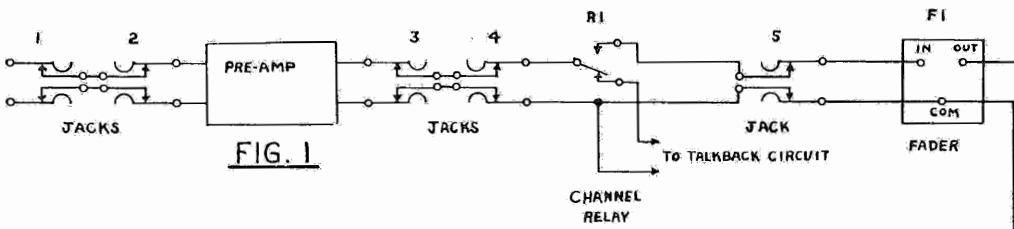
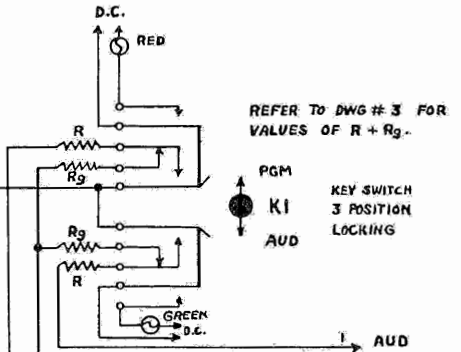


FIG. 1

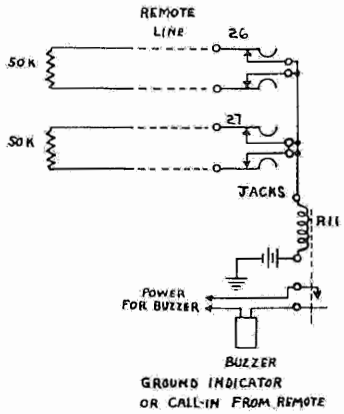


REFER TO DWG # 3 FOR VALUES OF R + R9.

GROUND AT THIS POINT OF THE SYSTEM

ALL D.C. FOR RELAYS AND CONSOLE INDICATOR LIGHTS SHOULD BE WELL FILTERED

CONNECT 1, 2 + 3 PARALLEL WITH REST OF KEY SWITCHES IN MIXER SYSTEM



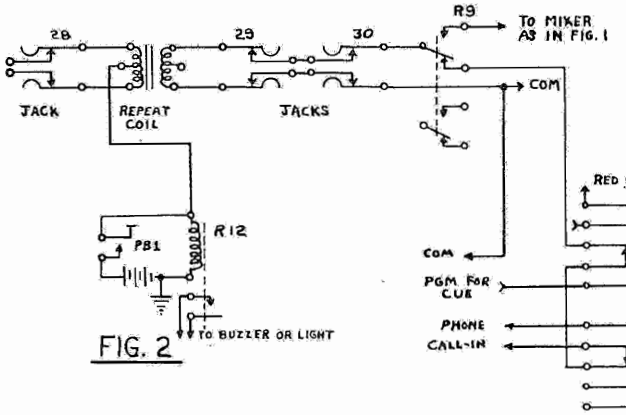


FIG. 2

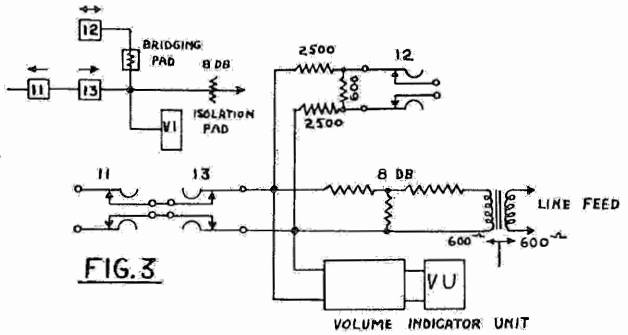


FIG. 3

DWG. NO. 5

WIRING DETAIL

JACKS, KEY SWITCHES & RELAYS

REMOTE CUE KEY SWITCH

SPECIAL ANTI-SIDE TONE CIRCUIT

*REPRINTED FROM THE ENGINEERING NOTICES OF THE NATIONAL BROADCASTING COMPANY**

Purpose

The circuit described herein is designed to provide two-way conversation on the air or three-way conversation with loudspeakers at all points, the loudspeakers and microphones being open at all times. This is made possible without cut-off or switching systems.

General

Referring to figure 1, if we assume that R-1, R-2 and R-3 are all of equal value and R-1^1, R-2^1 and R-3^1 are of equal value then, if a voltage be applied across R-1, a voltage will be observed across all other resistances of the network except R-1^1. This will be apparent with reference to Wheatstone Bridge circuit theory. if, now, the resistance R-1 represents a microphone output and the resistance R-1^1 be a loudspeaker input then when the microphone represented by R-1 is spoken into no feedback will be noted from the adjacent loudspeaker represented by the resistance R-1^1. Similarly, R-2 and R-3 may be microphones and R-2^1 and R-3^1 may be adjacently mounted loudspeakers.

In the case noted above full three-way conversation may be held. If it is desired to communicate between two points and have the resulting conversation transmitted to local or network channels, then we assume that R-1 and R-2 be the two sources of program and R-1^1 and R-2^1 be their adjacently located loudspeakers. R-3 becomes a pure resistance and R-3^1 will be the input to the outgoing line or channel amplifier.

It will be obvious that for proper operation of this circuit all of the resistances shown in figure 1 representing as they do the output of microphone amplifiers or input of loudspeaker amplifiers must be accurately balanced against each other, that is R-1, R-2 and R-3 must have very nearly the same values within close limits and the same will be true of R-1^1, R-2^1 and R-3^1. In order to accomplish this close balance it will be necessary in some cases to isolate these circuits by use of balanced H pads.

It is most convenient, in this connection, to arrange the output of the microphone amplifiers for 125 ohm operation and to terminate the same in a 125 ohm resistor. The variation in balance with this arrangement is reduced to a satisfactory minimum.

The loudspeaker amplifier input is usually of high impedance subject to some variation with a change in the volume control. It is, therefore, found best to isolate the inputs to these loudspeakers with suitable H pads. A 6 db 6000 to 6000 ohm pad is generally sufficient isolation.

Typical Circuits

Figure 2 shows a typical 3 way talking circuit with loudspeakers at all talking points. Figure 3 shows a two way talking circuit feeding a program bus for network or local station feed.

Precaution

Although primary feedback into the talking circuit by the loudspeaker located adjacent to the microphone is eliminated by use of this circuit a source of secondary feedback is possible. This occurs when a signal from, let us say, microphone #1 heard on loudspeaker #2, re-enters microphone #2 and is transmitted back to loudspeaker #1. A judicious choice of loudspeaker levels will minimize this difficulty.

Discussion

This circuit has been used to advantage in such broadcasts as those originating on the yacht "Seth Parker" in which a conversation with the studio is carried on during the broadcast.

No appreciable frequency discrimination is noted by use of this bridge circuit.

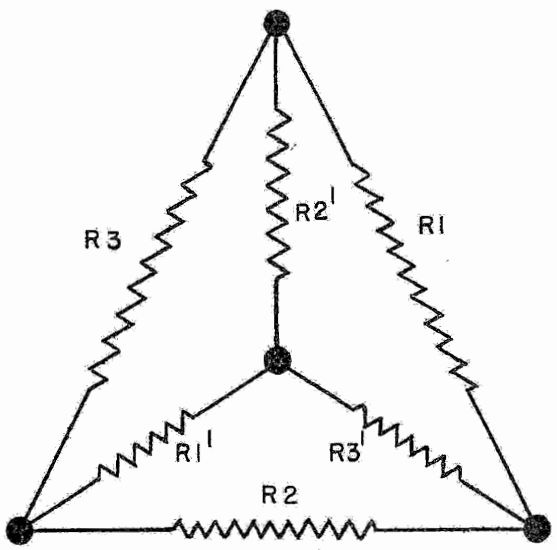


FIG. 1

3-8-01

*Compiled by Mr. Raymond A. Monfort and Mr. Donald H. Castle.

3-8-02

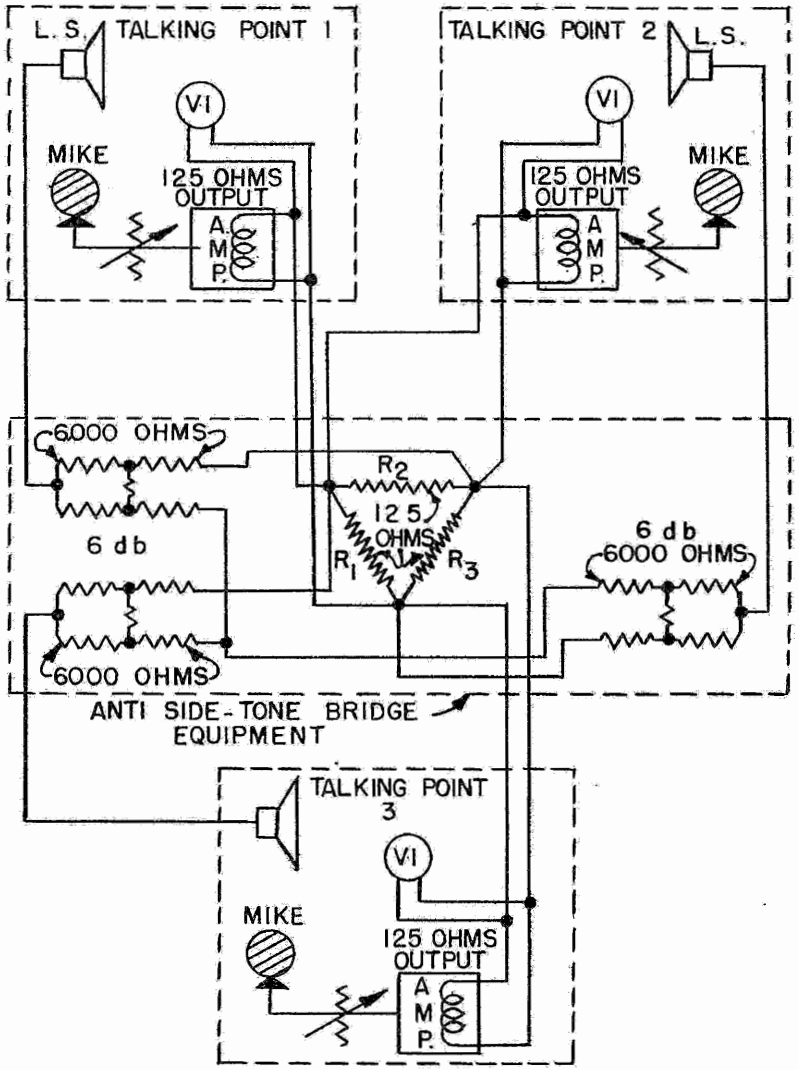


FIG. 2

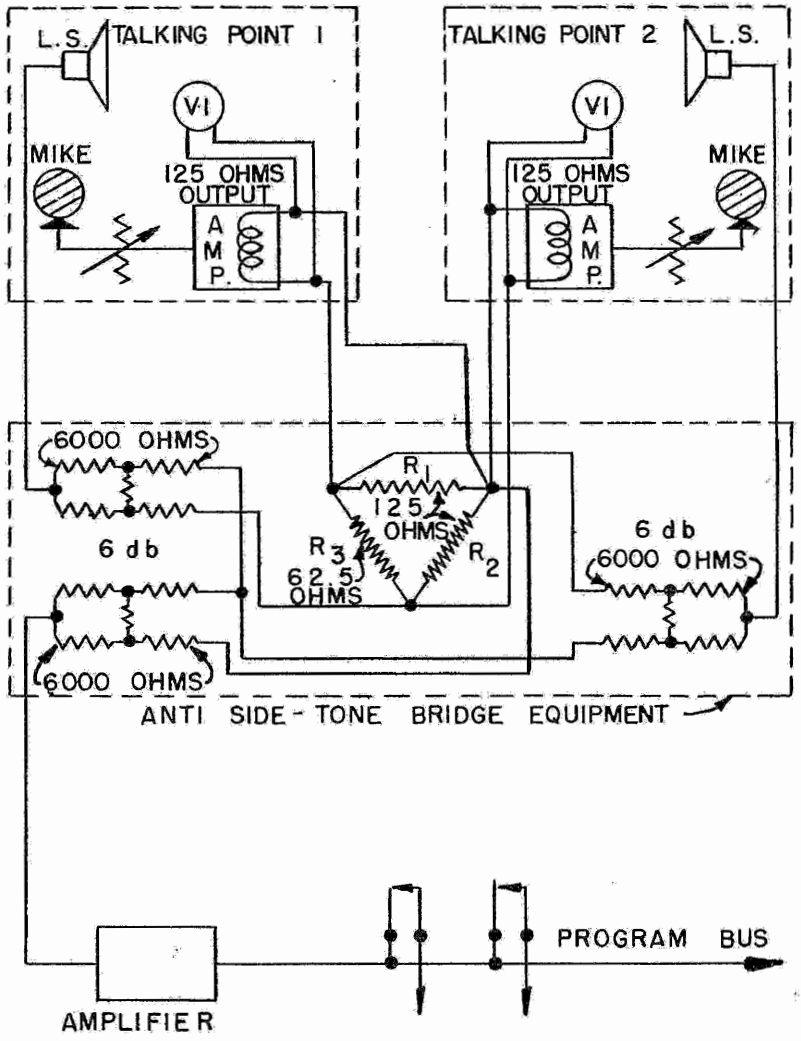


FIG. 3

REMOTE PICKUP BROADCAST COVERAGE TESTS ON 152.93 Mc

CONDUCTED BY THE GENERAL ENGINEERING DEPARTMENT OF THE AMERICAN BROADCASTING COMPANY

FOREWORD

From the following data it will be evident that FM mobile relay broadcasting in the 152-162 megacycle 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 may be expected.

PRESENT FREQUENCY ALLOCATIONS

Remote pickup broadcasting units have demonstrated their value to the broadcasting industry by providing the means whereby special events of general public interest are made available for broadcasting despite the lack of wire lines between the station and the spot where the event is taking place.

The assigned frequencies in the groups around 2000 kc have generally been used for all spot pick-ups close to or beyond the limits of line of sight transmission. Those frequencies in the 30 to 40 megacycle region have usually been employed where the pick-up point is within the line of sight distance. The use of the higher frequencies, where possible, is preferred to the 2000 kc channels because of the smaller units and simpler antennas available for these frequencies.

RECENT ALLOCATIONS[1]

Allocation proceedings held by the FCC in 1948-49 provided in addition to the 2000 kc blocks of frequencies 50 other channels for remote pickup broadcast services, namely: 19 exclusive 20 kc channels from 26.11 megacycles to 26.47 megacycles; 9 shared and 2 restricted 60 kc channels in the 152-162 megacycle band; and 20 exclusive 100 kc channels between 450.05 megacycles and 451.95 megacycles. Rules relating to these assignments appear in Part 4 of FCC's Rules and Regulations.

PURPOSE OF THE TEST

The accelerated wartime development of transmitters and receivers for use on frequencies between 100 and 200 megacycles resulted in production of equipment suitable for broadcast use on channels in the 152 to 162 megacycle band. The Facilities Section of the General Engineering Department of ABC, therefore, undertook to investigate the usefulness of the 152 to 162 megacycle band for mobile relay broadcasting by determining the maximum useful range of transmissions from a mobile unit to a receiving point 900 feet above sea level in midtown Manhattan. The following tests were made during the fall of 1946, the results of which showed that this band would provide excellent coverage within line of sight distance.

Comparison can also be made with the probable results to be expected on the 26 megacycle channels as these assignments will follow very closely the previous experience on the 30 to 40 megacycle channels, which have been deleted from remote pickup use.

EQUIPMENT

Transmitter

A transmitter powered from the six-volt car battery was used in the mobile unit. It is designed for communication type of service, and has the following specifications:

Assigned Frequency	152.93 mc
Output Power	15 watts
Frequency Stability	± .005%
Method of Modulation ...	Phase
Frequency Deviation for 100% Modulation	± 20 kc
Audio Response	± 1 db from 500-3000 cps
Duty	Intermittent

Receiver

A receiver powered from 115 volt 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 UV for 20 db noise suppression
Selectivity	6 db down at ± 20 kc 85 db down at ± 120 kc
Audio Response	± 2.5 db from 350-5000 cps
Duty	Continuous

Signal strength readings were made at the receiver by measuring the current in the first

[1] Altered by NAB to conform with FCC actions.

TABLE I

SIGNAL STRENGTH AT RECEIVER INPUT IN MICROVOLTS					
TRANSMITTING ANTENNA		RECEIVING ANTENNA 5 ELEMENT YAGI			
		POLARIZATION			
TYPE	POLARIZATION	VERTICAL		HORIZONTAL	
		uV	Db	uV	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

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 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 microvolts. The curve of Figure 1 was plotted from the above test. With this curve it is a simple matter to convert all of the readings taken in this test to microvolts of signal at the input of the receiver.

Antennas

A. 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.

B. 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 feet 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 towards the mobile transmitter during all of these tests although no attempt was made to rotate it for best results on each transmission. This practice was followed as published data on multi-element antenna arrays indicated that signals at the receiver should be essentially constant as long as the mobile unit was within ± 15 degrees of the heading of the array.

C. Receiving Antenna Pattern--In order to check the actual variation in received signal for the 15 degree 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

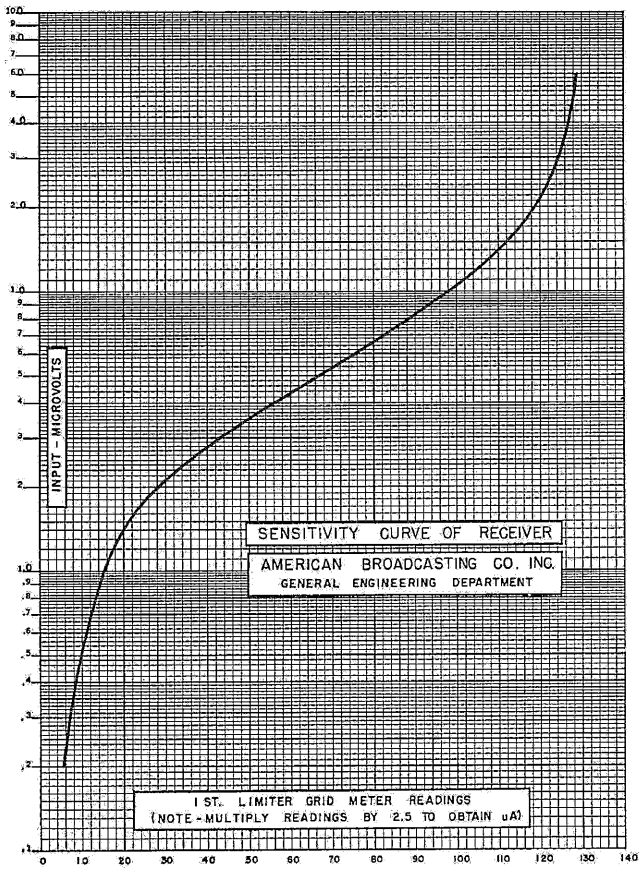


Figure 1

the signal. The receiver was located about one-half mile away with a clear line of sight path from it to the transmitter. A 4" 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 taken of the receiver meter for each of these points. The results converted to microvolts input to the receiver were plotted as shown in Figures 2 and 3.

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%. For purposes of these tests, this 10% 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, (Figure 4) making the following information readily available:

1. Location of Transmission Point.
2. Distance from Transmission Point to Receiver Location.

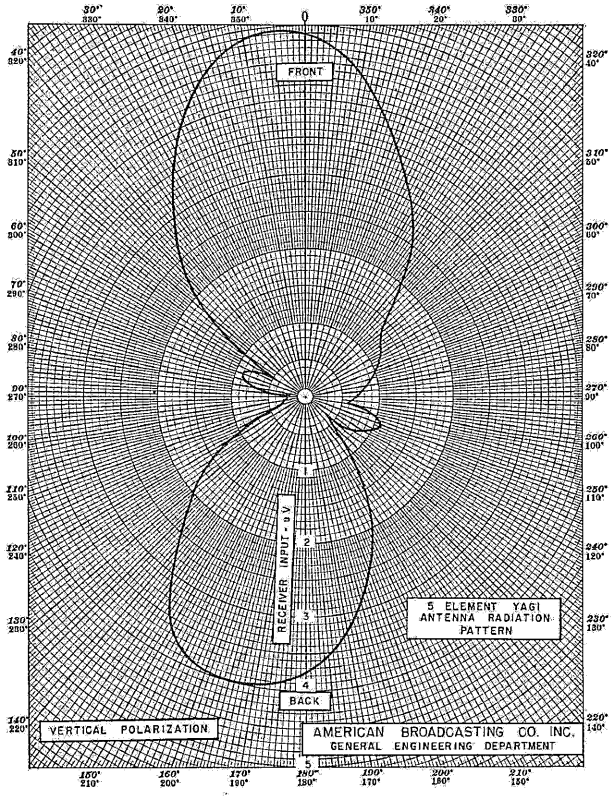


Figure 2

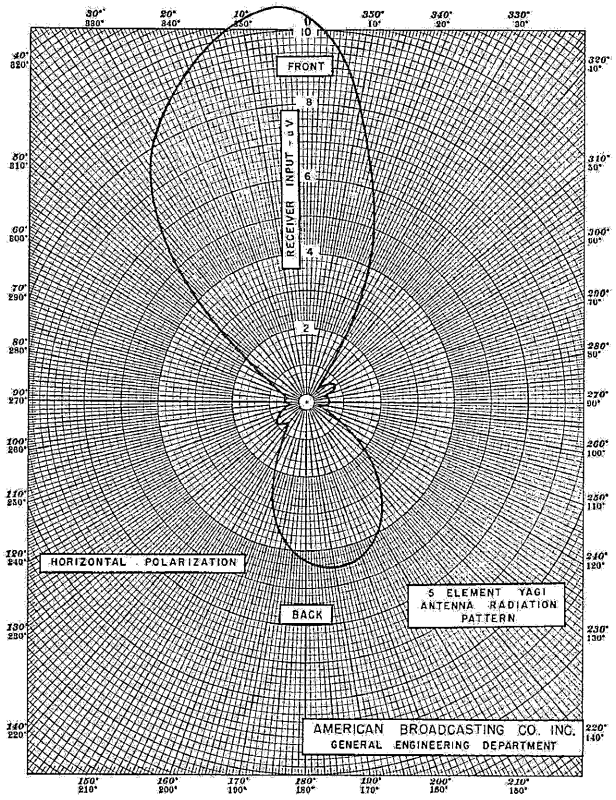


Figure 3

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 megacycle 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 non-usable 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 30-40 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 Rivers. 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 non-usable 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 of the transmission points in Manhattan fall within a five mile circle. Following the completion of runs in other directions, a general pattern of results based on distance became apparent. For example, inside a five mile circle, all transmissions except those previously noted and those from a small area near North Bergen, New Jersey, were received with good signal strength. The few points of non-usable signal within the ten mile circle were caused by shielding from large buildings or hills close to the transmitter and directly in the transmission path. Beyond the ten mile circle, results became somewhat erratic and were completely dependent on the terrain. Figure 4 shows the results obtained on all transmissions from the mobile unit to the fixed receiver.

Comparison of Antennas and Polarization

A. Changes in Transmitting Antennas--All of 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:

(a) Quarter wave vertical whip.
(b) Half wave dipole.
(c) Half wave folded dipole.

The latter two were operated both vertically and horizontally polarized at a height of nine feet 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 1 shows the signal strength expressed 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

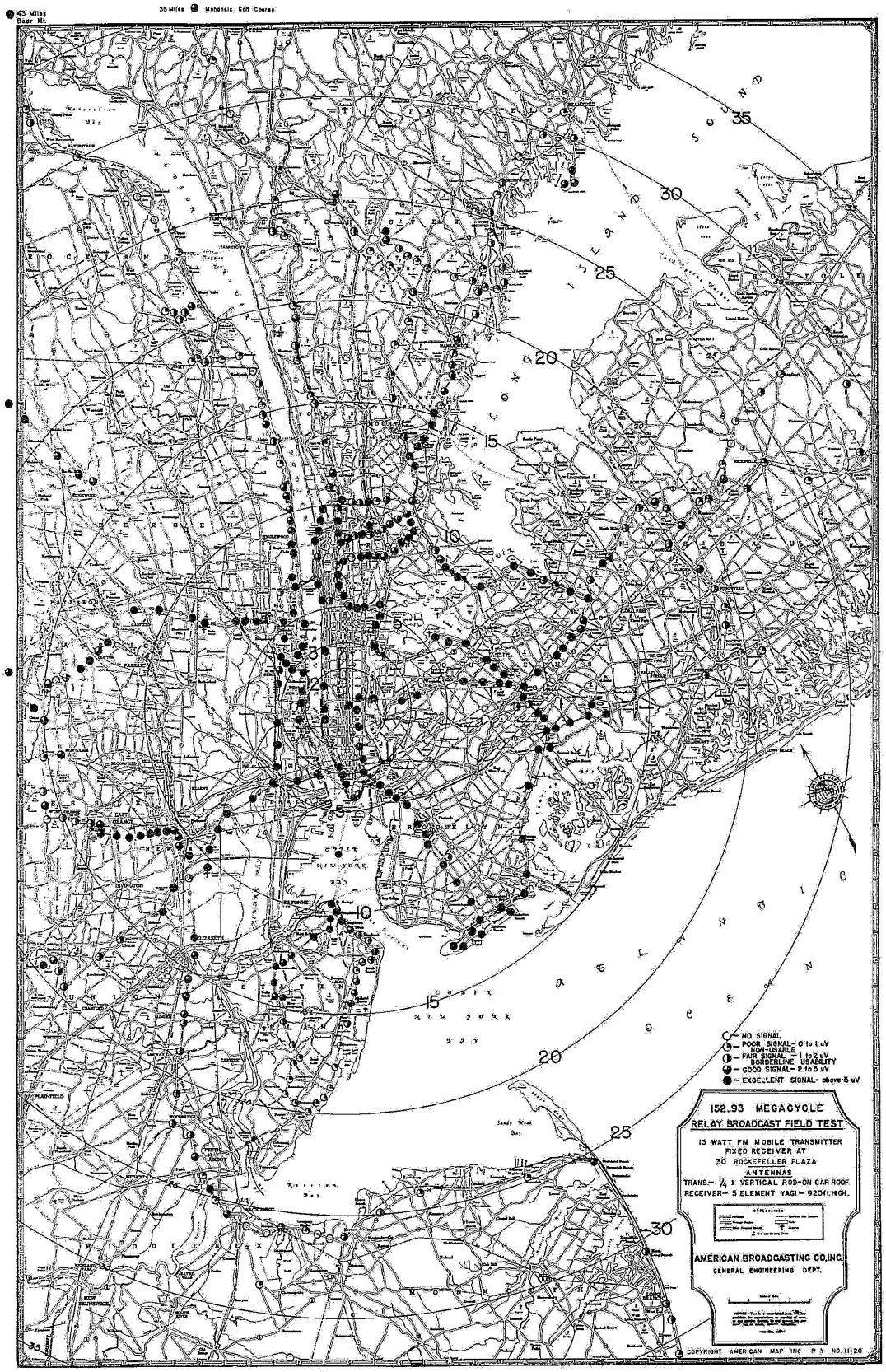


Figure 4

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the vertical quarter wave whip antenna at the mobile transmitter and the vertically polarized Yagi antenna at the receiver as the zero db reference level.

An additional mobile antenna test was made from Staten Island. At a point on Hylan Boulevard twenty-one 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.

B. Change In Receiving Antenna--The five element Yagi antenna was used for reception in all of 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 route 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 II

DISTANCE (MILES) FROM RECEIVER	uV INPUT TO RECEIVER 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	.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 principle 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 feet above ground atop the mobile unit, and with a directional receiving antenna having gain of at least 6 db mounted 900 feet 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% coverage within a radius of 10 miles.
3. 85% 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 pick-up point from many spots throughout the parade route. Similar results would be expected in the proposed 25 to 28 mc band.

The General Engineering Department, therefore, recommends the use of 152 to 162 mc FM equipment for mobile relay broadcasting. The mobile units should be equipped with a transmitter having a power output of from 15 to 30 watts, and facilities should be provided to use antennas with higher gain than the conventional quarter wave vertical whip. A directive array with a gain of at least 6 db should be used at the receiving point.

A PRACTICAL 26 MC REMOTE PICKUP BROADCAST SYSTEM

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This article describes in detail the conversion of war surplus transmitting and receiving equipment for remote pick-up short wave broadcast relay use.

PART I

The FCC has recently assigned exclusively to the remote pickup broadcast service the following 19 channels between 26.11 mc and 26.47 mc.

26.11 mc	26.19 mc	26.27 mc	26.35 mc	26.43 mc
26.13 mc	26.21 mc	26.29 mc	26.37 mc	26.45 mc
26.15 mc	26.23 mc	26.31 mc	26.39 mc	26.47 mc
26.17 mc	26.25 mc	26.33 mc	26.41 mc	

Under Part 4, Subpart D,[1] 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 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 similar to the following:

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 + .005% of carrier frequency in kc)
   Example: 2(8.5 + .00005 x 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 inches high)

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 (.005%)
   Means for maintaining frequency tolerance (temperature controlled CT cut crystal)
   External means employed to insure 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.

The equipment described has been in use for about two years, and a hundred or more transmissions have been successfully relayed over KFBC. About a score of other stations located in nine states have used identical equipment, also successfully, for several months. The range of reasonably quiet transmission is determined largely by the height and efficiency of the receiving antenna. Several stations report ranges of from ten to twenty-five miles. A good average figure is about four or five 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 152-162 mc band. Little difficulty has been experienced in towns of less than 100,000 population from these effects.

Noise, measured through both transmitter and receiver, exclusive of atmospheric interference, will be better than 50 db below maximum modulation. Distortion will be less than 3% at maximum modulation, overall. Frequency modulation is used, and though the frequency response, may not be termed High Fidelity it will be better than that designated for Class C lines.

This article, the drawings and the circuits refer to the materials listed in Part 2. In

[1] See Section 1, Article 7, for FCC Rules and Regulations.

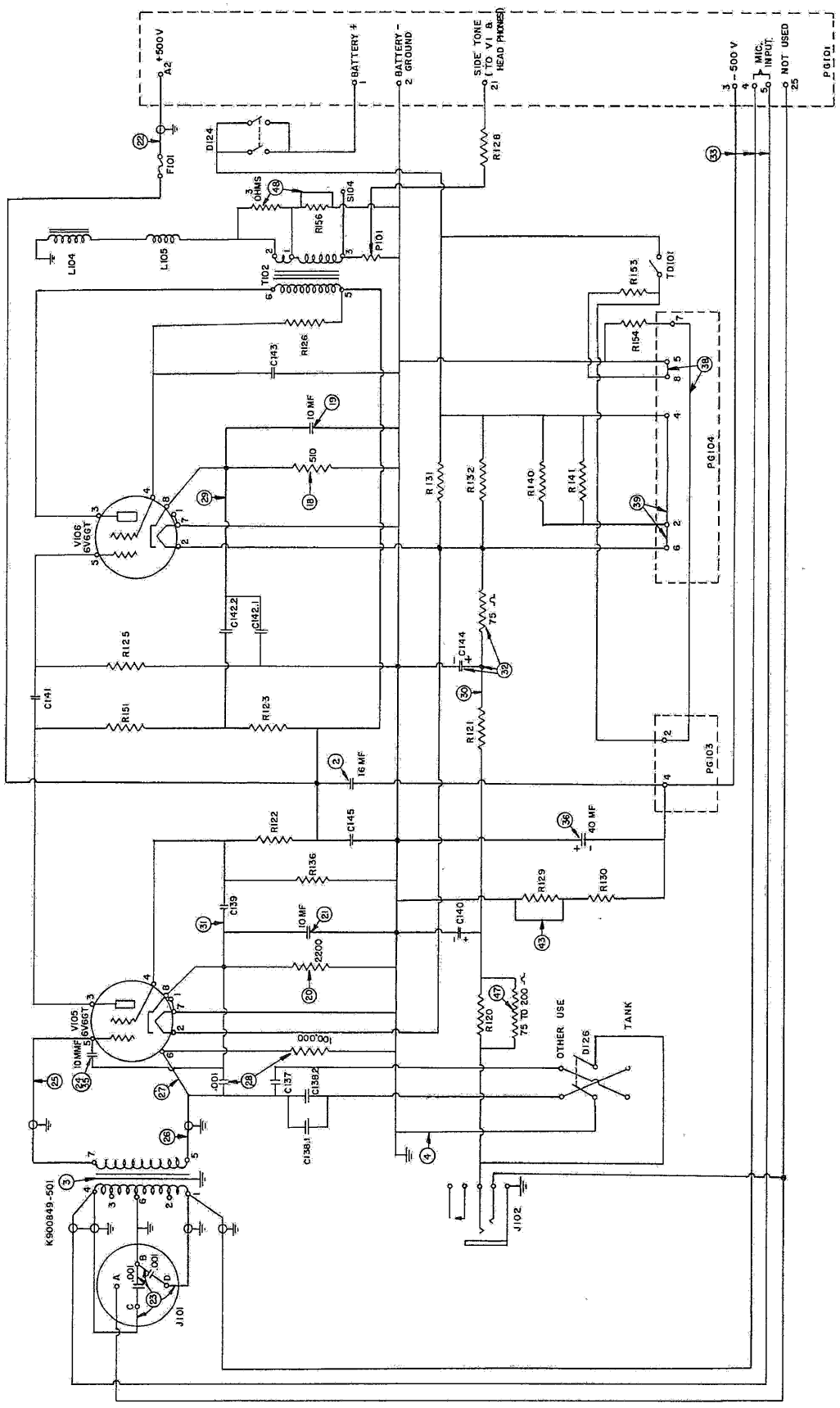

Fig. 1.--BC 604 Transmitter, audio circuits, converted. 31 indicates reference to paragraph 31, Part 6.

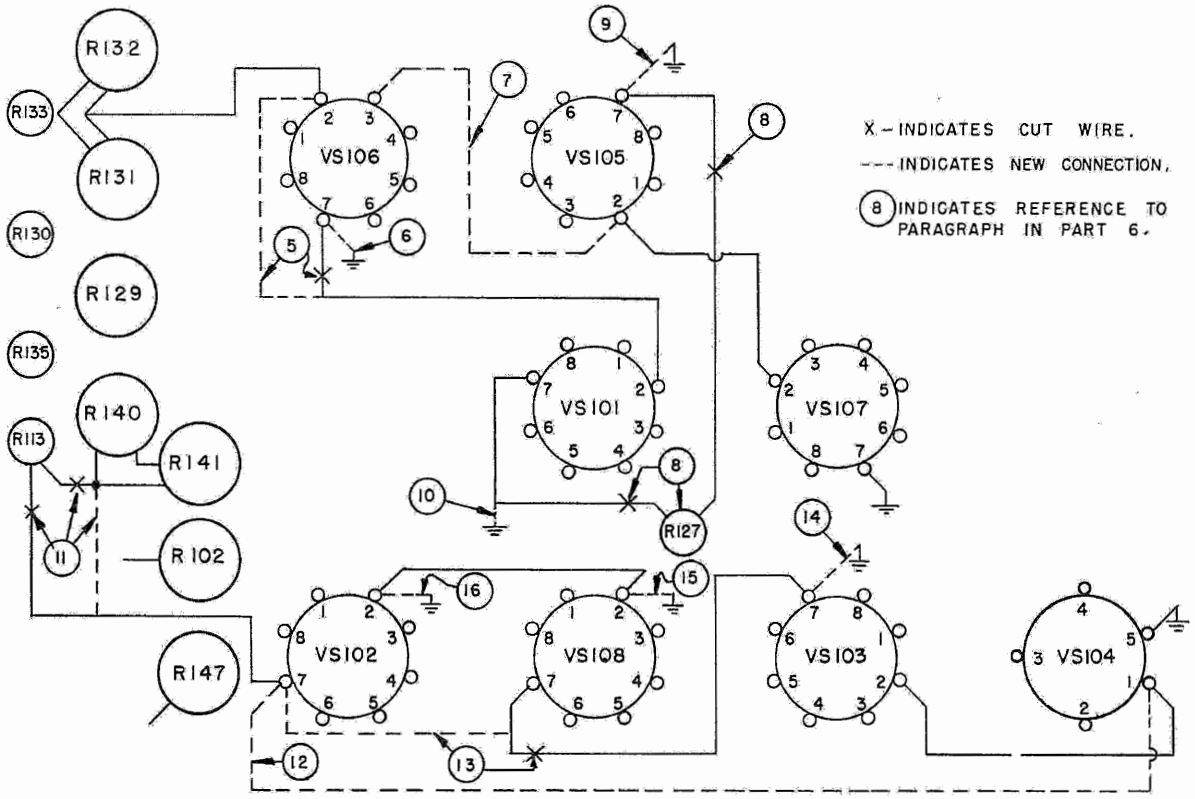

Fig. 2.--BC 604 Transmitter, filament circuit wiring diagram, showing changes made in Part 6.

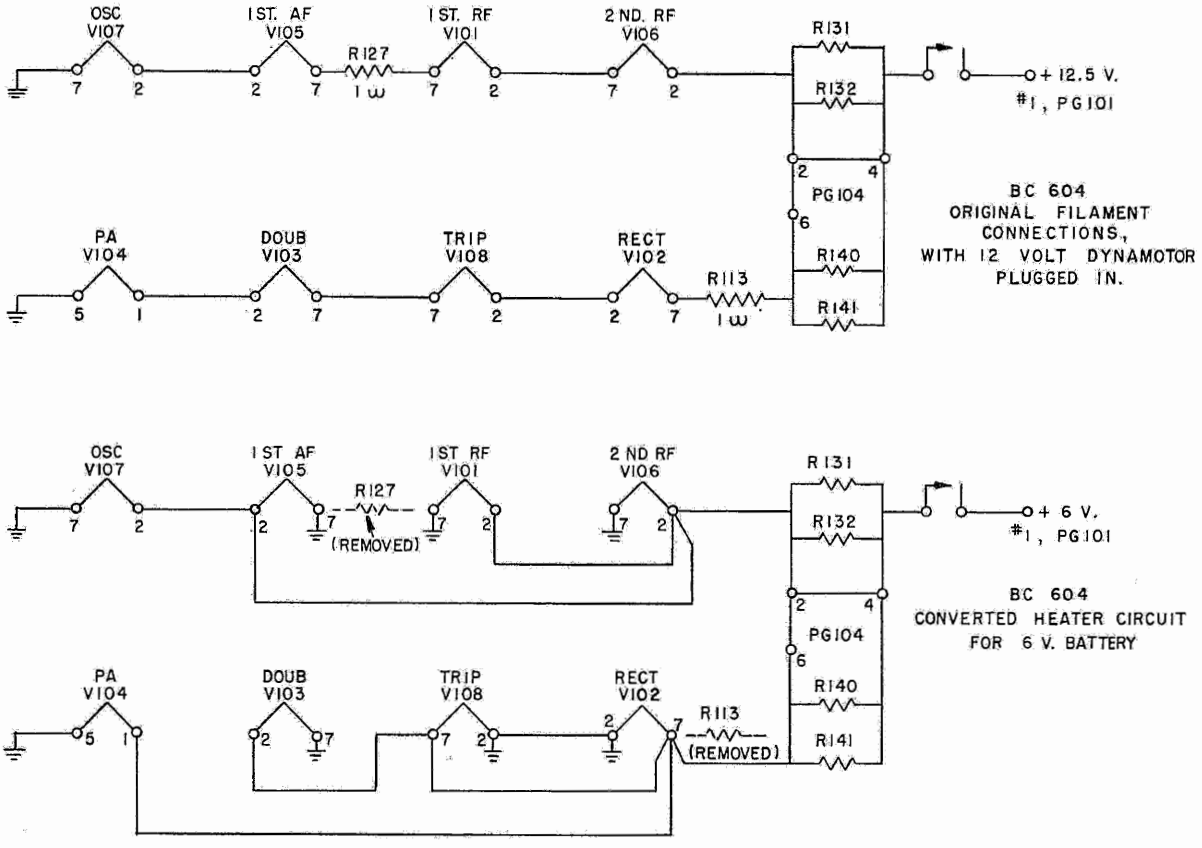

Fig. 3.--BC 604 Transmitter, original filament schematic and converted heater schematic.

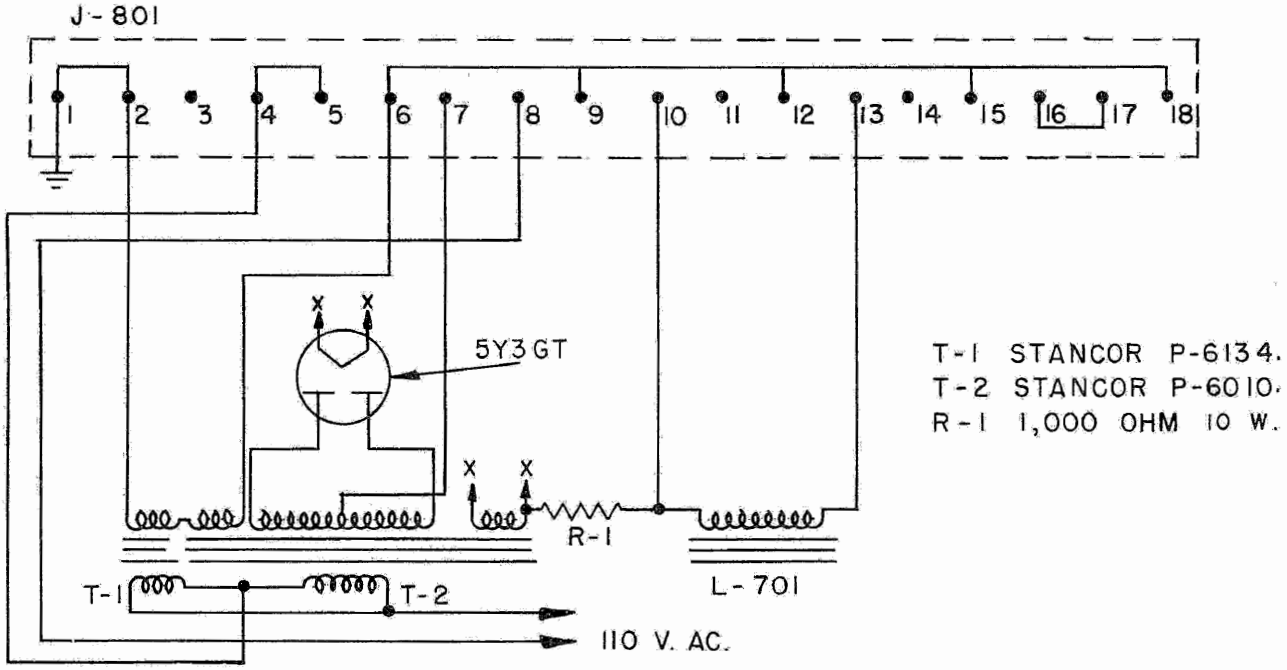

Fig. 4.--BC 603 Receiver, 110 V AC power supply.

many cases, such as the plugs, sockets and cables, substitute materials will serve equally as well. Circuit drawings and diagrams are furnished only for the changes made 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 Dynamotor PE 103. However, the circuit diagram of this unit, as well as changes, is included as Figure 6.

The major units, except the dynamotor are component parts of SCR 508 (SCR 528 and SCR 538 also contain the same components). 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, VI meter, will likely be new materials. The total cost of all materials, war surplus and new, will likely be less than $200. Spray painting of the components is recommended. Masking of the front panel and name plates will be found quite simple. Duco Feather Grey #246-54909 or equivalent is recommended.

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 Freq.	Carrier Freq.	FCC Channel
61	483.333 kc	26.1 mc	26.11 mc
62	485.185 kc	26.2 mc	26.21 mc
63	487.037 kc	26.3 mc	26.31 mc
64	488.889 kc	26.4 mc	26.41 mc

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 exactly fit the corresponding FCC channel. 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 either thin rubber tubing, rubber tape, or masking tape. A few light strokes of very very fine sandpaper will take off sufficient material to raise the frequency measureably. 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.

PART 2

MATERIALS NEEDED

Transmitter

1 BC 604 transmitter
6 6v6GT tubes

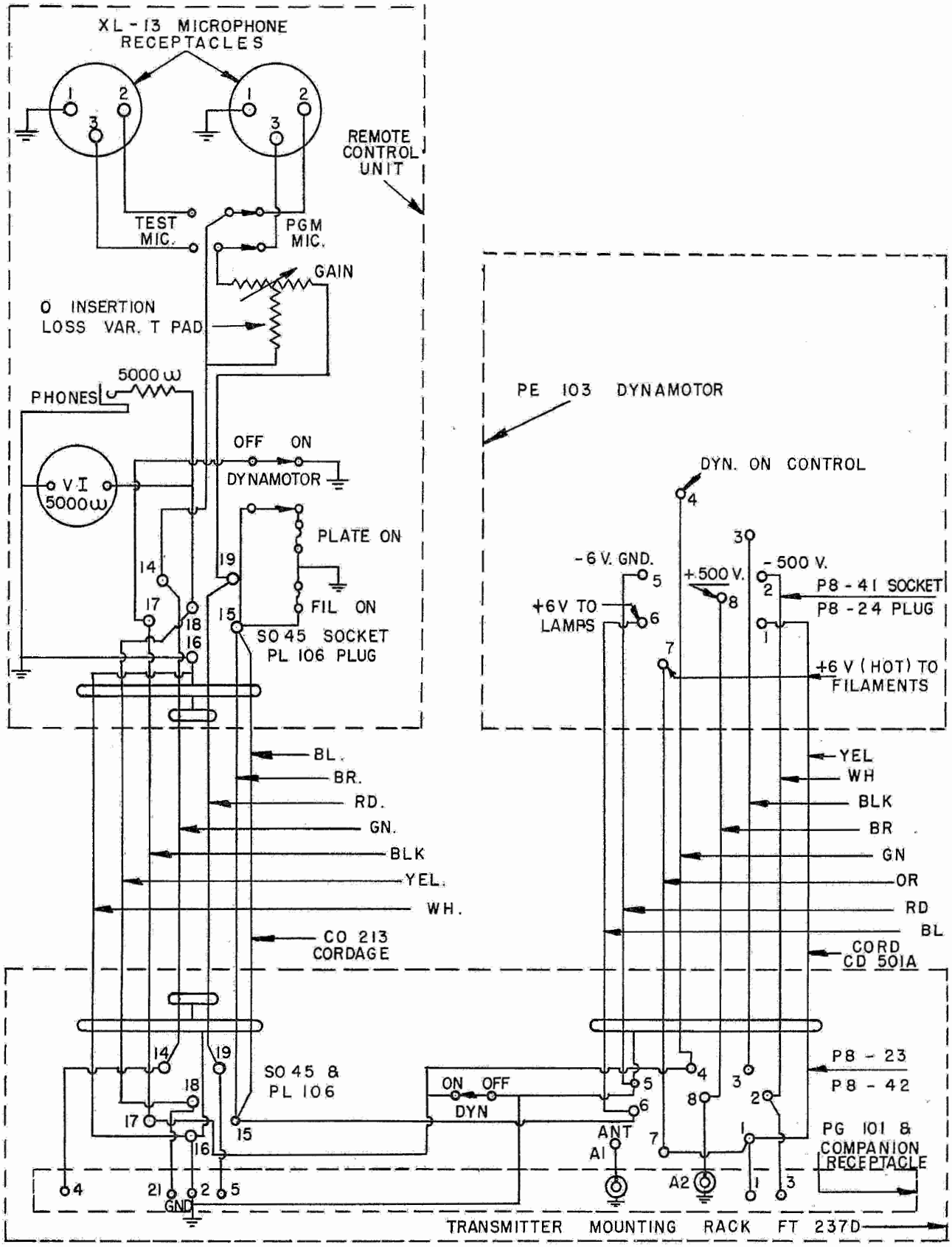

Fig. 5.--FT 237D Mounting, schematic as modified; remote control schematic; and connections for interconnecting cords, plugs, and sockets.

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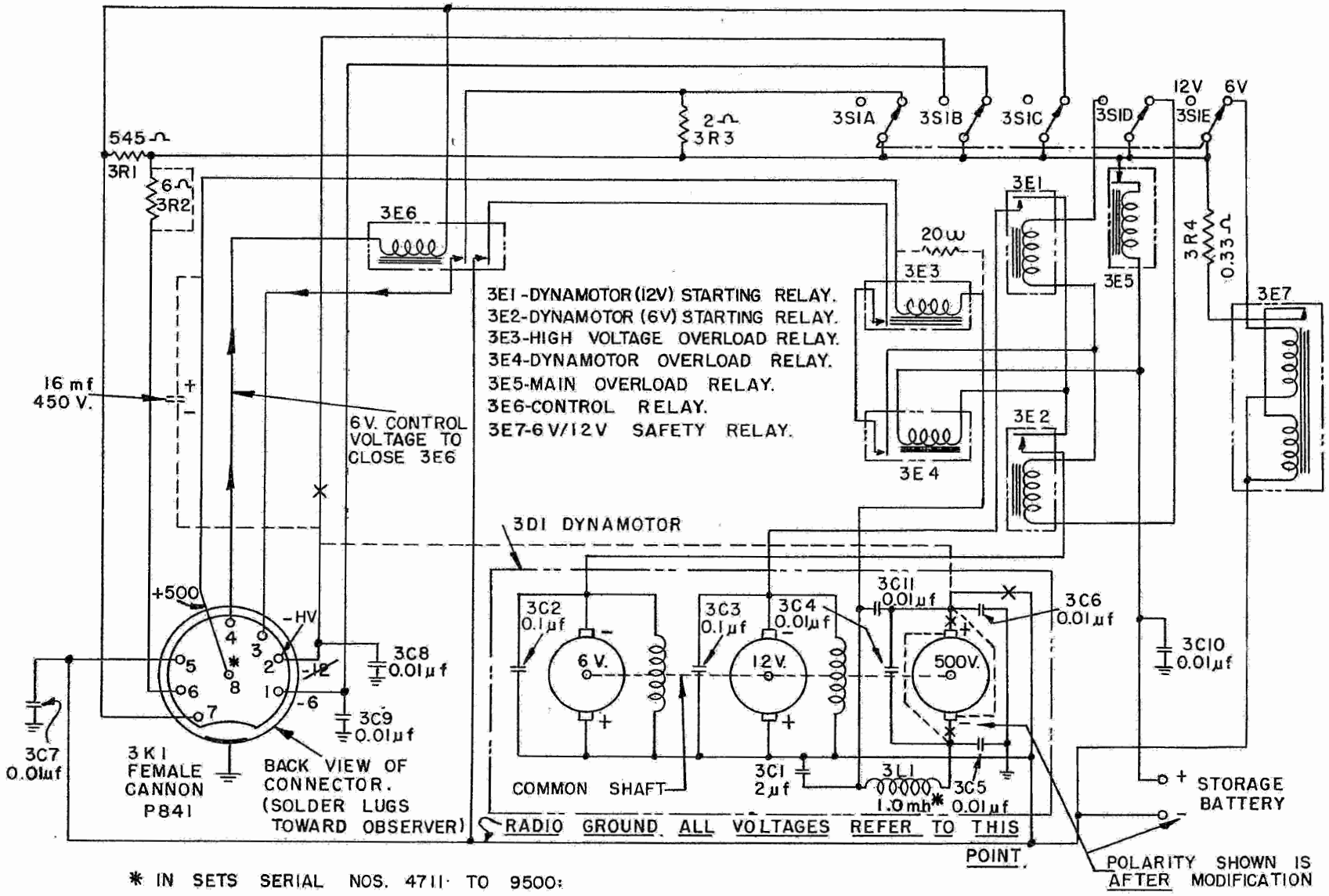


Fig. 6.--PE 103 Dynamotor schematic, showing modifications.

1 6L6 tube
1 807 tube
1 RCA K900849-501 microphone input transformer, or equivalent
3 .001 300v mica condensers
1 10 mmf 300 v mica condenser
1 2200 ohm 1/2 watt carbon resistor
1 510 ohm 1/2 watt carbon resistor
1 16 to 20 mfd 450 volt tubular electrolytic condenser
1 10-10 mfd 25 volt tubular electrolytic condenser
1 40 mfd 25 volt tubular electrolytic condenser insulated tie points
2 75 ohm 1/2 watt wire wound or carbon resistors
7 feet of shielded insulated stranded, single conductor hook up wire
5 feet of insulated stranded single conductor hook up wire
18" Varnished cambric tubing
20 feet lacing cord
1 3 ohm 2 watt wire wound resistor
1 Crystal, in FT 241 mounting
1 100,000 ohm 1/3 watt carbon resistor

Receiver

1 BC 603 Receiver
1 1/2 watt 2500 ohm resistor
1 small banana pin and socket
1 miniature bayonet base lamp socket
2 20 mfd 250 volt tubular electrolytic condensers
1 .1 mfd 300 volt paper condenser

BC 603 Receiver Power Supply

1 base from dynamotor DM 34 or DM 36
1 Stancor plate transformer P-6134 or equivalent
1 Stancor filament transformer P-6010 or equivalent
1 1000 ohm 10 watt resistor, wire wound
1 octal tube socket
1 110 volt power cord and convenience plug
1 5Y3GT tube

Transmitter Mounting

1 Transmitter mounting FT 237D
1 Socket SO-45
1 Cannon receptacle, male, P8-42
1 SPST toggle switch

Dynamotor

1 PE 103 Dynamotor
1 20 ohm 1/2 watt wire wound resistor
1 16 mfd electrolytic tubular condenser, 450 v

Remote Control Unit

1 Box, removed from Dynamotor BD 77c or similar, or plain steel box, 9" long, by 5-1/2" wide, by 3" deep
1 No-insertion loss, T wire wound or carbon 250 ohm volume control (1800 ohm simple rheostat in shunt with mic will work quite well)
2 miniature bayonet-base pilot lamp mountings and 6v lamps
1 V I meter, Weston Model 301, type 23, 5000 ohm resistance, or equivalent
1 open circuit headphone jack (two in parallel if desired)
1 hinged jack dust cover
1 six contact banana plug, male, receptacle, SO-45
2 microphone sockets, to match station's mike plugs
1 DPST toggle switch
1 DPDT toggle switch
1 5000 ohm 1/4 watt carbon resistor

Transmitting Antenna

1 Commercial police type mobile antenna mounting swivel, spring, and insulator
1 Mast Section MS 49
1 Mast Section MS 50
1 Mast Section MS 51

Cables

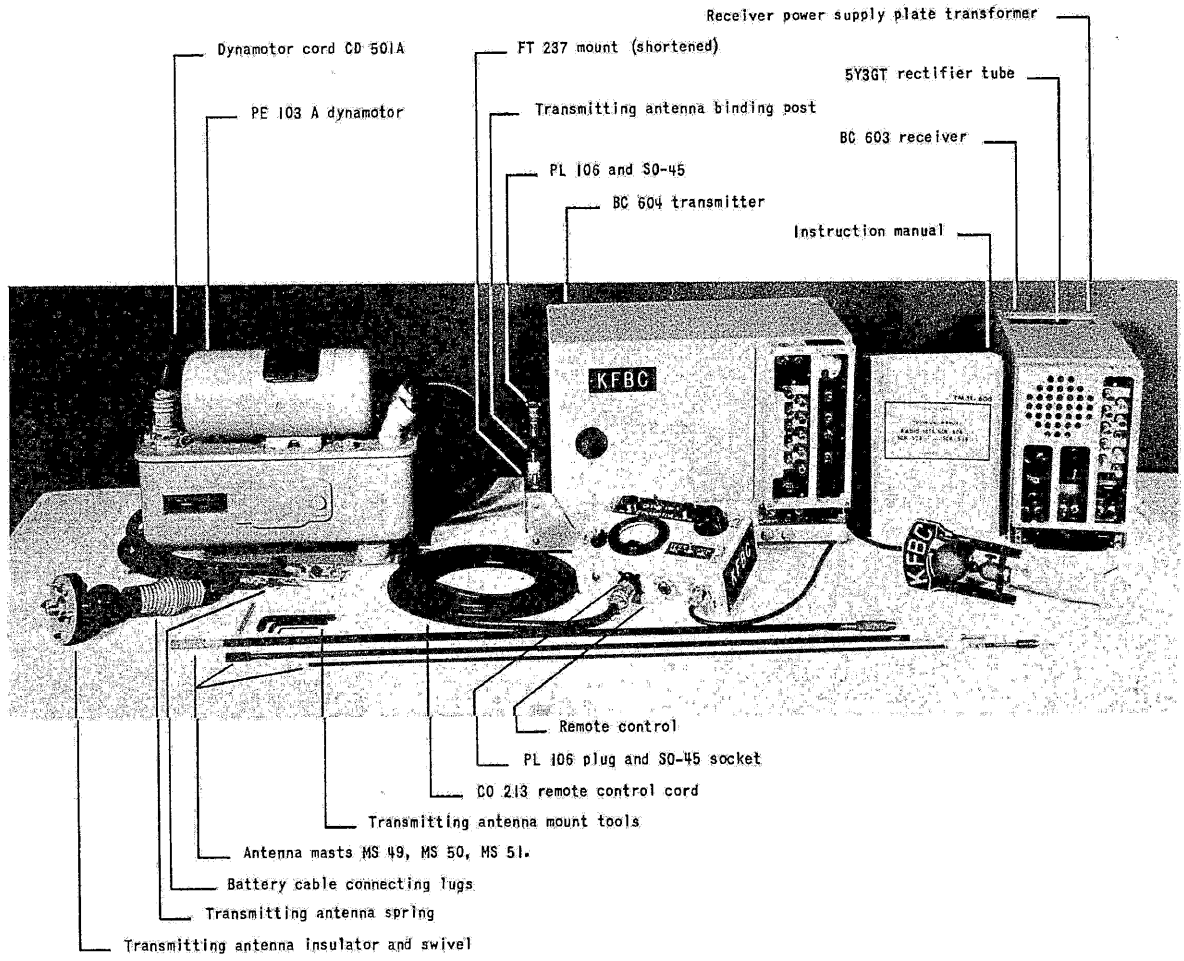
1 Dynamotor cable shielded, CD 501A, with male plug, P8-24 on one end, and female connector P8-23 on the other end, 8 contact. (7 contacts only used). This fits the socket P8-41 on the PE 103 dynamotor, and connects the dynamotor to the transmitter mounting.
1 15 ft. length Cordage CO 213. This is a seven conductor rubber covered, shielded cable, with two of the conductors separately shielded within the overall shield. CO 213 is a component part of SCR 508.
2 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.

PART 3

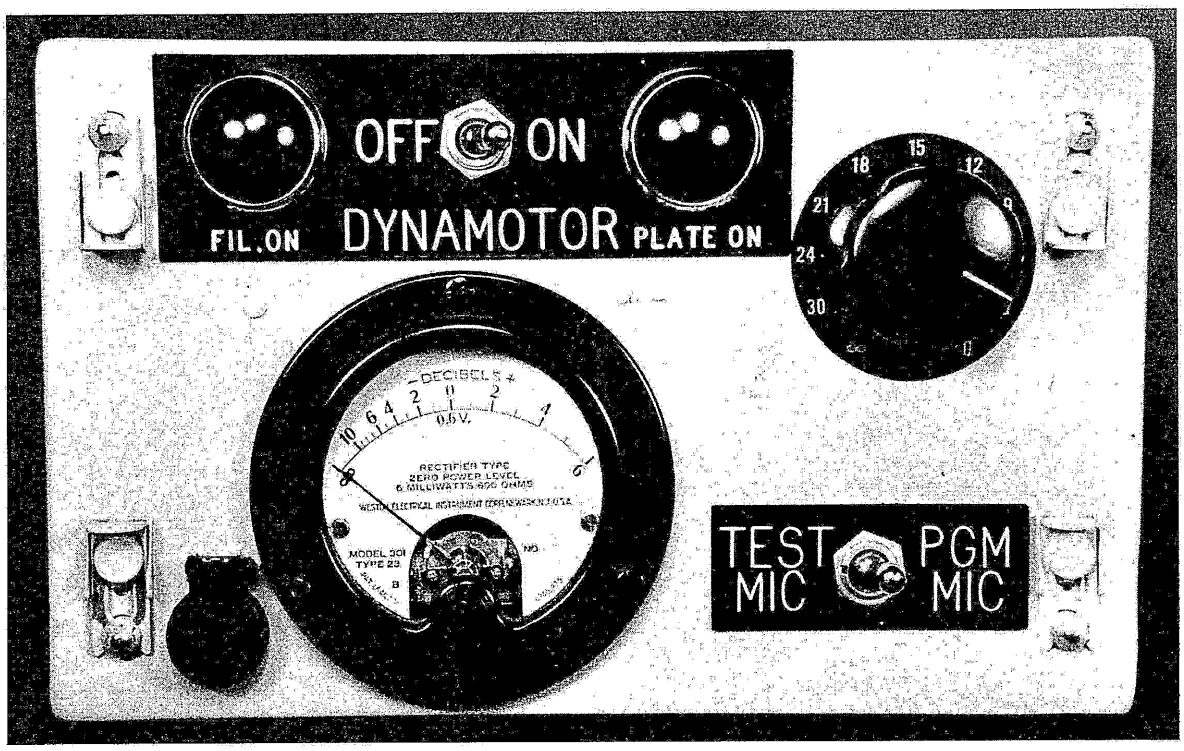
Installation

Receiver

Results as regards distance covered without objectionable noise will depend largely upon the height and efficiency of the receiving antenna. A ground plane quarter wave antenna or co-axial 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



View of the Various Components of the System



Remote Control Unit

quiet location on a 40 foot telephone pole. The receiving antenna is matched to a concentric transmission line such as RG 12U 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

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 inches. 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 1-1/4 inches diameter thru the floor. Pass the + low voltage lead thru 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 under side of the floor of the car to prevent chafing and shorting. By means of cable CD 501A connect dynamotor to transmitter mounting.

Remote Control

Pass remote control cable around the back of the rear seat, forward to the driver's seat. Lay the remote control on the seat. Make the cord sufficiently long so that the operator may stand on the street with the remote control in hand, beside the car.

PART 4

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 controls). If left on continuously, this switch causes a small drain of about 15 milliamperes 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, by 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 re-adjustment. 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 months without any re-adjustment of any kind. Since the equipment draws approximately 32 amperes from the 6 volt battery, it is well to run the car engine if transmissions are longer than 15 minutes.

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 mic will give better over-all results than a high quality broadcast type mic. The close-talking variety such as T-17 is most suited. The carbon mic is plugged into the "CARB MIC" jack. The volume control on the remote control is turned off during use of the carbon mic. No variable volume control for carbon mic is provided. However, the "TANK-OTHER USE" switch is a high-low carbon mic volume control. The gain for a given carbon mic can be adjusted by shunting resistor R120 within the transmitter. The volume will be indicated on the VI meter. It should be anticipated that the announcer will use a high voice level under high noise conditions.

PART 5

Transmitter Notes

Since the Type 1619 tubes have been replaced in the RF lineup with Type 6V6GT, and since the 6V6GT has a different internal capacitance between the elements than 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 degrees, in order to bring the circuits into resonance. Some will be increased, some decreased. The tuneup 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 9th 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 the tuning lock loosened until maximum output into the dummy antenna is had, all in accordance with instructions contained in the technical manual.

By using an absorption type wave meter, the proper harmonic can easily be selected and with such an instrument at hand, it should not be 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 conversions outlined herein, are:

Meter Position	Circuit Metered	Meter Reading
2	RF Amp. grid	19
3	Rectifier grid	21
4	Doubler grid	20
1	Tripler grid	23
5	Power Amp. 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 VI meter. With a meter as specified, the proper setting of this control will be about 15 degrees less than maximum clockwise position. Apply 1000 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 VI meter and headphones of the remote control disconnected, measured with a vacuum tube voltmeter, with SIDETONE at maximum clockwise. This will produce a frequency swing of about 5 kc. Modulation peaks will achieve the legal limit of 8.5 kc swing. Connect the VI meter, insert high impedance headphones, and adjust SIDETONE control to indicate + 4 on the VI Meter.

If the transmitter is adjusted so that a reading of other than 20 or 21 with meter selector on position 3 is 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 ten 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.

PART 6

BC 604 Transmitter

Following is a step by step procedure for modifying the BC 604 transmitter. The essential modifications are: Change microphone input transformer to improve frequency response and reduce noise; Change direct heated filament tubes to cathode type, to adapt 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 bias of audio stages from cathode resistors instead of filament drop. Figures 1, 2, & 3 pertain to these notes, and the numbers circled in Figures 1 and 2 refer to the same paragraph of these notes.

1. Unsolder heavy wires and smaller wire from contacts of dynamotor relay S102. Clip leads to coil of S102, at S102. Remove 4 screws holding relay S102, and remove relay. Remove 2 screws holding condenser C162.

Clip strap connecting + end of C162 to tie point. Cut wire connecting - end of C162 to R133, at R133. Remove C162. Unsolder heavy wire that connected relay S102 at #1 and #3, PG104, and discard. Splice heavy wire that formerly connected #1, PG101 to contact of S102 to smaller wire that formerly connected to same contact of S102, and slip piece of spaghetti over splice. This wire feeds battery to filaments. This operation removes the dynamotor relay and associated condenser since they are no longer needed, but preserves the filament feed.

2. Mount 16 mfd 450V electrolytic lengthwise of transmitter in space formerly used, in part, by dynamotor relay S102. Connect positive end of this condenser to hot terminal of C145 (or R147) with a wire about 6" long and 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 space formerly occupied by relay S101 and condenser C162.

4. Disconnect WH lead that connects D126 (Tank-other use) switch to #2 VS107, at #2 VS107, and ground D126 using same WH wire, shortened, connecting at solder lug close to D126. (This is necessitated by other changes in filament circuit.) Clip wire at #2, VS107. Don't try to unsolder it here.

5. Change lead connected to #2, VS101 from #7, VS106 to #2, VS 106. Filament.

6. Ground #7, VS106 to ground lug, not to #8, VS106, because #8, VS106 will be lifted from ground later. Filament.

7. Disconnect 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 lead from #7, VS105, which runs to R127, and pull from cable and discard. Also discard R127, unsoldering other lead to R127 at R127. Filament.

9. Ground #7, VS105.

10. Ground #7, VS101, using wire that formerly connected #7, VS101, to R127.

11. Cut strap connecting R113 to R140 and R141 at R140 and R141. Remove screw holding R113 and disconnect R113 from #7, VS102 at R113, and use wire formerly connected to R113 to connect #7, VS102 to R140 and R141 at former junction with R113. Cut yel wire that connects to lamp ES101 from R113 and reconnect to R140 and R141 at former junction of R140 and R141 with R113. (Cut wire from R113. Don't try to unsolder.) This connection is made to the accessible end of R141. Discard R113. Filament.

12. Connect #7, VS102 to #1, VS104, with a wire 13" 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 510 ohm, 1/2 watt, resistor between #8, VS106 and ground, removing ground from #8, VS106. Cathode bias resistor.

19. Install 10 mfd 25 or 50V electrolytic condenser between #8 and ground, VS106, + to #8 (cath). Cathode by-pass.

20. Install 2200 ohm, 1/2 watt, resistor between #8 and ground, VS105, removing ground from #8, VS105. Cathode bias resistor.

21. Install 10 mfd 25V or 50V electrolytic condenser between #8 and ground, VS106, + to #8. Cathode by-pass.

22. Disconnect BL-YL wire connecting #8 on PG103 (+HV) to F101 at F101, and tape end and tuck under cable, and use concentric line that connects C161 to #A2, Pg101, for this + HV lead, making +B come through A2 on PG101 for using external dynamotor. Disconnect C161 from end of co-ax transmission line. Cut BL and GR wires from center contact of S101. Unsolder bus wire connecting L111 to S101 at L111 and discard bus. Unsolder short co-ax 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 relay mounting screw hole near end of co-ax cable connecting to A2, PG101. Solder end of co-ax to tie point. Connect tie point to F101 by means of an insulated stranded wire 19" long, taking this wire through hole A. Tie this wire to cable at top of transmitter, also at end removing plate at right end of transmitter to make 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 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 soldering lug and small 6-32 nut. Run wire from this soldering lug to ground at C143. Slip spaghetti over ends of wires removed from C and D, J101.

24. Remove lead connecting #5, VS105 to #5, T101 and discard lead. If a small mica condenser is connected to #5, VS105, leave it connected to #5 but move other end from #2, VS105 to #8, VS105.

25. Run shielded lead from #7 transformer K900849-501 to #5, VS105. Ground shield at both ends. Audio grid lead.

26. Connect shielded wire from #5, transformer K900849-501 to #6, VS105, (used as tie point). Ground shield at both ends.

27. Disconnect wire that runs from junction of C137 and C138 to #4, T101 at T101 end, and connect 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" long, which is stranded. Do not solder #6, VS105, until after next step is completed.

28. Connect 1/3 watt, 100,000 ohm resistor from #6, VS105, to #1, VS105, and a .001 postage stamp condenser from #6, VS105, to #8, VS106.

29. Disconnect BL-OR wire connecting C of C142.1 and C142.2 to C139 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 by-pass, 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 1/2 watt resistor from #2, VS106 to the tie point. Remove dust shield from trimmer condensers and S104. Disconnect C144 from radio-interphone relay S104, at S104, also at C144, and discard the wire. Connect a new wire 8" 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 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" long.
Connect #1, transformer K900849-501 to #4, PG101, using shielded wire and ground shield at transformer end.
Connect #4, transformer K900849-501 to #5, PG101, using shielded wire and ground shield at transformer end.
This operation disconnects mike circuit of T101 and substitutes transformer K900849-501 for T101 and connects -HV of dynamotor to R130.
Disconnect present wires from #4, PG101 and #5, PG101 and slip spaghetti over ends and tuck under cable. Slip spaghetti over new wires to be connected to #3, #4, #5, of PG101 and slide same over terminals after soldering.

34. Disconnect at socket 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 Para. 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 shield, so spaghetti can be slipped over end of entire cable and cable tucked away adjacent to relay S103. R148 may also be disconnected from #6, VS106, also at its other end, and discarded.

35. Connect A 10 mmf. condenser from #5, VS105, to #8, VS105, keeping leads not over 3/8" long. Some transmitters already have such a condenser connected from #5, VS105 to #2, VS105. If so, this condenser has been re-connected in Para. 24.

36. Lay a 40 MF, 25V or 50V, tubular electrolytic condenser in the space between the end of transmitter and PG103 and PG104, and connect the positive end of 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 way, disconnect same 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 wire at #20, PG101, and at 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 24V 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, and cover cut end with spaghetti and tuck under 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 DC 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 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 quickly block all tubes 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 short RF co-ax cable that connects to "ANT" post and solder free end of this co-ax to 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 bus so it will not short to ground.

45. Mount a 3-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 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 lamp E101, which is a 24V lamp and replace with a 6V to 8V or a 12V lamp. The 24V lamp removed, is used in the receiver.

47. Shunt R120 (200 ohms) with a 75 ohm 1/2 watt resistor. The carbon mike current feed was designed to work from 12V and having added 75 ohms in series with R121 already in Para. 32, it is now necessary to reduce the total resistance in the carbon button circuit so that the 6V 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 25 ohm resistor, which, while increasing the current flow, will act as a voice frequency load, reducing the signal level.

48. Clip BL shielded wire from terminal #0 of L105 and clip RD-BL shielded wire from #2, T102, and clip the ground wire of this shielded twisted pair and slip spaghetti over the bared end of the cable and tuck away in space around relay S103. Unsolder 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" long to #2, T102, skin and tin the other end of 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 strap at #2, VS104 (screen grid) and solder clipped end to adjacent terminal of R114, thus connecting R114 and R116 in parallel. By means of an insulated wire 4" long, connect the original junction of R114 and R116 to #2, VS104.

50. Install tubes in transmitter as follows:

V101	6V6GT	V104	807
V102	6V6GT	V106	6L6
V103	6V6GT		
V105	6V6GT		
V107	6V6GT		
V108	6V6GT		

PART 7

Transmitter Mounting

Mounting FT 237D is a component of SCR 508, SCR 528, SCR 538. FT 237D is designed to accommodate one BC 604 transmitter and two BC

resistors to the circuit, with their positions interchanged. In other words, change R10 from the original value of 250 M ohms to 1 meg ohm and change R11 from the original value of 1 meg ohm to 250 M ohms. This reduces the audio level at the grid of the 1st 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 and 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 110V AC.

PART 10

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 ac power supply is available, it is modified to operate from such a power source, rather than from a dc 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. A 1000 ohm 10 watt resistor is used as a resistance filter, and 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. plate supply. Figure 4 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.

PART 11

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 to switch 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 mic. 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 placed in an out-of-the-way place.

If more than one mic at a time is needed, a regular 4 channel remote amplifier is connected in place of the program mic, by means of suitable level reducing pads and isolation coils. Since the volume indicator is fed from the output of the audio amplifier at about 0 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 overall shield of the cable. Such a cable is CORDAGE 213, a component of SCR 508. Figure 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.

RADIO INTERFERENCE IN AREAS OF HIGH FIELD INTENSITY

By P. A. Young
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It is well known that Standard Broadcast Receivers located within regions of high field intensity are especially liable to interference. In the FCC Standards of Good Engineering Practice, 1940 revision, it is stated: "The 'blanket area' of a broadcast station is defined as that area adjacent to the transmitter in which the usual broadcast receiver would be subject to some type of interference to the reception of other stations due to the strong signal from the station."

Certain published articles[1] have dealt with one phase of such interference, but antedating them are several unpublished reports[2] of one organization relating experience gained by investigation of a great number of interference cases. Out of a total of more than 1,000 complaints handled, 80% originated inside a one volt per meter contour and 95% occurred within a one-half volt per meter contour. The interference encountered was generally separable into two major types, (1) blanketing and (2) cross modulation.

BLANKETING

Blanketing occurs when a high level carrier overloads a radio receiver. This is evidenced by broad tuning about the fundamental frequency, and is often accompanied by distortion and blocking. Correction entails reducing the blanketing frequency input level to the receiver by such means as a wave trap.

CROSS MODULATION

Cross modulation introduces an undesired modulation on the carrier frequency of a desired signal. This interference is created by intermodulation of two or more fundamental frequencies transmitted through a nonlinear element; intermodulation produces spurious frequencies corresponding to the sums and differences of both fundamentals and their integral multiple frequencies; also, the original modulation of both fundamentals is combined to form a multiple modulation imposed upon each fundamental and spurious frequency radiated from a cross modulation source. Cross modulation has two general origins, (a) the input tube of a receiver, and (b) an external circuit element.

Receiver Cross Modulation is caused by nonlinear tube response to high input. Correction procedure is, like blanketing, to reduce the input level of the interfering frequency.

External Cross Modulation occurs in a nonlinear element of a circuit external to either radio transmitter or receiver. This circuit must possess means to collect radio energy of two or more fundamental frequencies, intermodulate them, cross modulate their initial intelligence, and then radiate the resultant multiple modulated fundamentals and spurious frequencies. Some of the collectors most frequently found were metal roofs, downspouts, gas and water pipes, furnace pipes and electric wires.

Experiments have determined that sustained cross modulation is only generated by a low impedance circuit. The majority of nonlinear elements found were low pressure contacts between oxidized metal surfaces. Those most common were between BX and plumbing, gas and water pipes, furnace and water pipes, vent pipes and metal roofs, and the overlapped joints in downspouts.

Experience indicates that cross modulation is usually confined within the 50 mv/m contours of the affected fundamentals. Certain exceptions noted had one fundamental of only 10 mv/m but in all such cases the numerical product of both fundamental field strengths in mv/m exceeded 5,000.

Before any field work is attempted, partial lists of possible spurious frequencies should be prepared. Select two fundamental frequencies with high field intensity in the region experiencing interference. Label these frequencies f_1 and f_2 and substitute them in the following table[3]:

TABLE I

$f_1 + f_2$	$f_1 + 2f_2$	$2f_1 + f_2$
$f_1 - f_2$	$f_1 - 2f_2$	$2f_1 - f_2$

The sign of the results have no significance and can be disregarded.

[1] *See appended bibliography.*

[2] *Unpublished reports of The Crosley Radio Corporation:*

a. Blanketing and Crosstalk Studies to January 1, 1937, G. E. Branch, G. F. Leydorf

b. Continuation of Blanketing and Crosstalk Studies to May 1, 1937, G. E. Branch, J. C. Brill, G. F. Leydorf, P. A. Young.

c. Methods of Investigating and Correcting Crosstalk as of August 28, 1937, G. E. Branch, J. C. Brill, G. F. Leydorf, P. A. Young.

d. Report on Radio Interference Investigations conducted during the past year, June 3, 1938, J. C. Brill, P. A. Young.

[3] *See footnote 2a, mathematical analysis by G. F. Leydorf. Also, Terman, Radio Engineers Handbook, 1943, p. 647.*

EXAMPLE:

Suppose that $f_1 = 550$ kc/s; $f_2 = 1360$ kc/s

Substitute these values into Table I to obtain Table II shown below.

The terms of Table I that include an integral multiple do not signify the presence of second harmonic. It is emphasized that cross modulation can be generated without the existence of a second harmonic of any kind. It is also pointed out that cross modulation may be produced without a true rectifying action, only a nonlinear voltage-current characteristic being required.

The spurious frequencies listed in Table II are merely a small number of the total combinations that are possible. Cross modulation may occur without any of these particular frequencies being present. However, if present they do positively denote cross modulation.

Spurious frequencies have been utilized in correction work because they vary directly with the interference level. Elimination of the source completely removes all these artificial frequencies, whereas only the cross modulation background disappears if listening to a broadcast station. Furthermore, these spurious frequencies are still fairly strong when the undesired modulation on the desired frequency is reduced below an audible level. Therefore Table II should be expanded to include all radio stations affording high field strength to the area under consideration.

The test equipment required is a readily portable battery receiver of high sensitivity, well shielded, and tunable over a reasonable range of spurious frequencies, together with an electro-statically shielded loop antenna. Flexible shielded leads and a handle several feet long will permit the loop to be readily probed about among pipes and wires. In use the portable set is tuned to one of the spurious frequencies, a pipe or other conductor approached with the loop until a strong signal is located, and then this conductor followed until contact with some other metallic object is found. The contact is varied by moving one conductor and noting any change in spurious signal. This procedure is continued with each contact point being corrected until the spurious frequency either disappears or is so reduced that no undesired signal is audible upon the fundamental of the desired station. Correction may follow either of two procedures:

1. A short-circuit permanently and directly across the nonlinear element. Example: self-tapping screws through both downspout sections at an overlap joint.
2. An open-circuit permanently insulating the contact surfaces of the nonlinear element. Example: wood strips secured by friction tape between the contact portions of gas and water pipes.

Either correction method is quite satisfactory, the case of application determining the choice for each located source.

Building design has been found the principal obstacle to satisfactory correction of external cross modulation. Most buildings have numerous inaccessible metal-to-metal contacts, such as plumbing and conduit inside walls, that are potential interference sources. In large structures the required bonding or insulating of all casual metallic contacts would entail extensive building alterations.

Based on experience, some estimates of satisfactory correction expectancy for cross modulation originating within various size buildings are presented:

Structure	Estimated Satisfactory Correction - %
Single family home	*95*
Two family home	*80*
Four apartment building	*50*
Ten apartment building	*1*

Much external cross modulation trouble could be avoided by the adoption of adequate bonding and insulation practice in building construction. The proper construction procedures could be readily worked out by joint committees composed of qualified representatives of the radio industry and the building industry. It is highly desirable that this be done at an early date, particularly in regard to housing construction.

BIBLIOGRAPHY

D. E. Foster, A New Form of Interference - External Cross Modulation, R.C.A. Review, April 1937

A. James Ebel, A Note on the Sources of Spurious Radiations in the Field of Two Strong Signals, Proceedings I.R.E., February, 1942.

TABLE II

550 + 1360 = 1910	550 + 2720 = 3270	1100 + 1360 = 2460
550 - 1360 = 810	550 - 2720 = 2170	1100 - 1360 = 260

PRACTICAL ANALYSIS OF UHF, TRANSMISSION LINES, RESONANT SECTIONS, RESONANT CAVITIES & WAVE GUIDES

By J. R. Meagher & H. J. Markley

Field Engineers

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PREFACE

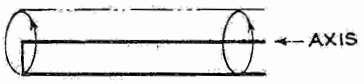
This paper was prepared as an aid to the many members of our country's Armed Forces engaged in the installation, operation and maintenance of Ultra High Frequency Radio-Electronic Equipment. It is hoped that this paper will also benefit others who are concerned with the design and production of this type of equipment.

Every effort has been made to explain the theories involved in the simplest manner without the use of mathematics. The contents have been limited to subjects of current importance.

TRANSMISSION LINES

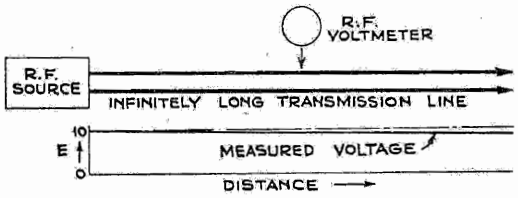
A transmission line is a means of transferring r-f energy from a source to a load in an efficient manner.

For simplicity, most of the illustrations in this booklet show parallel-wire transmission lines, but the information also applies to coaxial lines. The similarity between a section of parallel-wire line and a coaxial section may be seen by rotating a parallel-wire section about one wire so the outer arm forms a cylinder as shown.

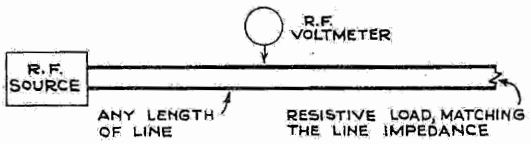


The r-f voltmeter, referred to in the text, usually consists of an r-f rectifier and meter which indicates the rectified peak amplitude of the r-f voltage at any point along the line.

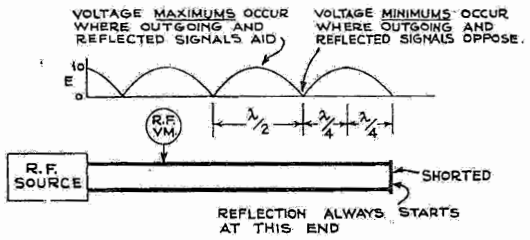
Standing Waves on Lines



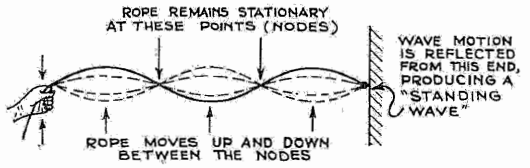
In this illustration, an r-f source is feeding r-f energy into a transmission line. If the line is infinitely long, the signal never reaches the end, and therefore cannot be reflected, so there are no "standing waves." The r-f voltage measured along the line gradually decreases due to losses in the line.



If the line is *terminated* in a resistive load that matches the line impedance (also termed "surge" or "characteristic" impedance), the outgoing signal is completely absorbed by the load. As a result, there are no reflections and no standing waves, and the voltage is essentially the same at all points along the line.



If the load is not resistive and matched to the line impedance, it reflects signal back into the line. *The combination of the outgoing and reflected signal produces a standing wave on the line.*



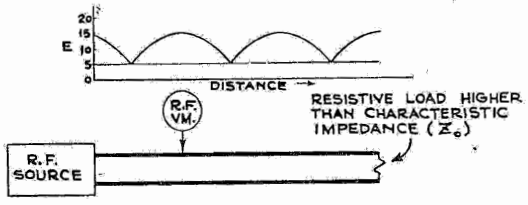
This analogy shows standing waves produced by wave motion and reflection on a rope. A similar analogy can be made to standing waves of sound along a pipe.

Standing Wave Radio

$$\text{The standing-wave ratio} = \frac{\text{Minimum Voltage}}{\text{Maximum Voltage}}$$

This ratio indicates the ratio of mismatch of the load impedance.

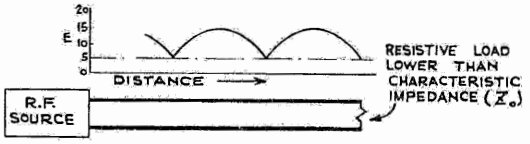
In the example shown below, the voltage at minimum's is 5, and the voltage at maximum's is 15.



The ratio is $\frac{5}{15}$ or 1 to 3.

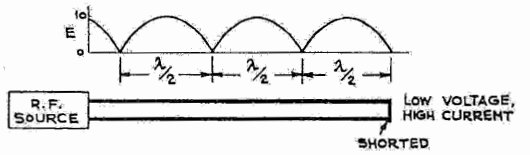
Hence, the load impedance is either 3 times larger than the line impedance, or one-third of the line impedance. (In the foregoing example, the voltage at the load is maximum, so the load impedance is higher than the line impedance.)

If the load has an appreciable reactive component the standing-wave ratio is only a rough indication of the impedance mismatch. This can be seen from the curves in the appendix.

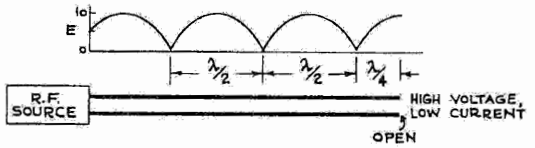


In the example shown above, the voltage at the load is minimum, so the load impedance is lower than the line impedance.

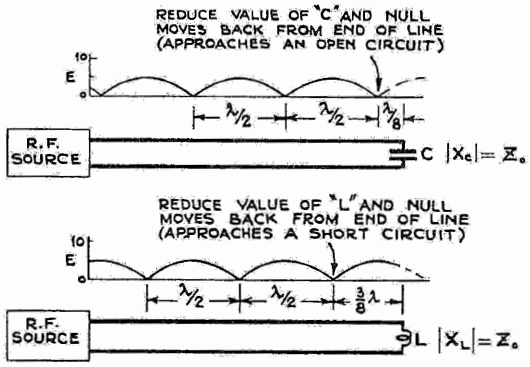
Position of Voltage Minimums and Maximums



If the end of the line is shorted, the voltage at the short is low and the current is high. The first voltage minimum occurs a half-wave back from the end of the line.



If the end of the line is open, the voltage at the end is high, and the current is low. The first voltage minimum occurs a quarter-wave back from the end of the line.



For loads containing reactance, the standing-wave will be shifted, depending on the nature of the load.

Often it is desirable to speak of electrical degrees rather than fractions of a wave-length:

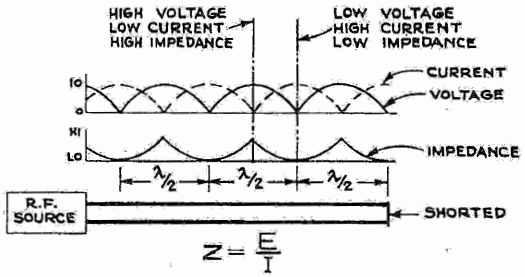
$\frac{1}{8}\lambda = 45°$	$\frac{1}{2}\lambda = 180°$	$\frac{7}{8}\lambda = 315°$
$\frac{1}{4}\lambda = 90°$	$\frac{5}{8}\lambda = 225°$	$\lambda = 360°$
$\frac{3}{8}\lambda = 135°$	$\frac{3}{4}\lambda = 270°$	

Impedance at Different Points Along the Line

The impedance at any point along the line is determined by the ratio of voltage to current at that point: If the voltage is high, the current at the same point is low, and therefore the impedance at that point is high.

If the line has low losses, and no energy is absorbed by the termination, the low-impedance points are equivalent to short-circuits, and the high-impedance points are equivalent to open circuits. If there is energy loss in the line or termination, the impedance tends to become more uniform along the line. *When the load matches the line, the impedance becomes uniform along the line, and is equal to the "characteristic" impedance.*

It should be noted that an open circuit, a short-



circuit or a pure reactance at the end of the line will not absorb power. Standing-waves will therefore exist with such loads.

Summary--Effect of Line Termination

(1) If a line *of any length* is correctly terminated with a resistive load that matches the line impedance, there are no reflections, and no standing-waves.

(2) If a line is not correctly terminated, the signal is reflected back from the load and this results in standing-waves.

(3) The value and nature of the load determines the *ratio* of voltage at maximum and minimum points along the line, and also the *position* of these maximum and minimum points.

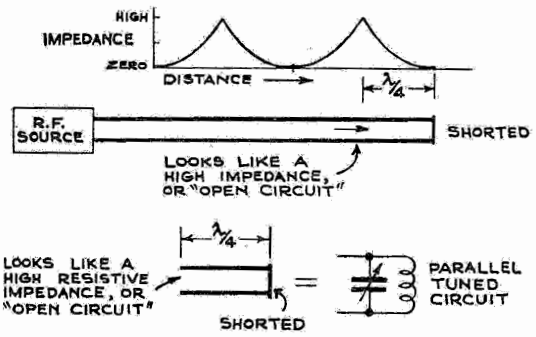
In most applications where a line is used to connect a signal source to a load (for instance, to connect a transmitter to an antenna) it is generally desirable to make the load match the line. *If the load is not matched, the length of the line becomes critical,* and incorrect length may affect the power output and frequency of the source. *When the load is matched to the line, the length of the line is not critical.* ("Matching" means that the load must be resistive and equal to the line impedance.)

Resonant Sections

Quarter-wave and half-wave sections and their action as tuned circuits will now be considered. This action will be explained on the basis of change in impedance produced by standing waves along an opened or shorted line.

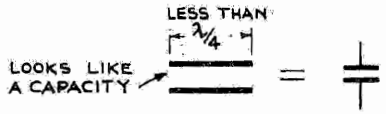
When sections of line are used as tuned circuits, their action depends on the existence of reflections and standing-waves to produce the effect of high-impedance and low-impedance tuned circuits. Therefore, sections of lines, when used as tuned circuits or transformers are either effectively shorted or opened at the end to produce the maximum standing-wave ratio and the highest or lowest possible input impedance, as desired in the application.

Quarter-Wave Shorted Section

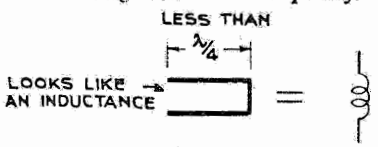


The quarter-wave shorted section at the end of the line looks like a high-impedance to the input signal, and being tuned, it is resistive. The equivalent conventional circuit is a parallel-tuned circuit, for it also has high resistive impedance at the resonant frequency.

The action of a quarter-wave section may also be explained as follows:

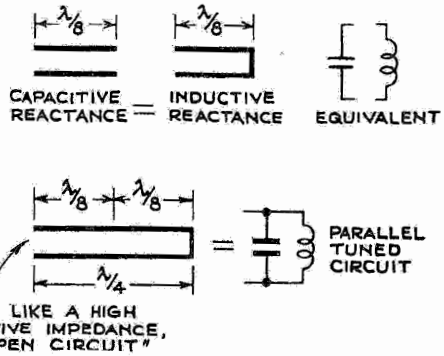


A section of line open at each end and less than a quarter-wave long acts like a *capacity.*



A section of line shorted at one end and less than a quarter-wave long acts like an *inductance.*

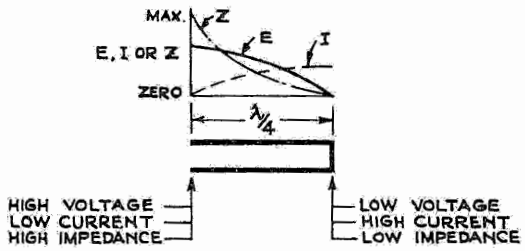
The capacitive reactance of a section of line one-eighth wave-long, open at the ends, is equal to the inductive reactance of a section of line one-eighth wave long, shorted at one end: The values of these reactances are equal to the "characteristic" impedance. (The "characteristic" or "surge" impedance depends on the size and spacing of the conductors.)



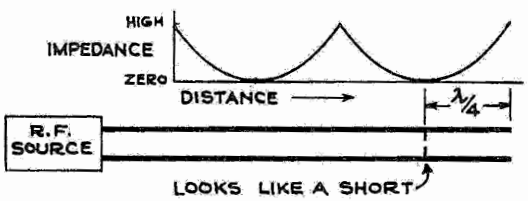
If the two sections are combined, the result is a resonant circuit that has high-resistive impedance, like a parallel-tuned circuit.

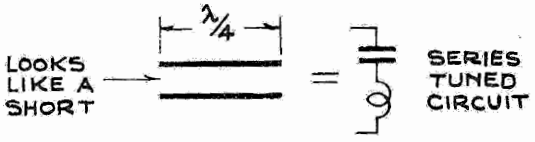
(This example is given because it is simple to visualize. Naturally, any two sections that add in length to equal one-quarter-wave electrically will have equal reactance and will produce the same result.)

The voltage, current, and impedance relations for a quarter-wave section are shown below:



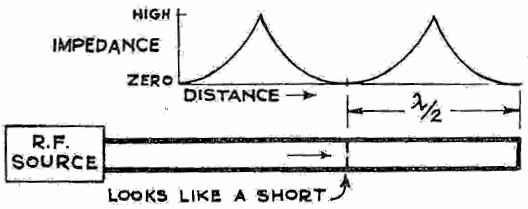
Quarter-Wave Open Section

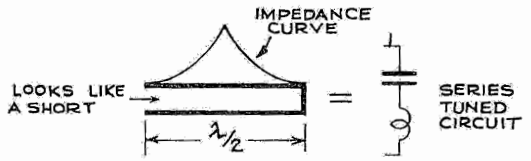




The quarter-wave section at the end of the line has very low input impedance, and, being tuned, it is resistive. It is equivalent to a conventional series-tuned circuit.

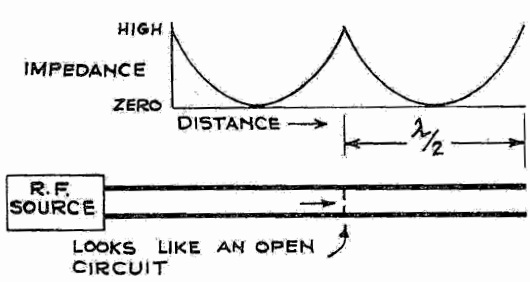
Half-Wave Shorted Section

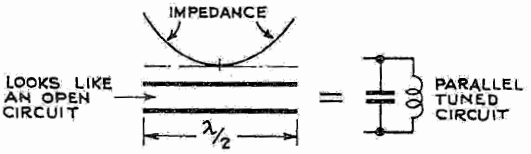




The half-wave shorted section at the end of the line also has low resistive input impedance. It corresponds to a series-tuned circuit.

Half-Wave Open Section





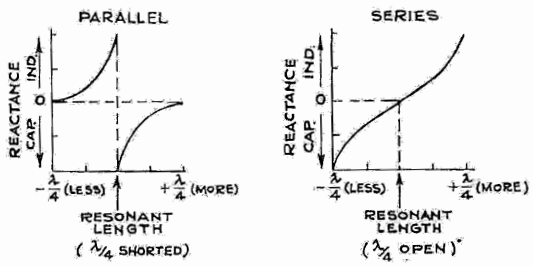
The half-wave open section at the end of the line has high input impedance. This section corresponds to a parallel-tuned circuit.

Tuning Characteristics of Resonant Sections

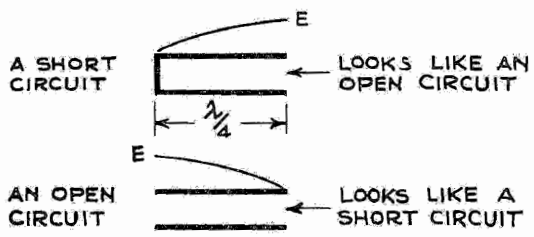
We have seen the four principal resonant sections:

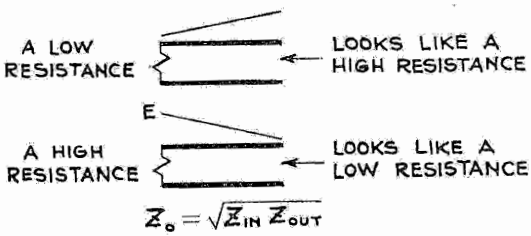
1. Quarter-wave, shorted } Equivalent to a parallel-tuned circuit
2. Half-wave, open }
3. Quarter-wave, open } Equivalent to a series-tuned circuit
4. Half-wave, shorted }

If a section of line is tuned above or below the resonant input frequency (by making the line shorter or longer) the effect is the same as in a conventional tuned circuit. The section will no longer look resistive. Either capacitive or inductive reactance will predominate. This is shown further in the tables on page 6 and in the graphs at right.



Quarter-Wave Line "Inverts" the Load



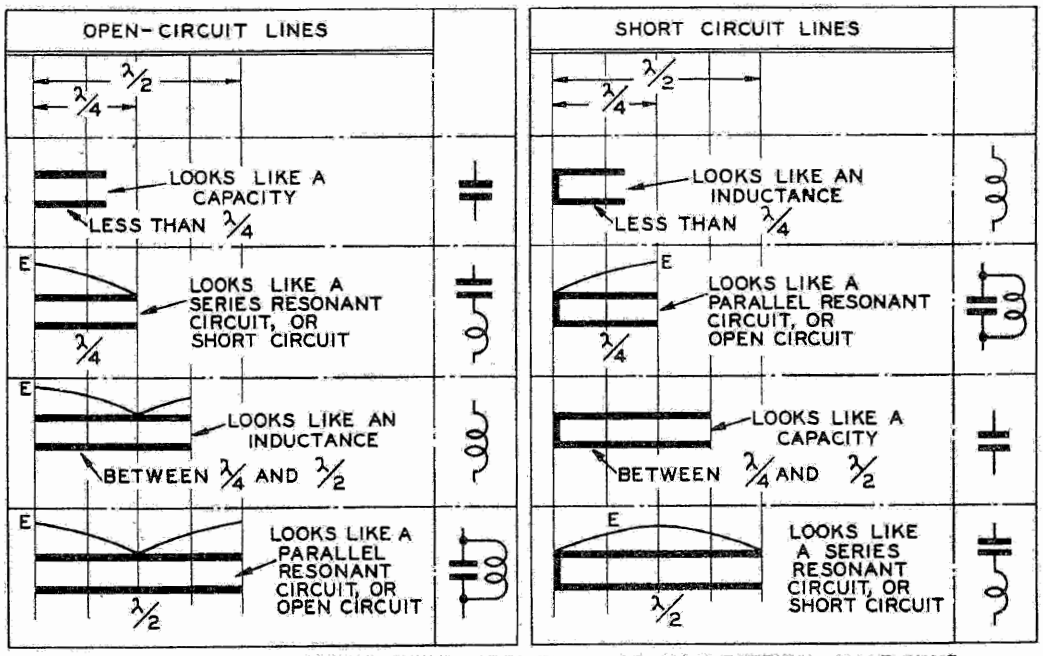


A quarter-wave line "inverts" the load as seen by source.

The input impedance in the above cases can be determined as follows:

$$\text{Input impedance} = \frac{(\text{Line impedance})^2}{\text{Load impedance}}$$

Characteristics of Line Sections



CHARACTERISTICS REPEAT WHEN MULTIPLES OF AN ELECTRICAL HALF WAVE ARE ADDED.

Tuning Characteristics of Resonant Sections and Conventional Circuits

WHEN INPUT FREQUENCY IS CONSTANT, AND THE CIRCUIT IS ADJUSTED		CONVENTIONAL CURCUIT	RESONANT SECTION	WHEN THE CIRCUIT IS CONSTANT, AND THE INPUT FREQUENCY IS ADJUSTED.	
ABOVE RESONANCE (SECTION MADE SHORTER) LOOKS LIKE	BELOW RESONANCE (SECTION MADE LONGER) LOOKS LIKE			ABOVE RESONANCE LOOKS LIKE	BELOW RESONANCE LOOKS LIKE
INDUCTANCE ($X_C > X_L$)	CAPACITY ($X_L > X_C$)	AT RESONANCE THESE CIRCUITS LOOK LIKE A HIGH RESISTIVE IMPEDANCE, OR "OPEN CIRCUIT"	E, λ/4, E, λ/2	CAPACITY ($X_L > X_C$)	INDUCTANCE ($X_C > X_L$)
CAPACITY ($X_C > X_L$)	INDUCTANCE ($X_L > X_C$)	AT RESONANCE THESE CIRCUITS LOOK LIKE A LOW RESISTIVE IMPEDANCE, OR "SHORT CIRCUIT"	E, λ/4, λ/2	INDUCTANCE ($X_L > X_C$)	CAPACITY ($X_C > X_L$)

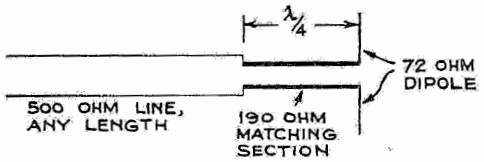
TUNED LINE CHARACTERISTICS REPEAT WHEN MULTIPLES OF AN ELECTRICAL HALF WAVE ARE ADDED

QUARTER-WAVE MATCHING SECTION

The "inverting" property of a quarter-wave section can be put to practical use when it is necessary to match a line of one impedance to a load of a different impedance. To do this, the section must have an impedance calculated as follows:

$$Z_{\text{MATCHING SECTION}} = \sqrt{Z_{\text{LINE}} \times Z_{\text{LOAD}}}$$

For example: A 500-ohm line can be matched to a 72-ohm dipole through a quarter-wave section of 190 ohms.



The *line* looks into a load of

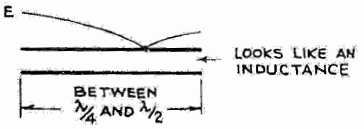
$$\frac{(\text{Z of matching section})^2}{\text{Z of load}} \text{ or 500 ohms.}$$

The *antenna* looks into a source of

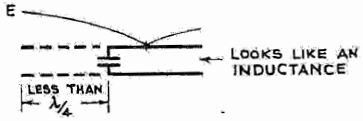
$$\frac{(\text{Z of matching section})^2}{\text{Z of line}} \text{ or 72 ohms.}$$

"INVERSION" OF CAPACITY AND INDUCTANCE

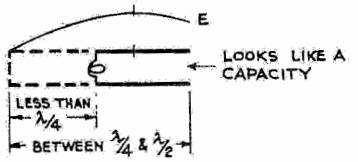
Inversion of capacity and inductance can be explained as follows:



An open section of line between one-quarter and one-half wave long looks like an inductance to the source.

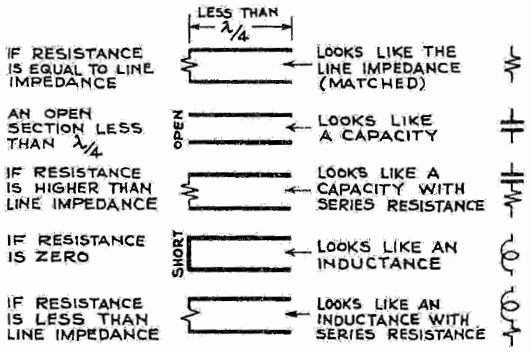


If a part (less than one-quarter wave) is replaced by a capacity (an open section less than one-quarter wave looks like a capacity), the section still looks like an inductance to the source.

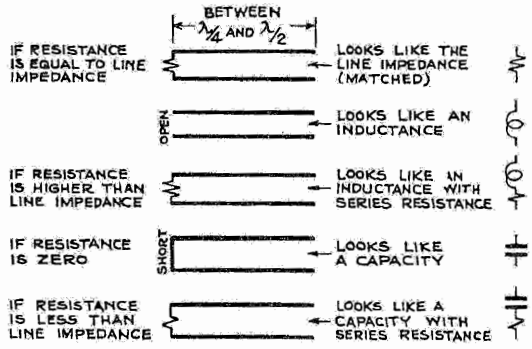


A shorted section between one-quarter and one-half wave looks like a capacity. If part (less than one-quarter wave) of the shorted end is replaced by an inductance, the section will still look like a capacity to the source.

SECTIONS LESS THAN QUARTER-WAVE

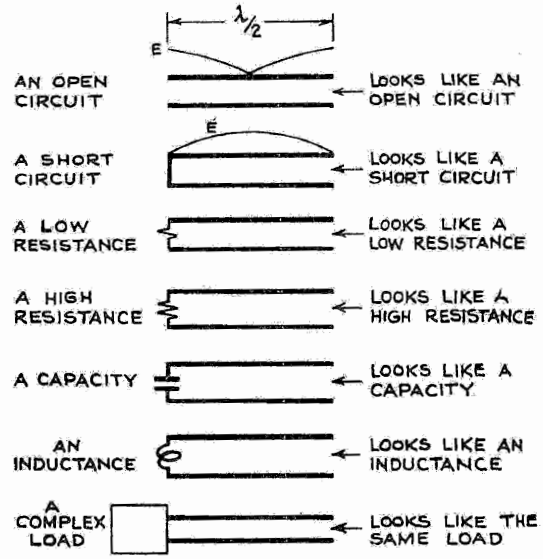


SECTIONS BETWEEN ONE-QUARTER AND ONE-HALF WAVE



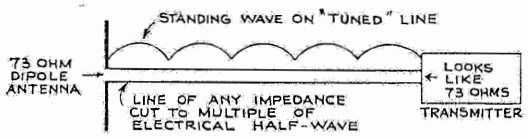
HALF-WAVE LINE "REPEATS" THE LOAD

A half-wave line acts as a "double inverter" and hence will "repeat" whatever appears on the far end:



A line that is any multiple of one-half wave has the same characteristics.

The action of a half-wave section, or a line cut to a multiple of a half-wave, is used extensively in practical applications. For example, if a dipole antenna with an impedance of 73 ohms is to be coupled to the output of a transmitter, through an open-wire line (spaced pair) with a characteristic impedance of several hundred ohms, the line can be cut to a multiple of an electrical half wave.



The transmitter will look into a load of 73 ohms, regardless of the impedance of the line.

"Tuning Out" the Reactance of a Load

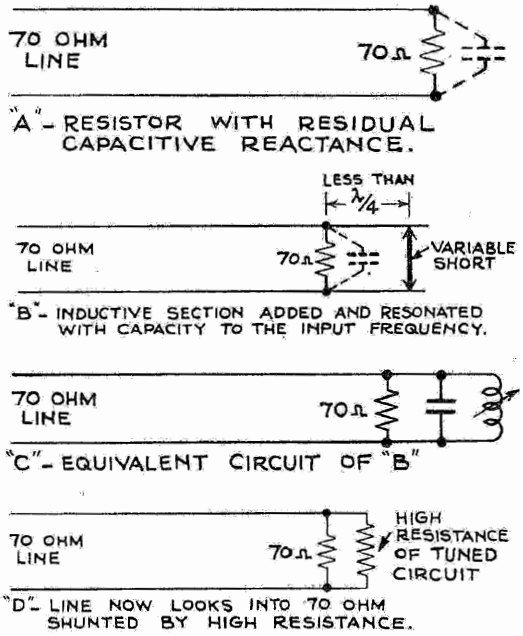
One of the important applications of tuned-line sections is to "tune out" the effects of residual capacitive or inductive reactance in a load, so the load will look like a pure resistance.

For example, assume that a 70-ohm resistor is used to terminate a 70-ohm line. If this line, with its resistor termination is connected to a slotted line and checked for match over a wide range of frequencies, it will be found that at some frequency the termination looks resistive. This is the resonant frequency of the resistor. Above and below this frequency the resistor has capacitive or inductive reactance and no longer matches the line. In other words, the resistor is not a "pure resistance" at most frequencies.

At the required operating frequency, the resistor may look like a resistance with shunt capacity as shown in "A." If an inductive section of line is connected to the termination as shown in "B," it may be adjusted to resonate with the capacity, to look like a parallel-tuned circuit.

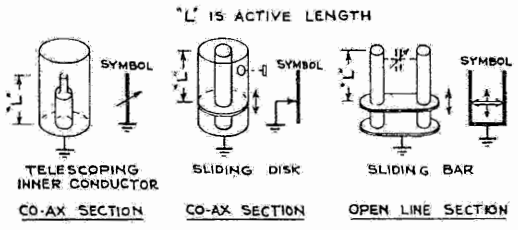
The line, therefore, instead of seeing a resistance with shunt capacity, now sees a resistance with a shunt parallel-tuned circuit, as shown in "C."

The parallel-tuned circuit looks like a high resistive impedance as shown in "D," and, therefore, has little effect on the total resistance. If the combined resistance is correct, the line will be "matched."



Tuned-Line Sections—Types of Construction

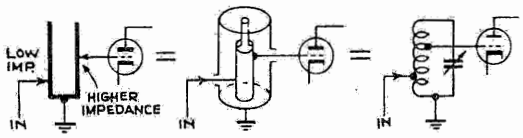
The characteristics of tuned lines are used to good advantage in UHF equipments. Quarter-wave and half-wave sections are used as parallel- and series-tuned circuits, as step-up and step-down transformers, as impedance and phase inverters, and even as insulators. Such sections of line take the place of conventional tuned circuits which become too small and inefficient at ultra-high frequencies. The tuned-line sections are made in both co-axial form, and in open-line type, from metal tubes and rods; generally silver-plated to reduce r-f losses. Some representative types of construction are sketched at left. Methods of adjustment to resonate the sections are indicated.



Some sections are cut short, and resonated with an adjustable capacitor (indicated by dotted lines) instead of being resonated with a sliding disc or bar.

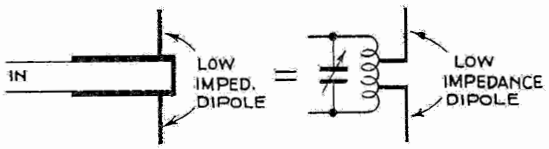
Quarter-Wave Sections as Transformers

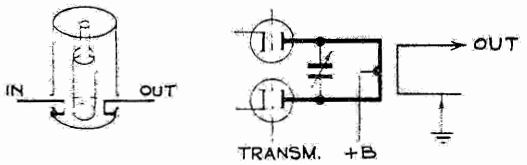
A quarter-wave section (co-ax or "open-line" type) shorted at the end, may be used as a step-up transformer, similar to a parallel-tuned auto-transformer. When a resonant section is "loaded" with reactance, for example, connected to the grid of a tube, the section must be readjusted to obtain electrical resonance).



A quarter-wave shorted section may be used as a step-down transformer.

Inductive coupling to tuned sections is sometimes done as shown in the following two different examples:





Co-Ax Arms on Tuned Sections

In push-pull UHF circuits, lengths of co-ax are frequently used to form the arms of one-quarter or one-half wave shorted sections. This is done for several reasons, including:

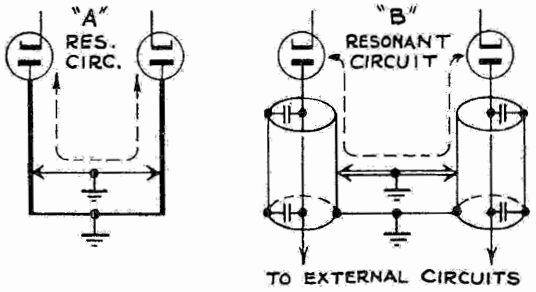
(1) The inner conductors may be used to carry d-c and a-c supply voltages, or low-frequency signals, to the tube elements.

(2) The outer conductors can be grounded.

(3) A sliding bar on the outer conductors can be used to adjust the electrical lengths of the section mentioned in (1) above.

In such applications, capacitors are used at the end of the co-ax to place the inner and outer conductors at the same r-f voltage.

An example of co-ax arms forming tuned sections is shown in the illustration.



"A" is the quarter-wave shorted section required for input tuning. But it is necessary to take the diode currents to external circuits, and (for constructional reasons) the arms of the section must be grounded. "B" shows how "A" is rearranged to do this. *The co-ax lines do not act as tuned sections by themselves, but form the arms of the quarter-wave shorted section shown in "A."*

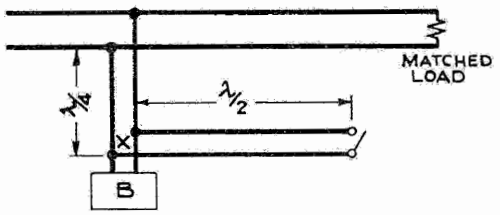
Miscellaneous Application of Tuned Sections

Tuned sections are put to many uses in addition to that of replacing conventional tuned circuits.

Some miscellaneous uses are described to indicate several of the many applications.

(1) Use of Sections in Switching Circuits

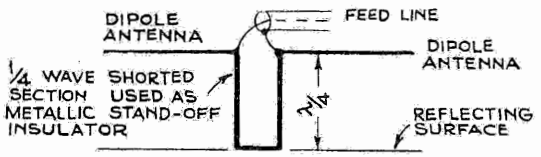
In some equipments it is necessary at times to prevent signals from "A" getting to "B." This is accomplished by shorting the end of the one-half wave section. By virtue of the action of one-half wave sections, this short appears as a short across "B" input line at "X." The one-quarter-wave line, being thus shorted at "X," looks like a high impedance to the signal from "A."



When it is desired to leave signals through to "B," the switch is opened at the end of the one-half-wave line. At "X," the one-half-wave resonant line now looks like an open circuit. With no short at "X," the one-quarter-wave section is simply an ordinary part of the line, and signals can pass to "B."

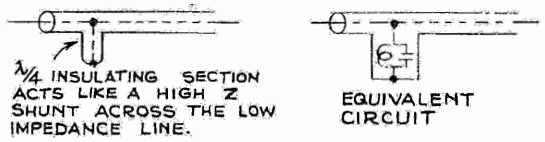
(2) Quarter-Wave Shorted Section Used as an Insulator

(a) A quarter-wave shorted section looks like a high resistive impedance. This fact is utilized in some antenna systems by employing one-quarter-wave shorted sections as metallic stand-off insulators to support and space a dipole antenna one-quarter wave from a reflecting surface, as shown below:



The quarter-wave section looks like a high impedance to the antenna feed line. (The feed line can be run inside one arm of the quarter-wave section.)

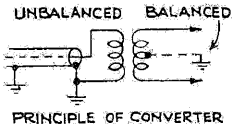
(b) Another example of a quarter-wave "insulator" is shown below, together with an analogy of a conventional parallel-tuned circuit.



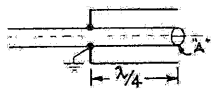
(3) Line Balance Converter (Bazooka)

In some applications, it is necessary to change from a co-axial transmission line (unbalanced, since outer conductor is grounded) to a balanced transmission line or load (both conductors approximately the same impedance above ground).

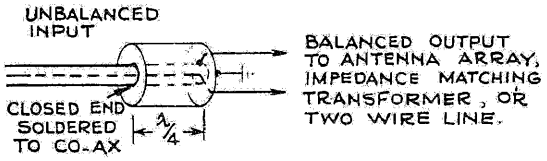
A "bazooka" is used for this purpose. The action is shown in the sketches, and may be explained as follows:



PRINCIPLE OF CONVERTER



BAZOOKA FORMS SHORTED QUARTER WAVE SECTION PLACING "A" AT HIGH Z TO GROUND.



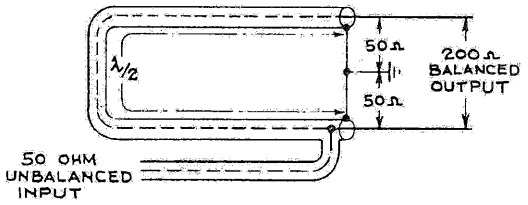
1. The quarter-wave shorted section effectively removes the r-f ground from the end of the outer conductor of the co-axial line.

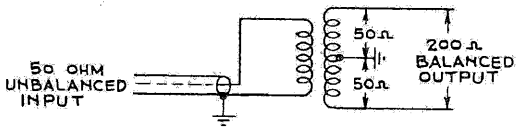
2. Both the inner and outer conductors of the co-axial line are now at a relatively high impedance above ground, and effectively balanced to ground.

3. The bazooka may be used in reverse manner to feed from a balanced circuit to an unbalanced circuit.

(4) Half-Wave Phase and Impedance Converter

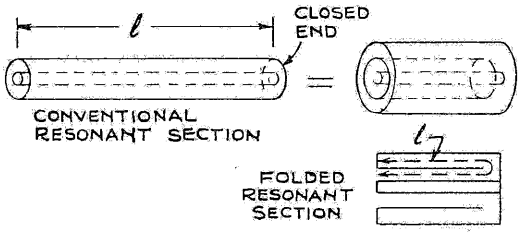
The following arrangement is used in some applications. The action may be reversed, to feed from high-impedance balanced input to low-impedance unbalanced output.





(5) "Folded" Resonant Section

At relatively low frequencies, the physical length of a resonant section may be too long for convenient use, and a "folded" section may be used. The effective length of the folded section is indicated by the dotted line. More than one "fold" may be used for further reduction of the physical length.



Characteristic Line Impedance

The impedance of a line (also termed "surge" or "characteristic" impedance) depends on the dimensions and spacing of the conductors, and the dielectric constant of the insulating material.

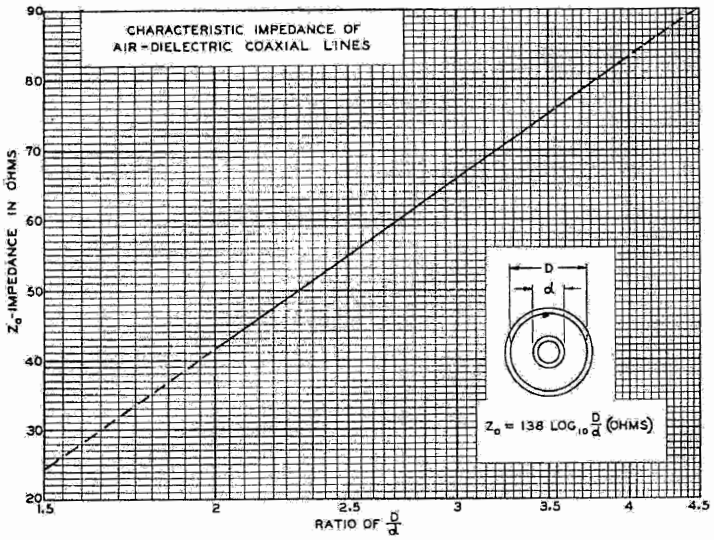
Neglecting Losses—

$$Z_{OHMS} = \sqrt{\frac{L_{HENRYS}}{C_{FARADS}}}$$

In solid dielectric lines (as compared with air dielectric) the impedance is reduced by the factor $\sqrt{1/k}$, where "K" equals the dielectric constant of the insulating material (and has the effect of increasing "C" per unit length in the general formula).

Aircraft Antenna Cable, using solid dielectric is frequently 70 or 50 ohms. Seventy (70)-ohm cable is convenient for use with quarter-wave dipoles and other antennas that have a radiation resistance of 70 ohms. Fifty (50)-ohm cable is used extensively in conjunction with suitable matching on low-impedance array-type antennas.

The two charts on the following page show how the impedance of co-axial and parallel-wire lines varies with the dimensions and spacing of the conductors.



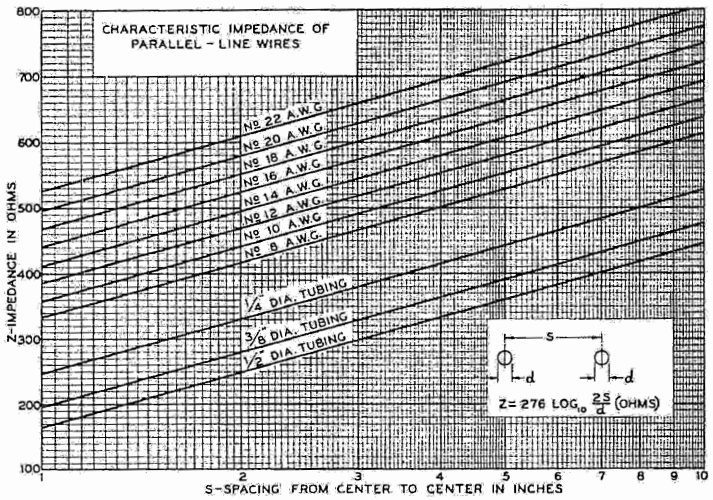
Impedance chart for air-dielectric co-axial lines.

Example: For a 50-ohm line, "D" is 2.3 times larger than "d". For a 70-ohm line, "D" is 3.2 times larger than "d".

NOTE: Refer to Section 6 of NAB Handbook for enlargements of these two charts.

Impedance chart for parallel-wire lines.

Example: To obtain a line impedance of 500 ohms, using No. 14 wire, the spacing (S) must be approximately 2 inches.



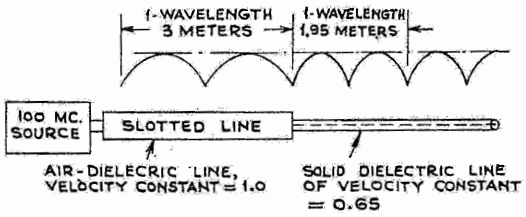
Velocity Constant of Lines

Radio waves travel at a speed of 300 million meters per second in air. The speed is reduced in lines that have spacing insulators or solid dielectric. In a slotted measuring line, with no spacing insulators, the speed is essentially the same as in air.

The speed in solid-dielectric lines of high quality, such as UHF aircraft antenna cable, is about 60-70 per cent of speed in air. Reels of such cable are tagged with the measured velocity constant of a sample cut from the reel.

The fact that the velocity is less in the cable than in air means that a wavelength in the cable will be shorter than in air; since the wavelength equals velocity divided by frequency. For example, a wavelength in air at 100 mc. is 3 meters, but in a solid-dielectric cable with a velocity constant of 65 per cent, a wavelength at 100 mc. is only 3 x .65, or 1.95 meters.

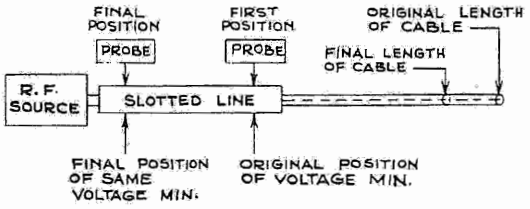
The lower velocity in solid-dielectric lines is illustrated below. A 100 mc. signal is fed through a



slotted line (air dielectric) and into a solid dielectric line that has a velocity constant of 0.65 (65 per cent of that in air).

A slotted line can be used to check the velocity constant of a co-ax cable.

The equipment is set up as shown:



The end of the cable is left open. Standing waves are therefore set up along the cable and slotted line. The probe is set accurately at the first point of minimum voltage at the cable-side of slotted line. A piece of cable is cut off at the end of the line. This shifts the voltage minimum point to the left, and the probe is reset accurately to the new position of the voltage minimum.

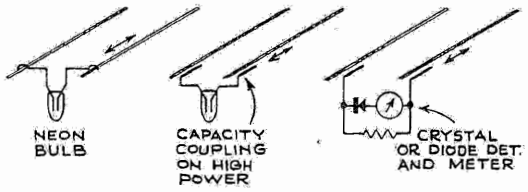
The ratio of the length of the piece of cable cut off to the distance that the probe is moved is the velocity constant of the cable. (In practice, small increments of cable are cut off until nearly the entire length of the slotted line has been traversed by the probe. Each step is plotted, and the slope of the line indicates the velocity constant).

As an example, if the length of cable cut-off is 1 foot, and the probe has been moved 2 feet, the velocity constant is .5, or 50 per cent.

Standing-Wave Indicators for Open-Wire Lines

A small neon bulb may be used to show existence of standing waves on open-wire lines. If the line is correctly terminated (no standing waves) the bulb will have constant brilliance as it is moved along the line.

Better indication can be obtained by using a crystal or diode rectifier and a meter, capacitively coupled to the line as shown.



Slotted Measuring Line

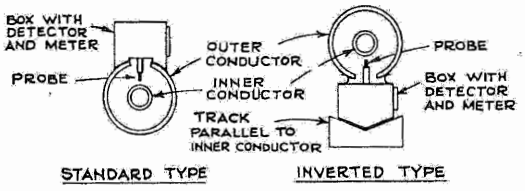
A "slotted line" is a section of co-axial line with a slot along the outer tube to permit loosely coupling an r-f voltmeter probe to the inner conductor.

The slotted line is used to determine:

(1) Ratio of voltages at maximum and minimum voltage points of standing waves along the line.

(2) Position of these points with respect to a "Reference" point.

From this data it is possible to determine the resistive and reactive nature of a load at a specified frequency.



Some Principal Applications Are

(1) To adjust antennas for correct match to a line at a specified frequency.

(2) To determine the resistive and reactive components of a load at a specified frequency, or over a range of frequencies; i. e., impedance and phase angle.

(3) To adjust input systems of receivers, dummy loads, etc., for correct match to a line.

Considerable care is taken in the design and construction of slotted lines to secure:

(1) Uniform impedance throughout the length.

(2) Uniform spacing of the probe in its travel along the inner conductor.

(3) Good grounding of the probe box to the outer conductor.

(4) Rigidity of the co-ax assembly, and minimum slop in travel of the voltmeter probe.

The impedance of the slotted line should equal the impedance of the associated co-ax line. Some slotted lines are equipped with two or more mechanically interchangeable inner conductors of different diameters so the impedance can be changed to match the impedance of commonly used co-ax lines (70 and 50 ohms, and some 63 and 40 ohms).

The r-f voltmeter used in conjunction with the slotted line is usually a diode or crystal detector with a current meter and tuned input, capacitively coupled to the inner conductor.

Diode and crystal detectors are insensitive and require a high-output UHF oscillator to excite the line. It is sometimes possible to use the UHF receiver (from an equipment) as an indicator, fitting the input of the receiver with a suitable probe. In this case, owing to the high sensitivity of the receiver, a low-powered UHF generator may be used for the source.

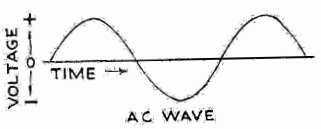
When adjusting antennas, the object in most cases is to "match" the antenna to the line. This is usually done by changing the antenna length and/or the antenna matching stub for *minimum* standing-wave ratio.

For some antennas, and in other applications of the slotted line, it is necessary to determine the resistive and reactive components and phase angle.

This requires checking both the standing-wave ratio and the distance from a minimum (or maximum) voltage point with respect to a "reference" point. This subject is covered in the appendix.

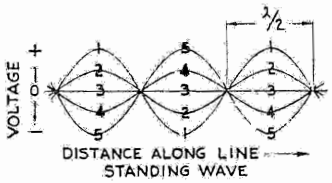
Additional Data on Standing Waves

An a-c wave may be drawn as a change in *voltage* during a period of *time*, as shown below.



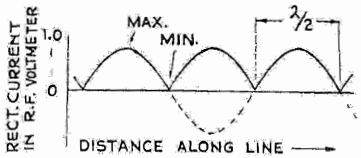
A standing wave is not as easy to show, because it involves changes in *voltage* with *time*, and with *distance* along the line.

The voltages between node points of a standing wave changes from positive to negative values and back during the time equivalent to one cycle of the r-f source. This r-f change in voltage is roughly indicated by curves 1 to 5 and back in the following sketch.



At some instant, the voltage along the line may be shown by one of these curves. It will be noted that the term "standing" wave can be misinterpreted. In a standing wave the *position* of max. and min. points does stand still, but the voltage changes at the r-f rate.

When an r-f voltmeter is moved along the line, it indicates the relative amplitude of the r-f voltage variation at each point along the line. The rectified r-f current in the meter circuit may be zero at nodes, and increases to a max. when the r-f voltmeter is moved to each voltage max. point. Thus the *measured* standing wave appears as shown below. (This is a sine wave with the negative half-cycles "flopped up.")

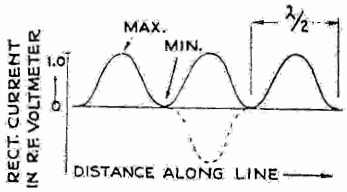


By turning one of the half-cycles down, as shown in dotted lines, it will be seen that the curve is a sine wave.

The standing wave that exists on the line is a sine wave, providing the r-f source is sine wave; that is, a fundamental frequency with no harmonics. For slotted-line measurements, the generator must furnish sine wave output. If harmonics are present, some of the min. points, with the line open or shorted will not be zero.

If the standing wave on the line is sine wave, the *measured* standing wave will be sine wave, providing the r-f voltmeter is *linear*.

If the rectifier in the r-f voltmeter is not linear, the measured standing wave will not be sine wave, but will appear as shown.



By turning one of the half-cycles down, as shown in dotted lines, it will be seen that the standing wave, as measured with a non-linear detector, is far from being a sine wave.

It will be noted that with a non-linear detector, the voltage min. points are not as "sharp" as indicated in the preceding illustration, which shows a standing wave measured with a linear detector.

The graph on page 24 shows how a non-linear detector introduces distortion in measuring a sine wave standing wave.

This non-linearity causes error in measuring standing wave ratios. In some applications of the slotted line, as for example when adjusting an antenna to "match" the line, this error may be ignored.

In other applications where it is necessary to determine the standing wave ratio accurately, correction can be determined in this way:

1. Plot the standing wave as measured with *the particular detector* at the *desired frequency*, with the line open or shorted, and with the generator output adjusted for exactly full-scale deflection at the max. voltage points.
2. Construct a sine wave (half-cycle) on top of the measured standing wave, with zero and max. points coinciding as shown in the graph on page 24. The sine wave indicates the current that would flow if the detector were linear.

Assume that a particular load produces a standing wave with a measured ratio of

$$\frac{\text{VOLTAGE MIN.}}{\text{VOLTAGE MAX.}} = \frac{0.21}{0.6} = 0.35$$

Reference to the curve shows that the value of 0.21 on the *measured* curve corresponds to 0.39 on the sine wave curve.

Also the value of 0.6 on the measured curve corresponds to 0.71 on the sine wave curve. The corrected standing wave ratio is therefore

$$\frac{0.39}{0.71} = 0.55 \text{ (instead of 0.35).}$$

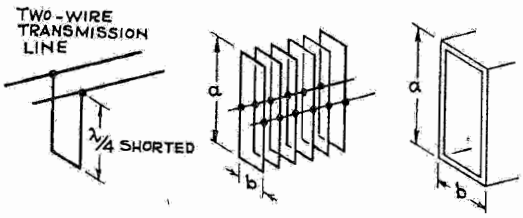
Wave Guides

A wave guide is a simple hollow metal tube having no central conductor. The losses are relatively low, since they will be produced mainly by the "inner skin" of the tube (which is of large perimeter and hence gives low loss). The *inner surface* should be clean and smooth. The *outer surface* can be grounded at any point since the r-f penetrates only a thin skin of the inner surface. *Sharp bends* are usually avoided, and all bends and twists are arranged to prevent a change in "mode" of propagation, or reflections. Instead of a hollow metal guide, a *solid dielectric* may be used as a wave guide. The action in this case is comparable to light waves traveling inside a *lucite rod.* In general, the loss in a solid dielectric wave guide is greater than in a hollow wave guide.

A wave guide cannot be conveniently treated like an ordinary transmission line. Wave guides must be approached from the viewpoint of an electromagnetic wave in a dielectric, using the same basis of treatment as that of radiation.

Wave guides may be rectangular, round, or oval. At the present time, rectangular wave guides are most simple and common; this discussion will refer to rectangular wave guides for the most part, but much of this information can be extended to guides of other shapes.

The following development of a simple type wave guide is intended to serve as a means of bridging the gap between transmission lines and wave guides, although they operate on different principles.

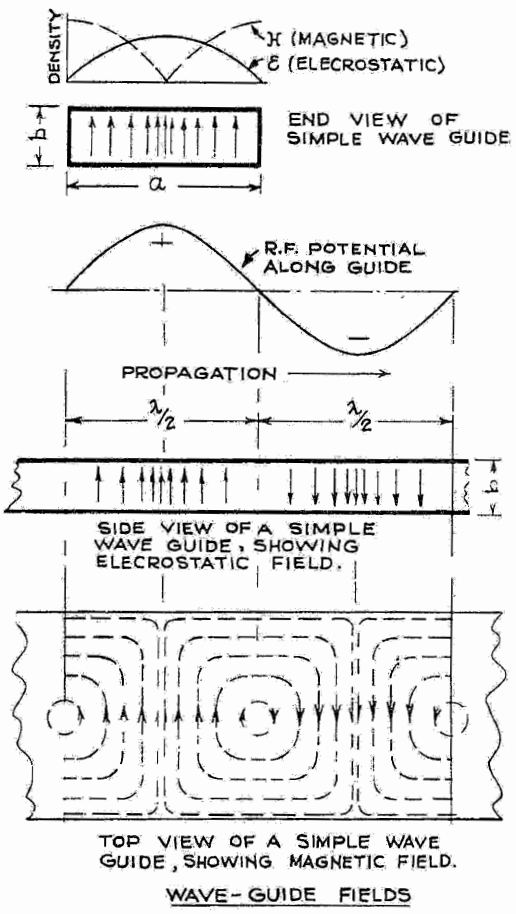


Above at left is shown a section of two wire transmission line. A quarter-wave resonant stub has been added across the line. The ends of the stub where connected to the transmission line, will represent a high impedance—many times higher than the impedance of any practical two wire transmission line. As a result the stub will have a negligible effect.

Suppose an infinite number of quarter-wave shorted stubs are added, resulting in a continuous pipe of rectangular cross section, or one type of wave guide. See illustration above.

"a"—Has a minimum dimension of half a wavelength (in order to propagate a signal) but it may be greater. The "cut-off" frequency depends on dimension "a".

"b"—Is not critical except for voltage breakdown or the possibility of operation in a wrong "mode".



WAVE-GUIDE FIELDS

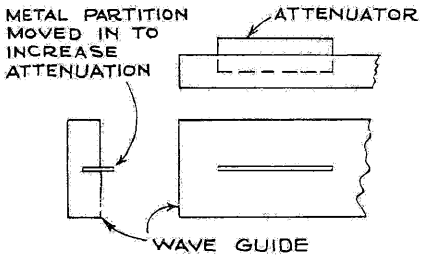
For a simple rectangular wave-guide, the electrostatic lines of force and density of distribution of the E & H fields are shown in the illustration. The electro-magnetic lines of force may be thought of as "whirlpools" in a plane, perpendicular to the electro-static lines of force, traveling down the tube in the direction of propagation. A rectangular wave guide will transmit satisfactorily if the component of the electric field tangent to the side surface is zero at every point on the surface.

A two-wire and a co-axial transmission line are shown with the magnetic and electrostatic fields indicated. A transmission line may be thought of as a guide for magnetic and electrostatic fields.

7. For some purposes, usually test, a wave guide may be matched to air by increasing the internal cross section of the guide slightly at the "air" end; normally an r-f choke, as shown above, is also used.

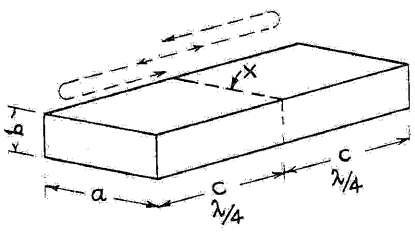
   The end of the wave guide may also be flared outward (increasing the cross section) and used for radiation.

8. A wave-guide attenuator may consist of a movable metal partition as shown below; the attenuation increasing as the partition is moved in.



9. Standing-wave ratios are checked in a manner similar to that used for a co-axial line. A section of wave guide with a narrow slot parallel to the axis of the wave guide (located in the maximum of the electro-static field) is used. A probe with a "crystal detector" or an instrument fuse (1/200A heated to almost the blowing point by d-c) is used to detect the presence of standing waves, as with a slotted co-axial measuring line. Due to the much higher frequency, measurements are considerably more delicate.

10. A section of wave guide may be used as a tuned circuit or as a transformer. In the accompanying illustration, if r-f energy is introduced at "X," reflection will occur at the closed ends. If dimension "C" is correct, the r-f voltage will be reinforced at "X." In this example "C" is a quarter of a (guide) wavelength, however other lengths may be used as long as the reflected voltage arrives back at "X" in phase with the r-f source.

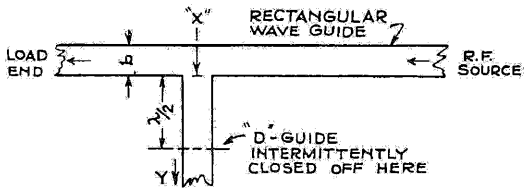


   The resonant effect is due to reflections (from the closed ends) setting up standing waves in the guide. The action is similar to that of a "cavity resonator."

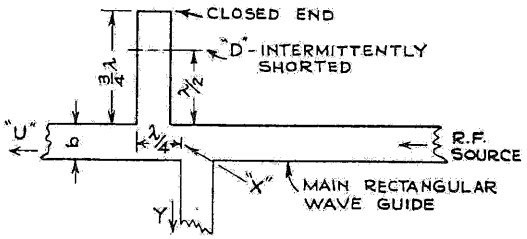
   The r-f energy may be introduced inductively, capacitively, or by radiation. Output may be obtained in a similar manner.

11. Sections of open and closed wave guides may be used in switching circuits, etc. In the following examples where a quarter or three-quarters wavelength is indicated, any odd multiple of a quarter wavelength may be used. Where a half wavelength is indicated, any multiple of a half wavelength may be used. (Electrical wavelength in the guide is referred to, not physical length).

   In the illustration below an intermittent short at "D" (mechanical or by means of a special tube) is used. A short at "D" will result in effectively a "solid wall" looking in at point "X" when "D" is shorted.



   In the following illustration an intermittent short at "D" (mechanical or by means of a special tube) is used.



   When "D" is shorted, effectively a "solid wall" will result at the junction of the closed stub to the main wave guide. Paths "Y" and "U" may receive energy.

   When "D" is not shorted, effectively a "solid wall" will result looking in at point "X" which is two half waves (a full wave) from the closed end. There will be no transmission in the direction "U" but there will be transmission in direction "Y."

12. A typical wave guide in practical use now, which happened to be a standard size of rectangular tubing:

   Width—about 1.5% greater than a half wavelength (about as small as can be used).

   Thickness—about 44% of the width.

   Wavelength—about 40% longer than in air (standing-wave measurement).

   Loss—about 1/10 db per meter correctly matched).

   Standing Wave Ratio—of as high as 3 to 1 may be tolerated.

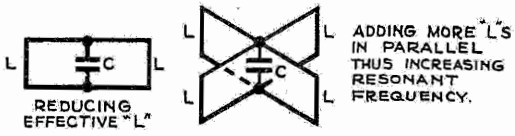
Cavity Resonators

Cavity resonators are tuned resonant circuits for extremely high frequencies where it becomes impossible or impractical to use tuned lines or lumped circuits.

No unique definition of L, C and R can be found in a cavity resonator. A cavity resonator is similar to a wave guide in that electro-magnetic lines of force oscillate back and forth within the cavity in some particular mode, depending upon the shape and method of excitation of the cavity.

UHF cavity resonators may be compared to conventional acoustic resonators. An example is the boomy sound in a room with smooth hard surfaces (good acoustic reflectors). Sound from a source will be reflected from wall to wall with only slight absorption of energy at each reflection. If the frequency of the sound is such as to produce standing waves between two surfaces, or combination of surfaces, the sound is reinforced. The resonant frequency depends on the room dimensions. The "Q" depends on the reflectivity of the walls and other losses.

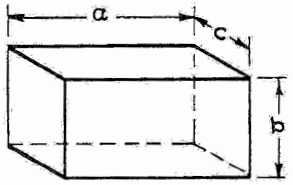
Developing a Simple Resonant Cavity



If it is desired to increase the resonant frequency, we can parallel the inductances "L," thus making the equivalent "L" quite small. There are limits as to how small "C" may be made practically, so the only thing left to do is to decrease the effective "L" of the circuit in order to tune to a higher frequency. See diagram at right.

As shown at the right above, more and more inductive stubs may be added, thus decreasing the effective "L" and increasing the resonant frequency. If this is carried on to the extreme, a closed chamber or resonant cavity results. (Strictly speaking, it is not proper to talk of the inductance of a cavity resonator.)

Modes of Operation of Cavity Resonators



Consider a rectangular section. The description of the "Mode" would be given in terms of electromagnetic fields and various frequencies. Various frequencies of oscillation (different modes) are possible, because wave energy may be propagated and reflected from various surfaces. There is also the possibility of an oscillation that is a harmonic of the basic wave. Two important points in cavity resonators are (1) how oscillations are forced and (2) how energy is removed. They will effect the mode of operation.

The r-f energy may be introduced to or removed from the resonant cavity, inductively, capacitively, or by radiation.

The energy is in the electrostatic field at one instant and in the magnetic field an instant later, oscillating from one field to the other at the frequency of the applied energy.

In referring to cavity resonators the idea that a conductor is always an "equipotential surface" is untrue; voltages and currents reverse themselves in a space measured in centimeters. An *electrostatic field* can terminate only on electrical charge, hence there must be appropriate distribution of charge on the surface. A *magnetic field* can cease suddenly only on a surface carrying current, hence there must be current flowing in the inside surface of the resonator (only penetrates a very thin skin of the metal surface and cannot be detected on the outside of the resonator).

A general statement, for simple resonators, can be made that it is necessary to have a dimension of an electrical half wave or multiples of a half wave since the electrostatic field is a maximum at the center and minimum at the sides of a simple resonator, otherwise the electrostatic field would be shorted out. (Refer to the data covering a section of wave guide used as a tuned circuit.)

Position of Standing Waves for Various Loads

With the load *short circuited,* any convenient point of *minimum voltage* on the slotted line may be used as the *"reference point."*

To determine KX° by the position of voltage maximum, place the scale so 0° is at a reference point, as shown at top of following chart.

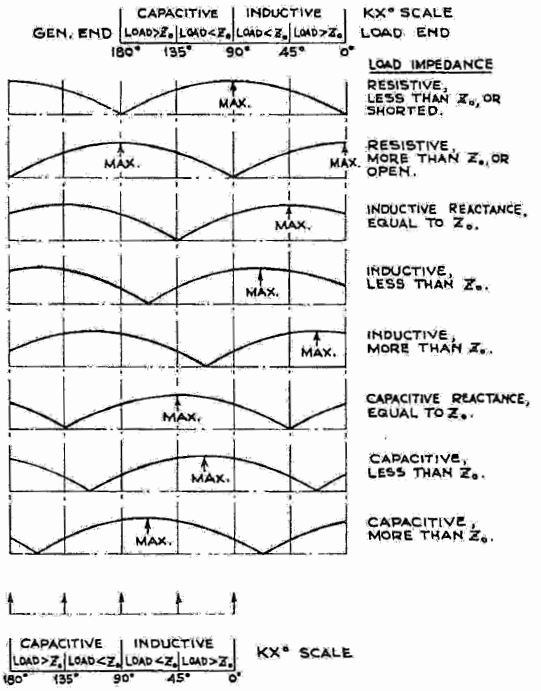
To determine KX° by the position of voltage minimum, place the scale so 90° is at a reference point, as shown at bottom.

The answer is the same in either case.

Owing to the "sharper" indication, it is generally preferable to use a minimum voltage point to determine KX°. However, when using a relatively low frequency, a half-wavelength may be longer than the slotted line and the minimum voltage points may fall beyond the ends of the slotted line. In such cases, it is possible to use a maximum voltage point in determining KX°.

The procedure is to short circuit the load and locate the minimum voltage point nearest the load end of the slotted line. Use this as the "reference point." (If the minimum voltage reference point is not close to the load end of the slotted line, change the length of the transmission line so that the minimum voltage reference point is near the load end of the slotted line. Place the prepared scale (shown in previous sketch) so that the *zero-degree mark is at the reference point.*

Remove the short-circuit and locate the first maximum voltage point from the reference mark (on generator side of reference mark). The reading on the degree scale at this maximum voltage point is KX°.



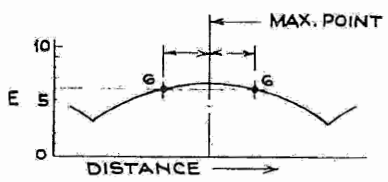
Load Connected Directly at End of Slotted Line

In some applications, the load is connected directly to the end of the slotted line, without using a transmission line. In this case the question of using the minimum or maximum voltage point in determining KX° again depends on the required operating frequency and the length of the slotted line.

With relatively high frequencies, use the first procedure (in which a voltage minimum is used in determining KX°).

With relatively low frequencies, use the point where the load is connected to the slotted line as the "reference point." Place the scale so the zero degree mark is at this reference point. The first maximum voltage point, from the reference point, is KX°.

Note on Obtaining Maximum Voltage Point



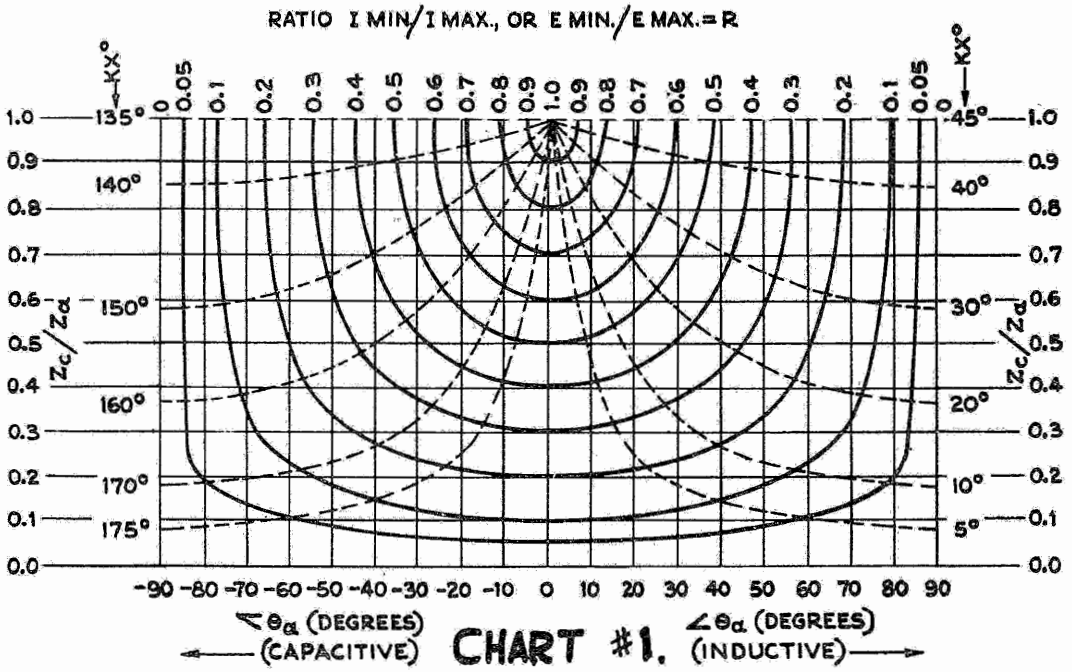
As an aid in obtaining accurate location of maximum voltage points, it is suggested that two voltage points of equal magnitude be selected, one on each side of the maximum point, then choose the distance half way between these two points as the maximum point. This same system may be used to determine the location of *minimum* voltage points.

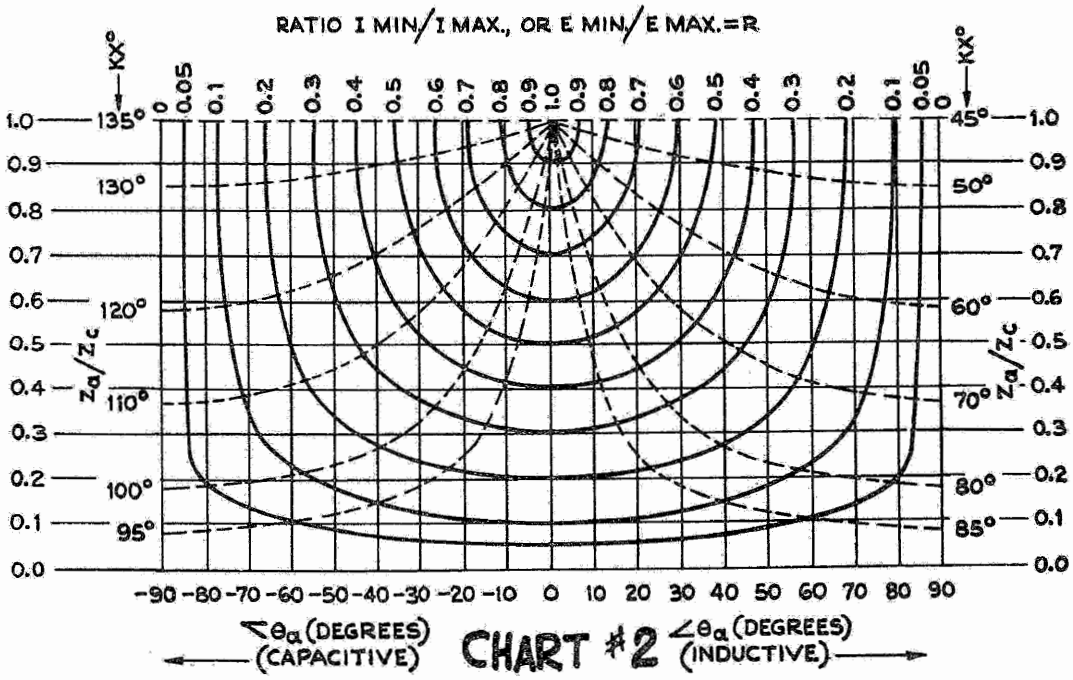
Charts for Use with Slotted Line

Z_c = CHARACTERISTIC IMPEDANCE (SURGE IMP.) OF CONCENTRIC TRANSMISSION LINE OR PARALLEL WIRE LINE.

Z_a = MAGNITUDE OF LOAD IMPEDANCE (TERM IMP.) AT END OF TRANSMISSION LINE

θ_a = ANGLE OF LOAD IMPEDANCE





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Charts for Use with Slotted Line

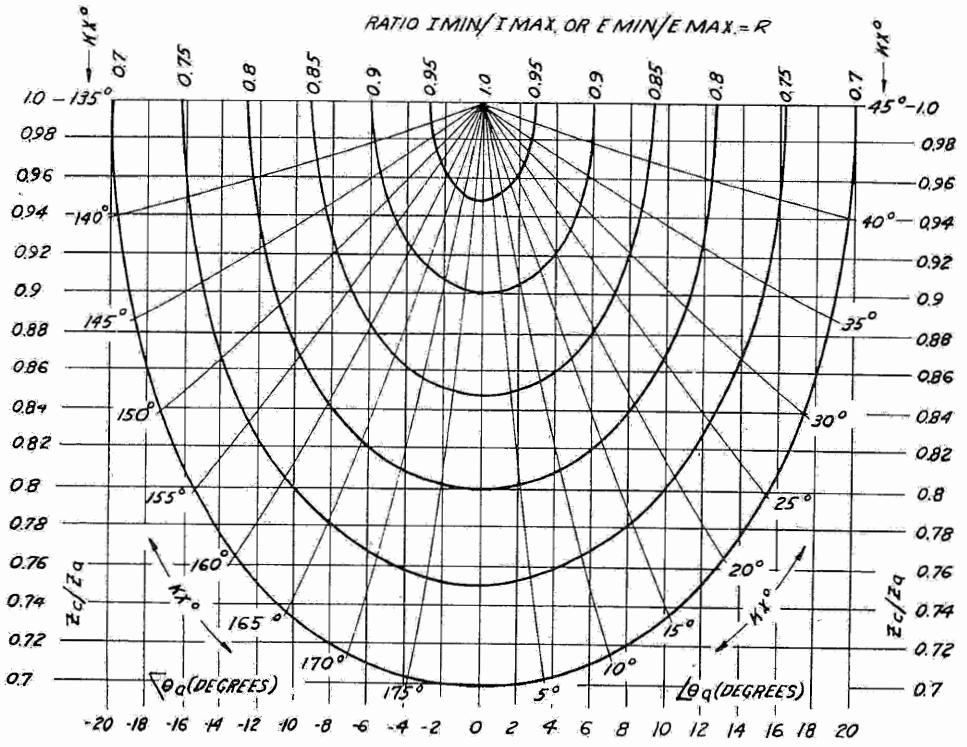


CHART Nº 3 - ENLARGEMENT OF PART OF CHART Nº 1

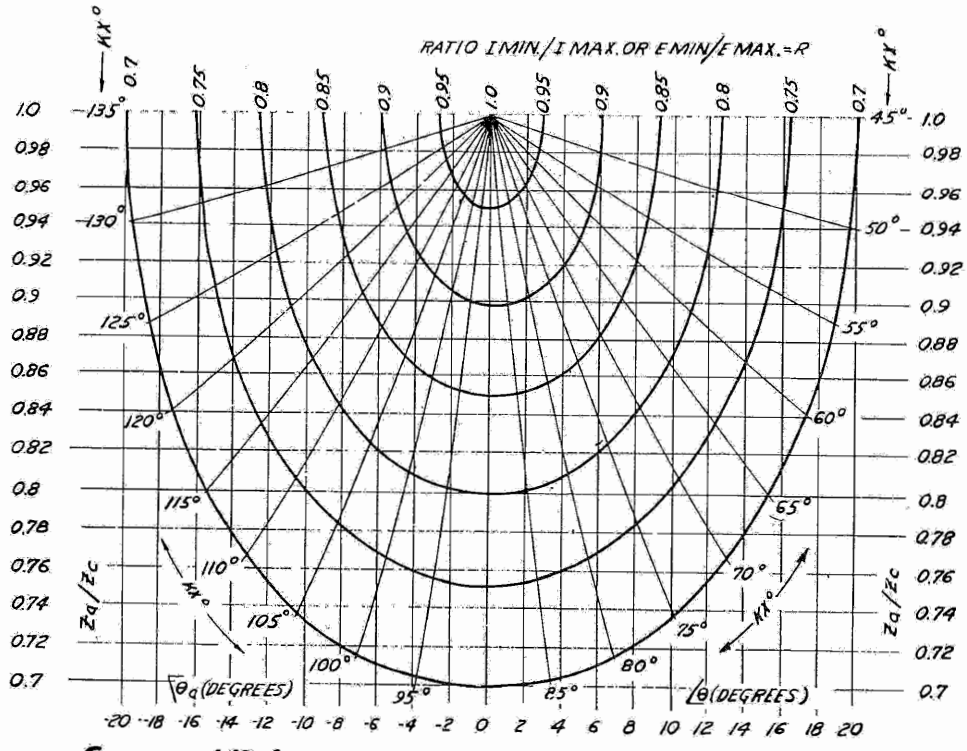
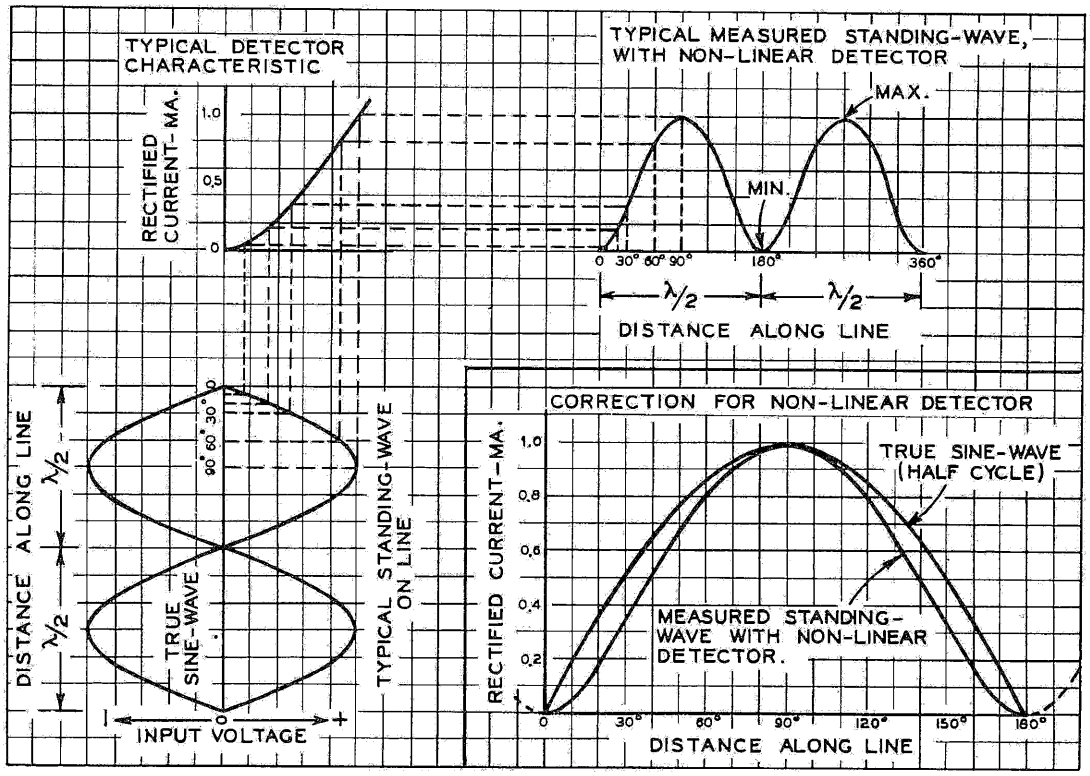
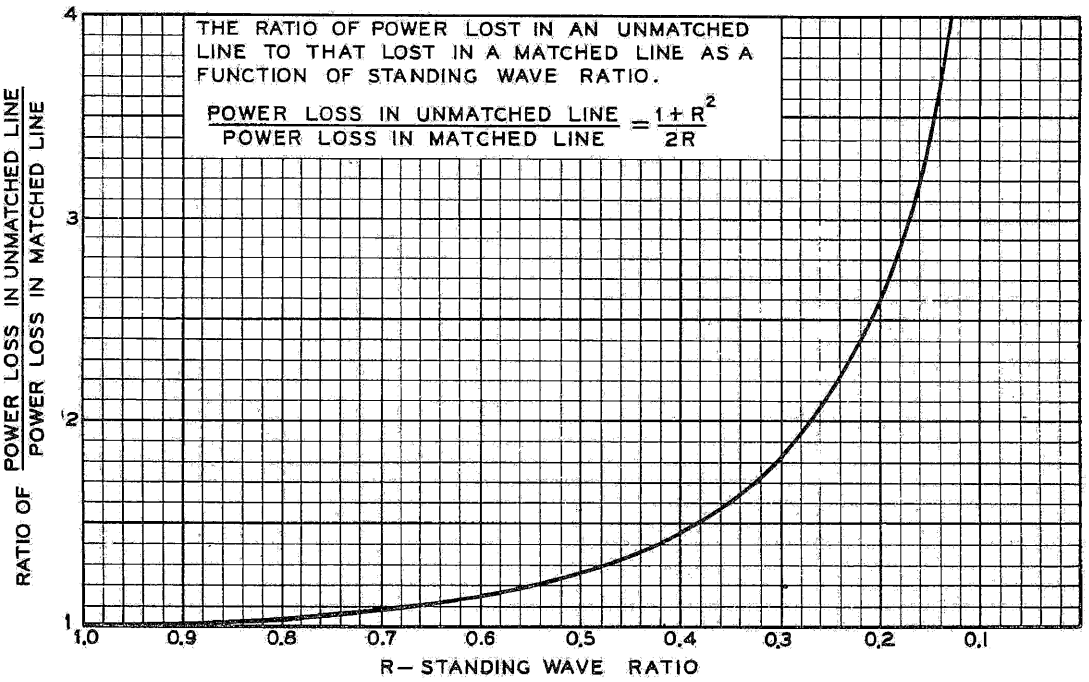


CHART Nº 4 - ENLARGEMENT OF PART OF CHART Nº 2

Effect of Non-Linear Detector



Ratio of Power Loss in Unmatched Line



Abridgement of Design Data for Beaded Coaxial Lines

By C. R. Cox

Andrew Company, Chicago, Illinois

Reprinted Through Courtesy of Electronics

Beaded Coaxial Lines are sometimes called air-dielectric lines, because most of the space between the two conductors is occupied by air or some other gas.

Beaded lines, utilizing conductors made of rigid or semiflexible copper tubing, have long been used in broadcast, police, and other transmitting installations, and now are being installed in hundreds of new f-m and television stations.

Compared to solid-dielectric cables, beaded lines offer the advantages of higher transmission efficiency, particularly at uhf and vhf, and higher power-carrying capacity. They also, have superior resistance to heat. However, lack of flexibility and the inconvenience of having to maintain an internal gas pressure combine to make the beaded line undesirable in portable equipment.

CHARACTERISTIC IMPEDANCE OF BEADED LINES

In a beaded line, the regularly spaced inner-conductor supports introduce reflections whose effects depend on insulator spacing and frequency, and on the size, shape, and electrical characteristics of the insulators. When the bead spacing is small compared to a wavelength, it is a simple matter to calculate an average capacitance per unit length and an average characteristic impedance and thus reduce the analysis to that of a uniform transmission line. As the bead spacing approaches a quarter wave, however, the recurrent discontinuities due to insulators cannot be averaged uniformly in respect to length, and a more involved analysis is necessary.

Characteristic impedance is normally defined as the impedance looking into an infinite length of line. In a beaded line, the characteristic impedance is defined only at the midpoints between insulators. At all other points, the characteristic impedance includes a reactive component. The impedance may be calculated from Eq. 1 below, provided the proper interpretation is given to k, the average dielectric constant.

$$Z_0 = 138\, k^{-1/2} \log_{10} (b/a) \qquad (1)$$

When the bead spacing is less than 2 percent of a wavelength, the factor k may be determined from

$$k = [W\,(K-1) + 12]/12 \qquad (2)$$

OPTIMUM IMPEDANCE VALUES

Any choice of a standard characteristic impedance must be a compromise between mechanical convenience, attenuation, power-handling capacity (flashover), and temperature rise. The relation between these factors and the diameter ratio is shown in Fig. 1. The curves suggest the following

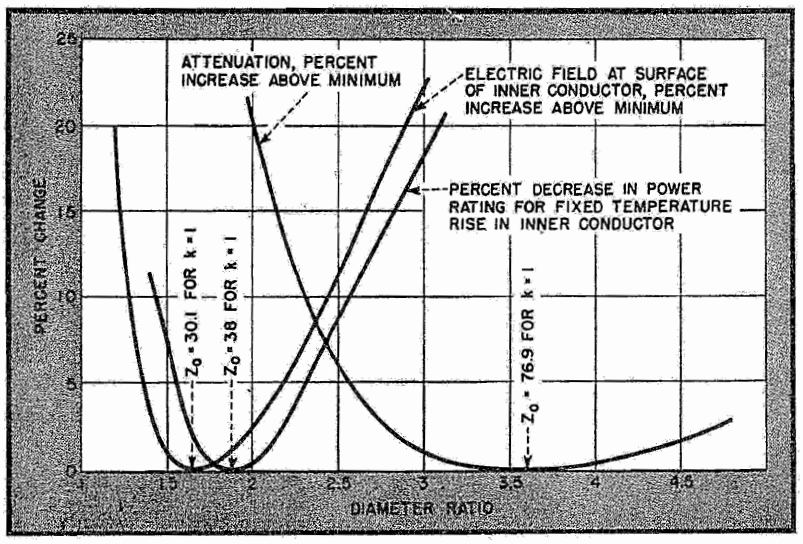


FIG. 1—Effect of diameter ratio b/a (which determines characteristic impedance as set forth in Eq. 1) on attenuation and on power-handling capacity as limited by flashover and by temperature rise. (Temperature-rise curve calculated from data compiled by H. P. Thomas of the General Electric Co.)

optimum impedances: for maximum power-handling capacity as limited by flashover, 30 ohms; for maximum power-handling capacity as limited by temperature rise of inner conductor, 38 ohms; for maximum transmission efficiency, 77 ohms.

In practice it has become common to use 70-ohm cables in standard broadcasting and 51.5-ohm cables in f-m and television broadcasting. These two impedances are also standard for solid-dielectric lines, and hence it is possible to connect rigid and solid-dielectric lines together without matching sections.

Tolerances on characteristic impedance in standard a-m broadcasting, where the lines are sometimes short and standing waves are frequently ignored, are not as important as in television where requirements are severe, and a 10 percent standing wave is thought to be the maximum allowable for proper system performance. Since variations in antenna impedance over the television channel may account for most of the 10 percent, it is thought desirable to hold the characteristic impedance of the line to within plus or minus 2 percent.

The effect on characteristic impedance of variations in conductor dimensions and dielectric constant of the insulating material may be determined by differentiating Eq. 1 and 2 above, treating the differentials as increments.

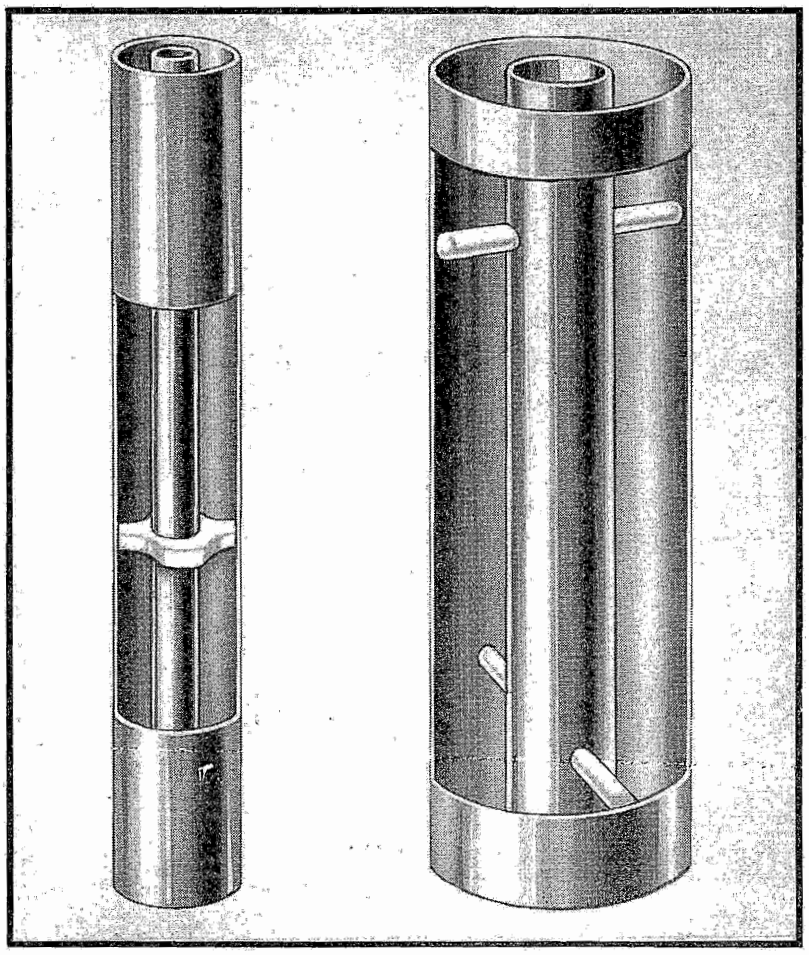
$$\Delta Z = \frac{60\,\Delta b}{\sqrt{k}\,b} \tag{3}$$

$$\Delta Z = -\frac{60\,\Delta a}{\sqrt{k}\,a} \tag{4}$$

$$\Delta Z = -\frac{W Z_0 \Delta K}{24\,k} \tag{5}$$

INSULATOR SPACING

Two contradictory requirements influence the determination of insulator spacing. Close spacings are desirable for constant impedance and to make the line as uniform as possible. Large spacings are desirable to minimize insulator loss. The practical solution to this dilemma has been to keep insulation loss down by making the insulators as small as possible consistent with mechanical strength. The spac-



Cutaway views of coaxial cable with centering bead (left) and large-diameter line employing cross-pin construction

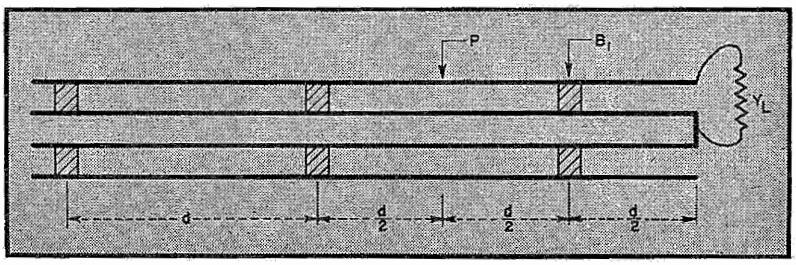


FIG. 2—Beaded coaxial transmission line terminated by an admittance

ing is then selected so that the impedance at the highest operating frequency differs from the low-frequency value by not more than 2 or 3 percent. This principle has led to spacings of 12 inches in lines used for f-m and television, at frequencies from 44 to 216 mc. At standard broadcast frequencies insulator spacing is not as important, and may be determined from mechanical considerations alone.

A mathematical expression for the impedance of a beaded line, in which insulators are spaced 2 percent or more of a wavelength apart, is easy to formulate but difficult to solve rigorously. To begin, it is convenient to write the familar impedance transformation equation in terms of admittance

$$Y = Y_c\left[\frac{Y_L \cos \beta l + jY_c \sin \beta l}{Y_c \cos \beta l + jY_L \sin \beta l}\right] \qquad (6)$$

In the above, Y_c is the characteristic admittance of the line without any bead effect. The problem is illustrated in Fig 2, in which Y_L is an arbitrary load admittance. The characteristic admittance of the line with beads is, by definition, that value of Y_L which appears unmodified at point P after transformation by two sections of line of length $d/2$ with the capacitance due to a bead connected across their junction (at point B_1).

GRAPHICAL SOLUTION

The admittance at B_1 is the admittance of the bead ($Y_B = jwC$) plus the admittance due to Y_L after transformation by $d/2$, as in Eq. 7 (Table I). The admittance at point P is then given by Eq. 8, and the characteristic admittance Y_o of the line with beads is obtained by inserting the value of Y_1 from Eq. 7 into Eq. 8 as is done in Eq. 9. Since Y_o must be a pure conductance, the desired solution is that value of $Y_L = Y_o$ which causes the reactive term on the right-hand side of Eq. 9 to vanish. The characteristic impedance is then

$$Z_0 = 1/Y_0 \qquad (10)$$

By using the Smith transmission line chart[1] a graphical solution of Eq. 9 is possible. Figure 3 shows a center section of the chart, on which have been drawn several lines corresponding to steps in the solution. The following example is illustrated:

Outer conductor 3.125 OD x 3.027 ID
Inner conductor 1.200 OD x 1.130 ID
Width of ceramic bead 0.375 inches

The characteristic impedance and admittance, omitting bead effect, are calculated from Eq. 1,

Table I—Design Equations for Beaded Coaxial Line

$$Y_1 = Y_B + Y_c\left[\frac{Y_L \cos\frac{\pi d}{\lambda} + j\,Y_c \sin\frac{\pi d}{\lambda}}{Y_c \cos\frac{\pi d}{\lambda} + j\,Y_L \sin\frac{\pi d}{\lambda}}\right] \qquad (7)$$

$$Y_P = Y_c\left[\frac{Y_1 \cos\frac{\pi d}{\lambda} + j\,Y_c \sin\frac{\pi d}{\lambda}}{Y_c \cos \qquad Y_1 \sin\frac{\pi d}{\lambda}}\right] \qquad (8)$$

$$Y_P = c\left\{\frac{\left[Y_B + Y_c\left(\frac{Y_L \cos\frac{\pi d}{\lambda} + j\,Y_c \sin\frac{\pi d}{\lambda}}{Y_c \cos\frac{\pi d}{\lambda} + j\,Y_L \sin\frac{\pi d}{\lambda}}\right)\right]\cos\frac{\pi d}{\lambda} + j\,Y_c \sin\frac{\pi d}{\lambda}}{Y_c \cos\frac{\pi d}{\lambda} + j\left[Y_B + Y_c\left(\frac{Y_L \cos\frac{\pi d}{\lambda} + j\,Y_c \sin\frac{\pi d}{\lambda}}{Y_c \cos\frac{\pi d}{\lambda} + j\,Y_L \sin\frac{\pi d}{\lambda}}\right)\right]\sin\frac{\pi d}{\lambda}}\right\} \qquad (9)$$

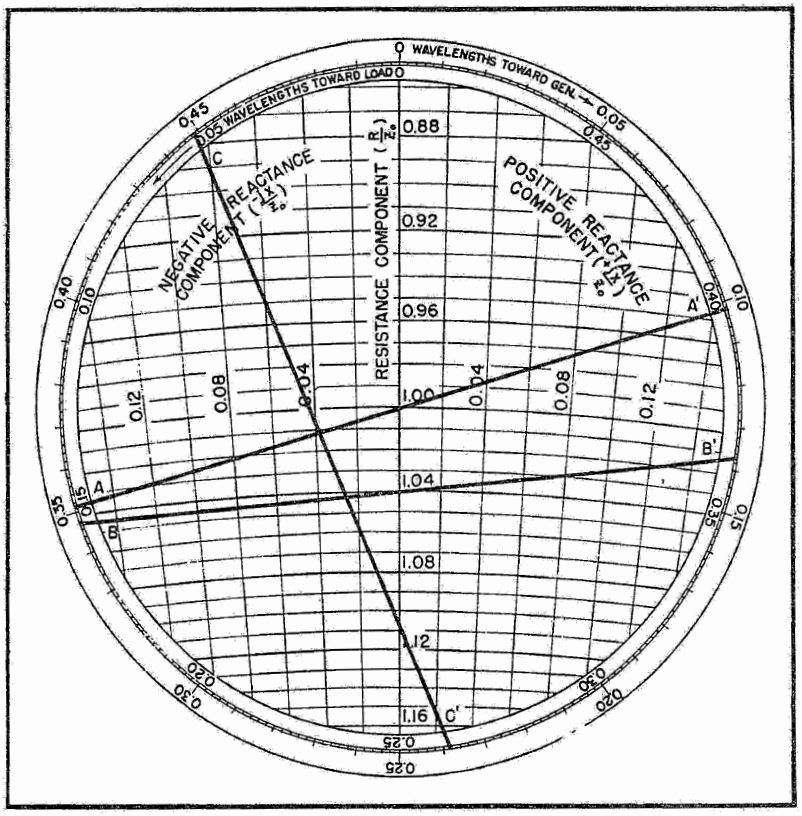


FIG. 3—Use of inner portion of Smith transmission line chart to obtain a graphical solution of Eq. 9, for determining the characteristic impedance and admittance of a beaded coaxial line at 200 mc for the example set forth in the text

using $k=1$, $b = 3.027$, and $a = 1.2$, as $Z_c = 55.5$ ohms and $Y_c = 0.018$ mho. The added capacitance due to the addition of a bead of dielectric constant $K = 6.0$ is calculated from electrostatics to be 2.86 micromicrofarads. Bead susceptance Y_B corresponding to this capacitance is then calculated and normalized by dividing by $Y_C = 0.018$, giving the following susceptance and half-bead spacing ($d/2\lambda$) values for three frequencies

Freq	50 mc	100 mc	200 mc
Y_B	$j0.000898$	$j0.001796$	$j0.003592$
Y_B/Y_C	$j0.0499$	$j0.0998$	$j0.1996$
$d/2\lambda$	0.0254	0.0508	0.1016

Since any acceptable value of Y_L/Y_C must be a pure conductance, all possible values of this quantity lie on the vertical axis of the chart. Looking into the line at the first bead, however, the admittance values on the vertical axis appear to be rotated through an angle $d/2\lambda = 0.1016$ (at 200 mc), so that all possible solutions now lie on the line AA'. To all points on AA' we must now add the normalized susceptance Y_B/Y_C of the first bead, just as in Eq. 7. Line BB' represents the sum of these two admittances, and corresponds to Y_1 in Eq. 7. To transform the admittance Y_1 into the admittance Y_P at P, the ends of BB' are rotated through an angle $d/2\lambda = 0.1016$ forming a new line CC'. The intersection of CC' with the vertical axis at the point $Y_P/Y_C = 1.106$ corresponds to the value of Y_L which causes the reactive term in the right-hand side of Eq. 9 to vanish. Multiplying this solution by $Y_C = 0.018$ and inverting, we get an impedance of 50.2 ohms. Similar procedures give impedances of 51.4 ohms for 100 mc and 51.5 ohms for 50 mc.

It is also possible to determine characteristic impedance by assuming open and short-circuit conditions at the end of the line and calculating back to the midpoint between beads, using Eq. 6 a total of four times. This method is less tedious than solving Eq. 9, but is not as rapid as the graphical solution.

INSULATOR MATERIALS

Steatite is commonly used for insulator beads because of its excellent electrical and mechanical properties. Various grades are available, the less expensive grades being entirely suitable for use at standard broadcast frequencies where insulation loss is an insignificant part of the total loss. Comparative efficiencies of 3-1/8-inch diameter, 500-foot lines with bead spacing of 12 inches an $Z_o = 51.5$ ohms are given below for two insulator materials (Alsimag 196 is the cheaper, and use of the more expensive Teflon is justifiable only at uhf)

Material	Loss factor	Eff at 1 mc	Eff at 200 mc
Alsimag 196	0.012	98.8%	67.8%
Teflon (Poly F-1114)	0.0004	98.8%	82.5%

Because creepage distances are small, steatite line insulators must be impregnated to prevent surface moisture films due to condensation. Waxes were used for this purpose until the recent appearance of water-repellent low-volatility silicone fluids. Insulators treated with these solutions maintain a high surface resistivity even in a moist atmosphere, and the impregnant is not volatilized when heated (as in soldering). Surface glazing is occasionally used on large cable beads, but only because of the ease of cleaning which a glazed surface affords. Glazing is expensive, and offers no measurable improvement in surface resistivity.

A few thermoplastic materials have been successfully used for insulators in radar cables. Although some of these plastics, notably Polystyrene, Polyethylene, and Teflon, display superior electrical properties, there are still mechanical difficulties to overcome.

INSULATOR SHAPES

A few commonly used insulator shapes are illustrated in Fig. 4. For low-loss uhf operation (30-300 mc) it is desirable to minimize the discontinuities introduced by inner conductor supports so that insulators may be kept far apart. Discontinuities are minimized in the first four bead shapes by reducing the volume of dielectric material as much as possible. The scheme shown in Fig. 4A is good electrically because excess dielectric material has been removed from the region around the inner conductor where the electric field, and hence the capacitance per unit volume, is greatest. Temperature rise due to insulator loss is also greatest in this region; consequently, mechanical fracture due to large temperature gradients is less likely with the configuration of Fig. 4A.

The cross-pin construction in Fig. 4D is useful principally in large-diameter lines. In Fig. 4E the sides of the bead have been made concave to increase the flashover rating of the cable. This design is used at broadcast frequencies, and is just the opposite of what is needed for low-loss constant-impedance operation at ultrahigh frequencies.

THEORETICAL ATTENUATION

Attenuation is defined as the loss in decibels per hundred feet at a specified frequency and at a temperature of 25 degrees centigrade. Both conductor loss and insulation loss contribute to attenuation, and these terms may be computed separately and added together to obtain total attenuation. In terms of resistance R in ohms per foot and conductance G in mhos per foot, the attenuation is

$$\text{db per 100 ft} = 434\left(\frac{R}{Z_0} + G Z_0\right) \qquad (11)$$

For radio frequencies Russell's expression[2] for resistance R may be used, so that the conductor loss only becomes

$$\text{db per 100 ft} = \frac{0.432 f^{1/2}(a+b)}{a\, b\, Z_0} \qquad (12)$$

Equation 12 assumes that both inner and outer conductors are made of chemically pure copper, which although commercially available is quite expensive. Ordinary conductor copper has a conductivity of 95 percent. When this is used, Eq. 12 becomes

$$\text{db per 100 ft} = \frac{0.443 f^{1/2}(a+b)}{a\, b\, Z_0} \qquad (13)$$

The principal problem in determining insulator loss is that of evaluating the shunt conductance G. This quantity is the reciprocal of the parallel resistance R_P due to the imperfect dielectric in one foot of line. If we let R_S be the corresponding equivalent series resistance due to dielectric losses in one foot of line, and X be the reactance due to that portion of a single foot of line which is occupied by insulation, then

$$R_P = \frac{X^2}{R_S} = \frac{X^2}{X P_F} = \frac{X}{P_F} \qquad (14)$$

$$G = \frac{1}{R_P} = \frac{P_F}{X} = \frac{P_F\, 2\pi f \times 10^6\, K\, C\, W}{12} \qquad (15)$$

The insulation loss is obtained by inserting Eq. 15 into the second term of Eq. 11, letting

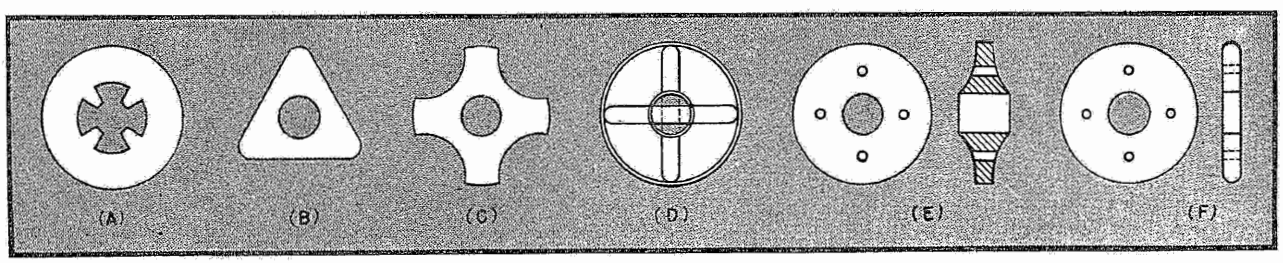


FIG. 4—Typical insulator shapes used in beaded coaxial transmission lines

L_F (loss factor) equal the product of dielectric constant K and power factor P_F, and using Eq. 1 for the characteristic impedance

$$\text{db per 100 ft} = 0.231\, k^{-1/2} L_F\, Wf \qquad (16)$$

By applying Eq. 2, Eq. 16 may be written in another form

$$\text{db per 100 ft} = \frac{2.77\, P_F f K (k-1)}{k^{1/2}(K-1)} \qquad (17)$$

For solid dielectric, $K = k$ and the insulation loss becomes $2.77\, P_F f K^{\frac{1}{2}}$.

ANALYSIS OF EQUATIONS

Several approximations have been made in deriving Eq. 16 and 17. In practical cases, however, it happens that for frequencies less than 200 mc the conditions under which the approximations become poor ones are those for which the insulation loss is a relatively small part of the total, so that no substantial error in the total attenuation is produced.

The importance of having good insulation in lines used at ultrahigh frequencies can be seen by comparing Eq. 16 and 13. Since insulation loss increases directly with frequency, while conductor loss increases only with the square root of frequency, the former term may easily account for a substantial part of the total attenuation at 200 or 300 mc. At 200 mc, for instance, in 500 feet of 3-1/8-inch coaxial line, the difference between a steatite bead costing 10 cents and one costing 31 cents is the difference between an efficiency of 77 percent and one of 68 percent. Also, while conductor loss is roughly inversely proportional to diameter, insulator loss is independent of diameter, provided the relative volume and distribution of insulating material remains the same for all diameters. This fact has imposed a limiting factor on the development of vhf solid dielectric cables, because no matter how large a diameter is used no improvement in insulation loss can be obtained.

MEASURED ATTENUATION

In a complete transmission line system, containing connectors and other cable fittings, the measured attenuation is usually slightly greater than that predicted by Eq. 13 and 16. To allow for this discrepancy, standard attenuation ratings have been made 10 percent greater than the theoretical values. Standard attenuation curves for the nominal 70-ohm cables used in the broadcast band are given in Fig. 5, and curves applying to the 51.5-ohm cables used for f-m and television equipment are given in Fig. 6. The latter curves are based on the use of copper having 95-percent conductivity and insulators with a dielectric constant of 6.0 and a maximum loss factor of 0.004 at 100 mc. A derating factor of 1.1 was applied to give the required 10-percent increase of attenuation above theoretical values. Efficiency may be obtained from attenuation by using the equation

$$\text{Eff} = \frac{100}{\text{antilog}\left(\dfrac{L \times \text{db per 100 ft}}{1{,}000}\right)} \qquad (18)$$

Transmission line loss is increased by standing waves, due to improper termination, and by elevated temperature. An enclosed line, operating at f-m or television frequencies with restricted air circulation and carrying the maximum rated power, may suffer a temperature rise of almost 40 C. Under these conditions, the insulation loss is increased approximately 50 percent and the conductor loss is increased approximately 13 percent. At standard broadcast frequencies (500-1500 kc) coaxial lines develop only negligible amounts of heat, so the attenuation ratings are approximately the same for maximum power as for low power.

Coaxial transmission lines are occasionally connected in parallel, to form an unbalanced line of half the original impedance, or in series, to form a balanced line of twice the original impedance. No improvement in attenuation is obtained from these special arrangements, and it is easily shown that the overall efficiency in either case is the same as it would be if only one line of the same diameter were used.

POWER-HANDLING CAPACITY

Maximum power ratings for coaxial lines used at frequencies above 50 mc have been calculated on a theoretical basis, using a temperature rise of 40 C in the outer conductor as a

Table II. Maximum Power Ratings of Coaxial Lines in Watts

Diam in inches	A-M	F-M			Television		
	0.5–50 mc	50 mc	100 mc	200 mc	50 mc	100 mc	200 mc
3/8	500	.....	.....	.....	.....	.....	.....
7/8	3,000	2,600	1,700	1,100	4,100	2,700	1,800
1 5/8	12,000	9,100	5,700	4,000	14,500	9,100	6,300
3 1/8	50,000	36,000	24,000	15,000	58,000	38,000	24,000
6 1/8	150,000	134,000	95,000	67,000	214,000	151,000	107,000

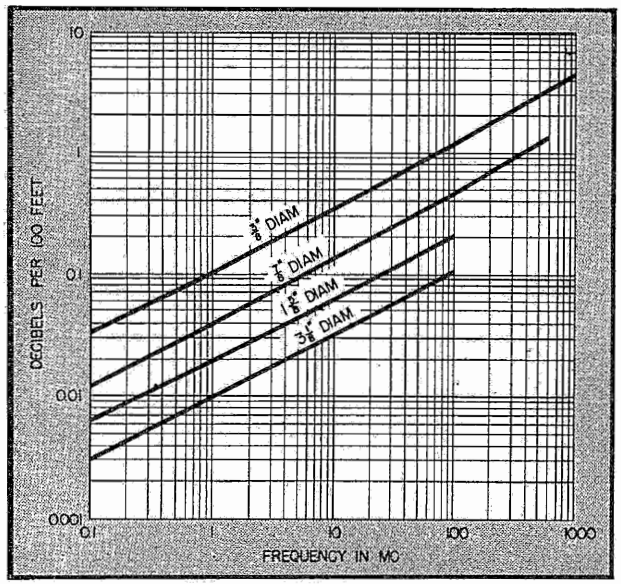


FIG. 5—Standard attenuation curves for nominal 70-ohm beaded coaxial cables used in broadcast-band work

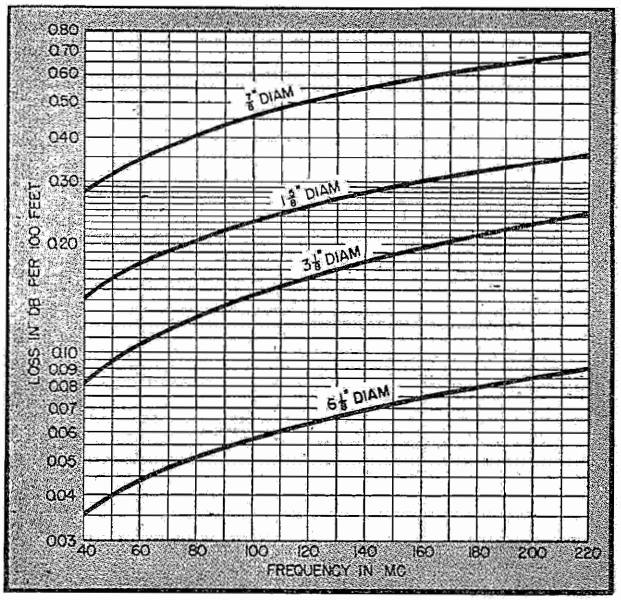


FIG. 6—Standard attenuation curves for 51.5-ohm beaded coaxial cables used with f-m and television equipment

limiting factor. At lower frequencies, voltage breakdown becomes a limitation, and ratings must be based on experience because breakdown usually occurs at lower voltages than theoretical considerations would indicate.

The following procedure is used to determine a power rating based on temperature rise:

(1) The efficiency of a length L (feet) is determined from attenuation figures in which copper loss has been increased 13 percent and insulation loss 50 percent.

(2) A power in watts which will produce a 40 C temperature rise in the outer conductor is calculated by multiplying the total surface area of the given length of conductor by the heat emissivity factor p and dividing the result by 1 - efficiency.

(3) A maximum power rating for unity standing wave is obtained by dividing the result of step 2 by a factor of 2.

(4) A maximum power rating for any standing wave ratio other than unity is obtained by dividing the result of step 3 by the proposed ratio. For ordinary a-m broadcasting, the ratio may be 2.0, for television it may be 1.1, and for f-m broadcasting it may be 1.75.

Suggested maximum power ratings for various services and frequencies are given in Table II. These are maximum ratings, based on temperature rise or flashover. Except when lines are very short, they should not be operated at maximum power because of attenuation.

In step 2, it is assumed that after equilibrium is attained all of the heat generated inside the line is delivered to the outer conductor, where it is radiated into space (the process involves both radiation and convection). The factor p is the heat emissivity of the surface of a copper tube, in watts per square inch for a 40 C temperature rise. This factor, which depends somewhat on diameter, has been studied by power transmission engineers who frequently use copper tubes for busses. An average value is 0.25 watt per square inch.

In step 3, a safety factor of 2 has been applied because tubes enclosed in buildings or ducts or placed against walls suffer a loss of heat emissivity.

The inner conductor operates at a much higher temperature than the outer conductor, and a rise of 75 C may occur for a 40 C rise in the outer conductor. The difference between inner and outer conductor temperatures causes differential expansion, which must be accommodated in suitable expansion joints. The insulators also generate heat (4.5 watts per insulator in a 3-1/8-inch line carrying 25,000 watts at 200 mc) and are further heated by thermal energy received from the inner conductor. Temperature gradients exist in the insulators, and can cause fracture if power ratings are exceeded.

Large-diameter lines are produced in hard-temper rigid lengths of 20 feet, which must be interconnected on the job by suitable couplings. Soft-temper coaxial cables of 3/8-inch and 7/8-inch diameter are produced in continuous 100-foot coils which may be factory-spliced to any

Symbols Used

Z_0 = characteristic impedance measured at midpoint between adjacent insulators
b = inside diameter of outer conductor in inches
a = outside diameter of inner conductor in inches
k = average dielectric constant
K = dielectric constant of insulating material ($K = 6.0$ for steatite)
W = effective width of insulating material in inches per foot of line
$\beta = 2\pi/\lambda$
$Y_0 = 1/Z_0$ = characteristic admittance measured at midpoint between adjacent insulators
$Y_C = 1/138 \log_{10}(b/a)$ = characteristic admittance of line without beads
R = conductor resistance (inner plus outer) in ohms per foot
G = shunt conductance due to imperfect insulators, in mhos per foot
f = frequency in mc
$R_p = 1/G$ = shunt resistance in one foot of line due to imperfect dielectric
$R_S = X^2/R_p$ = equivalent series resistance corresponding to R_p
$C = 7.35 \times 10^{-12}/\log_{10}(b/a)$=capacitance per foot without beads
P_f = power factor of dielectric material
$X = 1/2\pi fKC \times 0.0833W \times 10^6$ = reactance due to that portion of 1 foot of line which is occupied by insulation
$L_f = KP_f$ = loss factor of insulation
σ = heat emissivity in watts per square inch
L = length of line in feet

desired length and shipped under gas pressure with end terminals attached.

The method of attaching insulators to the inner conductor varies with diameter, but in general an attempt is made to perform the attachment without seriously degrading the flashover characteristic. Any small deformation of the inner conductor encourages concentration of charge, and sharp corners or edges on crimped or swaged inner conductors must be carefully avoided. In 1-5/8-inch diameter and larger cables, in which the inner conductors are tubular, a good fastening may be made by inserting a spinning tool inside the inner conductor and spinning a ridge on both sides of the bead.

Coaxial lines must be pressurized with a dry gas to prevent condensation of moisture on insulator surfaces. Air and nitrogen are both used for this purpose. There is nothing critical about the amount of pressure, and anything from 1 to 30 pounds is satisfactory.

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[2] Russell, Alexander, Effective Resistance and Inductance of Concentric Mains, *Philosophical Magazine*, 6th series, 17, p. 524. Apr. 1909.

THE MEASUREMENT OF AUDIO DISTORTION

By H. H. Scott, Hermon Hosmer Scott, Inc.

Any modification of an audio-frequency signal between the point where it reaches the microphone and the point where it is reproduced by a loudspeaker may be considered as "distortion". In general usage the term has, however, come to have a more restricted meaning--namely, the introduction of extra components into the signal which were not originally present. This article is concerned with this type of distortion, variously known as "non-linear," "amplitude" or "harmonic" distortion, which, however, may include the generation of components which are not necessarily harmonically related to the signal.

The simplest measurement of non-linear distortion is obtained by applying a single sine-wave signal to a transmission system and measuring the various components in the output of the system with a wave analyzer. At low levels in a good system over 99% of the output voltage will be at the applied fundamental frequency, but there will also exist a percent or less of distortion components corresponding, in this case, to exact multiples of the fundamental frequency. Of these components, known as harmonics, the second and third (corresponding to twice and three times the fundamental frequency, respectively) are generally the strongest, but higher-order harmonics may also be present at appreciable amplitudes. There will also exist in the output of the system other spurious components, consisting of the fundamental and harmonics of the power-supply frequency, various noise components resulting from tube hiss and other circuit disturbances, pickup from other circuits, and other extraneous components. Many of these can also be measured on an analyzer or other distortion-measuring device. As the signal level is increased until various parts of the system overload, harmonic distortion may rise to 5%, 10% or even higher values, which in most cases are distinctly noticeable, and which are annoying in real high-quality reproduction.

Conventional practice has been to measure non-linear distortion in terms of the harmonic components added to a single-frequency testtone by the system, and various limits have been set, depending upon the requirements of the problem. For instance, distortion as high as 10% is considered tolerable in a single-tube output amplifier stage by many designers of home-type sound-reproducing equipment, such as phonographs and radios. At the other extreme, we have the new FCC requirements for frequency-modulation systems, which specify a total distortion between the microphone terminals and the modulated signal as radiated by the antenna as low as 2.5% for an entire system, including many amplifiers, transmission lines or other studio-transmitter links, various control and amplifier equipment, and the transmitter itself.

In general, for systems of comparable design features which exhibit similar characteristics in regard to the generation of harmonics, a low level of harmonic distortion measured in this manner is an indication of excellence. For systems exhibiting different characteristics, however, and which overload in various manners, it has long been realized that the amount of distortion which is audible to the ear is not necessarily related exactly to the single-frequency harmonic measurements. This is particularly true in the case of home-type receivers or other sound-reproducing equipment which must be built to meet price competition. The reason for this lies in the fact that the distortion characteristics of a non-linear system are far more complicated than can be determined by a simple single-tone measurement.

For instance, if two tones (f_1 and f_2) are applied simultaneously to a non-linear system, the distortion products include not only the harmonics of those two tones but also frequencies equal to the sum and difference of the two tones ($f_1 + f_2$, $f_1 - f_2$) and higher-order intermodulation products (such as $f_1 + 2f_2$, $f_1 - 2f_2$, $2f_1 + f_2$, $2f_1 - f_2$, etc.) which theoretically may include beats between the fundamental and all of the possible harmonics of one tone and the fundamental and all possible harmonics of the other. It will be observed that it is only by accident that any of these so-called intermodulation components ever coincide with a harmonic of one of the original frequencies. Hence, this intermodulation distortion represents discordant components added to the signal. Since any musical instrument produces tones which contain harmonics as well as the fundamental frequency, it is obvious that a moderate increase in the harmonics themselves need not be annoying. However, the addition of discordant components is distinctly audible, and it is the presence of such intermodulation products which most people call distortion. In any practical system the intermodulation products may become serious under conditions where the actual addition of harmonics themselves is of little consequency. The picture is further complicated by the fact that non-linearity in the amplitude characteristics of a system, which accounts for the distortion, is often a function of frequency, particularly at the lower and higher ends of the frequency range. This is particularly true in systems involving transformers, speakers and other electro-mechanical transducers, tone control, and filter, push-pull or feedback circuits.

The amount of distortion, therefore, is a function not only of amplitude but also of frequency.

In a system producing serious distortion it is almost impossible to simulate by any reasonable measurements the actual results which will be obtained when a signal such as music from a large orchestra is impressed upon a system. With each of the thousands of components producing intermodulation with the others, the resulting jumbled noise as heard by the ear is, however, a good indication of what is happening. The problem of distortion measurements is, therefore, to provide the simplest type of measurement which can be correlated with distortion as heard by the ear.

For years the total rms value of the harmonics added to a single tone has been used as a measure of such distortion. Where the total distortion may be kept low and the system is designed in accordance with the best standards of engineering practice without the necessity to cut corners to save cost, this type of measurement is generally satisfactory. In the case of the FM transmitter, for instance, if the total distortion is below 2.5% it is not likely that any distortion which may occur will be sufficiently serious to be noticeable. Nevertheless, it is still not impossible. As the quality of the system decreases, it becomes more important to make additional measurements to determine whether or not serious intermodulation takes place. Until further information as a result of experience becomes available, however, it may be assumed that for equipment of the type used in high-quality broadcasting a measure of the single-tone harmonic distortion will generally suffice.

A common fallacy in making harmonic measurements has been to assume that harmonics above the range of hearing were of no importance since they could not be heard. It will be noted, however, that the new FCC requirements for FM specify harmonic measurements as high as 30,000 cycles, although admittedly, no one can hear such harmonics themselves. The reason for this is that the presence of such harmonics, whether they are heard or not, indicates that distortion is taking place, and the generation of such harmonics indicates the presence to an indeterminate degree, which may be serious, of intermodulation products which may fall within the range of hearing--in fact, within the range where the ear is most sensitive. Thus, these high-frequency harmonic measurements are specified rather than more elaborate intermodulation measurements in an attempt to assure that the intermodulation shall not be serious. For a system of fundamentally high quality and designed in accordance with best engineering practice, this is not an unreasonable assumption.

In terms of what the customer hears on his receiver, distortion measurements are probably the most important measurements to be made on a radio-transmitting system. The maintenance of low-distortion limits insures, in general, clear, natural reproduction of the signals, limited only by the capabilities of the receiving system.

FCC Requirements

The Federal Communications Commission in its Standards of Good Engineering Practice concerning FM Broadcast Stations, requires that the overall harmonic distortion at any modulating frequency between 50 and 15,000 cycles be within the following limits:

Modulating Frequency	Distortion
50 to 100 cycles	*3.5%*
100 to 7500 cycles	*2.5%*
7500 to 15,000 cycles	*3.0%*

Standard test frequencies are 50, 100, 1000, 5000, 10,000 and 15,000 cycles.

Such measurements should be made employing the standard 75-microsecond de-emphasis in the measuring equipment and the 75-microsecond pre-emphasis in the transmitting equipment and should include all harmonics up to 30 kc. Measurements should be made at 25%, 50% and 100% modulation. This latter requirement has introduced certain difficulties, since commercially available analyzers will not tune much above 18 kilocycles, and distortion meters are limited in their sensitivity by the noise in the measured signal. The FCC allows a maximum of -60 db below 100% modulation for the FM noise level of the entire system in the range from 50 to 15,000 cycles. 100% modulation is equivalent to ±75 kc swing.

Since these tolerances include the entire transmitting system from the microphone to the antenna, it is obvious that any unit of the system must be better. The FCC recommends that none of the three main divisions of the system (transmitter, studio-to-transmitter link, and audio facilities) contribute over one-half of the total distortion.

For television transmitters and performance requirements of the frequency-modulated sound channel are the same as for FM broadcasting excepting that 100% modulation is equivalent to ±25 kc swing, and the allowable noise level is -55 db.

For amplitude-modulated broadcast systems the FCC has not established any definite distortion requirements. Proposed RMA standards for the transmitter alone allow a distortion of 3% for modulation percentages up to 85% and

5% for modulation percentages between 85% and 95%, for a range of fundamentals between 50 and 7500 cycles and including all harmonics up to 24 kilocycles. The allowable noise level is 60 db below 100% modulation. Proposed RMA standards for distortion in the audio facilities have a limit of 2% from 100 to 7500 cycles and 3% from 50 to 100 cycles. All of these distortion measurements are rms values--that is, the amplitudes of the various harmonics are combined by taking the square root of the sum of the squares of the individual components.

Signal Sources for Distortion Measurements

The lowest distortion obtained in any type of commercially available oscillator is found in the R-C feedback type, usually push-button operated, in which the distortion is generally better than 0.1% throughout most of the operating range. In this type of oscillator an R-C feedback network, usually of the parallel-T type, provides a high degree of degeneration for all harmonic voltages. The extremely good waveform at low frequencies is made possible by the absence of inductance coils or other non-linear elements. In commercial push-button oscillators of this type the standard frequencies include all of the FCC test frequencies. For highly accurate measurements of distortion such an oscillator is a distinct advantage since the inherent distortion in the test signal will always be small compared to the amount to be measured in the transmitted signal. An oscillator with low distortion such as the above is to be preferred for the FCC proof of performance tests.

For ordinary maintenance checks on transmitters other types of oscillators may be used, and if they are to be used also for running response curves, etc. certain of the continuously variable types may be considered more convenient. Continuously variable oscillators are generally either of the beat-frequency type or of the R-C type. High-grade units of the beat-frequency type may have distortion as low as 0.2% throughout most of the frequency range, but the distortion tends to rise to relatively high values at low frequencies. The most important advantage of the beat-frequency oscillator as a standard test instrument is that the complete audio-frequency range is available on a single dial, which may have a logarithmic or other desired scale shape.

A third type of oscillator not yet in commercial production and known as the double-beat or multiple-beat allows the simultaneous application of two test frequencies, thus facilitating measurements of intermodulation distortion. There are considerable theoretical reasons to believe that when such oscillators are available two-tone distortion tests will become quite generally used, particularly in cases where high amounts of distortion are encountered, since it is usually agreed that the intermodulation products are considerably more annoying than the spurious harmonics. Of course, intermodulation measurements can always be made using two individual oscillators.

Distortion-Measuring Instruments

The most common form of distortion-measuring instrument is the distortion meter. Various types have been manufactured over a period of years, earlier types being of the fixed-frequency variety. More recent types have been continuously adjustable. One of these has operated by bucking the transmitted signal against the applied signal, which requires careful adjustment of both phase and amplitude and measuring the resulting difference, which is an indication of distortion. The most recent types involve null circuits of the Wien bridge, parallel-T or similar types, which attenuate the fundamental sufficiently so that the remaining signal represents almost entirely the harmonics and noise. Switching the null network out of the circuit allows direct measurement of the noise, which obviously should be considerably lower than the level of the harmonics if accurate measurements are to be made. This fact limits the usefulness of the distortion meter in some applications. The distortion meter readings, of course, represent the total of all harmonics combined, there being no indication of the relative amplitude of each individual harmonic.

In using a distortion meter, a preliminary check should be made of the noise level in the system under test to be sure that it is not comparable to the magnitude of the distortion to be measured. This is particularly important in circuits having de-emphasis, since the standard 75-microsecond de-emphasis curve is down approximately 8.2 db at 5000 cycles, 11.4 db at 7500 cycles, 13.6 db at 10,000 cycles and 17 db at 15,000 cycles. For proof of performance tests on FM transmitters the FCC has accordingly agreed to require the 50% and 25% modulation distortion measurements only for frequencies of 5000 cycles and below as a temporary measure. The problem is further complicated in the case of television transmitters, where the allowable noise level is 5 db higher.

One of the earliest, and still one of the best methods for measuring distortion is the wave analyzer. Such devices in present commercial forms are generally of the heterodyne type, having a fixed-frequency filter. In such an analyzer tuning is accomplished by heterodyning the component being measured up to the filter frequency. The use of a fixed filter allows a very high degree of selectivity. Consequently such measurements are relatively

unaffected by noise and other factors, even under conditions where distortion meter measurements may be useless. Present commercial types of wave analyzers, however, do not tune to frequencies above approximately 18 kilocycles, which limits their use for some of the high-frequency distortion measurements now required by the FCC. The great advantage of the analyzer, however, is its versatility. Since it measures such component separately, it may be used equally well for single-tone harmonic measurements or for multi-tone intermodulation measurements.

Another distortion-measuring device is the so-called intermodulation meter, which is intended only for intermodulation measurements. Such a device is quite similar to a modulation meter as used for measuring percentage modulation of a broadcast station excepting that the intermodulation meter is an audio-frequency instrument. It measures the depth of modulation produced on one tone, generally at a high audio frequency, by another tone, generally of a low audio frequency. This type of intermodulation meter is often limited to operation at only a few selected frequencies.

Coupling Test Equipment To Transmitter

Fig. 1 shows the conventional means for coupling the test oscillator to the transmitter, and in general this simple arrangement will be found quite satisfactory. The resistance R_S should equal the impedance from which the equipment under test is designed to work. The attenuator, which is of the T type, should be of the impedance from which the equipment under test is designed to work, or a matching pad should be interposed. The connections shown are for unbalanced circuits. If the circuits are balanced an H-type attenuator must be used, and one-half of the resistance R_S should be inserted in each input lead. A VU meter is shown for convenience, but any good audio-frequency or vacuum-tube voltmeter may be substituted. For a 600-ohm circuit R_S will equal 600 ohms, and the input level to the equipment will be the reading of the VU meter minus 6 db minus the setting of the attenuator. The attenuator may be eliminated in cases where the input level is sufficiently high so that it can be read on the VU meter directly.

For measurements on audio-frequency sections of the transmitter the distortion meter or analyzer may be connected directly to the output of the audio-frequency equipment, as shown in Fig. 2. The resistance R_L, in parallel with the input impedance of the distortion meter or analyzer, should equal the rated load impedance for the equipment.

For measurements of distortion on an amplitude-modulated carrier the arrangement shown in Fig. 3 may be used. The AM demodulator is generally included as a part of the amplitude-modulation monitoring equipment, but the arrangement shown is typical. Suitable values for the circuit are as follows:

C_1 = 50 micromicrofarads

C_2 = 35 micromicrofarads

$L_1 = L_2$ = 25 millihenries

$R_1 = R_2$ = 100,000 ohms

D_1 = 6AL5 or 6H6

The audio-frequency input impedance of the distortion meter or analyzer should be large compared to $\frac{1}{2}R_2$ to avoid distortion at high modulation percentages.

For testing frequency-modulated transmitters the same system is used except that a frequency-modulation discriminator must be used in place of the AM demodulator. The requirements for this demodulator are sufficiently strict and the adjustments sufficiently critical so that no simple diagram would be of any use. Generally a suitable discriminator will be included as part of the frequency-modulation monitoring equipment utilized with the transmitter.

Before making distortion measurements it is well first to connect the distortion meter or analyzer directly to the output of the oscillator to determine that the distortion in the applied signal is sufficiently low for the tests. This check should be made with the oscillator terminated in the same value impedance as it will be operating into during the tests but without the equipment to be tested actually connected. When checking the noise level of the system prior to making measurements with a distortion meter, if it is found that hum or other noise components are abnormally high it may be necessary to use an isolating transformer at the output of the oscillator. This is particularly true when working with low-level input circuits. Needless to say, all low-level leads should be well shielded.

Differences Between Distortion Measurements On AM and FM Transmitters

On AM transmitters the distortion measurements are fairly simple because of the relatively high tolerances and the flat frequency response. However, it is characteristic of AM transmitters that the distortion rises rapidly as 100% modulation is approached. With certain types of AM transmitters, particularly

those employing Class B systems, it may also be found that the distortion increases at very low modulation levels. The FM transmitter, on the other hand, must be capable of swinging to an extent equivalent to 133% modulation, considering a 75-kilocycle swing as 100%. Hence the distortion of an FM transmitter should not rise noticeably in the neighborhood of 100% modulation. The television transmitter must be able to swing 40 kilocycles, which is the equivalent of 160% modulation. The lower allowable distortion of the FM transmitter, plus the fact that a de-emphasis circuit which further reduces the amplitude of the high-frequency harmonics is used for the measurements, somewhat complicates the measurement of FM transmitters, particularly at higher modulation frequencies, and care should be taken to check noise levels to be sure that they are not interfering seriously with the measurements.

For transmitters with sufficiently low distortion to meet the FCC and RMA requirements it is probable that simple single-tone harmonic measurements with a distortion meter or a wave analyzer will provide a satisfactory check on operating performance. In cases where, in spite of low harmonic measurements, however, the quality as judged by the ear appears to be rough or distorted, the source of such difficulty can generally be most easily traced by resorting to two-frequency intermodulation measurements, which may be made with a wave analyzer and either two oscillators or a double-beat oscillator. Such measurements may be particularly valuable in case of high-frequency distortion in FM transmitters, since the relative sensitivity of harmonic measurements is so greatly reduced by the de-emphasis circuit.

Relative Value of Different Types of Distortion Measurements

The choice between various types of distortion measurements is a subject which cannot be easily settled at the present time because of the relatively limited experience with all except the single-frequency type. To meet the FCC Proof of Performance tests single-frequency tests are required, and such tests are probably satisfactory for ordinary routine checks on high-grade equipment. In cases, however, where audible distortion exists to a degree considerably higher than the harmonic measurements would indicate, intermodulation measurements are generally desirable. In some instances a simple two-tone check with an intermodulation meter may be sufficient, but in general more complete tests utilizing a wave analyzer and either a double-beat oscillator or two high-quality oscillators are desirable.

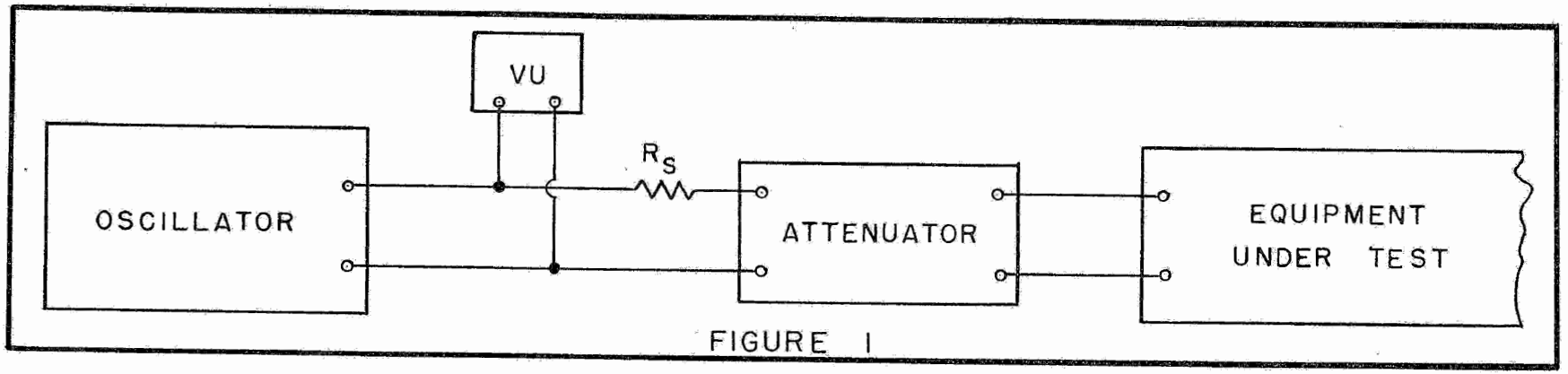

FIGURE 1

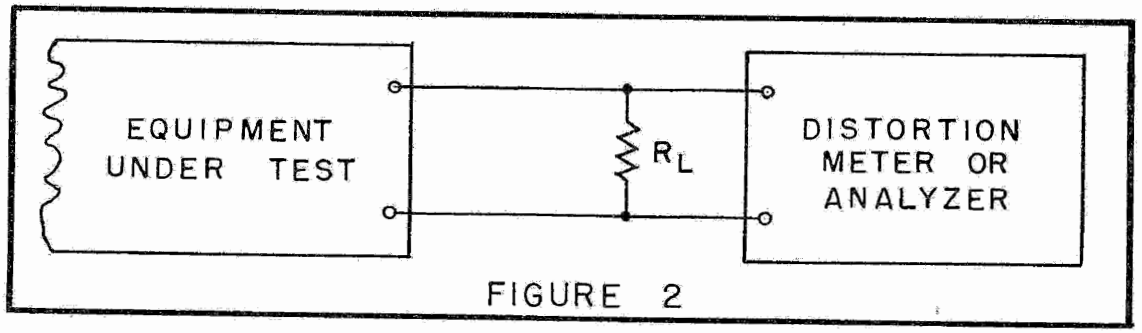

FIGURE 2

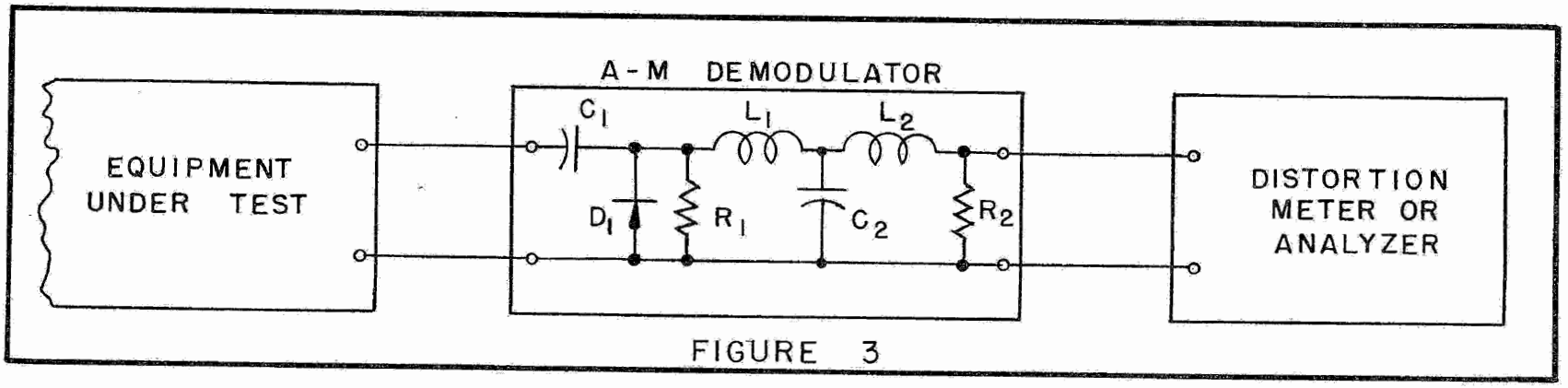

FIGURE 3

LOCATION AND SIZE CONSIDERATIONS
of
TELEVISION TRANSMITTING AND PROGRAMMING PLANTS

Before examining requirements for the location and size of the individual components of a television plant, it appears appropriate to emphasize one general point which is made almost without exception by television station owners, managers, engineers, and production people at stations of all sizes and types. Their advice is this:

Maintain the maximum degree of flexibility in all building plans. Prepare for almost constant change during the first few years of operation, and be sure that expansion will be possible without upsetting operations too seriously and bringing on undue expense. The nature of the business is such that even the most meticulously made plans will require modification from time-to-time (probably much more often than one would prefer) to keep in step with the progress of this dynamic new industry.

The discussion which follows is divided into two main sections, namely: location of the transmitting and programming plants; and "rule of thumb" estimates which may be applied with regard to the amount of operational space required at the transmitting and programming plants. The first section pertaining to location of sites is based almost in its entirety upon two papers prepared by the RCA Victor Division of the Radio Corporation of America. The contents of this section have been reviewed by RCA and it is included herein with their permission.

The section pertaining to "Size and Design" is taken largely from Chapter Four of the NAB Staff Study entitled "Report on the Visual Broadcasting Art". This section was compiled after considerable research into the problems encountered by those television stations in actual operation and is intended as a guide to those who will be called upon to prepare estimates, design data, and general information in connection with the planning of television operations. Although the discussion is not of the slide-rule variety it is set forth here primarily because the engineering department of a station is, almost without exception, called upon initially by management to prepare the first phases of such data. It is obviously impossible at this early state of the television art to give definite formulae for what may be termed standard practice in the design of almost any of the complexities covered in these discussions. It is, however, hoped that by setting down here what others have learned through experience, the all important stage of planning a television plant may be more thoroughly and less arduously accomplished.

SELECTING SITES

Even before an application for a construction permit can be filed, the prospective television station licensee is faced with the necessity of deciding upon locations for both his programming and transmitting plants. Although these decisions can under some circumstances be changed later, they are crucial ones, naturally, affecting vitally future day-to-day operations of a successful applicant.

Establishing both transmitting and programming facilities in the same location frequently offers several immediate advantages, which the broadcaster will undoubtedly want to capitalize upon if possible. It is advisable to study the two sites separately at first, however.

The antenna's location governs to a major degree the coverage which a station can expect. And, as in all types of broadcasting, the programming plant cannot be placed in too remote and inaccessible a spot. In many cases, obviously, the disadvantages of a single location can easily outweigh all other considerations.

While the location of the studio site is a matter dictated to a considerable degree by commercial reasons, the location of the transmitting equipment and antenna is almost entirely an engineering problem.

The importance of situating the transmitter most advantageously is of such magnitude that selection of this site must be given precedence.

TRANSMITTER

The factors which govern the location of television transmitters are several, and their relative importance will vary widely with local conditions. Some of these factors have to do with competition, prestige, population distribution and other local conditions about which it is obviously impossible to generalize. The technical requirements, on the other hand, are fairly universal and can be set down in well-defined terms.

BASIC REQUIREMENTS

The objectives in choosing a transmitter site are as follows.

(A) The location should be centrally located with respect to the area to be served (unless a directional antenna is to be used).

(B) The location must be as high as possible--always higher than surrounding buildings or elevations where there are no obstacles to reflect the transmitted signal.

(C) Power, water, and other facilities must be accessible, and it must be possible to accomplish all of this within the bounds of economic reason.

Some pertinent excerpts from the FCC's Standards of Good Engineering Practice for Television Broadcast Stations should serve to amplify and emphasize these points:

> 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.
>
> 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.

These considerations, coupled with the fact that television (like FM and unlike AM) requires no extensive ground system, has led many telecasters to place their antennas atop the tallest available building. The business district and population center do not always coincide, of course, but such structures are apt to be centrally located. If there are no other tall buildings nearby to deflect signals, the problem of attaining height can be solved in this manner. Thus, if we assume that the antenna and terrain are such that approximately uniform transmission occurs in all directions, then the site must obviously be near the center of the area. This is illustrated in Figure 1.

The difficulty of finding a central location will vary with the nature of the local terrain. It is desirable to serve the retail shopping or "trade" area surrounding the city in which the station is located and it will often be found that this area lies more or less symmetrically around the city. Thus, if a suitable site in the city is available, such a location will automatically answer the economic service requirements.

IMPORTANCE OF HEIGHT

Height of an antenna above prevailing ground level will determine the "Horizon" for the station as well as the ability to avoid shadows from obstructions. While VHF signals travel somewhat beyond the mathematical horizon, the attenuation beyond it is relatively sharp. For most practical purposes, over flat terrain, a factor of four-thirds of the distance to the horizon may be used as a criterion when considering the radius of service for VHF television. On UHF channels it is felt that unity, rather than the four-thirds factor, will provide a more accurate indication. In general, the higher the antenna the greater the coverage will be.

An economic limit will be imposed by the height of existing elevations or the cost of erecting a tower to support the antenna. Among the ready-made means of gaining height are the use of buildings and hills. However, a hill some distance from the settled area will not be satisfactory because, while it provides good height, it will be so far away that the signals will be relatively weak by the time they reach the area to be served.

This serves to emphasize the fact that while height is important, it is not the sole consideration. A television antenna 1500 feet high would have a line-of-height horizon of some 47 miles on level country. Unless the effective power (transmitter power times antenna gain) is sufficiently great to produce a usable signal at 47 miles, the range will actually be less than the distance to the horizon. Hence, the effective power should be great enough to realize the advantages of a high antenna location.

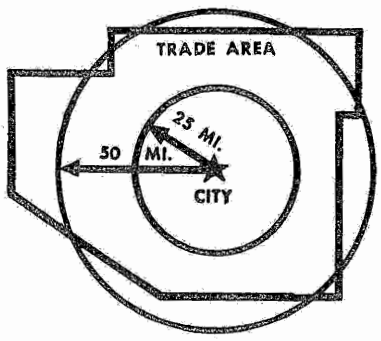

Fig. 1.--Where the trade area of a city is more or less symmetrical, a site near the city will give the most uniform coverage.

PRACTICAL CONSIDERATIONS

Height, despite its great desirability, should not be allowed to become a fixation. Every site selected as meeting the foregoing two requirements, that is, of central location and of height, should be subjected to a careful consideration as to its practical merits. It is obviously not wise to plan a mountain-top installation to obtain height if the installation cost will be prohibitive. On the other hand, certain types of tall building construction may preclude the use of antennas with high gain and it may be necessary to use larger transmitters.

There are certain practical requirements which a site must meet. These should be checked when preliminary consideration is being given to the site.

For example, an important consideration for "mountain-top" locations is the availability of power. In most cases power lines will have to be built to the location. The cost of this must be considered, particularly if the location is very remote. Telephone lines also will have to be built or a radio link established. Finally, there is the building itself to consider. This building must house the transmitter, provide living space for operators, storage space for spares and, preferably, provision for originating recorded programs in an emergency.

Another consideration--which may apply whether the antenna is mounted on a building, a tower, or a mountain top--is the question as to whether the civil aeronautics authority will give the necessary approval. In some locations --near airports or on airways--the CAA will not approve structures which exceed certain heights.

VARIOUS TYPES OF TELEVISION SITES

There are several kinds of locations which may meet the requirements of a television site as listed above. These are of five general categories which may be described as follows: (A) locations involving the use of a tall building; (B) locations on mountain tops or high natural elevations; (C) locations at the site of AM transmitter plants with the television antenna mounted on the AM tower; (D) locations involving the use of low buildings on which a steel tower is erected to give the required height to the television antenna; and (E) dual location of a television antenna and an FM transmitter, with the television antenna and the FM antenna mounted on the same tower. In some cases, use of a common site and tower by several television stations will be highly desirable for all concerned. Special multiplexing equipment or combination TV antenna systems are now available for this purpose.

Some of the advantages and disadvantages of these types of locations, as well as particular considerations to be applied in considering each, are as follows:

(A) Locations Using Tall Buildings

The most popular type of location is on a tall building in the center of the "principal city." The transmitter is usually located on one of the top floors and the antenna erected on the top of the building, with studio located either in the same or a different building as shown in Figs. 2 and 3.

For such use, the buildings chosen are usually 300 feet to 600 feet tall (with a few, of course, even taller). If the surrounding countryside is reasonably level, an antenna located on such a building will provide very effective coverage. Moreover, the field pattern of such an installation is highly advantageous in that it automatically results in the highest

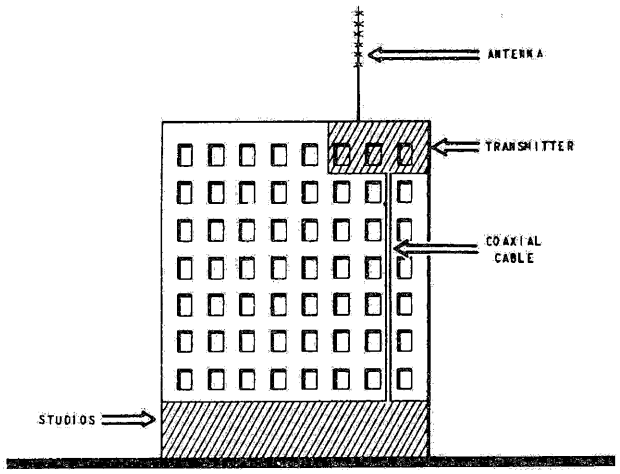

Fig. 2.--Studio and transmitter in same building.

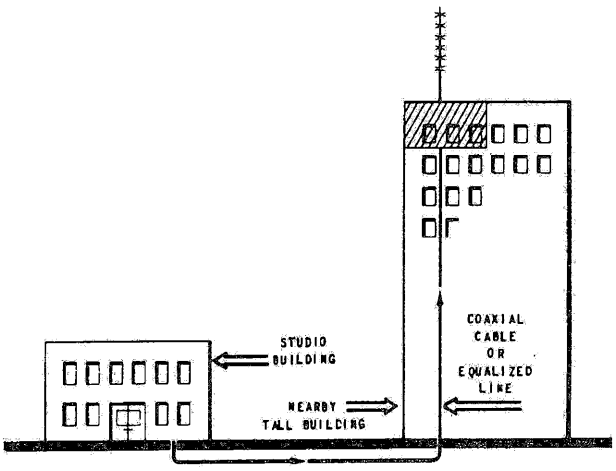

Fig. 3.--Transmitter on a nearby tall building.

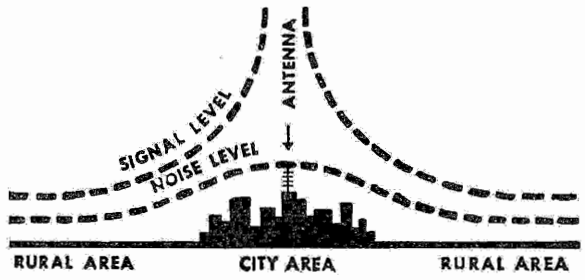

Fig. 4.--A "city-located" station has its highest signal where most needed; i.e., where noise level is highest.

signal strength in the center of the built-up area, where interference (such as ignition noises) is also strongest. The signal decreases going away from the downtown area, as does the interference noise, with the result that signal-to-noise ratio is of the same order throughout the service area (Figure 4).

Installation on a tall building has the further advantage that no land need be purchased, no transmitter building need be erected, there are no power lines to erect to a remote spot and no so-called studio-transmitter-link is required (since for the short distances between studio and transmitter satisfactory telephone lines are usually available). Thus, the first cost of a location of this latter type is low. The eventual cost depends on the rental. If this is high, the long-time cost may exceed that of a site and building owned outright by the station.

In the way of disadvantages, there is the fact that buildings are limited as to height and in many instances will be surrounded by nearby hills. In this case, shadows may exist behind the hills. Even nearby buildings of greater or equal height have been known to cause shadow patterns, even in the monitors of the transmitting station.

Another common drawback is that it is often not possible to erect a multilayer antenna, so that desirable antenna gain must be sacrificed.

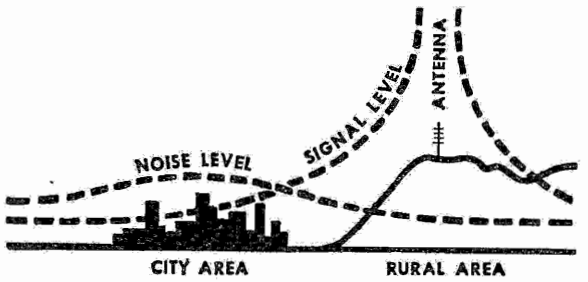

Fig. 5.--A "mountain-top" station has its highest signal where least needed; i.e., where noise level is lowest.

Finally, there are the usual difficulties entailed in making a fairly complicated and elaborate installation in a building owned by another party.

(B) Locations on Mountain Tops

Quite the other extreme, as far as the cost and labor of installation go, are the locations on mountain tops or high hills. Such locations have just one advantage, namely, height. As noted above, the effect of height on coverage is striking. By locating the transmitter on a mountain or other natural elevation, it is possible to obtain coverage not practical by any other means. This factor alone justifies such locations where large rural coverage is required.

The disadvantages of mountain tops are several. They entail the purchase of land and the construction of buildings, power lines and other services under the most difficult conditions. The locations are remote, inconvenient, and often almost inaccessible. The signal distribution is bad in that the signal is greatest where it is little used and much less (ordinarily) where it is most needed (Figure 5).

It should be noted that the competitive situation (where there are other stations located in the principal cities) suffers in this respect. As Figure 6 shows, the station in town has a strong signal where most of the audience lives; the mountain-top station, if very far away, is much weaker.

The above conditions, of course, apply only to installations on remote mountain tops. In some cases, moderately high hills exist on the edge of town, or even in the town. These are natural sites for television stations if procurable. In the cases of very hilly cities, they will be almost a necessity.

In many cases, however, the city in question will--because of irregularities of terrain or the proximity or distance of other cities--lie to one side of or in one end of the trade area with which it is associated, as shown in Figure 7. Again, because of availibility or non-availability of suitable elevations, it may be necessary to locate the transmitter to one side of the area, regardless of symmetry. The question then arises as to how to satisfy the requirement that coverage be provided to the proper areas.

Antennas which give radiation patterns of special configuration, such as shown in Figure 8, can be designed, and some are actually in use for television broadcast purposes. It is relatively simple to combine in one design both high gain and special directivity. With such antennas it is possible to provide more complete coverage in an irregularly shaped service area. Co-channel protection of nearby TV station is also possible

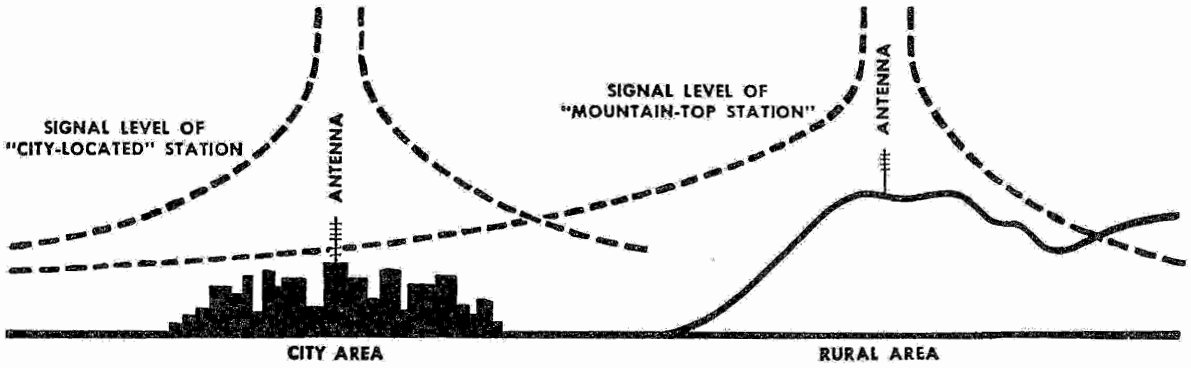

Fig. 6.--The signal of a "mountain-top" station may suffer by comparison with that of a competitive "city-located" station.

with directional arrays. That directive antennas will in the future be used to a very considerable extent seems fairly certain.

(C) Use of AM or FM Tower

When the television station is to be under the same ownership as an existing AM broadcasting station, there is a third possibility which is sometimes worth considering, viz., location of the television transmitter in the same building with the AM transmitter. The television antenna may then be mounted on top of one of the AM towers.

The chief advantage of this type of installation is the saving effected, not only in first cost, but in operating cost as well. First costs are low because there is no land to purchase, no building or tower to erect, little or no extra cost for running in power lines, etc. Operating costs are lower because of the centralization of operating and maintenance facilities.

Cooperative effort can (and has been known to) reduce the individual station's costs and difficulties in those instances where more than one licensee plan to place their transmitters in the same area. Incidentally, FCC regulations require sharing of sites where competition would be unduly restricted if one licensee gained exclusive rights to the only desirable location.

There are several disadvantages to this type of installation. For one thing, the location is usually not the very best and some sacrifice of coverage is entailed. For another, mounting the television antenna on the AM tower is a tough mechanical job. Unless the tower has been especially designed for the purpose, it will usually not support an elaborate array. (One way to get around this is to remove part of the existing tower, allowing the television section to replace it approximately as to weight and wind resistance.) Again, a problem occurs in bringing the television transmission line around the tower insulators (if of insulated type), although this can be handled by installation of suitable blocking circuits. Also, there is the fact that the tower is usually several hundred feet from the building, which, together with the height of the tower, makes for a rather long transmission line with losses which may run to 20 percent or 30 percent of the transmitter output. Finally, the AM band lies completely within the range of video frequencies; therefore, special shielding or other

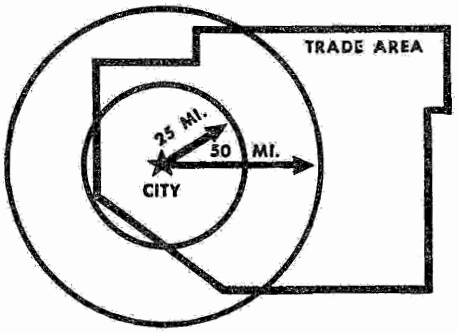

Fig. 7--Where the area is not symmetrical about the city, it will usually not be possible to cover the whole area with a non-directive antenna.

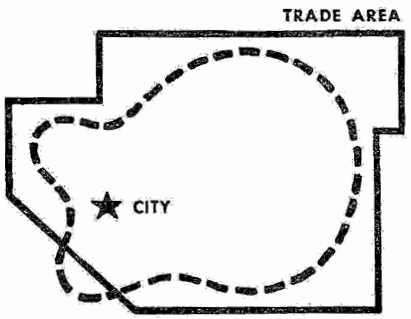

Fig. 8--Directional antennas are recommended for use in irregularly shaped service areas. or where it is necessary to protect the coverage of another television station.

installation precautions will undoubtedly be necessary in order to prevent interference with the video signal.

In the event existing AM and FM stations find that their present sites and towers can be used for television, the chances will no doubt be far better for FM installations since the propagation characteristics of FM and TV have much in common. But, as stated before, placing a television antenna atop a standard broadcast station tower may prove practicable if the latter happens to be properly located.

Superimposing television transmission on an existing FM operation can, in some cases, be accomplished either by placing a separate TV antenna on top of the one being used for FM or by "triplexing" the TV sight and sound plus the FM aural service on a single antenna. The latter possibility, however, is restricted to certain appropriate combinations of FM and TV channels. And, if all other factors should be favorable, this triple-duty antenna can be mounted on an AM tower.

While aural FM and TV combinations are commonplace, dual or triple transmission from an AM mast figures in the television picture less frequently. Changes in the over-all height of an AM radiator can create difficulties for that service, particularly in a complicated directional array. The problem of electronic isolation is much greater when AM is involved than with the simpler combination of FM and TV.

Of interest in this connection, however, is the fact that Commission rules do permit the approval of site proposals for TV involving directional antenna systems. At least one operating station has received permission to use its out-of-town AM tower in combination with a directional television pattern. The Commission emphasizes, however, that "it is generally preferable to choose a site where a non-directional antenna may be employed".

Any combination of transmissions from the same antenna assembly requires special Commission approval. As a basis for considering a proposal of this type, the FCC demands "complete verified engineering data showing that satisfactory operation of each station will be obtained without adversely affecting the operation of the other station," as well as evidence to show that other rules concerning antenna height, field intensity, etc., are being complied with properly.

(D) Use of Special Structures

If there are no mountain tops nor other high elevations within reasonable distance--and no sufficiently high buildings available--only two alternatives are left. One, of course, is to make the best of lower points, using increased power to make up the difference and hoping that the shadows will not be too bad. The other, and better alternative, is to erect a special structure to support the television antenna. Usually this will be a steel tower of the self-supporting type, although guyed towers are in use. In extreme cases, this tower may rest on the ground itself; more usually it will be erected on a building of medium height.

What are the advantages of this type of installation? The most obvious, of course, is that it offers a much greater latitude in the choice of the building to be used. Not only does this choice allow the selection of a good space for the transmitter, but also it may permit the studios to be located in the same building as the transmitter, or vice versa, if the studio site has already been decided on.

Imposing masts jutting five hundred feet and more into the air are not uncommon among today's television stations, particularly in flat areas where terrain advantages are few and difficult to capitalize upon. In hillier country, shorter towers frequently enable a station to approach the 500 feet-above-average-terrain norm prescribed by the FCC for stations of the metropolitan class.

The disadvantage of higher towers is the added cost of the steel which must be erected. In most cases, the roof, if a building is used, will require extra reinforcing (usually a frame of I-beams) which, together with the difficult working requirements, tends to make erection costs a sizable item. Obviously, the first and most important thing to check when considering an installation of this type is whether the roof will support the tower and what the cost of the extra construction is likely to be.

While possible disadvantages of this type installation are obvious, experience has shown that in addition to the definite plus value of being able to choose among several different locations, this choice can make easier the matching of strongest signal area with densest population. The station's bargaining position with real estate agencies is improved, also.

CALCULATION OF COVERAGE

For purposes of filing an application for construction permit with the Federal Communications Commission, it is presently necessary to calculate the five millivolt per meter and one-half millivolt per meter signal contours. This will, of course, provide an indication of the expected coverage. Such data should be prepared by a qualified engineer.

It is beyond the scope of this discussion to describe in detail the methods used for determining the coverage of a television station. However, a review of the factors involved in

location studies may be useful in illustrating some of the problems.

The factors which influence the coverage of a television station are not entirely identical with those which determine the range of a standard broadcast station. The coverage of a television station will be affected by:

(A) Power of transmitter
(B) Gain of antenna
(C) Height of antenna above prevailing ground level
(D) Obstructions between transmitting and receiving antennas
(E) Noise level at receiving location

The power of the transmitter and the gain of the antenna are completely interchangeable as far as coverage is concerned. A one-kilowatt transmitter used with an antenna whose power gain is four will produce the same results as a two-kilowatt transmitter and an antenna with power gain of two. It would thus appear that one might use a very low-power transmitter and a high-gain antenna with resulting economy. However, there are limits to each. First, television antennas must be broad band and an increase in antenna gain is often accompanied by a decrease in bandwidth. Also, as antennas are increased in gain, they become taller, heavier, more costly, and require more substantial and expensive supports. Antenna power gain of the order of four is practical in most cases and, with a five-kilowatt transmitter, will produce the equivalent of twenty kilowatts radiated power.

Obstructions between transmitting and receiving antennas will cause shadow areas where signals will be weak or even unusable. Such obstructions may be groups of tall buildings or hills. Naturally, antenna height will aid in overcoming the effect of such obstructions. Shadow areas behind interfering objects do not extend indefinitely, but tend to "fill in" because of refraction effects. In general, obstructions near the transmitting station will create shadow areas of greater extent than if they are farther from the station.

It will be important to examine the shadow areas and to determine whether or not they fall over important residential sections. If so, an alternative transmitter site may be preferable. With fairly level territory, shadows can be predicted within reasonable limits, but in hilly terrain, the problem is both complicated and helped by the fact that signals may be reflected from some hills. Some reflections may tend to reduce shadows, but may also result in both a direct and reflected signal being received in some spots, causing "ghosts". The problem of location in rough terrain is one which demands individual study.

Noise level at the receiving location is not within the control of the transmitting station, but the location of the transmitting antenna can be planned to produce maximum signal strength at points where noise level is highest. High receiving noise level will generally be experienced in densely populated areas, along main highways and near railways or manufacturing areas. It is usually most important to provide high signal strength to densely populated sections. This means that if the station is closest to such areas, the signal strength will be greatest where it is most needed (re Fig. 5). Rural and suburban areas can ordinarily be served successfully with signal intensities considerably lower than in metropolitan localities.

In cases where suggested antenna locations are questionable, the Commission recommends, and may sometimes require, that special propagation tests be conducted and field intensity measurements taken. Recently developed items of equipment utilizing a pulse technic offer promise of greatly simplifying this advance testing of sites.

Stations contemplating the selection of a site in a thickly populated part of town may want to give some thought to what effect their transmission might have on other activity in the area. If it appears that the proposed station's "blanket area" may interfere with reception of other stations in the vicinity, the Commission may require that the applicant "assume full responsibility for the adjustment of reasonable complaints arising from excessively strong signals of the applicant's station."

No serious problems of this nature have developed with present transmitter powers, but the possibility will be present when higher power transmitters come into use.

Television service conveys more intelligence than audio transmission and, in general, requires a higher signal strength for satisfactory operation. Hence the importance of a reasonably high effective power of the station.

From the foregoing, it will be apparent that antenna height and proximity to built-up areas are desirable from a coverage standpoint. In many cities this points to the use of a tall building in the business area as a transmitter site because height can thus be obtained economically, also, business districts are usually centrally located. As an alternative, a hill near the center of the city may be equally desirable.

Speaking in general, the problems inherent in locating a television transmitter are capable of solution, but they must be approached with intelligence based on technical experience.

PROGRAMMING PLANT

Practical aspects of day-to-day operation can influence the choice of a programming plant location to a much greater degree than the selection of a transmitter site. In many respects the factors which determine the desirability of a particular spot as a location for a television programming center are identical to those which would affect a similar decision in aural broadcasting.

The location for the programming plant should be chosen with care -- for the suitability of this location may have considerable bearing on the successful operation of the station. On it may depend the availability of programs, the operating convenience, and other considerations of interest to the station owner and station staff.

While there are certain factors which must always be considered in choosing a location it is not possible to lay down general rules which will be applicable in every instance. Local conditions are usually the determining factor and these may vary greatly. For instance, in some cases the competitive situation or the necessity of maintaining prestige may outweigh ordinary economic considerations. Again, it may be desirable to combine the television operations (or some part of them) with another business which is under the same ownership. Obviously, every prospective station owner will have to evaluate such factors himself in order to arrive at the most satisfactory overall solution.

CONSIDERATIONS IN CHOOSING A LOCATION

There are certain considerations which apply to every possible site and it will be of value to set these down as a sort of preliminary check list. These considerations are:

(A) Adequate space for operations.
(B) Cost of land and buildings (or rent and building modifications).
(C) Provision for future expansion.
(D) Convenience of reaching location.
(E) Freedom from interference.
(F) Facilities: Power, water, etc.
(G) Nearness to outside program sources.
(H) Location with relation to transmitter site.

(A) Adequate Space for Operations

Space requirements may well be the most influential of all factors. A full section must be devoted to the many facets of that subject. However, before going into this subject we will first discuss the other factors.

(B) Cost of Land, Buildings or Rent

It is essential to know the initial capital expenditures as well as the likely operating costs of the plant, exclusive of broadcasting equipment.

The real estate market, and other local factors, will have important bearing on the decision. Real estate rentals and purchases are especially important in television because of the relatively large amounts of space needed.

If the studios are housed in a specially constructed building, the initial costs will include land, structure, furnishings, etc. The operating cost can be arrived at by amortizing the investment (initial cost) over the period permitted for tax purposes and adding thereto the estimated taxes, repairs, building service, heat and air conditioning, etc. If the studios are to be located in an existing structure, the cost of modifying the space to its original condition will constitute capital expenditures. In this case, rent for space, taxes, and plant operations will comprise the principal operating expenses. It is suggested that in making cost comparisons the equipment and broadcasting operating costs be figured separately, since these are somewhat independent of plant location and are dependent upon the type of service to be rendered. However, if the sites being compared affect such costs, of course they should be considered.

In a good many cases, the station owner must choose between locating his studios in an existing building in the business area of a city or erecting a suitable structure on the outskirts of the city. An examination of the initial and operating cost of each choice should be made, taking into consideration the other factors which are listed above. It should be kept in mind that suitable studio space in existing buildings will not be easy to locate because of limited ceiling height, close spacing of columns, etc. Such structures as public halls, warehouses, garages are likely prospects for investigation.

In the selection of land outside the business area, building restrictions, limitations on trucking in streets and tax rates must be examined. Local zoning restrictions must be met. With props and scenery going to and fro, there will be more commercial traffic around a television studio.

(C) Provision for Expansion

Most television station operators will wish to provide, initially, only such facilities as are required immediately or in the near future. This will keep the initial expenditures at a reasonable level and prevent an over heavy amortization during the formative period. Moreover, operating expenses, including rent, will be kept to a minimum if the plant size is not too large.

An inadequate layout, however, will be a severe handicap to operations. Hence, the wisest course will be to arrange for space to be added when needed or to deliberately install more space than will be required initially, leaving the extra rooms in an unfinished condition. If a specially built structure is to be used, the architect can design the ultimate building and indicate the portions which are to be erected initially.

Curtain walls can be used at points where additions are to be made. It may be economical to install heating, cooling and other common facilities of such a size that no replacement need be made when building additions are made. If the building is a low-cost structure, provision for expansion may be limited to providing an oversize plot of land with the initial structure located so that additions can be made.

Studios in office buildings or other centrally located structures are more likely to be limited when additional space is sought. If space is rented, an option may be taken on adjacent quarters and plans made initially for the ultimate use of the space.

The problem of providing for expansion is considered in greater detail in the section on Size and Design.

(D) Convenience in Reaching Locations

Television is likely to employ actors who may appear in theaters or other entertainment centers. If the studio location is difficult to reach, actors may be unable to take part in their performances and also telecast. Clients may object to visiting a remotely located studio. Time will be saved for remote crewmen going to and from location. Adequate public transportation for staff members is essential.

Obviously, the central city location is likely to be the most convenient and the far distant studio the most objectionable from the viewpoint of accessibility.

In a number of cities there will be found areas which are not far from the business center and which are not built up with either high grade business structures or residential construction. Providing that adequate transit facilities exist, such localities may be potential studio sites. It is likely that land costs will be low and no great objection can be raised to traveling time.

Lowest land costs and best opportunities for expansion will exist outside city limits. Such sites may be advantageous, particularly in cases of cities whose residential reaction lies in one direction away from the downtown area or in the instance of "Twin Cities" where a site between the two may not be inconvenient to reach.

In any event, the wise planner will be sure that his studios can be reached easily in a reasonably short time.

(E) Freedom from Interference

Just as in the case of sound broadcasting studios, it is unwise to select a location for television studios which will result in troubles costly to eliminate. Such sources of trouble include vibration, noise and electrical disturbances.

Studios located in factory buildings or in newspaper plants where large presses are mounted are likely to experience trouble from vibration.

Vibration is apt to cause microphonic effects in both picture and sound circuits. It can be corrected by special arrangements for "floating" the studio on suitable absorbing materials, but the cure is expensive and requires careful engineering treatment. The best solution is to avoid such locations.

Noise will cause trouble chiefly in the sound circuits--by pickup in the microphones. In quiet locations, simpler sound proofing may be satisfactory. Use of sound absorbent material between walls and ceiling spaces may be sufficient, and may also serve as heat insulation.

In the case of studio buildings on a separate plot, the best cure for noise is a quiet location. Some common sources of noise are heavy street traffic, railroad whistles and airplanes. Studio buildings located near airports or along airways will be subject to roar from passing planes. Since air travel is on the increase, it is well to select a location which is unlikely to be near a future air route.

In either city or suburban locations, if more than one studio is planned, arrangements must be made to keep sound originating in one studio from being transmitted into the other. This problem is common to standard broadcast studios and may be handled by conventional means, and is treated at some length in the "Studio" Section of this Handbook.

Electrical disturbances are not usually a serious consideration in sound broadcasting but present problems peculiar to television. Changing electric fields caused by breaking or switching high power electric circuits may affect video systems. Sources of such disturbances are elevator contactors, heavy electrical machinery, electric locomotives or traction systems, smoke or dust precipitators, X-ray machines and radio transmitters including high frequency and standard band broadcast stations. Inasmuch as AM broadcast carrier frequencies are well within the range of the video channel, elimination of R-F pickup in cameras is apt to be a problem. Such cases may occur if the television studio is

close to a high power transmitting antenna. Note that no interference results from location of a television studio near a broadcasting studio, unless the broadcast transmitter is there, too.

If electrical disturbances are prevalent, but other factors are favorable, shielding can be resorted to. Either the studio or the source of the disturbance may be shielded, depending on which is the most practical method. Adequate shielding and bonding is somewhat costly and hence it is better to avoid the problem if possible rather than to attempt a solution.

(F) Facilities

Water, power, and other public utilities must be accessible. A television studio's power requirements will be far greater than those in aural broadcasting, and a well-regulated source of power, preferably coming from the same system supplying power to residential areas, will be required thus, if any "hum" is present in the picture signals, it will be synchronous with the "hum" in the receiver and will not be disturbing. While this is not apt to be a major factor, it is worthy of consideration.

Steady power supplies, free from voltage fluctuation, will greatly simplify operating problems. In urban locations such power sources are usually available, but a special transformer and distribution circuit may be required to carry the lighting load. The switching of lights should not affect the power source for equipment.

Both single phase and three phase supplies are desirable. Video equipment is designed primarily for single phase operation, but some associated equipment such as film projectors may require three phase supplies. It may be advantageous to operate banks of lights across different phases to reduce "hum".

(G) Nearness to Program Sources

The propagation characteristics of television signals do not enter this phase--with one exception. If the studio location is to be used as either a transmitting or receiving point for microwave relay connections, consideration must again be given to height, centrality of location, and freedom from obstructions.

Microwave relay links are highly-directional, have a limited range and are extremely sensitive to physical obstructions in their line-of-sight transmission path. It is usually necessary to be able, theoretically at least, to see the receiving antenna from the point of origination.

If the main programming center is built on low ground or in the midst of tall buildings, its value as a receiving point for the mobile unit's microwave relay will be very limited. Since the remote truck will be operating at constantly changing points, many of which may be difficult to work at best, a receiving antenna that is high and free of obstructions in all directions will save many man-hours which would otherwise be spent trying to line up an acceptable connection. And since about fifteen miles is the maximum range for most relay transmitters, a central location is desirable. As an alternative in the instance of outlying studios, a steel tower may be used to give adequate height to the receiving antenna for the relay system, or the relay receiver may be located in the main transmitter building and its antenna installed on the main antenna tower or support.

Signals from the field apparatus may also be transmitted by short distance telephone circuits or coaxial cables to the studio or to the main television transmitter directly. If the studio is in mid-city, it will probably be convenient to send the field signals there, for handling and retransmission to the main transmitter. Some advantages can be realized by locating the studio centrally with respect to points where outside programs would take place. Such points might be theatres, arenas, stadiums, auditoriums, athletic fields, churches, department stores, etc. Line circuits can thus be reduced to the minimun length.

(H) Location with Relation to Transmitter Site

The location of the studios, with respect to the location of the transmitter, is another factor which will have an important bearing on the initial and operating costs of a television station. While it is not necessary to have the studios and transmitter in the same building, or even nearby, it should be recognized that program lines in addition to possible network, studio-transmitter, other special video lines, and many aural circuits will be necessary. Usual practice at present is to feed the audio portion of remote originations by regular telephone company lines.

In general, there are four situations which may arise. These are:

(A) Studio and transmitter in same building.
(B) Transmitter in a nearby building.
(C) Transmitter located in suburbs.
(D) Transmitter on a mountain top, etc.

In the first three, the audio circuits will undoubtedly be telephone lines. In the fourth they may be either telephone or radio relay.

The video link in (A) will undoubtedly be coaxial cable. In (B) and (C) it may be either coaxial cable, equalized telephone line, or microwave relay--with the latter two most likely. In (D) it will almost certainly be R.F. relay.

It will be quite obvious that the cost of link circuits will vary greatly from one installation to another. Locating the studios and transmitter in the same building will ordinarily be the least expensive. When the transmitter is in a nearby building the initial cost will depend on the problem met in running the connecting coaxial cable. In either event the maintenance cost should be relatively low. Moreover, the proximity of studio and transmitter operations makes for convenience and some saving in operating cost. A transmitter location in the suburbs (with studios downtown) ordinarily means a distance which will make a coaxial line very expensive and an equalized telephone line may be the alternative. In this case the rental is an additional cost which must be considered. Transmitter locations on a remote mountain top will almost certainly require a radio link. This will necessitate a high location for the antenna of the studio relay transmitter as well as other provisions which may make the original cost fairly high. The operating and maintenance costs, however, should be relatively low.

Stations planning mountain top locations will probably find purely academic any further discussion of concentrating all station activity in one spot.

Those which have a choice, though, may find that certain economies in both construction and operating costs can be achieved by a single location--in such ways as these:

Need for studio-transmitter links is eliminated;

Duplication of some facilities, such as maintenance shops, can be avoided;

Cost of original building construction or adaptation can be reduced if all units are housed together;

Test pattern transmission periods can be handled by transmitter personnel alone without installation of duplicate picture projection instruments;

Some master control functions can, in certain types of operation, be assumed by the transmitter crew.

Stations attempting to operate near minimum expense levels may find the latter two points of keen interest. If an extra person must be on duty at the programming center to originate the test pattern signal, manpower costs will be increased. Or if duplicate equipment is installed at the transmitter, an extra ten or twelve thousand dollars must be spent.

A similar situation can prevail during portions of the active programming schedule--during periods of solid network service, for example. It is not unusual for stations with direct interconnected network service to complete all local production early in the evening, at least on certain days of the week. Some of them have their plants so arranged that all operations after that time can be integrated with transmitter control, thereby permitting manpower economy.

Film projection facilities will be required at the transmitter if activity of this character becomes very extensive, of course, and stations with only station identification instruments there will be unable to concentrate operations in this manner.

Unless studios for live shows are a part of the plant, program operations will almost certainly be carried on at the transmitter location. Some stations which do have studios, but cannot feasibly have them at the transmitter site, are dividing their program operations, putting everything except studios at the transmitter and manning the studio location only for special features.

This latter arrangement does make particularly difficult, however, the integration of film into studio productions, an increasingly popular method of handling titles, commercials, and special effects.

There are many situations, of course, in which a single location would involve over-riding disadvantages. A mountain-top transmitter site, as mentioned earlier, comes near ruling out such a possibility completely, especially if a studio is desired.

Some building-tops which provide splendid transmitter sites simply will not accommodate a programming plant adequately. In other such cases, the rent may be prohibitively high.

Even stations which erect towers in open area on level ground may find that the cost of constructing new buildings is too expensive, compared to cost of renting existing space elsewhere.

In summary, though, this generalization seems safe enough: Most stations prefer to concentrate all their activity in the fewest possible number of places, and integrate all operations as closely as possible, consistent with the situation which exists in their company and community.

SIZE AND DESIGN

At the outset of discussions relating to size and design it may prove valuable to draw in the broad outlines of a television plant for purposes of perspective, by comparison with aural broadcasting. Operational layouts of these two broadcasting services are remarkably parallel. Both concern studio, remote, network, and mechanically reproduced programs, feeding into master control for mixing, and being fed to a transmitter.

Experienced broadcasters entering the visual field will be faced with some familiar decisions: Shall master and studio control be combined or separate? How can studio area be provided for peak demand without wasting a lot of space? And, how can additional production facilities be added to the original nucleus without upsetting the basic arrangement?

While the outlines and proportions bear some resemblance, the scale of the two services will be quite dissimilar. Obviously, even the housing of equipment and personnel calls for more floor area.

Some authorities on both aural and visual broadcasting have found that television demands three or four times as much space as a comparable aural operation--when studios are involved.

Deciding what constitutes "comparable" aural and visual stations is important, of course. The answer can be found, within limits, by examining major points of comparison, such as: (1) availability of network service; (2) emphasis placed on live studio programming; (3) amount of time devoted to mechanically reproduced programs, i.e. records and transcriptions in aural and film in visual; and (4) extent to which special events, sports, and other outside program sources are utilized.

Space needs at the programming plant are really determined by the extent to which the station uses each of the four programming sources: network, film, remotes, and studios.

Transmitter

A good round-figure starting point when calculating the floor area needed for a 5 KW transmitter installation is 1000 square feet. This space should accommodate a modest storage compartment and maintenance workshop in addition to the basic transmitting equipment.

In a 500 watt installation, the transmitter proper will be about one-half to one-third the size of the 5 KW unit, but several pieces of associated equipment will be of the same size. Consequently, a little more than half of 1000 square feet will probably be required. About 600 square feet should be a good working figure for the smaller transmitter.

If necessary, both these figures can be trimmed about 20% by exercising extreme care in fitting the various pieces of equipment together. A more likely prospect, though, is some expansion of these average minima to provide more elbow room and space for future expansion.

It should be kept in mind that some stations using 5 KW's of power initially will want to step up to 50 KW's when transmitters of that size become available. And, FCC willing, a normal progression from 500 watts to 5 KW's is always possible.

You will recall from the discussion above that stations with separate transmitting and programming plants often find it advisable to have station identification equipment at the transmitter. Stations anticipating such an eventuality will want to pad these estimates a bit to provide room for two or three racks of equipment, turntables and the like.

Exact dimensions of individual pieces of equipment will vary among different manufacturers. Some fluctuations will also occur in a few of the components according to the channel used, lower frequencies in general requiring larger units. But these differences should not be great enough to cause serious trouble unless the square footages quoted above are being trimmed too closely.

These figures cover operating area only. Such additional features as sleeping and cooking facilities, lounges, baths, etc. must be based strictly upon the local situation. Problems in this area, of course, are not different from those encountered in aural broadcasting.

Since equipment racks are usually about seven feet tall, minimum ceiling height is approximately nine feet. More height facilitates cooling.

To get some idea of the total amount of land required for a transmitting plant located on the ground, we must look at the base of the tower as well as the transmitter house. Using the building as the base of the tower is not an unheard of arrangement, but more often the tower is based on the ground alongside the building.

Since no elaborate ground system is necessary with a television antenna, the transmitter house and the tower base are the only two factors--except in some cases where local zoning regulations may enter the picture.

Height is the principal factor governing size of a tower's foundation, of course, with weight and design variations exerting lesser influences. Self-supporting structures varying in height from 200 to 500 feet must have foundations covering something like 500 to 5000 square feet respectively, with gradations in between.

Guyed towers, of course, require much more space, since anchorages for guys must be available on all four sides at a distance which approaches the tower height.

Providing some protection against the future construction of tall buildings or other obstructions in the vicinity of the station's antenna is another factor which may influence the size of a transmitter site. To insure against some obstacle

being built which would interfere with the station's coverage pattern, a prospective licensee might possibly find it wise to option a larger plot of ground than would otherwise be necessary.

Even stations with a building-top antenna installation may want to give some consideration to such a possibility.

In any event, a study should be made of the various measures of protection which may be afforded by zoning and other local regulations.

Programming Plant

A clear view of the station's future program structure is invaluable at this stage of development. The greater depth of focus the planner can obtain, including the reasonably distant as well as immediate future in his visualization of program operations, the greater chance there will be of building a plant which will need a minimum of major alteration.

Deciding which of television's program sources (network, film, remotes, and studios) will be employed is not enough. It is important to know the extent to which each of the four program sources will be employed. A program philosophy for the new station now becomes essential.

The fact that outlining a completely firm program pattern is patently impossible accounts for the emphasis given earlier to the importance of flexibility. On the other hand, there will undoubtedly exist some fairly clear idea of the emphasis to be given programs from each of the program sources.

The availability or absence of network programs is an obvious factor. Stations planning to use large quantities of film, including perhaps off-the-tube recordings of network features, will want to provide more operating area in the projection department than a station which expects to use film only for commercials and to fill unavoidable gaps between other types of programs. There are cases in which outside pickups are featured to such an extent that two mobile units have been found necessary. This point is most pronounced in the decision concerning studio size.

With these thoughts in mind, the discussion of space requirements in the ensuing paragraphs can be interpreted properly. As always, the thinking here is in terms of average minima. Depending upon the emphasis to be placed upon each of the program sources to be incorporated in a plant, it is logical that these requirements may be shaded slightly or increased considerably.

We will now look at the program sources and control room needed to mix any combination of the four.

Program Nucleus

The heart of a television programming plant is a synchronizing generator.

Closely associated with the sync generator usually is a monoscope,* a simple, one-picture camera used extensively for visual station identification and test pattern transmission.

These two pieces of equipment, along with amplifiers, monitors, power supplies, turntables, audio oscillators, and switching gear, both audio and video, comprise the basic control center of a television programming plant. Around this center is built the master control unit.

An announcers' booth is operated in close conjunction with this control setup to complete a "programming nucleus." Such facilities and functions will be found, in one form or another, at every television station.

Onto this torso may be appended any combination of the four basic programming sources. Naturally, the more sources a station uses, the more complex this control center will become.

When film is used, the camera control apparatus fits logically into this unit. Only in extremely large installations are separate film control rooms to be found.

The mobile unit's microwave relay receiver can be housed here advantageously, reception conditions permitting.

Network service requires certain terminal equipment. While the communications company's coaxial line amplifiers or radio receivers need not be in the control room itself, they are frequently. Regardless, space must be provided for these common-carrier installations, and these needs will logically fit as part of the master control operation.

A major problem is posed when the programming plant contains a studio: Will the foregoing equipment, which is of the genus master control, be placed in the same room with studio control?

In an elaborate plant with a wealth of facilities, the answer will be a simple no. The question is closer when there is only one studio and a concerted effort is being made to keep costs at a minimum.

Considerable duplication of equipment can be avoided if the two control operations are

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*Or a "Flying Spot" camera, now commercially produced, which permits transmission of slide transparencies without more elaborate film equipment.

housed together, and the possibilities of some personnel doubling in brass are increased.

A number of stations now on the air do utilize, or did utilize at one time, a single location for all their programming control. During periods of relatively simple activity, when there is ample off-the-air time to accommodate all rehearsals, there appears to be no doubt that such an arrangement is advantageous.

The success of such a combined operation depends largely, however, upon simplicity of program schedule. When it becomes necessary to conduct studio rehearsals while other program operations are in progress, complications begin to set in. Additional manpower and equipment may become essential. If so, economy is lost, and confusion can be avoided by separating studio and master control.

With these thoughts in mind, stations which decide to begin with one control room may want to provide space for a divided operation in the future when activity is intensified.

Where there are multiple control rooms, certain advantages accrue from having them located as closely together as possible. Use of the same test gear in both is facilitated, for example.

Switching systems can be arranged so as to permit integration of all program sources at either master or studio control--if it is desired.

Exact space and layout requirements depend to some extent upon the make of equipment to be used. This is particularly true in the control center, where a large amount of equipment must be fitted into a comparatively small area.

Decisions should be made as to exactly what pieces of equipment will be used and plans made accordingly. Assuming that the initial installation will have some degree of permanence, it will certainly be desirable to provide extra room for future expansion.

Looking for average minimum requirements, however, this general rule-of-thumb may be found to have some practical value:

Start with about 150 square feet of space for basic control.

Add about 50 square feet for an announcers' booth.

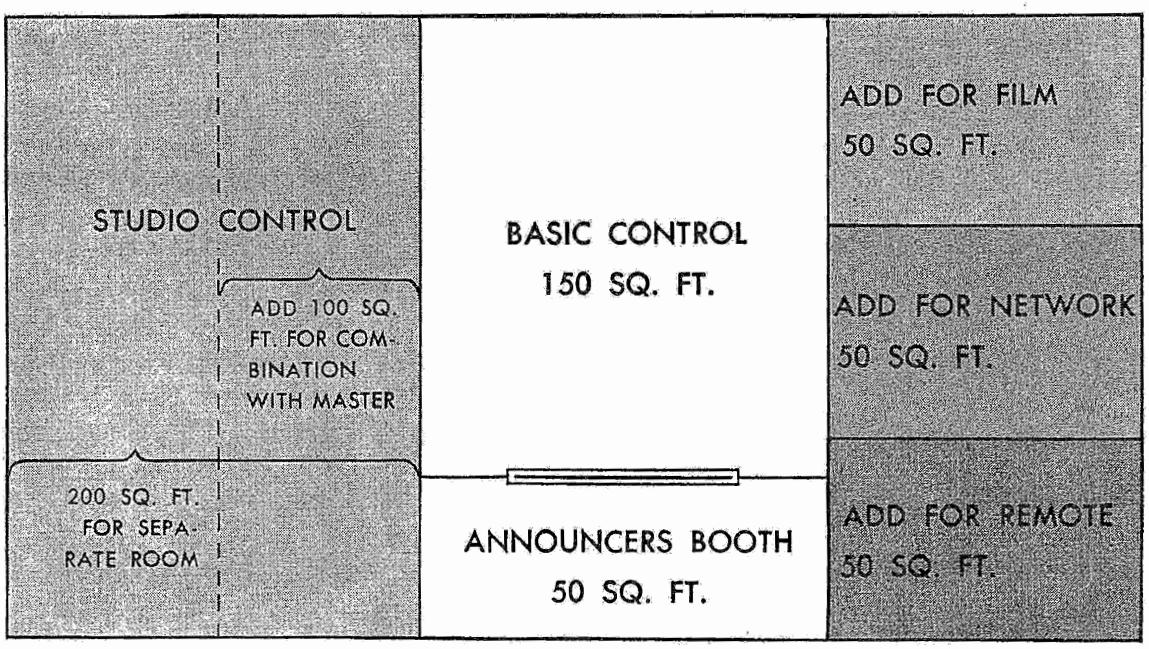
Add 50 square feet for <u>each</u> of these <u>three</u> program sources; network, remotes, and film.

Add 100 square feet for a two-camera studio control setup which is combined with master control.

Add another 100 square feet if studio control is to be separate from master control.

Although controls for a third camera will occupy only a very few additional square feet, a three-camera installation, by its very nature, is likely to be more lavish and require something like twice the amount of space shown above for studio control.

Ceiling height is not a critical factor in the <u>master</u> control section, since seven-foot-high racks will be the tallest items of equipment to be accommodated. It will be well to keep in mind, however, that a considerable amount of heat is generated by an extensive control installation;



greater ceiling height will be valuable in heat dissipation.

The desired shape of a master control room will also be determined to some degree by the type of equipment used, but almost any installation will be composed of some combination of equipment racks and one or more consoles.

Sync generator, monoscope, amplifiers, some monitors, patch panels, microwave receivers, and other miscellaneous apparatus will normally be rack-mounted.

Special switching instruments, film camera controls, audio control equipment, and master monitors will usually fit together into one or more consoles.

AT&T terminal equipment is also rack-mounted but usually in special units which are only about four feet tall. One rack of amplifiers is required for each incoming (network, remotes, etc.) and each outgoing (network feeds, transmitter, etc.) line.

Actually, there is no striking difference between the physical space and layout needs of a video master control room and those for a comparable aural operation--except that there is apt to be a lot more of everything when the visual and the aural are combined in television.

Studio Control Room. The first step in designing a studio control room is to decide what the role and position of program producers* shall be. If there will be a technical director, or switcher, and assistants to the director, needs will be greater than the more modest situations in which the producer does his own switching.

It may be well to keep in mind that a number of stations feel strongly that the producer, especially on studio shows, cannot do his own switching and maintain program quality. Consequently, even stations which are not planning to use special switchers may want to provide space and facilities for this activity in the event it should prove essential in their particular operation.

In addition, those stations whose program activities normally permit the director to do his own switching may find that on special features from time-to-time the services of a specialist in this job are indicated. The arrangement can be such that operation with or without a special switcher is optional.

Next step is to decide who, if anyone, must see into the studio from the control room. There is some disagreement among stations on this point, ranging from a few who feel it is not really important whether or not anyone can see into the studio, over to the other extreme where it is felt everyone in the control room should have the best possible view of the entire studio.

Acceptors of blind operation feel it is more important for both technicians and program people in the control room to concentrate on what they have on the monitoring screens rather than on what they could see through the studio window.

While not disagreeing exactly with the keep-your-eyes-on-the-monitor school, proponents of the other extreme feel that there are certain times--emergencies as a prime example--when the best possible vision for everyone concerned is invaluable.

In the middle is a group of stations which follow a compromise course. They believe that camera control men should be so placed that they must watch their monitors exclusively, but that directors must be able to see into the studios, at least when the occasion warrants.

It is difficult to disagree with those who point out that on extemporaneous programs, for instance, the director may miss much that is of interest unless he is able to observe activity in the studio directly and instruct his cameraman accordingly.

On the other hand, there is ample evidence that blind operation is certainly possible. Some stations do it, and most remote programs, the most unrehearsed of all originations, are usually handled blind from the mobile unit.

There appears to be a definite consensus, however, in favor of visibility, at least for directors, whenever it is feasible.

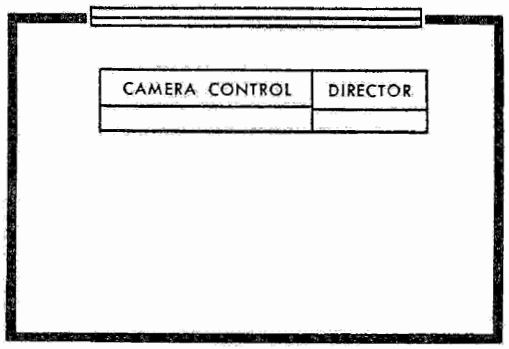
With these two dominant factors in mind, studio control rooms are usually laid out in one of four or five different ways:

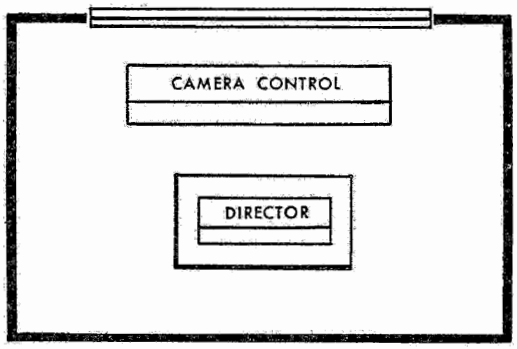
Simplest arrangement of all calls for only one console, placed in front of and facing the studio window. The director sits alongside his camera control men. One disadvantage is that the director gets only an angled view of the individual camera monitors.

To overcome this handicap, a number of stations place the director in a raised position immediately behind the main console. Here he gets a more direct view of the monitors and can see into the studio over the heads of the operators.

Biggest disadvantage of this system is that the director--since people are working in front

*Since it is the general trend for individual stations not to have both a producer and a director assigned to a given program and working in the control room simultaneously, the two terms will be used interchangeably.





of him--must sometimes be an acrobat in order to see the particular monitor or other view he needs at the moment. Not only is his observation of the monitors sometimes obstructed, but they are apt to be a little distant at best.

These problems are often overcome by putting two or more special monitors immediately in front of and below the director. One of these always carries the on-the-air picture, the other (or others), previews of upcoming shots.

All of these are systems in which everyone is afforded the best possible view of the studio. When it is not considered important that camera control men be able to see the studio, this basic console is moved away from the window, usually to one side. In the simplest setup of this type, the director sits at an angle which permits him to see both the studio and the monitors.

More elaborate version of this layout calls for the director to have two or more special monitors and sit directly in front of and facing the studio window.

When visual monitors are placed directly in front of studio windows, high intensity light from the studio floor may interfere with proper viewing. Various devices, including special glass to reduce glare and amount of incoming light, shields over the monitors, specially-constructed consoles, and other arrangements, are in use to meet this problem.

It is easy to find flaws in any of these arrangements. Sitting alongside his camera control men, the director gets a poor view of certain monitors. Behind them, his view is sometimes obstructed. With camera controls to one side of the window, and the director placed at an angle to see both, he may develop neck motion not unlike a tennis fan sitting on the net line. And with monitors jammed up against the studio window, he may be bothered by contrast between viewing screens and studio lights.

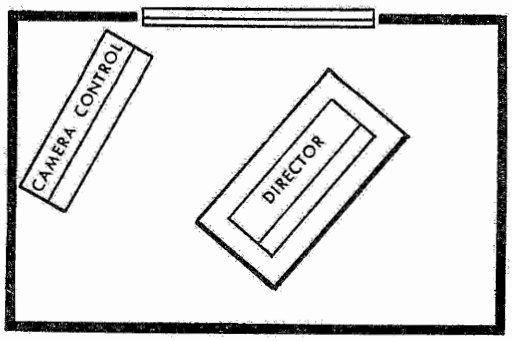
Ceiling height is a factor to be considered in studio control room design, especially if the director and his immediate associates are to work on a raised platform.

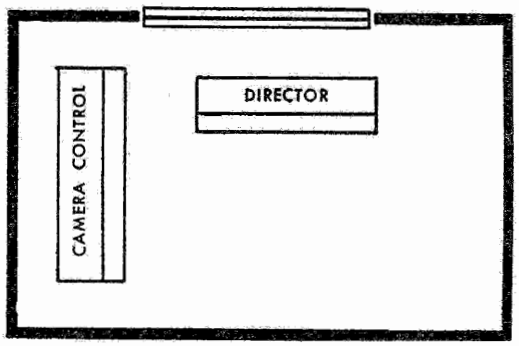
Something like three feet seems to be standard elevation for such a platform. With a ceiling height of eight or nine feet, a problem can easily arise. Ten feet is likely to be the minimum.

It is not difficult to arrange the room in such a way that any equipment racks which may be needed in studio control are on the lower floor level. Therefore, the only problem is to obtain sufficient head room for personnel standing on the platform.

Securing plenty of ceiling height is not difficult usually, since the studio proper will almost surely be abnormal in that sense, probably extending through two floors of average dimensions.

Some stations take advantage of this fact and raise even the lower control room level two or three feet above the studio floor. Some





studio designers point out, however, that the control room should not be raised all the way to the second story level, unless perhaps the studio is enormous. Extreme height creates an angle of view which reduces visibility sharply in the studio area immediately below the control room.

Maintenance Shop. Schedules and facilities for maintenance are a major topic of interest among television station engineers. They urge uniformly that careful advance thought be given the subject.

Desirable size of a maintenance shop will fluctuate according to the amount of equipment to be serviced, naturally. A workable rule of thumb for determining average minimum needs runs like this:

BASIC	FILM	REMOTE	STUDIO
100 SQ. FT.	50 SQ. FT.	100 SQ. FT.	100 SQ. FT.

Start with 100 square feet. Add fifty feet for film equipment servicing. Add 100 each for studios and remotes.

This programming plant maintenance shop should be located so that remote gear can be unloaded easily. If station layout makes it impossible to do this and keep the shop conveniently located with respect to other programming equipment, two shops may possibly be indicated. If so, start with 100 square feet in each case and add according to the formula outlined above.

If programming maintenance facilities can be combined with the transmitter shop, which is separately provided for in this plan, so much the better. Economy can be achieved.

Network

Since terminal and related apparatus for incoming network service will be housed in the main control room, or at least in space allocated for that purpose, no additional operating area need be provided for handling network programs.

Film Facilities

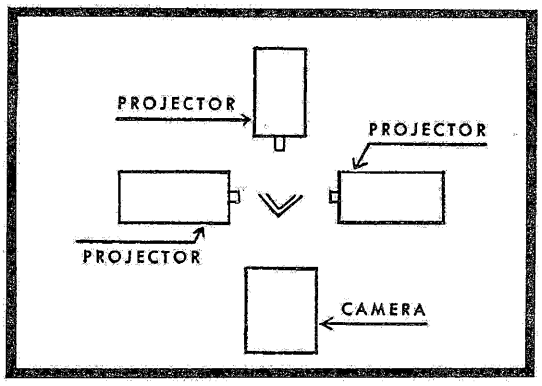
A careful examination of local ordinances on fire prevention, as they relate to the handling of motion picture film, is a good starting point in the planning of projection and preview rooms. Rigid regulations devised originally for theaters will often apply to television stations.

Provisions for use of 16 mm film will be very simple, as a general rule. Stock used for this size is nearly always non-inflammable.

Most 35 mm prints are highly combustible, however, and meticulous precautions against fire are indicated. Projection rooms, for preview as well as on-the-air operations, must be completely fireproof. Special vaults are normally provided for film storage.

Some stations planning to use only 16 mm film at the outset have found it desirable to design their projection rooms to 35 mm standards in order to avoid rebuilding later if and when they find the larger scale desirable.

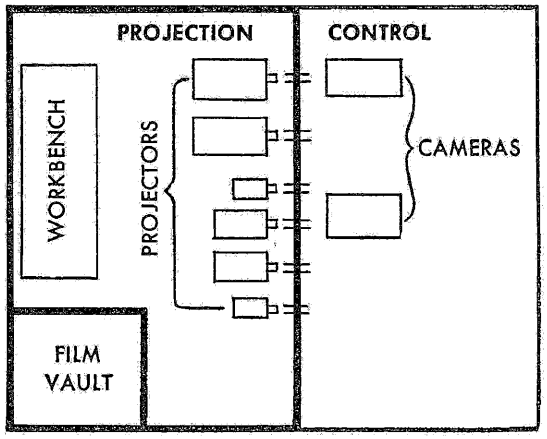
With 16 mm equipment, projectors and film cameras are usually housed in the same room. Only the camera control gear is in the control room. The same is very often true when 35 mm projectors are used. In these cases, two or more projectors are clustered around a single film camera, with a mirror arrangement permitting instant changeover from one projector to another.



On the other hand, some local laws require, and some stations prefer, a fireproof wall between their 35 mm projectors and film cameras. Under this arrangement, control and projection rooms are usually side-by-side, and the entire camera chain is housed in the control room. This involves projecting the picture through small ports in the fireproof wall separating the two rooms, in this fashion:

Space needs in the projection room begin around 200 square feet. This would be ample for a modest outfit consisting of one camera, two 16 mm projectors, and one slide projector, plus a worktable, monitor, and small storage cabinet.

About 50% more space than this is required for a 35 mm installation consisting of the same items of equipment, plus a storage vault. The projectors are larger; the vault is extra; and a 35 mm operation is inherently more elaborate.



An extra camera with a cluster of auxiliary equipment, such as spare slide projectors, balopticon, etc., can be added to either of these units within something like 100 square feet of additional space.

Consequently, these estimates are based on an average need of 200 square feet for a two-projector, one camera 16 mm installation; 300 square feet for a similar 35 mm outlay; and 100 square feet for an auxiliary camera cluster.

In those cases where the cameras are in the control room, separated by a fireproof wall, the projection room maybe somewhat smaller than this figure, but the saved space must be added to the program nucleus.

Preview Room. The program department will need a place to screen film in advance, to time, edit, cut, and splice the reels before they are ready to go to the projection room. The sales department will want a place to preview film for clients, to check slide and film commercials before they are finally approved, and do a variety of other chores in connection with sales of film features. Using the main projection facilities for these purposes is not usually feasible.

It is not at all unusual to see directors and salesmen using the walls of their offices for these purposes, at the present stage of development, but a special preview room is a useful arrangement which experienced stations turn to whenever possible. If 35 mm film is used, a special fireproofed room is essential.

One station which is building new studios, incorporating features based on several years of operation, is placing its special clients' room alongside this previewing room and providing a port in the wall between the two. In this way, slides and motion picture film can be projected through the port onto a screen in the clients' room, thereby putting projection equipment to double duty.

The desirable size of a preview room will bear some relationship to the extent of projection room facilities. One station which uses both 16 and 35 mm projectors has separate cubby-holes for previewing each size film. This gives more freedom in using the facilities.

Something like 150 square feet will probably be the smallest amount of working space that you will want to provide in a preview room. A station which also uses 35 mm equipment will probably have an operation warranting about twice that much space, or more.

Film Production

Stations which plan to shoot motion picture film locally and process it themselves will need extra room in which to house this activity. Space needs outlined above apply to film projection, rather than production.

In any operation, motion picture production facilities can be useful, especially for filming commercials, titles, and special features. Where local newsreels are to be emphasized, this phase of the planning takes on particular importance.

Some stations farm out this entire activity to commercial concerns, thereby eliminating the need for film production facilities in their own plants. This is especially true of stations which do not feature newsreels, although a few stations--in cities where a local processing outfit is

16 MM 1 CAMERA 2 PROJECTORS AND ASSOCIATED FACILITIES 200 SQ. FT.	AUXILIARY CAMERA CLUSTER 100 SQ. FT.	35 MM 1 CAMERA 2 PROJECTORS AND ASSOCIATED FACILITIES 300 SQ. FT.

geared up to high speed--have been successful in handling even this latter undertaking on a contract basis.

Generally, though, stations which specialize in newsreels handle their own film production from start to finish. They have their own cameras and all the laboratory equipment needed to process the film from the time it is exposed until it actually goes on the air.

Most stations use a standard processor, which carries out the entire processing of 16 mm film in one continuous operation. Exposed film is fed into the machine and a completed product comes out a few minutes later ready for editing and projection.

A simple, one-processor installation of this type, along with a modest area for splicing gear and film storage as well as space for mixing the developing chemicals, requires approximately 150 square feet as a minimum.

Although there are stations which find two processors necessary to meet their demands for speed, quantity, and insurance against operating difficulty, very few stations have more than one processor. At least one station which has given great emphasis to film production, especially newsreels, reports that it has operated for over a year with only one machine, on a very demanding schedule, and has had no trouble with breakdowns or other mishaps.

If a second processor is used, space must, of course, be increased accordingly. More space will also be necessary if a station expects to find multiple copies of some film essential.

A station planning to supply other organizations with copies of its newsreel footage, for example, would probably find a special printing machine necessary, in order to make several copies of each item.

For normal operations, though, the processor will turn out a master copy which can be used directly on the air. This is known as a "reversal". A standard processor can turn out positives and negatives as well as reversals.

Printing and associated activity will require something like an extra 100 square feet--in addition to the 150 square feet specified above for processing.

Expansion. In the midst of examining the broad outlines of a television operation, this may be a good point to pause for a moment and restore perspective by looking closely at one of the many small operational problems which crop up after a station gets underway.

A visual time signal can be a valuable station-break feature. An effective presentation is to show an actual clock, so that the second hand may be seen moving precisely up to the minute mark.

The immediately obvious way of doing this, of course, is with a studio camera. But even at stations where these cameras are conveniently located for such a purpose, operating studio equipment for an occasional odd feature can, at times, be an expensive proposition.

In this case, as in others, a balopticon is a useful piece of equipment. With it the film camera can be used for picturing the clock and its associated commercial or station identification, without actually putting anything on film.

Should you be interested in the principle, an intense light is reflected off the clock, through a lens, and focused on the tube of the film camera--in the same manner that motion picture projectors focus their pictures on the camera tube.

The clock is only one example of work the "balop" can do. It also affords a convenient and less expensive means of reproducing still pictures directly from glossy prints, art work from the original drawings, etc.

Principles of the balopticon aside, though, our point is that stations seem to be constantly finding new gadgets which simplify their problems and increase the station's effectiveness. The original blueprints should be drawn to accommodate this natural growth.

While it is true that a one-film-camera station may find that it can "multiplex" (with mirrors) a balop into its single channel, it is also true that over a period of time the station will probably want to add other projection room items, such as, perhaps, a kaleidoscope (which permits projection of moving patterns onto a screen that would otherwise be still), and soon two film cameras would become essential.

Many stations consider two film camera chains essential right from the start as insurance against loss of commercials resulting from trouble in a single-chain installation.

New inventions and equipment improvements must also be expected over the normal life span of a television plant. While there were no revolutionary changes in equipment during 1948, certain changes will almost surely come during the next few years. True, new models do not make existing equipment useless, but there is always the possibility that the improvements will be so great that stations will find replacements or additions advisable.

To cite an example in the area just discussed, a new camera is being developed in the laboratories which some people believe will be superior

to the iconoscope for film reproduction. If so, space and operational requirements in the projection and control rooms might be altered.

No doubt this point has been belabored, but it is advice which experienced telecasters emphasize: keep your plant flexible; prepare for change and expansion, in the film and all other departments.

Remotes

Inclusion of remote origination facilities in the programming apparatus of a station involves space and layout considerations and three points:

Storage area is required for the vehicle, or vehicles as the case may be.

Maintenance shop capacity must be expanded so as to permit servicing of field equipment.

Receiving instruments--line terminals, equalizing amplifiers, cables, monitors, microwave relay gear--must be housed.

Space for the latter two functions has been earmarked in our previous discussion of the program nucleus. They will be integrated with similar needs created by other program sources.

Here then only vehicular storage space will be considered.

A composite of the mobile units sold by regular equipment manufacturers would have overall dimensions running something like these: twenty-five feet long, bumper-to-bumper; eight feet wide; and ten feet tall, at the extremes. Such a vehicle would completely cover 200 square feet. To provide 2-1/2 feet of clearance all around the vehicle, plus 50 additional square feet for miscellaneous storage, this square footage jumps quickly to 500.

Stations which build (or have specially built) their own mobile units, starting with large truck or bus chassis, frequently end up with vehicles having proportions somewhat larger than those described above. Even the so-called standard models are changed from time-to-time. It is important, therefore, to know the exact dimensions of the truck to be housed before any close decisions are made.

A few stations have found that two mobile units are essential to meet their requirements, a decision which has perfectly obvious effects upon garage needs. An additional 300 square feet, in combination with the original 500 should do nicely for a second unit.

More commonly accepted is the need for an auxiliary vehicle to work with the main mobile unit. Several stations have found a small pickup truck, station wagon, or other vehicle of this size essential for use in transporting personnel to and from distant or out-of-the-way pickup points, advance surveying of locations, and other odd jobs for which the main mobile unit is totally unsuited.

One station which scrutinized its costs very closely found that it could save money by purchasing a small pickup truck. Savings came primarily in the form of fewer manhours wasted. Prior to purchase of the "tender," the entire remote crew sometimes had to ride to location in the main unit, with the result that several people were on the scene several hours too early.

About 200 square feet should be ample storage space for most auxiliary vehicles.

While there is disagreement among experts concerning the usefulness of mobile power plants for remote pickups, station builders may wish to investigate their possible value in the particular operation being planned and, perhaps, provide space for such an outfit in the part of the plant devoted to field facilities.

Mobile generators have been tried and abandoned in some instances because the frequency of their power output could not be maintained at a stable 60 cycles per second. In at least one case, however, a station has found that it can secure reasonable steadiness and tolerate the slight variations in frequency.

Technical experts of this station report that the discrepancy between the frequency of city current and its self-generated power is no greater than the difference between its city current and power being used at network origination points in other cities.

If it is decided to use a generator, space should be provided for it in addition to the other items accounted for here:

First mobile unit--500 square feet.

Second unit--300 square feet.

Small tender--200 square feet.

Building Studios

The television station construction permittee who can look far into the future and visualize clearly what his studio programming schedule will be like is indeed a fortunate, and probably nonexistent, person.

The importance of plant flexibility, emphasized throughout this section, is most readily apparent in the studio considerations. Here the needs rise and fall sharply in proportion to the amount of time devoted to studio programs. (With a couple of motion picture projectors, for

instance, it would be at least possible to handle almost any quantity of film the station may wish to broadcast, but studio requirements do not maintain such equilibrium.)

The most immediately important objective, therefore, is to tailor the studio layout as closely as possible to the station's program structure.

Is it planned to do dramatic programs? They make great demands on studio space.

Are across-the-board shows planned which need pretty much the same set every day? A homemakers' program with a kitchen setting might be an example. If so, it may be wise to provide space to keep such sets intact, avoiding the expense of striking and resetting them several times a week.

How will audience participation programs and other shows be handled where an audience must be seated? If there is only one big studio, with sets and props all over the place, accommodating numerous program guests can be difficult and expensive.

Are vaudeville-type variety programs planned? If so a raised stage is desirable with curtains, wings, and many of the provisions of a legitimate theater. Intimate night club style variety shows can be produced more easily on the main studio floor.

Keep in mind, too, that a one-minute local live spot announcement can be as demanding upon studio space as a more elaborate production.

Studio Space Requirements. The rapid expansion of television has brought with it a decided trend toward larger and larger studios, not only among network production centers but among individual stations as well.

Granting that the local programming situation is the controlling factor, let's scrutinize existing operations in search of some general guidance:

Among non-network owned stations on the air at the beginning of 1949, the range in floor area for main studios was from slightly more than 500 square feet to more than 4000 square feet. About two-thirds of all stations on the air had principal studios with square footage ranging between 1000 and 2000. Of remaining stations, about half had smaller studios and the other half had more than 2000 square feet.

Anticipating with reasonable accuracy the maximum number of staging areas, with sets actually in place, which a station will need at any one time is the first key to matching studio facilities and program structure. This may be an impossible objective, true, but at least it gives us something definite at which to shoot.

If it is planned to originate, for example, an early evening children's program followed closely by a regular news program which uses a fairly elaborate set, it will probably be found that two staging areas are essential.

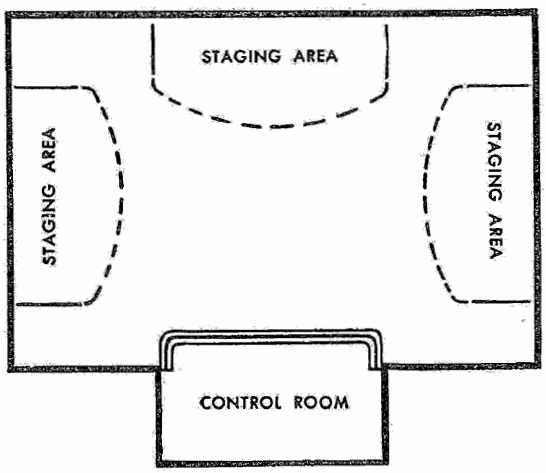
Perhaps, as in the example cited above, there may be a daily homemakers' show which requires a permanent set. Or there may be any number of other sets and scenes which it would be desirable to keep in position on a semi-permanent basis. Like one station, there may be a series of commercials requiring use of an actual filling station scene on a regular basis. The question raised here is whether it is less expensive in the long run to provide more space than to be continually striking and resetting the same scene.

Dramatic programs will often require several sets, and they must be in place for rather extensive periods to accommodate lengthy rehearsals. Audience participation programs may require the use of more than one staging area--one area for the performers, another for the audience.

The tendency among individual stations to use simple, impressionistic sets does provide one means for reducing these needs. Another simple expedient is to provide curtains which may be used to divide staging areas into smaller units. Other methods of increasing the usefulness of studio space will undoubtedly occur to the designer, but he may want to let such developments prove helpful as natural expansion takes place, rather than counting on them from the first.

Once some estimate has been made of the number of staging areas which will be required, we can turn our attention to various studio sizes and see how many such areas each affords.

Stations with about 1000 square feet of studio floor area find that they can usually squeeze three pretty good-sized sets into that area--one at each end of the studio and a third along the wall opposite the control room, in this fashion:



If space falls a little under 1000 square feet, it may be wise to consider the third area as a spare for tight squeezes only. If space is too tight, cameras, microphone booms, floor lights perhaps, and other off-set equipment will continually be trespassing on the center stage while working the end areas. For these reasons, it may prove inadvisable to keep a set in place for long periods in the third space even when a full 1000 square feet are available.

As we move up from 1000 square feet, the number of staging areas is increased. Several stations with studios of 1200-1300 square feet find that they can accommodate four separate staging areas. This increases to six or eight when something like 3000 square feet are available.

It is safe to think of a single staging area as requiring between 300 and 500 square feet of space--so long as we are continuing to think about average station needs rather than those in network production centers.

More flexibility and operating elbow room is obtained by having two or more of these staging areas housed in a single studio. In this way it is possible to overflow the restricted areas when some elaborate show requires more space. And even in run-of-the-mill operations, the cameramen and other off-set people have more freedom of position.

When we group a number of staging areas within the same walls, though, schedule conflicts begin to arise, and another question is raised:

How Many Studios? Where local programming schedules are extensive, the advantages of having more than one studio are obvious. No matter how many staging areas a single studio may contain, rehearsing one program while another is being broadcast from there is not feasible. Even rehearsing two programs simultaneously becomes difficult.

Building and equipping two or more studios of goodly proportions is, of course, one happy solution to such scheduling problems, provided, naturally, that the amount and quality of production warrants the expenditure. Other than network-owned stations which also serve as major chain production centers, however, few stations have such elaborate facilities.

A somewhat more popular procedure is to provide a second, very modestly equipped studio for simple news programs, interviews, and other "intimate" programs.

Still, stations which have more than one completely equipped studio, built especially for television, are in the minority. Expensiveness of equipment and the fact that, with careful scheduling, so much can be accomplished in one unit has led most telecasters to this at-least-for-the-time-being decision.

Among stations with only one studio, four devices to alleviate the shortage of facilities have found fairly wide acceptance:

Installing at strategic spots curtains which may be lowered to divide the main studio up into smaller units. With this arrangement, two rehearsals may be conducted simultaneously, and, if the curtains are sufficiently sound-absorbent, one program may be rehearsed while another is actually being broadcast.

Building but not equipping a second studio. This additional unequipped unit serves nicely in some operations as a rehearsal studio. Preliminary planning and practice can be done here, thus cutting down the amount of time spent in the camera-equipped studio. In some cases the rehearsal studio is equipped with lights, making it possible to actually broadcast from there by bringing in field equipment.

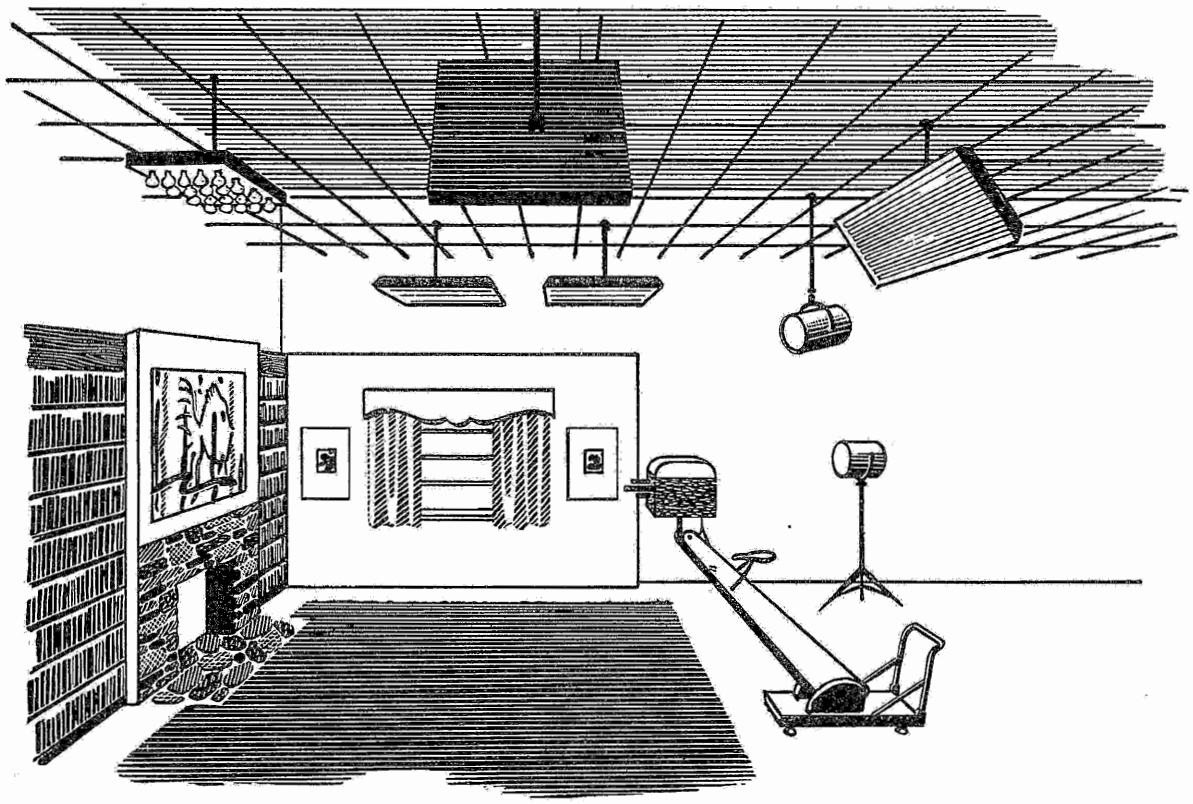
Preparing an aural studio for television use. In those operations where TV and AM or FM are closely associated physically, the installation of video circuits, additional electrical wiring to carry the load of lights, and some system of either mixing or adding audio circuits, frequently makes it possible to utilize the space for video during hours when it would otherwise be idle.

Utilizing a theater or some other existing auditorium for the origination of special shows. Mobile equipment is often used for this purpose. The addition of some special lighting will probably be necessary, however, and you may find it necessary to change camera tubes to obtain the best effect.

These last two devices sometimes offer a handy means of housing programs that require a studio audience, such as audience participation and variety shows. They may also provide a raised stage, wings, and other features of a legitimate theatre which are valuable on some features.

Ceiling Height. Putting television studios in office buildings where ceiling height is normally restricted to about nine feet is possible. Programs are being produced regularly and successfully under these conditions. However, it will be found that those responsible for such operations are the first to say emphatically that greater ceiling height is extremely desirable.

With a low ceiling, cameramen must be very careful to avoid getting overhead lights in their pictures. Thus the variety of interesting camera work which can be put into a program is sharply curtailed. If a crane-type camera dolly is available, this is particularly true. Under



a nine-foot ceiling, this valuable instrument cannot be extended to its full height, which normally permits shots down into a set.

Keeping microphone booms out of the picture is especially difficult with a low ceiling, and has the effect of limiting camera angles still further. Other disadvantages could be enumerated, but suffice it to say that we must look higher to find our "average minimum" requirement in this area.

On the opposite extreme, ceiling heights of 50 feet and more are in use. Motion picture sound stages are often that high, and some of them are in use for television. Even a few of the big studios built exclusively for television have heights approaching this figure. These are network production centers, though, and stations will rarely, under present standards and practices, find themselves dealing with ceiling heights measuring above the twenties.

Some of the governing factors are these:

Flats and other items of background scenery are usually about ten feet high.

If cameras are to have full freedom of movement, they must be able to shoot down into sets.

Lights will require two, three or more feet of vertical space above the camera and microphone operating area--exact amount of space depending upon type of lighting fixtures and arrangement used.

Cycloramas and other special scenic effects can take up additional space.

Spare overhead space will probably enable you to keep ropes, cables, and many other bits of paraphernalia off the crowded studio floor.

Taking all or part of these factors into account, something like 12 to 14 feet is usually accepted as the absolute minimum for satisfactory operation. The really desirable low point usually falls between 18 and 22 feet. Stations which have freedom of choice usually select heights in the latter vicinity but occasionally go on up to the high twenties.

All of this boils down almost always to a very natural solution: Let the studios extend through two floors. Twice the normal ceiling height of, say, 9 to 12 feet puts the studio ceiling in a very comfortable area.

Studio Design. Simplicity is the dominant motif in all television studio design. The objective is to provide the maximum amount of open working area. Organic encumbrances will be numerous at best, so any semblance of decorative froufrou is usually avoided assiduously.

Elaborate and glamourous acoustical treatment of walls, for instance, is futile. Scenery and draperies will nearly always cover the walls to a point well above head-height, nullifying or reducing the effect of sound treatment and covering any attractive design which may have been achieved. Standard practice is to use rock wool, held in place by narrow-mesh chicken wire, as the sound proofing material, and this treatment is most often seen around television stations. In some cases rock wool blankets cover the entire wall and ceiling area; in others, walls are covered only down to the normal top level of scenery. Stations in the latter group say the walls are always covered by flats, drapes and other scenery anyway. Some stations use asbestos sheeting around all or part of the lower wall area, below the scenery level.

A grille of pipes or angle iron is usually found in the overhead area of the studio, providing a means of suspending lights and other paraphernalia. Height and extent of this grille usually depends upon the type of lighting arrangement used. Curtains dropping from travelers in this grille can be used to give greater flexibility in cutting off sections of the staging areas. Some of the more elaborate studios have catwalks around the walls above the camera zone which give lighting technicians and other studio workers easier access to the overhead area.

Concrete seems to be the most popular material for studio floors, although heavy linoleum blocks are sometimes employed. Important thing is to have a substantial floor which will bear up under constant moving of heavy props, such as kitchen ranges, refrigerators, even automobiles, plus cameras, microphone booms, and the like. When cement is used, a smooth, waxed surface to avoid powdering has been found valuable.

Not only must the surface withstand this wear, but the structural stability must be such that vibration will not be transmitted to the cameras. As discussed earlier, microphonic effects can cause serious interference in the picture tube. Heavy cork under concrete has been used to minimize this possibility.

In this connection, some stations find that one-foot square markings etched into the floor are a boon to production people. When plotting motion, these stations find that the lines are great time savers for directors, cameramen, performers, et al. This is a controversial point, however, because other stations object to any pattern at all on the floor. They feel that the floor shows so often in their pictures that any visible markings become objectionable to viewers.

Large doors opening into the studio are highly desirable. The heavy props mentioned above are usually bulky. Room enough to drive automobiles on set is one common criterion. At least one station has made specific provision to drive its mobile unit into the studio, facilitating use of remote equipment inside. In some instance, huge doors on two sides of the studio are available. Freight elevators are essential, of course, when studios are above the ground level.

The most common studio shape is rectangular. Keeping the walls clear of protruding obstructions is considered desirable. A control room jutting out into the studio area can reduce appreciably the usability of floor space, although some stations prefer a slight protrusion to increase visibility.

At least at present, then, the layout and design of a television studio proper presents no vast and complicated issues. A simple box-like structure, without fancy adornment, and with straight, clean lines, appears to be ideal. Recall to mind the enormous sound stages of Hollywood and you will see the parallel. Even in fabulous, lavish Hollywood, these are simple, austere structures, designed to provide the maximum amount of enclosed space, with ample access to the outside world.

Auxiliary Space. The studio proper represents only a small part of the space needs created by studio programming. Storage area, carpenter and paint shops, dressing rooms, and space for other activities incidental to production of local live programs frequently occupy much more area than the studio itself.

One rule-of-thumb which has gained rather wide acceptance in the industry is this: floor area devoted to these auxiliary services should be at least 150% as large as the studio.

As would be expected, a number of today's stations have a higher proportion than this, and, on the other hand, some of them work with virtually no auxiliary space.

Stations in the latter category usually construct and paint many of their sets and props right in the studio, and store a substantial amount of scenery and stage property there, too. The net result is that, in terms of space used, the proportion is closer to the above rule-of-thumb than might be first expected.

The need for plenty of storage space, conveniently located, is a point which is stressed uniformly by all experienced television operators who use studios, large or small.

Initial decision to be reached when planning dressing rooms is whether or not individual cubicles will be provided for stars. Stations generally are inclined toward the practice of

having only two main dressing rooms, one for men and one for women, to be used by all performers.

Whatever the final decisions may be concerning exact amounts of space to be devoted to each of these supporting activities, their value will be increased by placing them as close to the studio as possible. When costume changes are necessary during a performance, distant dressing rooms can be a problem. Proximity of storage space, especially for items in current use, is of obvious importance.

If storage and studios are on different floors, freight elevators, or at least some system of ramps for slight elevations, will be essential. All connecting doors should be designed to accommodate the largest props.

Studio Lighting

Universal acceptance of the image orthicon camera for studio as well as field work has shifted the emphasis in studio lighting. Creating a sufficient amount of light is no longer the serious problem it was when iconoscopes were the standard studio camera. Present-day practices and theories revolve around getting the right kind of light in proper quantities in the right places to produce the best artistic effect.

Since iconoscopes are generally used now only with motion pictures, slides, balopticons, and other devices which make it possible to project intense light into the camera, the "ike's" characteristics need not influence any part of a television station's illumination plan.

Lighting specialists in the new medium have found no existing system which applies exactly in their field. Movies are made in short "takes" which seldom last more than two or three minutes. Continual rearrangement of lights between takes is possible. During a continuous television performance, few if any changes can be made.

Techniques of the legitimate theater correspond more closely to demands of video, in this respect, but again there is a vital difference: Television's ever-inquisitive cameras pry around and shoot from two, three, even four directions--contrasted with the audience's constant position in the theater.

In one important way, though, television's lighting needs have been moving toward those of the theater and movies. Stage illumination is designed to react directly on the human eye. Hollywood's procedures were devised to reflect light rays through a lens and record properly on film. Television lighting must be controlled so that it will create a pleasing and reasonably accurate impression when it has been reflected through a lens and fallen on the face of an electronic tube. The newest of these image orthicon camera tubes have color response which according to the manufacturer compares favorably with both panchromatic film and the human eye.

Improvements which are being made constantly in the pickup tubes alleviate many lighting problems, but contribute to the lack of uniformity which exists in much available literature on the subject. The switchover from iconoscopes to orthicons is a prime example, but the same effect extends to more recent developments.

Amount of Light. The term foot candle, a standard unit for measuring amounts of light, is the amount of light which a single candle throws on a one-square foot spherical surface at a uniform distance on one foot.

Demonstrations have shown that certain image orthicon cameras can produce a satisfactory picture with as little as one or two foot candles of light. It might be easy to assume, therefore, that normal indoor illumination levels would be suitable for studio purposes. Such is not the case.

True, these exceptionally low light levels will be useful for special effects. And they are indispensable for on-the-spot pickups where there just isn't any more light. But for all practical purposes, the television lighting man will be using greater intensities of illumination.

First of all, there is depth of focus. In television, as in photography, the less light there is present, the wider the lens opening must be. Axiomatically, the wider the lens opening, the shallower the depth of focus.

Take an example. A glee club is being televised. Its members stand several rows deep. If light levels are extremely low, it may be impossible to bring all rows into proper focus. With more light, the lens can be "stopped down" more, thus increasing depth of focus and making it possible to get a clear picture of the entire group. Maintaining focus on moving objects is much easier with greater depth of tolerance.

The need to develop contrast and shading of light is another of the several reasons why studio lighting levels will be higher than normal room illumination. Pictures will be more interesting if there is back, side, and other highlighting, in addition to general illumination.

Scientists doing research on orthicon tubes have found that light levels lower than about sixty to eighty foot candles are impractical for normal studio usage. Below that, planned lighting on the set can be too easily upset by stray rays spilling over from another staging area, or coming through an unexpectedly opened door, or from a variety of unwanted sources.

Even the latest studio image orthicons are designed, therefore, to function at optimum light levels of approximately 100 foot candles.

Kind of Light. Acceptance of the image orthicon for studio work has brought with it a corresponding increase in the use of fluorescent light sources. The relatively small amounts of light which can be created by fluorescent means were of little value in meeting the "ikes" enormous demands, but today's modest needs have brought the glowing tubes into their own.

Fluorescent light cannot be easily focused, however, and this disadvantage, among others, leads to one general pattern which now exists:

Some combination of fluorescent and incandescent light is the most widely used type of illumination among operating stations.

A few stations still use incandescent exclusively, and there is strong sentiment in some quarters for mercury-vapor lamps.

The latter have a long history in television, and have often been a subject of controversy. Their ability to produce high intensity light made them valuable for use with iconoscopes. In some instances, their use has been discontinued with the installation of orthicon camera chains.

At the same time, however, one of the foremost Hollywood lighting firms has recently made a series of tests, conducted in conjunction with an operating station, in which it concluded that cadmium-mercury lamps are highly desirable for television.

When incandescent and fluorescent light sources are used in combination, the most common method of mixing is to use fluorescent for general illumination, or "key" lighting, and incandescent for highlights. The glowing tubes provide a softer, more diffused light, with fewer harsh shadows--ideal for overall illumination. Incandescent is sharper, more dramatic and manageable, qualities which make it preferable for highlighting.

Blending key and highlighting is an artistic matter, and no precise formula for mixing the two has universal acceptance. The designers of the newest orthicon tubes speak, however, in terms of fifty or more foot candles of key lighting, with enough additional special light to bring the level up to approximately 100 foot candles.

If the studio light is unbalanced, the black-and-white picture produced by the camera will not be a faithful reproduction of the original. Some colors will be darker, others lighter than expected, depending upon the color deficiency of the particular light source.

Used alone, incandescent lamps furnish light that is heavily weighted in favor of the red end of the color spectrum and almost totally lacking on the opposite (blue) extreme. Fluorescent light is better balanced, but blues do predominate somewhat in some types, a fact which favors its combination with red-rich incandescent.

Some other advantages of fluorescent lights are these:

Less heat is produced, reducing the air conditioning load.

Fewer infra-red rays are radiated, increasing performer comfort. (Infra-red rays release their heat only when they strike a solid object, such as a performer. Therefore, no amount of air conditioning can remove this type discomfort. Heat filters do help.)

Higher efficiency produces more light per unit of electricity. This can permit economy in operation, even though initial cost is higher.

Scientists working on the project feel at the time of this writing that fluorescent tubes of 3500 degrees kelvin white or, perhaps, 4500 degrees kelvin white will prove to be the best source of general illumination for the latest orthicon camera tubes.

Incandescent lamps in use run the gamut from small "birdseye" bulbs, with self-contained reflectors, to enormous floods and focusing spotlights.

Placement of Lights. The big issue here is whether all lights will be overhead or whether there will be additional fixtures on the studio floor.

Mounting all lights on the ceiling offers some operational advantages which are easily apparent. Studio floors have a tendency to become cluttered even under the best circumstances. Cameras can have more freedom of movement if they are not crowded by floor lights.

Some stations with extensive production experience find that they can operate very satisfactorily with nothing but ceiling lights. One system which was designed with this point in mind is known as the "inverted pyramid" system.

On the other hand, a number of stations report that they have found floor lights absolutely essential to obtain the kind of artistic effect they must have. One of the motion picture lighting companies has concluded that ceiling-mounted lights alone will not suffice in television.

This is but one example of the highly divergent opinions which pervade this phase of television. Fortunately, floor lights are a plug-in proposition. They can be used, or not,

as the situation indicates, provided that power outlets are installed and the current they draw will not overload the wiring system.

Broadcasters entering television may find studio lighting the most foreign subject with which they must cope in the visual field. Those who have had experience caution against underestimating its importance. Even with hundreds of thousands of dollars worth of electronic equipment, no better image can be transmitted than the one which is focused on the face of the camera tube. Lighting determines to a very large degree whether that picture will be sharp, clear, and pleasing.

Even among experienced telecasters, however, there is no far-reaching agreement on the principles of television lighting. At the point where light is focused through the camera lens and onto the photosensitive surface of the cathode ray tube, electronics meets and joins forces with art and its variety of individual preferences.

* * * *

Conclusion

After decisions have been reached concerning the type of transmitting and programming facilities to be used, overall space needs for a television station can begin to take shape. Now that the individual components of a television plant have been examined, perhaps we can back away and get a long shot of the entire scene.

Outside the programming and transmitting plants, the principal space requirement is for offices. Here, of course, we move into an area where needs are determined by factors not peculiar to television. The amount of space to be devoted to personnel offices, and its arrangement, is something which is determined to a greater degree by the station's philosophy of operation than any other factor.

The same is true of space to be devoted to lobbies, reception rooms, lounges, and other special features which may be included in a broadcasting plant. In all these respects, the needs are no different from those with which aural broadcasters are already intimately acquainted.

Some overall guidance in this area may possibly be obtained however, from another rule-of-thumb which has been kept in mind during the building of several existing stations: Total space needs frequently run to about five or six times the amount of studio floor area used.

On this basis, a television station with a 1500 square foot studio would need a total area of approximately 9000 square feet. If we follow the rule-of-thumb stated above for determining auxiliary studio space needs, some 3750 square feet of this total would be required for the studio and its associated storage area, dressing rooms, carpenter shops, etc.

Any such formula must be used with extreme caution, of course. Stations utilizing network, film and remote program sources extensively, and using only a tiny studio for intimate programs, such as interviews, news shows, and the like, would obviously find such a proportion completely out of the question. In some cases it would not work at all--for stations without any studios, for example.

But most stations do have studios of substantial size, and it is quite true that live talent studios are the dominating influence in the building of a television plant.

This brings us back to the major theme: intelligent planning of a television station's physical outlay depends largely upon the possibility of visualizing to the clearest possible degree that station's future programming structure.

INTERCONNECTING FACILITIES FOR BROADCASTING

(Revised and Amended as of August 1949)

(The material in this Section was prepared by the American Telephone and Telegraph Company and was derived in part from the results of cooperative activities with the Columbia Broadcasting System, the Mutual Broadcasting System and the National Broadcasting Company.)

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PART 1 - GENERAL

With a few exceptions the interconnecting circuits used in audio and television broadcasting - between pickup points and studios, between studios in different cities and between studios and their associated transmitters - are furnished by the facilities of the telephone companies. The transmission of broadcast program material over these circuits and networks requires a certain amount of transmission supervisory activity in which the broadcasters and the telephone company are mutually involved.

The common problem of the telephone company and the broadcasters in this connection is the transmission of audio or television programs from the point of origination to one or more transmitting stations throughout the country. The ultimate objective is the transmission and reception of these programs without noticeable loss of fidelity compared with the original production. Obviously, there are a great many factors both physical and economic which stand in the way of full attainment of this objective. The development of new equipment, the adoption of new methods, and the increased knowledge of line transmission phenomena, however, all contribute toward the better control or elimination of the factors and permit a closer approach to the ideal.

In this Section of the Engineering Handbook will be a description of the various types of services offered by the telephone companies as well as a discussion of principles and practices which will assist the broadcaster in obtaining optimum results with these services. A statement of rates and charges for these services is beyond the scope of this Section and for information on these matters reference should be made to the local telephone company.

It is planned that additional parts will be issued in this Section to cover new aspects of broadcasting as practices become sufficiently well stabilized to warrant formal treatment.

PART 2 - COMMON TERMINOLOGY

In order to facilitate a proper understanding between the representatives of the broadcasters and the representatives of the telephone company who deal with the technical problems of interconnecting facilities the following terminology has been established.

BROADCASTING TERMS

1. Studio

In general a studio consists of an enclosed space specially arranged and permanently equipped for use of performing groups with their attending studio technicians, engineers, or program control operators who regulate or control level transmitted from this point for each specific program. Studios may be on the same premises with master control or at other fixed locations.

2. Master Control

This is the central point of a broadcasting plant at which supervision is exercised by the broadcaster over program transmission. It is also the main point with which the telephone company checks volume or video signal level.

3. Transmitter

Unless otherwise qualified this refers to the audio or television broadcasting transmitter complete with power, audio, video and radio equipment and radiating system. In a few cases where this point is connected by audio or video channels directly with a test room, the telephone company checks volume or video signal level with this point.

4. Broadcasting Plant

The combination of 1, 2, and (where on same premises) 3 above.

5. Field Pickup - Remote Origination

These terms indicate a point of program origin outside of the regular studio location, at which the same functions are performed as at a studio, but where portable pickup equipment is used. The telephone company checks volume, or video signal level, with this point when program is transmitted from it directly to a telephone toll office.

TELEPHONE COMPANY TERMS

1. Telephone Company

In this Section this term refers to a Bell System Telephone Company, either an Associated Company or the Long Lines. Where other than Bell System Telephone Companies are involved, there may be instances where practices differing from those discussed in this Section will prevail, and in such cases, it is desirable to reach a mutual understanding regarding local practices.

2. Associated Company

This term refers specifically to an Associated Bell System Company whose function is to conduct that part of the various services, including program transmission which, in general, do not extend outside the limits of its particular service area. The Associated Companies are -

New England Telephone and Telegraph Company
Southern New England Telephone Company
New York Telephone Company
Bell Telephone Company of Pennsylvania
Diamond State Telephone Company
New Jersey Bell Telephone Company
Chesapeake and Potomac Telephone Company
Chesapeake and Potomac Telephone Company of Baltimore City
Chesapeake and Potomac Telephone Company of Virginia
Chesapeake and Potomac Telephone Company of West Virginia
Southern Bell Telephone and Telegraph Company
Ohio Bell Telephone Company
Michigan Bell Telephone Company
Indiana Bell Telephone Company
Wisconsin Telephone Company
Illinois Bell Telephone Company
Northwestern Bell Telephone Company
Southwestern Bell Telephone Company
Mountain States Telephone and Telegraph Company
Pacific Telephone and Telegraph Company
Cincinnati and Suburban Bell Telephone Company
Bell Telephone Company of Canada

3. Long Lines

This term refers specifically to the Long Lines Department of the American Telephone and Telegraph Company. The function of the Long Lines Department is to conduct that part of the various services including program transmission which, in general, interconnect the territories of the different Associated Bell System Companies.

4. Test Room - Toll Office

As referred to in program transmission service activities, these terms usually refer to a long distance telephone office where the loops from the local broadcasting plants connect with the sound or television program network circuits. This is the office with which the broadcasters' operating personnel communicate in reference to routine program transmission matters. In most cases this office is in the same city with the broadcasting plant but in a few cases it may be in a nearby city on a main telephone route.

5. Loop

In this Section this term may refer to either of the following:

a. Local loops, i.e., the audio or video channels connecting a field pickup point with the broadcasting plant, or interconnecting various units of the broadcasting plant within a local service area.

   The circuits between the main studio and its associated broadcast transmitter are commonly referred to as "studio-transmitter" circuits.

b. Network loops, i.e., those connecting a broadcasting plant or a field pickup with the telephone company test room at which point connection is made with an intercity program circuit.

6. "Line" and "Drop" Terminals

These terms refer to those terminals of equipment facing toward and away from the line, respectively. For example, the "line" side of a coil on a loop is that facing the loop, and the "drop" side is that facing the other office equipment.

PART 3 - AUDIO AND VIDEO TRANSMISSION CHANNELS AVAILABLE TO BROADCASTERS

The following types of audio and video transmission channels are generally offered by Bell System Companies, subject to the availability of facilities.

Audio

Interexchange Channels, providing for the use of program transmission facilities for the transmission of program material, are furnished under the schedule classifications shown below:

Studio-to-Transmitter Channels are not provided under the above schedules. The requirements of such facilities vary widely as between cases and the channels are provided on a basis to meet the particular requirements of each case.

Local Channels are furnished under the Schedule F classification which provides for program transmission facilities within a program exchange area between stations, or between stations and the point of connection with interexchange channels.

Video

Interexchange Channels are furnished with a frequency range of approximately 3 megacycles for monthly use and for occasional use.

Local Channels are furnished with a frequency range of approximately 4 megacycles for monthly use and for occasional use.

Studio-to-Transmitter Channels are furnished with a frequency range of approximately 4 megacycles for monthly use.

Note: Specific service offerings are set forth in tariffs of the Bell System Companies.

To further this mutual understanding the practices and procedures described in this Part are presented as the results of experience which has resulted in generally satisfactory service.

PART 4A - PROGRAM LOOP TRANSMISSION AUDIO CHANNELS

The common meeting ground of the telephone companies and the broadcasters is on each telephone loop interconnecting them and it is here that the principal need for uniformity of thought and practice exists. With the benefits of a uniform type of volume level indicator (See Part 5 - The Standard Volume Indicator) and with proper mutual understanding, possibility of confusion at this point should be minimized.

EQUIPMENT ARRANGEMENTS ON NON-LOADED EQUALIZED LOOPS

Transmission over a circuit such as a non-loaded program loop, is usually equalized over a desired band of frequencies by application of measures which introduce certain amounts of loss at low frequencies and progressively decreasing amounts toward the higher frequencies to counteract the opposite characteristic of the bare circuit by itself. Two general methods are widely used to accomplish this. One is to bridge across the circuit a special attenuation equalizer which produces a greater loss at low frequencies than at high, this difference being adjustable as required for different loops. The other is to apply repeating coils of 4:1 impedance ratio at the two ends of the loop circuit. These introduce mismatch losses at the low frequencies and will equalize short lengths of cable, depending on the gauge of conductors and frequency bandwidth desired. For example, the second method may be used to provide transmission uniform to within about 1 db from 35 to 8,000 cycles for the cable lengths and gauges listed in Table 1. Beyond these lengths the special equalizer has to be added or used by itself without the assistance of 4:1 impedance ratio coils. For those circuits involving the transmission of frequencies from about 30 cycles to 15,000 cycles, the 4:1 impedance ratio coils together with a special equalizer are generally used in providing a circuit whose transmission frequency response is uniform within about 1 db of the response at 1,000 cycles.

Schedule	*Use*	*Approximate Frequency Range*
AAA	Continuous	50 to 15,000 cycles per second
BBB	Occasional	" " " " " "
AA	Continuous	50 to 8,000 " " "
BB	Occasional	" " " " " "
A	Continuous	100 to 5,000 " " "
B	Occasional	" " " " " "
C	Continuous	200 to 3,500 " " "
D	Occasional	" " " " " "
E	Occasional	300 to 2,500 " " "

TABLE 1

Lengths of Non-Loaded Cable Which Can Be Equalized By Use Of 4:1 Coils Alone

Gauge	Length (Miles)
16	5
19	2.3
22	1.5

With loops combining various gauges of conductors other lengths would, of course, apply.

When equalized loops are furnished by the telephone company and no special requirements are imposed as to the arrangements to be employed, equalizers and 4:1 impedance ratio coils are likely to be used in combination. By proper adjustment of the equalizer, it is also possible to secure comparable transmission characteristics with 1:1 impedance ratio coils, except in the cases of loops of irregular makeup and of lengths approaching the limits which can be equalized in one section. Other considerations, involved in the use of volume indicators on loops, may control as to which method is preferable. Where the arrangement shown in Fig. 7 of Part 5 is used it is important to reduce deviations in volume indicator readings to a minimum and it is also desirable to keep the size of the pad between the volume indicator and the loop as small as possible. In this case, therefore, a 4:1 impedance ratio transmitting coils should be avoided.

If the deviations caused in the volume indicator readings are to be compensated, or if the volume indicator can be adequately isolated, the equalizing effect of the 4:1 impedance ratio transmitting coil may be combined with that of the equalizer if desired.

The use of a coil at the receiving end of a loop is usually desirable for minimizing danger of noise or other unbalance effects. Whether this coil should be of 1:1 or 4:1 impedance ratio will depend largely upon the results obtainable with the equalizer used. Certain equalizers are designed to operate with 4:1 impedance ratio coils between them and 600-ohm receiving terminal circuits; that is, facing 150 ohms. Others are designed to face 600 ohms directly, requiring 1:1 impedance ratio coils.

In order to minimize the possibility of experiencing noise or crosstalk disturbance on program loops, the attenuation equalizer, when used, should be installed at the receiving end of the loop.

In a case where a loop may be used for either transmitting or receiving, duplicate coil and equalizing equipment should be available at both terminals of the loop. When the direction of transmission is to be changed, the equalizer at the normal receiving terminal should be disconnected and another equalizer connected at the terminal which is to be made receiving. If different coil arrangements are used at the two terminals, similar changes should be made in this equipment. The equipment arrangements at both terminals should provide means for making these changes readily.

In Fig. 1 are shown arrangements of loop equipment to suit various conditions. Discussion of the important differences between these follows:

Fig. 1-A - For Use With 600-Ohm Transmitting Equipment

This arrangement minimizes deviations in volume indicator readings, where the volume indicator is used directly on the output of an amplifier, transmitting through a pad to a loop. It affords the flexibility of a special equalizer in providing for either short or long loops, and it provides a coil at the receiving end for minimizing noise. This coil is of 4:1 impedance ratio, which assumes an equalizer designed to face a 150-ohm impedance.

Fig. 1-B - For Use With 600-Ohm Transmitting Equipment

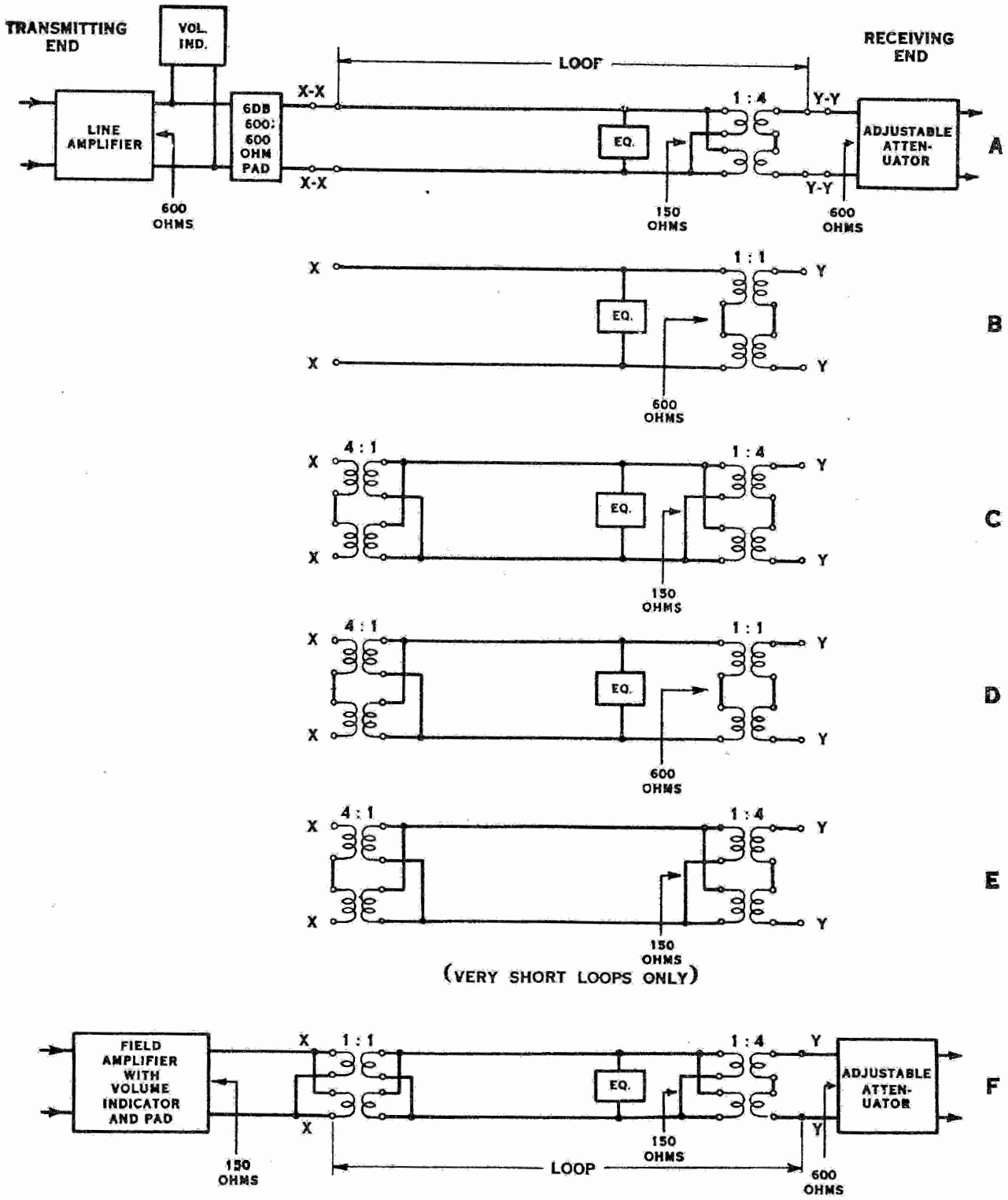
This arrangement which minimizes volume indicator deviations to the same degree as Fig. 11-A differs only in using a 1:1 impedance ratio coil at the receiving end, which assumes an equalizer designed to face 600 ohms.

Note: In either Fig. 1-A or Fig. 1-B a 1:1 impedance ratio coil may be provided at the transmitting end, if required, for protection or for correction of unbalance difficulties, without appreciable altering the results obtainable. This coil, if provided, should be included with the loop when it is being equalized.

Fig. 1-C - For Use With 600-Ohm Transmitting Equipment

The use of a 4:1 impedance ratio coil at the transmitting end in this case assumes that the higher impedance presented to the transmitting circuit by the loop is not objectionable and that the equalizing effect of this coil may, therefore, be utilized. It also assumes a condition where better results are obtained by having the equalizer face a 150-ohm impedance at the receiving end.

This arrangement is usually applied when equalized loops of considerable length are furnished by the telephone company and when no



EQUIPMENT ARRANGEMENTS
ON NON-LOADED EQUALIZED LOOPS

FIG. 1

5-6-05

special requirements are specified by the broadcaster. If it is desired to avoid the 4:1 impedance ratio coil at the transmitting end this should be so specified in the order placed with the telephone company. A suggested wording of orders for this arrangement is as follows:

> "Install loop equalized for use with 600-ohm transmitting equipment without four to one impedance ratio coil at transmitting point."

Fig. 1-D - For Use With 600-Ohm Transmitting Equipment

This arrangement differs from Fig. 1-C only in assuming an equalizer which affords the best results facing a 600-ohm termination.

Fig. 1-E - For Use With 600-Ohm Transmitting Equipment

Coils of 4:1 impedance ratio, used alone are quite generally used by the Telephone Company for equalizing very short loops where there are no other controlling factors, (see discussion and Table 1 on page 1). The impedance presented by the loop from the transmitting point, as in other cases utilizing a 4:1 impedance ratio transmitting coil, is increased, and this fact must be taken into consideration in the use of volume indicators on such loops.

Fig. 1-F - For Use With 150-Ohm Transmitting Equipment

The Telephone Company will normally equalize a loop for use with 600-ohm transmitting apparatus. Where it is planned to use 150-ohm transmitting apparatus and it is desired to have the loop arranged for this, therefore, the order placed with the Telephone Company should so specify. A suggested wording of orders for this arrangement is as follows:

> "Install loop equalized for use with 150-ohm transmitting equipment."

The arrangement at the transmitting point for this condition is shown including a 1:1 impedance ratio transmitting coil with the halves of both the primary and the secondary windings connected in parallel. This affords the preferable arrangement of this coil from the standpoint of its internal resistance and equalization should be adjusted with the coil connected in this manner, if it is left on the circuit.

PROVISION FOR 150-OHM RECEIVING EQUIPMENT

The arrangements shown in Fig. 1 assume use of 600-ohm receiving equipment for service. If 150-ohm receiving equipment is used, the drop windings of the receiving coils should be connected in parallel, instead of in series as shown.

> *Note:* If a 600-ohm transmission measuring set is used at the receiving end during equalization, the receiving coil connections should be as in Fig. 1 during equalization, but their drop winding should be paralleled when the 150-ohm service equipment is connected.

The proper methods of wiring Western Electric Company 111-C and 119-C coils for various conditions are shown in Table 2.

LOOP EQUALIZATION

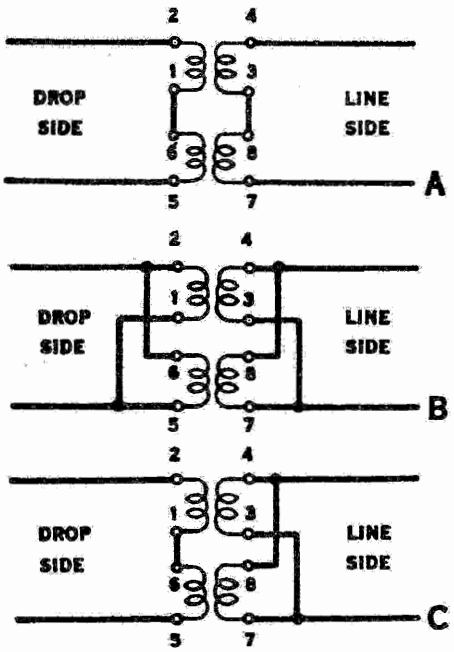
The operation of equalizing a non-loaded loop consists of modifying its electrical characteristics until its insertion loss; that is, the loss it causes when connected between the transmitting and receiving circuit impedances with which it is to be used, is essentially the same at all frequencies within the band to be transmitted. Insertion loss includes not only the attenuation loss of the conductors, coils, etc., but also such reflection and interaction losses as may be present due to junctions of dissimilar impedances at the terminals or other points. It is important, therefore, that testing methods employed in equalization work properly take into consideration the effects of impedance junctions between the testing equipment and the loop circuit.

Where equalization tests can be conducted through the actual amplifier and output pad which will be used in service, this is advantageous as far as reflection loss considerations are concerned. Use of an amplifier in this way for equalization, however, carries with it a complication in the matter of adjusting the levels of the testing frequencies. This can be appreciated from contemplation of the fact that the output circuit of an amplifier is essentially a voltage in series with an impedance. With a properly equalized circuit connected directly to a transmitting amplifier of the impedance for which equalization was provided, maintenance of the voltage (E) constant over a range of frequencies should result in reception of uniform levels at these frequencies by receiving equipment of the proper impedance at the far end of the loop.

Since the transmitting voltage (E) has to reach the loop terminals through the output impedance of the amplifier, and since the impedance of a non-loaded loop is higher at low frequencies than at high frequencies, the voltages measurable across the terminals of the loop under these conditions will not be uniform, but will be higher at the low frequencies than at high frequencies. Obviously, therefore,

TABLE 2

Terminal Connections and Impedance Data For
Western Electric Company No. 111-C and No. 119-C Coils



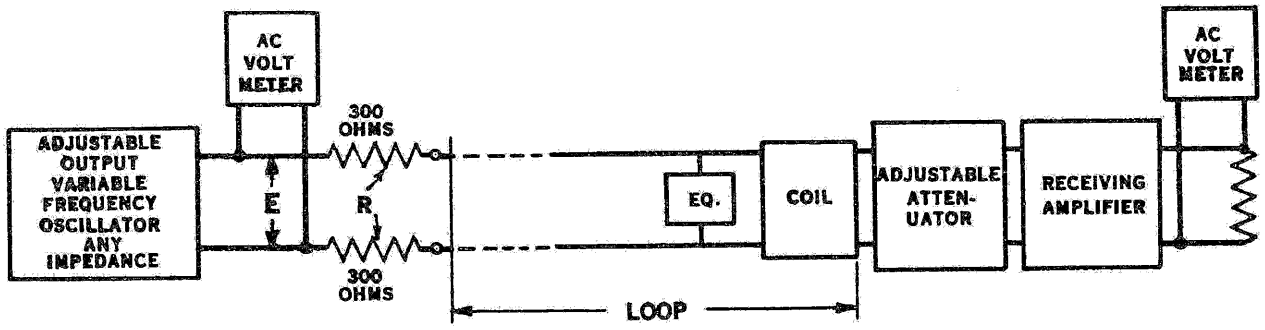
	111-C		119-C	
	Impedance Ratio	Nominal Impedances In Ohms	Impedance Ratio	Nominal Impedances In Ohms
	Drop Line	Drop Line	Drop Line	Drop Line
A	1:1	600:600	1.15:1	600*:600*
B	1:1	150:150	1.15:1	150*:150*
C	4:1	600:150	4.6:1	600*:150*

*Note: The No. 119-C coil was designed to make a 600-ohm termination look as nearly as practicable like 600-ohms when seen through the coil from its line side, instead of slightly higher due to the resistance of the coil, as is the case with a coil of exactly 1:1 impedance ratio. For most purposes, however, the No. 119-C coil may be used wherever the No. 111-C would serve.

adjustment of testing levels applied to the loop for equalization by maintaining a constant voltage across the output terminals of the transmitting amplifier, as indicated by a voltmeter or volume indicator at that point, would not be the equivalent of maintaining the voltage (E) constant and would result in an improperly equalized circuit; that is, one in which, under service conditions, low frequencies would be transmitted at higher levels than high frequencies. To avoid this, sufficient transmitting pad loss should be introduced between the amplifier and the loop, to make the voltage at the amplifier terminals practically independent of the loop impedance. Under this condition, substitution of a 600-ohm resistance for the loop at either the high or low extremities of the frequency range should leave the volume indicator reading virtually unchanged. This will usually require a total loss of 12 or 15 db.

Use, in the manner discussed, of the volume indicator built into many types of field amplifier would be subject to the objection mentioned if the output circuit contains only a small pad of ordinary type.

It should be borne in mind in this connection that the use of smaller amounts of pad loss during service conditions than during equalization does not involve the transmission frequency performance of the circuit but only the deviation of the volume indicator readings from the true values; i.e., what they would be with a pure 600-ohm resistance load.



Note: Coils to be used at either or both ends should be included as parts of the loop during equalization.

FIG. 2

If a convenient means were available for measuring the voltage (E) in an amplifier directly instead of through the output impedance, this would be useful for equalization purposes. A testing circuit which is the equivalent of such an arrangement, and others which produce the same results, are discussed in the following paragraphs, for use under field or plant conditions.

A generator which meets the foregoing requirements can be provided quite simply as shown in Fig. 2. The oscillator should be a variable frequency oscillator of low harmonic content and should have an adjustable output which will remain constant at any frequency. Constant output at different frequencies is not necessary, however. The meter may be a volume indicator or an a-c voltmeter which has a flat frequency characteristic over the desired band, or is one whose deviations with frequency have been determined, so that proper correction at each frequency can be made.

The oscillator is adjusted to maintain the same reading of the voltmeter for any testing frequency during equalization of a given circuit. This provides the required constant voltage (E). The two 300-ohm series resistances provide the required 600-ohm impedance which remains constant for any frequency or any load. (If equalization is required for use with 150-ohm transmitting equipment the series resistances should be 75 ohms in each side). The equalizer is adjusted until the same level (into a 600-ohm load) is obtained from the receiving amplifier at all frequencies.

Caution: In this connection it must be borne in mind that an ordinary 600-ohm pad should not be substituted for the series resistances in this circuit as erroneous measurements would result. Maintenance of the voltage (E) constant produces effectively a zero impedance across the terminals of the voltmeter. A pad substituted for the series resistances would, therefore, behave effectively as if its input terminals were shorted instead of terminated by 600 ohms as would be necessary to make it present a 600-ohm impedance to the loop. A 600-ohm pad may, however, be used between the series resistances and the loop as it will then be properly terminated.

The arrangement shown in Fig. 3 makes use of a 600-ohm oscillator which may be equipped with a pad if necessary for securing uniformity of its output impedance over the testing range of frequencies. The oscillator and pad are first connected to the measuring set and the oscillator adjusted until an appropriate testing level, such as 1 milliwatt, is indicated by the measuring set, at the first testing frequency. Without making any change in the oscillator the loop is then connected in place of the measuring set, the level at the receiving end of the loop is noted and recorded. For each measurement at other testing frequencies, the oscillator is adjusted to show the same value on the measuring set at the transmitting end; that is, 1 milliwatt, before transferring the connection of the oscillator and pad to the loop circuit. The adjustment of the equalizer is altered until uniform levels are received at all frequencies.

Fig. 4 illustrates the use of a field pickup amplifier having a built-in volume indicator. Testing power in this case may be transmitted over a spare loop from an oscillator in the broadcasting plant since the portable amplifier affords a convenient means of adjusting testing levels. A portable oscillator may, however, be used at the field testing point.

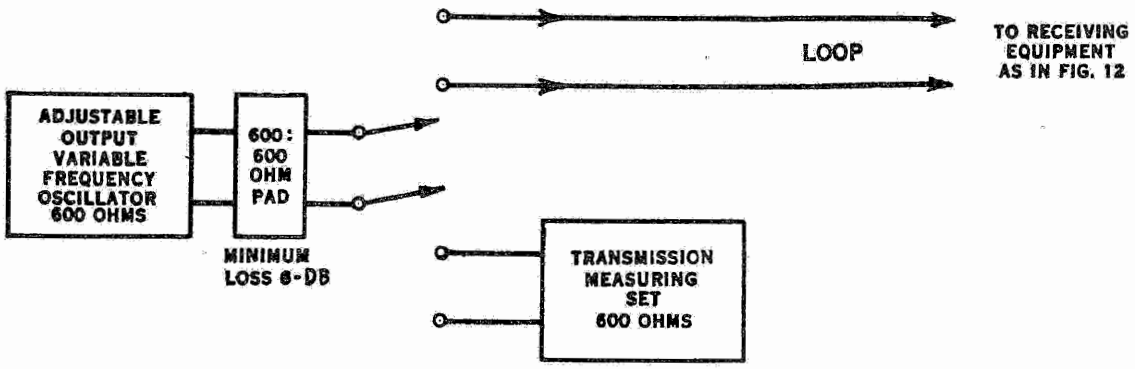


Fig. 3

A correct procedure in this case, where the test amplifier is of 600 ohms output impedance and where 600-ohm transmitting equipment is to be used in service is as follows at each testing frequency: a. Connect 600 ohms resistance (R) to the output terminals of the amplifier; b. Adjust the output to the desired testing level as shown by the volume indicator; c. Substitute the loop (with coil, if used) for resistance (R) without changing the output; d. Record level into 600 ohms at receiving point. Adjust equalization until levels under (d) are uniform.

An alternative method is to add 600 ohm pads between the amplifier and the loop to provide a total loss of 12 or 15 db. The amplifier output is then adjusted, with the loop and coil connected, to obtain uniform readings on the volume indicator at each frequency.

Equalizing For Use With Other Than 600-Ohm Transmitting Equipment

Where the test transmitting equipment used in Figs. 3 and 4 is of different impedance than the transmitting equipment to be used in service, a coil of proper impedance ratio should be so connected to the loop terminals during equalization as to compensate for this difference in impedance or incorrect equalization will result. If, for example, 600-ohm testing equipment is used, as shown in Figs. 3 and 4 and the service equipment is to be of 150 ohms output impedance, a 4:1 impedance ratio coil should be used with its low impedance side connected to the loop. The loop and coil are then substituted for the 600-ohm measuring set in Fig. 3 or for the 600-ohm resistance (R) in Fig. 4. After equalization the coil should be reconnected for 1:1 impedance ratio as shown in Fig. B, Table 2, if it is to be left on the circuit.

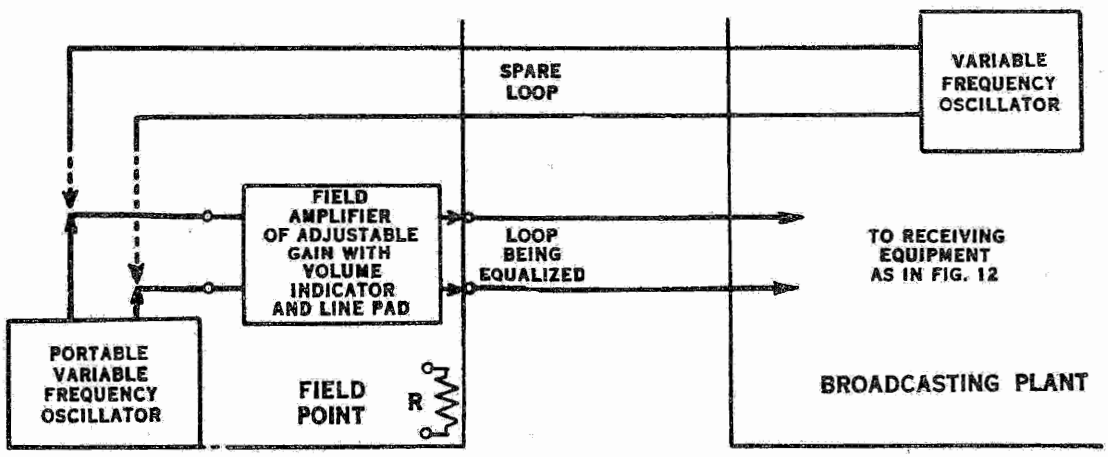


Fig. 4

and studio, or studio and network consist of either point-to-point radio or non-loaded cable conductors. In the latter case, the cable pairs are either similar to those normally used for telephone subscriber service, or, more frequently, special 16-gauge polyethylene string-insulated video pairs included in the exchange cable complement. Because of the high cable loss in the upper video frequencies, amplifiers and equalizers are required every few miles. The sound portion of the television program is carried by separate audio facilities similar to the regular program loops discussed in Part 4A.

The question of input and output levels in video loops is currently being reviewed. Under present operating practice, however, video channels are generally designed to provide 0 db loss for a 2-volt ± 25% signal.* The repeating coils used in the establishment of local video channels introduce low frequency distortion in the video signal. This distortion may be removed by means of a device known as a clamper, placed at the output of the video channel, which restores the essential low frequency components. The signal is delivered by the broadcaster without pre-emphasis from a 75-ohm unbalanced line or from a 110-ohm balanced circuit. The 110-ohm balanced input is suitable for connection directly to the nominal 110-ohm balanced cable conductors while the 75-ohm unbalanced input must be converted to a balanced 110-ohm impedance by means of a repeating coil to prevent reflections and to minimize the effect of any longitudinal noise voltages which may be present.

EQUALIZATION OF VIDEO CABLE LOOP

As noted in reference to audio frequency facilities, equalizing a loop consists of modifying the electrical characteristics until the insertion loss (the additional loss caused when it is inserted between normal transmitting and receiving circuit impedances) is essentially the same at all frequencies in the transmitted band. This insertion loss includes not only the attenuation loss of the conductors, coils, etc., but also the reflection and interaction losses which may be present due to junctions of dissimilar impedance at the terminals or other points.

With the present video transmission systems for cable facilities, the equalizer equipment is associated with the amplifiers. These may consist of amplifier input or output networks in conjunction with other basic equalizers located between sections of the amplifier, or may include fixed equalizers not associated with input or output networks and located within the amplifiers. In addition, a variable equalizer is also provided which permits independent adjustment in relatively small steps of the "slope" "bulge" characteristics. In some cases, mop-up or special equalizers may also be included. Flat gain adjustments can, of course, also be made at the amplifier points. Phase equalization within the transmitted band is automatically introduced by the attenuation equalizers. Residual phase distortion near the upper frequency limit is reduced by means of phase equalizers inserted at amplifier points.

The method of measuring the insertion loss of the video circuit is essentially the same as that discussed in Part 4A in reference to equalization of audio loops, with the exception, of course, that different line impedances are involved. To produce the equivalent of a one volt peak-to-peak testing level, a signal generator is required having an output impedance equal to the nominal line impedance and delivering a one volt peak-to peak signal when terminated in this nominal impedance. Under these circumstances the actual voltage across the line terminals will vary with frequency depending on changes in line impedance, and will be one volt peak-to-peak only when the line impedance is equal to the nominal value. If a signal generator such as illustrated in Figure 2 of Part 4A is used, the constant driving voltage should be adjusted to two volts peak-to-peak since when impedances are matched, one-half the driving voltage will be developed across the internal impedance of the generator and the other across the line terminals.

EQUALIZATION OF RADIO CIRCUITS

Equalization of loops consisting of point-to-point radio channels is not usually required in the field since the terminal apparatus is designed to exhibit a flat attenuation-frequency characteristic and is capable of delivering a 2-volt peak-to-peak signal with 0 db loss.

TESTING FREQUENCIES

Preliminary adjustment of the slope and bulge equalizers is made at 10 kc, 1-megacycle and 3.8-megacycles. The difference between 10 kc and 3.8-megacycle loss is representative of the line slope characteristics whereas, with the slope equalizer inserted, the difference between 1-megacycle and 3.8-megacycle loss is adjusted to zero by means of the variable bulge equalizer. Having thus obtained a tentative equalizer setting, an adjustment of equalization is made at additional frequencies throughout the transmitted frequency band. The testing frequencies suggested for preliminary adjustments and for over-all equalization are listed as follows:

*Peak-to-peak measurement.

Suggested Testing Frequencies - Video Loops

Preliminary Check	*Over-all Equalization Measurements*
	60 cycles
	5 kilocycles
10 kilocycles	10 "
	25 "
	50 "
	75 "
	100 "
	150 "
	200 "
	250 "
	300 "
	400 "
	500 "
	600 "
1 megacycle	800 and at 200 kc
3.8 megacycles	intervals between 1.0 and 4.6 megacycles

EQUALIZATION TESTING LEVELS

The input level customarily used in equalizing a video loop is a signal of 1-volt peak-to-peak (zero dbv). Although somewhat higher levels can probably be tolerated, this reference has been found convenient and various signal generators and detectors have been calibrated to read in db above or below 1-volt peak-to-peak, based on a nominal circuit impedance of either 75 ohms, or 110 ohms. *The testing levels employed in line-up and equalization should not be confused with the voltages which are impressed by the broadcaster during transmission of a video signal.*

As noted previously, a device known as a clamper is sometimes used to reduce the effects of excess loss in the low frequencies. It should be noted in this connection that an attenuation-frequency run made with a sine wave signal generator will *not* show the effect of the clamper at the low frequencies for a video signal even though the clamper is operating in the circuit at the time of the tests. This results from the fact that the effect of the clamper on the very low frequencies is based upon the presence at all times of a large component of video line frequency at 15.75 kc.

PART 5 - THE STANDARD VOLUME INDICATOR

GENERAL CHARACTERISTICS

The standard volume indicator now in general use in the communication industry, including the major broadcasters and the Bell Telephone System, is one having characteristics as prescribed in American Recommended Practice for Volume Measurement of Electrical Speech and Program Waves - ASA C16.5-1942."*

The volume indicator is calibrated to read volumes in terms of vu (defined below) and is designed to be bridged across a 600-ohm circuit. The essential characteristics of the instrument are as follows:

1. It employs a full wave, copper oxide rectifier contained within the instrument case.

2. The dynamic characteristic is such that the sudden application of a single frequency volume of such value as to give a steady state reading of 100 (0 vu mark) will cause the pointer to overswing by 1 to 1-1/2 per cent (0.1 to 0.15 vu). The pointer speed is such that under the same conditions, a deflection of 99 per cent of the steady state value is reached 0.3 second after the sudden application of the single frequency voltage. (This characteristic is consistent with C.C.I.F. recommendations).

3. The scale card is a cream yellow and has markings in black and red. The scale markings indicate per cent voltage (0 to 100) and vu (-20 to +3).

4. The instrument sensitivity does not depart more than 0.2 db from its value at 1000 cps over the frequency range from 35 to 10,000 cps nor more than 0.5 db over the range from 25 to 16,000 cps.

5. The instrument is capable of withstanding without injury or effect on calibration, voltage peaks of ten times the voltage equivalent to a reading of 100, (zero vu mark) for at least 0.5 second, and a continuous overload of five times that voltage.

STANDARD REFERENCE VOLUME

Standard reference volume level (zero vu) shall be defined by specifying (a) the characteristics and method of use of the volume indicator instrument, and (b) a steady state reference of 1 milliwatt. The impedance of the circuit across which the instrument is calibrated shall be 600 ohms. The characteristics of the instrument as well as the value of the calibrating power are important features of the definition.

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* The standard volume indicator and the subject of volume measurements is treated comprehensively in a paper "A New Standard Volume Indicator and Reference Level" by H. A. Chinn, D. K. Gannett and R. M. Morris - Proceedings of IRE January 1940.

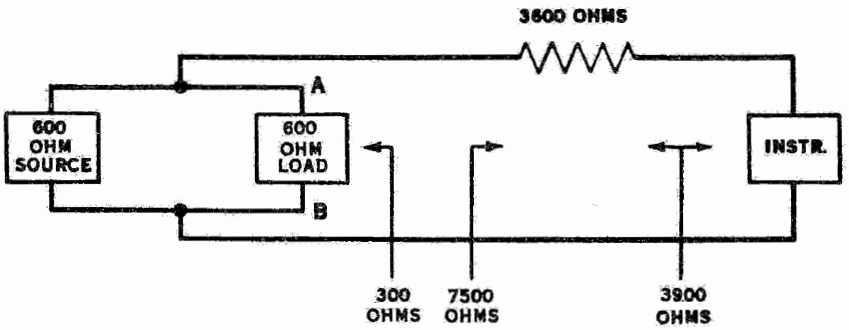


FIG. 1

In order to avoid the more cumbersome term "db above (or below) reference volume level" and confusion with several earlier standards, the readings of the standard volume indicator are designated as so many "vu" numerically equal to the number of db above (or below) the reference volume level. Volumes above and below reference are designated + and −, respectively. It should be borne in mind that volume expressed in "vu" *implies a measurement made with the standard instrument. Most previous types of volume indicators, even when recalibrated to a 1 milliwatt basis will not give indications on all types of program material corresponding to those of the new instrument.*

THE CIRCUIT OF THE STANDARD VOLUME INDICATOR

In order to calibrate and use the volume indicator intelligently it is necessary to understand clearly certain basic details of its design.

The dynamic characteristic of the standard volume indicator is fully as important and fundamental as any other feature in its design. In order to maintain the proper dynamic characteristic it is necessary that the instrument, with its internal impedance of 3900 ohms, always be used in such a manner as to face 3900 ohms. The arrangement of the volume indicator in its simplest form, therefore, is as shown in Fig. 1.

As can be seen in this figure, the instrument faces 3900 ohms (3600 ohms in series with 300 ohms). The complete volume indicator, therefore, presents a shunt impedance of 7500 ohms to the circuit across which it is bridged.

Under this condition a voltage of 1.228 volts rms, sine wave, applied across the load circuit terminals A and B should cause the pointer of the instrument to deflect to the 100 mark and will indicate that +4 vu (or 4 db above 1 milliwatt) is being dissipated in the load. This is the most sensitive arrangement of the standard volume indicator as it is available today.

In practice it will generally be necessary to read volume levels higher than +4 vu. This is made possible by inserting between the 3600 ohm resistance and the instrument a calibrated attenuator. A T-type attenuator of 3900:3900 ohms impedance is employed for this purpose in order to avoid changing the impedance relationships which would alter the dynamic characteristic of the volume indicator. The arrangement with the attenuator is shown in Fig. 2.

The variable attenuator in its "+4 vu" position or setting has zero insertion loss. Consequently, with this setting the instrument will still indicate 100 with an applied voltage of 1.228 volts rms, sine wave. Higher volume levels are read by adjustment of the attenuator to insert corresponding amounts of loss. The upper range of the volume indicator may be extended to any useful limit by suitable design of the attenuator.

CALIBRATION OF THE STANDARD VOLUME INDICATOR

None of the circuit arrangements described has taken into consideration any means for correcting the indications of a volume indicator or for bringing two or more instruments into alignment. Methods of accomplishing this are shown in the following Fig. 3, 4, and 5.

Referring to Fig. 3, a variable calibrating resistor R-2 of approximately 1000 ohms is used in conjunction with the attenuator. One-half of this value is removed from the 3600-ohm resistance R-1 shown in the previous arrangements. The result is a means of calibrating the volume indicator without materially altering the shunt impedance of the circuit or the dynamic characteristic of the instrument as it still faces approximately 3900 ohms. Many commercial types of attenuators now available for use with the new standard volume indicator have resistor R-1 built into the series arm of the attenuator for simplicity in wiring connections.

The first step in calibration is to make sure the instrument pointer stands on 0 of the 0-100 scale when no voltage is applied. If not, it should be brought to 0 by means of the me-

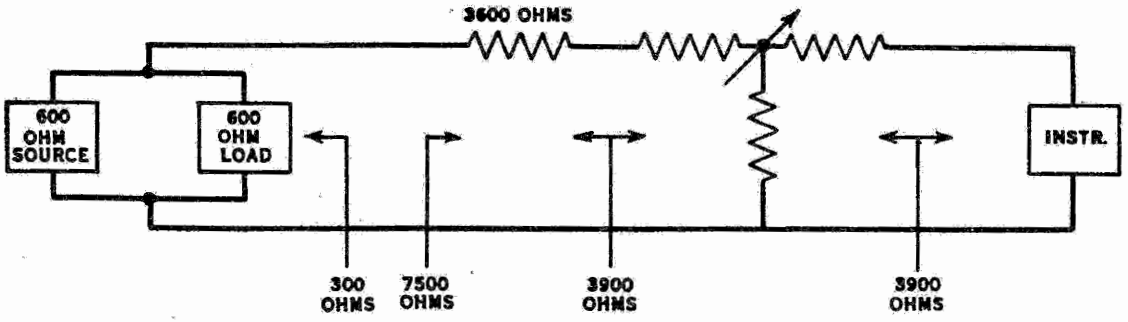


FIG. 2

chanical pointer adjustment on the front of the instrument. The next step varies slightly, depending upon the way in which the volume indicator is to be used, as set forth in the following paragraphs.

Method No. 1

This method is used in those cases where the volume indicator is permanently connected across and provides compensation for the bridging loss of the instrument. With the attenuator A in Fig. 3 set on step +4 vu (zero insertion loss) and a voltage of 1.228 volts rms, sine wave, applied to the load terminals, the calibrating resistor R-2 is varied until the pointer is deflected to the 100 mark. The volume indicator is then calibrated for use bridged across the 600-ohm load into which the measured volume is being transmitted.

Method No. 2

For routine checking of the calibration of volume indicators a "reference" instrument properly calibrated may be used in a simple comparison method as shown in Fig. 4.

An oscillator or other source of a-c voltage of adjustable output is required. To the terminals of this source the reference volume indicator and the volume indicator to be calibrated are connected in parallel. The attenuators of both volume indicators should be set on +4 vu. The applied voltage should be adjusted until the reference volume indicator pointed is at the 100 mark. If the pointer of the volume indicator being checked is not then on the 100 mark, its calibrating resistor should be adjusted until it reads the same as the reference volume indicator. It is then calibrated for the same method of use as the reference volume indicator.

Some volume indicators are equipped with a "1 mw." step - which effectively taps off a portion of the 3600-ohm series resistance. If bridged across a 600-ohm resistance in which one milliwatt of single frequency power is being dissipated with the attenuator set on this step, the instrument should show a deflection of 100. Since this arrangement alters the impedance which the instrument faces and hence its dynamic characteristics, it *must not* be used to indicate program volume. Furthermore, since the scale is also altered the markings will not be accurate except at the 100 mark.

Method No. 3

This method of calibrating, shown in Fig. 5 is applied when the volume indicator is to be

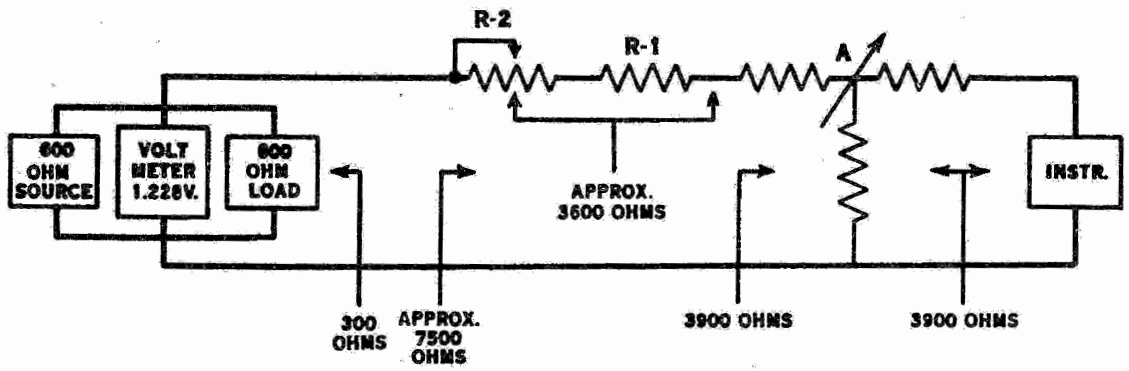


FIG. 3

used in such a manner that its bridging loss does not affect the circuit being fed, as for example, when it is to be energized by a separate amplifier terminated in 600 ohms. Both the source and the measuring circuit used in this method must be of 600 ohms impedance.

The source is adjusted until the measuring apparatus indicates 4 db above 1 milliwatt with the volume indicator not connected. The volume indicator is then connected to the circuit. Without making any change in the generator setting, adjust the resistor R-2 in the volume indicator circuit until the meter deflection is 100 divisions with sensitivity (attenuator) set for +4 vu. The measuring set should read about 0.3 db lower with the volume indicator connected.

METHODS OF CONNECTING VOLUME INDICATORS

In the methods of use of volume indicators outlined in this Section, the gain of an amplifier is considered as that determined by one of the following methods:

a. Voltage gain in db $= 20 \log_{10} \dfrac{\text{Voltage measured across the output terminated in 600 ohms (or other load impedance to be connected)}}{\text{Voltage measured across the input}}$

Voltage gain determined by this method may properly be used as the gain of any amplifier in the cases to be discussed.

b. The gains of amplifiers whose output and input impedances are both 600 ohms, and which are used between those impedances, can be measured correctly with 600-ohm transmission measuring equipment.

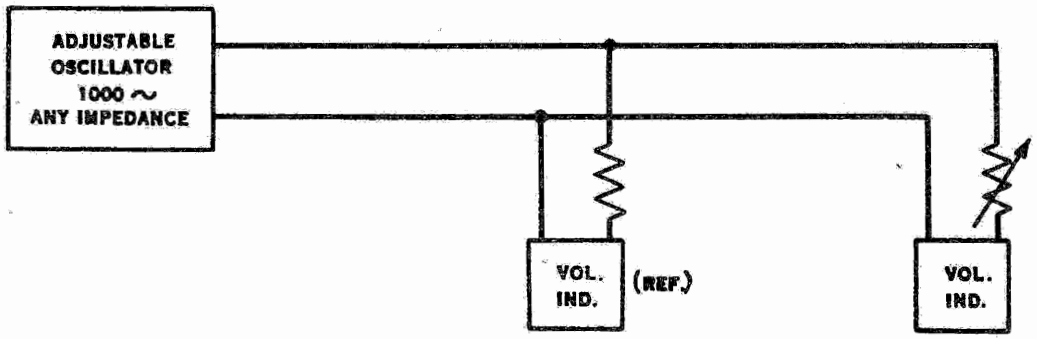


FIG. 4

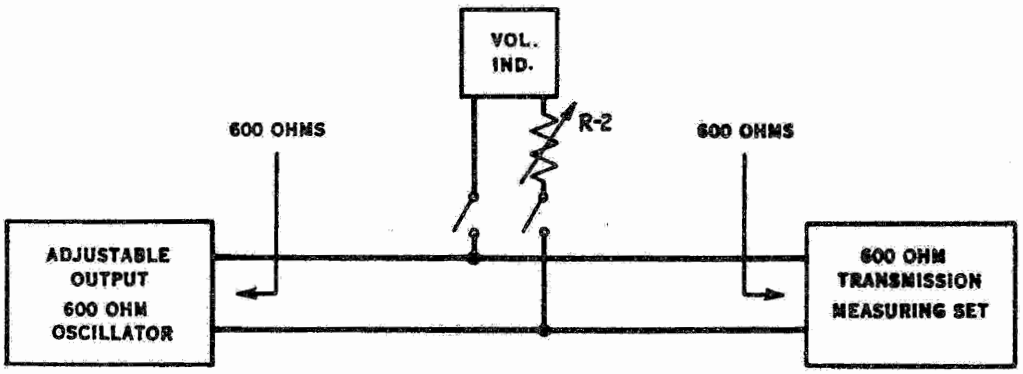


FIG. 5

Following are 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. It should, therefore, be calibrated by Method 1 or Method 2 under "CALIBRATION."

Method 1-A (Fig. 6)

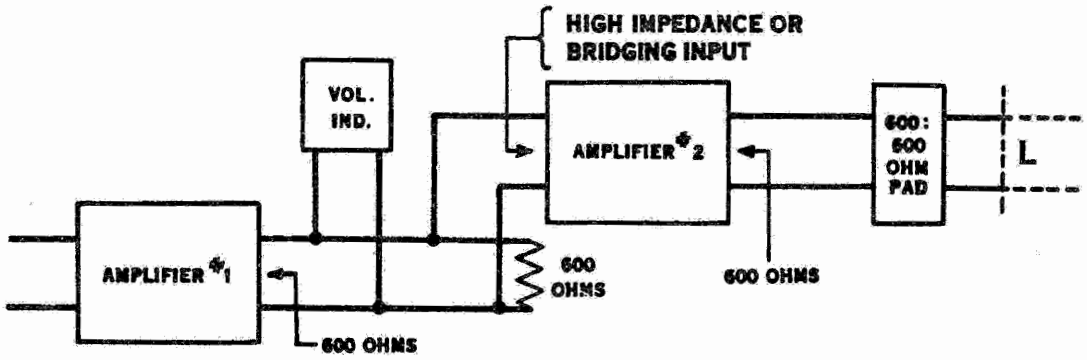


FIG. 6

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.

Method 1-B (Fig. 7)

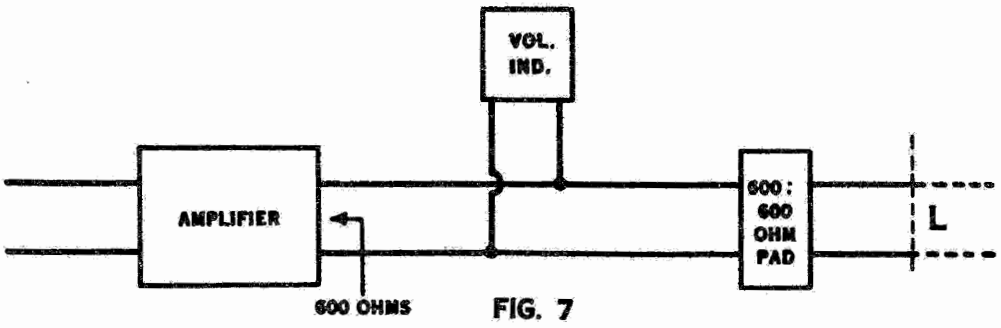


FIG. 7

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 may be determined as given under the heading "CORRECTION OF VOLUME INDICATOR READINGS".

Following are three variations of a method of use of the volume indicator in which it should be calibrated by Method 3 under "CALIBRATION".

Method 2-A

This method, shown in Fig. 8, 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.

Method 2-B

The volume indicator in the arrangement shown in Fig. 9 does not take any power from the main circuit.

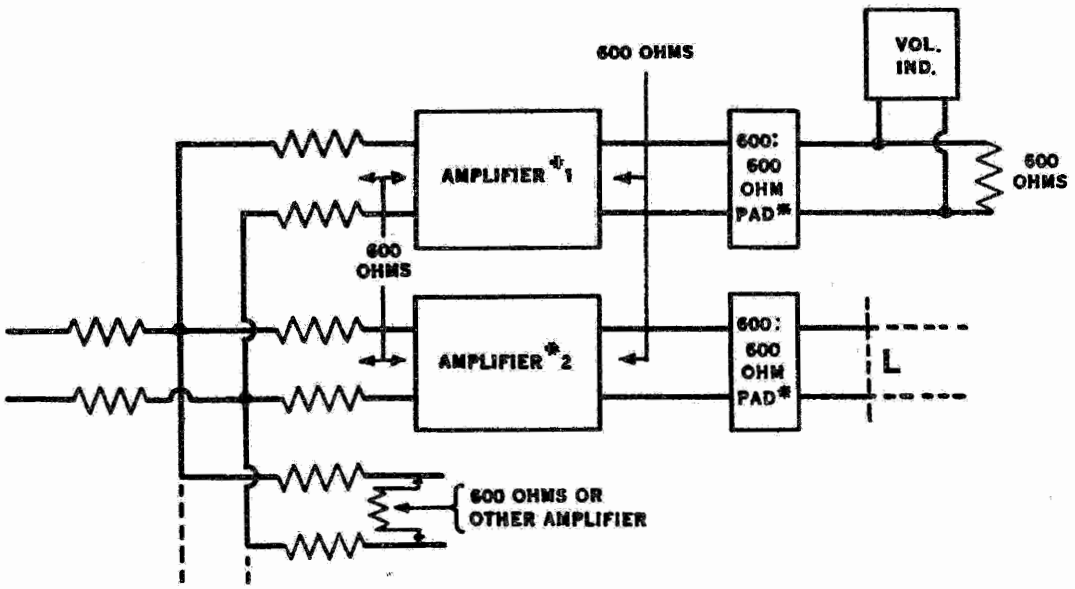


FIG. 8

The volume indicator reading minus the gain of amplifier No. 2, less the loss of the pad, gives the volume at Point L. (See Note under Method 1-B).

Method 2-C

Fig. 10 shows two ways of connecting volume indicators by means of bridge circuits.

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 6db. The balance obtainable with an amplifier of 600 ohms 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 action of a volume indicator on average program material is influenced mainly by the voltages developed at the point where it is connected, at the frequencies below 1000 cycles. The impedance presented by a loop below 1000

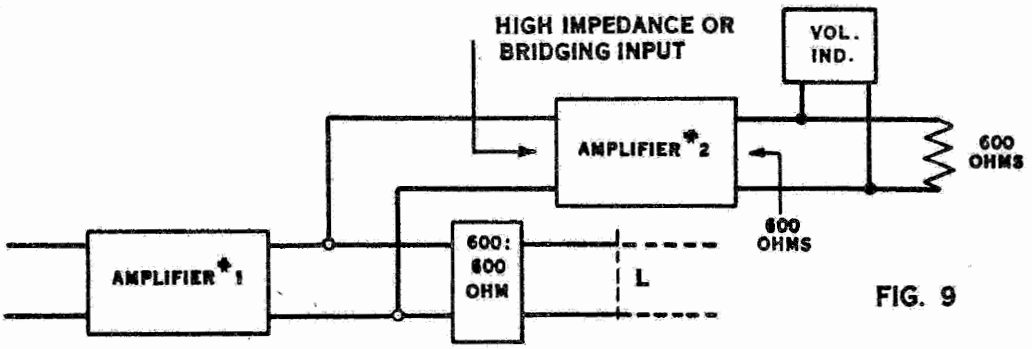


FIG. 9

* Pads may be omitted where not required for impedance reasons.

cycles, 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 loop for correct readings. For the usual loop of non-loaded cable this impedance varies with frequency, the range of variation depending upon the length, the gauge of the conductors, the equalizing arrangement applied (see Part 4 - "Program Loop Transmission"), and, if a transmitting coil be used, upon the ratio of this coil. If this be a 1:1 impedance ratio coil or if the coil be omitted

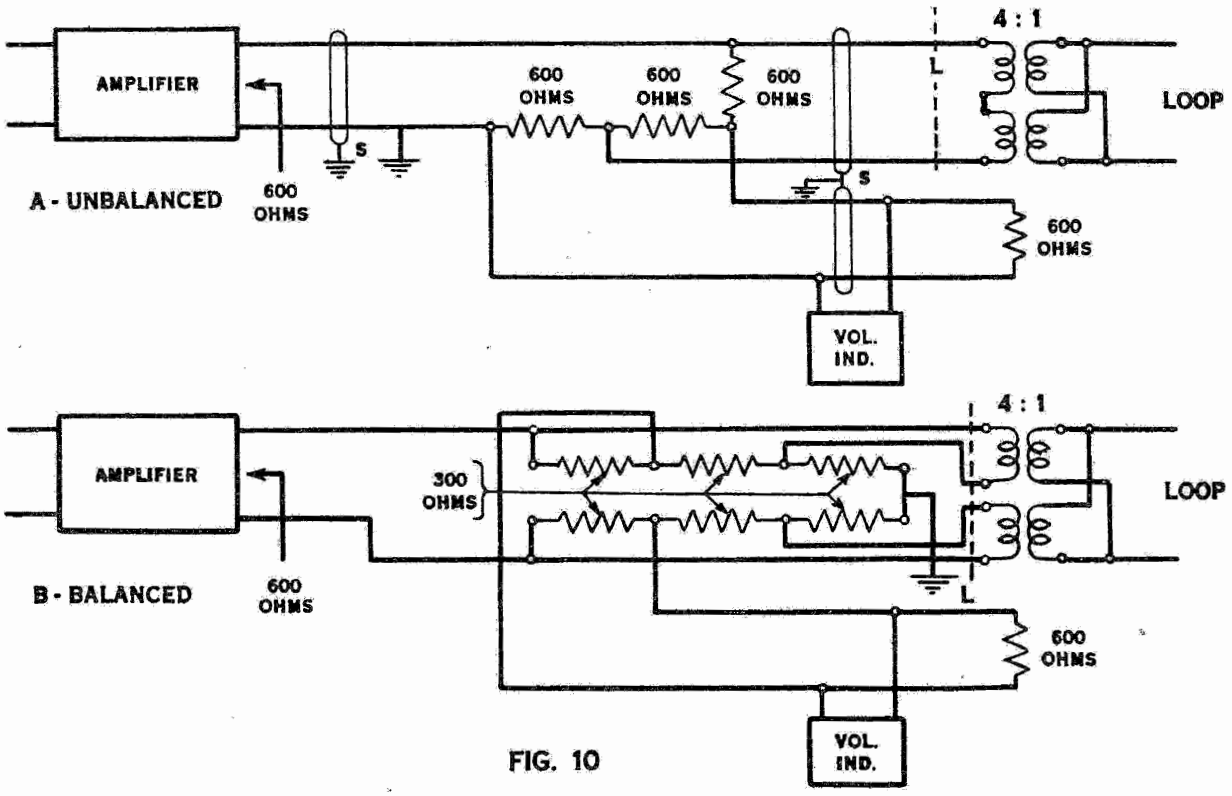


FIG. 10

altogether, a 6 db pad will normally be sufficient to make the readings of the volume indicator on average program material agree within two or three-tenths of a db with what they would be if the volume indicator faced a pure 600-ohm resistance in the direction of the loop. If, however, a 4:1 impedance ratio coil be used at the transmitting point, as is done in certain equalizing arrangements, the impedance faced by the volume indicator will be much higher than with a 1:1 impedance ratio coil and the deviations, even with a 6 db pad may be a db or more. Use of larger pads will reduce these deviations as shown in the APPENDIX, but this will increase the output requirements on the amplifier and alternative arrangements, as discussed subsequently, should be considered.

Most amplifiers now in use in broadcasting plants for transmitting into loops have adequate output capacity to permit use of 6 db isolation pads and still apply a +8 vu level to the loop without objectionable distortion.

MINIMUM VALUE OF TRANSMITTING PAD

Taking all of the foregoing factors into consideration, 6 db should be the minimum isolating value for a transmitting pad where transmitting coils of 1:1 impedance ratio are used, or where coils are omitted entirely.

SPECIAL ISOLATING MEASURES

Where transmitting coils of 4:1 impedance ratio are used, other measures will be required for obtaining a correct indication of the volume being transmitted to the loop. Among these may be mentioned -

(a) The use of pads larger than 6 db where practicable;

(b) The application of specially designed impedance adjusting pads;

(c) The use of pads which provide isolation between two branches of a circuit by application of the Wheatstone bridge principle, or

(d) The connection of the volume indicator to a paralleling branch of the circuit having a separate amplifier, as is shown in Fig. 8. This arrangement is one used quite generally by the telephone company in its offices.

Output circuits utilizing the Wheatstone bridge principle may be designed in various forms, both balanced and unbalanced, and with various amounts of loss.

An example of a balanced type output circuit is shown by Fig. 10B. The circuit in this case incorporates a 4:1 impedance ratio coil connected to the loop. The loss of this circuit is about 6 db and the isolation of the volume 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 are considered for reducing the influence of nonuniform loop impedance on the accuracy of volume indicator readings. Application of some of the arrangements discussed, particularly in the cases of Figs. 7 and 9, may still leave a residual error, of which it will be desired to dispose. The amount of this error can be determined by comparing the reading on a steady tone of 400 or 500 cycles, having the loop connected in the normal operating condition, with the reading obtained with a 600-ohm resistance substituted for the loop.

In this test the transmitting coil, if used, forms part of the loop, and should be disconnected with the loop when the 600 ohms is substituted. Tones of the frequencies mentioned may safely be transmitted at normal operating volumes 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. 7. Connect the 600-ohm resistance in place of the loop (and coil) 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 loop (and coil). 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. 9, the correction may be determined by the same procedure as just described for Fig. 7. In this case, however, the gain of amplifier No. 2 is adjusted to obtain the desired compensation.

In the arrangements shown in Figs. 6, 8, and 10, 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 0-100 scale on the volume indicator.

The broadcasters prefer the use of the 0-100 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 db. The justification for this lies in the relationship to the need for changing amplifier gains or pad values which are designated in terms of db. The use of the term vu in this connection is permissible, although incorrect.

APPENDIX

EFFECT OF TRANSMITTING PAD LOSS ON VOLUME INDICATOR READINGS

A test was made for the purpose of demonstrating the relative effectiveness of different amounts of loss in a transmitting pad, in reducing the deviations of volume indicator readings when connected across a loop, from the readings when connected across a 600-ohm resistance, which is the reference load condition for the standard volume indicator.

The loop used consisted of about five miles of 19 gauge nonloaded cable conductors. The coil and equalizer arrangements were as shown in Part 4, Figs. 1, A, B, C, and D.

The Western Electric 23-A equalizer used was readjusted for each condition to obtain optimum equalization.

The coils were Western Electric Company No. 111-C.

TESTING PROCEDURE

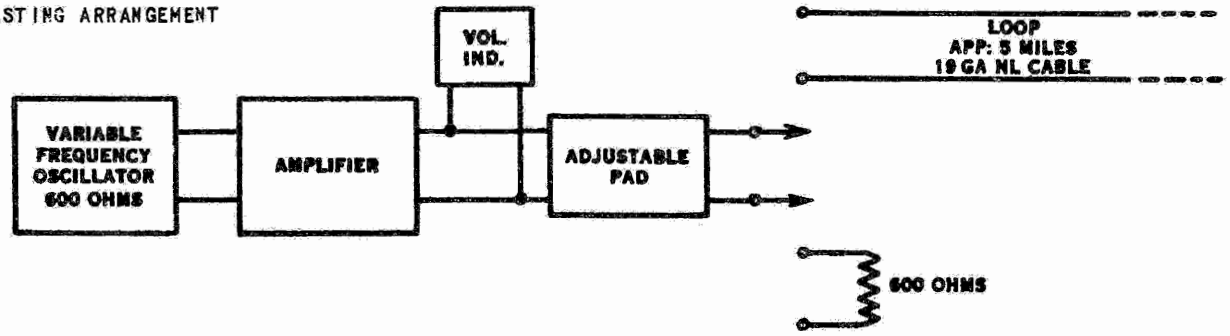
1. With 0 db loss in the adjustable pad the output was connected to a 600 ohm resistance. The oscillator was adjusted until the volume indicator read +8 vu.

2. Without changing the oscillator the output was transferred to the loop (with coil, when used).

3. The volume indicator readings were recorded for the following amounts of loss in the adjustable pad: 0 db, 6 db, 10 db.

4. Steps 1, 2, and 3 were repeated at each testing frequency.

TESTING ARRANGEMENT



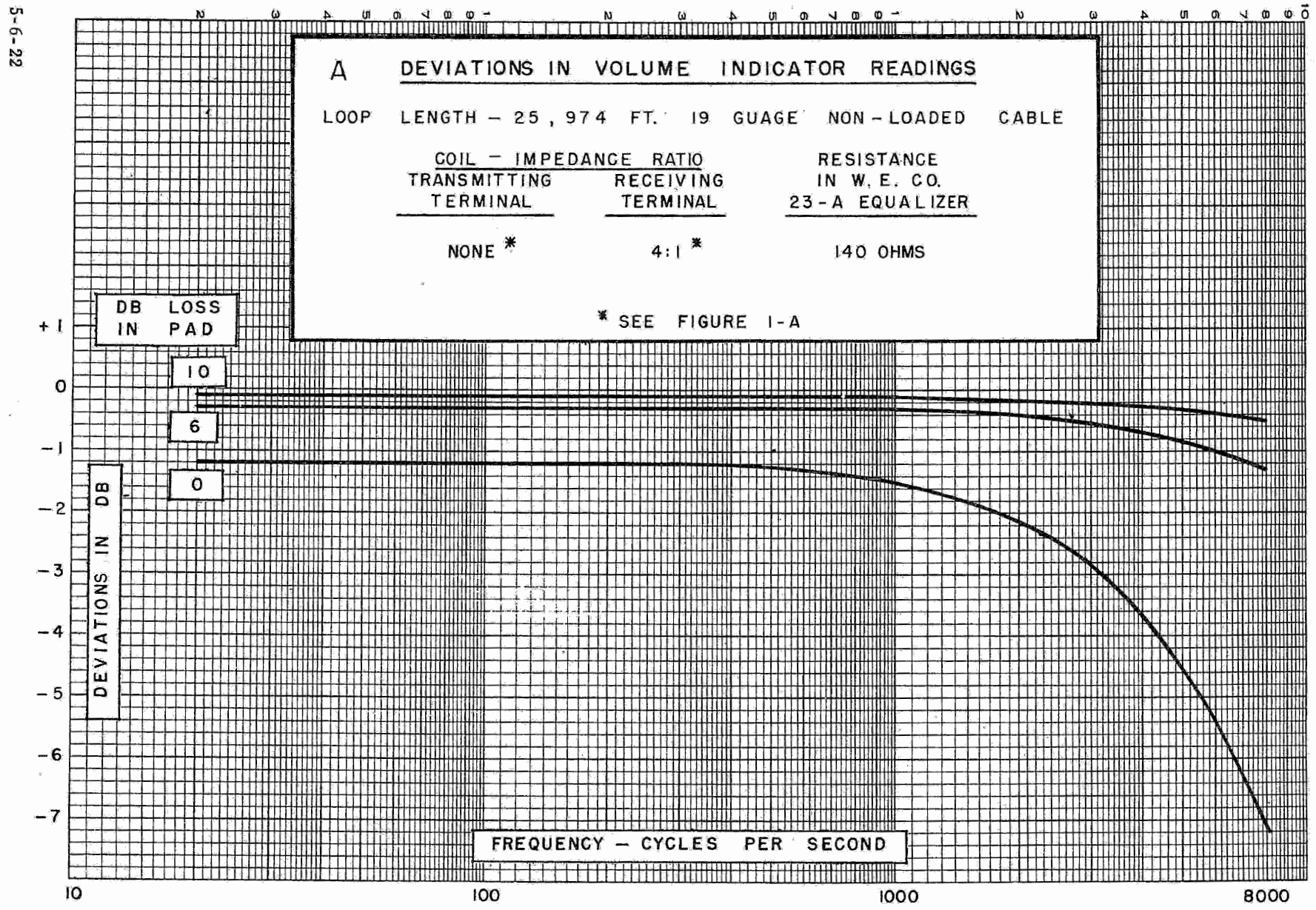
5. Steps 1, 2, 3, and 4 were repeated for each of four conditions of the loop equipment shown as A, B, C, and D, in Figure 1 (Part 4), except that receiving coil was omitted entirely in B and D.

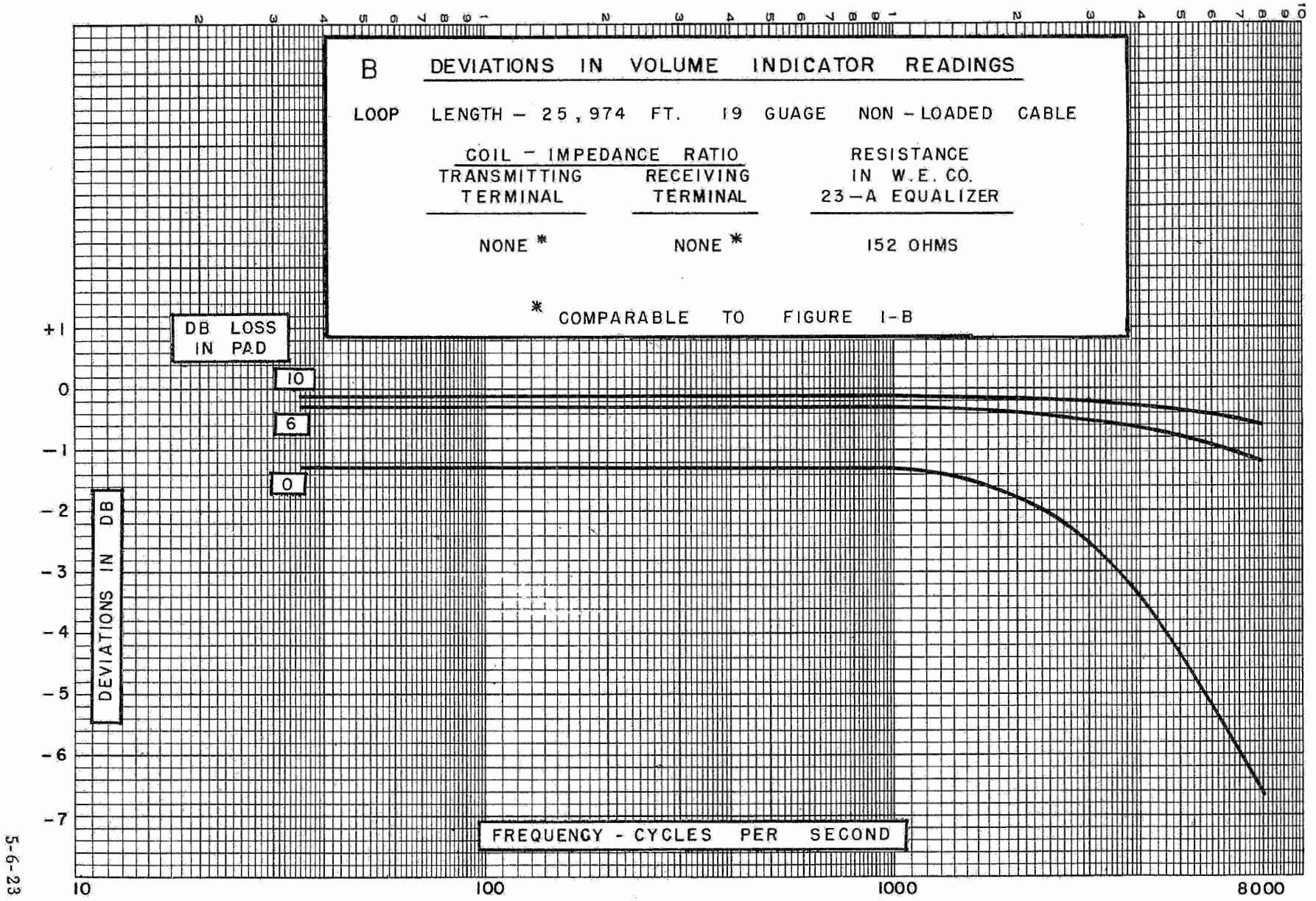
RESULTS

The results of these tests are shown by the four accompanying sets of curves. Deviations identified by (+) indicate that the readings were higher for the loop than for the 600-ohm termination. It can be seen that the deviation can be reduced to a small amount (about .3 db) by use of a 6 db transmitting pad, if no coil (or a 1:1 impedance ratio coil) be used at the transmitting point, but that where a 4:1 impedance ratio transmitting coil is used a pad of at least 10 db will be required to obtain a comparable reduction.

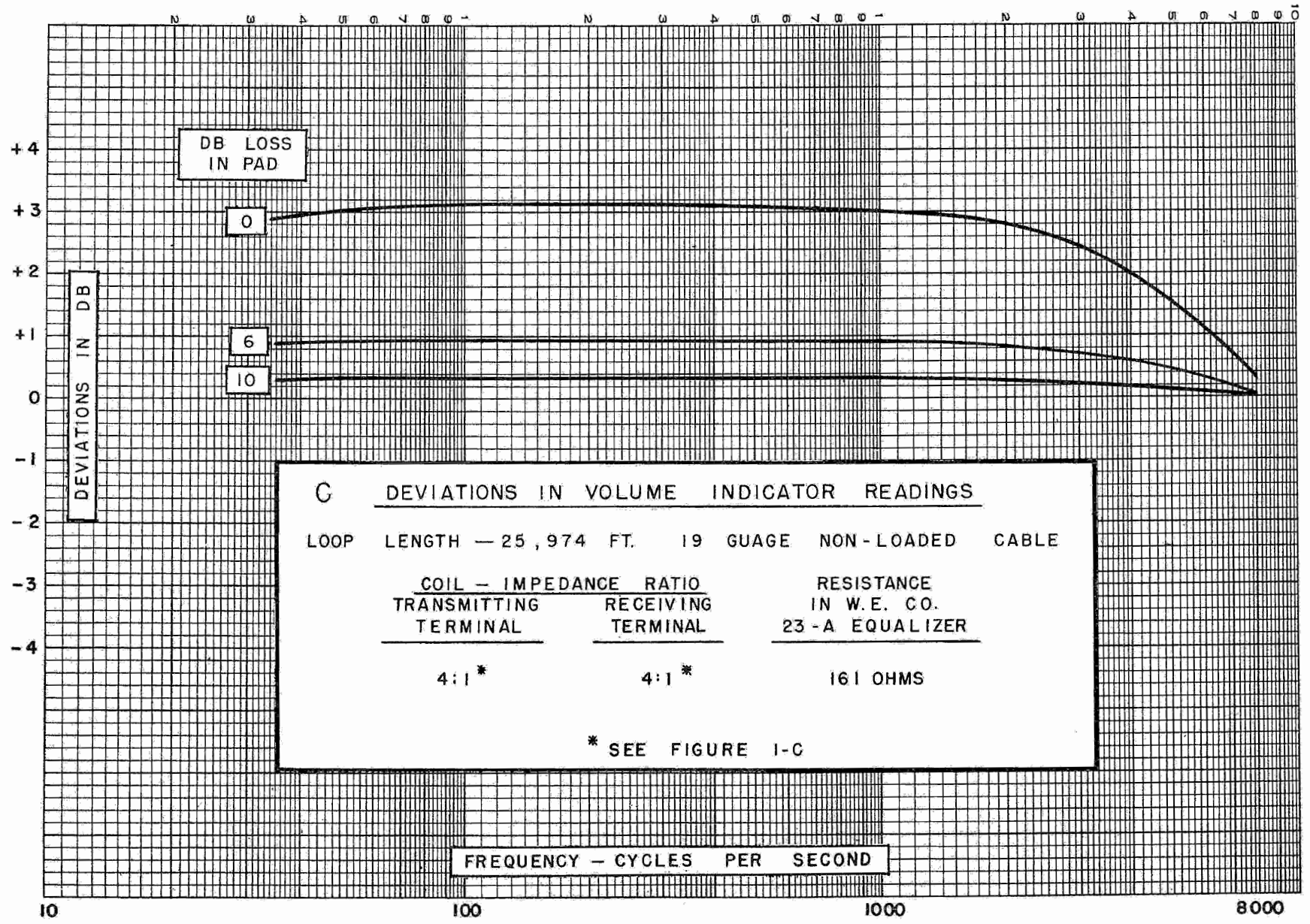
Note: The data obtained from these tests apply strictly to the specific loop tested. Loops of other makeups would show the same tendencies but the magnitudes of the effects might be different. For example, a loop of considerable length containing smaller than 19 gauge conductors would normally produce volume indicator readings greater than the 600-ohm termination, even with the transmitting coil omitted.

5-6-22


A DEVIATIONS IN VOLUME INDICATOR READINGS
LOOP LENGTH – 25,974 FT. 19 GUAGE NON-LOADED CABLE
COIL – IMPEDANCE RATIO
TRANSMITTING TERMINAL
RECEIVING TERMINAL
RESISTANCE IN W. E. CO. 23-A EQUALIZER
NONE *
4:1 *
140 OHMS
* SEE FIGURE 1-A
DB LOSS IN PAD
10
6
0
DEVIATIONS IN DB
+1
0
-1
-2
-3
-4
-5
-6
-7
FREQUENCY – CYCLES PER SECOND
10
100
1000
8000


B DEVIATIONS IN VOLUME INDICATOR READINGS
LOOP LENGTH — 25,974 FT. 19 GUAGE NON-LOADED CABLE
COIL — IMPEDANCE RATIO
TRANSMITTING TERMINAL
RECEIVING TERMINAL
RESISTANCE IN W.E. CO. 23—A EQUALIZER
NONE *
NONE *
152 OHMS
* COMPARABLE TO FIGURE 1-B
DB LOSS IN PAD
10
6
0
DEVIATIONS IN DB
+1
0
-1
-2
-3
-4
-5
-6
-7
FREQUENCY - CYCLES PER SECOND
10
100
1000
8000

5-6-23

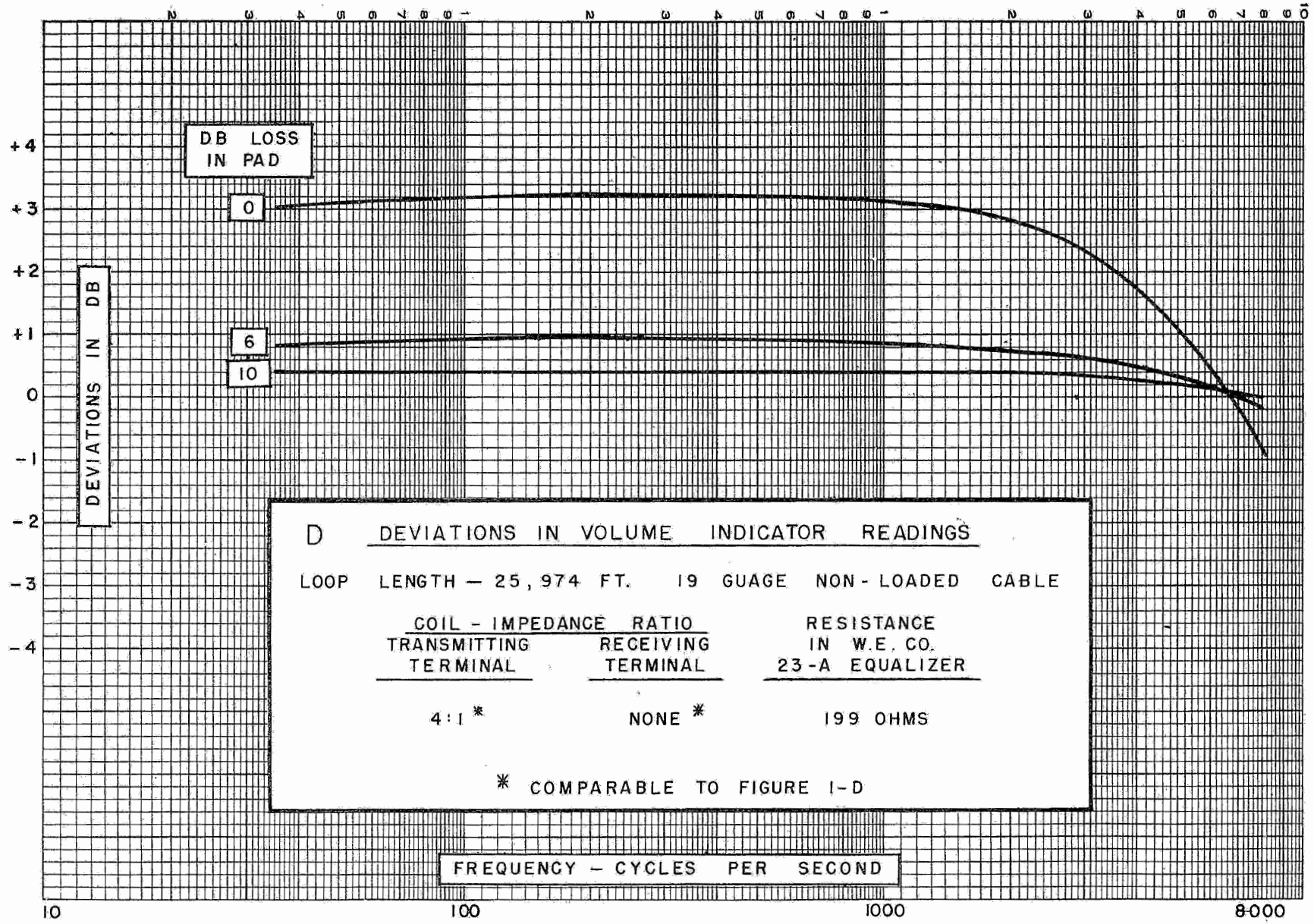


C DEVIATIONS IN VOLUME INDICATOR READINGS

LOOP LENGTH — 25,974 FT. 19 GUAGE NON-LOADED CABLE

COIL — IMPEDANCE RATIO		RESISTANCE
TRANSMITTING TERMINAL	RECEIVING TERMINAL	IN W.E. CO. 23-A EQUALIZER
4:1 *	4:1 *	161 OHMS

* SEE FIGURE 1-C


DB LOSS IN PAD
0
6
10
DEVIATIONS IN DB
+4
+3
+2
+1
0
-1
-2
-3
-4
D DEVIATIONS IN VOLUME INDICATOR READINGS
LOOP LENGTH — 25,974 FT. 19 GUAGE NON-LOADED CABLE
COIL - IMPEDANCE RATIO
TRANSMITTING TERMINAL
RECEIVING TERMINAL
RESISTANCE IN W.E. CO. 23-A EQUALIZER
4:1 *
NONE *
199 OHMS
* COMPARABLE TO FIGURE 1-D
FREQUENCY — CYCLES PER SECOND
10
100
1000
8000

5-6-25

PART 6 - NETWORK OPERATION - AUDIO CHANNELS

PERFORMANCE CONSIDERATIONS

The interexchange audio program networks utilized in providing program transmission service are designed to afford the transmission performance necessary for the grade of service involved. If the expected results are to be obtained and detrimental reaction on or from other communication services is to be avoided, however, certain technical requirements must be observed in their use. This necessitates that all concerned have adequate information covering these requirements. The more general considerations relating to the operation of local program channels are covered in PART 5 of this Handbook. There remain some additional aspects of program channel operating, however, which apply specifically to interexchange networks. These are discussed in some detail in the following paragraphs.

The flexibility in application of the services available to the users may lead to unsatisfactory results in some cases if attempts are made to utilize the services beyond the limits of their capabilities. The probability of actual trouble from this, in the case of high quality services, is relatively slight since the influence of all factors limiting circuit performance has been greatly reduced in their design and since these services are given close supervision by the telephone company. In the case of medium quality service, however, such close supervision is not provided and, as the performance capabilities of the circuits are considerably less, and vary considerably with distance, they are much more susceptible to the ill effects of improper demands upon them.

VOLUME CONSIDERATIONS

Proper results from any broadcasting system are dependent upon having proper volume levels at every point in the system from pick-up to transmitter output, including intervening network connections. Insufficient volume results in more noise being heard with the program and excessive volume tends to increase distortion generally or produce overloading on the volume peaks.

Different parts of the system such as amplifiers, local channels, line circuits, etc., are designed to operate at different volume levels, depending on their functions, their positions in the circuit, or upon limitations due to interference considerations. For example, at amplifier points on open wire circuits the volumes are allowed to reach maximums of +14 vu. On long distance-type cable circuits comparable maximum volumes are +4 vu or +8 vu depending on the type of service involved.

It becomes readily apparent that an overall system comprising many component parts connected in series should be so "lined up" (the losses and gains so adjusted) that the proper maximum volume applied at the originating point will produce the proper maximum volume at all other points, such as amplifier outputs, in receiving local channels, etc.

The technique of controlling volume at originating points is based on one fairly obvious general principle, namely, keeping the average volume as high as possible without having to reduce too many volume peaks and thereby sacrifice desired volume range.

Program volume is controlled by attention, primarily, to the maximum levels. Consistent with this, engineering and operating practices applied to program networks by the telephone company are prepared with the assumption that maximum program volumes will be kept up to the proper level at the pick-up points, normally +8 vu, (except in a few special cases) into the transmitting local channel. Responsibility for the actual volume conditions throughout the system, including the networks, thus attaches itself to the control operator at the program source. No satisfactory substitute for this situation has been found, as attempts to compensate, at other points, for improper control at the originating point has been found by experience to lead to serious confusion and sometimes to upset the coordinated operation of the system.

A general principle can be evolved from this, which is to correct volume irregularities wherever they occur, only at their sources and not by compensating adjustments at circuit terminals. This requires locating the source of the irregularity by comparisons of volume peaks at successive points along a route toward the originating point. Obviously, efficient communication circuits between offices along the routes are necessary to permit doing this properly.

The considerations relating to the control of the volume at points on a network also apply to the amplifiers and other equipment at the broadcasters' premises at points where program material is received from one network and switched or retransmitted on to other networks. This and other factors involved in retransmission of programs are discussed later.

OPERATION OF MEDIUM QUALITY PROGRAM FACILITIES

As mentioned in PART 3 of this Handbook, medium quality program channels are available which are capable of transmitting a frequency band somewhat narrower than the 5 or 8 kc facilities. For this type of service, the facilities are usually of the type designed primarily for long distance telephone service but with their normal amplifier equipment adjusted to permit passing a somewhat wider band than for message

purposes and to transmit at levels which will take full advantage of the controlled volume of the program material.

An important difference between medium quality and high quality transmission is that medium quality transmission deteriorates rapidly with distance, while high quality transmission suffers relatively little from circuit length. This is due to the fact that the medium quality circuits lack design and operating refinements present in the high quality networks for reducing objectionable effects which are cumulative with distance.

NON-AMPLIFIED MEDIUM QUALITY CIRCUITS

In a relatively few instances it may be found possible, temporarily, to provide short circuits for medium quality program service without line amplifiers at intermediate telephone offices. Under such circumstances, these short circuits have no intermediate equipment to restrict the frequency band transmitted and the only band limitation for the network is the "cutoff" of the line and local channel facilities. While this will vary somewhat between cases, the band will sometimes be wide enough to permit transmission approaching that obtainable from the regular high quality services, since delay distortion from such short lengths will normally be unimportant. In addition, these circuits afford the advantage of transmitting in either direction. It is important for the control of noise in such instances, of course, to arrange for switching equalizers and pads in and out of the circuits so that equalization will always take place at the receiving end of the channel. Taken at face value, these features appear to make "non-amplified" circuits very attractive by use in building up networks. This conclusion, however, fails to take into consideration the fact that the attractive features are primarily due to the short lengths of the circuits and not to their having different basic transmission characteristics. If used in tandem between studios to form long connections, the cumulative impairments characteristic of long lengths of circuit will make themselves apparent just as if only a single long circuit were involved. In fact, noise will tend to be somewhat higher in such a tandem arrangement than in a single circuit of equivalent length because of less favorable levels. The possibilities of operating irregularities and interference will also be increased because of routing the circuit through one or more retransmission points.

SUPPLEMENTARY EQUALIZATION

Supplementary equalization measures are sometimes applied to long medium quality circuits by broadcasters in an effort to widen the effective band width and so obtain additional benefits normally associated with wider band services. In many of these cases no serious difficulty is encountered in widening the band up to the cutoff of the line facilities. A comparable improvement in quality may not be obtained, however, as noise and distortion effects will tend to become more objectionable.

Attempts may be made to improve low frequency performance of medium quality circuits by application of low frequency pre-emphasis in material transmitted into the circuit. This is likely to result in trouble as low frequency levels considerably in excess of the 1,000 cycle reference levels may reach line amplifiers in the initial portion of the circuit and produce serious distortion on program material having high level low frequency components, such as pipe organ music, due to overloading. In specially designed program circuits, because of these considerations, equalization is distributed along the circuit and is applied at the receiving ends of the sections concerned only.

RETRANSMISSION OF PROGRAMS

In some cases the broadcasters receive programs from one network and switch or retransmit them to another. In these cases the broadcaster's retransmitting amplifiers and associated equipment become virtually units in a larger network. Their operation, consequently, becomes subject to the same requirements of other amplifiers in the networks, if they are to be kept from affecting all results disproportionately. Some of the technical requirements for the equipment which are of particular importance in this connection are as follows:

1. The amplifier should be stable in gain and have ample gain and volume capacity to apply +8 vu to the transmitting loop (through any necessary pads) with a few db of margin for safety and without introduction of objectionable noise or distortion. They should also make no appreciable change in the transmission-frequency characteristic of the transmitted band.

2. The amplifier should have a gain adjustment of positive type with which gain can be changed known amounts and set definitely at desired values. The steps should be 2 db or less. Mechanical detents are desirable so that gain adjustments will be protected against accidental change. Slide wire controls are not generally as suitable for this use.

3. A standard volume indicator should be available with arrangements to permit correct measurements of the volume fed to the outgoing loop.

4. Adequate input pads should be available, if needed to keep normal volumes received from the network from overloading any amplifier involved in retransmission.

5. The gain of the retransmitting amplifier should be adjusted so that normal (maximum) level from the receiving loop from the telephone company office will result in application of +8 vu to the transmitting loop at the broadcasting station. The method for doing this differs depending upon whether or not the circuit from which program is received employs line amplifiers. The procedures for both of the conditions mentioned are discussed in following paragraphs. These procedures apply basic principles which take into consideration the impedance characteristics of the local telephone circuits involved and should result in transmission values which can be coordinated with those of the telephone company. In the use of commercial testing equipment for such measurements it should be made sure that the same basic principles are applied.

6. The high and low frequency delay-frequency characteristics (sometimes referred to as delay distortion of phase distortion) of all equipment used (coils, amplifiers, equalizers, etc.) should be such as not to contribute any appreciable amount to the over-all network.

ADJUSTMENT OF GAIN OF RETRANSMITTING AMPLIFIERS

A. Where the incoming interexchange circuit utilizes amplifiers in the normal manner.

1. At the broadcasting station connect a 600-ohm resistance across the output of the retransmitting amplifier circuit in place of the transmitting (out-going) loop, and connect a standard volume indicator across this 600-ohm resistance. If a 600-ohm pad is normally used between the amplifier and the loop the 600-ohm resistance should be connected to the output of the pad, in place of the loop, and the volume indicator connected across the input of the pad.

2. Have the telephone office, at which the receiving (incoming) loop connects to the line circuit, transmit 1000-cycle test tone at a level of 0 vu (1 milliwatt) into the receiving loop.

3. Adjust the gain of the retransmitting amplifier until the volume indicator shows that 0 vu of test tone is being fed to the 600-ohm resistance. This is indicated by a scale reading of -4 with the attenuator set on +4 vu if no pad is involved. If there is a pad between the volume indicator and the 600-ohm resistance the volume indicator should read higher than 0 vu by the loss in db in the pad. If the volume indicator is to remain connected to the circuit for service it should be calibrated for use in this manner as brought out in Method 1 on Page 7 of the brochure mentioned earlier. If removed after the gain is adjusted calibration should be by method 2.

4. Replace the 600-ohm resistance by the loop. Note the reading of the volume indicator again. The algebraic quantity that must be added to this reading to obtain the reading when the 600-ohm resistance was connected, is the correction that should be added to the volume indicator readings under service conditions to obtain the actual volume fed to the loop (or pad if used). With actual program the normal corrected maximums should reach +8 vu into the loop.

B. Where the incoming interexchange circuit is of the non-amplified type (no amplifier at the telephone office, although one is required at the retransmitting point).

1. Communicate with the station transmitting on the interexchange circuit and request transmission of 0 dbm of 1,000-cycle test tone into the local circuit. (Oscillator should present 600 ohm impedance to local circuit.)

2. Adjustments should then be made at the retransmitting station as described for interexchange circuits utilizing amplifiers.

After establishing the correct normal setting of gain for the retransmitting amplifier at a broadcasting station this gain should be maintained at all times unless some change is made which will change the input to the amplifier. In this case a new normal setting should be established by repeating the procedure described for determining correct gain adjustments.

If transmission through the station concerned is sometimes reversed the proper gain for both directions of transmission should be determined. The necessary change in gain between the two directions may be made by insertion of different pads in the input circuit.

A testing frequency of 1000 cycles is specified for making the foregoing adjustments as this is the standard testing frequency utilized

for "line-up" work on program and other circuits in the telephone plant and is the frequency at which amplifier gains and circuit losses are coordinated in obtaining proper transmission levels throughout the telephone plant.

Because of possibility of interference with other circuits frequencies as high as this can not safely be transmitted in local cable plant at levels greater than 0 dbm (1 milliwatt).

In the case of high quality program circuits 500 cycle test tone may be used for similar purposes, where it is desired to transmit full +8 dbm of test tone, (at a normal +8 vu point) as interference effects are much less at this frequency, and transmission loss at 500 cycles will be closely similar to that at 1000 cycles. In the case of medium quality circuits, however, equal uniformity in transmission loss at different frequencies can not be assured, and some over-all error might result from assuming 500-cycle test results to be equal to those at 1000 cycles if used for several points which might operate in tandem.

PROCEDURE IN CASE OF IMPROPER VOLUME RECEIVED FROM THE INTEREXCHANGE CIRCUIT

As indicated earlier, program network operating and maintenance procedures are based upon the assumption that the originating point will properly regulate the volume fed to its transmitting loop. The question, therefore, arises as to what should be done if this is not the case or if some network transmission irregularity develops which results in improper volume reaching the various tributary stations. This is of particular importance in the case of medium quality services since the closer supervision given the high quality services simplifies detection of the sources of volume irregularities.

If volume irregularities are noted, it should first be ascertained that this discrepancy is actually present on the incoming loop and that some irregularity in the station equipment is not accountable. Having determined this, the telephone company should be notified and will determine whether the circuit to the next interconnecting point toward the originating point is at fault. If not, it may either be assumed that the next station is also experiencing the trouble and is taking similar steps, or that station may be communicated with by the broadcaster to verify this.

AN EMERGENCY BROADCAST TIME SYSTEM*

(From the Engineering Notices of the National Broadcasting Company)

As network broadcasting continues to develop, it requires more and more careful and exact timing. The awkward pauses heard at the end of programs, cuts at the start of broadcasts, and many other similar troubles are usually traced directly to faulty timing.

In an attempt to overcome these troubles, in so far as is possible, a system has been devised to provide accurate and automatic time checks to all who might be concerned.

The system in its present form provides audible "beeps" three, two, and one minutes before each quarter hour. Three "beeps" indicates 3 minutes before the quarter hour, two "beeps", two minutes before the quarter hour, one "beep", one minute before. The start of the first "beep" in each case is exactly on the minute. Each "beep" is a 1000 cycle note for a duration of slightly more than 1/2 second.

In addition to providing accurate and automatic time checks, the system also provides an excellent warning to operating personnel that switching periods are "coming up." It is now recognized that the warnings have saved many switches that would have otherwise been overlooked.

The "beeper" time checks are supplied to all broadcast studio booths, superimposed over all announce delite** outgoing channel monitoring, connected to a house monitoring selector level, appears at the Master Control Desk, at Transmission Operating, the Division Engineer's office, the Maintenance Group Office, the Field Office, Air-Conditioning Office, and at Transmission arranged so that the "beeps" can be fed to radio and private lines.

The "beeps" are used in the broadcast studio booths by the Production Director and Engineer to check the accuracy of the booth clock. Experience has revealed that a large number of clocks fed from a common and accurate source are not necessarily exactly alike. Defects in the clocks sometimes cause errors that are not immediately noticed unless there is an auxiliary means of checking them. The audible "beeper" continuously available, results in clock errors being noticed and corrected before any harm is done. If a booth clock is wrong or not operating at all, the broadcast still starts on time from the audible time checks.

Some broadcast studios are operated without a Production Director. Others, usually repeater studios, are operated without either a Production Director or Engineer in the studio announce booth. The time checks superimposed over outgoing channel monitoring provides the correct time to the announcer at his delite** to check the clock there.

The "beeps" are available on a House Monitoring Selector Level to permit any office with a loudspeaker to obtain correct "broadcast time." It is also used by the Maintenance Engineers to set office clocks wherever loudspeakers are located. Sometimes it is used by office personnel as a warning to monitor a special program that they are particularly interested in. The loudspeaker is dialed to the "beeper" level and left there. The 3, 2, and 1 minute "beeps" serve as a warning that the program time is approaching. Before the actual broadcast time the loudspeaker is silent except for the "beeps" permitting concentration on work at hand without interference by broadcast program.

The time checks are used at Transmission Operating and at the Master Control Desk as warnings that switching periods are approaching.

Another important use is the feeding of time checks to remote pickup points over private lines and business phones. The business phone connections are received in the Master Control Room on a PLX Board from the building PBX. The "beeps" are fed to these lines in multiple so that normal conversation is not interferred with. The time checks are available on a spare PLX jack which is connected in parallel with all local private lines and PBX business phones that are being used for program coordination and "go aheads". The announcer receives the time checks at the pickup by listening to the engineer's private line receiver. The engineer lifts the receiver away from his ear slightly and the announcer hears the check by standing near the engineer.

Providing the automatic time checks frees the Transmission Operating Engineer in Master Control the last few minutes before switching time to make last minute patches, clear trouble, make changes, etc. The saving of time resulting from not tieing up personnel with giving verbal time checks is very appreciable and improves the overall operating efficiency.

It should be noted from the attached diagrams that a loudspeaker is automatically connected across all PLX and PBX lines receiving

*System developed by Mr. Edwin Costello, New York NBC Maintenance Engineer, in cooperation with the Maintenance Staff.

**The word "delite" is used by NBC to identify a studio control position or console used by announcers.

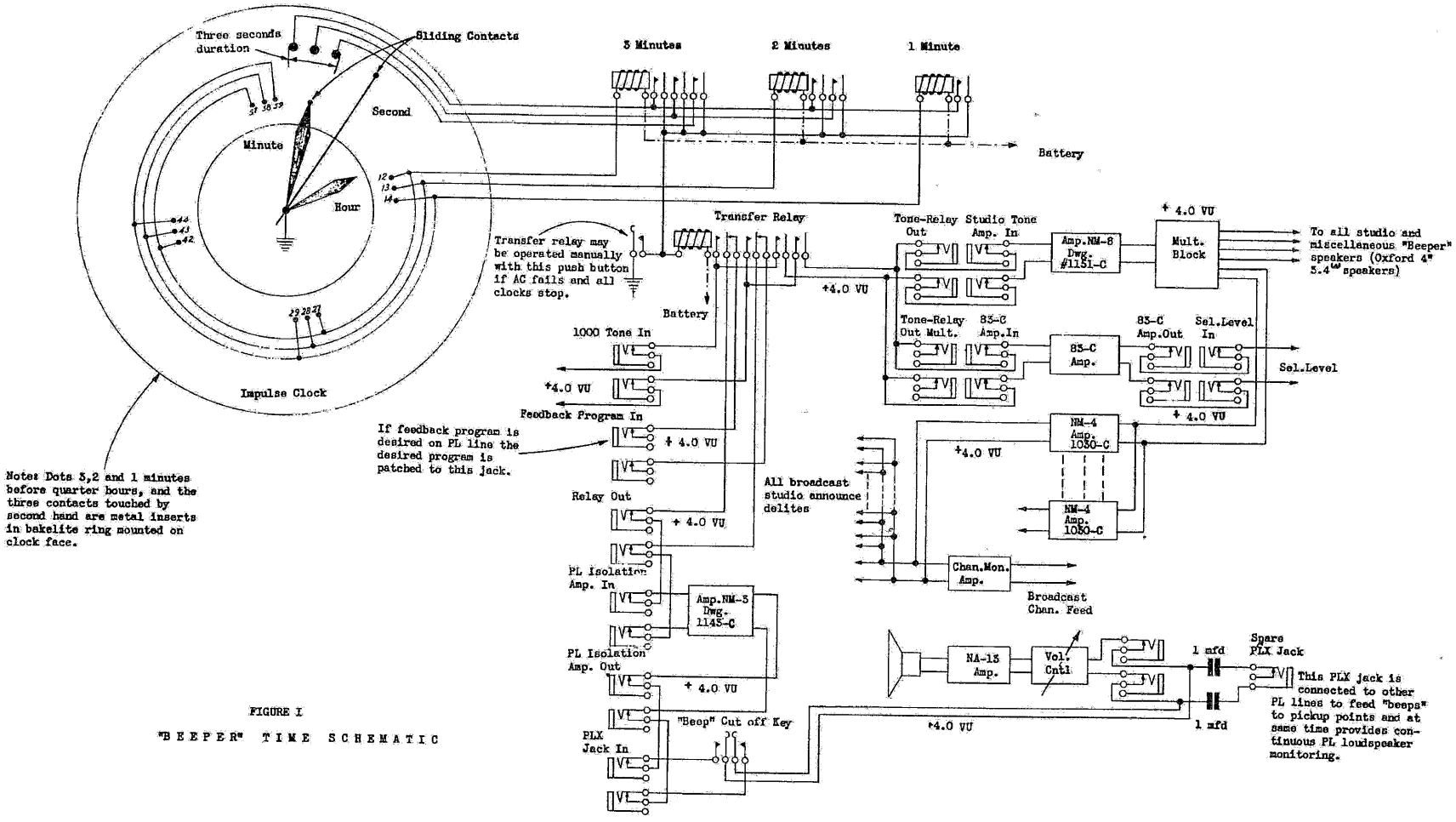


FIGURE I

"B E E P E R" T I M E S C H E M A T I C

time checks. This loudspeaker provides a continuous monitor of lines without an engineer continually listening to a phone. Considerable operating time can be saved by this loudspeaker monitor alone.

Figure 1 shows the contacts added to an electric clock face, the relay system operated by the clock, and associated equipment used to feed the resulting "beeps" to monitoring points. Operation levels and notes make the diagram self-explanatory and no further discussion required.

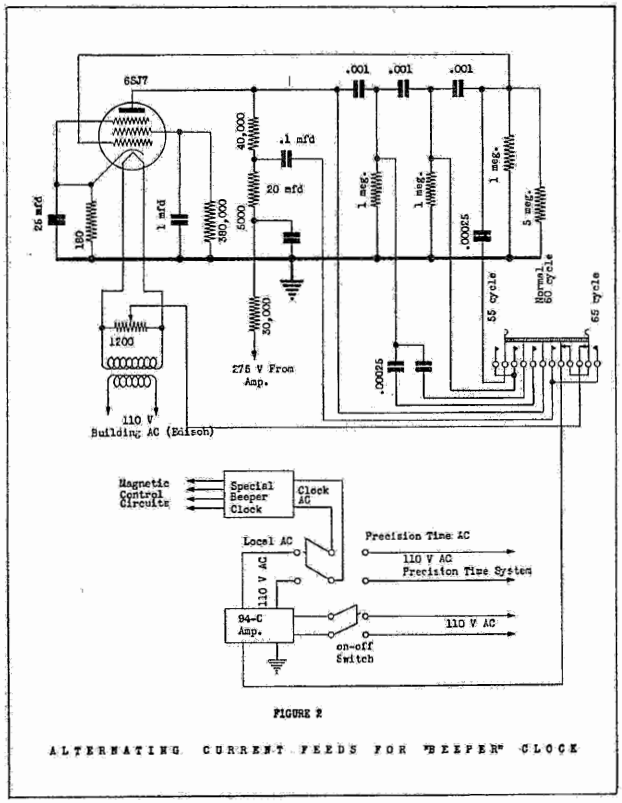


FIGURE 2

ALTERNATING CURRENT FEEDS FOR "BEEPER" CLOCK

Figure 2 shows the AC feed to the electric clock. Under the present normal operating conditions the switch is thrown to the Precision Time feed. If the Precision Time equipment fails or the clock requires correction the 94-C amplifier is turned on and the clock switch thrown to the local AC feed position. The "beeper" clock is then corrected by operating the oscillator switch in the 94-C input to change its driving frequency either faster or slower as required. Prior to the installation of the local Precision Time system, the clock was fed continuously from the 94-C. Due to poor 60 cycle frequency control it was found necessary to correct the "beeper" clock as often as once an hour.

If all AC feeds fail entirely the 3, 2, and 1 minute "beeps" can be supplied manually by

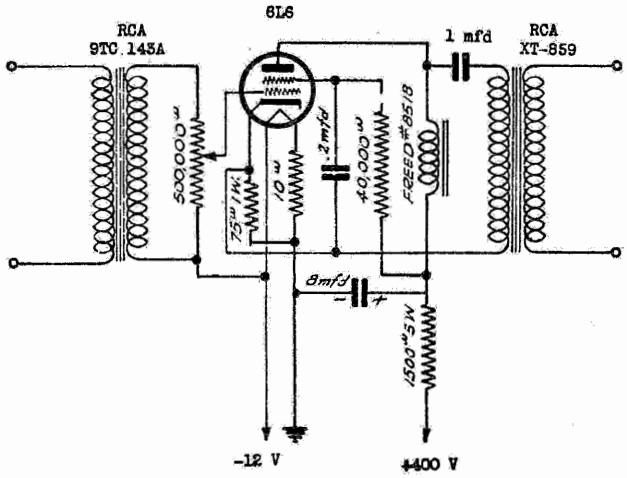


FIGURE 3

STUDIO "BEEPER" TONE AMPLIFIER

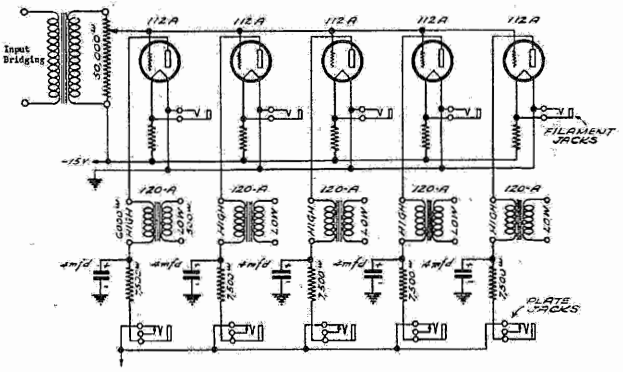


FIGURE 4

"BEEPER" TONE HEAD SET MONITORING ISOLATION AMPLIFIER

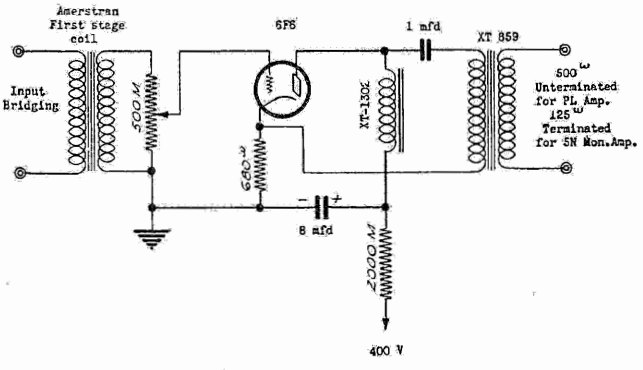


FIGURE 5

OFFICE MONITORING AND PRIVATE LINE ISOLATION AMPLIFIER

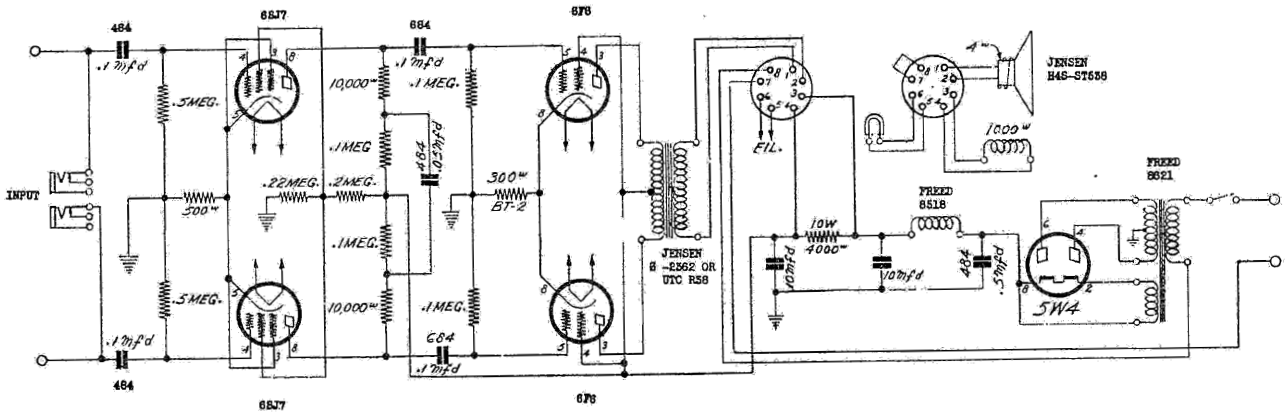


FIGURE 6

NA-13 MONITORING AMPLIFIER

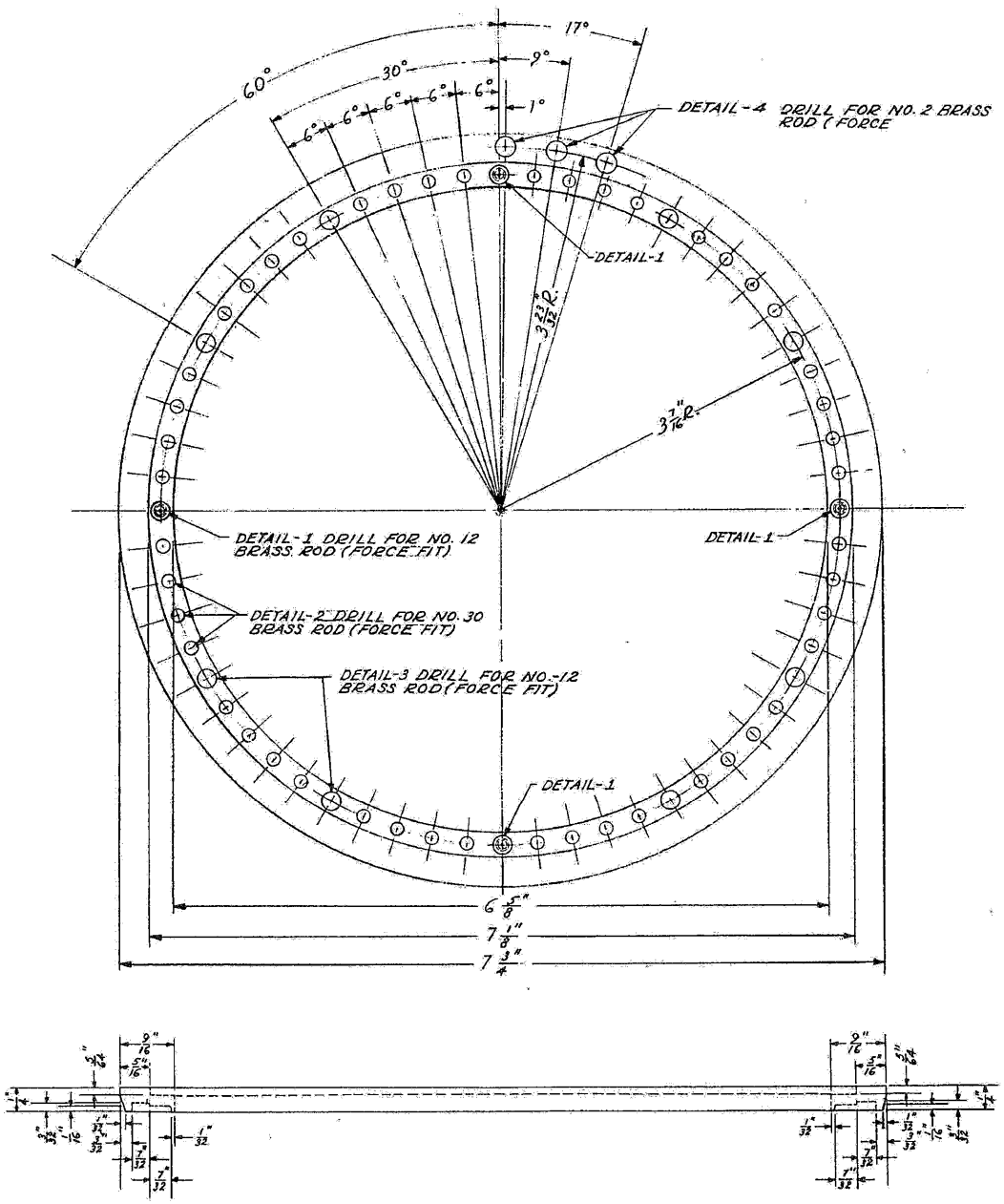
FIGURE 7

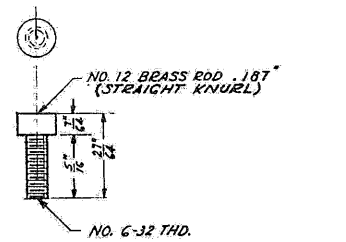
PHOTOGRAPH VIEW OF MASTER CLOCK FOR "BEEPER" SYSTEM

operating the push button associated with the transfer relay shown on Figure 1. The time to operate the relay manually is taken from a Western Union spring operated clock mounted beside the "beeper". The Western Union clock installation is inexpensive and provides an excellent emergency time system. The clock is corrected electrically from a central office once each hour. All equipment associated with the entire "beeper" system, except the clock itself and one monitor speaker, is DC operated in order to provide this emergency feature.

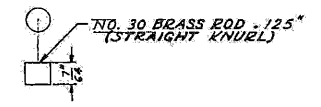
Figures 3, 4, and 5 are diagrams for the DC operated amplifiers. Some of the amplifiers are of an old design but are utilized here for economical reasons. Any amplifier that would accomplish the same purpose may, of course, be substituted.

Figure 6 shows the design of the AC operated NA - 13 amplifier. If AC fails, the loss of this amplifier will not interfere with the emergency DC operation of the system itself. The NA - 13 is used as a private line monitor and for "beeper" warnings at Transmission Operating.

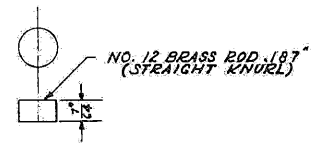




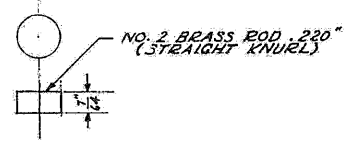
DETAIL - 1
4 REQ.



DETAIL-2
48 REQ



DETAIL-3
8 REQ.



DETAIL-4
3 REQ.

FIGURE 8

ELECTROACOUSTICS

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THEORY OF SOUND WAVES[1]

Sound (or a sound wave) is an alteration in pressure, stress, particle displacement, or particle velocity that is propagated in an elastic material; or the superposition of such propagated alterations. Sound (or sound sensation) is also the sensation produced through the ear by the above alterations.

Wave equation

The behavior of sound waves is given by the wave equation

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} \tag{1}$$

where p is the instantaneous pressure increment above and below a steady pressure (dynes/centimeter^2); p is a function of time and of the three coordinates of space. Also,

t = time in seconds

c = velocity of propagation in centimeters/second

∇^2 = the LaPlacian, which for the particular case of rectangular coordinates x, y, and z (in centimeters) is given by

$$\nabla^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \tag{2}$$

For a plane wave of sound, where variations with respect to y and z are zero, $\nabla^2 p = \partial^2 p/\partial x^2 = d^2p/dx^2$; the latter is approximately equal to the curvature of the curve showing p versus x at some instant. Equation (1) states simply that, for variations in x only, the acceleration in pressure p (the second time derivative of p) is proportional to the curvature in p (the second space derivative of p).

For a gas (as air), the velocity of propagation c is related to other parameters of the medium by the equation

$$c = \sqrt{\gamma p_0/\rho_0} \tag{3}$$

where

γ = ratio of the specific heat at constant pressure to that at constant volume

p_0 = the steady pressure of the gas in dynes/centimeter^2

ρ_0 = the steady or average density of the gas in grams/centimeter^3

The range of variation of these parameters is given in Fig. 1 for typical substances at standard conditions (20 degrees centigrade, 760 millimeters of mercury).

Sinusoidal variations in time are usually of interest. For this case the usual procedure is to put p = (the real part of $\bar{p}\epsilon^{j\omega t}$), where $\bar{p}$ now satisfies the equation

$$\nabla^2 \bar{p} + (\omega/c)^2 \bar{p} = 0 \tag{4}$$

The vector complex velocity $\bar{v}$ of the sound wave in the medium is related to the complex pressure $\bar{p}$ by the formula

$$\bar{v} = -(1/j\omega\rho_0)\ \text{grad}\ \bar{p} \tag{5}$$

The specific acoustical impedance $\bar{Z}$ at any point in the medium is the ratio of the complex pressure to the complex velocity, or

$$\bar{Z} = \bar{p}/\bar{v} \tag{6}$$

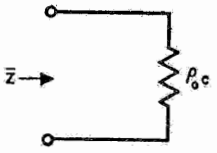
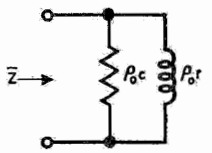
The solutions of (1) and (4) take particularly simple and instructive forms for the case of one dimensional plane and spherical waves in one direction. Fig. 2 gives a summary of the pertinent information.

[1] Lord Rayleigh, "Theory of Sound," vols. I and II, Dover Publications, New York, New York; 1945. P. M. Morse, "Vibration and Sound," 2nd edition, McGraw-Hill Book Company, New York, New York; 1948.

Fig. 1—Table of sound-propagation parameters in various substances.

substance	density ρ_0 grams/centimeter^3	velocity of propagation c centimeters/second	characteristic acoustic resistance $\rho_0 c$ grams/centimeter^2/second
Air	0.00121	34,400	41.6
Hydrogen	0.00009	127,000	11.4
Carbon dioxide	0.0020	25,800	51.3
Salt water	1.03	150,400	155,000
Mercury	13.5	140,000	1,900,000
Hard rubber	1.1	140,000	150,000
Hard glass	2.4	600,000	1,440,000

Fig. 2—Table of solutions for various parameters.

factor	type of sound wave: plane wave	type of sound wave: spherical wave
Equation for p	$\frac{\partial^2 p}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$	$\frac{\partial^2 p}{\partial x^2} + \frac{2}{r}\frac{\partial p}{\partial r} = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$
Equation for $\bar{p}$	$\frac{d^2\bar{p}}{dx^2} + \left(\frac{\omega}{c}\right)^2 \bar{p} = 0$	$\frac{d^2\bar{p}}{dx^2} + \frac{2}{r}\frac{d\bar{p}}{dt} + \left(\frac{\omega}{c}\right)^2 \bar{p} = 0$
Solution for p	$p = F\left(t - \frac{x}{c}\right)$	$p = \frac{1}{r} F\left(t - \frac{x}{c}\right)$
Solution for $\bar{p}$	$\bar{p} = \bar{A}\epsilon^{-j\omega x/c}$	$\bar{p} = \frac{1}{r}\bar{A}\epsilon^{-j\omega r/c}$
Solution for $\bar{v}$	$\bar{v} = \frac{\bar{A}}{\rho_0 c}\epsilon^{-j\omega x/c}$	$\bar{v} = \frac{\bar{A}}{\rho_0 cr}\left(1 + \frac{c}{j\omega r}\right)\epsilon^{-j\omega r/c}$
$\bar{Z}$	$\bar{Z} = \rho_0 c$	$\bar{Z} = \rho_0 c \Big/ \left(1 + \frac{c}{j\omega r}\right)$
Equivalent electrical circuit for $\bar{Z}$		

where

p = excess pressure in dynes/centimeter^2

$\bar{p}$ = complex excess pressure in dynes/centimeter^2

t = time in seconds

x = space coordinate for plane wave in centimeters

r = space coordinate for spherical wave in centimeters

$\bar{v}$ = complex velocity in centimeters/second

$\bar{Z}$ = specific acoustic impedance in dyne-seconds/centimeter^3

c = velocity of propagation in centimeters/second

$\omega = 2\pi f$; f = frequency in cycles/second

F = an arbitrary function

$\bar{A}$ = complex constant

ρ_0 = density of medium in grams/centimeter^3

Fig. 3—Table of intensity levels.

type of sound	intensity level in decibels above 10^{-16} watts/centimeter^2	intensity in microwatts/centimeter^2	root-mean-square sound pressure in dynes/centimeter^2	root-mean-square particle velocity in centimeters/second	peak-to-peak particle displacement for sinsuoidal tone at 1000 cycles in centimeters
Threshold of painful sound	130	1000	645	15.5	6.98×10^{-3}
Airplane, 1600 r.p.m., 18 feet	121	126	228	5.5	2.47×10^{-3}
Subway, local station, express passing	102	1.58	40.7	0.98	4.40×10^{-4}
Noisest spot at Niagara Falls	92	0.158	12.9	0.31	1.39×10^{-4}
Average automobile, 15 feet	70	10^{-3}	0.645	15.5×10^{-3}	6.98×10^{-6}
Average conversational speech $3\frac{1}{4}$ feet	70	10^{-3}	0.645	15.5×10^{-3}	6.98×10^{-6}
Average office	55	3.16×10^{-5}	0.114	2.75×10^{-3}	1.24×10^{-6}
Average residence	40	10^{-6}	20.4×10^{-3}	4.9×10^{-4}	2.21×10^{-7}
Quiet whisper, 5 feet	18	6.3×10^{-9}	1.62×10^{-3}	3.9×10^{-5}	1.75×10^{-8}
Reference level	0	10^{-10}	2.04×10^{-4}	4.9×10^{-6}	2.21×10^{-9}

For example, the acoustical impedance for spherical waves has an equivalent electrical circuit comprising a resistance shunted by an inductance. In this form, it is obvious that a small spherical source (r is small) cannot radiate efficiently since the radiation resistance, $\rho_o c$ is shunted by a small inductance $\rho_o r$. Efficient radiation begins approximately at the frequency where the resistance $\rho_o r$ equals the inductive (mass) reactance $\rho_o c$. This is the frequency at which the period ($= 1/f$) equals the time required for the sound wave to travel the peripheral distance $2\pi r$.

Sound intensity

The sound intensity is the average rate of sound energy transmitted in a specified direction through a unit area normal to this direction at the point considered. In the case of a plane or spherical wave, the intensity in the direction of propagation is given by

$$I = p^2/\rho c \quad \text{ergs/second/centimeter}^2$$

where

p = pressure (dynes/centimeter^2)
ρ = density of the medium (grams/centimeter^3) and
c = velocity of propagation (centimeters/second)

The sound intensity is usually measured in decibels, in which case it is known as the intensity level and is equal to 10 times the logarithm (to the base 10) of the ratio of the sound intensity (expressed in watts/centimeter^2) to the reference level of 10^{-16} watts/centimeter^2. Fig. 3 shows the intensity levels of some familiar sounds.

ACOUSTICAL AND MECHANICAL NETWORKS AND THEIR ELECTRICAL ANALOGS[2]

The present advanced state of the art of electrical network theory suggests its advantageous application, by analogy, to equivalent acoustical and mechanical networks. Actually, Maxwell's initial work on electrical networks was based upon the previous work of LaGrange in dynamical systems. The following is a brief summary showing some of the network parameters available in acoustical and mechanical systems and their analysis using LaGrange's equations.

Fig. 4 shows the analogous behavior of electrical, acoustical, and mechanical systems. These are analogous in the sense that the equations (usually differential equations) formulating the various physical laws are alike.

[2]E. G. Keller, "Mathematical Engineering," 1st ed., John Wiley, New York, New York; 1942. H. F. Olson, "Dynamical Analogies," 1st ed., D. Van Nostrand, New York, New York; 1943.

LaGrange's equations

The LaGrangian equations are partial differential equations describing the stored and dissipated energy and the generalized coordinates of the system. They are

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_v}\right) + \frac{\partial F}{\partial \dot{q}_v} + \frac{\partial V}{\partial q_v} = Q_v, \quad v = 1, 2, \ldots, n, \tag{7}$$

where T and V are, as in Fig. 4, the system's total kinetic and potential energy (in ergs), F is ½ the rate of energy dissipation (in ergs/second, Rayleigh's dissipation function), Q_v the generalized forces (dynes), and q_v the generalized coordinates (which may be angles in radians, or displacements in centimeters). For most systems (and those considered herein) the generalized coordinates are equal in number to the number of degrees of freedom in the systems required to determine uniquely the values of T, V, and F.

Example

As an example of the application of these equations toward the design of electroacoustical transducers, consider the idealized crystal microphone in Fig. 5.

This system has 2 degrees of freedom since only 2 motions, namely the diaphragm displacement x_d and the crystal displacement x_c, are needed to specify the system's total energy and dissipation.

A sound wave impinging upon the microphone's diaphragm creates an excess pressure p (dynes/centimeter^2). The force on the diaphragm is then pA (dynes), where A is the effective area of the diaphragm. The diaphragm has an effective mass m_d, in the sense that the kinetic energy of all the parts associated with the diaphragm velocity $\dot{x}_d$ ($=dx_d/dt$) is given by $m_d\dot{x}_d^2/2$. The diaphragm is supported in place by the stiffness S_d. It is coupled to the crystal via the stiffness S_o. The crystal has a stiffcess S_c, an effective mass of the m_c (to be computed below), and is damped by the mechanical resistance R_c. The only other remaining parameter is the acoustical stiffness S_a introduced by compression of the air-tight pocket enclosed by the diaphragm and the case of the microphone.

The total potential energy V stored in the system for displacements x_d and x_c from equilibrium position, is

$$V = \tfrac{1}{2}S_d x_d^2 + \tfrac{1}{2}S_a(x_d A)^2 + \tfrac{1}{2}S_c x_c^2 + \tfrac{1}{2}S_o(x_d - x_c)^2 \tag{8}$$

The total kinetic energy T due to velocities $\dot{x}_d$ and $\dot{x}_e$ is

$$T = \tfrac{1}{2}m_c\dot{x}_c^2 + \tfrac{1}{2}m_d\dot{x}_d^2 \tag{9}$$

Fig. 4A—Table of analogous behavior of systems—parameter of energy dissipation (or radiation).

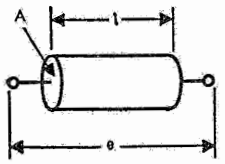
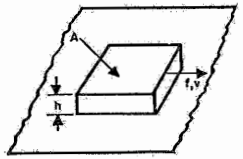
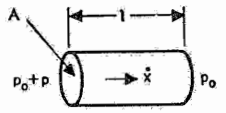
electrical	mechanical	acoustical
		
current in wire	viscous damping vane	gas flow in small pipe
$P = Ri^2$ $i = \frac{e}{R} = \frac{dq}{dt} = \dot{q}$ $R = \frac{\rho l}{A}$	$P = R_m v^2$ $v = \frac{f}{R_m} = \frac{dx}{dt} = \dot{x}$ $R_m = \frac{\mu A}{h}$	$P = \dot{R}_a \dot{X}^2$ $\dot{X} = \frac{p}{R_a} = \frac{dX}{dt}$ $R_a = \frac{8\mu\pi l}{A^2}$
where i = current in amperes e = voltage in volts q = charge in coulombs t = time in seconds R = resistance in ohms ρ = resistivity in ohm-centimeters l = length in centimeters A = cross-sectional area of wire in centimeters^2 P = power in watts	where v = velocity in centimeters/second f = force in dynes x = displacement in centimeters t = time in seconds R_m = mechanical resistance in dyne-seconds/centimeter μ = coefficient of viscosity in poise h = height of damping vane in centimeters A = area of vane in centimeters^2 P = power in ergs/second	where $\dot{X}$ = volume velocity in centimeters^3/second p = excess pressure in dynes/centimeter^2 X = volume displacement in centimeters^3 t = time in seconds R_a = acoustic resistance in dyne-seconds/centimeter^5 μ = coefficient of viscosity in poise l = length of tube in centimeters A = area of circular tube in centimeters^2 P = power in ergs/second

Fig. 4B—Table of analogous behavior of systems—parameter of energy storage (electrostatic or potential energy).

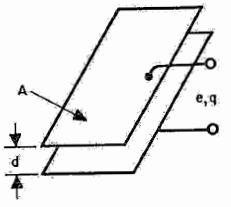
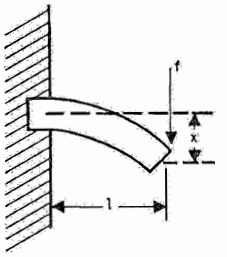
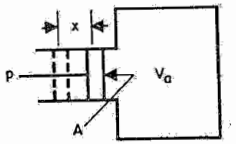
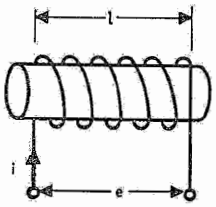
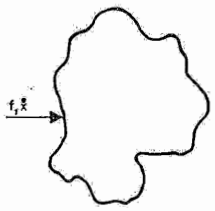
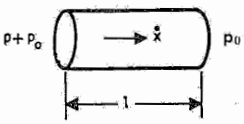
electrical	mechanical	acoustical
		
capacitor with closely spaced plates	clamped-free (cantilever beam)	piston acoustic compliance (at audio frequencies, adiabatic expansion)
$W_e = \frac{q^2}{2C} = \frac{Sq^2}{2}$ $q = Ce = \frac{e}{S}$ $C = \frac{kA}{36\pi d} \times 10^{-11}$	$V = \frac{x^2}{2C_m} = \frac{S_m x^2}{2}$ $x = C_m f = \frac{f}{S_m}$ $C_m = \frac{l^3}{3EI}$	$V = \frac{X^2}{2C_a} = \frac{S_a X^2}{2}$ $X = C_a p = \frac{p}{S_a} = xA$ $C_a = \frac{V_o}{c^2 \rho}$
where C = capacitance in farads S = stiffness = $1/C$ W_e = energy in watt-seconds k = relative dielectric constant (= 1 for air, numeric) A = area of plates in centimeters^2 d = separation of plates in centimeters	where C_m = mechanical compliance in centimeters/dyne S_m = mechanical stiffness = $1/C_m$ V = potential energy in ergs E = Young's modulus of elasticity in dynes/centimeter^2 I = moment of inertia of cross-section in centimeters^4 l = length of beam in centimeters	where C_a = acoustical compliance in centimeters^5/dyne S_a = acoustical stiffness = $1/C_a$ V = potential energy in ergs c = velocity of sound in enclosed gas in centimeters/second ρ = density of enclosed gas in grams/centimeter^3 V_o = enclosed volume in centimeters^3 A = area of piston in centimeters^2

Fig. 4C—Table of analogous behavior of systems—parameter of energy storage (magnetostatic or kinetic energy).

electrical	mechanical	acoustical
		
for a very long solenoid	for translational motion in one direction m is the actual weight in grams	gas flow in a pipe
$W_m = \frac{Li^2}{2}$	$T = \frac{mv^2}{2}$	$T = \frac{M\dot{X}^2}{2}$
$e = L\frac{di}{dt} = L\frac{d^2q}{dt^2} = L\ddot{q}$	$f = m\frac{dv}{dt} = m\frac{d^2x}{dt^2} = m\ddot{x}$	$p = M\frac{d\dot{X}}{dt} = M\frac{d^2X}{dt^2} = M\ddot{X}$
$L = 4\pi ln^2 Ak \times 10^{-9}$		$M = \frac{pl}{A}$
where L = inductance in henries W_m = energy in watt-seconds l = length of solenoid in centimeters A = area of solenoid in centimeters^2 n = number of turns of wire/centimefer k = relative permeability of core (= 1 for air, numericl	where m = mass in grams T = kinetic energy in ergs	where M = inertance in grams/centimeter^4 T = kinetic energy in ergs l = length of pipe in centimeters A = area of pipe in centimeters^2 p = density of gas in grams/centimeter^3

(This neglects the small kinetic energy due to motion of the air and that due to the motion of the spring S_o). If the total weight of the unclamped part of the crystal is w_c (grams), one can find the effective mass m_c of the crystal as soon as some assumption is made as to movement of the rest of the crystal when its end moves with velocity $\dot{x}_c$. Actually, the crystal is like a transmission line and has an infinite number of degrees of freedom. Practically, the crystal is usually designed so that its first resonant frequency is the highest passed by the microphone. In that case, the end of the crystal moves in phase with the rest, and in a manner that, for simplicity, is here taken as parabolically. Thus it is assumed that an element of the crystal located y centimeters away from its clamped end moves by the amount $(y/h)^2 x_c$, where h is the length of the crystal. The kinetic energy of a length dy of the crystal due to its velocity of $(y/h)^2 \dot{x}_c$ and its mass of $(dy/h)w_c$ is $\frac{1}{2}(dy/h)w_c (y/h)^4 \dot{x}_c^2$. The kinetic energy of the whole crystal is the integral of the latter expression as y varies from 0 to h. The result is $\frac{1}{2}(w_c/5)\dot{x}_c^2$. This shows at once that the effective mass of the crystal is $m_c = w_c/5$, i.e., 1/5 its actual weight.

The dissipation function is $F = \frac{1}{2}R_c \dot{x}_c^2$. Finally, the driving force associated with displacement x_d of the diaphragm is pA. Substitution of these expressions and (8) and (9) in LaGrange's equations (7) results in the force equations

$$\left.\begin{aligned} m_d\ddot{x}_d + S_d x_d + S_o A^2 x_d + S_o(x_d - x_c) &= pA \\ m_c\ddot{x}_c + S_o(x_c - x_d) + R_c\dot{x}_c &= 0 \end{aligned}\right\} \qquad (10)$$

These are the mechanical version of Kirchhoff's law that the sum of all the resisting

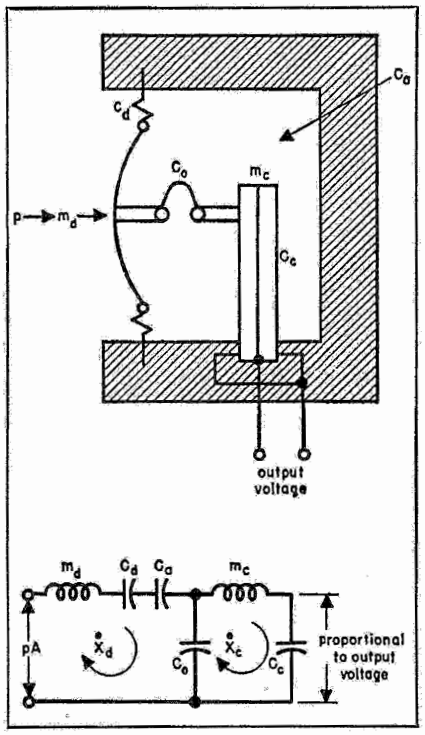


Fig. 5—Crystal microphone analyzed by use of LaGrange's equations.

forces (rather than voltages) are equal to the applied force. The equivalent electrical circuit giving these same differential equations is shown in Fig. 5. The crystal produces, by its piezoelectric effect, an open-circuit voltage proportional to the displacement x_c. By means of this equivalent circuit, it is now easy, by using the usual electrical-circuit techniques, to find the voltage generated by this microphone per unit of sound-pressure input, and also its amplitude-and phase-response characteristic as a function of frequency.

It is important to note that this process of analysis not only results in the equivalent electrical circuit, but also determines the effective values of the parameters in that circuit.

SOUND IN ENCLOSED ROOMS[3]

Good acoustics--governing factors

Reverberation time or amount of reverberation: Varies with frequency and is measured by the time required for a sound, when suddenly interrupted, to die away or decay to a level 60 decibels (db) below the original sound.

The reverberation time and the shape of the reverberation-time/frequency curve can be controlled by selecting the proper amounts and varieties of sound-absorbent materials and by the methods of application. Room occupants must be considered inasmuch as each person present contributes a fairly definite amount of sound absorption.

Standing sound waves: Resonant conditions in sound studios cause standing waves by reflections from opposing parallel surfaces, such as ceiling-floor and parallel walls, resulting in serious peaks in the reverberation-time/frequency curve. Standing sound waves in a room can be considered comparable to standing electrical waves in an improperly terminated transmission line where the transmitted power is not fully absorbed by the load.

Room sizes and proportions for good acoustics

The frequency of standing waves is dependent on room sizes: frequency decreases with increase of distances between walls and between floor and ceiling. In rooms with two equal dimensions, the two sets of standing waves occur at the same frequency with resultant increase of reverberation time at resonant frequency. In a room with walls and ceilings of cubical contour this effect is tripled and elimination of standing waves is practically impossible. The most advantageous ratio for height: width: length is in the proportion of $1:2^{1/3}:2^{2/3}$ or separated by 1/3 or 2/3 of an octave.

In properly proportioned rooms, resonant conditions can be effectively reduced and standing waves practically eliminated by introducing numerous surfaces disposed obliquely. Thus, large-order reflections can be avoided by breaking them up into numerous smaller reflections. The object is to prevent sound reflection back to the point of origin until after several re-reflections.

Most desirable ratios of dimensions for broadcast studios are given in Fig. 6.

Optimum reverberation time

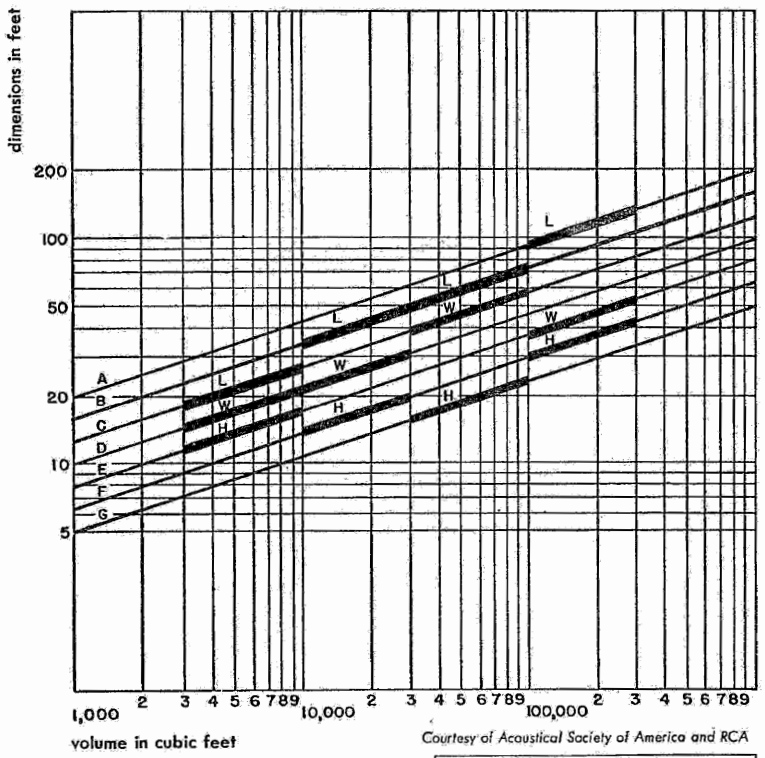
Optimum, or most desirable reverberation time, varies with (1) room size, and (2) use, such as music, speech, etc. (see Figs. 7 and 8).

These curves show the desirable ratio of the reverberation time for various frequencies to the reverberation time for 512 cycles. The desirable reverberation time for any frequency between 60 and 8000 cycles may be found by multiplying the reverberation time at 512 cycles (from Fig. 7) by the number in the vertical scale which corresponds to the frequency chosen.

Computation of reverberation time

Reverberation time at different audio frequencies may be computed from room dimensions

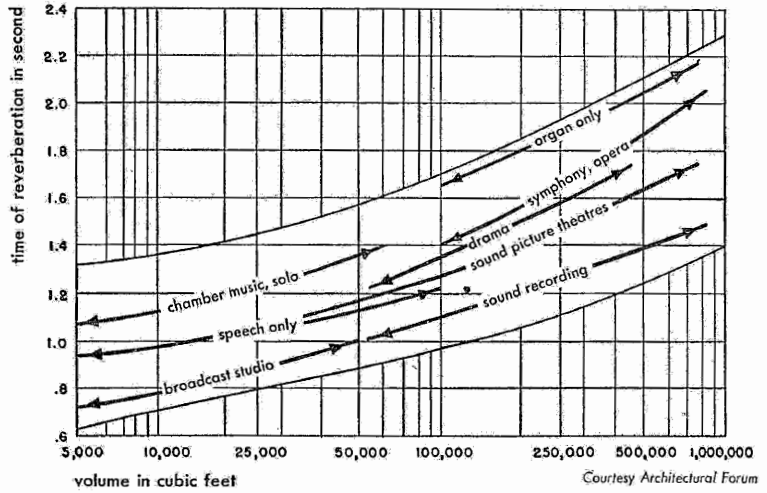
[3] F. R. Watson "Acoustics of Buildings," 1st ed., John Wiley and Sons, New York, New York; 1941.



Courtesy of Acoustical Society of America and RCA

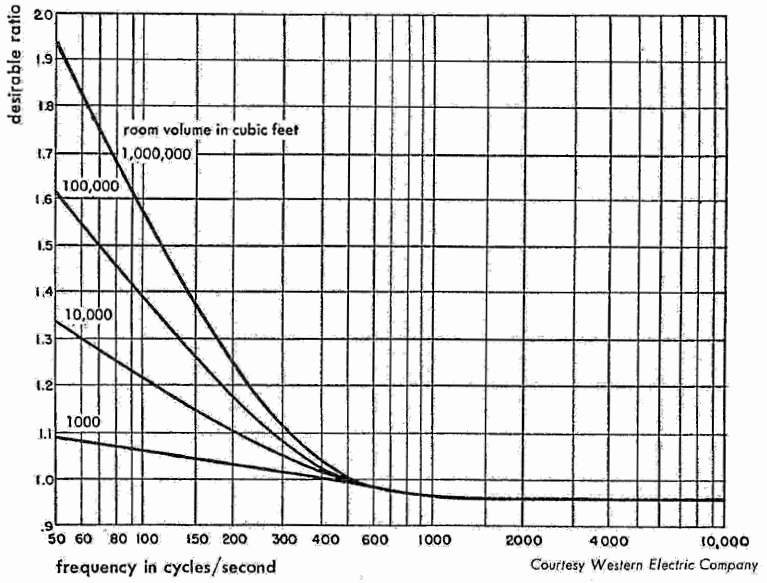
type room	H:W:L	chart designation
Small	1:1.25:1.6	E:D:C:
Average shape	1:1.60:2.5	F:D:B:
Low ceiling	1:2.50:3.2	G:C:B:
Long	1:1.25:3.2	F:E:A:

Fig. 6—Preferred room dimensions based on $2^{\frac{1}{3}}$ ratio. Permissible deviation ±5 percent.



Courtesy Architectural Forum

Fig. 7—Optimum reverberation time in seconds for various room volumes at 512 cycles per second.



Courtesy Western Electric Company

Fig. 8—Desirable relative reverberation time versus frequency for various structures and auditoriums.

Fig. 9—Table of acoustical coefficients of materials and persons*

description	sound absorption coefficients in cycles/second						authority
	128	256	512	1024	2048	4096	
Brick wall unpainted	0.024	0.025	0.031	0.042	0.049	0.07	W. C. Sabine
Brick wall painted	0.012	0.013	0.017	0.02	0.023	0.025	W. C. Sabine
Plaster + finish coat Wood lath—wood studs	0.020	0.022	0.032	0.039	0.039	0.028	P. E. Sabine
Plaster + finish coat on metal lath	0.038	0.049	0.060	0.085	0.043	0.056	V. O. Knudsen
Poured concrete unpainted	0.010	0.012	0.016	0.019	0.023	0.035	V. O. Knudsen
Poured concrete painted and varnished	0.009	0.011	0.014	0.016	0.017	0.018	V. O. Knudsen
Carpet, pile on concrete	0.09	0.08	0.21	0.26	0.27	0.37	Building Research Station
Carpet, pile on ⅛ in felt	0.11	0.14	0.37	0.43	0.27	0.25	Building Research Station
Draperies, velour, 18 oz per sq yd in contact with wall	0.05	0.12	0.35	0.45	0.38	0.36	P. E. Sabine
Ozite ⅜ in	0.051	0.12	0.17	0.33	0.45	0.47	P. E. Sabine
Rug, axminster	0.11	0.14	0.20	0.33	0.52	0.82	Wente and Bedell
Audience, seated per sq ft of area	0.72	0.89	0.95	0.99	1.00	1.00	W. C. Sabine
Each person, seated	1.4	2.25	3.8	5.4	6.6	—	Bureau of Standards, averages of 4 tests
Each person, seated	—	—	—	—	—	7.0	Estimated
Glass surfaces	0.05	0.04	0.03	0.025	0.022	0.02	Estimated

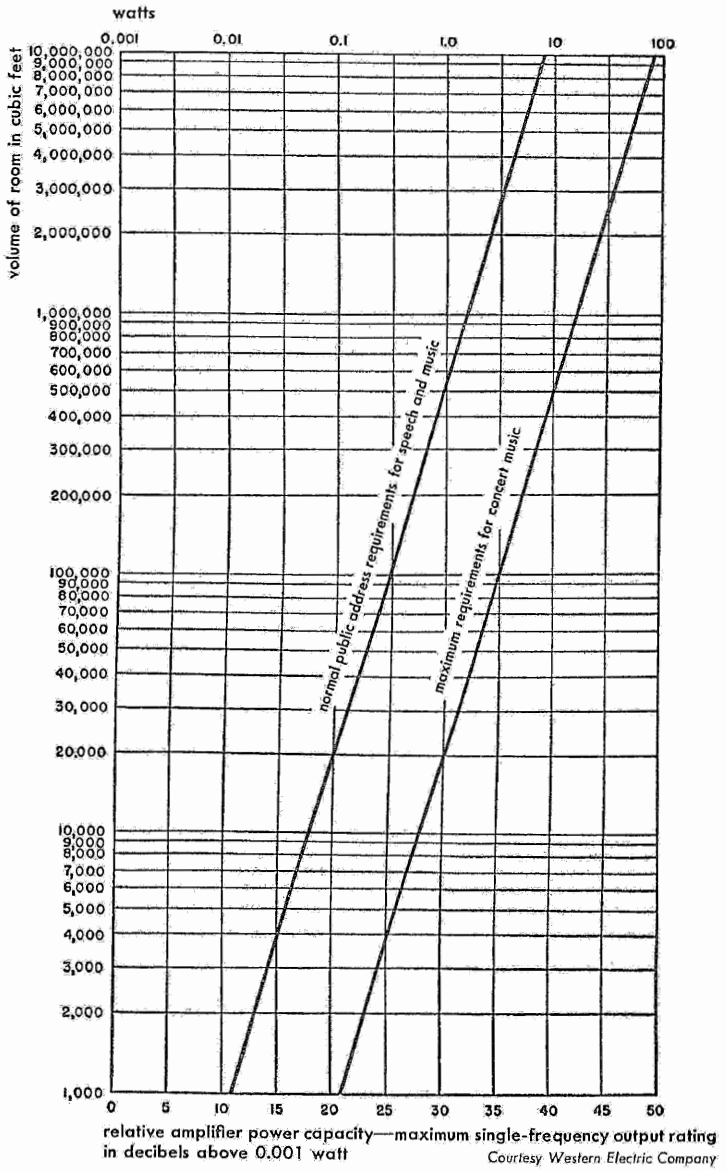
* Reprinted by permission from Architectural Acoustics by V. O. Knudsen, published by John Wiley and Sons, Inc.

Fig. 10—Table of acoustical coefficients of materials used for acoustical correction

material	cycles/second						noise-red coef *	manufactured by
	128	256	512	1024	2048	4096		
Corkoustic—B4	0.08	0.13	0.51	0.75	0.47	0.46	0.45	Armstrong Cork Co.
Corkoustic—B6	0.15	0.28	0.82	0.60	0.58	0.38	0.55	Armstrong Cork Co.
Cushiontone A-3	0.17	0.58	0.70	0.90	0.76	0.71	0.75	Armstrong Cork Co.
Koustex	0.10	0.24	0.64	0.92	0.77	0.75	0.65	David E. Kennedy, Inc.
Sonacoustic (metal) tiles	0.25	0.56	0.99	0.99	0.91	0.82	0.85	Johns-Manville Sales Corp.
Permacoustic tiles ¾ in	0.19	0.34	0.74	0.76	0.75	0.74	0.65	Johns-Manville Sales Corp.
Low-frequency element	0.66	0.60	0.50	0.50	0.35	0.20	0.50	Johns-Manville Sales Corp.
Triple-tuned element	0.66	0.61	0.80	0.74	0.79	0.75	0.75	Johns-Manville Sales Corp.
High-frequency element	0.20	0.46	0.55	0.66	0.79	0.75	0.60	Johns-Manville Sales Corp.
Absorbatone A	0.15	0.28	0.82	0.99	0.87	0.98	0.75	Luse Stevenson Co.
Acoustex 60R	0.14	0.28	0.81	0.94	0.83	0.80	0.70	National Gypsum Co.
Econacoustic 1 in	0.25	0.40	0.78	0.76	0.79	0.68	0.70	National Gypsum Co.
Fiberglas acoustical tiletype TW-PF 9D	0.22	0.46	0.97	0.90	0.68	0.52	0.75	Owens-Corning Fiberglas Corp.
Acoustone D 11/16 in	0.13	0.26	0.79	0.88	0.76	0.74	0.65	U. S. Gypsum Company
Acoustone F 13/16 in	0.16	0.33	0.85	0.89	0.80	0.75	0.70	U. S. Gypsum Company
Acousti-celotex type C-6 1¼ in	0.30	0.56	0.94	0.96	0.69	0.56	0.80	The Celotex Corp.
Absorbex type A 1 in	0.41	0.71	0.96	0.88	0.85	0.96	0.85	The Celotex Corp.
Acousteel B metal facing 1⅝ in	0.29	0.57	0.98	0.99	0.85	0.57	0.85	The Celotex Corp.

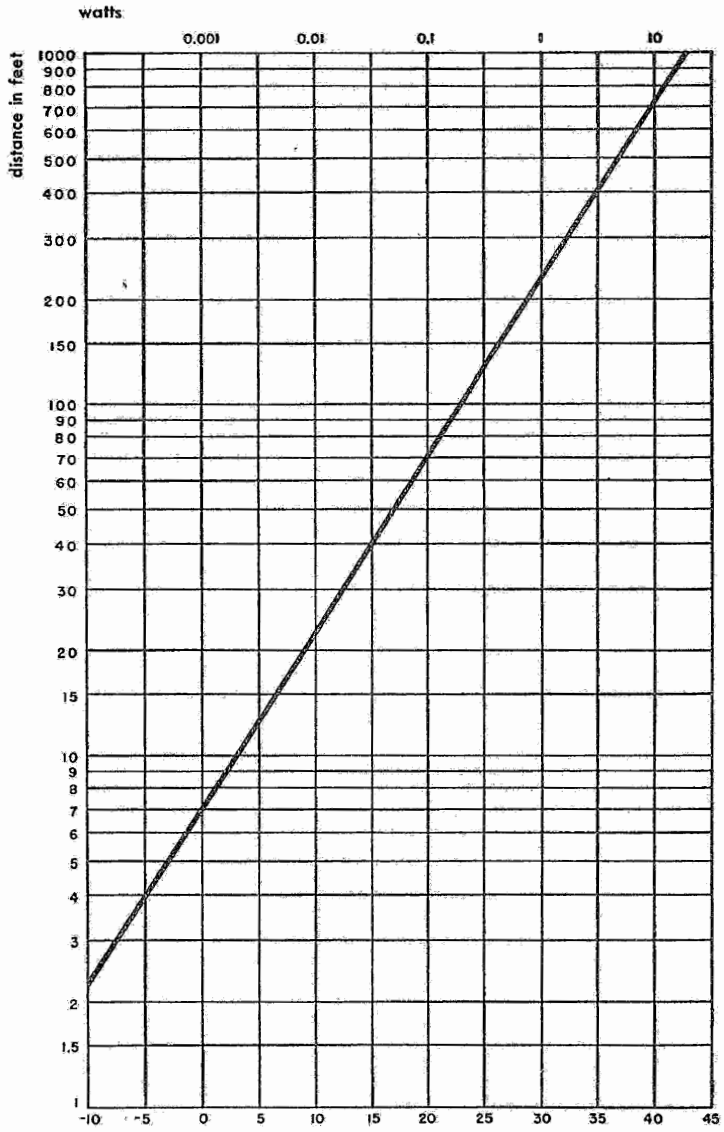
Courtesy Acoustics Materials Association

* The noise-reduction coefficient is the average of the coefficients at frequencies from 256 to 2048 cycles inclusive, given to the nearest 5 percent. This average coefficient is recommended for use in comparing materials for noise-quieting purposes as in offices, hospitals, banks, corridors, etc.



Courtesy Western Electric Company

Fig. 11—Room volume and relative amplifier power capacity. To the indicated power level depending on loudspeaker efficiency, there must be added a correction factor which may vary from 4 decibels for the most efficient horn-type reproducers to 20 decibels for less efficient cone loudspeakers.

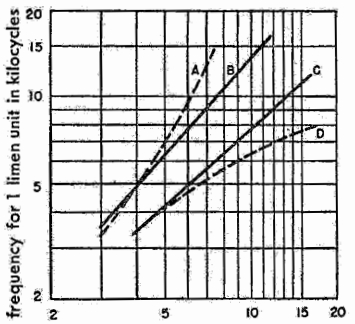


Courtesy Western Electric Company

Fig. 12—Distance from loudspeaker and relative amplifier power capacity required for speech, average for 30° angle of coverage. For angles over 30°, more loudspeakers and proportional output power are required. Depending on loudspeaker efficiency, a correction factor must be added to the indicated power level, varying approximately from 4 to 7 decibels for the more-efficient type of horn loudspeakers.

Fig. 13—Table showing bandwidth increases necessary to give an even chance of quality improvement being noticeable. All figures are in kilocycles.

minus one limen		reference	plus one limen	
speech	music	frequency	music	speech
—	—	3	3.0	3.3
3.4	3.3	4	4.8	4.8
4.1	4.1	5	6.0	6.9
4.6	5.0	6	7.4	9.4
5.1	5.8	7	9.3	12.8
5.5	6.4	8	11.0	—
5.8	6.9	9	12.2	—
6.2	7.4	10	13.4	—
6.4	8.0	11	15.0	—
7.0	9.8	13	—	—
7.6	11.0	15	—	—



Courtesy of Bell System Technical Journal

Fig. 14 — Minimum-discernable-band-width changes. Curves show:
A—Plus 1 limen for speech
B—Plus 1 limen for music
C—Minus 1 limen for music
D—Minus 1 limen for speech

and average absorption. Each portion of the surface of a room has a certain absorption coefficient a dependent on the material of the surface, its method of application, etc. This absorption coefficient is equal to the ratio of the energy absorbed by the surface to the total energy impinging thereon at various audio frequencies. Total absorption for a given surface area in square feet S is expressed in terms of absorption units, the number of units being equal to $a_{av}S$.

$$a_{av} = \frac{\text{(total number of absorption units)}}{\text{(total surface in square feet)}}$$

One absorption unit provides the same amount of sound absorption as one square foot of open window. Absorption units are sometimes referred to as "open window" or "OW" units.

$$T = \frac{0.05V}{-S \log_e(1 - a_{av})}$$

where T = reverberation time in seconds, V = room volume in cubic feet, S = total surface of room in square feet, a_{av} = average absorption coefficient of room at frequency under consideration.

For absorption coefficients a of some typical building materials, see Fig. 9. Fig. 10 shows absorption coefficients for some of the more commonly used materials for acoustical correction.

PUBLIC-ADDRESS SYSTEMS[4]

Electrical power levels for public-address requirements

Indoor: Power-level requirements are shown in Fig. 11.

Outdoor: Power-level requirements are shown in Fig. 12.

Note: Curves are for an exponential trumpet-type horn. Speech levels above reference--average 70 db, peak 80 db. For a loudspeaker of 25-percent efficiency, 4 times the power output would be required or an equivalent of 6 decibels. For one of 10-percent efficiency, 10 times the power output would be required or 10 decibels.

SOUNDS OF SPEECH AND MUSIC[5]

A large amount of data are available regarding the wave shapes and statistical properties of the sounds of speech and music. Below are given some of these data that are of importance in the design of transmission systems.

Minimum-discernible-bandwidth changes

Figure 13 gives the increase in high-frequency bandwidth required to produce a minimum discernible change in the output quality of speech and music.

These bandwidths are known as difference-limen units. For example, a system transmitting music and having an upper cutoff frequency of 6000 cycles would require a cutoff-frequency increase to 7400 cycles before there is a 50-percent chance that the change can be discerned. (Curve B, Fig. 14.)

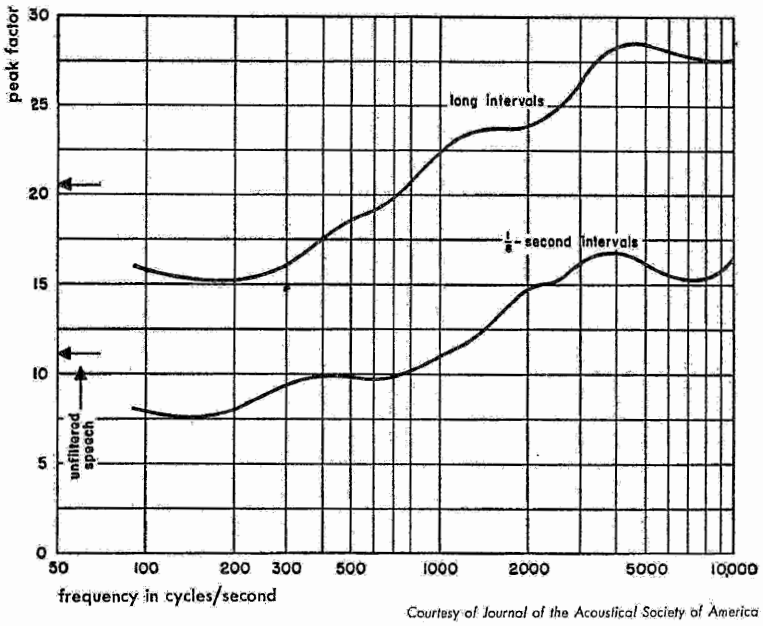
Fig. 14 is based upon the data of Fig. 13. For any high-frequency cutoff along the abscissa, the ordinates give the next higher and next lower cutoff frequencies for which there is an even chance of discernment. As expected, one observes that, for frequencies beyond about 4000 cycles, restriction of upper cutoff affects music more appreciably than speech.

Peak factor

One of the important factors in deciding upon the power-handling capacity of amplifiers, loudspeakers, etc., is the fact that in speech very large fluctuations of instantaneous level are present. Fig. 15 shows the peak factor (ratio of peak to root-mean-square pressure) for unfiltered (or wideband) speech, for separate octave bandwidths below 500 cycles, and for separate ½-octave bandwidths above 500 cycles. The peak values for sound pressure of unfiltered speech, for example, rise 10 decibels higher than the averaged root-mean-square value over an interval of 1/8 second, which corresponds roughly to a syllabic period. However, for a much longer interval of time, say the time duration of one sentence, the peak value reached by the sound pressure for unfiltered speech is about 20 decibels higher than the root-mean-square value averaged for the entire sentence.

[4] H. F. Olson, "Elements of Acoustical Engineering," 2nd ed., D. Van Nostrand, New York, New York; 1941.

[5] H. Fletcher, "Speech and Hearing," 1st ed., D. Van Nostrand Company, New York, New York; 1929. S. S. Stevens, and H. Davis, "Hearing," J. Wiley and Sons, New York, New York; 1938.



Courtesy of Journal of the Acoustical Society of America

Fig. 15—Peak factor (ratio of peak/root-mean-square pressures) in decibels for speech in 1- and 1/2-octave frequency bands, for 1/8- and 75-second time intervals.

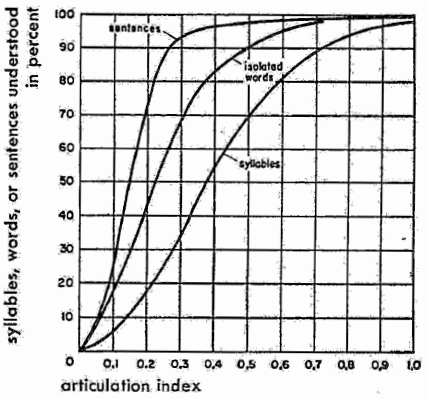


Fig. 17—Relations between various measures of speech intelligibility. Relations are approximate; they depend upon the type of material and the skill of the talkers and listeners.

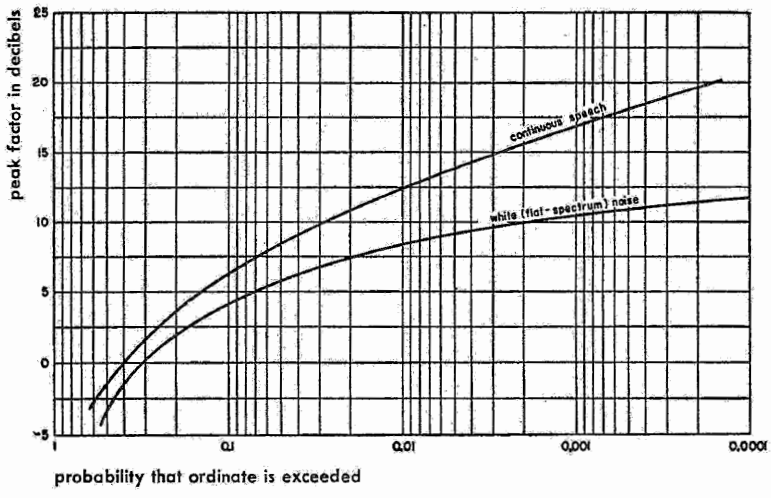
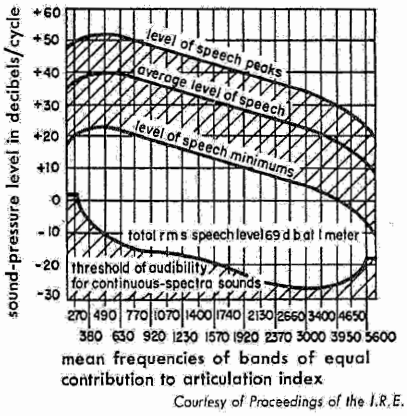


Fig. 16—Statistical properties of the peak factor in speech. The abscissa gives the probability (ratio of the time) that the peak factor in the uninterrupted speech of one person exceeds the ordinate value. Peak factor = (decibels instantaneous peak value) — (decibels root-mean-square long-time average).



Courtesy of Proceedings of the I.R.E.

Fig. 18—Bands of equal articulation index. 0 decibels = 0.0002 dyne/centimeter.

Thus, if the required sound-pressure output demands a long-time average of, say, 1 watt of electrical power from an amplifier, then, to take care of the instantaneous peaks in speech, a maximum-peak-handling capacity of 100 watts is needed. If the amplifier is tested for amplitude distortion with a sine wave, 100 watts of peak-instantaneous power exists when the average power of the sine-wave output is 50 watts. This shows that if no amplitude distortion is permitted at the peak pressures in speech sounds, the amplifier should give no distortion when tested by a sine wave of an average power 50 times greater than that required to give the desired long-time-average root-mean-square pressure.

The foregoing puts a very stringent requirement on the amplifier peak power. In relaxing this specification, one of the important questions is what percentage of the time will speech overload an amplifier of lower power than that necessary to take care of all speech peaks. This is answered in Fig. 16; the abscissa gives the probability of the $\frac{\text{peak}}{\text{long-time-average}}$ powers exceeding the ordinates for continous speech and white noise. When multiplied by 100, this probability gives the expected percent of time during which peak distortion occurs. If 1 percent is taken as a suitable criterion, then a 12 decibel ratio of $\frac{\text{peak}}{\text{long-time-average}}$ powers is sufficient. Thus, the amplifier should be designed with a power reserve of 16 in order that peak clipping may occur not more than about 1 percent of the time.

SPEECH-COMMUNICATION SYSTEMS

In many applications of the transmission of intelligence by speech sounds, a premium is placed on intelligibility rather than flawless reproduction. Especially important is the reduction of intelligibility as a function of both the background noise and the restriction of transmission-channel bandwidth. Intelligibility is usually measured by the percentage of correctly received monosyllabic nonsense words uttered in an uncorrelated sequence. This score is known as syllable articulation. Because the sounds are nonsense syllables, one part of the word is entirely uncorrelated with the remainder, so it is not consistently possible to guess the whole word correctly if only part of it is received intelligibly. Obviously, if the test speech were a commonly used word, or say a whole sentence with commonly used word sequences, the score would increase because of correct guessing from the context. Fig. 17 shows the interrelationship between syllable, word, and sentence articulation. Also given is a quantity known as articulation index.

The concept and use of articulation index is obtained from Fig. 18. The abscissa is divided into 20 bandwidths of unequal frequency interval. Each of these bands will contribute 5 percent to the articulation index when the speech spectrum is not masked by noise and is sufficiently loud to be above the threshold of audibility. The ordinates give the root-mean-square peaks and minimums (in 1/8-second intervals), and the average sound pressures created at 1 meter from a speaker's mouth in an anechoic (echo-free) chamber. The units are in decibels pressure per cycle relative to a pressure of 0.0002 dynes/centimeter^2. (For example, for a bandwidth of 100 cycles, rather than 1 cycle, the pressure would be that indicated plus 20 decibels; the latter figure is gotten by taking 10 times logarithm (to the base 10) of the ratio of the 100-cycle band to the indicated band of 1 cycle.)

An articulation index of 5 percent results in any of the 20 bands when a full 30-decibel range of speech-pressure peaks to speech-pressure minimums is obtained in that band. If the speech minimums are masked by noise of a higher pressure, the contribution to articulation is accordingly reduced to a value given by 1/6 [(decibels level of speech peaks) - (decibels level of average noise)]. Thus, if the average noise is 30 decibels under the speech peaks, this expression gives 5 percent. If the noise is only 10 decibels below the speech peaks, the contribution to articulation index reduces to (1/6) x 10 = 1.67 percent. If the noise is more than 30 decibels below the speech peaks, a value of 5 percent is used for the articulation index. Such a computation is made for each of the 20 bands of Fig. 18, and the results are added to give the expected articulation index.

A number of important results follow from Fig. 18. For example, in the presence of a large white (thermal-agitation) noise having a flat spectrum, an improvement in articulation results if pre-emphasis is used. A pre-emphasis rate of about 8 decibels/octave is sufficient.

LOUDNESS

Equal loudness contours: Fig. 19 gives average hearing characteristics of the human ear at audible frequencies and at loudness levels of zero to 120 decibels versus intensity levels expressed in decibels above 10^{-16} watt per square centimeter. Ear sensitivity varies considerably over the audible range of sound frequencies at various levels. A loudness level of 120 decibels is heard fairly uniformly throughout the entire audio range but, as indicated in Fig. 19, a frequency of 1000 cycles at a 20-decibel level will be heard at very nearly the same intensity as a frequency of 60 cycles at a 60-decibel level. These curves explain why a loudspeaker operating at lower-than-normal level sounds as though the higher frequencies were accentuated and the lower tones seriously attenuated or entirely lacking; also, why music, speech, and other sounds, when

reproduced, should have very nearly the same intensity as the original rendition. To avoid perceptible deficiency of lower tones, a symphony orchestra, for example, should be reproduced at an acoustical level during the loud passages of 90 to 100 decibels.

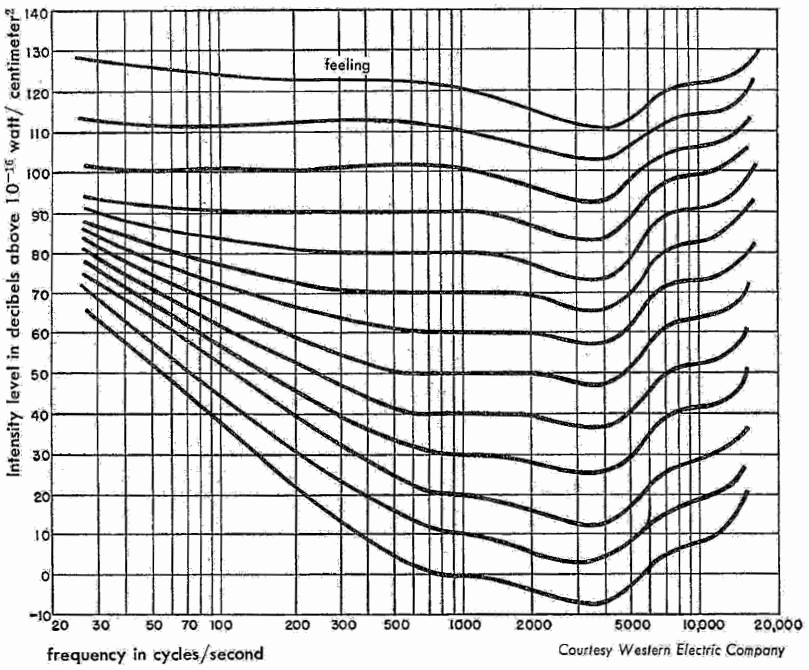


Fig. 19—Equal loudness contours.

PRACTICAL DESIGN OF VIDEO AMPLIFIERS

By Elliott A. Henry

(Reprinted through the courtesy of the RCA Victor Division, Radio Corporation of America.)

Revised 1949 by Mr. Henry, now with Globe Products Corp., Bridgeport, Conn.

In the past few years many excellent articles and papers have been published in various technical magazines on the subject of video amplifiers and the many types of compensation used to extend the frequency range of resistance-capacity-coupled amplifiers. The majority of these articles have dealt with the mathematical analysis or have had primarily a theoretical approach. A few have presented a generalized introductory discussion of the subject. It seems that a wide gap exists in the published information on this subject. It is the intent of this article to attempt to bridge that gap by presenting practical design data for video amplifiers. The mathematics will be kept to simple algebra. Such other information as is pertinent to the subject, for example, some data on vacuum tubes, will be included for the sake of completeness.

If the underlying causes of trouble or limitations of performance are thoroughly understood, it will be easier to comprehend the methods of overcoming these limitations. We shall, therefore, commence this article with a discussion of the factors limiting the frequency range of the conventional R-C (resistance-capacitance) coupled amplifier.

As pentode tubes are almost universally used in video amplifiers, the following discussion will be based primarily upon their use and on the assumption that the value of the grid resistor is much greater than the plate load impedance, as is the case in video amplifiers. However, as triodes are occasionally used, sufficient data are included to cover the compensation of triode amplifier stages also.

In order better to understand the frequency response limitations of conventional R-C coupled amplifiers, let us examine the plot of output voltage versus frequency, Figure 2, of a typical amplifier stage, Figure 1.

At F_o, zero frequency, the output voltage is zero. As the frequency is increased, the output voltage rises to a maximum somewhat higher in frequency than F_1, remains essentially constant until the frequency is somewhat lower than F_2, and then continually decreases as the frequency is further increased. The two frequencies, F_1 and F_2, are considered the useful limits of the pass-band of an audio frequency amplifier and are the frequencies at which the output of the amplifier is 70.7% of the output at the mid-frequency range. This loss of response, or output, of the amplifier at

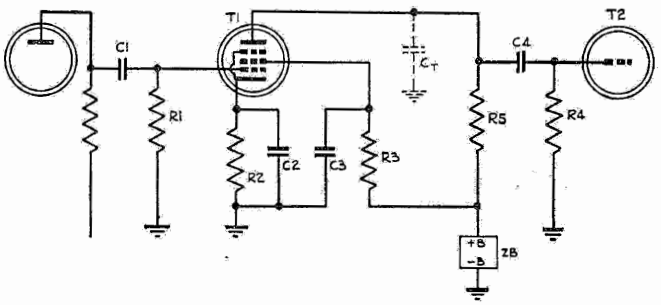


FIG. 1. *Conventional R-C coupled amplifier stage.*

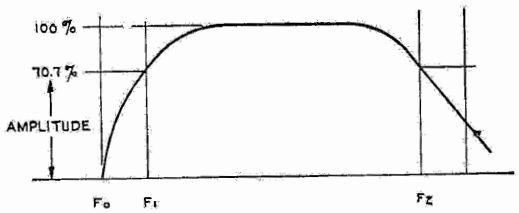


FIG. 2. *Gain-Frequency plot of Figure 1.*

F_1 and lower and at F_2 and higher both result from the change of reactance (X_C) of condensers with the change in frequency. Either the high or low frequencies will be attenuated, depending upon the location or function of the various condensers, including stray and circuit capacities. In order to demonstrate this more clearly, high and low frequency attenuation will be considered as separate problems.

Unequal gain in an amplifier is referred to as frequency distortion because a complex wave in passing through the amplifier will have its wave shape altered, or distorted, if all of its harmonic components do not receive the same degree of amplification. If the phase delay is not proportional to frequency, the wave may be further distorted. This is called phase distortion.

In the following discussion major emphasis has been placed on the frequency response rather than the phase characteristic of amplifiers. This has been done for two reasons: First, to keep the mathematics to simple algebra; second, an amplifier compensated in accordance with the design data herein presented will be corrected for both frequency and phase distortion and it is perhaps easier to visualize results in terms of frequency response rather than phase characteristic. The importance of the phase characteristic of a video amplifier cannot be over emphasized. For example, an amplifier stage with a response curve such as Figure 2 would

not be suitable for video work as the phase angle would increase 45^0 at F_1 and decrease 45^0 at F_2 from the mid-frequency value and therefore a change in the phase angle of 90^0 over the operating range F_1 and F_2. General practice indicates that the frequency response should not drop more than 2% of F_1 and F_2 in a video amplifier if these frequencies are to be considered the limits of the useful pass band of the amplifier.

LOW FREQUENCY ATTENUATION

Low frequency attenuation, or low frequency distortion as it is sometimes called, may be introduced in any one of four places or any combination of the four. Referring to Figure 1, these four places or networks are: the grid resistor-condenser coupling network, R_1-C_1 or R_3-C_3; the cathode resistor by-pass condenser network, R_2-C_2; the screen resistor by-pass condenser network, R_3-C_3; and the internal impedance, Z_b, of the power supply. How the grid resistor-condenser combination acts to reduce the gain at low frequencies may be seen by referring to Figure 3.

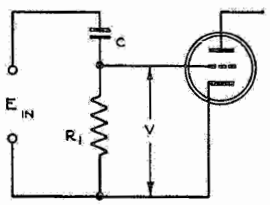


FIG. 3. *Grid coupling network.*

With E constant, the voltage, V, impressed across the grid to cathode may be expressed as $\frac{V}{E}$ and is equal to the resistance, R, divided by the impedance of R and C or:

$$\frac{R}{\sqrt{R^2 + X_c^2}} = \frac{V}{E} \qquad \textit{(Eq. 1)}$$

As the reactance of a condenser is inversely proportional to frequency, the ratio of resistance to impedance, and thus $\frac{V}{E}$ decreases as the frequency decreases. This means the voltage available to drive the following stage is less at the low frequencies than at the high frequencies; and with the gain in the tube equal at both frequencies, the output voltage will be down in the same proportion as the input voltage. This ratio $\frac{V}{E}$ expressed in percentage, is the coupling efficiency of the grid resistor-condenser combination. For example, let us assign values to R and C, Figure 3, and with a constant voltage, E_{in}, see how V varies with frequency.

If $C = .05$ ufd.
$R = 250{,}000$ ohms
$E_{in} = 10$ volts

and the two frequencies are

$F_1 = 30$ cycles
$F_2 = 1000$ cycles

then at F_2: $X_c = \frac{1}{2\pi FC} = 3184$ ohms.

From Equation 1:

$$\frac{V}{10} = \frac{25 \times 10^4}{\sqrt{625 \times 10^8 + 10.1 \times 10^6}} = \frac{250{,}000}{250{,}020} \cong 1$$

Therefore, V $\cong$ 10 volts or a coupling efficiency of practically 100% at 1000 cycles.

At F_1:

$X_c = 10.6 \times 10^4$ ohms

$$\frac{V}{10} = \frac{25 \times 10^4}{\sqrt{625 \times 10^8 + 112 \times 10^8}} = \frac{25}{27.2} = .92$$

So V = 9.2 volts and the coupling efficiency is 92% at 30 cycles. Therefore, the output voltage of the stage will be 8% lower at 30 cycles than at 1000 cycles, other factors being equal.

Low frequency distortion may result from the cathode resistor-condenser combination, R_2-C_2 of Figure 1. This results from degeneration, as the impedance in the cathode circuit will vary with frequency, and the gain of a stage with cathode degeneration is reduced by the factor:

$$\frac{1}{1 + G_m Z_k} \qquad \textit{(Eq. 2)}$$

In other words, the gain of a stage, other things being equal, is:

$$A = A_1 \times \frac{1}{1 + G_m Z_k} = \frac{A_1}{1 + G_m Z_k} \qquad \textit{(Eq. 3)}$$

where A is the actual stage gain, and
A_1 is the stage gain without degeneration,
G_m is the mutual conductance in Mhos,
Z_k is the cathode circuit impedance (impedance of R_2-C_2 in parallel) in ohms.

This impedance, Z_k, is detailed in Figure 4 and is given by:

$$Z_k = \frac{R\,X_c}{\sqrt{R^2 + X_c^2}} \qquad (Eq.\,4)$$

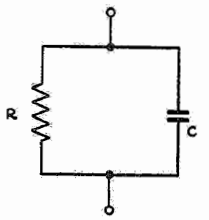


FIG. 4. *Equivalent cathode or plate load network.*

Thus if, in Figure 1, R_2 was 1000 ohms, C_2 was 10 ufd., G_m 5000 umhos, and the stage gain without degeneration 10, the actual gain at 1000 cycles would be:

$$X_{C2} = 15.9 \text{ ohms at 1000 cycles}$$

$$Z = \frac{1000 \times 15.9}{\sqrt{10^6 + 253}} = \frac{15{,}900}{1000.125} \cong 15.9 \text{ ohm}$$

$$A = \frac{10}{1 + .005 \times 15.9} = \frac{10}{1 + .0795} = 9.25$$

or a loss of gain at 1000 cycles of 7.5%. Now let's see what the gain of the same stage is for a frequency of 20 cycles.

$$X_{C2} \cong 800 \text{ ohms at 20 cycles}$$

$$Z = \frac{10^3 \times 800}{\sqrt{10^6 + 64 \times 10^4}} = \frac{8 \times 10^5}{\sqrt{164 \times 10^4}} = \frac{8 \times 10^5}{1280} = 625 \text{ ohms}$$

$$A = \frac{10}{1 + .005 \times 625} = \frac{10}{1 + 3.125} = \frac{10}{4.125} = 2.42$$

Thus, the output of the stage under these conditions will be only about one-fourth, at 20 cycles, of the output at 1000 cycles.

The effect of R_3-C_3, Figure 1, is similar in effect to the results of cathode degeneration mentioned above; but as the screen current is only about 10% of the plate current and the screenplate transconductance only about 12% of the control grid, or cathode, to plate transconductance, the effect is much smaller and can usually be made negligible by making the time constant of R_3-C_3 at least three times as long as the period of the lowest frequency it is desired to pass.

$$\text{Or, } TC = RC > 3\,\frac{1}{F} \qquad (Eq.\,5)$$

where C is in farads,
R is in ohms,
F is the lowest frequency in the pass-band.

The total impedance of the screen circuit is essentially the reactance of C_3; and, whereas in the case of cathode degeneration, if the product of G_m Z_k equals one, the gain will be reduced 50%, the effect of the screen is so much less that a reduction of gain, at the lowest frequency, of only 2% would result if G_m Z_s equaled 2 (G_m being the control grid-plate transconductance).

For example, a 6F6 is desired to pass 30 cycles (Figure 1).

$$Z_s \cong X_{C3} \text{ then } X_{C3}\,G_m = 2$$

$$X_{C3} = \frac{2}{G_m} = \frac{2 \times 10^6}{2500} = 800 \text{ ohms.}$$

$$X_{C3} = 800 \text{ ohms at 30 cycles} = 6.64 \text{ ufd.}$$

We would use the next larger commercial size, or 8 ufd. To determine R_3:

$$RC = 3\,\frac{1}{F} = \frac{3}{F} = \frac{3}{30} = .1$$

$$R = \frac{.1 \times 10^6}{8} = \frac{10^5}{8} = 12{,}500 \text{ ohms}$$

Therefore, we would use a value of 12,500 ohms or larger for R_3.

In the event that the value of the screen voltage dropping resistor, R as determined above, should be too large to allow the proper screen current, R may be set by screen requirements and the by-pass condenser C, determined from equation 5 using R as selected and solving for C.

The fourth place for low frequency distortion is the internal impedance of the power supply, Z_b. Unless a regulated power supply of the electronic type is used, the impedance is essentially the reactance of the output filter condenser and will vary with frequency as outlined previously. A method for making the effect of this impedance negligible is the use of R-C filters. These filters, if properly designed, may also provide correction for either R_1-C_1 or R_2-C_2, Figure 1, but not both at the same time. Design data for these correction networks is given in the section on low frequency compensation.

LOW FREQUENCY CORRECTION

Of the four places or networks at which low frequency distortion may be introduced, two, R_3-C_3 and Z_b, can be made negligible by proper design. In addition to making negligible

the internal impedance of the power supply, we may correct for either R_1-C_1 or R_2-C_2 by the addition of an R-C filter, C_5-R_6, Figure 5.

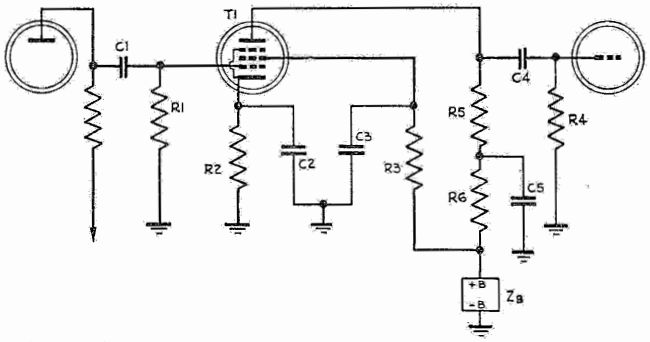


FIG. 5. *Amplifier stage with low frequency correction network (R_6-C_5).*

To correct for R_1-C_1 or R_4-C_4: Make the grid resistor (R_1 or R_4) as high as permissible; 500,000 ohms is a convenient value. Make the coupling condenser (C_1 or C_4) a nominal value such as .1 ufd. It is desirable to keep this value high but care must be taken to avoid making the capacity too large or trouble may be encountered from leakage and "hang over" effects. Now make the time constant of the grid resistor-condenser (R_1-C_1 or R_4-C_4) equal to the time constant of R_5-C_5 and make R_6 greater than 20 times the reactance of C_5 at the lowest frequency it is desired to pass. For example: If in Figure 5 we make R_4 equal 500,000 ohms, C_4 equal .1 ufd., R_5 equal 1000 ohms, and desire to provide correction to 30 cycles, then the time constant of R_4-C_4 will equal .05 seconds or 50,000 microseconds. Leaving the TC in u's, will give our answer directly in ufds.

$$TC = RC = .1 \times 500{,}000 = 50{,}000$$

$$\text{and } C_5 = \frac{50{,}000}{1{,}000} = 50 \text{ ufd.}$$

and $R_6 > 20\ X_{C5}$ at 30 cycles $= 20 \times 106 = 2120$ ohms or greater.

What actually happens is that as the voltage across R_4 decreases, as a result of the rising reactance of C_4 (as the frequency is decreased), the reactance of C_5 also increases and as a consequence, the parallel impedance of C_5-R_6 is added to R_5 as part of the plate load impedance. Where the plate load is small in comparison to the plate resistance, the gain from grid to plate is given by:

$$A = G_m Z_p \qquad \textit{(Eq. 6)}$$

where A is the stage gain,
G_m is the transconductance in mhos,
Z_p is the plate load impedance.

As we have made the time constants of C_4-R_4 and C_5-R_5 equal, the voltage across the plate load impedance will rise in proportion to the loss of voltage across C_4 and the voltage across R_4 will remain constant.

It might be pointed out that although at times it is expedient to make either C_4 or R_4 somewhat lower in value, such as to use a standard size capacitor for C_5, this should be done with caution. If the values of C_4 or R_4 are reduced, the amount of correction necessary is increased and errors become magnified. Good practice demands good design first so that minimum correction need be used.

If it is desired we may use C_5-R_6 to compensate for the frequency distortion of R_2-C_2 instead of R_1-C_1. To see how this can be done refer again to Figure 5. It has been previously shown that the impedance in the cathode circuit varies with frequency; and therefore, the AC voltage developed across this impedance will be, according to ohms law:

$$E = IZ \qquad \textit{(Eq. 7)}$$

and, therefore, a function of frequency. This voltage will appear across the plate load resistor, R_5, amplified by the stage gain. Now the plate current flows through both R_2-C_2 and R_6-C_5, so the same kind of distortion will be generated in both circuits if the time constants are equal; but as the current flows through these networks in opposite directions, the distortion across R_5, resulting from R_2-C_2, will be cancelled by the distortion from C_5-R_6, if the distortion components are equal in magnitude. This condition is met when:

$$R_2 C_2 = R_6 C_5 \qquad \textit{(Eq. 8)}$$

$$\text{and } \frac{C_2}{C_5} = \frac{R_6}{R_2} = A$$

where A equals the stage gain as defined in Equation 6 for pentodes and Equation 11 for triodes. For example, if we assign values of 200 ohms to R_2 (Figure 5), a nominal value of 100 ufd. to C_2, and a stage gain of 10, and wish to determine the value of C_5 and R_6 then:

$$\frac{C_2}{C_5} = \frac{100}{C_5} = 10 \text{ so } C_5 = 10 \text{ ufd.}$$

$$\frac{R_6}{R_2} = \frac{R_6}{200} = 10 \text{ so } R_6 = 2000 \text{ ohms}$$

The second condition may be checked by substituting in Equation 8:

$$200 \times 100 = 2000 \times 10$$
$$1 = 1$$

Therefore, both conditions have been met. There will be no frequency distortion from plate to ground resulting from R_2-C_2 and the phase delay will be proportional to frequency. However, more about the phase delay later.

We now find ourselves in the position of being able to make two of the four circuits causing low frequency distortion negligible and being able to compensate for either of the other two but not both. Now without compensating, as previously explained, the only way of minimizing the effects of the coupling efficiency of R_1-C_1 or R_4-C_4, Figure 5, is by increasing the values of either the resistor, condenser, or both. There are limits as to how far this can be carried, and generally the reactance of the coupling condenser cannot be kept low enough, at the lowest frequency, to give completely satisfactory results. So it is generally good practice to utilize C_5-R_6 to compensate for R_1-C_1 or R_4-C_4 and use other means to minimize the effects of R_2-C_2, Figure 5.

There are three methods generally used to accomplish this. First, eliminate R_2-C_2, ground the cathode directly, and apply fixed bias to the tube through the grid resistor. Second, eliminate the cathode by-pass condenser, C_2, and accept the consequent loss in stage gain. The gain will be reduced by the factor given in Equation 2; but the reduction in gain will be constant at all frequencies, so with other factors being equal there will be no low frequency distortion. The third method is to make C_2 very large and accept what comes out. This is not as bad as it sounds, since 1000 ufd. low voltage electrolytics are available at reasonable costs and certainly cost less than an additional stage which might be required to bring up the overall gain of the amplifier. The reactance of a 1000 ufd. condenser at 30 cycles is 5.31 ohms and in the average circuit will cause negligible distortion.

HIGH FREQUENCY ATTENUATION

As we have seen from the foregoing, there are four places, or networks, in the conventional amplifier at which the low frequency output may be restricted, and actually only one place that correction may be applied (the others however being made negligible). The opposite is true for the high frequency limitations. We have only one (or what may be summed up and treated as one) place, or network, responsible for the reduction of output at the higher frequencies (F_2 and higher in Figure 2), but we have a choice of several correction circuits. For an explanation, let's take another look at Figure 4. We have a resistance, R, in parallel with a capacity, C. The impedance of this network is given by:

$$Z = \frac{R \times X_c}{\sqrt{R^2 + X_c^2}} \qquad (Eq.\ 9)$$

and, therefore, the impedance Z will be a function of frequency. Now if we let R, Figure 4, represent the plate load resistance of an amplifier stage such as R_5 in Figure 1 and C represent the total shunt reactance across this load resistor such as C_T in Figure 1, we can calculate the effective load impedance for any frequency. Equation 6 shows that where the plate load impedance is much less than the plate resistance of the tube, the gain of the stage is directly proportional to the plate load impedance. In other words, if the G_m of a tube is 9,000 umhos and the load impedance is 1000 ohms, the gain would be 9; while if the load impedance were raised to 2000 ohms, the gain would be 18. It is this shunt reactance in parallel with the plate load resistor that limits the high frequency response of the amplifier. This reactance is composed (Figure 1) of the output capacity of T_1 plus the input capacity of T_2 plus the stray circuit capacity, and summed up as C_T.

CIRCUIT AND STRAY CAPACITIES

Before taking up the problem of compensating for this condition, methods for determining C_T should be discussed, as all systems of high frequency compensation depend upon accurate knowledge of this capacity.

The input capacity, C_{in}, of a tube is defined as the capacity from the grid to all other elements and the output capacity, C_{out}, of a tube as the capacity from the plate to all other elements. This is emphasized because of the usual practice in tube manuals of listing the static inter-element capacities of triodes and summing the capacities up into C_{in} and C_{out} for multi-grid tubes. A good reason for this is that the dynamic capacities of triodes are more subject to variations than screen-grid tubes. Therefore, when dealing with triodes, remember to add the grid-place, C_{gp}, capacity to the plate-cathode, C_{pk}, capacity to determine the total output capacity, C_{out}; or for triodes,

$$C_{out} = C_{pk} + C_{gp}$$

In the case of a 6J5 where the tube manual lists C_{pk} as 3.6 uuf. and C_{gp} as 3.4, the output capacity will be 3.6 + 3.4 = 7.0 uuf.

In determining the effective, or dynamic, input capacity of a triode, the "Miller Effect" must be considered. When a triode is acting as an amplifier, the grid and plate voltages are out of phase. That is, if the grid voltage is changed one volt in the positive direction and the gain is ten, the plate voltage

will decrease ten volts. This gives a net change of eleven volts between the grid and plate and results in a capacity current in the grid circuit eleven times above the normal capacity current. This is known as the "Miller Effect," and from the above it can be seen that the dynamic input capacity is a function of the stage gain. The dynamic input capacity of a triode is given by:

$$C_{in} = C_{gk} + \left[C_{gp} (1 + A) \right] \qquad (Eq.\ 10)$$

where C_{in} is the dynamic input capacity.
C_{gk} is the capacity from grid to cathode,
C_{gp} is the capacity from grid to plate,
A is the stage gain.

From Equation 10 it is evident that the stage gain must be known before the dynamic input capacity can be determined. The gain of a triode is given by:

$$A = \frac{u\ Z_L}{Z_L + R_P} \qquad (Eq.\ 11)$$

where A is the stage gain,
u is the amplification factor of the tube,
Z_l is the plate load,
R_p is the plate resistance of tube.

For example, determine the stage gain and dynamic input capacity of a 6J5 working into a 20,000 ohm plate load. From the tube manual the plate resistance is 6700 ohms, u is 20, C_{gk} is 3.4 uuf., and C_{gp} is 3.4 uuf.

From Equation 11:

$$(Z_L = R_L)$$

$$A = \frac{20 \times 2 \times 10^4}{2 \times 10^4 + 67 \times 10^2} = \frac{4 \times 10^5}{2.67 \times 10^4} \cong 15$$

From Equation 10:

$$C_{in} = 3.4 + \left[3.4\ (1+15) \right] = 3.4 + 54.4 = 57.8 \text{ uuf.}$$

which is quite an increase from the static capacities.

Where the load of a triode is in the cathode instead of the plate circuit, cathode follower stage, the dynamic input capacity is given by Equation 31 in the cathode follower section. The grid to cathode capacity C_{gk} of any amplifier tube is modified, where cathode degeneration exists, by the factor $1 + G_m R_k$ where the cathode is unby-passed, and $1 + G_m Z_k$ where the cathode is partially by-passed and Z_k given by Equation 4. This reduction factor is seen to be the same as for the reduction of gain with cathode degeneration.

$$C_{eff} \cong C_{gk} \frac{1}{1 + G_m Z_k} = \frac{C_{gk}}{1 + G_m Z_k} \qquad (Eq.\ 12)$$

where C_{eff} is the effective capacity grid to cathode, C_{gk}
C_{gk} is the grid to cathode capacity without degeneration,
G_m is the transconductance in mhos,
Z_k is the cathode impedance.

In a pentode if the screen is by-passed to the cathode the entire input capacity may be degenerated. This, however, reduces the effective shielding of the screen grid. For example, determine the dynamic input capacity of an 1852 with an unby-passed 160 ohm cathode resistor ($Z_k = R_k$).

From Equation 12:

$$C_{eff} = \frac{11}{1 + .009 \times 160} = \frac{11}{1 + 1.44} = \frac{11}{2.44} = 4.52 \text{ uuf.}$$

With the screen by-passed to ground the effective input capacity would be about 10% higher.

Determining the stray capacity is perhaps the hardest job. There are no hard and fast rules for determining these strays. Sometimes the capacity of individual components to ground are measured and summed up but generally they are estimated as close as possible, which may involve a bit of "cut and try." Nominal variations are usually compensated for in critical or very wide band amplifiers by making the "peaking coil" with a variable hi-permeability iron core and adjusting the inductance during alignment of the amplifier. A close approximation of the stray capacity is 10 to 15 uuf. in a well-designed layout.

Another method of determining C_T is by measuring the gain of an uncompensated amplifier stage, Figure 1, in the mid-frequency range (between F_1 and F_2, Figure 2) and then measuring the frequency at which the gain drops to 70.7% of the mid-frequency gain. This will be F_2 in Figure 2. In an uncompensated amplifier the magnitude of C_T that, with a given plate load resistor, will cause the gain of the amplifier to drop to 70.7% of the mid-frequency gain, F_2, Figure 2, is given by:

$$C_T = \frac{1}{2\pi F R} \qquad (Eq.\ 13)$$

where C_T is in farads,
F is in cycles,
R is in ohms.

Essentially this states that when the shunt reactance across the plate load resistor and the resistor are equal, the response will drop to 70.7% of the mid-range value (Equation 4).

For example, by using the circuit in Figure 1, with R_5 1000 ohms, and a wide range vacuum tube voltmeter connected from plate to ground, we could determine C_T by measuring the voltage across R_5, with a constant voltage input to the grid of T_1, around 2500 cycles and then increasing the frequency until the voltage was 70.7% of the initial value. This frequency can then be substituted in equation 13, and we can solve for C_T. The C_T thus determined will include the input capacity of the vacuum tube voltmeter and this vacuum tube voltmeter input capacity must be subtracted from the calculated C_T. In order to minimize errors on the input voltage to the grid of T_1, resulting from shunt reactance across the grid, R_1 should be made very low in value, 50 to 100 ohms, while making the measurements.

As a practical example, if we proceed as above and measure 10 volts across R_5 at 2500 cycles and 7.07 volts at 2mc., then substituting in equation 36:

$$C_T = \frac{10^{12}}{6.28 \times 2 \times 10^6 \times 10^3} = \frac{10^3}{12.56} = 79.6 \text{ uuf.}$$

But we must subtract from this capacity the capacity of the vacuum tube voltmeter and assuming the vacuum tube voltmeter capacity to be 22 uuf., C_T will equal 79.6 minus 22 or 57.6 uuf. This value will include all circuit and stray capacity, and may be used as the basis for calculating the high frequency compensation networks, as outlined later. When the peaking coil is added to the circuit, care should be used in its mounting to disturb the circuit as little as possible. A good practice is to have a peaking coil of the same physical size mounted in place *but shorted out* during the above measurements. If the peaking coil is placed as in Figure 6, the effect of the capacity to ground of the peaking coil is minimum.

HIGH FREQUENCY COMPENSATION

In low frequency compensation we found it necessary to make the plate load impedance, and consequently the voltage gain, rise in proportion to the loss in voltage across C_4, Figure 5. In high frequency compensation, however, it is necessary to keep the plate load impedance, and thus the stage gain, constant over the desired frequency range.

One way of accomplishing this is to add an inductive reactance to the plate load network to counteract the effect on impedance, of the change of capacitive reactance with frequency, of the shunt circuit and stray capacity. Such a network is shown in Figure 6, and its impedance can be made essentially constant, from

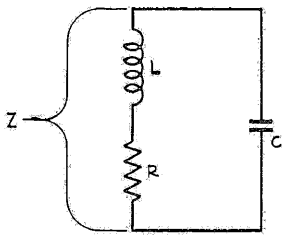


FIG. 6. *Basic shunt peaked network.*

zero frequency up to any frequency where the network proportions are such that the reactance of C is equal to the resistance of R and twice the reactance of L. The impedance of this network is given by:

$$Z = X_c \sqrt{\frac{R^2 + X_L^2}{R^2 + (X_c - X_L)^2}} \qquad \textit{(Eq. 14)}$$

Actually if a plot of impedance versus frequency is made, using the proportions above, it will be found that the impedance begins to rise at a frequency .2F where F is the chosen correction frequency and gradually rises as the frequency is increased to approximately .6F and then decreases, becoming equal to the low frequency impedance at F. The magnitude of this increase is about .5% at .2F and 3% at .6F. For example, if we assume F to be 5 mc., C to be 31.8 uuf., L to be 15.9 uh, and R to be 1000 ohms, the impedance, Figure 6, will be:

At 5 mc. $X_c = 1000$ ohms
$X_L = 500$ ohms

$$Z = 1000 \sqrt{\frac{10^6 + 25 \times 10^4}{10^6 (1000\text{-}500)^2}} = 1000 \sqrt{\frac{1.25 \times 10^6}{1.25 \times 10^6}}$$
$$= 1000 \sqrt{1} = 1000 \text{ ohms}$$

At 4.5 mc. $X_c = 1112$ ohms
$X_L = 450$ ohms

$$Z = 1112 \sqrt{\frac{10^6 + .2025 \times 10^6}{10^6 + (1112\text{-}450)^2}} = 1112 \sqrt{\frac{1.2025 \times 10^6}{1.43825 \times 10^6}}$$
$$= 1112 \sqrt{.834} = 1112 \times .913 = 1016 \text{ ohms}$$

At 3 mc. $X_c = 1668$ ohms
$X_L = 300$ ohms

$$Z = 1668 \sqrt{\frac{10^6 + 9 \times 10^4}{10^6 + (1668\text{-}300)^2}} = 1668 \sqrt{\frac{1.09 \times 10^6}{2.87155 \times 10^6}}$$
$$= 1668 \sqrt{.37966} = 1668 \times 616165 = 1027 \text{ ohms}$$

At 1 mc. $X_c = 5000$ ohms
$X_L = 100$ ohms

$$Z = 5000 \sqrt{\frac{10^6 + 10^4}{10^6 + 24.01 \times 10^6}} = 5000 \sqrt{\frac{1.01 \times 10^6}{25.01 \times 10^6}}$$
$$= 5000 \sqrt{.040384} = 5000 \times .201 = 1005 \text{ ohms}$$

This plate load network is a parallel resonant circuit of very low Q and we are actually working along the resonance curve. By increasing the correction frequency, F, the linearity over a desired frequency range can be made almost perfect at a sacrifice of gain. Design data for this is covered under "Shunt Peaking."

Generally speaking, high frequency compensation of amplifiers is based upon wave filter theory, and the more complex the filter used, the higher the gain. The more complex types of filters are usually used where highest possible gain or very sharp cut-off characteristic are of prime importance. The most widely used types of high frequency compensation are:

1. Shunt Peaking
2. Series Peaking
3. Combination or Series-Shunt Peaking

The gain of the different types are in the order listed above, with series peaking giving 50% more gain than shunt peaking and combination peaking giving 80% more gain than shunt peaking. Combination peaking is widely used as the best compromise between maximum gain and simplicity.

SHUNT PEAKING

Referring to Figure 7, there are three components which we are interested in, in order to extend the high frequency range of the stage.

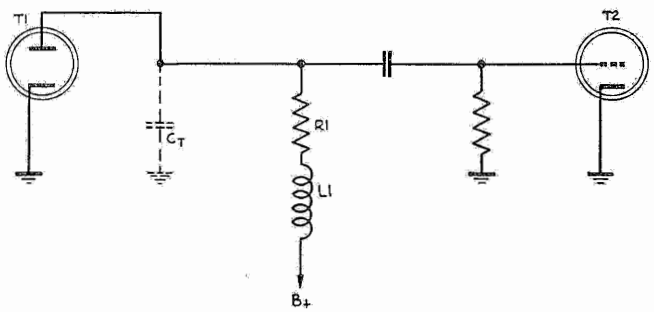


FIG. 7 *Shunt peaked stage.*

These are labeled C_T, R_1, and L_1. C_T can be determined by the methods previously outlined. R_1 is made equal to the reactance of C_T at the highest frequency of correction. Let us label this frequency F_c; then:

$$R_1 = X_{C_T} \text{ at } F_c \qquad \textit{(Eq. 15)}$$

And L_1 is such that its reactance at F_c is one-half of X_{CT} at F_c, or:

$$X_{L_1} = \frac{X_{C_T}}{2} \text{ at } F_c \qquad \textit{(Eq. 16)}$$

or $$L_1 = \frac{R_1}{4\pi F_c} \qquad (Eq.\ 17)$$

For example, suppose it is desired to extend the bandwidth of the stage in Figure 7 to 5 megacycles and C_T was 25 uuf. Then:

$$Xc_T = \frac{1}{6.28 \times 5 \times 10^6 \times 25 \times 10^{-12}} = \frac{10^6}{785} = 1273 \text{ ohms}$$

Therefore, R_1 equals 1273 ohms (Equation 15) and:

$$L_1 = \frac{1273}{12.56 \times 5 \times 10^6} = \frac{1273}{62.8 \times 10^6} = 20.3 \times 10^{-6} \text{henries}$$

$L_1 = 20.3$ uh.

The stage gain, given by Equation 8, assuming T_1 to be an 1852, will be 1273 times .009 or 11.45. Equations 15, 16 and 17 are satisfactory for shunt peaking where only one or two stages are required. Actually the response, using these formulae, at F_c is the same as the low frequency response, but there is about a 3% rise in output somewhat lower in frequency than F_c. Shunt peaking can be made nearly perfect if F_c is made about 40% greater than the highest correction frequency desired. As this would result in a reduction in gain of 30%, an accepted compromise is to design for a reduction in gain of 15%.

If a conservative design is desired, or several stages are to be cascaded, the following formulae may be used. Still referring to Figure 6, Equation 15 may be replaced by:

$$R_1 = .85\ Xc_T \text{ at } F_c \qquad (Eq.\ 18)$$

and Equation 17 may be replaced by:

$$L_1 = \frac{.3}{(2\pi F_c)^2 C_T} \qquad (Eq.\ 19)$$

If we recalculate the previous example, R_1 and L_1 would be:

$$R_1 = .85 \times 1273 \cong 1080 \text{ ohms}$$

$$L_1 = \frac{.3}{(6.28 \times 5 \times 10^6)^2 25 \times 10^{-12}} = \frac{.3}{(3.14 \times 10^7)^2 25 \times 10^{-12}}$$

$$= \frac{3 \times 10^5}{9.85 \times 2.5 \times 10^3} = \frac{300}{24.6} = 12.2 \text{ uh.}$$

and the stage gain will be .009 x 1080 = 9.72.

SERIES PEAKING

The basic circuit of a series peaked stage is shown in Figure 8.

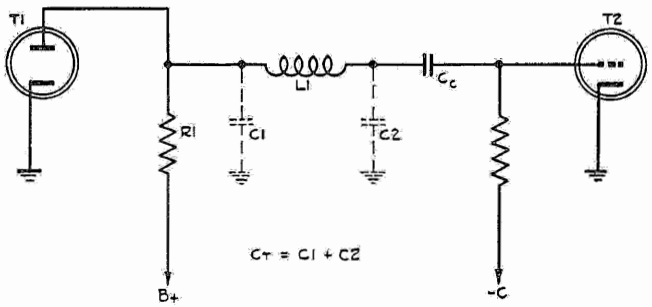


FIG. 8. *Series peaked stage.*

Here again we are interested in three components, L_1, R_1, and C_T, broken down into C_1 and C_2. C_T can be determined by the methods previously outlined; but in addition to knowing C_T, we want a 2/1 ratio between C_1 and C_2, although the ratio may be reversed by moving R_1 to the opposite side of the coil L_1, Figure 8. The rule is to keep the load resistor on the low capacity side of the filter. (See Figure 9.)

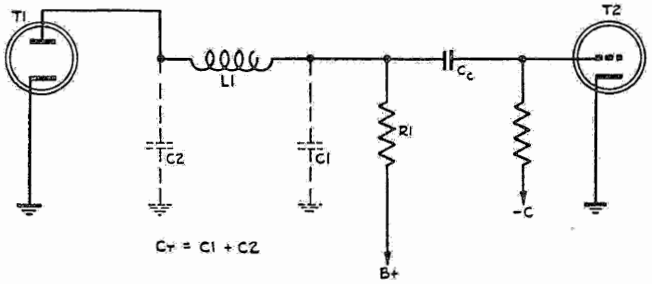


FIG. 9. *Series peaked stage.*

Usually, with a bit of juggling, the ratios may be kept close to 2/1. For instance, the coupling condenser, C_c, could be moved to the plate side of L_1, Figure 8, thus shifting the capacity to ground of C_c from C_2 to C_1. Referring to Figures 8 or 9:

$$C_T = C_{out} \text{ of } T_1 + C_{in} \text{ of } T_2 + C_{stray} = C_1 + C_2 \qquad (Eq.\ 20)$$

$$C_2 = 2C_1 \qquad (Eq.\ 21)$$

$$R_1 = 1.5 \times Xc_T \text{ at } F_c \qquad (Eq.\ 22)$$

$$L_1 = \frac{1}{2(\pi F_c)^2 C_1} = .67\ C_T R_1^2 \qquad (Eq.\ 23)$$

In using Equation 23, it is suggested that the second portion be used, that is, where C_T is used to determine L_1, because C_T is more important than the division of C_1 and C_2 in the compensation network and in all probability less error will be made in determining C_T than C_1.

For example let us calculate R_1, L_1, and the stage gain of Figure 8, assuming T_1 to be an 1852, F_c to be 5 mc., and C_T to be 30 uuf., with $C_2 = 2C_1$.

Then from Equation 22:

$$R_1 = 1.5\ X_{C_T} = 1.5 \times 1060 = 1590 \text{ ohms}$$

And from Equation 23:

$$L_1 = .67 \times 30 \times 10^{-12} \times 1590 = 51 \times 10^{-6} \text{ henries}$$
$$L_1 = 51 \text{ uh.}$$

And the stage gain will be:

$$A = G_m Z_p = .009 \times 1590 = 14.3$$

The series peaked network is characterized by a sharper cutoff and a more linear phase characteristic than the shunt peaked network.

SERIES-SHUNT OR COMBINATION PEAKING

Combination peaking, as its name implies, is a combination of shunt and series peaking and has a still sharper cutoff than series peaking. Here again our problem is similar to series peaking in that a 2 to 1 division of the capacity C_T is required for best performance of the stage. The same rule applies on the location of the load resistor; that is, place the load resistor on the low capacity side of L_2. (See Figures 10 and 11).

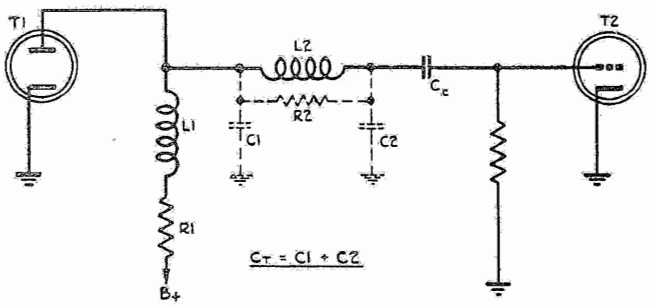


FIG. 10. *Combination peaked stage.*

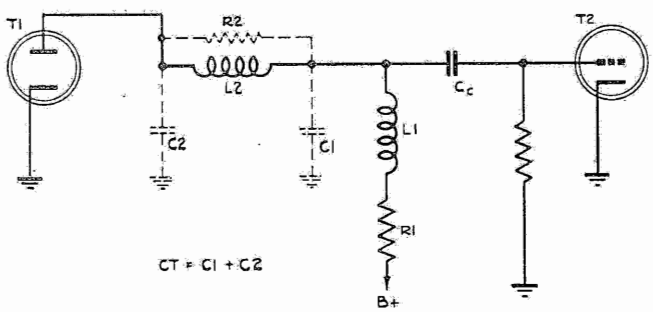


FIG. 11. *Combination peaked stage.*

R_1 and L_1 may be reversed, and usually it is desirable to do this as the stray capacity, which composes part of C_1 and C_2, would be smaller with a resistor connected to either side of L_2 than if L_1 were so connected (smaller physical size, primarily).

Referring to Figures 10 or 11, the design criteria for combination peaking is:

$$C_T = C_1 + C_2$$

$$C_2 = 2C_1$$

$$L_1 = .12 \times C_T \times R_1^2 \qquad \textit{(Eq. 24)}$$

$$L_2 = .52 \times C_T \times R_1^2 \qquad \textit{(Eq. 25)}$$

$$R_1 = 1.8\ X_{C_T} \text{ at } F_c \qquad \textit{(Eq. 26)}$$

If required, start with $R_2 \cong 5R_1$ by experiment.

A high distributed capacity in coil L_2 or improper ratio between C_1 and C_2 may cause a rise in response in the higher frequency portion of the pass-band. This rise can usually be flattened out by the addition of the resistor R_2, Figures 10 and 11, to lower the Q of L_2. The exact value will have to be determined by experiment in each case. A good starting value is about five times the value of the plate load resistor.

As an example, suppose we use the same specifications we used in the example for series peaking, in calculating L_1, L_2, and R_1, Figure 10.

From Equation 26:

$$R_1 = 1.8 \times 1060 = 1908 \text{ ohms}$$

From Equation 24:

$$L_1 = .12 \times 30 \times 10^{-12} \times 3.64 \times 10^6 = 13.1 \times 10^{-6} \text{ H.} = 13.1 \text{ uh.}$$

From Equation 25:

$$L_2 = .52 \times 30 \times 10^{-12} \times 3.64 \times 10^6 = 56.7 \times 10^{-6} \text{ H.} = 56.7 \text{ uh.}$$

And the stage gain is:

$$A = .009 \times 1908 = 17.17.$$

THE HIGH PEAKER STAGE

One problem usually encountered in transferring the video voltage output of an Iconoscope into the grid of the first amplifier stage is that of getting the maximum signal to noise ratio. The most satisfactory method for accomplishing this is to provide the highest possible signal input into the grid of the first amplifier stage without regard for frequency distortion, then carefully preserve

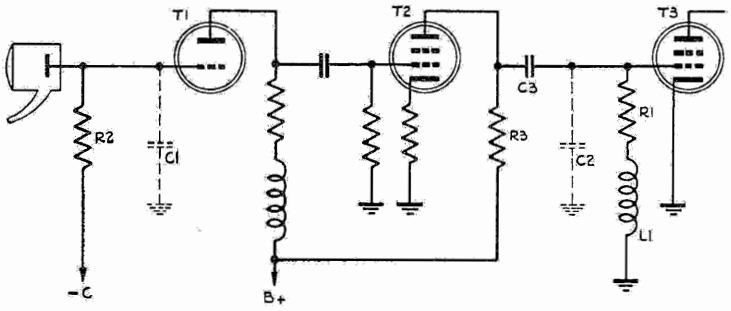


FIG. 12. *"Hi-Peaker" stage.*

this distorted signal while it is being amplified in one or two stages, and finally introducing a complementary network that gives equal and opposite distortion to that generated by the input network. With frequency components from 30 cycles to about 4 mc. in the output signal of an Iconoscope, developed across R_2 in Figure 12, it is readily seen that the shunt reactance of C_1 will severely limit the high frequency components.

If the linearity is preserved, that is, compensating as previously outlined between T_1 and T_2, to keep intact this distorted waveform, we can insert the network R_1-L_1 as the load for T_2. This network is complementary to the network R_2-C_1, and has the opposite impedance and phase characteristic, provided the time constants are equal. The time constants will be equal when:

$$R_2 C_1 = \frac{L_1}{R_1}$$

A stage with this type of correction is called a "High Peaker" stage, and the design data are:

C_1 = total ckt. and stray capacity (input stage)
C_2 = total ckt. and stray capacity (hi-peaker stage)
R_2 = nominally 100,000 ohms

$$R_3 > 10 \times X_{L_1} \text{ at } F_c \qquad (Eq.\ 27)$$

$$X_{C_3} < .1\ R_3 \text{ at lowest frequency} \qquad (Eq.\ 28)$$

$$R_1 = \frac{L_1}{R_2\ C_1} \text{ where R = ohms, L = uhenries. C = ufds.} \qquad (Eq.\ 29)$$

$$L_1 = \frac{25.33 \times 10^3}{(2\ F_c)^2 \times C_2} \qquad (Eq.\ 30)$$

where L is in uh.,
C is in uuf.,
F is in mc.

Thus, with Equations 27, 28, 29 and 30, we can design a satisfactory compensating network. Equation 30 shows that the resonant frequency of L_1-C_2 is twice the cutoff frequency, F_c.

For an example let's determine L_1, R_1, R_3, and C_3 of Figure 12, assuming C_1 to be 12 uuf. and C_2 to be 30 uuf., F_c is 5 mc., and 30 cycles the lowest frequency.

From Equation 30:

$$L_1 = \frac{25.33 \times 10^3}{10^2 \times 30} = \frac{253.3}{30} = 8.43 \text{ uh.}$$

From Equation 29:

$$R_1 = \frac{L_1}{R_2 \times C_1} = \frac{8.43}{10^5 \times 12 \times 10^{-6}} = \frac{843}{12} = 7.25 \text{ ohms}$$

From Equation 27:

$$R_3 > 10 \times 6.28 \times 5 \times 10^6 \times 8.43 \times 10^{-6} = 2650 \text{ ohms or greater}$$

From Equation 28:

$$X_{C_3} = < .1 \times 2650 = 265 \text{ ohms or less}$$
$$C_3 = 20 \text{ ufd. or more}$$

And the stage gain, if T_2 is an 1852, will be:

$$A = .009 \times 7.25 = .06525$$

From this it is apparent that the stage is operating at a loss, but the actual overall voltage output will be greater than if we had used a much lower value for R_2 in an attempt to preserve the high frequency response into T_1; also the signal to noise ratio will be better.

PHASE CHARACTERISTICS

These correction circuits will provide essentially flat frequency response to F_c and a phase shift proportional to frequency; or

saying it another way, the time delay is independent of frequency. Up to now little has been said of the phase characteristic of amplifiers. The phase characteristic is relatively unimportant in amplifiers designed for audio work, as the human ear is very insensitive to phase distortion, but becomes very important in video work or wherever complex waves are to be amplified without distortion. Without going too deeply into the subject of complex waves, which is beyond the scope of this article, every complex wave is composed of the fundamental frequency and any number of harmonics, having various phase relationship with each other, and whose amplitude and phase may be expressed by a Fourier Series. To see why it is important that the phase shift be proportional to frequency, that is, the second harmonic should be delayed twice as much as the fundamental, the third harmonic three times, etc., let's take a look at Figure 13.

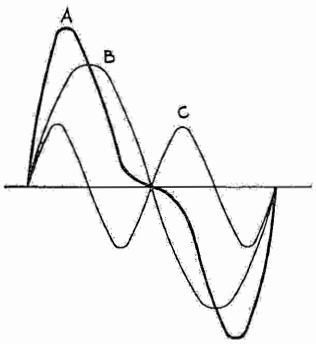


FIG. 13. *Complex wave with components in phase.*

Wave A is a complex wave composed of the fundamental wave B and the second harmonic C in phase. If the wave A is passed through an amplifier that delayed waves B and C the same amount, for instance 30°, the wave shape would be as shown in Figure 14.

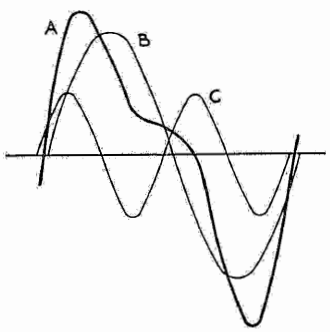


FIG. 14. *Complex wave after both component waves are delayed 30°.*

Wave C goes through two cycles, 720 electrical degrees, while wave B goes through one cycle, 360 electrical degrees; or to put it another way, with respect to time, wave C is traveling twice as fast as wave B. Therefore, if both waves are delayed 30°, wave C will be ready to repeat its cycle 50% sooner than wave B; or with respect to wave B, wave C will be advanced in phase. When these two waves are summed up, with the altered phase relationship, we will get wave A in Figure 14. Compare this with wave A in Figure 13. Both are composed of the same two frequencies, only the phase relationship has been changed. If the phase characteristic of the amplifier is proportional to frequency, the wave coming out of the amplifier would be the same shape as the input wave, provided the frequency response is uniform. As a point of interest, the shorter the pulse, the greater the number of harmonics present and the wider the bandwidth of the amplifier required to pass the pulse without distortion. A single impulse of infinitesimal duration contains all frequencies from zero to infinity of equal amplitude.

CATHODE FOLLOWERS

Cathode follower is the name given to a stage when the load is in the cathode instead of the plate circuit. This type of circuit finds its widest use in video work as an impedance changing device. As the output voltage of an amplifier taken from the plate circuit is at a comparatively high impedance, unless changed by an impedance changing device such as a transformer, securing a proper match into a transmission line of nominal impedance is therefore somewhat of a problem. This is especially true in video work where a wide frequency range is encountered, and the design of a transformer with flat output from 30 cycles to 4 or 5 mc. presents quite a few difficulties. The simplicity and low cost of the cathode follower is primarily responsible for its popularity. Either pentodes or triodes may be used and a conventional circuit for each is shown in Figures 15 and 16 respectively.

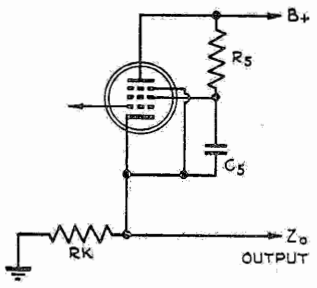


FIG. 15.
Pentode cathode follower.

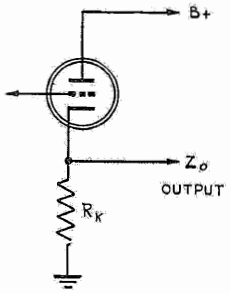


FIG. 16.
Triode cathode follower.

Both the input conductance and the grid to cathode capacity of the tube in a cathode follower stage are modified by the factor

$$\frac{1}{1 + G_m R_k}.$$

The pentode cathode follower stage is used in preference to the triode in applications where the lower input capacity or a higher output voltage is desired. The effective internal impedance of the tube is the reciprocal of the grid to plate transconductance in mhos and must be added in parallel to the cathode resistor to determine the output impedance, Z_o, Figures 15 and 16.

In a triode cathode follower stage, Figure 16, the dynamic input capacity is given by:

$$C_{eff} = \frac{C_{gk}}{1 + G_m R_k} + C_{gp} \qquad (Eq.\ 31)$$

and if a pentode is used, as in Figure 15, the dynamic input capacity will be:

$$C_{eff} = \frac{C_{in}}{1 + G_m R_k} \qquad (Eq.\ 32)$$

And the stage gain is given by:

$$A = \frac{G_m R_k}{1 + G_m R_k} \qquad (Eq.\ 33)$$

The effective output impedance, Z_o, is given by:

$$Z_o = \frac{\frac{1}{G_m} \times R_k}{\frac{1}{G_m} + R_k} \qquad (Eq.\ 34)$$

From Equation 33 it can be seen that the stage always operates with a gain of less than 1 and the higher the value of R_k the closer to unity the gain becomes. The circuit in Figure 17 is sometimes used to secure higher output voltages.

In this circuit R_k is divided into two parts, R_1 and R_2, arranged so the dc voltage drop across R_1 is equal to the required grid bias, and as the grid is returned to the junction of R_1 and R_2, the correct bias will be obtained; the G_m will not change, but R_k will be increased and thus the voltage output (Equation 33). Similarly Z_o will be changed (Equation 34).

For example let's determine the effective input capacity, stage gain, and effective output impedance of an 1852 cathode follower stage with a 160 ohm cathode resistor. From the tube manual, C_{in} is 11 uuf. and the G_m is 9,000 umho's (.009 mho).

From Equation 31:

$$C_{in} = \frac{11}{1 + .009 \times 160} = \frac{11}{2.44} = 4.52 \text{ uuf.}$$

From Equation 33:

$$A = \frac{.009 \times 160}{1 + .009 \times 160} = \frac{1.44}{2.44} = .59$$

From Equation 34:

$$\left(\frac{1}{G_m} = \frac{1}{.009} = 111\right) \quad Z_o = \frac{111 \times 160}{271} = 65.7 \text{ ohms}$$

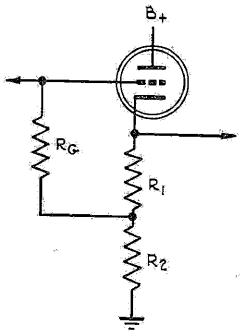


FIG. 17. *Cathode follower with Z_o matched to load.*

By using the arrangement in Figure 17, we could get a perfect match into a 72 ohm line by leaving R_1 equal to 160 ohms and by making R_2 equal to 45 ohms. The gain, A, and Z_o would be then:

$$\text{unloaded—} \quad A = \frac{.009 \times 205}{1 + .009 \times 205} = \frac{1.845}{2.845} = .648$$

$$\text{loaded—} \quad A = \frac{.009 \frac{72 \times 205}{72 + 205}}{1 + .009 \frac{72 \times 205}{72 + 205}} = \frac{.009 \times 54.7}{1 + .009 \times 54.7} = \frac{.492}{1.492} = .33$$

With a normal bias of 3 volts on the grid, the maximum voltage output would be 3 x .33 or .99 peak volts. In terms of peak to peak voltage, and assuming the grid swing was from 0 to 6 volts, the output would be 1.98 volts peak to peak.

The output impedance will be:

$$Z_o = \frac{111 \times 205}{316} = \frac{22755}{316} = 72 \text{ ohms}$$

DESIGN HINTS

It is evident, from the foregoing design data, that the limiting factor, in securing

good high frequency response, is the shunt reactance across the plate load resistor and that this shunt reactance has a direct bearing on the gain of the amplifier. Therefore, good practice demands that every effort be made to keep the stray and circuit capacity at a minimum. A well-designed layout and careful planning will pay big dividends.

The practice of placing a small paper or mica condenser across a large electrolytic by-pass condenser to by-pass the high frequencies is sometimes dangerous, as far as flat frequency response is concerned. The inductance of the electrolytic and the paper or mica condenser may form a parallel resonant circuit; and this may cause either an increase or decrease in the gain, depending on the location of the network, at its resonant frequency.

Care should be used in selecting resistors as there is a wide variation in the high frequency characteristics between the products of different manufacturers. Wire wound resistors for plate loads should be used with extreme caution. The inductance and distributed capacity may be quite high and upset the network.

When triodes are used in wide band amplifiers where the required plate load is comparable to the plate resistance of the tube, the plate resistance should be considered in selecting the plate load resistor value. The plate load resistor should be of such a value that when it is in parallel with the plate resistance of the tube, the resistance of the combination will equal the calculated value. For example, if a 6J5 is used and the calculated load resistance is 1000 ohms, a plate load resistor of 1175 ohms would be used.

$$R = \frac{1000 \times 6700}{6700 - 1000} = 1175 \text{ ohms}$$

Test and Alignment

As it is a general practice to design video peaking coils with movable powdered iron cores in order to adjust their inductance to compensate for minor variations in circuit and wiring capacities, a rapid method of adjustment is desirable. Although this adjustment may be accomplished and the gain-frequency characteristic determined by the use of a radio frequency signal generator and a wide range vacuum tube voltmeter to monitor the output, this method requires so much time that it has been generally discarded in favor of visual techniques.

The low-frequency response, below 100 Kcs., phase shift, and transient response are tested by applying square-waves to the amplifier input and observing the resulting pattern on an oscilloscope screen. For this test it is desirable to couple the output of the amplifier directly to the CRO deflecting plates as this prevents errors from being introduced by the CRO amplifier. Overshoot, ringing, phase shift, and frequency response are readily determined from the distortion to the original square-wave by the amplifier. The input signal level should be kept low to prevent one or more of the amplifier stages from being driven to cut-off and thus prevent a true picture of the amplifier characteristic.

A typical arrangement for visual alignment or test of the amplifier response above 100 Kcs. is shown in block form in figure #19. The use of a sweep-generator of the type normally used for television I.F. amplifiers will be very satisfactory and in addition will readily allow detail examination of small portions of the amplifier pass-band, especially when used with the "Baseliner," essentially a mechanical DC restorer used to blank, or discharge the input condenser of, the CRO for 180 degrees of the modulation cycle. The use of the linear detector makes the response pictured on the CRO screen independent of the characteristic of the CRO amplifier. The CRO time base will, of course, be governed by the type of modulation used in the sweep generator. Where sinusoidal modulation is used, a sinusoidal time base will be required to produce a linear gain-frequency trace.

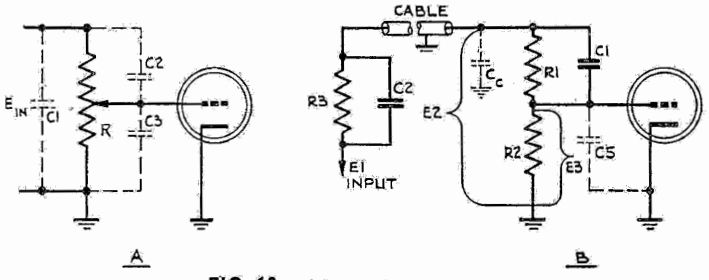


FIG. 18. *Attenuating systems.*
A. *Uncompensated.* B. *Compensated.*

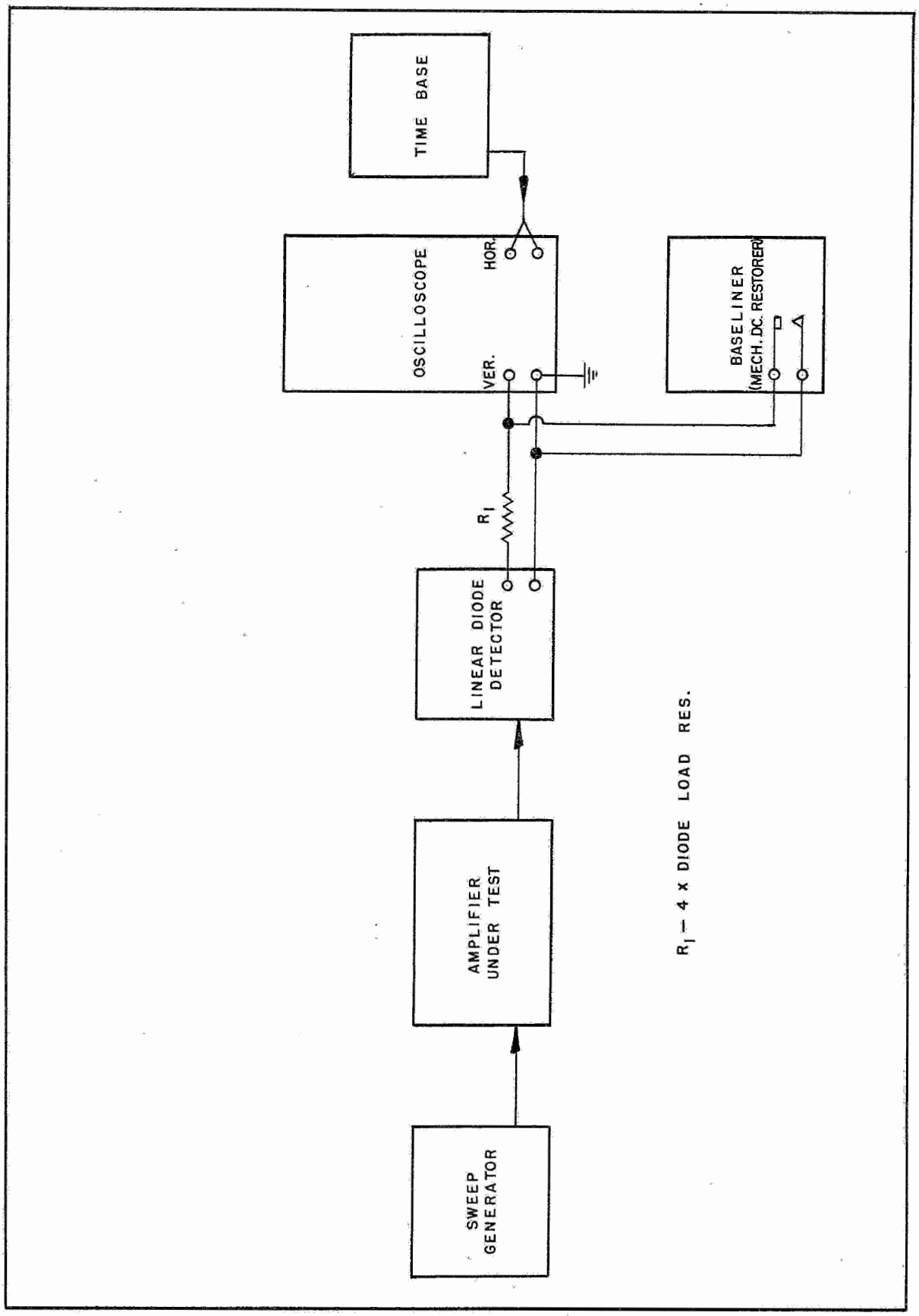

TIME BASE
OSCILLOSCOPE
HOR.
VER.
BASELINER
(MECH. DC. RESTORER)
R_I
LINEAR DIODE DETECTOR
AMPLIFIER UNDER TEST
SWEEP GENERATOR
R_I — 4 x DIODE LOAD RES.

FIG. 19

Alignment is completed by adjustment of the inductance of the peaking coils until a uniform response is obtained over the pass-band.

ATTENUATORS

The effects of the circuit and stray capacities, C_1, C_2, and C_3 in Figure 18a are negligible at audio frequencies but become increasingly important as the frequency is increased. At video frequencies they cause reduced input impedance as well as frequency and phase distortion. The frequency and phase distortion, and to a certain extent, the input impedance will vary with the position of the slider on R. This condition can be remedied by use of a compensated step type attenuator. Figure 18b is a schematic of the basic circuit of an input cable and attenuator system generally used on wide range oscilloscopes.

Ignoring the input cable for the moment, the ratio of output voltage, E_3, to the input voltage of the attenuator, E_2, will be independent of frequency if the time constants of R_1-C_1 and R_2-C_S are made equal. As C_S is the sum of circuit and stray capacities, and thus fixed, the design procedure is to set the values of R_1 and R_2 for the voltage ratio desired, and then make C_1 such value that:

$$TC = R_1 C_1 = R_2 C_s \text{ or } C_1 = \frac{R_2 C_s}{R_1} \quad (Eq.35)$$

This means that a different value of C_1 will be required for each step of the attenuator; and since, as will be explained below, it is desirable to keep the total resistance of R_1 and R_2 constant, these values will have to be changed for each step also.

It is generally desirable to load the circuit supplying the signal voltage as little as possible. Yet means must, however, be provided for making connection to the signal voltage source, and a low capacity cable with an isolation resistor in the probe is usually satisfactory. Even with so-called low capacity cable, the capacity of a five foot section plus fitting and circuit capacity is considerable at video frequencies.

The voltage division can be made independent of frequency in the same manner as outlined for the attenuator. That is, by considering R_1 and R_2 as one resistor and summing up the cable and fitting capacity together with the effective capacity of C_1 and C_S in series, as one capacity, C_c, and then adding the capacity C_2, across the isolation resistor, R_3, making its value such that the time constants of R_3-C_2 and $(R_1 + R_2)$-C_c are equal. This is the same as Equation 35. This will mean, of course, that E_2 will become

$$\frac{R_1 + R_2}{R_1 + R_2 + R_3} \times E_1$$

but by making the reduction a factor of 10 and increasing the gain of the amplifier by the same factor, our overall gain remains the same and we have secured a coupling and attenuating system that has a high input impedance and gives minimum distortion of the wave shape of the signal. The effective input impedance will be a resistance equal to $R_1 + R_2 + R_3$ with a parallel capacity equal to C_2 and C_c in series and may be calculated for any frequency by Equation 4. For example, if we wished to have E_3, Figure 18b, one-tenth of E_2, and E_2 one-tenth of E_1, and C_s is 50 uuf. with C_c being 200 uuf., we could proceed with design by making:

$R_2 = 10{,}000$ ohms

$R_1 = 90{,}000$ ohms

$R_3 = 900{,}000$ ohms

$$C_1 = \frac{R_2 C_s}{R_1} = \frac{10^4 \times 50}{9 \times 10^4} = \frac{50}{9} = 5.56 \text{ uuf.}$$

$$C_2 = \frac{(10^4 + 9 \times 10^4)200}{9 \times 10^5} = \frac{2 \times 10^7}{9 \times 10^5} = \frac{200}{9} = 21.1 \text{ uuf.}$$

And the input impedance will be one megohm with 19 uuf. in shunt (21.1 and 200 uuf. in series). By always keeping the total resistance of R_1 and R_2 equal to 100,000 ohms one setting of C_2 would be correct for any setting of the attenuator.

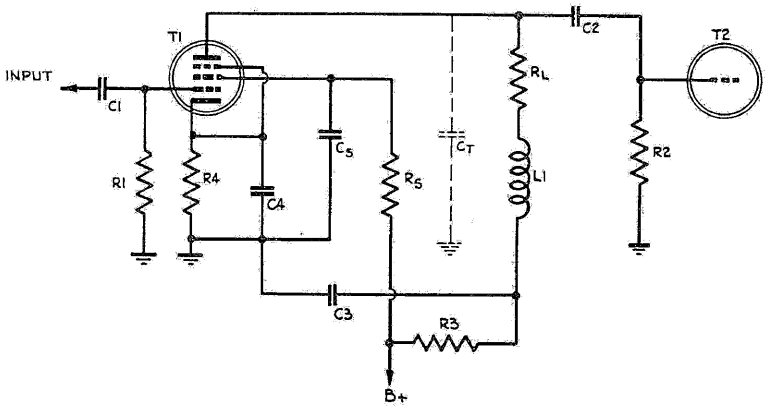
SUMMARY

As a final summary, the following three design charts have been prepared. There is one chart for compensated stages using Shunt high frequency peaking, one for Series high frequency peaking, and one for Combination high frequency peaking. Low frequency compensation data is included on each to keep each chart complete in itself.

Of the numerous reference sources used in writing this article, the author desires to give special mention to lecture notes of Mr. T. M. Gluyas of RCA, on the subject of "Generation and Application of Non-Sinusoidal Waves."

DESIGN CHART NO. 1

Compensated stage with shunt high frequency peaking.



$Gain = G_m R_L$

$C_T = C_{pk} + C_{gk}$ of T_1 and T_2 respectively + wiring capacity

F_C = highest frequency of correction

F_1 = lowest frequency of correction

$$\left.\begin{aligned} R_L &= X_{C_T} \text{ at } F_C \\ L_1 &= \frac{R_L}{4\pi F_C} \end{aligned}\right\} \text{ General}$$

$$\left.\begin{aligned} R_L &= .85\ X_{C_T} \text{ at } F_C \\ L_1 &= \frac{.3}{(2\pi F_C)^2 C_T} \end{aligned}\right\} \text{ Conservative}$$

$$X_{C_S} < \frac{2}{G_m} \text{ at } F_1$$

$$R_S > \frac{3/F}{C_S} \text{ at } F_1$$

To compensate for R_1—C_1 or C_2—R_2

$$C_3 = \frac{C_2 R_2}{R_L}$$

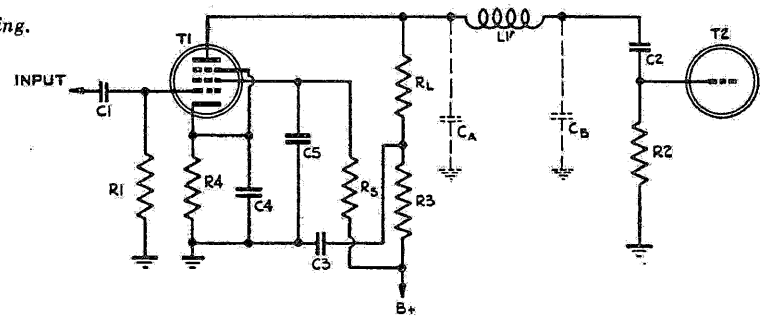
$R_3 > 20\ X_{C_3}$ at F_1

To compensate for R_4—C_4

$$R_4 C_4 = R_3 C_3 \text{ and } \frac{R_3}{R_4} = \frac{C_4}{C_3} = G_m R_L$$

DESIGN CHART NO. 2

Compensated stage with series high frequency peaking.



$Gain = G_m R_L$

$C_T = C_A + C_B$

$C_B = 2\ C_A$

F_C = highest frequency of correction

F_1 = lowest frequency of correction

$R_L = 1.5\ X_{C_T}$ at F_C

$L_1 = .67\ C_T R_L^2$

$$X_{C_S} < \frac{2}{G_m} \text{ at } F_1$$

$$R_S > \frac{3/F}{C_S} \text{ at } F_1$$

To compensate for R_1—C_1 or R_2—C_2

$$C_3 = \frac{C_2 R_2}{R_L}$$

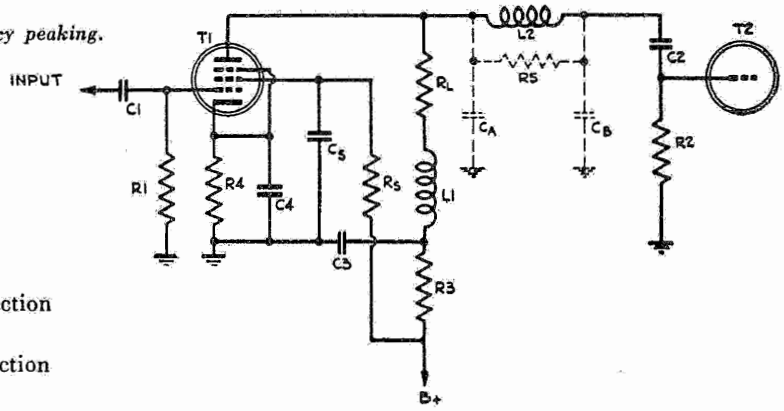
$R_3 > 20\ X_{C_3}$ at F_1

To compensate for R_4—C_4

$$R_4 C_4 = R_3 C_3 \text{ and } \frac{R_3}{R_4} = \frac{C_4}{C_3} = G_m R_L$$

DESIGN CHART NO. 3

Compensated stage with combination high frequency peaking.



$$\text{Gain} = G_m R_L$$

$$C_T = C_A + C_B$$

$$C_B = 2\ C_A$$

F_C = highest frequency of correction

F_1 = lowest frequency of correction

$$R_L = 1.8\ Xc_T \text{ at } F_C$$

$$L_1 = .12\ C_T R_L^2$$

$$L_2 = .52\ C_T R_L^2$$

$$Xc_3 = \frac{2}{G_m} \text{ at } F_1$$

$$R_S > \frac{3/F}{C_S} \text{ at } F_1$$

$$R_5 \cong 5\ R_L \text{ by experiment}$$

To compensate for R_1—C_1 or R_2—C_2

$$C_3 = \frac{C_2 R_2}{R_L}$$

$$R_3 > 20\ Xc_3 \text{ at } F_1$$

To compensate for R_4—C_4

$$R_4 C_4 = R_3 C_3 \text{ and } \frac{R_3}{R_4} = \frac{C_4}{C_3} = G_m R_L$$

UHF COIL DESIGN

(Reprinted from Electronic Industries, August 1943)

The design of ultra-high-frequency circuit components frequently calls for the computation of inductances that are outside of the rules, tables and charts that have been found useful for coils for use at lower frequencies.

The following analysis deals with inductances of a size useful in the highest frequency ranges at which the usual negative-grid triode oscillator will work. In other words, the coils described are about as small as a coil can be, in practical design and still be called a "coil."

The problem has two parts--the first, to determine the dimensions to give a certain inductance—and second, to compute the resulting inductance from a given set of dimensions. At first it might seem that these problems are identical, but unlike computations of many-turn single layer coils, the inductance formula that takes into consideration the wire size and turn-spacing so complicates the design that a rigid method that will give a predetermined inductance is not always practicable. The easiest way out is that suggested in the following analysis: use a system that will give the nearest approximation and still is simple enough to permit several dimensional variations to be determined by comparison, to be followed by a more rigorous determination when the rough set of values has been indicated.

Chart I is first referred to, if it is not known just how much inductance is needed in a certain set-up for a given frequency. This is the well-known LC relation but is extended to the particular inductance range useful at 30-3000 megacycles. While this chart is arranged to cover the usual values of L and C, many unusual values of L/C are found in modern circuits, so in case it does not fit, multiply or divide the L scale by 10 and do the reverse to the C scale.

Of course, both L and C refer to the total values present, and not those of the coil and condenser alone.

Coil Dimension Factors

Chart II provides an easy method of finding out constructional details when a given inductance is needed. It is based on a "current sheet" formula, as is usual in such charts, and while it may be in error 5-10 per cent in some remote cases, it does give an easy way of determining how big a certain coil should be. The method of using this chart is illustrated by an example on the chart itself. At the left is a scale which takes care of the factor of winding pitch, or "turns per inch" in practical units. The family of curves at the right end of Chart II determines the "shape factor." It is to be noted that coils with small diameters have a considerable inductance shift with a slight change of that diameter, as evidenced by the steepness of the curves. In using these curves, take note that the diameter of a coil is equal to the diameter of the winding form plus the diameter of one wire. The length of a coil is equal to number of turns times the distance between centers of adjacent turns. In selecting the shape values for a proposed coil, it is suggested that the wire size and pitch be selected first, so that the "turns-per-inch" value

CHART I -- Nomographic chart of LC values in the short wave range

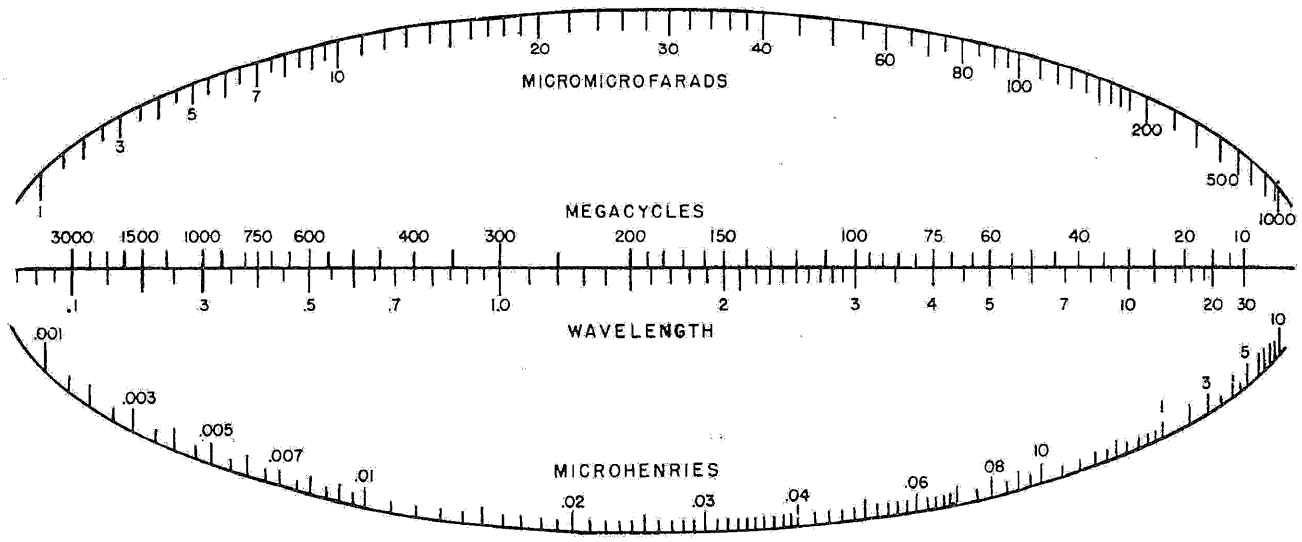


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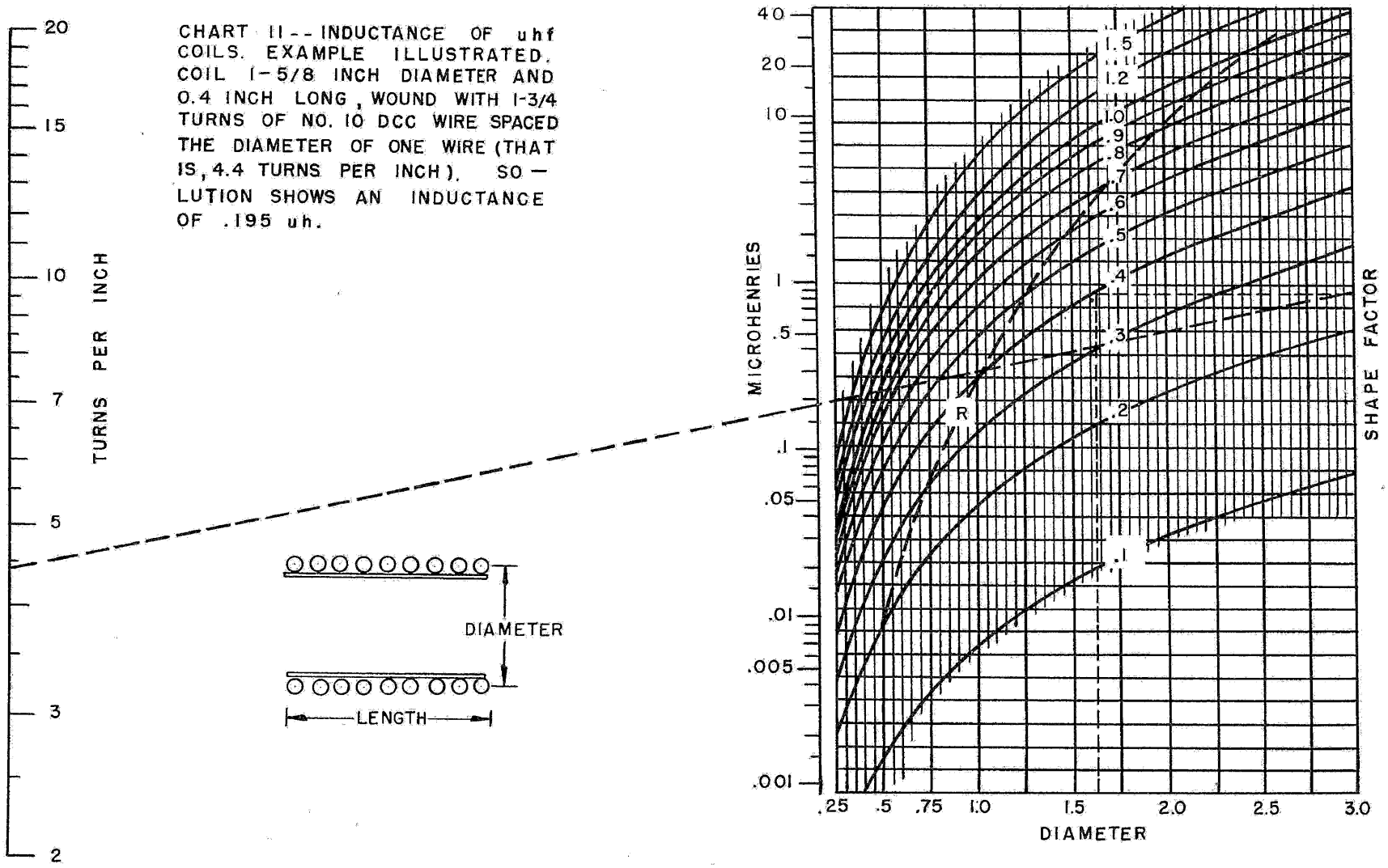
CHART II -- INDUCTANCE OF uhf COILS. EXAMPLE ILLUSTRATED. COIL 1-5/8 INCH DIAMETER AND 0.4 INCH LONG, WOUND WITH 1-3/4 TURNS OF NO. 10 DCC WIRE SPACED THE DIAMETER OF ONE WIRE (THAT IS, 4.4 TURNS PER INCH). SOLUTION SHOWS AN INDUCTANCE OF .195 uh.



can be indicated on the left scale. A dotted line from this point through the inductance value on center scale is extended to the Shape Factor scale at extreme right. It will be noted that several different diameter-to-length ratios can be used to give a certain inductance, giving considerable leeway in design. Pairs of values that can be used are on the same horizontal line extending toward the left from the required Shape Factor point.

Opinions differ somewhat as to the best shape ratio and there is no single universal rule that covers all cases. A value of D/l equals 2.46, has been suggested by Bull. No. 74 of the Bureau of Standards as giving the maximum inductance with a given length of wire. The locus of points bearing this relation is shown as the broken line (R).

Some designs will be based on purely physical details--the winding form must have a certain diameter, so that it will fit into a given shield. Other designs must be based on obtaining the highest possible Q. Still again, the design might be based on temperature drift considerations.

In the latter case, it will be seen that if all dimensions of a coil change linearly due to temperature, a first order change is noted in the inductance—the greater the expansion, the greater the inductance. However, few coils follow this simple rule in practice: sometimes the diameter changes according to the expansion coefficient of copper, and the length according to the expansion of the material in the winding form. A material that expands twice as far as copper would seem to offer the best solution.

However, in the range of frequencies under discussion, many other effects enter into the problem, and when all is said and done, it is probable that very few uses for a zero-coefficient coil are found anyway, since the usual tuned circuit requires the coil shift to partially make up for the capacitance shift as well if it is at all possible.

Chart II is not complete inasmuch as it gives no indication of the inductance of a single turn. Rather than to complicate the basic chart, Chart III takes care of this special case. While the inductance of a single turn is mainly dependent on the turn diameter, the wire size also has some effect. The central scale of Chart III takes care of this, based on factor (turn diameter/wire diameter).

Other factors of importance that alter the inductance are, the change in the resistance of the coil with both frequency and temperature shifts, and the change in the amount of inductance in the circuit as the variable condenser is rotated, caused by a shift of the physical point where the center of capacitance is located as the plates become more or less enmeshed.

This brings up the question of how much the length of the leads from the coil to the rest of the circuit increases the inductance. This is a simple factor to figure, according to the rules, but actually, the shorter the leads the closer the coil is to other metallic objects that alter the field pattern and therefor the inductance. Tests have shown that it is hardly possible to improve the accuracy of the inductance computations as determined by the chart,

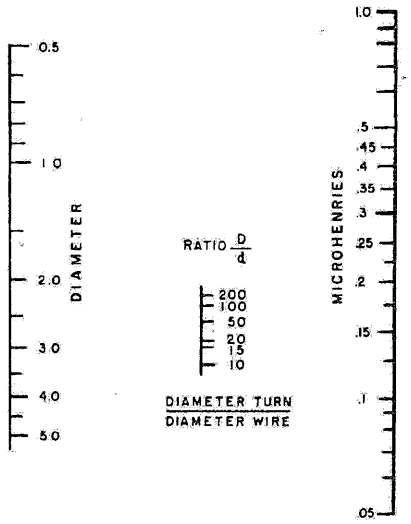


CHART III -- Nomographic charts showing inductance of single turn loops

in practical cases, and in fact it is just as difficult to predetermine the circuit capacitance when all factors are considered. It is possible, however, to strike pretty close to what is wanted and it will be found that these circuits are easy to trim to the desired frequency.—R.R.B.

SINGLE JACKS FOR BROADCAST APPLICATION

Howard A. Chinn[1] *and Robert B. Monroe*[2]

(Reprinted from Audio Engineering, Vol. 31, No. 6, July 1947)

A bank of Telephone-Type Jacks, known as a jack field, is employed in essentially every broadcasting, recording, or public-address audio system. It is the usual practice to connect the input and output of the important circuits and components of the system to these jacks. The connections are made in a manner which permits access to the circuits by placing a plug or patch cord into the proper jacks. Furthermore, auxiliary "make" contacts are employed on each jack so that when there are no patch cords in the jack field, the components and circuits are connected together in their *normal* sequence, see Fig. 1. These auxiliary contacts are called "normals", for obvious reasons.

A jack field, incorporated in an audio system, provides a high degree of operational flexibility. By the use of patch cords various operations may be quickly performed, as for example:

(a) A defective component may be readily replaced by another similar unit, or may be removed completely from the circuit by patching around the unit.

(b) Whenever necessary, the program circuits may be rearranged as desired.

(c) Special-effect devices, such as filters or reverberation facilities, may be inserted in any desired program channel.

In addition to the operational conveniences made possible by the jack field, test and measurement of the facilities are greatly simplified as it is possible to make direct connection to the terminals of various components of the system. Location of a defective unit is thereby greatly facilitated.

The plugs currently employed in the majority of professional audio systems are the "twin" type, Fig. 2. With these twin-type plugs it becomes necessary to employ jacks in pairs. This arrangement of twin plugs and jack pairs has been in use in broadcast plants since the early days of radio broadcasting. Their introduction to radio work was a carry-over from the practice on "Long Line" circuits used for network program distribution at telephone exchanges. The performance of these plugs and jacks over a period of many years has always been reliable. However, the following points, which may be considered disadvantages, have been noted:

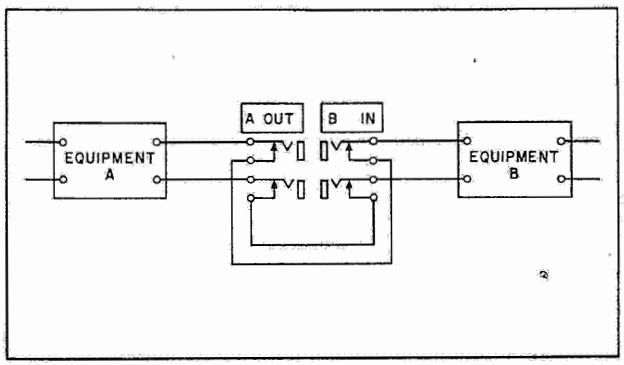


Fig. 1. Jacks incorporated in an audio system permit access to the input and output of the various equipment units by placing a plug or patch cord into the proper jacks. When no patch cords are in use the components are automatically connected in their normal sequence by means of the auxiliary jack contacts shown. These contacts and the associated wiring are called circuit "normals".

(a) Care must be exercised to insert the plug correctly polarized. If this is not done the polarity of the circuit may be reversed.[3]

(b) A relatively large amount of panel space is required for the jack field.

(c) The cost of the jack field and associated patch cords is high.

Inasmuch as the trend in the design of audio facilities is to reduce the size of installations, a study was made to determine the possibility of employing single plugs and jacks without sacrificing any of the features of the traditional twin units. The successful application of single jacks would overcome the shortcomings of the double units mentioned above; that is, less panel

[1]Chief Audio Engineer, Columbia Broadcasting System.

[2]Engineer, Columbia Broadcasting System.

[3]This may lead to several undesirable consequences. In unbalanced-to-ground arrangements reversal of the plug will ground the wrong side of the circuit. If this does not short circuit the program material (depending on grounding arrangement employed) it will place a ground on the high side of unbalanced elements. In most cases, particularly in the case of filters and attenuators, the characteristics of the unit may be considerably altered. Polarity reversal in both balanced and unbalanced-to-ground arrangements causes loss of phasing, if employed.

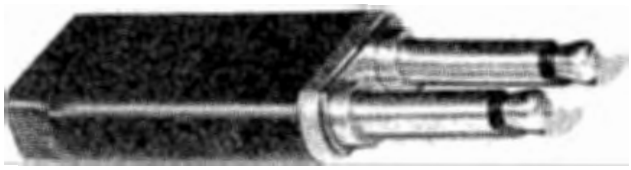


Fig. 2. The "twin" type of plug currently employed in the majority of audio systems. Jacks are used in pairs with this type of plug.

space would be required for a given number of jack circuits; the cost would be lower; and all possibility of reversing the circuit by improper insertion of the plug would be eliminated.

SINGLE PLUGS AND JACKS

To perform the same operations now accomplished by twin plugs, it is necessary that the single plug accommodate three conductors; two for the program circuit and one for ground. This requirement can be met by the "tip, ring and sleeve" type plug of the general type used on telephone switchboards.

It must be pointed out, however, that the usual telephone-type single plugs (such as the W.E. type 110) are *not* satisfactory for broadcast use, Fig. 3. This can be readily observed by visual inspection of the operation of these units. As this type of plug enters the jack, a point is reached where the tip of plug momentarily touches both program springs of the jack. During this period, the plug short-circuits program material on the jack. For this reason, these telephone-switchboard plugs cannot be considered for broadcast use.

This difficulty can be avoided by employing a different type of tip, ring and sleeve plug constructed with a shorter tip. Such plugs have been made for telephone applications and are available. An example of a plug of this type is the W.E. type 291-E which was employed in this study, Fig. 4.

The single jacks employed were the W.E. type 239-A. These jacks are designed to operate with the W.E. type 291-A plug and contain the necessary

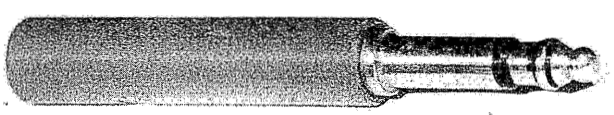


Fig. 3. A tip, ring, and sleeve type of single plug often used in telephone switchboard work. This type of plug is not satisfactory for use in audio systems as explained in text.

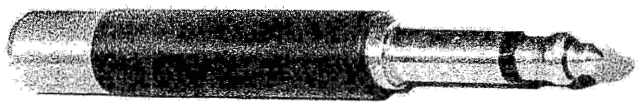


Fig. 4. This type of single plug, constructed with a shorter tip than the plug of Fig. 3, is satisfactory for use in audio systems. It is used in conjunction with the jack in Fig. 5.

contact springs for two program circuits, each of which is provided with a "normal" contact. The ground circuit is carried in the usual manner, through the frame of the jack which is equipped with a terminal lug, Fig. 5.

It is often necessary in the design of audio systems to employ a few jacks equipped with auxiliary "make" or "break" contacts to accomplish some special circuit changes when a plug is placed in the jack. Jacks of the type under discussion are also available with these auxiliary contacts.

EXPERIMENTAL TESTS

As part of the early study of single plugs and jacks, an audio jack field consisting of 24 single jacks mounted on a conventional jack mounting panel was set up for the purpose of checking the operational performance of single plugs and jacks. Various amplifiers and other components were connected to this jack field, which was then normalled to simulate a conventional studio audio channel complete from microphone input circuits to program line output. Visual and aural monitoring facilities were included in this experimental set-up to make it resemble as closely as possible an actual installation.

The plugs and jacks in this experimental system were associated with both balanced-to-ground and unbalanced-to-ground circuits. In the case of the balanced circuits both the tip and the ring of the plugs, as well as the corresponding contacts of the jacks, were high with respect to ground; however, the wiring was so

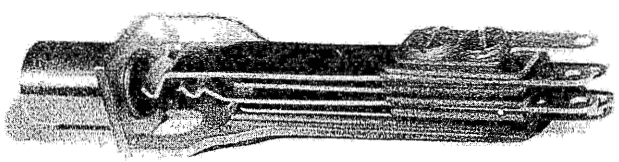


Fig. 5. The type of single jack shown above was used in all the measurements, investigations, and applications described in this text.

arranged that in the case of unbalanced circuits the tip was high and the ring low.

Patch cords, equipped with single plugs, were employed to check the ability of this jack field to perform all the usual jack field operational requirements, such as substituting amplifiers, patching out various components and making multiple connections.

It was found that the operation of these single jacks and plugs was entirely satisfactory and equivalent in all respects to the performance of the conventional double units.

Tests were made to determine the cross-talk introduced in audio circuits by single jacks as compared with that introduced by the more conventional "double" jacks. These tests were made on a balanced-to-ground, terminated, 600-ohm circuit by applying a sine wave of 15,000 cps to a jack, or in the case of double jacks to a pair of jacks, and measuring the signal crossing into adjacent jacks. The results of these tests are tabulated below:

Cross-Talk To:	Single Jacks	Double Jacks
Adjacent Left-Hand Jack(s)	-139 db	-132 db
Adjacent Right-Hand Jack(s)	-137 db	-128 db
Jack(s) Immediately Above	-140 db	-114 db

It will be noted that cross-talk is lower in the case of single jacks. *This is an important consideration in the design of audio facilities for present-day standards.*

SHUNT CAPACITY

Inasmuch as shunt capacity is an important factor in audio systems, measurements were made of the shunt capacity of both single jacks and pairs of jacks. The measured values are as follows:

SHUNT CAPACITY IN MICROMICROFARADS

Single Jacks	
Tip-Spring to Ring-Spring	10
Tip-Spring to Ground	14
Ring-Spring to Ground	10

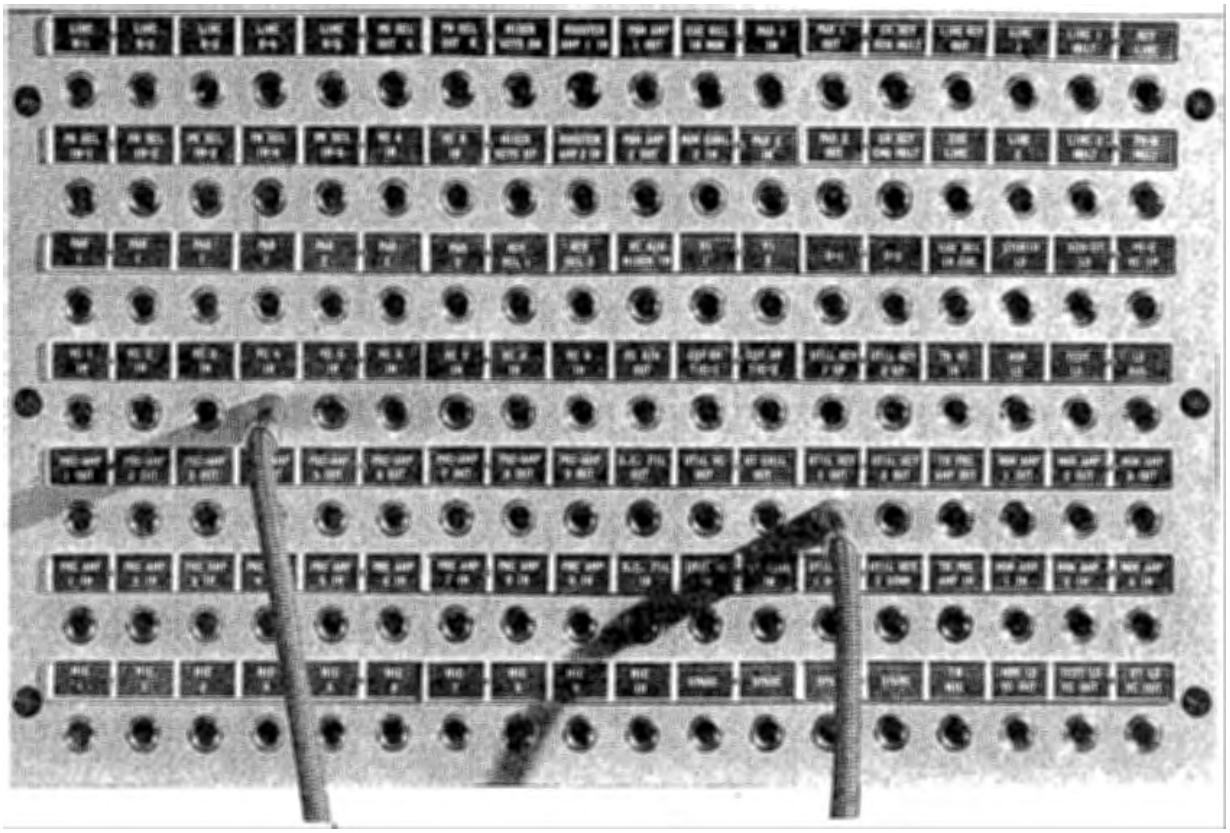


Fig. 6. The jack field of the CBS 3-B studio control console. 126 jack circuits are mounted on a panel only 9 by 14-1/2 inches in size. The spacing between jacks is 3/4 inches, the spacing between rows 1-1/4 inches.

Double Jacks	
Tip-Spring to Tip-Spring	5.5
Jack 1 Tip-Spring to Ground	13
Jack 2 Tip-Spring to Ground	13

It is seen that the shunt capacity between program springs is slightly higher in the case of single jacks. It is not believed, however, that this will cause any difficulty in new audio facilities, inasmuch as 150-ohm circuits will probably be used in most future systems designed for wide-band transmission. The reduction of circuit impedance by a factor of four will more than offset any effect of the slightly greater shunt capacity on the higher audio frequencies.

PRACTICAL APPLICATION

Audio installations employing single plugs and jacks have now been made at CBS stations in New York, St. Louis, and, presently, in Hollywood. Three of these installations are shown in Figs. 6, 7, and 8. In addition, Station WWL at New Orleans has incorporated these jacks in a post-war studio control console.

As a result of the experience which has been gained with these installations, it has become evident that single jacks offer several advantages over the twin units. These advantages include: (a) smaller space requirement, (b) lower cost, (c) lower cross-talk, and (d) impossibility of incorrect patch cord insertion.

Fig. 7. A modified W.E. 25-B studio control console. The use of single jacks permitted 32 jack circuits to be mounted in the panel space originally accommodating 20; an increase of 60 per cent.

It is believed that the use of single jacks of the type that retain all the advantages of double units marks a step forward and will find wide application in the future.

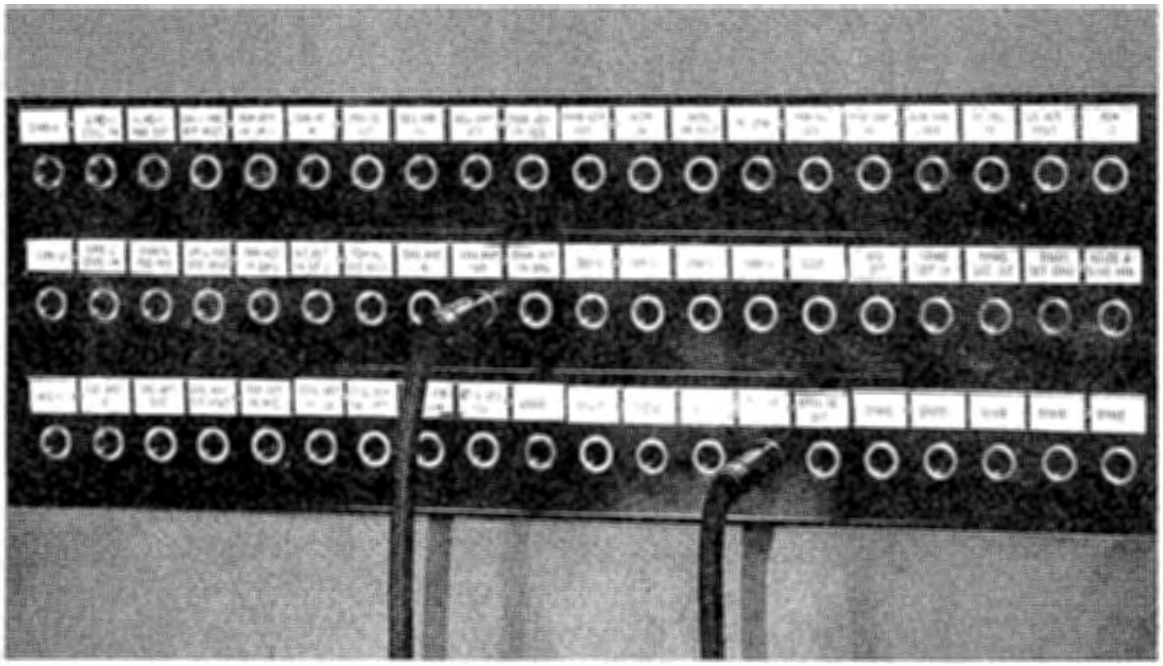


Fig. 8.

Supplement No. 1

to

NAB (NARTB) ENGINEERING HANDBOOK

(Fourth edition, 1949)

Maintenance of Television Equipment

(Although this article has been prepared primarily for television stations, much of the material will be found useful in AM and FM radio stations as well)

INSTRUCTIONS FOR FILING

To open binder, pull up on the ring and slide the cover of the binder upwards. Lift up on the metal bar, and the posts are open for insertion of the punched Supplement pages.

Supplement No. 1 should be filed at the end of Section 5, "General Engineering" immediately ahead of the division tab for Section 6, "Charts-Graphs-Tables-Notes".

MAINTENANCE OF TELEVISION EQUIPMENT

PREVENTIVE VS CASUAL MAINTENANCE

Many prospective television broadcasters will 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 will serve admirably—certain techniques will be 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 NARTB in the early part of 1952 reveals 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, two 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 prospective 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 $100, this loss being a little more than the amount needed to pay the maintenance man's salary for a week according to the same NARTB 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 "trouble-shooters". It will thus be seen that while no formal preventive maintenance schedule is in force in the station, a 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 whether 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 a number of articles and panel discussions by practical television broadcast engineers, the need for preventive maintenance has been stressed, but due to the present highly flexible state of the art, very little of a definite nature can be prepared. In this article, 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 may 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 may 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. 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 idiosyncracies 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 article to replace the specific instructions

given by the manufacturer for the care and maintenance of each equipment item. The purpose of the article 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 manufacturer's instruction manuals, and (2) the experience of the chief engineer and his staff as the station develops.

STUDIO PREVENTIVE MAINTENANCE SCHEDULE

Daily

Dusting.

Check for signs of overheating on all equipment.

Check pick-up equipment for abnormal conditions such as position of control knobs and poor picture quality which may not have been reported.*

Check cameras for geometric distortion, alignment and resolution.

The film photographic sound track scanning system must be checked. The exciter lamp condition should be noted and, in addition where provided, the adjustment of the lamp filament alignment with the optical assembly should be checked. 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. Photo cells should be examined for oil on the glass.

Projection lenses should be wiped with lens tissue. Coated lenses should be cleaned very carefully in accordance with the manufacturer's instructions.

Check need for unusual control knob settings on synchronizing generator.

Clean film projectors in accordance with manufacturer's instructions, checking especially for accumulations of dust, lint and emulsion on gate, pressure shoe rollers, teeth, picture aperture, etc.

Visually check 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 RTMA or SMPTE.

Check amplitude and pulse widths of synchronizing generator.* 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 air filter on power supply and clean or replace if clogged.

Lubricate 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.

Tube checks 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 insure that no unusual conditions have resulted from tube removals and replacements.

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.)

After 1000 Hours

Blowers should be cleaned and oiled in accordance with instructions furnished by manufacturer.

* During camera set-ups, need for unusual control settings should be observed by the operator and reported.

* Some manufacturers recommend this be done daily.

FIELD PICKUP (REMOTE) PREVENTIVE MAINTENANCE SCHEDULE

(This is also applicable to S-T-L)

NOTE: These daily, weekly and monthly schedules will naturally be revised in accordance with usage given equipment.

Daily

Check switching system for abnormal conditions such as poor picture output when compared to input.

Check cameras for geometric distortion, alignment and resolution.

Check pick-up equipment for abnormal conditions. (See "Studio" schedule.)

Check all equipment for overheating.

Dusting.

Weekly

Internal and external cleaning of cameras and power supplies. (See notes on "Studio" schedule.)

Check and readjust controls.

Inspect and tighten cable connectors and clamps.

Check amplitude and pulse widths of synchronizing generator. (Some manufacturers recommend this be done daily.)

Lubrication of 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

Tube checks on all equipment. (See "Studio" schedule.)

Record and compare cable socket voltages.

Check air filter on power supply and clean or replace if clogged.

Check and clean relays and switch contacts in all equipment. (See "Studio" schedule.)

After 1000 Hours

Blowers should be cleaned and oiled in accordance with instructions furnished by 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

NOTE: In connection with the following schedules, reference should be made to the FCC Rules Governing Television Stations. The RTMA "Electrical Standards For Television Broadcast Transmitters, Channels 1-13—TR-104-A" will also be found helpful.

Daily

Check filament line voltages every hour and adjust if required. FCC Rules governing transmitter logs (Sec. 3.663) require that operating constants of 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.

Dusting and general inspection for overheating or other signs of abnormal operation.

Weekly

Tube checks on all tubes which are not metered in the transmitter.

Clean internal parts of transmitter (insulators, etc.)

General performance check of noise, distortion and frequency characteristics of aural transmitter.

General performance check of visual frequency and broadband characteristics of visual transmitter.

(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.)

Inspection of blowers and flowmeters. Clean and/or lubricate if required.

Test door-interlocks and disconnect-switches being certain 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 non-energized readings.

Monthly

Inspection and lubrication of small blower motors.

Test spare tubes required by FCC.

Clean socket contacts if necessary.

Service relay contacts if necessary.

Check air filters and clean or replace as necessary.

Visually check condition of water in cooling system.

Quarterly

Operate all spare mercury vapor tubes for 30 minutes (See instructions furnished by manufacturer.)

Detailed inspection of every unit in transmitter using tests recommended by manufacturer.

Service all power contactors if necessary after inspection.

Flush and refill water-cooling system.

Make visual inspection of physical condition of antenna tower and transmission line.

Inspect and test tower lighting equipment according to Part 17 of FCC Rules.

Semi-annually

Tighten all connections, both electrical and mechanical, in transmitter and associated equipment.

Lubricate exhaust fans.

Lubricate high-pressure blowers and check operation of air interlocks.

Lubricate water cooling system.

Check outdoor protection to 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 so 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. Regular inspection of safety interlocks 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 making repairs 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 measuring high-voltages, 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 working on circuits carrying high R-F 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 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 naptha 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 new station's technical staff.

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. 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, naptha, etc.*—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 beginning any tests, instruction books and schematics should be closely studied and safety precautions observed. Inspection may be made by feel (for overheating), smell (this often locates an overheated part such as a transformer or reactor), and visual inspection for loose, broken, warping or cracked connections, 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 semi-annually 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 in the Camera Chains section 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 upon first 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 overall attenuation characteristics of the visual transmitter must be maintained, the aural transmitter and entire audio system must meet certain well defined operational characteristics with respect to distortion and frequency response. The scope of this article at the moment does not permit us to list all of the FCC Rules and Regulations pertaining to the required tests and operating practices, but these will more appropriately be included in subsequent articles. The matter of so called "proof of performance" on video transmitters is not altogether as well defined at the moment as the "proof of performance" required for the aural transmitter. We hope at a later date to have information on this subject. It is therefore necessary for us to confine the

* See Note 12 in "Safety" section.

material in this article to that maintenance required for the uninterrupted functioning of all mechanical items and the electrical portions containing expendable parts or where trouble more commonly occurs. In other sections of this Handbook will be found data on video amplifiers, terminal equipment, etc., which will prove helpful in understanding the design, operation and line-up of various segments of the television system.

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 tooth brush or flat pointed tooth pick 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 may 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. Oils flows more freely and penetrates faster when the machine is hot. Be extremely careful not to over-oil 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 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 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 pre-editing will save time and trouble in the long run.

Noisy projector mechanism: Check adjustment of claws, roller chain, drive chain and gears. Adjust as recommended by manufacturer.

Travel ghosts and picture jump: Check projector synchronization of the shutter with the pull-down mechanism. Trouble may be shutter out of adjustment, improper threading, claws worn or out of adjustment, worn rails or cam shaft. 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: Projection lens, condenser lens, or reflector dirty, or 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 dirty or emulsion coated. On 35 mm projectors, check fire rollers in 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. Pre-viewing of all film is recommended.

Picture, but sound weak or distorted or no sound: First, check audio level control and threading system. These are the principle causes. Open or shorted cables, burnt out fuses or lamps, improper seating of photoelectric tubes, improperly adjusted sound mirror are also frequent causes. Check for obstruction of light beam by foreign matter. If trouble is still not located, check further by manufacturer's instructions.

Sound, but no picture: Burnt out projection lamp.

Oscillation in preamplifier: Loose ground wires, output leads too near the input leads, or defective by-pass capacitor.

Hum level high: Check shield on audio line or photoelectric cell, filtering of photoelectric cell voltage or bad tubes.

No photoelectric cell voltage: A-C power may be off. Also check filter capacitors and rectifier tubes in preamplifier, fuse in A-C line to preamp, and for open resistors and broken or shorted wires.

Microphonics: Loose connections, poor contact between plug and socket, loose elements in PEC, or oil soaked wiring. Also check projector mechanism for excessive vibration. (Pre-amplifier tubes are often microphonic.)

Distortion: Most often found to be tube trouble or defective PEC or sound optics out of adjust-

* See Note 12 in "Safety" section.

ment. Other causes are due to leakage in speech lines or open coupling capacitor.

Tone unsteady—Wows: Check tension of pressure roller. Sound drum may be dirty or damaged. Check also for dirty pressure rollers, and dirty guide rollers. Sound drum shaft or bearings may be loose or worn. 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 shutter from the rotor shaft as this will require readjustment of the shutter for proper synchronization. Failure of drive motor to start, not running at proper speed, acceleration time too long, or drive motor starting then stopping, usually indicate 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 blower motor and drive motor. Check and tighten motor coupling and attachment of motor to bed plate. (In tightening screws, avoid forcing screws and damaging threads. If necessary, remove 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 35mm 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. 16mm test films are used for the following tests:

Sound Optical Assembly Adjustment

Two types of film are available, a 7000 cycle record for precision adjustments following overhaul and a 5000 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 output 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 .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 1000 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 .060 in. to .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 .005 in. wide, modulated at constant level, by a 1000 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 1000 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 3000 cycle flutter test film is a direct positive original recording and carries a 3000 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%.

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 photo tube 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% 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, orchestral and piano music.

The Society produces a sound service test film which contains title music, buzz track, sound focusing test, constant frequencies from 50 to 6000 cycles, dialogue and piano music. This film is intended to provide an inexpensive overall quick test of projector performance.

A complete list of 35mm and 16mm test films is shown in the catalog of the Society and Research Council and is available for the asking. See final section, "Test Charts, Slides and Films" for availability.

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.

In making tube checks, 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 orths, 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 RTMA 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 starts with the proper functioning of the synchonizing 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 semi-annually 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 synchonizing 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 insure 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 type tubes dictates 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 wait until the next day's operation begins only to find that, due 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, a large number of stations have found it profitable from a standpoint of economics, as well as trouble-free operation, to keep the equipment running on a 24-hour basis. This practice is applicable in many sections of the station's equipment 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 and 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 beginning internal cleaning 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 insure 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 one man who always has the responsibility for remote set-ups.

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 dust-proof.

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 1800 tubes in the overall system of studios and transmitter. These tubes range from the inexpensive miniature type to the image orthicons which cost about $1200 each. Naturally, it is impossible in an article of this type to completely cover the idiosyncrasies of such a variety of tubes, 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 same life expectancy of a tube used in video circuitry is not always as great as that of the same tube when used in audio equipment. However, many tubes may 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 pre-tested tubes should be instantly available to the operator for quick substitution when necessary. It may be found desirable to have certain tubes pre-marked 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, 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 period of 1000 hours and a pro-rated 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 the tube 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 insuring 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. See especially the notes from RCA on the 8D21.

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 electrostatically precipitated and form scale which interferes with the proper operation of the system.
3. Remove 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 cleaning the system, 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 turbulance in the tube passages with the possibility of an increase in microphonics.
7. It is highly important to protect 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 than when the system is first placed in operation, the temperature of the intake air and out-go 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 may 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 requiring attention only every few years.

The Image Orthicon

If improper operation is experienced, make as many checks on the adjustment of all controls on the camera as possible before attempting to dismantle the equipment. In many cases, dismantling can be prevented if these precautions are taken. The correct input signals and voltages should be available before beginning any work on the camera.

As with all tubes, the life of the image orthicon will be greatly increased by its proper operation:

1. The tube should be allowed to warm up before operation—if it is being used outdoors, the target heater may be used to shorten the warmup time and to keep the operating temperature at the correct level. Check the correct operating temperature limits recommended for each tube and be certain that they are maintained throughout the operation. Operating at temperatures lower than those recommended will result in "sticking"; excessive temperatures lead to migration of the photosensitive material among the elements of the tube, resulting in improper operation such as loss of resolution and possible permanent damage to the tube. Listen occasionally during the operation to be sure the blower is functioning.
2. Failure of scanning for even a few minutes when light is incident on the photocathode may permanently damage the surface of the target. If the camera must be left unattended for any reason, possible damage due to scanning failure may be avoided by capping the lens and biasing off the target. It is good insurance to avoid cutting off the beam current, since a small percentage of image orthicon tubes may be damaged by such a practice. The beam current should be kept as low as possible to give the best picture quality. The target should always be scanned to full size, and overscanned during rehearsal and stand-by periods.
3. The tube should never be allowed to focus on a stationary bright scene for more than a few seconds. Here again, the result will be "sticking" of the picture. If the retained or "sticking" picture persists, it can usually be removed by focusing the camera on a rough, white surface; in other words, by flooding the photocathode with light.
4. Continued operation of an image orthicon having an ion spot will eventually cause permanent damage to the target.
5. Check the scene illumination and use correct lens stop.
6. Use lowest beam current with proper target voltage for best signal-to-noise and gray scale reproduction.
7. New image orthicons should be tested immediately upon receipt and operated for several hours before being set aside as spares. Spares should be operated for several hours at least once a month to keep them free of any traces of gas which may be liberated during prolonged storage.

   At one time, a practice of "shelf rest" and/or rotation of image orthicon tubes was recommended. It has been found, however, that this does not necessarily result in longer tube life or improved operational quality and, in fact, once a tube has been placed in a camera, it is better to leave it there until it becomes defective.

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 use of 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 non-linearity are easily made during the time the camera is being used to show 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 non-linearity 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 the psychological standpoint 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 manu-

* See Note 12 in Safety section.

facturers) 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 temperature of a high-voltage capacitor may 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 dialectric leakage or improper ventilation. Prompt replacement will avoid loss of air time from over-heated capacitors.

Low-voltage capacitors do not require as 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 as 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. Excessive 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.

TEST CHARTS, SLIDES AND FILMS

Reference has been made in this article to test pattern charts, slides and films recommended by SMPTE and RTMA.

The Society of Motion Picture and Television Engineers (SMPTE), 40 West 40th Street, New York 18, N. Y. has test films available in both 16 mm and 35 mm sizes. The SMPTE "Test Film Catalog" which lists descriptions and prices of all test films produced and sold by the Society and the Motion Picture Research Council can be obtained free of charge by addressing SMPTE.

Radio Television Manufacturers Association (RTMA), 777 Fourteenth Street, N.W., Washington 5, D.C. furnishes a resolution chart which was prepared by its TR4 Committee on Television Transmitters for the purpose of standardizing resolution measurements. The cost is $2.00 per copy. RTMA does not furnish slides or test films, but its resolution chart has been prepared on slides, motion picture films (both 16 mm and 35 mm), film strips and photo paper sensitives by Loucks and Norling Studios, Inc., 245 West 55th Street, New York 19, N. Y. A copy of the current price list may be obtained from Loucks and Norling.

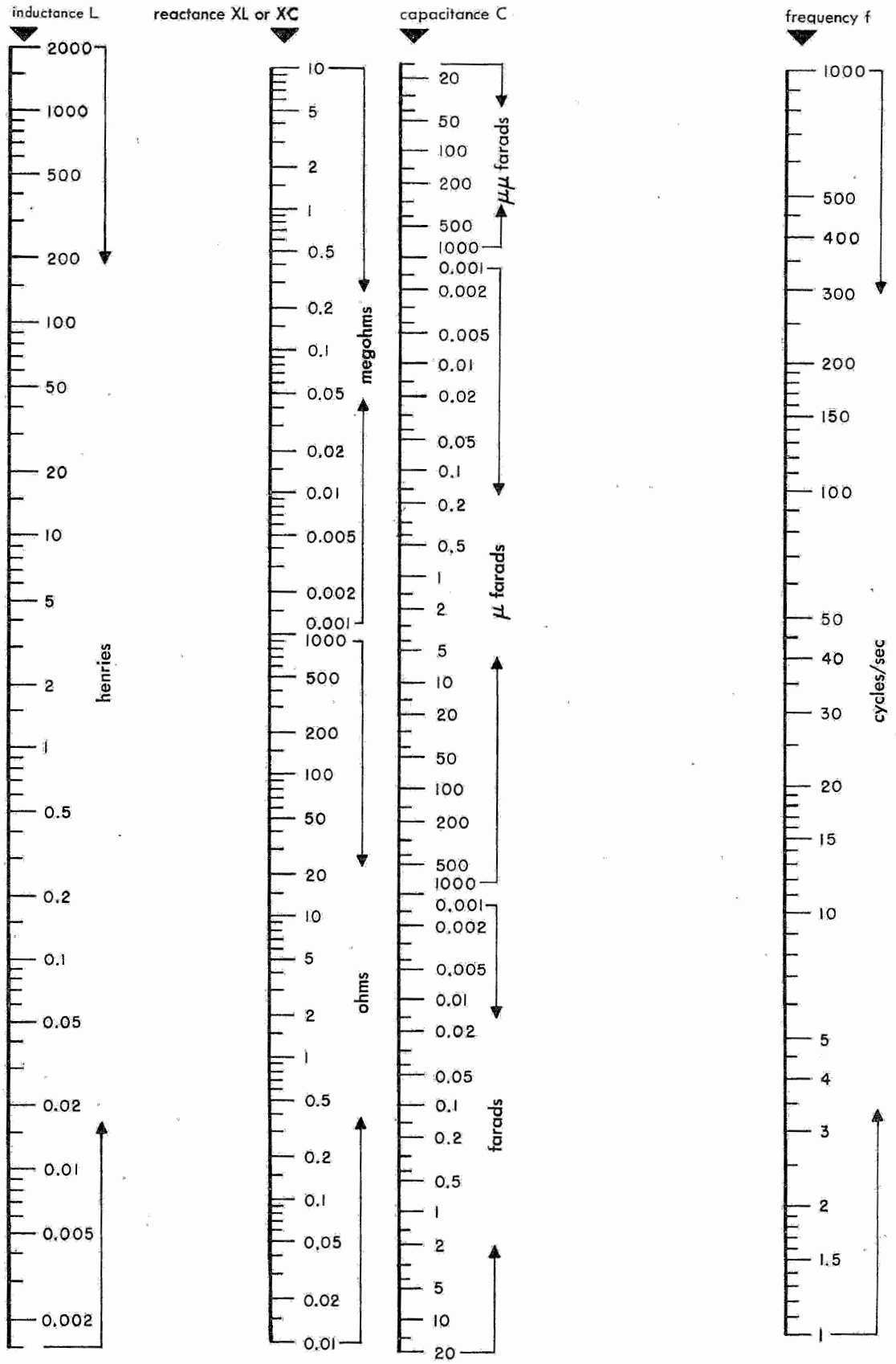
A television station may design its own personalized test pattern built around the ones recommended either by RTMA or SMPTE, or some completely different idea of its own which may then be reproduced on slides, films or opaques. At least one manufacturer can furnish a custom-built monoscope with a personalized pattern. Some stations use two different test patterns—one of the RTMA or SMPTE type which is used to check the alignment, resolution, etc. of pickup and projection equipment; and for "on the air" use, a much less complicated one which provides identification of the station and some engineering information for the use of servicemen in installing and adjusting receivers in the viewer's home. The designer of the second type of test pattern should remember that its primary purpose is to enable the viewer or serviceman to adjust the television receiver for maximum detail and not solely for its artistic possibilities.

Part 3 of the FCC Rules and Regulations, "Radio Broadcast Services" which includes the Standards of Good Engineering Practice for Television Stations may be ordered for 20¢ per copy from:

Superintendent of Documents
Washington 25, D.C.

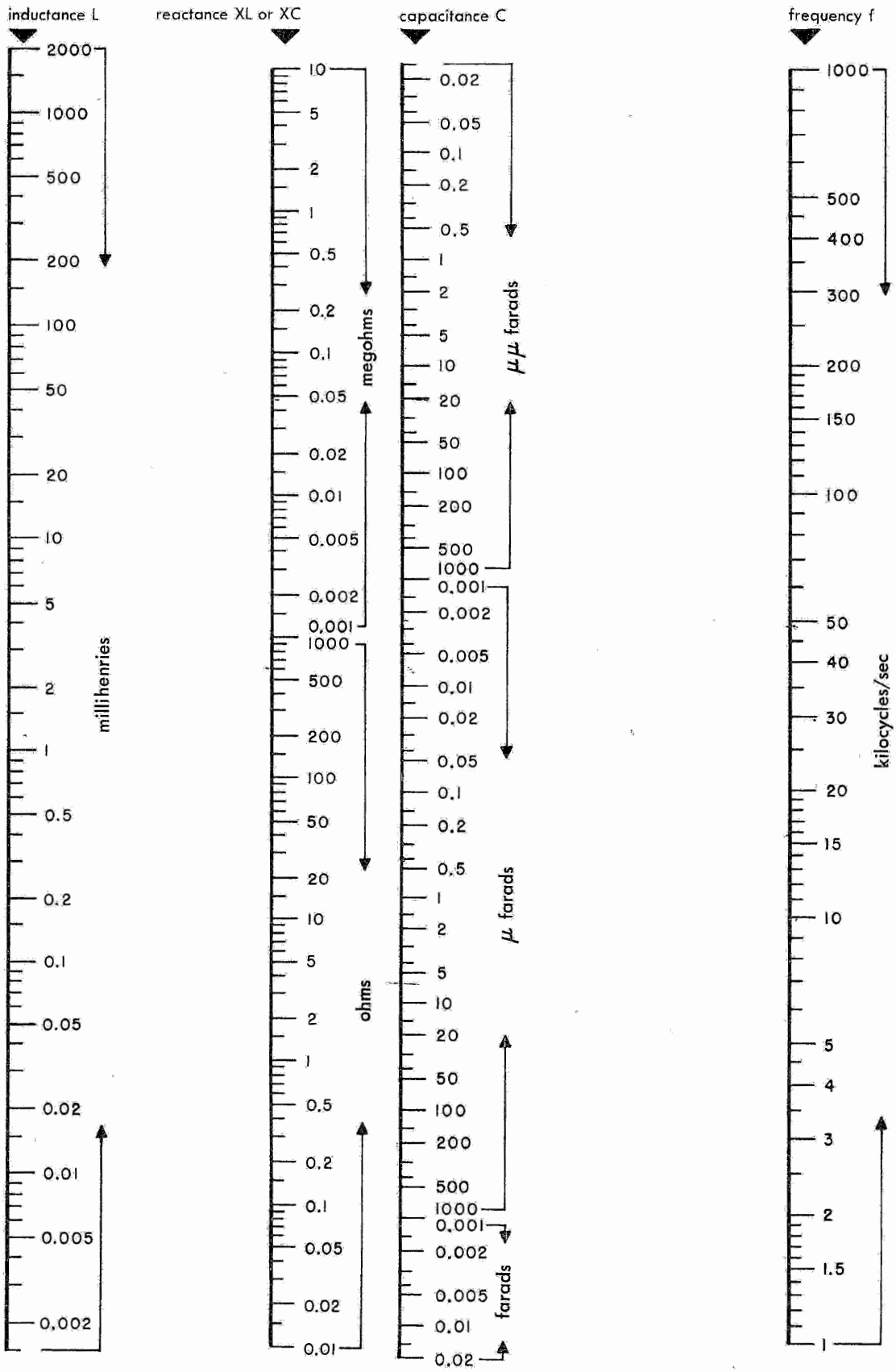
RTMA "Electrical Standards for Television Broadcast Transmitters Channels 1-13, TR-104-A" may be ordered for 90¢ per copy from:

Radio Television Manufacturers Association
Wyatt Building
Washington 5, D.C.



(Courtesy Hygrade Sylvania Corp.)

6-1-01



(Courtesy Hygrade Sylvania Corp.)

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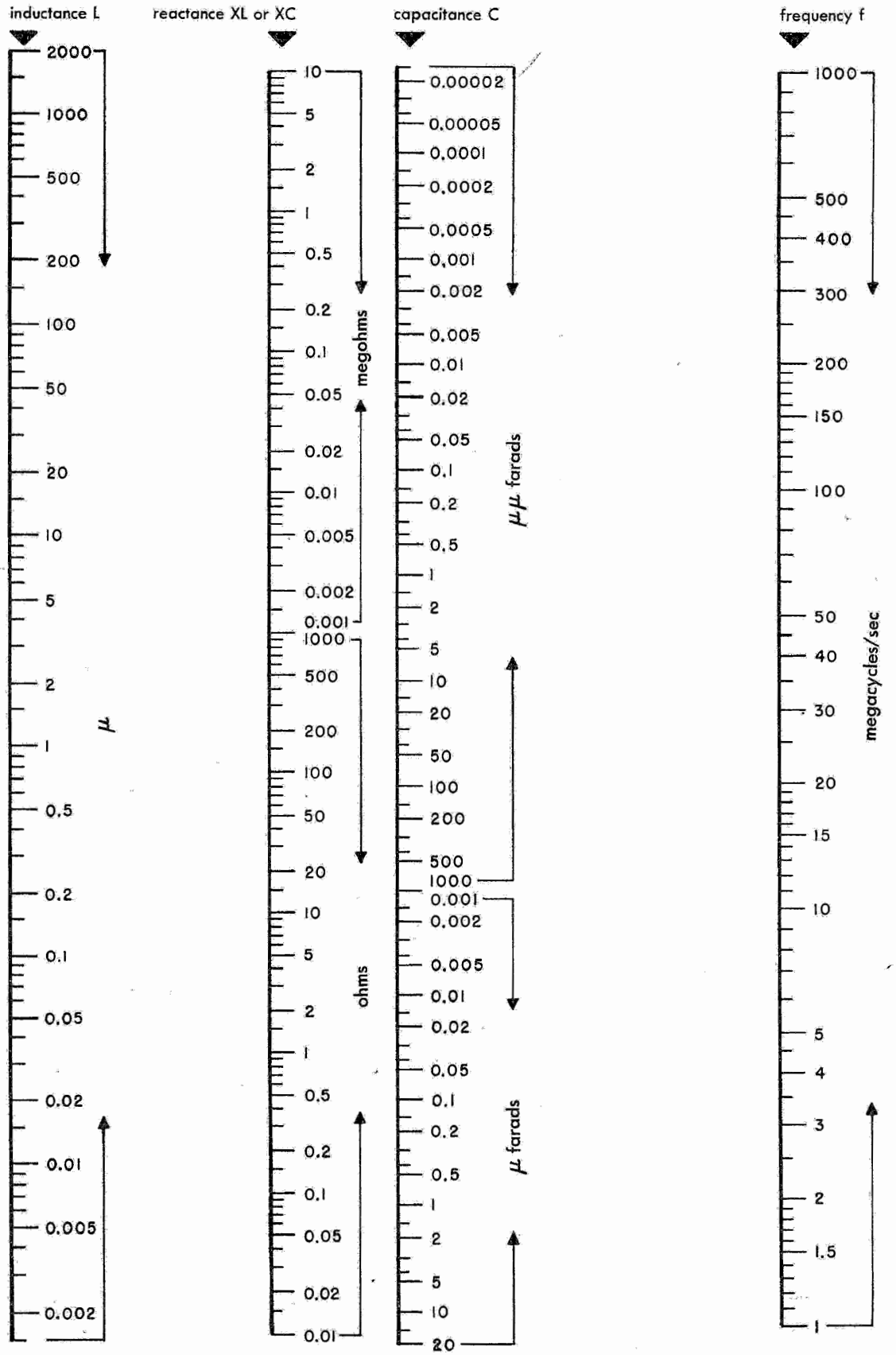

(Courtesy Hygrade Sylvania Corp.)

6-1-03

SILICON AND GERMANIUM RECTIFIERS

(Reprinted Through Courtesy of Electronics)

A modern crystal rectifier consists of a small-area contact between a tungsten whisker and a suitable semiconductor. It should not be confused with copper oxide or selenium rectifiers.

Developed as imperative components for microwave radar systems, the electrical characteristics and mechanical stability of the new crystal rectifiers makes them attractive to designers of modern electronic equipment. Point-contact rectifiers offer many possibilities in addition to the present uses as microwave converters, second detectors, beacon detectors and low-frequency diodes. They can replace many diodes with a saving in volume, weight, and filament power consumption. The low capacitance of the contact makes their use in uhf and shf applications desirable. Special kinds, such as welded-point crystals and silicon high back voltage crystals, are capable of still further development and use.

Table I shows uses and major characteristics of most currently available crystals. Those registered with the RMA Data Bureau are designated by an asterisk. The radar band in which each was used has been indicated in column "λ". After selecting a crystal type according to gross characteristics, the design engineer can find its exact characteristics in table II.

An analysis of physical composition; theory, and test procedures is given in an article, Crystal Rectifiers, by W. E. Stephens, Electronics, p 112, July 1946.

TABLE I

Uses and Major Characteristics														
FUNCTIONS AND CHARACTERISTICS	Converter	Video	Diode	Instrument Rectifier	2nd Detector	Least Sensitive	Moderate Sensitivity	High Sensitivity	Most Sensitive	High Burn-out	Medium High Burn-out	High Back Voltage	D-C Restorer	λ (cm)
TYPE NUMBERS														
1N21 (obs)	●					●								10
1N21A	●						●							10
1N21B*	●							●						10
1N21C	●								●					10
1N22				●										
1N23	●					●								3
1N23A	●						●							3
1N23B*	●							●						3
1N24 (obs)	●					●								1
1N25*	●					●				●				30
1N26*	●						●							1
1N27*		●												10
1N28	●						●			●				10
1N29*		●												10
1N30*		●												3
1N31*		●												3
1N32*		●												10
1N33		●									●			10
1N34*			●									●		
1N35*			●									●		
WE D171561					●							●		
WE D171612												●	●	
WE D172925												●	●	

TABLE II

Converter Rectifiers

		1N21(obs)	1N21A	1N21B*	1N21C	1N23	1N23A	1N23B*	1N24(obs)	1N25*	1N26*	1N28
Center frequency	(mc)	3060	3060	3060±5	3060	9375	9375	9375±30	24000	1000±10	24000±60	3060
Max. i-f impedance	(ohms)	....	....	800	....	....	....	600	.....	400	600	....
Min. i-f impedance	(ohms)	....	....	200	....	....	....	150	.....	100	300	....
Max. conversion loss	(db)	8.5	7.5	6.5	....	10.0	8.0	6.5	8.5	8.5	8.5	7.0
R-f signal input	(milliwatts)	0.5	0.5	0.5	0.5	....	....	1.0	.....	1.25	1.0	....
Mod. freq. load imp.	(ohms)	....	....	400	....	....	....	400	.....	200	500	....
D-c load resistance	(ohms)	....	....	100±10	....	....	....	100±10	.....	100±5	100±10	....
Max. output noise ratio		4.0	3.0	2.0	1.5	3.0	2.7	2.7	2.5	2.5	2.5	2.0
R-f signal input	(milliwatts)	....	....	0.5	....	....	....	1.0	.....	0.9	1.0	....
Reference resistance	(ohms)	....	....	400	....	....	....	300	.....	200	300	....
D-c load resistance	(ohms)	....	....	100±10	....	....	....	100±10	.....	20±2	100±10	....
Approx. rect. crystal current	(ma)	....	....	0.6	....	....	....	1.2	.....	1.2	.....	0.4

Video Rectifiers

		1N27*	1N29*	1N30*	1N31*	1N32*	1N33
Center frequency	(mc)	3295±40	3060±5	9375±30	9375±10	3000	2880
Max. video freq.	(mc)	5.0	.....	5.0	5.0	5.0	....
Min. video freq.	(cps)	500	.....	500	500	500	....
Max. video impedance	(ohms)	4000	.....	21000	24000	20000	10000
Max. forward voltage	(millivolts)	1	.....	.....	.....	.....	.....
Min. video impedance	(ohms)	....	6500	7000	6000	5000	2000
Max. forward voltage	(millivolts)	....	40	5.0	5.0	5.0	.....
Min. figure of merit		60	.....	55	55	100	40
Max. r-f power input	(microwatts)	5	.....	5	5	5	.....
Crystal circuit constant	(ohms)	1200	.....	1200	1200	1200	.....
Max. Conversion loss	(db)	....	8.0	.....	.....	.....	.....
R-f signal input power	(milliwatts)	....	0.5	.....	.....	.....	.....
Reference resistance	(ohms)	....	400	.....	.....	.....	.....
D-c load resistance	(ohms)	....	100±10	.....	.....	.....	.....
Rectified crystal current	(ma)	....	0.6	.....	.....	.....	.....

Diode Rectifiers

		1N34*	1N35*
Max. peak inverse voltage	(v)	50	50
Max. peak anode current	(ma)	60	60
Max. average anode current	(ma)	22.5	22.5
Max. surge current	(ma)	200	200
Max. reverse current (Eb = − 50 v d-c)		2.0	2.0
Operating range	(mc)	0-100	0-100
Units matched in pass direction	(%)	.....	10
Units matched in blocking direction	(%)	.....	20
Typical anode voltage	(v, a-c)	30	30
Typical load resistance	(ohms)	500	500
Typical minimum load voltage	(v, d-c)	10	10

Note: The 1N35 consists of two 1N34's mounted together

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Voltage or Current Ratio	Power Ratio	Power Ratio	Voltage or Current Ratio	—db+	Voltage or Current Ratio	Power Ratio
2.00	3.98	.0501	.224	13.0	4.47	19.95
2.02	4.07	.0490	.221	13.1	4.52	20.42
2.04	4.17	.0479	.219	13.2	4.57	20.89
2.07	4.27	.0468	.216	13.3	4.62	21.38
2.09	4.37	.0457	.214	13.4	4.68	21.88
2.11	4.47	.0447	.211	13.5	4.73	22.39
2.14	4.57	.0437	.209	13.6	4.79	22.91
2.16	4.68	.0427	.207	13.7	4.84	23.44
2.19	4.79	.0417	.204	13.8	4.90	23.99
2.21	4.90	.0407	.202	13.9	4.96	24.55
2.24	5.01	.0398	.200	14.0	5.01	25.12
2.27	5.13	.0389	.197	14.1	5.07	25.70
2.29	5.25	.0380	.195	14.2	5.13	26.30
2.32	5.37	.0372	.193	14.3	5.19	26.92
2.34	5.50	.0363	.191	14.4	5.25	27.54
2.37	5.62	.0355	.188	14.5	5.31	28.18
2.40	5.75	.0347	.186	14.6	5.37	28.84
2.43	5.89	.0339	.184	14.7	5.43	29.51
2.46	6.03	.0331	.182	14.8	5.50	30.20
2.48	6.17	.0324	.180	14.9	5.56	30.90
2.51	6.31	.0316	.178	15.0	5.62	31.62
2.54	6.46	.0309	.176	15.1	5.69	32.36
2.57	6.61	.0302	.174	15.2	5.75	33.11
2.60	6.76	.0295	.172	15.3	5.82	33.88
2.63	6.92	.0288	.170	15.4	5.89	34.67
2.66	7.08	.0282	.168	15.5	5.96	35.48
2.69	7.24	.0275	.166	15.6	6.03	36.31
2.72	7.41	.0269	.164	15.7	6.10	37.15
2.75	7.59	.0263	.162	15.8	6.17	38.02
2.79	7.76	.0257	.160	15.9	6.24	38.90
2.82	7.94	.0251	.159	16.0	6.31	39.81
2.85	8.13	.0246	.157	16.1	6.38	40.74
2.88	8.32	.0240	.155	16.2	6.46	41.69
2.92	8.51	.0234	.153	16.3	6.53	42.66
2.95	8.71	.0229	.151	16.4	6.61	43.65
2.99	8.91	.0224	.150	16.5	6.68	44.67
3.02	9.12	.0219	.148	16.6	6.76	45.71
3.06	9.33	.0214	.146	16.7	6.84	46.77
3.09	9.55	.0209	.145	16.8	6.92	47.86
3.13	9.77	.0204	.143	16.9	7.00	48.98
3.16	10.00	.0200	.141	17.0	7.08	50.12
3.20	10.23	.0195	.140	17.1	7.16	51.29
3.24	10.47	.0191	.138	17.2	7.24	52.48
3.27	10.72	.0186	.137	17.3	7.33	53.70
3.31	10.96	.0182	.135	17.4	7.41	54.95
3.35	11.22	.0178	.133	17.5	7.50	56.23
3.39	11.48	.0174	.132	17.6	7.59	57.54
3.43	11.75	.0170	.130	17.7	7.67	58.88
3.47	12.02	.0166	.129	17.8	7.76	60.26
3.51	12.30	.0162	.127	17.9	7.85	61.66
3.55	12.59	.0159	.126	18.0	7.94	63.10
3.59	12.88	.0155	.125	18.1	8.04	64.57
3.63	13.18	.0151	.123	18.2	8.13	66.07
3.67	13.49	.0148	.122	18.3	8.22	67.61
3.72	13.80	.0145	.120	18.4	8.32	69.18
3.76	14.13	.0141	.119	18.5	8.41	70.79
3.80	14.45	.0138	.118	18.6	8.51	72.44
3.85	14.79	.0135	.116	18.7	8.61	74.13
3.89	15.14	.0132	.115	18.8	8.71	75.86
3.94	15.49	.0129	.114	18.9	8.81	77.62
3.98	15.85	.0126	.112	19.0	8.91	79.43
4.03	16.22	.0123	.111	19.1	9.02	81.28
4.07	16.60	.0120	.110	19.2	9.12	83.18
4.12	16.98	.0118	.108	19.3	9.23	85.11
4.17	17.38	.0115	.107	19.4	9.33	87.10
4.22	17.78	.0112	.106	19.5	9.44	89.13
4.27	18.20	.0110	.105	19.6	9.55	91.20
4.32	18.62	.0107	.104	19.7	9.66	93.33
4.37	19.05	.0105	.102	19.8	9.77	95.50
4.42	19.50	.0102	.101	19.9	9.89	97.72
		.0100	.100	20.0	10.00	100.00

.309	.556	5.1	1.80	3.24	.0617	.246	12.2
.302	.550	5.2	1.82	3.31	.0603	.246	12.2
.295	.543	5.3	1.84	3.39	.0589	.243	12.3
.288	.537	5.4	1.86	3.47	.0575	.240	12.4
.282	.530	5.5	1.88	3.55	.0562	.237	12.5
.275	.525	5.6	1.91	3.63	.0550	.234	12.6
.269	.519	5.7	1.93	3.72	.0537	.232	12.7
.263	.513	5.8	1.95	3.80	.0525	.229	12.8
.257	.507	5.9	1.97	3.89	.0513	.227	12.9

"Industrial Electronic Distributors"

ELECTRONICS CORPORATION

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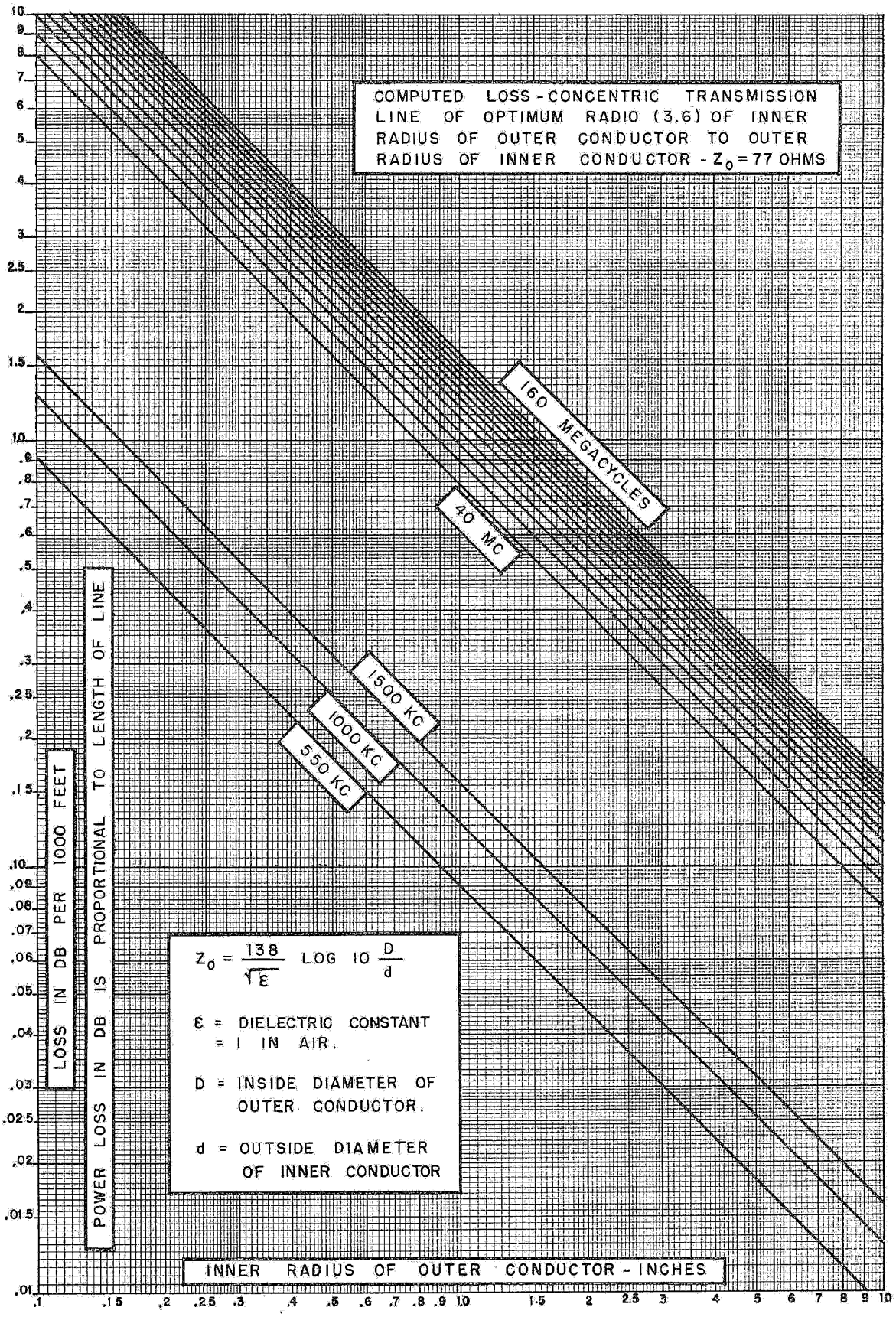

COMPUTED LOSS - CONCENTRIC TRANSMISSION LINE OF OPTIMUM RADIO (3.6) OF INNER RADIUS OF OUTER CONDUCTOR TO OUTER RADIUS OF INNER CONDUCTOR - Z_0 = 77 OHMS
160 MEGACYCLES
40 MC
1500 KC
1000 KC
550 KC
$Z_0 = \frac{138}{\sqrt{\varepsilon}} \log 10 \frac{D}{d}$
ε = DIELECTRIC CONSTANT = 1 IN AIR.
D = INSIDE DIAMETER OF OUTER CONDUCTOR.
d = OUTSIDE DIAMETER OF INNER CONDUCTOR
POWER LOSS IN DB IS PROPORTIONAL TO LENGTH OF LINE
LOSS IN DB PER 1000 FEET
INNER RADIUS OF OUTER CONDUCTOR - INCHES
10 9 8 7 6 5 4 3 2.5 2 1.5 1.0 .9 .8 .7 .6 .5 .4 .3 .25 .2 .15 .10 .09 .08 .07 .06 .05 .04 .03 .025 .02 .015 .01
.1 .15 .2 .25 .3 .4 .5 .6 .7 .8 .9 1.0 1.5 2 2.5 3 4 5 6 7 8 9 10

6-4-01

COMPARISON OF OPEN WIRE, SOLID DIELECTRIC LINES AND WAVEGUIDES

Reprinted from Electronics Buyers Guide

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--med 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. N.G. for H.F.	.....	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 dielectric	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°F--200°F for short time	220°F--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-med freq losses high at microwave	Good at high freq not at low--need spec for each	Good--at low and med not so good at microwave	Poor--loss too high	Best--but each freq 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

RESISTANCE VALUES OF SYMMETRICAL ATTENUATION NETWORKS

Frank H. McIntosh, Consulting Radio Engineer, Washington, D.C.

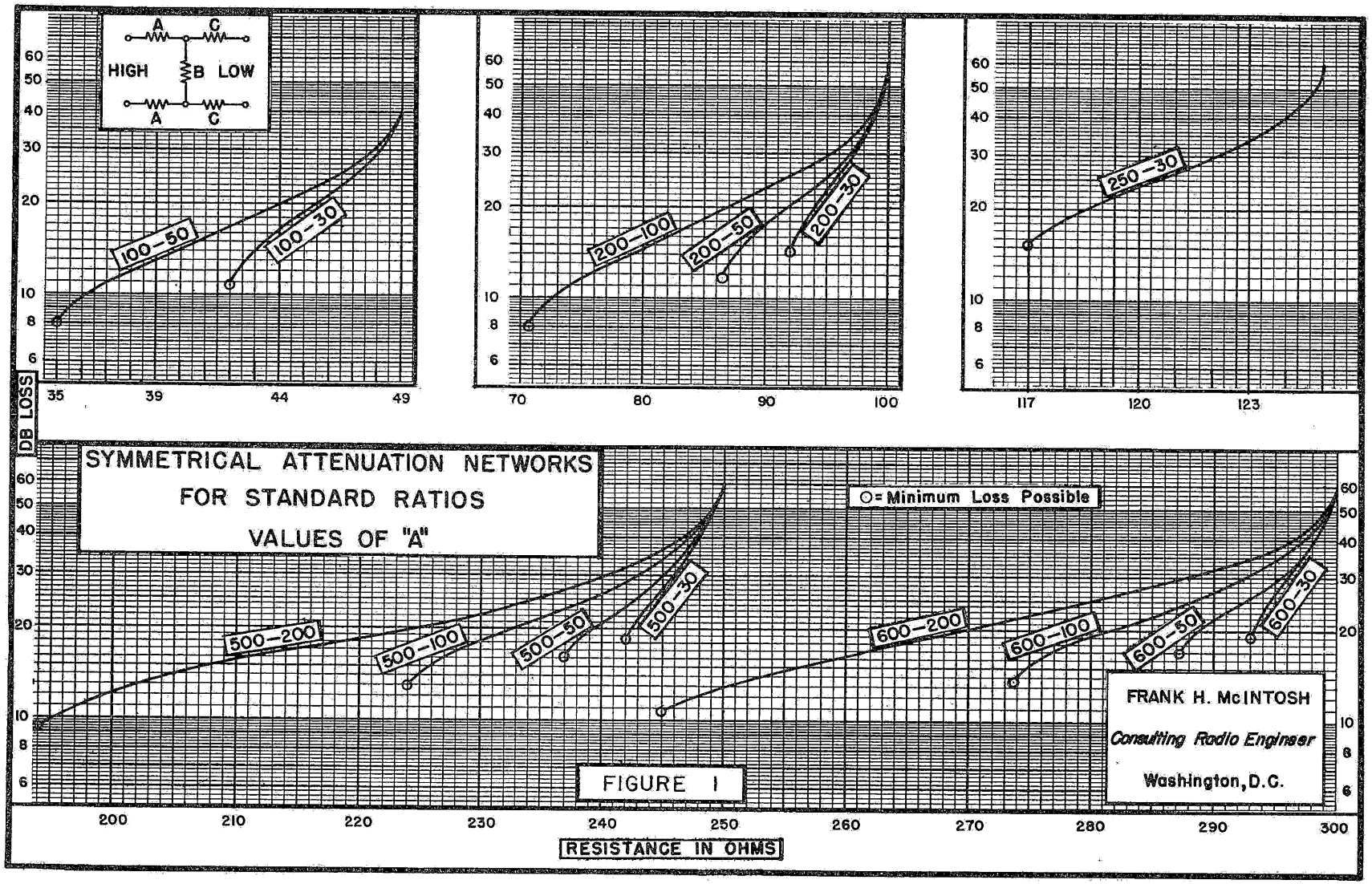
For ready reference and to satisfy most of the practical needs of the various artificial line pads, the following charts have been prepared:

Figures 1 to 3, 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 on Figure 1, while "C" values for the lower pad series leg resistances are shown on Figure 3. "B" is for the shunt or transverse resistor shown on Figure 2.

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 4 gives the resistance values for the series legs "A" of symmetrical pads having 1 to 1 impedance ratios. Figure 5 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" network.

6-6-02


A
C
HIGH
B
LOW
A
C
DB LOSS
60
50
40
30
20
10
8
6
100-50
100-30
35
39
44
49
200-100
200-50
200-30
70
80
90
100
250-30
117
120
123
SYMMETRICAL ATTENUATION NETWORKS
FOR STANDARD RATIOS
VALUES OF "A"
○= Minimum Loss Possible
500-200
500-100
500-50
500-30
600-200
600-100
600-50
600-30
FRANK H. McINTOSH
Consulting Radio Engineer
Washington, D.C.
FIGURE 1
200
210
220
230
240
250
260
270
280
290
300
RESISTANCE IN OHMS

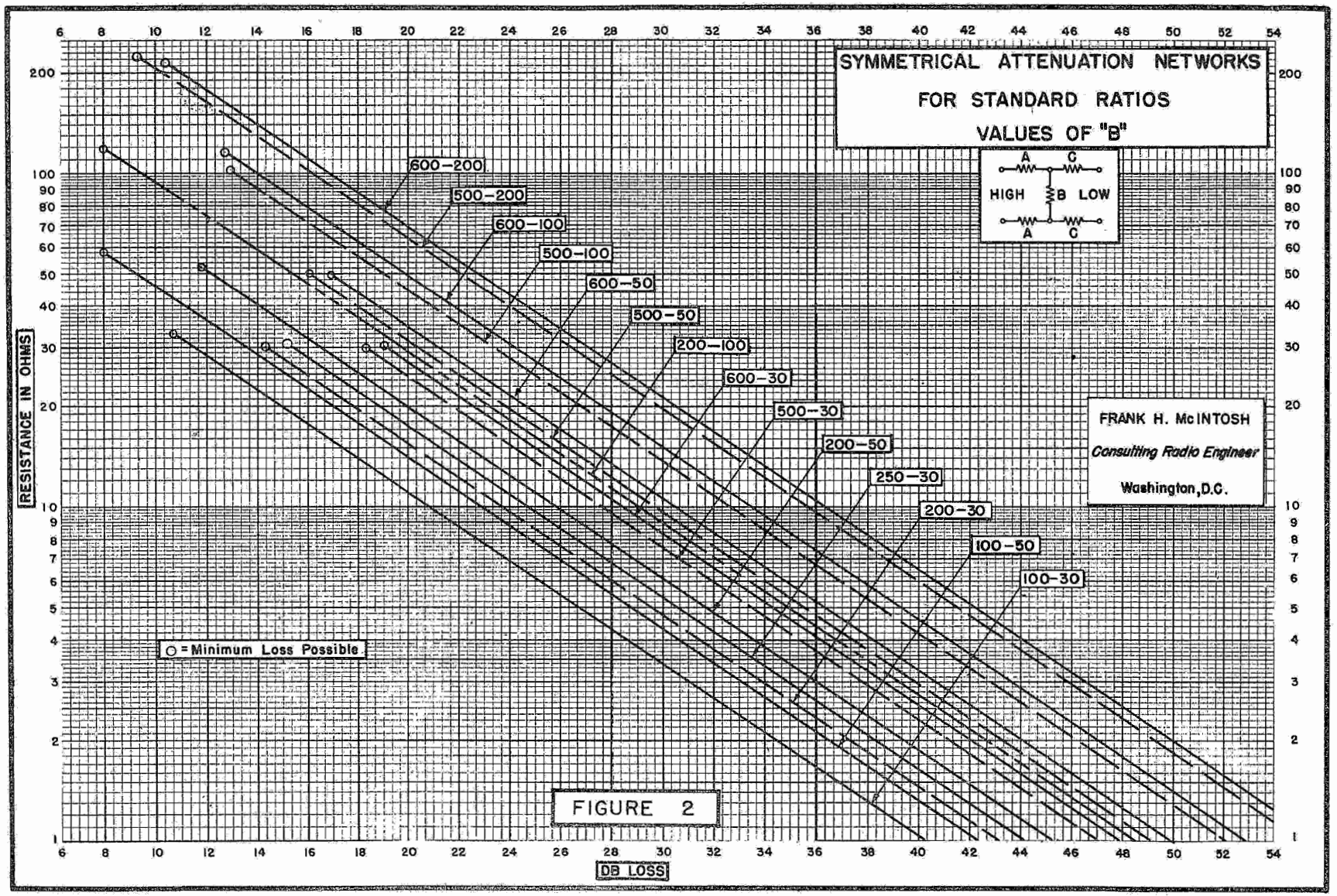


FIGURE 2

6-6-03

6-6-04

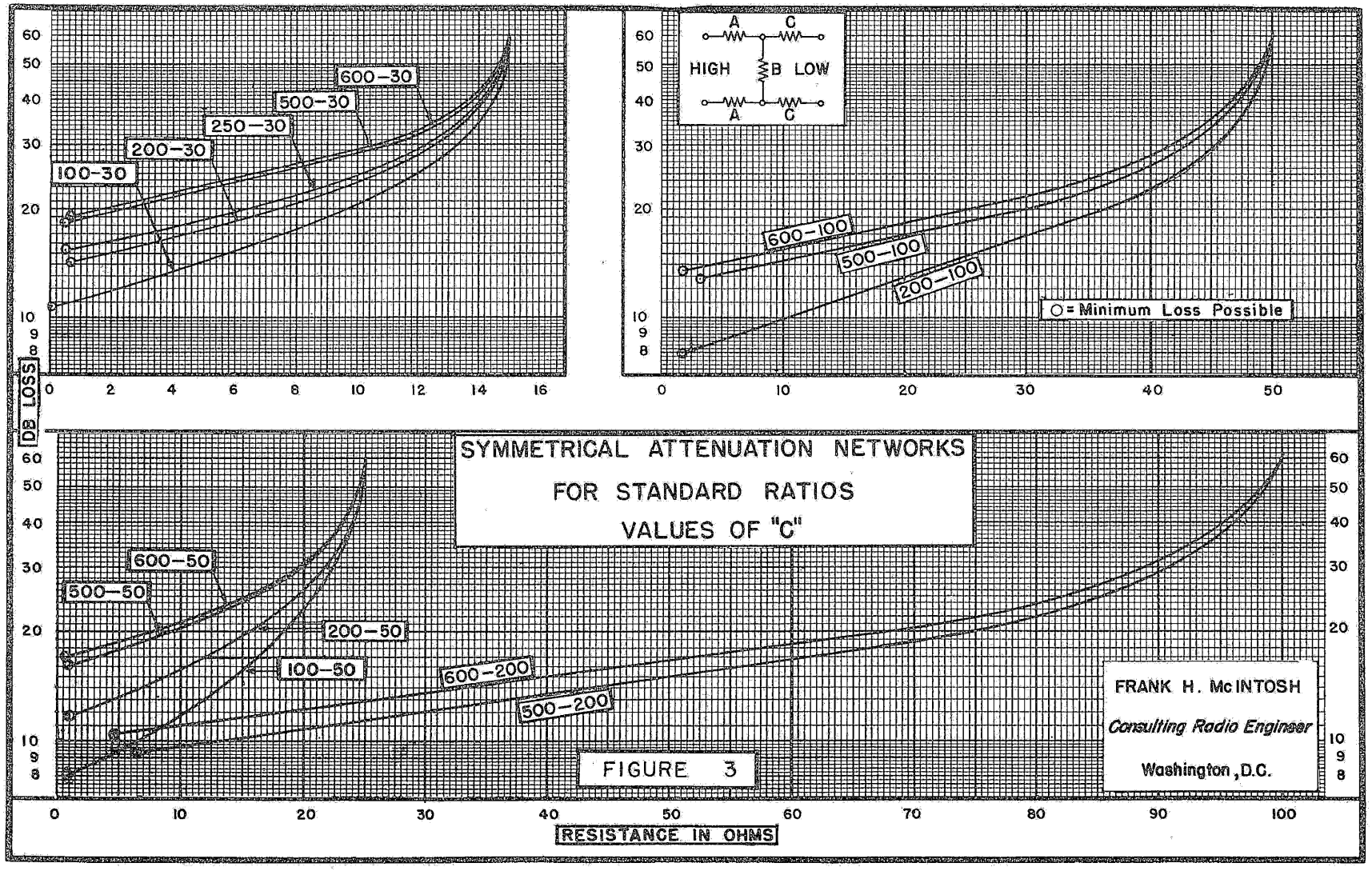


FIGURE 3

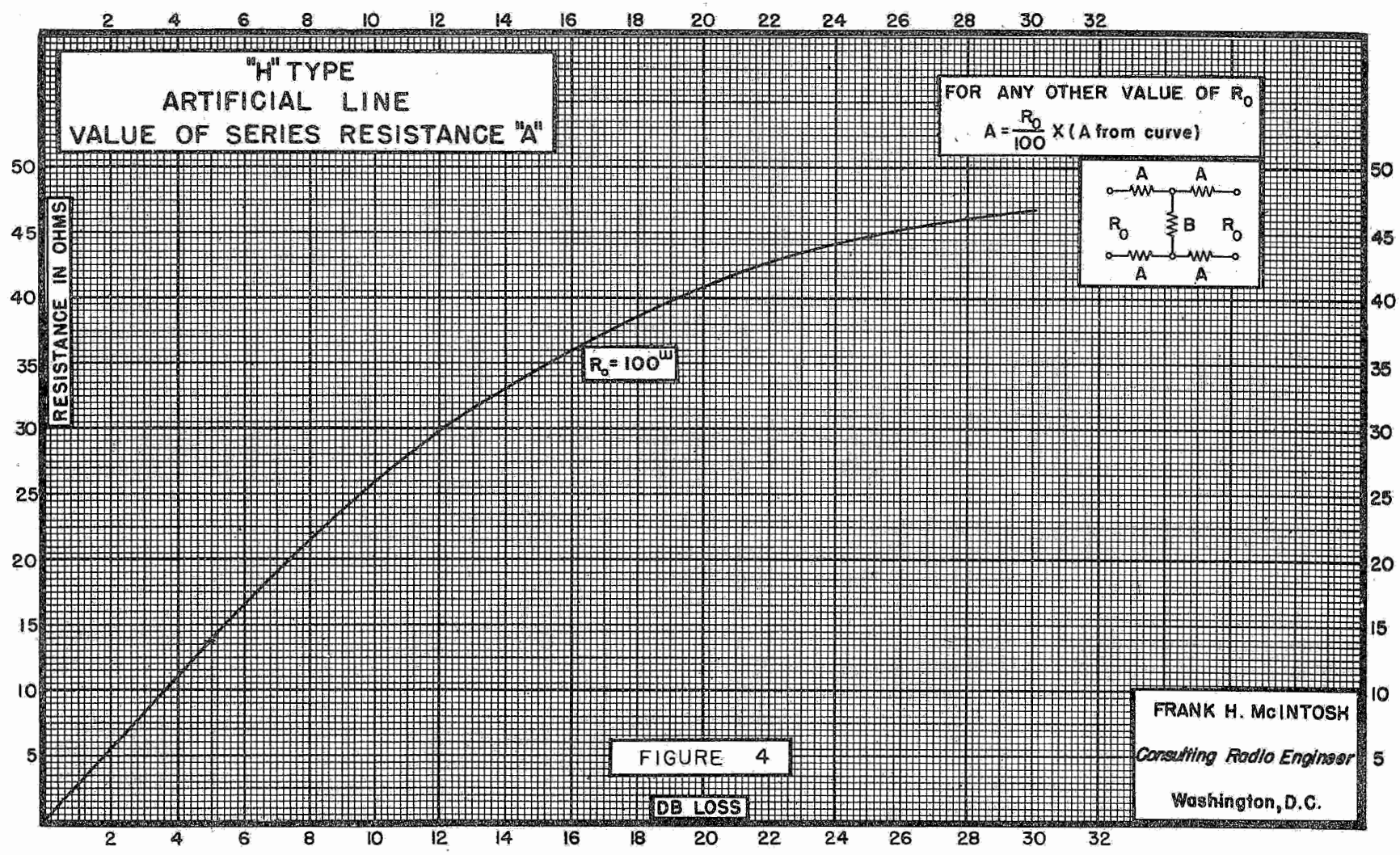
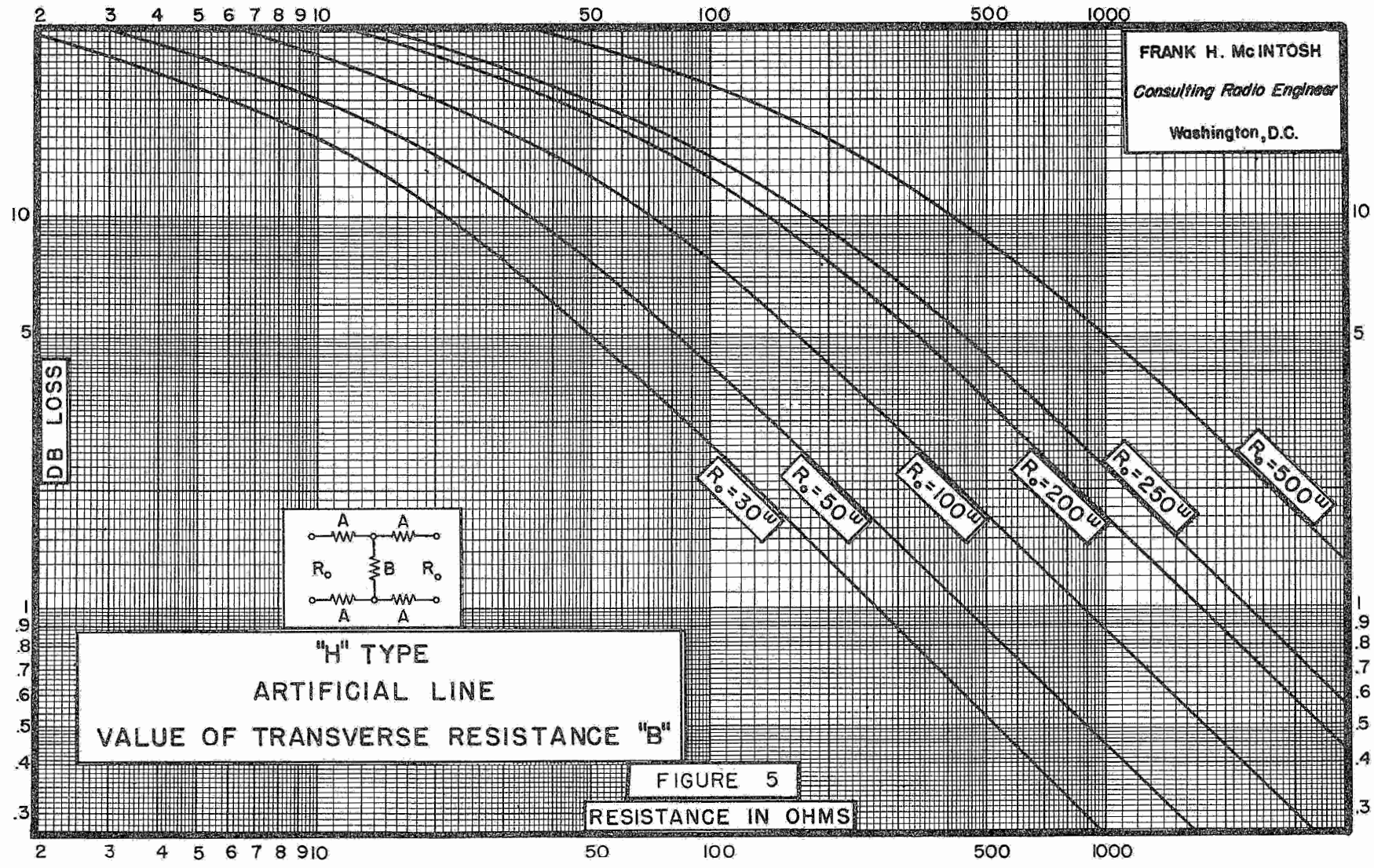


FIGURE 4

6-6-05


90-9-9
2 3 4 5 6 7 8 9 10 50 100 500 1000
FRANK H. McINTOSH
Consulting Radio Engineer
Washington, D.C.
10
5
1
.9
.8
.7
.6
.5
.4
.3
DB LOSS
R_o=30 ω
R_o=50 ω
R_o=100 ω
R_o=200 ω
R_o=250 ω
R_o=500 ω
A A
R_o B R_o
A A
"H" TYPE
ARTIFICIAL LINE
VALUE OF TRANSVERSE RESISTANCE "B"
FIGURE 5
RESISTANCE IN OHMS
2 3 4 5 6 7 8 9 10 50 100 500 1000

COUPLING AND TUNING CAPACITOR FOR VARIOUS ANTENNAS

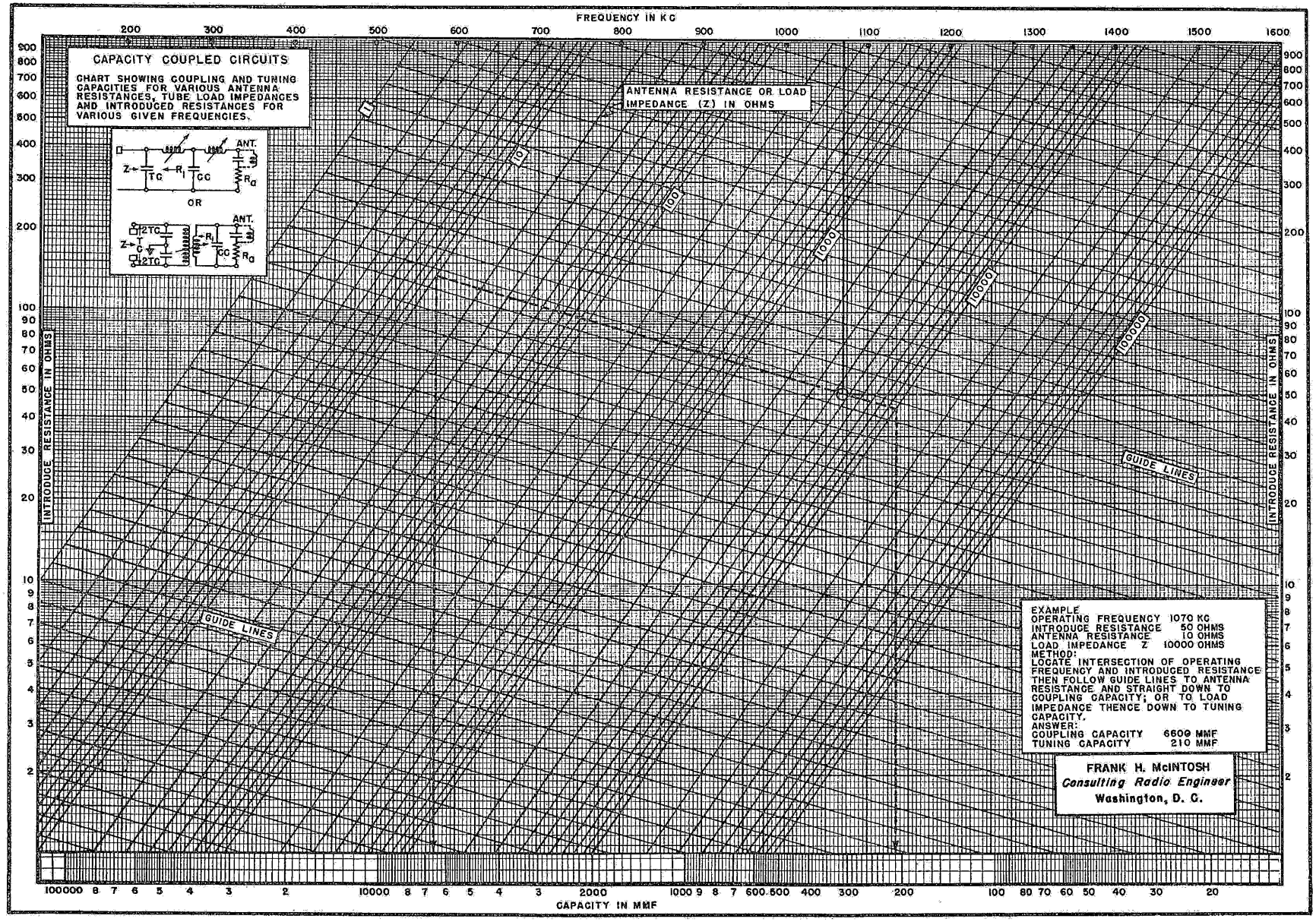
The attached chart has been found to be a useful tool for adjusting the transmitter output circuit using capacity coupling to the antenna or transmission line. The values of capacity shown are approximate but sufficiently close for practical purposes, since stray capacity of leads and components has 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.

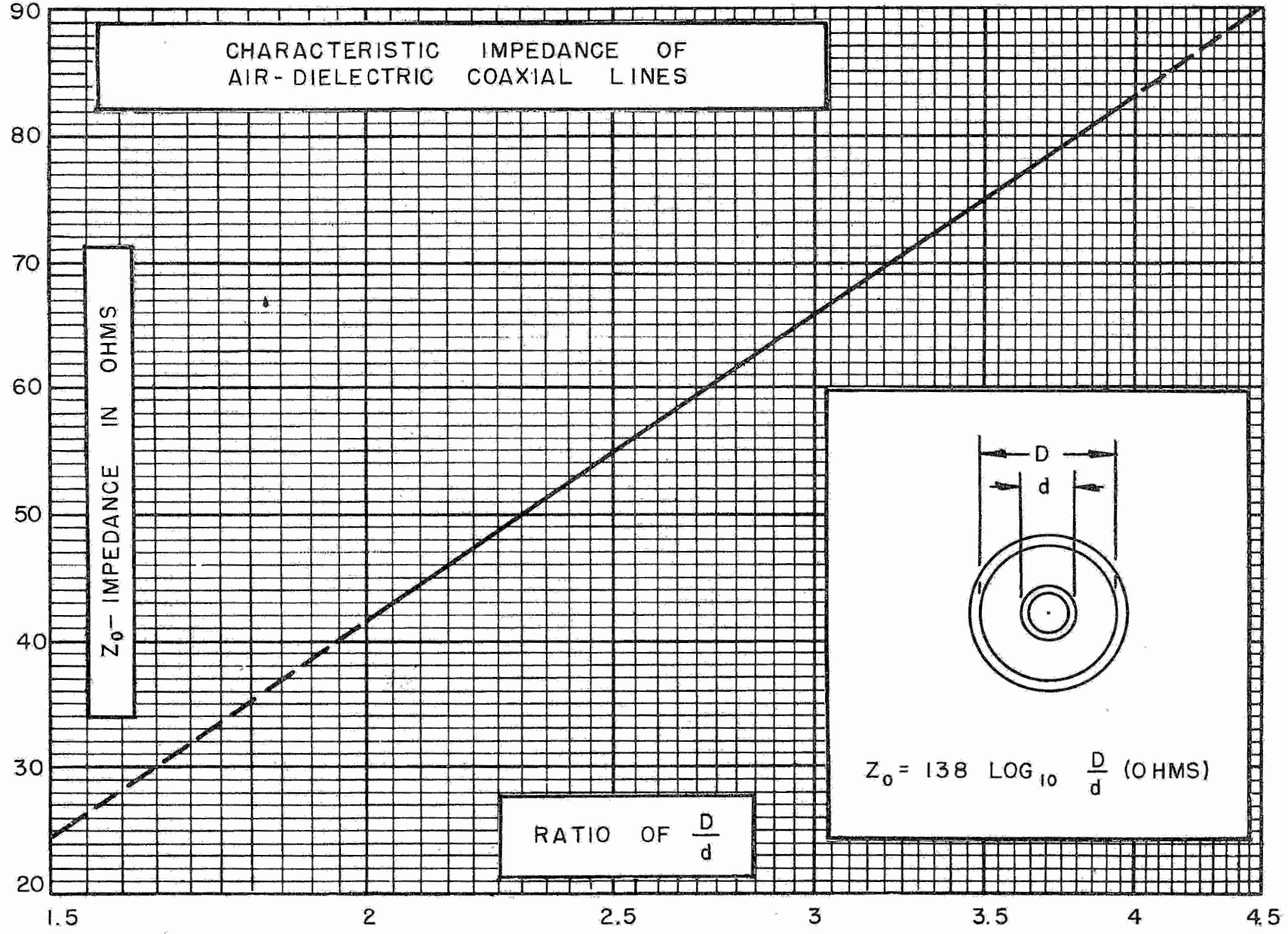
The introduced resistance is the net resistance component when section is adjusted resulting from the effect of the R_a (antenna or line resistance) and the coupling capacity C.C.

The Z is the load impedance for the tubes determined by dynamic characteristic for the particular tube and its operating voltages.

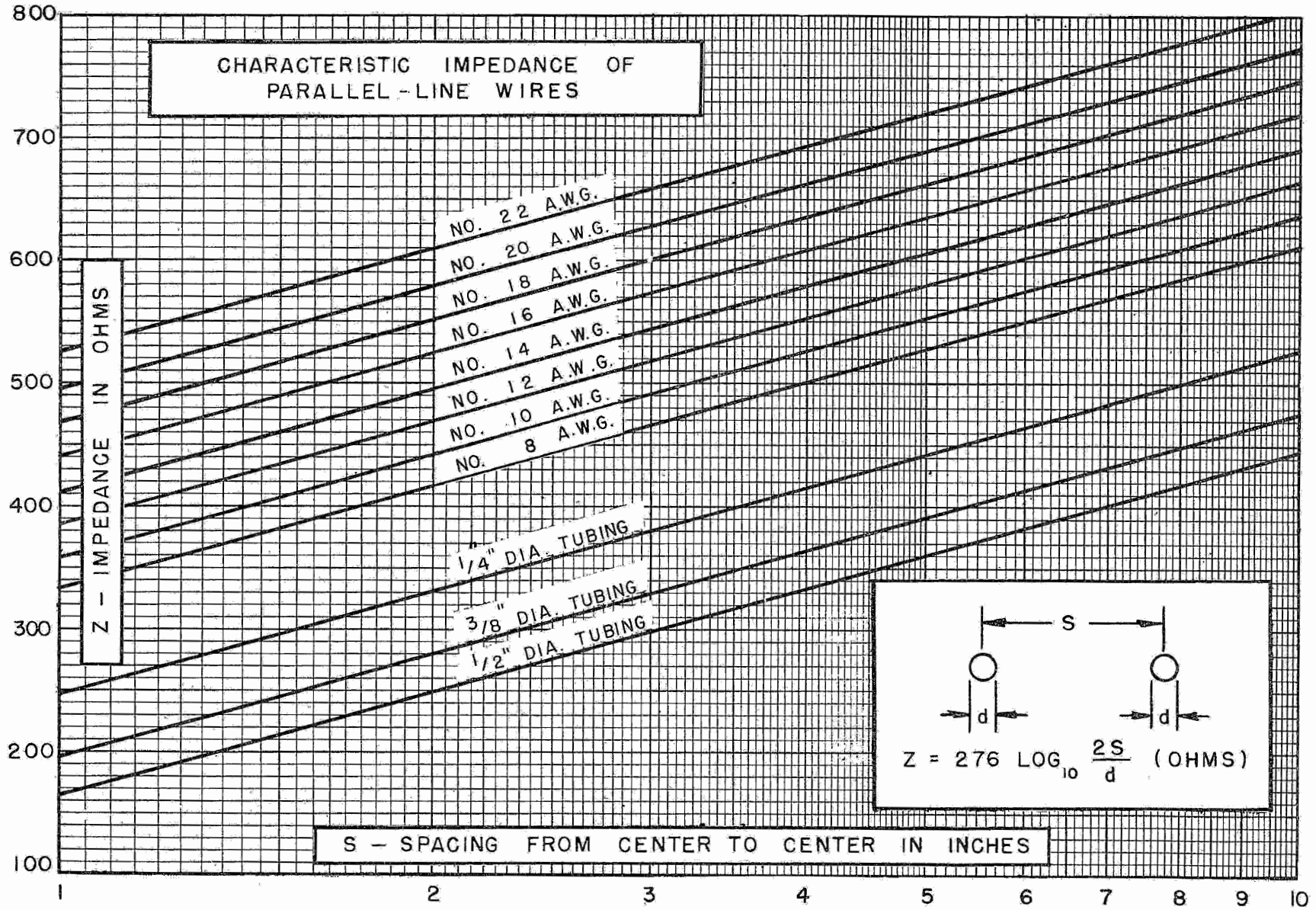
The value of introduced resistance used generally now lie between 50 and 100 ohms with the upper limit determined by the stray capacity. Formerly with high "C" ratios, introduced resistances were from 7 to 20 ohms which resulted generally in higher circuit losses.

6-7-02


FREQUENCY IN KC
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600
CAPACITY COUPLED CIRCUITS
CHART SHOWING COUPLING AND TUNING CAPACITIES FOR VARIOUS ANTENNA RESISTANCES, TUBE LOAD IMPEDANCES AND INTRODUCED RESISTANCES FOR VARIOUS GIVEN FREQUENCIES.
ANTENNA RESISTANCE OR LOAD IMPEDANCE (Z) IN OHMS
ANT.
Z
TC
CC
OR
2TC
INTRODUCE RESISTANCE IN OHMS
GUIDE LINES
10
50
150
1000
10000
100000
EXAMPLE
OPERATING FREQUENCY 1070 KC
INTRODUCE RESISTANCE 50 OHMS
ANTENNA RESISTANCE 10 OHMS
LOAD IMPEDANCE Z 10000 OHMS
METHOD:
LOCATE INTERSECTION OF OPERATING FREQUENCY AND INTRODUCED RESISTANCE THEN FOLLOW GUIDE LINES TO ANTENNA RESISTANCE AND STRAIGHT DOWN TO COUPLING CAPACITY; OR TO LOAD IMPEDANCE THENCE DOWN TO TUNING CAPACITY.
ANSWER:
COUPLING CAPACITY 6600 MMF
TUNING CAPACITY 210 MMF
FRANK H. McINTOSH
Consulting Radio Engineer
Washington, D. C.
100000 8 7 6 5 4 3 2 10000 8 7 6 5 4 3 2000 1000 9 8 7 600 500 400 300 200 100 80 70 60 50 40 30 20
CAPACITY IN MMF


CHARACTERISTIC IMPEDANCE OF
AIR-DIELECTRIC COAXIAL LINES
Z_0 – IMPEDANCE IN OHMS
90
80
70
60
50
40
30
20
1.5
2
2.5
3
3.5
4
4.5
RATIO OF $\frac{D}{d}$
D
d
$Z_0 = 138 \log_{10} \frac{D}{d}$ (OHMS)

10-8-9


CHARACTERISTIC IMPEDANCE OF
PARALLEL-LINE WIRES
Z - IMPEDANCE IN OHMS
800
700
600
500
400
300
200
100
NO. 22 A.W.G.
NO. 20 A.W.G.
NO. 18 A.W.G.
NO. 16 A.W.G.
NO. 14 A.W.G.
NO. 12 A.W.G.
NO. 10 A.W.G.
NO. 8 A.W.G.
1/4" DIA. TUBING
3/8" DIA. TUBING
1/2" DIA. TUBING
S
d
d
Z = 276 LOG10 2S/d (OHMS)
S - SPACING FROM CENTER TO CENTER IN INCHES
1
2
3
4
5
6
7
8
9
10

6-9-01

PHOTO-EFFECTIVENESS OF IMAGE ORTHICON WITH EQUAL WATTS OF TUNGSTEN FILAMENT AND FLUORESCENT LAMPS

Receptor	Lamp Type	Camera Lens Filters	Relative Conversion Efficiency*	Relative Signal Strength***	Color Balance Blue 3000-5300Å	Green 5300-5900Å	Red 5900-8000Å
Eye					.42	1.00	.43
Image Orthicon #5769	(4500 white (Fluorescent	none	8.5**	0.427	3.5	1.00	.43
		Wratten #7		0.166	.73	1.00	.77
	(3500 white (Fluorescent	none	6.9**	0.368	2.74	1.00	.86
		Wratten #7		0.151	.42	1.00	.99
	(Tungsten (3000° K	none	6	0.104	2.5	1.00	1.9
		Wratten #7		0.062	.7	1.00	1.8
		#7 + 9788		0.038	.8	1.00	.97
Image Orthicon #5820	(4500 white (Fluorescent	none	43**	1.8	1.7	1.00	.57
		Wratten #6		1.13	.95	1.00	.64
	(3500 white (Fluorescent	none	38**	1.6	1.11	1.00	.59
		Wratten #6		1.28	.56	1.00	.63
	(Tungsten (3000° K	none	40	.62	1.36	1.00	1.23
		Wratten #6		.46	.83	1.00	1.21

*Camera tube microamperes per lamp lumen on photo cathode.
**64T6 slimline lamps at 300 ma. operating current.
***Camera tube milliamperes per lamp watt.
Å = Angstrom Units

(Courtesy General Electric Company - Nela Park, Ohio)

DERIVATION OF PHOTO-EFFECTIVENESS CURVES

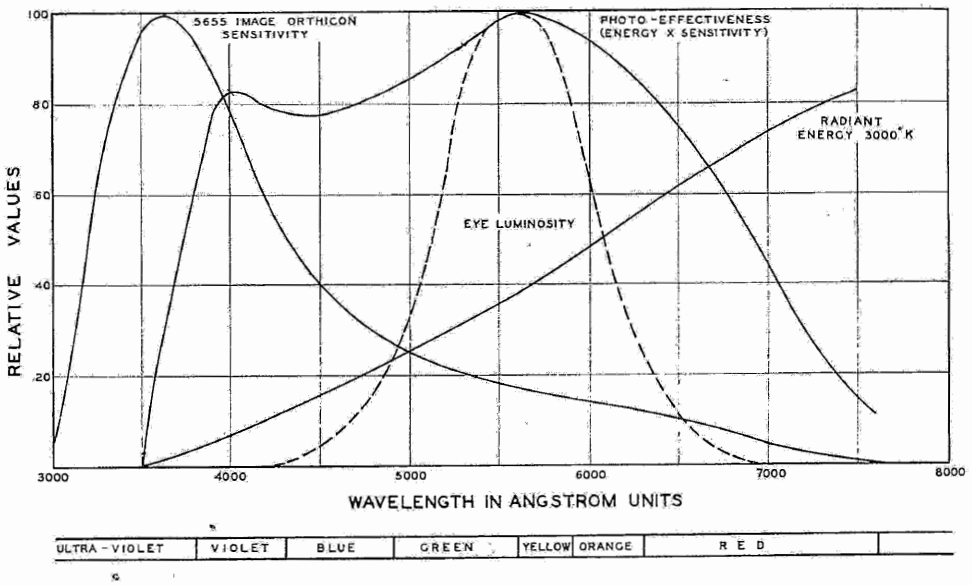


Fig. 1 - These derivation curves demonstrate the reason why blue and red objects frequently appear unnaturally bright in the receiver screen. The accompanying curves show how the proper use of filters corrects such distortion.

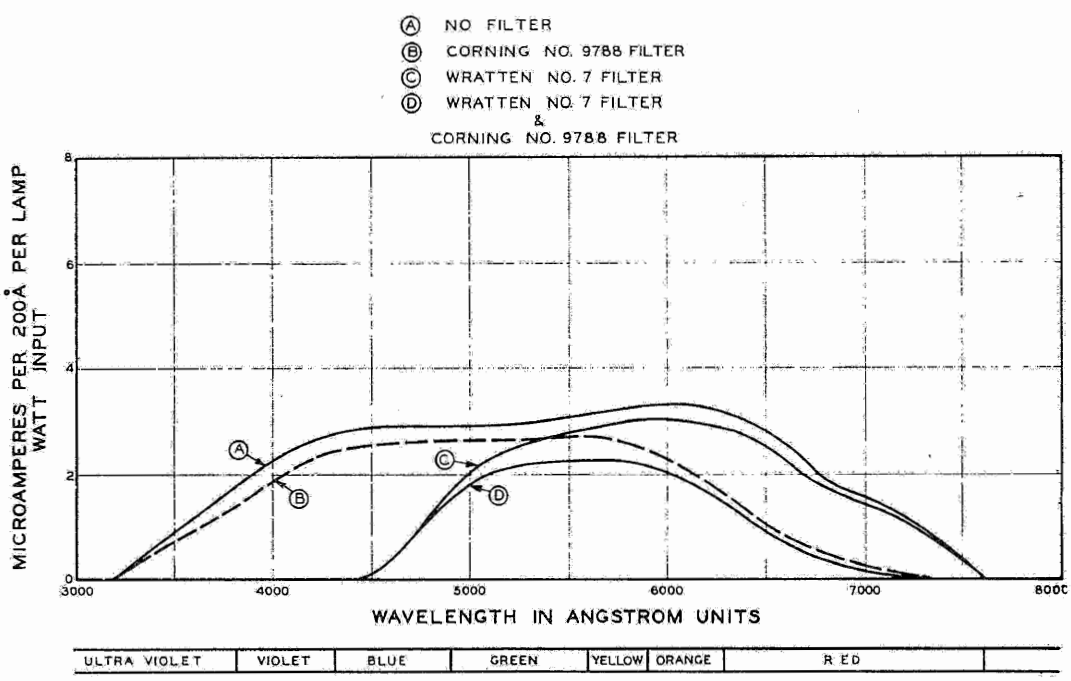


Fig. 2 - Unnatural brightness of blues and violets are reduced by camera lens filters such as the #7. Reds and oranges are improved by a filter similar to the 9788. The use of both filters results in the natural appearance of people and scenes.

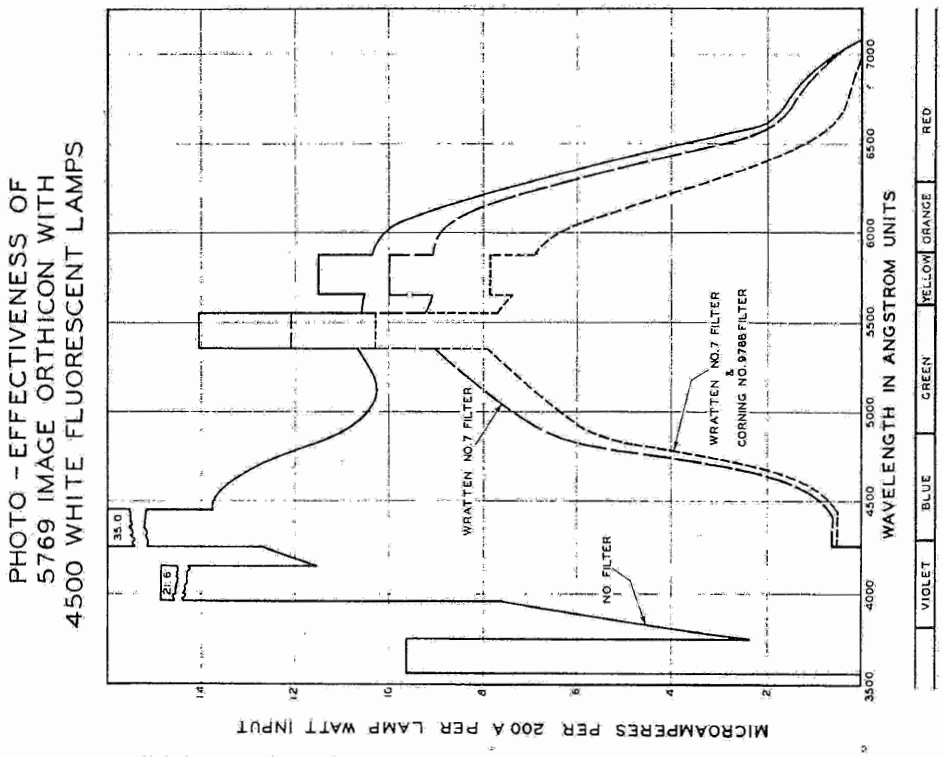


Fig. 3 - The appearance of blues and violets in scenes illuminated by 4500 white fluorescent lamps is greatly improved by the use of a #7 filter. The influence of the 9788 filter is also shown because it has so important an effect on the tungsten lighting usually used in combination with fluorescent lighting.

6-10-02

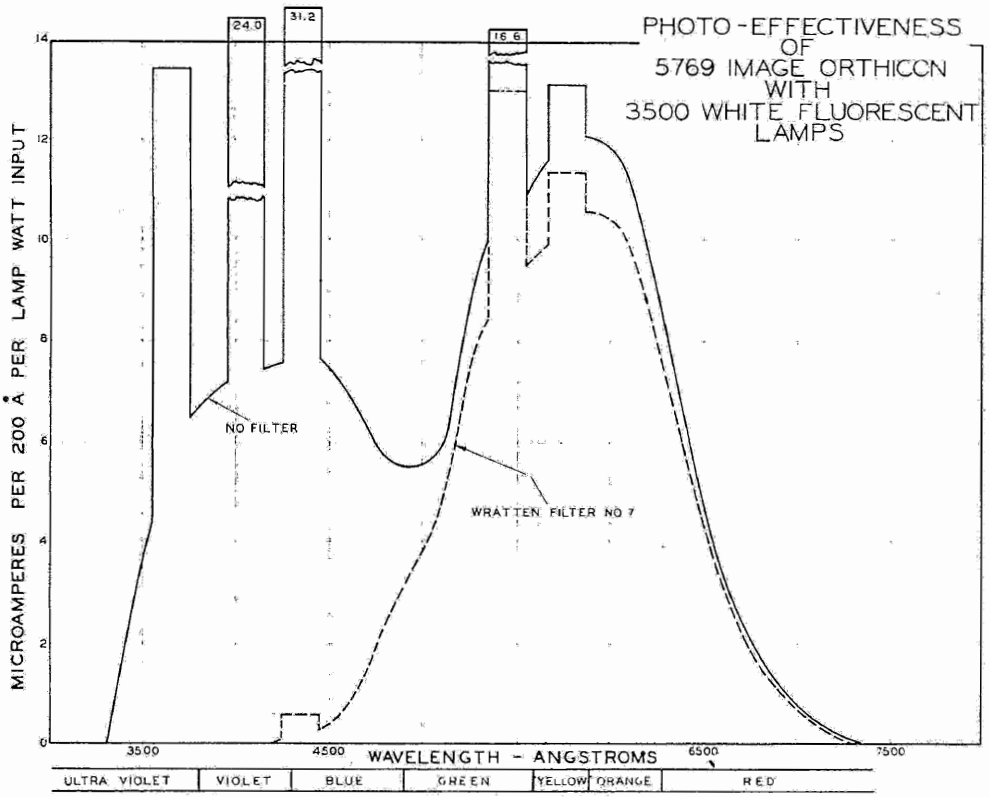


Fig. 4 - Excessive blue-violet response of the camera tube to 3500 white fluorescent lamps is effectively corrected by the #7 filter.

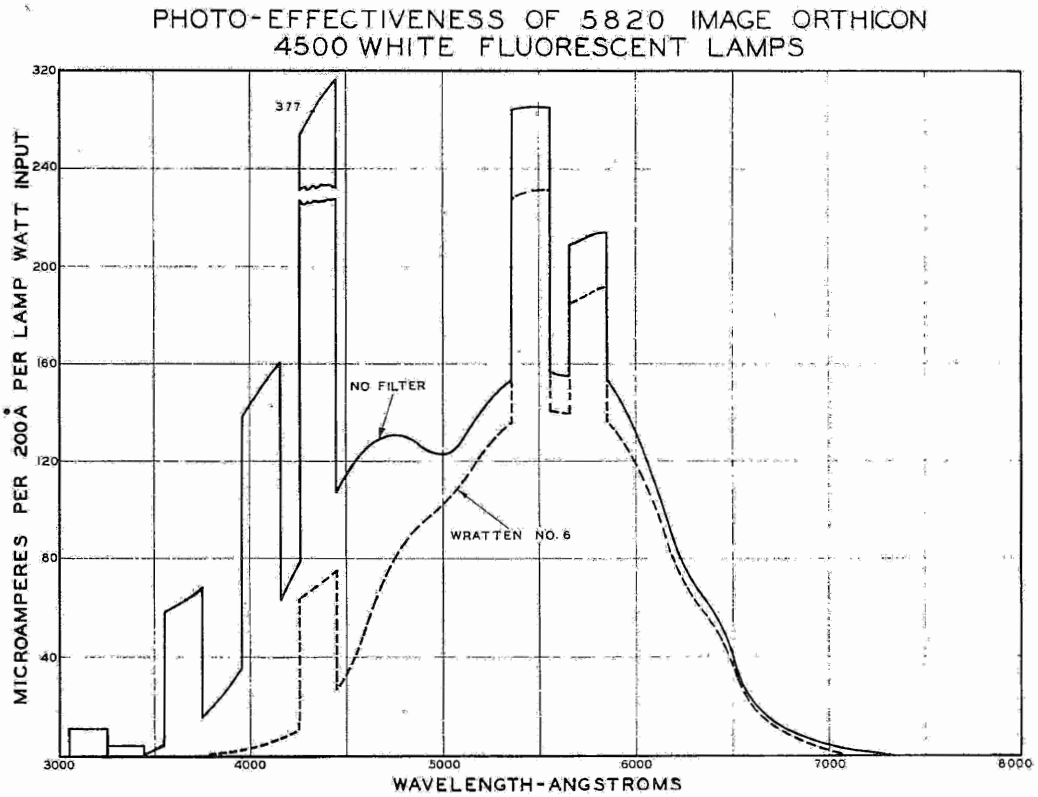


Fig. 5 - Reds and greens in scenes illuminated by 3500 white fluorescent and viewed by the 5820 image orthicon are naturally rendered. Blues which appear unnatural are improved by the use of a #6 filter.

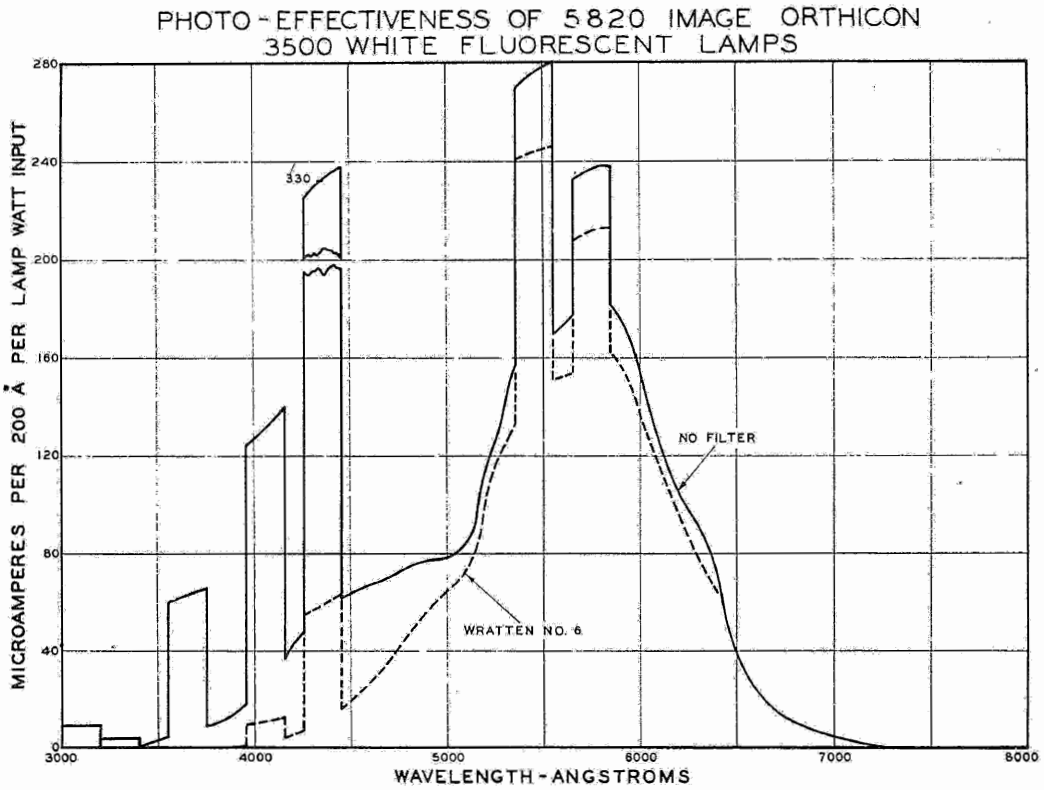


Fig. 6 - As with 4500 white fluorescent lamps, scenes illuminated with 3500 white lamps need the blue correction that the #6 filter provides.

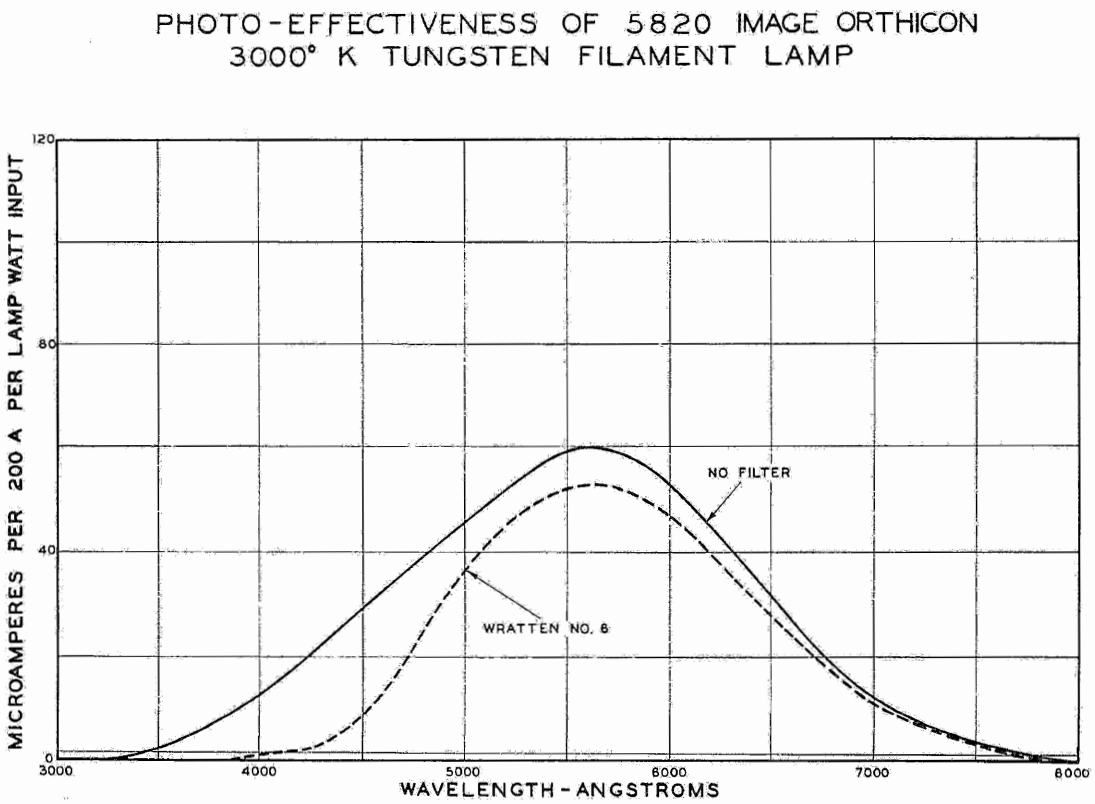
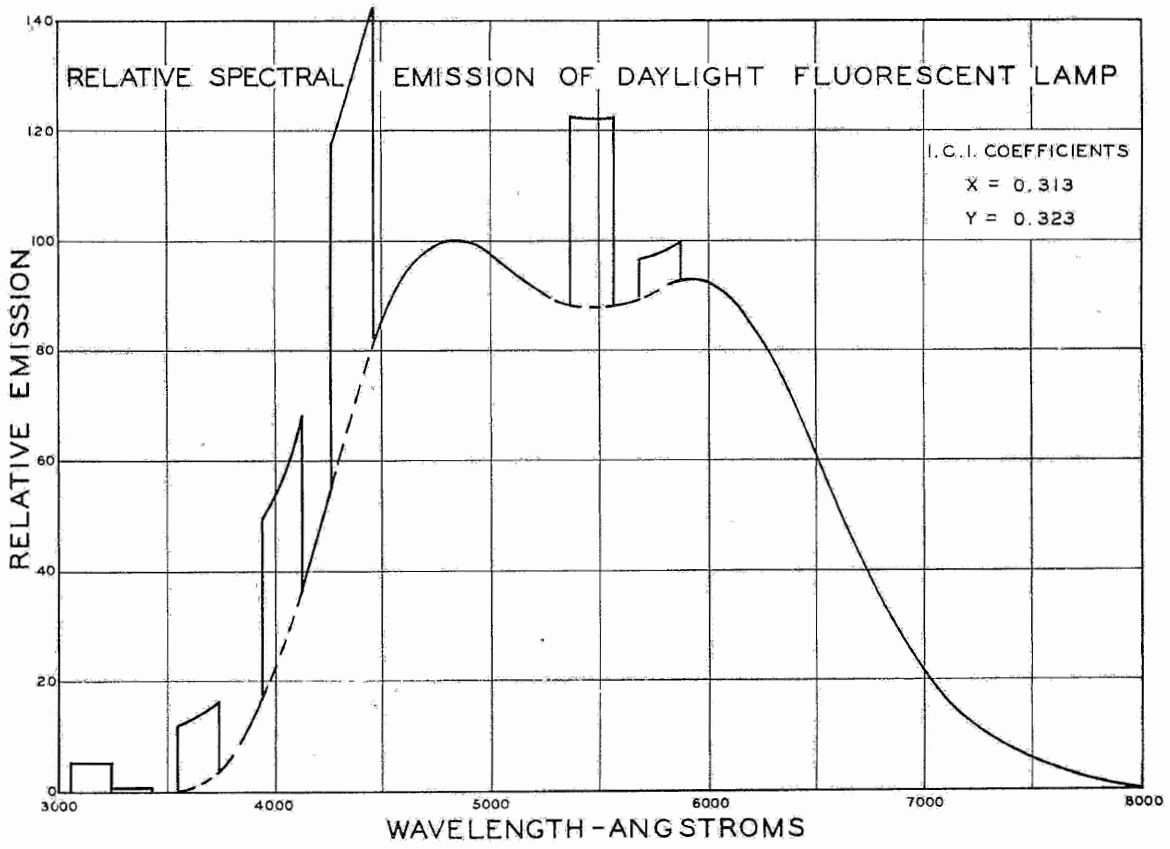
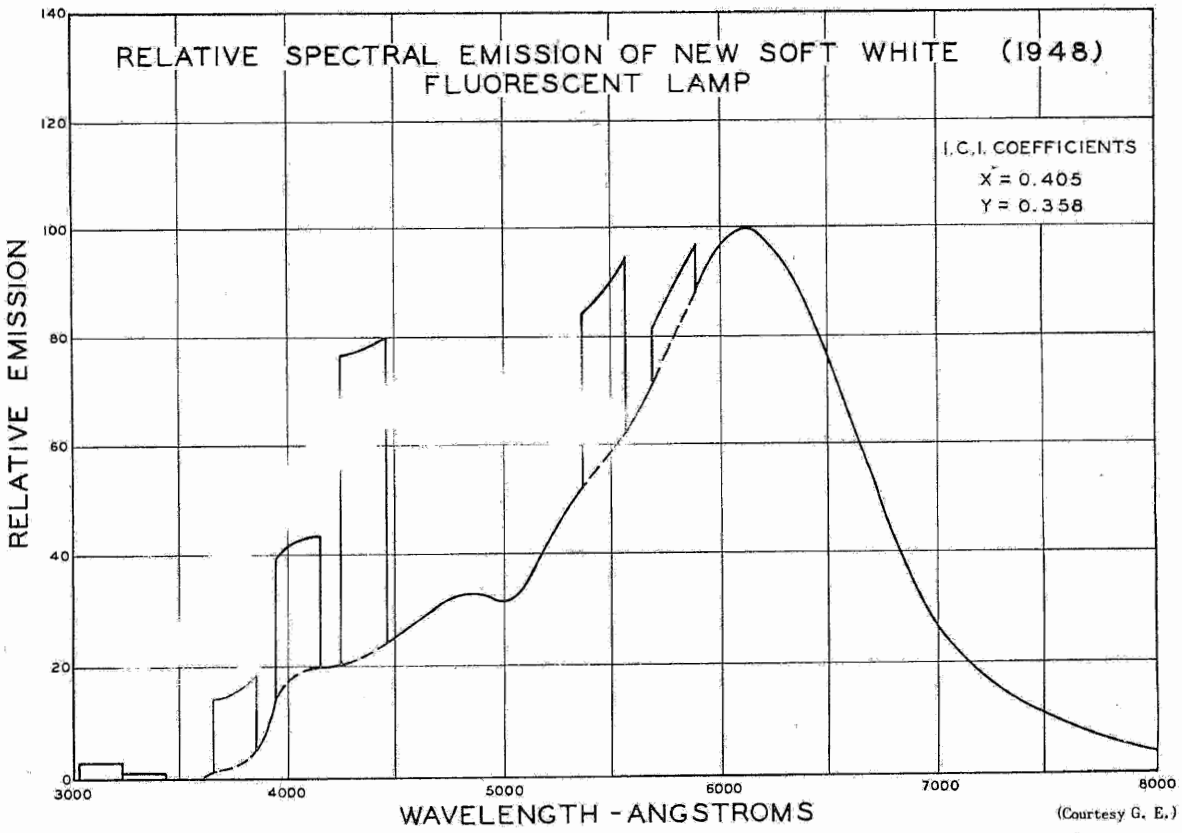


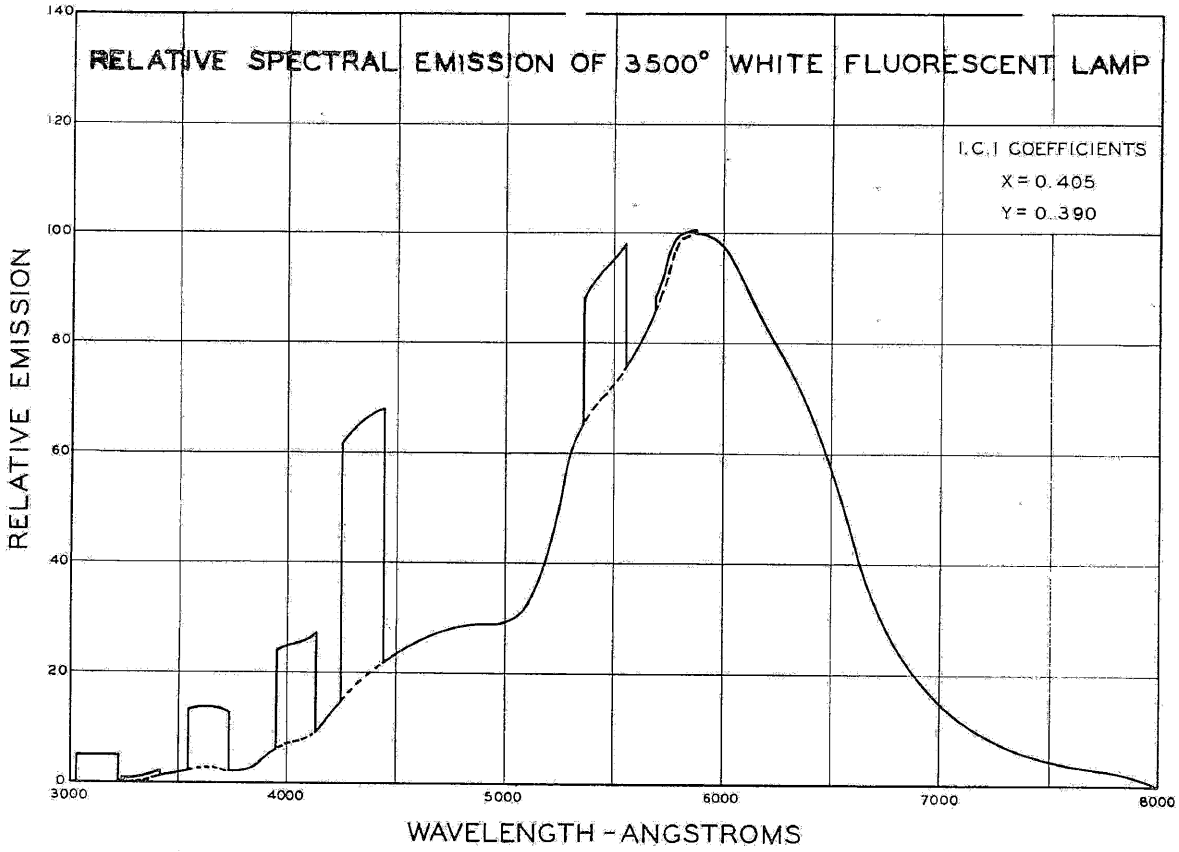
Fig. 7 - Colors in scenes illuminated by tungsten filament lamps appear very natural. Since filament and fluorescent sources may be used together, the effect of the #6 filter is shown.

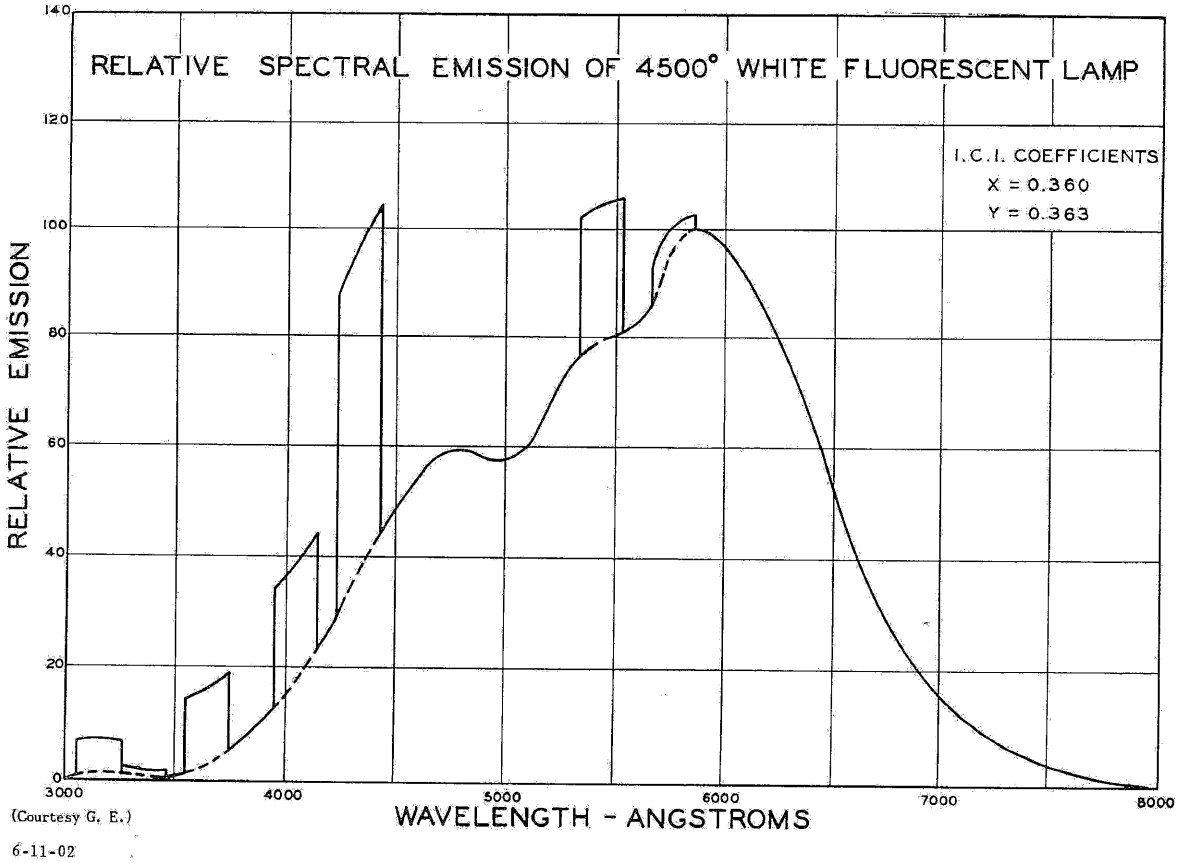




(Courtesy G. E.)

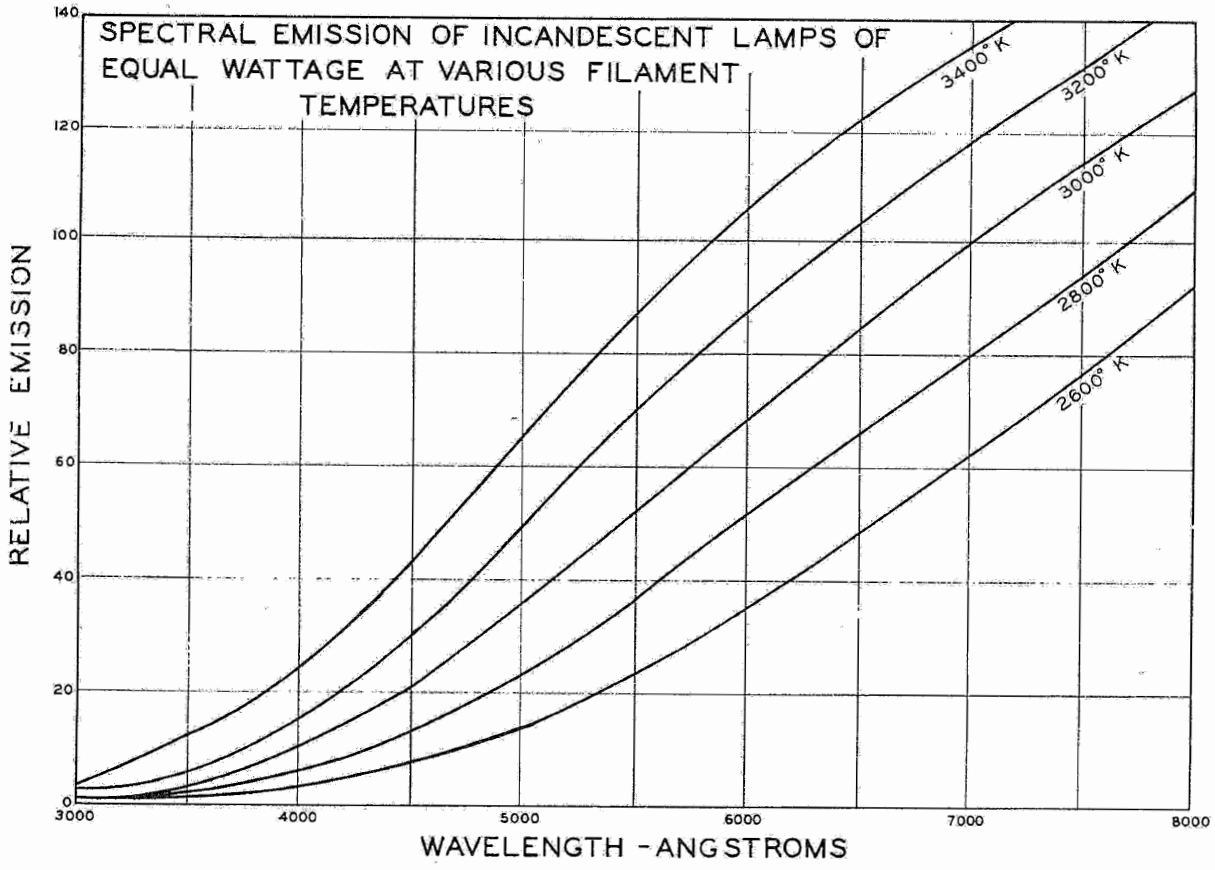
6-11-01

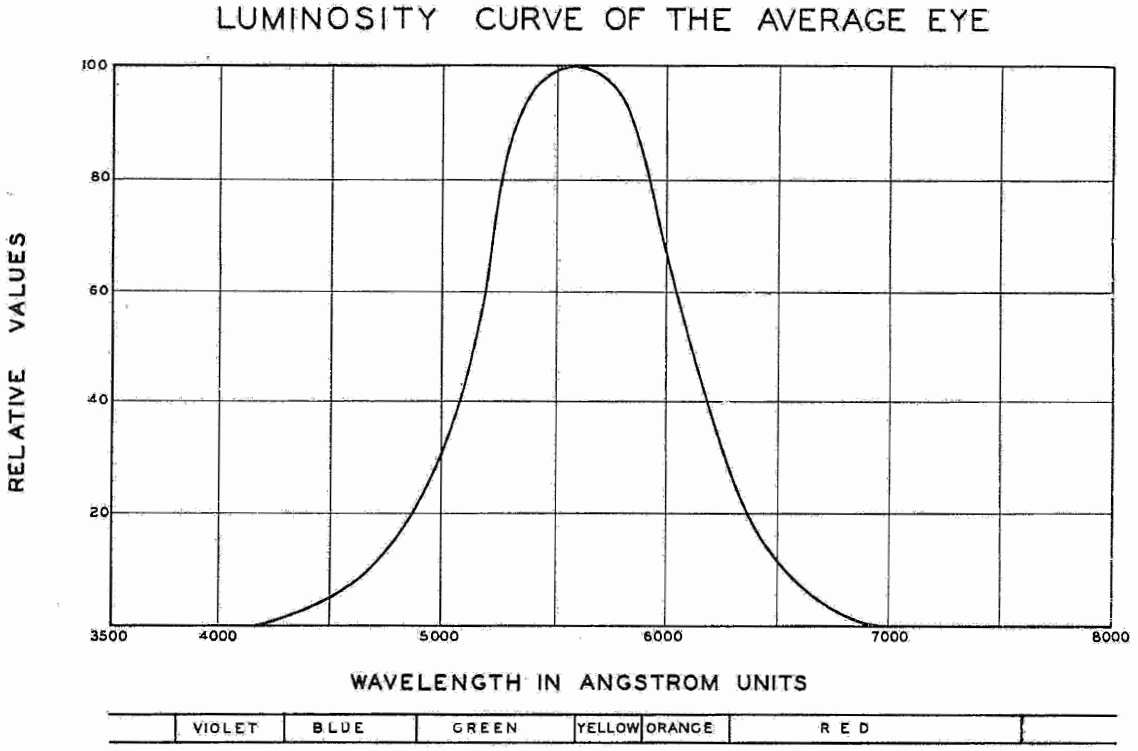




(Courtesy G. E.)

6-11-02



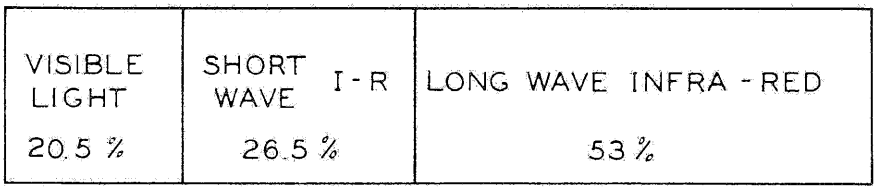


(Courtesy G. E.)

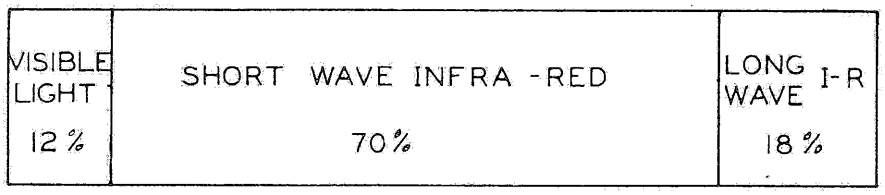
6-11-03

COMPARISON OF RADIANT ENERGY FROM TYPICAL FLUORESCENT AND TUNGSTEN SOURCES

FLUORESCENT LAMP

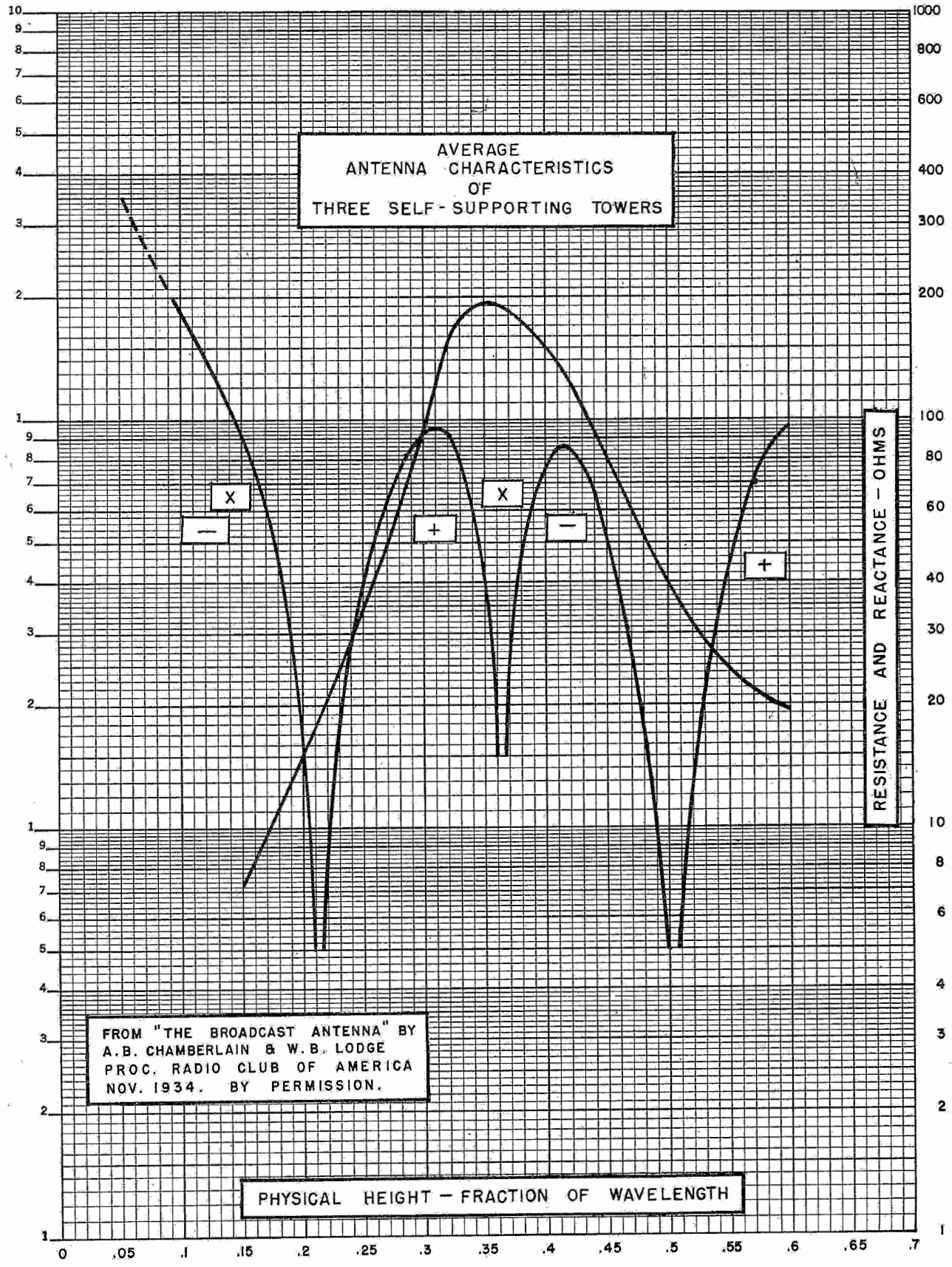


TUNGSTEN LAMP AT 3000°K

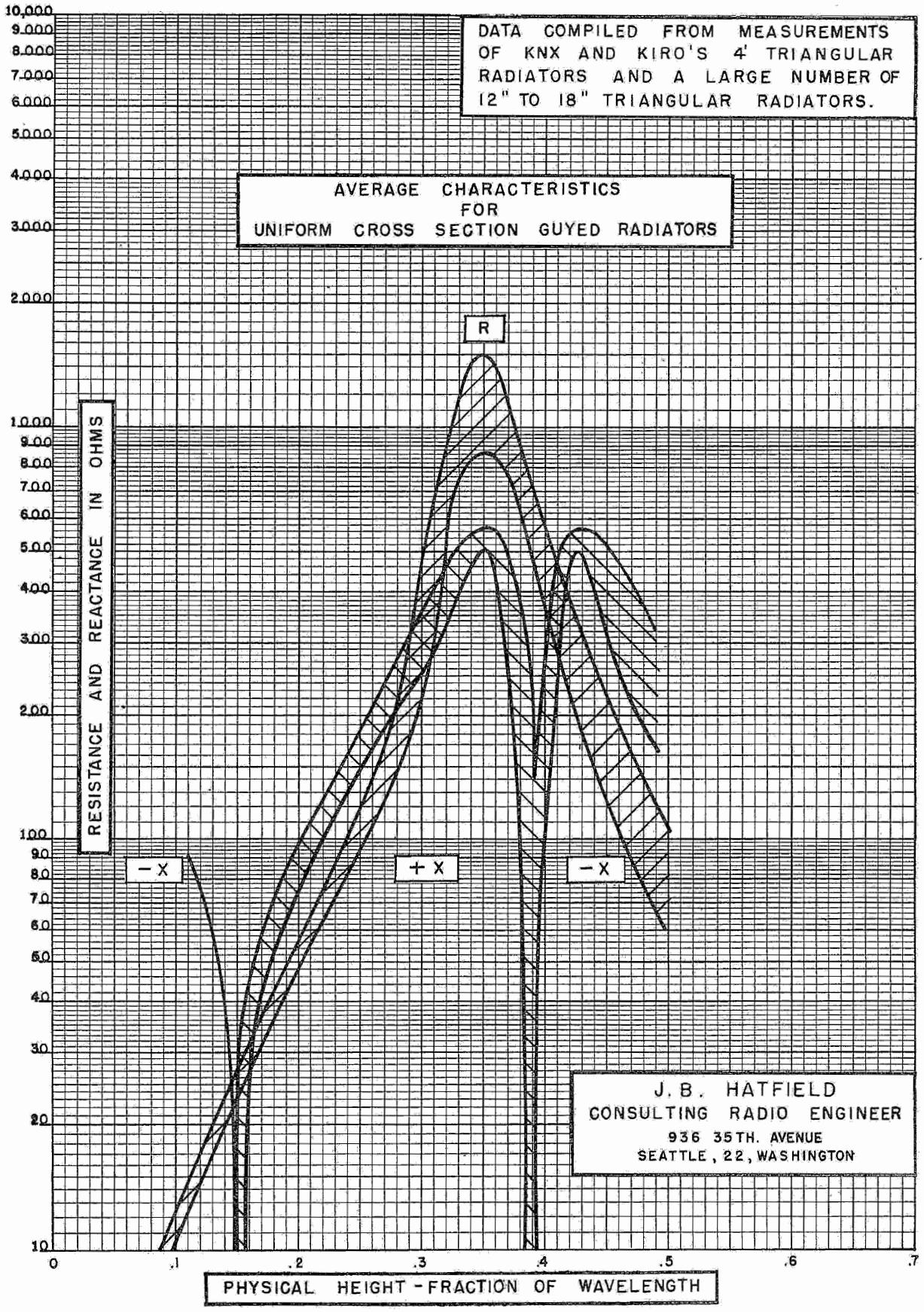


Courtesy G-E

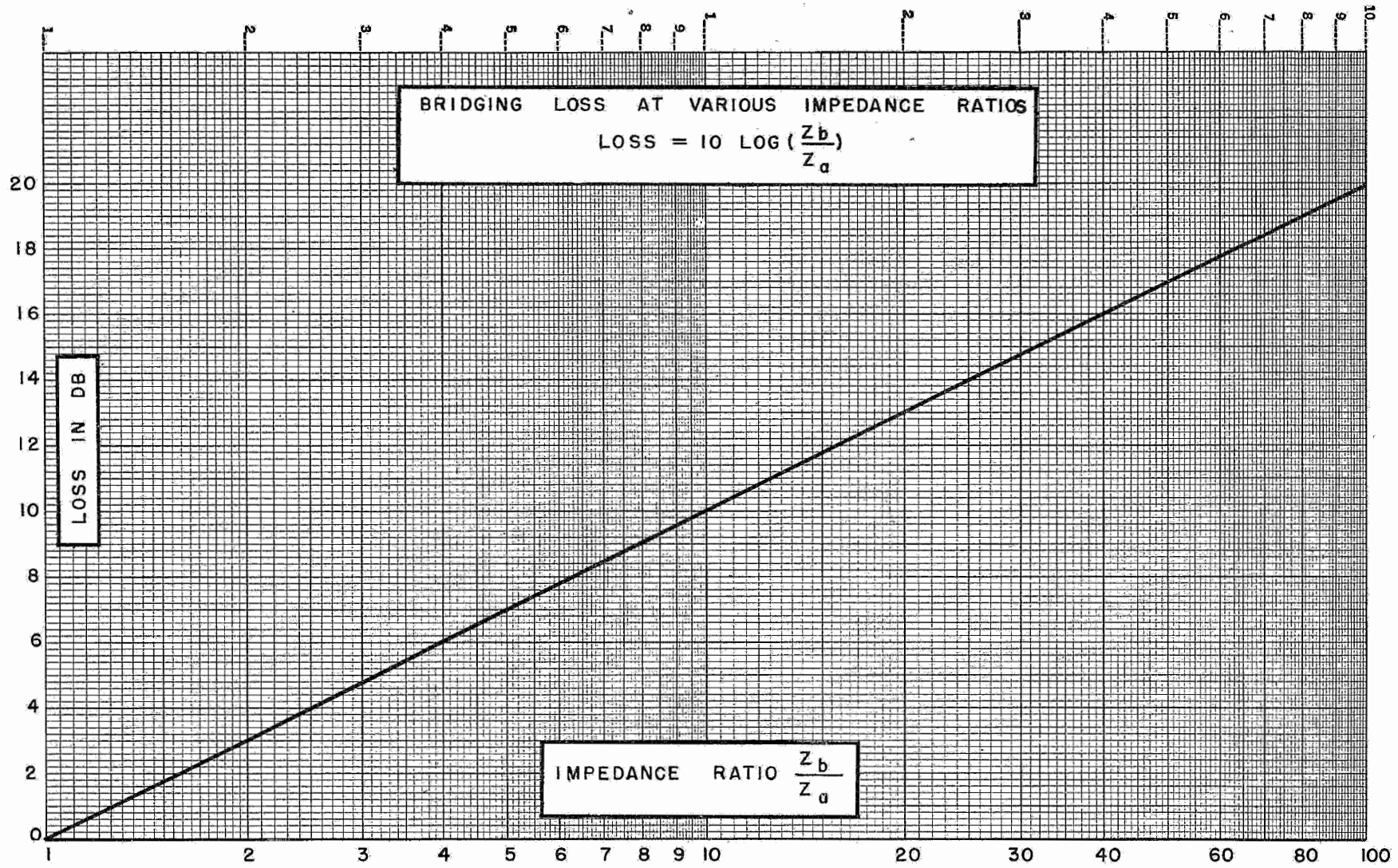
6-11-04


AVERAGE
ANTENNA CHARACTERISTICS
OF
THREE SELF-SUPPORTING TOWERS
X
—
+
X
—
+
RESISTANCE AND REACTANCE — OHMS
FROM "THE BROADCAST ANTENNA" BY
A.B. CHAMBERLAIN & W.B. LODGE
PROC. RADIO CLUB OF AMERICA
NOV. 1934. BY PERMISSION.
PHYSICAL HEIGHT — FRACTION OF WAVELENGTH
0
.05
.1
.15
.2
.25
.3
.35
.4
.45
.5
.55
.6
.65
.7
1000
800
600
400
300
200
100
80
60
40
30
20
10
8
6
4
3
2
1

6-12-01


DATA COMPILED FROM MEASUREMENTS OF KNX AND KIRO'S 4' TRIANGULAR RADIATORS AND A LARGE NUMBER OF 12" TO 18" TRIANGULAR RADIATORS.
AVERAGE CHARACTERISTICS FOR UNIFORM CROSS SECTION GUYED RADIATORS
RESISTANCE AND REACTANCE IN OHMS
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
R
−X
+X
−X
0
.1
.2
.3
.4
.5
.6
.7
PHYSICAL HEIGHT - FRACTION OF WAVELENGTH
J. B. HATFIELD
CONSULTING RADIO ENGINEER
936 35TH. AVENUE
SEATTLE, 22, WASHINGTON

6-13-01


BRIDGING LOSS AT VARIOUS IMPEDANCE RATIOS
LOSS = 10 LOG (Zb / Za)
LOSS IN DB
IMPEDANCE RATIO Zb / Za
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
5
6
7
8
9
10
20
30
40
60
80
100

6-14-01

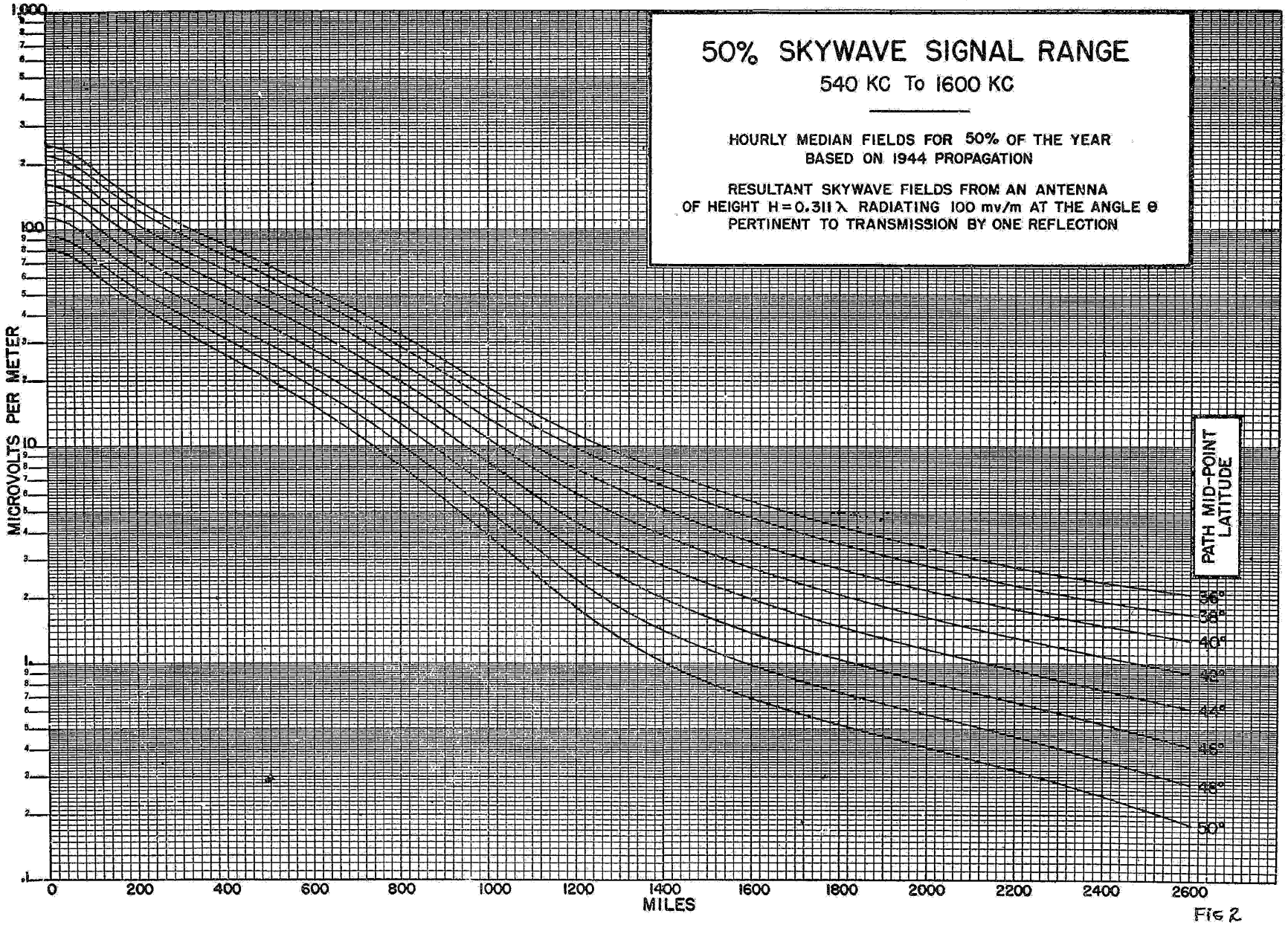

50% SKYWAVE SIGNAL RANGE
540 KC To 1600 KC
HOURLY MEDIAN FIELDS FOR 50% OF THE YEAR
BASED ON 1944 PROPAGATION
RESULTANT SKYWAVE FIELDS FROM AN ANTENNA
OF HEIGHT H = 0.311 λ RADIATING 100 mv/m AT THE ANGLE θ
PERTINENT TO TRANSMISSION BY ONE REFLECTION
MICROVOLTS PER METER
MILES
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
PATH MID-POINT LATITUDE
36°
38°
40°
42°
44°
46°
48°
50°

Fig 2

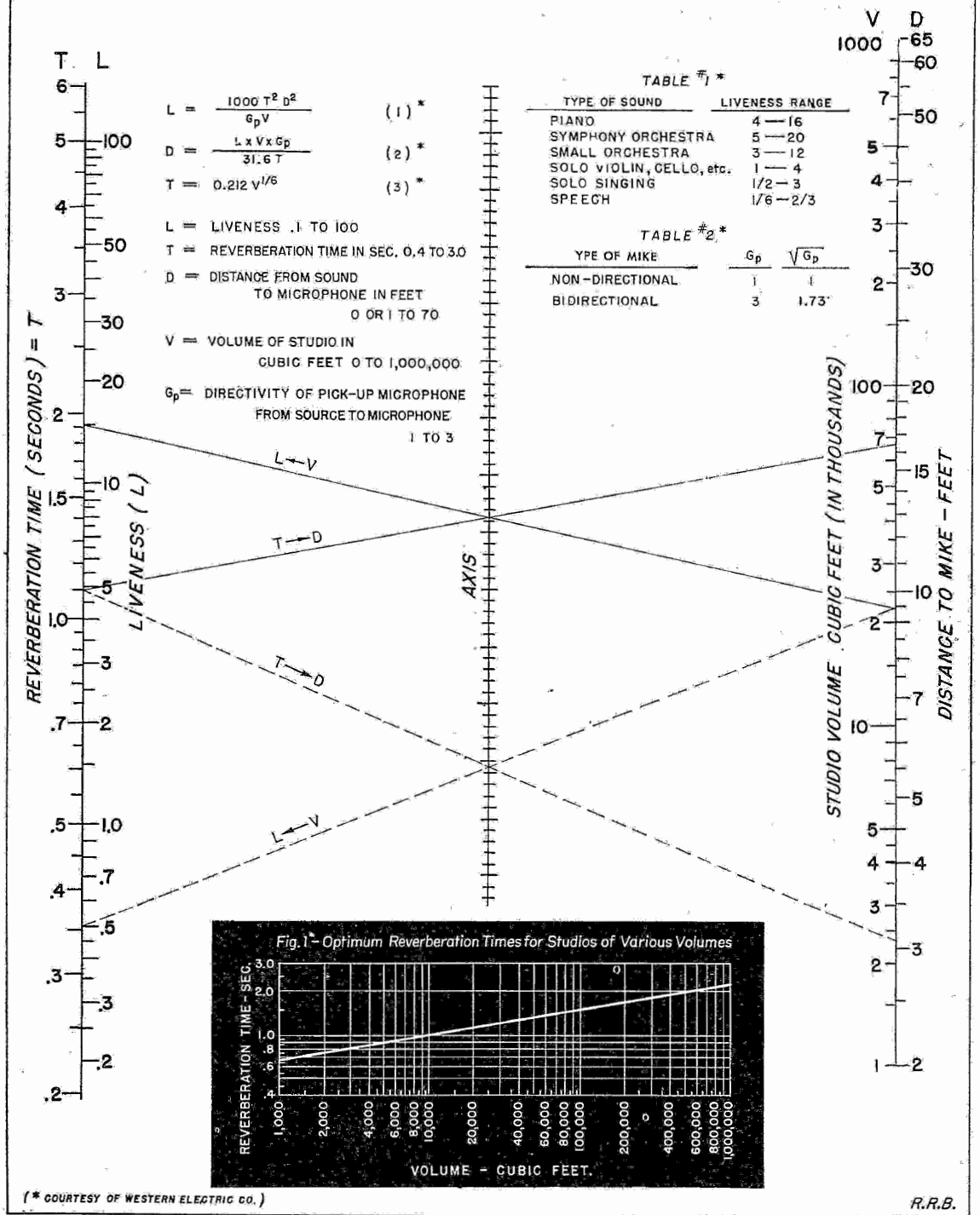
6-15-01

CONVERSION TABLE FOR UNITS OF LENGTH

MULTIPLY NUMBER OF → / BY ↘ / 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

(FROM THE IES LIGHTING HANDBOOK -- SEE NAB RECOMMENDED LIBRARY.)

NOMOGRAPH for MICROPHONE DISTANCES in LIVENESS BROADCASTING



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 22000 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 22000 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.

(Reprinted from TELE-TECH)

6-17-01

CLEANING RELAY CONTACTS

(From the Engineering Notices of The National Broadcasting Company)

There are three general methods of cleaning relay contacts. The choice between these methods depends upon the character and amount of deposit encountered. The interval between cleanings depends upon the same elements plus atmospheric conditions, and is best determined by experience.

In general, relay equipment is installed in spaces that are relatively clean and free from dust, and cleaning of contacts is rarely necessary. Such dust as may lodge on contact surfaces will be removed during the regularly scheduled routining. However, in the event that observation indicates that cleaning is necessary, the following methods are recommended. They have been developed in cooperation with the Automatic Electric Company which manufactures most of the relays used by NBC.

Method No. 1

Used when ordinary dust is present.

(a) Remove loose dust from relay contacts with a brush suitable for the purpose as, for example, a clean, dry, tooth brush. This is all that is necessary in the majority of cases.

Method No. 2

Used only when the contacts have become covered with a gummy or greasy substance which is not readily removable by dry brushing.

(a) Dip clean tooth brush in chemically pure carbon tetrachloride, shake off excess, and brush contacts vigorously.

(b) Allow spring assembly to dry for approximately five minutes.

(c) Brush contacts with a clean dry tooth brush which has not been immersed in carbon tetrachloride.

Method No. 3

Used only when contacts have become pitted in normal use.

(a) Apply standard contact cleaning tool (Automatic Electric Company's type H-42962-1) as required to dress up the contact. This tool consists of a piece of sandblasted clock spring steel.

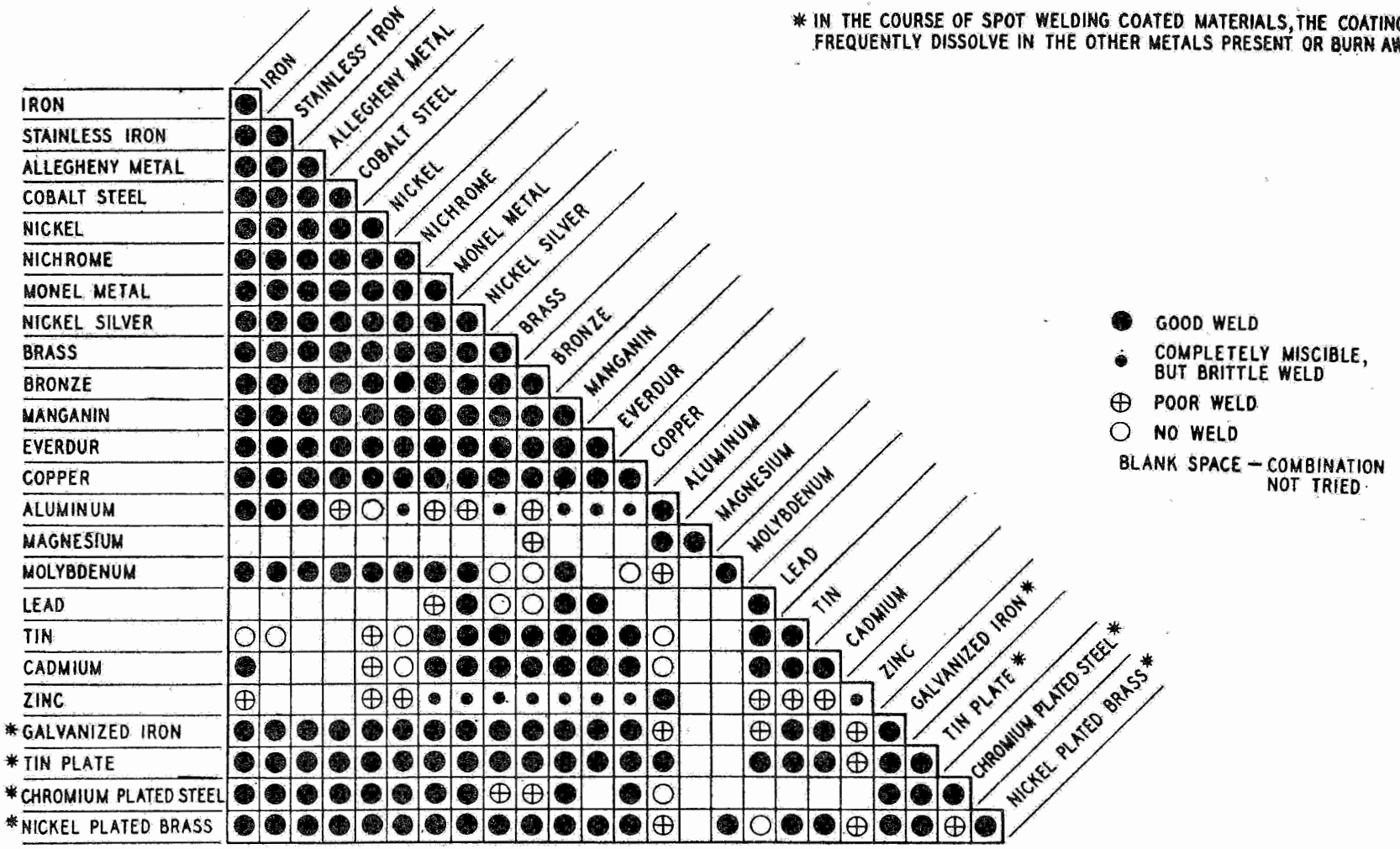
(b) Brush contacts with a clean dry tooth brush.

(c) Burnish contacts with a piece of smooth clock spring steel such as Automatic Electric's H-47386-1.

Notes:

1. It is not advisable to use a file when cleaning contacts, as the rough contact surface left by the file will readily collect dirt.

2. Strips of wood, paper, or fibre should not be used for cleaning contacts, as they generally leave minute particles of foreign material on the surface of the contact.



The welding characteristics of some 250 combinations of metals

(Reprinted from the Bell Laboratories Record)

6-19-01

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

6-20-01

A. COMPUTATION OF VERTICAL RADIATION CHARACTERISTICS

Two charts useful in the plotting of vertical radiation characteristics of a thin vertical wire appear in Section 2, Article 1, of this Handbook. However, for those who wish to compute the relative vertical radiation characteristics, the table below is suggested as a convenient means, using the following equation and table:

$$f_{(\theta)} = \frac{\cos (h \sin \theta) - \cos h}{\cos \theta \ (1-\cos h)}$$

* * * * * * * * * *

h = _____ cos h = _____ sin h = _____ 1 - cos h = _____

(h = height in electrical degrees)

1. θ	2. $\sin\theta$	3. $h \sin\theta$	4. $\cos(h \sin\theta)$	5. $\cos(h \sin\theta) - \cos h$	6. $\cos\theta$	7. $\frac{\cos\theta}{(1-\cos h)}$	8. $f\theta = \frac{5}{7}$
0°	(Relative value is always 1.0) (Horizon)						1.000
5°	.08716				.99619		
10°	.17365				.98481		
15°	.25882				.96593		
20°	.34202				.93969		
25°	.42262				.90631		
30°	.50000				.86603		
35°	.57358				.81915		
40°	.64279				.76604		
45°	.70711				.70711		
50°	.76604				.64279		
55°	.81915				.57358		
60°	.86603				.50000		
65°	.90631				.42262		
70°	.93969				.34202		
75°	.96593				.25882		
80°	.98481				.17365		
85°	.99619				.08716		
90°	(Relative value is always 0)						0.000

B. 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, $\text{Feet} = \frac{\text{Degrees}}{360°} \times \frac{300}{f(mc)} \times 3.281 = \text{Degrees} \times \frac{2.734}{f(mc)}$, the following ratio may be set up on the slide rule using C and D scales: $\frac{2.734}{f(mc)} = \frac{\text{Feet}}{\text{Degrees}}$. 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 may 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". The cost is 90¢ and the table may be ordered from the Hydrographic Office, Washington, D. C., or the Superintendent of Documents, Government Printing Office, Washington, D. C. Remittance must be made with the order; no postage is required.

The calculation sheet may 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 on page 6-22-02, bearings and distances may 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. Further, 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 H.O. No. 211 Tables - Ageton)

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 & 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 B3.

CALCULATIONS

(Follow rules closely for K, D, C, and B3)
-also (K∿La).

Lo' _____
Lo _____
t= _____
La' _____
K= _____
La _____
(K∿La)= _____

ADD--	SUBTRACT--	ADD--	SUBTRACT--
A1 _____	A3 _____	B2 _____	A2 _____
B1+ _____	B2- _____	B3+ _____	A5- _____
A2= _____	A4= _____	B4= _____	A6= _____

D= ____ ° ____ ' ____ "
D: ____ ° x 60 = ____ + ____ '=Dn ____ Miles
Dn ____ Miles x 1.152 = Ds ____ Miles

C*= ____ ° ____ ' ____ "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 A1.
4. Enter table with La' to find B1 and A3.
5. Add A1 and B1 for A2.
6. Enter table with A2 to find B2.
7. Subtract B2 from A3 for A4.
8. Enter table with A4 for arc K.
9. Determine arc for (K∿La).
10. Enter table with (K∿La) for B3.
11. Add B2 and B3 for B4.
12. Enter table with B4 to find A5 and arc D.
13. Subtract A5 from A2 for A6.
14. Enter table with A6 for bearing C.
15. Follow steps shown to find Ds & Dn.

6-22-02