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FCC STANDARDS OF GOOD ENGINEERING PRACTICE CONCERNING FM BROADCAST STATIONS

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 therefore.

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.

September 20, 1945.

1. **Definitions**

A. *FM BROADCAST STATION*--The term "FM broadcast station" means a station employing frequency modulation in the FM broadcast band and licensed primarily for the transmission of radiotelephone emissions intended to be received by the general public.

B. *FREQUENCY MODULATION*--The term "frequency modulation" means a system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous *amplitude* of the modulating signal (amplitude of modulating signal to be measured after pre-emphasis, if used) and the instantaneous radio frequency is independent of the *frequency* of the modulating signal.

C. *FM BROADCAST BAND*--The term "FM broadcast band" means the band of frequencies extending from 88 to 108 megacycles, which includes those assigned to noncommercial educational broadcasting.

D. *CENTER FREQUENCY*--The term "center frequency" means:

(1) The average frequency of the emitted wave when modulated by a sinusoidal signal.

(2) The frequency of the emitted wave without modulation.

E. *FREQUENCY SWING*--The term "frequency swing" means the instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

F. *FM BROADCAST CHANNEL*--The term "FM broadcast channel" means a band of frequencies 200 kilocycles wide and is designated by its center frequency. Channels for FM broadcast stations begin at 88.1 megacycles and continue in successive steps of 200 kilocycles to and including 107.9 megacycles.

G. *ANTENNA FIELD GAIN*--The term "antenna field gain" of an FM broadcast antenna means the ratio of the effective free space field intensity produced at one mile in the horizontal plane expressed in millivolts per meter for 1 kilowatt antenna input power to 137.6 mv/m.

H. *FREE SPACE FIELD INTENSITY*--The term "free space field intensity" means the field intensity that would exist at a point in the absence of waves reflected from the earth or other reflecting objects.

I. *MULTIPLEX TRANSMISSION*--The term "multiplex transmission" means the simultaneous transmission of two or more signals within a single channel. Multiple transmission as applied to FM broadcast stations means the transmission of

facsimile or other signals in addition to the regular broadcast signals.

J. *PERCENTAGE MODULATION*--The term "percentage modulation" as applied to frequency modulation means the ratio of the actual frequency swing to the frequency swing defined as 100 percent modulation, expressed in percentage. For FM broadcast stations, a frequency swing of ± 75 kilocycles is defined as 100 percent modulation.

K. *EFFECTIVE RADIATED POWER*--The term "effective radiated power" means the product of the antenna power (transmitter output power less transmission line loss) times (1) the antenna power gain, or (2) the antenna field gain squared.

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*--The term "antenna height above average terrain" means the average of the antenna heights above the terrain from two to ten 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.)

2. Engineering Standards of Allocation

A. Sections 3.202 to 3.205 inclusive of the Rules and Regulations describe the basis for allocation of FM Broadcast Stations, including the division of the United States into Areas I and II. Where reference is made in the Rules to antenna heights of Community Stations, Section 2 E (1) of these Standards should be consulted; for other classes of FM broadcast Stations, Section 2 E (2) should be consulted.

As noted in Section 3.204 (b) of the Rules, the Commission will designate service areas for Metropolitan Stations in Area II. In addition to the showing required by this Rule a special showing must be included in the application concerning the area proposed to be served, in the event that (1) such area is smaller than the service area designated by the Commission, or (2) such area is smaller than that which would appear to be the appropriate service area, in cases where it has not been designated by the Commission. The proposed are to be served must be substantially greater than that which could be served by a Community station.

B. In determining the predicted and measured field intensity contours of FM broadcast stations the following shall govern:

(1) Community stations will normally not be required to determine their contours.

(2) Metropolitan Stations shall determine the extent of their 1000 uv/m and 50 uv/m contours.

(3) Rural stations shall determine their 1000 uv/m, 50 uv/m and 20 uv/m contours.*

The above contours shall be determined 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 the 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	*1000 uv/m*
Rural areas	*50 uv/m*

A median field intensity of 3000 to 5000 uv/m should be placed over the principal city to be served, and a median field intensity of 1000 uv/m should be placed over the business district of cities of 10,000 or greater within the metropolitan district served. The field intensity to be provided over the main studio is specified by Sections 3.203, 3.204, and 3.205 of the Rules.

* The 20 uv/m contour is desired in this case for use by the Commission in determining the usability of a signal of such low intensity.

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:

(1) Community stations

A map, topographic where obtainable, shall be submitted for the area within 15 miles of the proposed antenna site. On this map shall be indicated the antenna location and a circle of 10 miles radius with the antenna location as center. Representative points shall be picked on this circle 15 degrees apart and the elevation of these points determined. The average elevation of these points will be considered the average elevation of the circle. The difference between the elevation of the center of the radiating system and the average elevation of this circle shall be considered the height of the antenna over the terrain 10 miles from the transmitter. In cases where the applicant believes this method to be grossly in error due to peculiarities of the terrain, this method shall be used for determining the antenna height but a showing may be made, if desired, determining the height by other means and describing the method used. Calculations of the service contours of Community stations are not required.

(2) Metropolitan and Rural stations

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 ten miles therefrom. Normally the radials are drawn for each 45^{0} 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 intensities (Figure 1).

The average elevation of the eight mile distance between two and ten 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% of the distance) in sectors and averaging these values.

To determine the distance to a par-

ticular 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 one 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 side departs widely from the average elevation of the two to ten 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 1,000 uv/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 precedure, see Section 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% of the time.

TABLE II

Channel Separation	Ratio of Desired to Undesired Signals
Same channel	*10:1*
Adjacent channel (200 kc removed)	*2:1*

Objectionable interference is not considered to exist when the channel separation is 400 kc or greater. Accordingly, FM broadcast stations in the same city or same area may be assigned channels 400 kc apart. 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 than 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 one percent of the time shall be employed. The one percent values for one 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.*

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.

* Figure 2 expected to be available approximately November 1, 1945.

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 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 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 must be non-directional and of the same polarization as the transmitting antenna.

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 thirty 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 2 E 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 of 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 Section 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 the antenna at a point of high elevation is necessary to reduce to a minimum the shadow effect on propagation due to hills and buildings which may reduce materially the intensity of the station's signals in a particular direction. The transmitting site should be selected consistent with the purpose of the station, i.e., whether it is intended to serve a small city, a metropolitan area or a large region. Inasmuch as service may be provided by signals of 1000 uv/m or greater field intensities in metropolitan areas, and inasmuch as signals as low as 20 uv/m may provide service in rural areas, considerable latitude in the geographical location of the transmitter is permitted; however, the necessity for a high elevation for the antenna may render this problem difficult. In general, the transmitting antenna of a station should be located at the most central point at the highest elevation available. In providing the best degree of service to an area, it is usually preferable to use a high antenna rather than a lower antenna with increased transmitter power. The location should be so chosen that line-of-sight can be obtained from the antenna over the principal city or cities to be served; in no event should there be a major obstruction in this path.

B. The transmitting location should be selected so that the 1000 uv/m contour encompasses the urban population within the area to be served and the 50 uv/m or the interference free contour coincides generally with the limits of the area to be served. It is recog-

nized 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 non-directional antenna may be employed.

C. In cases of questionable antenna locations it is desirable to conduct propagation tests to indicate the field intensity expected in the principal city or cities to be served and in other areas, particularly where severe shadow problems may be expected. In considering applications proposing the use of such locations, the Commission may require site tests to be made. Such tests should be made in accordance with the measurement procedure previously described, and full data thereon must be supplied to the Commission. Test transmitters should employ an antenna having a height as close as possible to the proposed antenna height, using a balloon or other support if necessary and feasible. Information concerning the authorization of site tests may be obtained from the Commission upon request.

D. Present information is not sufficiently complete to establish "blanket areas" of FM broadcast stations, which are defined as those areas adjacent to the transmitters in which the reception of other stations is subject to interference due to the strong signal from the stations. Where it is found necessary to locate the transmitter in a residential area where blanketing problems may appear to be excessive, the application must 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. As a means of minimizing interference problems, it is expected that stations adjacent in location will generally be assigned frequencies that are generally adjacent. Insofar as is feasible, frequency assignments for stations at separated locations will also be separated.

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 CAA for its recommendations. Antenna painting and/or lighting may be required at the time of construction or at a later date.

7. **Antenna systems**

A. It shall be standard to employ horizontal polarization. If the use of vertical polarization appears desirable in special circumstances, its use may be authorized upon a showing of need.

B. The antenna must be constructed so that it is as clear as possible of surrounding buildings or objects that would cause shadow problems.

C. Applications proposing the use of directional antenna systems must be accompanied by the following:

(1) Complete description of the proposed antenna system.

(2) Orientation of array with respect to true north; time phasing of fields from elements (degrees leading or lagging); space phasing of elements (in feet and in degrees); ratio of fields from elements.

(3) Calculated field intensity pattern (on letter-size polar coordinate paper) giving the free space field intensity in millivolts per meter at one mile in the horizontal plane, together with the formula used, constants employed, sample calculations and tabulation of calculation data.

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

D. Applications proposing the use of FM broadcast antennas in the immediate vicinity (i.e., 200 feet or less) of

(1) other FM broadcast antennas, or (2) television broadcast antennas for frequencies adjacent to the FM broadcast band, must include a showing as to the expected effect, if any, of such proximate operation.

In cases where it is proposed to use a tower of a standard broadcast station as a supporting structure for an FM broadcast antenna, an application for construction permit (or modification of construction permit) for such station must be filed for consideration with the FM application. Applications may be required for other classes of stations when their towers are to be used in connection with FM broadcast stations.

When an FM broadcast antenna is mounted on a non-directional standard broadcast antenna, new resistance measurements must be made of the standard broadcast antenna after installation and testing of the FM broadcast antenna. During the installation and until the new resistance determination is approved, the standard broadcast station licensee should apply for authority (informal application) to operate by the indirect method of power determination. The FM broadcast license application will not be considered until the application form concerning resistance measurements is filed for the standard broadcast station.

When an FM broadcast antenna is mounted on an element of a standard broadcast directional antenna, a full engineering study concerning the effect of the FM broadcast antenna on the directional pattern must be filed with the application concerning the standard broadcast station. Depending upon the individual case, the Commission may require readjustment and certain field intensity measurements of the standard broadcast station following the completion of the FM broadcast antenna system.

When the proposed FM broadcast antenna is to be mounted on a tower in the vicinity of a standard broadcast directional array and it appears that the operation of the directional antenna system may be affected, an engineering study must be filed with the FM broadcast application concerning the effect of the FM broadcast antenna on the directional pattern. Readjustment and field intensity measurements of the standard broadcast station may be required following construction of the FM broadcast antenna.

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.

In the event a common tower is used by two or more licensees for antenna and/or antenna supporting purposes, the licensee who is owner of the tower shall assume full responsibility for the installation and maintenance of any painting or lighting requirements. In the event of shared ownership, one licensee shall assume such responsibility and advise the Commission accordingly.

E. It is recommended that an emergency FM broadcast antenna be installed, or, alternately, an auxiliary transmission line or lines if feasible in the particular circumstances. Data thereon should be supplied with the application for construction permit; if proposed after station construction, an informal application should be submitted to the Commission.

F. 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 installation. 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.

8. Transmitters and Associated Equipment

A. Electrical Performance Standards - The general design of the FM broadcast transmitting system (from input terminals of microphone pre-amplifier, through audio facilities at the studio, through lines or other circuits between studio and transmitter, through audio facilities at the transmitter, and through the transmitter, but excluding equalizers for the correction of deficiencies in microphone response) shall be in accordance with the following principles and specifications:

(1) Standard power ratings and operating power range of FM broadcast transmitters shall be in accordance with the following table:

Standard Power Rating	Operating Power Range
250 watts	*250 watts or less*
1 kw	*250 watts - 1 kw*
3 kw	*1 - 3 kw*
10 kw	*3 - 10 kw*
25 kw	*10 - 25 kw*
50 kw	*10 - 50 kw*
100 kw	*50 - 100 kw*

Composite transmitters may be authorized with a power rating different from the above table, provided full data is supplied in the application concerning the basis employed in establishing the rating and the need therefor. The operating range of such transmitters shall be from one-third of the power rating to the power rating.

The transmitter shall operate satisfactorily in the operating power range with a frequency swing of ± 75 kilocycles, which is defined as 100% modulation.

(2) The transmitting system shall be capable of transmitting a band of frequencies from 50 to 15,000 cycles. Pre-emphasis shall be employed in accordance with the impedance-frequency characteristic of a series inductance-resistance network having a time constant of 75 microseconds. (See Figure 3). The deviation of the system response from the standard pre-emphasis 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 7500 cycles, and three db below the upper limit; from 100 to 50 cycles the lower limit shall fall from the three db limit at a uniform rate of one db per octave (four db at 50 cycles); from 7500 to 15,000 cycles the lower limit shall fall from the three db limit at a uniform rate of two db per octave (five 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%, 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
50 to 100 cycles	*3.5%*
100 to 7500 cycles	*2.5%*
7500 to 15000 cycles	*3.0%*

Measurements 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.*

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

* See Section 13 for measurement frequencies and other information.

± 75 kilocycles. The noise-measuring equipment shall be provided with standard 75-microsecond de-emphasis; 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% amplitude modulation. The noise-measuring equipment shall be provided with standard 75-microsecond de-emphasis; 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 Section 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 pre-emphasis in the transmitting system.

Construction. In general, the transmitter shall be constructed either on racks and panels or in totally enclosed frames protected as required by article 810 1/ 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 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.

1/ 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 perferred.
"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."

(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 overvoltage 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 coaxical, 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 ot 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 retained at the transmitter location.

F. Operation. In addition to specific requirements of the rules governing FM broadcast stations, the following operating requirements are specified:

(1) The maximum percentage of modulation shall be maintained in accordance with Section 3.268. However, precautions shall be taken so as not to substantially alter the dynamic characteristics of musical programs.

(2) Spurious emissions, including radio frequency harmonics, shall be maintained at as low a level as practicable at all times in accordance with good engineering practice.

(3) If a limiting or compression amplifier is employed, care should be maintained in its use due to pre-emphasis in the transmitting system.

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

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

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

No specific requirements are made with regards to the microphones to be employed. However, microphone performance (including compensating networks, if employed) shall be compatible with the required performance of the transmitting system.

No specific requirements are made relative to the design and acoustical treatment of studios. However, the design of studios, particularly the main studio, shall be compatible with the required performance characteristics of FM broadcast stations.

9. Indicating Instruments

An FM broadcast transmitter shall be equipped with suitable indicating instruments of acceptable accuracy to measure (1) the direct plate voltage and current of the last radio stage, and (2) the main transmission line radio frequency current or voltage.

The following requirements and specifications shall apply to indicating instruments used by FM broadcast stations:

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

(1) Length of scale shall be not less than 2 3/10 inches.

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

(3) Scale shall have at least 40 divisions.

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

B. Instruments indicating transmission line current or voltage shall meet the following specifications:

(1) Instruments having linear scales shall meet the requirements of A (1), (2), (3), and (4) above.

(2) Instruments having logarithmic or square law scales

(a) Shall meet requirements A (1) and (2) for linear scale instruments.

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

(c) No scale division above one-third full scale reading (in amperes) shall be greater than one-thirtieth of the full scale reading.

C. Radio frequency instruments having expanded scales.

(1) Shall meet requirements A (1), (2), and (4) for linear scale instruments.

(2) No scale division above one-fifth full scale reading (in amperes) shall be greater than one-fiftieth of the full scale reading.,

(3) The meter face shall be marked with the words 'Expanded Scale' of the abbreviation thereof (E. S.).

D. No instruments indicating the plate current or plate voltage of the last radio stage or the transmission line current or voltage 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 may be made by letter or telegram stating the necessity therefor and the period involved.

E. No required instrument, the accuracy of which is questionable, shall be employed. Repairs and recalibration of instruments shall be made by the manufacturer, or by an authorized instrument repair service of the manufacturer, or by some other properly qualified and equipped instrument repair service. In any event the repaired instrument must be supplied with a certificate of calibration.

F. Recording instruments may be employed in addition to the indicating instruments to record the transmission line current or voltage and the direct plate current and/or direct plate voltage of the last radio stage, provided that they do not affect the operation of the circuits or accuracy of the indicating instruments. If the records are to be used in any proceeding before the Commission as representative of operation, the accuracy must be the equivalent of the indicating instruments and the calibration shall be checked at such intervals as to insure the retention of the accuracy.

G. 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.

10. Auxiliary Transmitters

Auxiliary transmitters may not exceed the power rating or operating power range of the main transmitter, but need not conform to the performance characteristics specified by Section 8 A (2) to 8 A (5) inclusive. The subsequent portions of Section 8 apply to auxiliary transmitters.

11. Operating Power: Determination and Maintenance

A. The operating power of FM broadcast stations 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:

Operating power = Ep x Ip x 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. The operating power shall be maintained as near as practicable to the authorized operating power, and shall not exceed the limits of 5 percent above and 10 percent below the authorized power except in emergencies. 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 Inspector in Charge* of the district in which the station is located shall be notified in writing immediately thereafter and also upon the resumption of normal operating power.

12. Frequency and Modulation Monitors at Auxiliary Transmitters

Sections 3.252 and 3.253 require that each FM 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 aux-

* See Appendix 3 of Part I of the Rules and Regulations for addresses of Field Offices.

iliary 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 2000 cycles from the assigned frequency, even though exempted by the above from installating 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**

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.**

(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 overall 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

*Tentative Standard

**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.

shall be plotted below a standard 75 microsecond pre-emphasis curve (see Figure 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 de-emphasis 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.

(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 stand- and power rating of the transmitter to be produced at least six 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;

* Tentative Standard

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.

3. General Specifications.

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

(1) The unit shall have an accuracy of at least ± 1000 cycles under ordinary conditions (temperature, humidity, power supply variations and other conditions which may affect its accuracy) encountered in FM broadcast stations throughout the United States, for any channel within the FM broadcast band.

(2) The range of the indicating device shall be at least from 2000 cycles below to 2000 cycles above the assigned center frequency.

(3) The scale of the indicating device shall be so calibrated as to be accurately read within at least 100 cycles.

(4) Means shall be provided for adjustment of the monitor indication to agree with an external standard.

(5) The monitor shall be capable of continuous operation and its circuit shall be such as to permit continuous monitoring of the transmitter center frequency.

(6) Operation of the monitor shall have no deleterious effect on the operation of the transmitter or the signal emitted therefrom.

C. Tests to be made for approval of FM broadcast frequency monitors.

The manufacturer of a monitor shall submit data on the following at the time of requesting approval:

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

(2) Constancy of oscillator frequency when subjected to vibration tests which would correspond to the treatment received in shipping, handling and installing the instrument.

(3) Accuracy of readings of the frequency deviation instrument.

(4) Functioning of frequency adjustment device.

(5) Effects on frequency and readings, of the changing of tubes, of voltage variations, and of variations of room temperature through a range not to exceed 10^{0} to 40^{0} C.

(6) Response of indicating instrument to small changes of frequency.

(7) General information on the effect of tilting or tipping or other tests to determine ability of equipment to withstand shipment.

Various other tests may be made or required, such as effects of variation of input from the transmitter depending upon the character of the apparatus.

Tests shall be conducted in such a manner as to approximate actual operating conditions as nearly as possible. The equipment under test shall be operated on any channel in the FM broadcast band.

15. *Requirements for Type Approval of Modulation Monitors

Section 3.253 requires each FM broadcast station to have an approved modulation monitor in operation at the transmitter. This monitor may or may not be a part of the FM broadcast frequency monitor. Approval of a modulation 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).

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

* Tentative Standard

** 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.

A. A device for setting the transmitter input to the modulation monitor.

B. A modulation peak indicating device that can be set at any predetermined value from 50 to 120 percent modulation (± 75 kc swing is defined as 100 percent modulation) and for either positive or negative swings (i.e., either above or below transmitter center frequency).

C. An indicator using a meter having the characteristics and scale of a standard VU meter. A switch shall be provided so this meter will read either positive or negative swings. The accuracy of reading of percentage of modulation shall be within ± 5 percent modulation percentage at any percentage of modulation up to 100 percent modulation.

D. The frequency characteristic curve shall not depart from a straight line more than ± 1/2 db from 50 to 15,000 cycles. Distortion shall be kept to a minimum.

E. The monitor shall not absorb appreciable power from the transmitter.

F. Operation of the monitor shall have no deleterious effect on the operation of the transmitter.

G. General design, construction and operation shall be in accordance with good engineering practice.

16. Approved Transmitters.#

17. Approved Frequency Monitors.#

18. Approved Modulation Monitors.#

19. FM Broadcast Application Forms

FCC Form No. 314 - Application for Consent to Assignment of Radio Broadcast Station Construction Permit of License (See Rules Section 3.223).

FCC Form No. 315 - Application for Consent to Transfer of Control of Corporation Holding Construction Permit or Station License. (See Rules Section 3.223).

FCC Form No. 316 - Inventory of Station Property to be submitted with Forms FCC No. 314 and 315.

FCC Form No. 319 - Application for New FM Broadcast Station Construction Permit.

FCC Form No. 320 - Application for FM Broadcast Station License.

FCC Form No. 322 - Application for construction Permit, Modification of Construction Permit, or Modification of License for an Existing FM Broadcast Station.

FCC Form No. 328 - Income Statement to be submitted with Forms FCC No. 314 and 315.

FCC Form No. 340 - Application for New Noncommercial Educational Broadcast Station Construction Permit.

FCC Form No. 701 - Application for Additional Time to Construct Radio Station.

Additional forms and revisions of the above forms are being prepared. The appropriate forms to be employed may be obtained from the Commission upon request.

Lists of approved equipment will be issued from time to time for incorporation in these Standards.

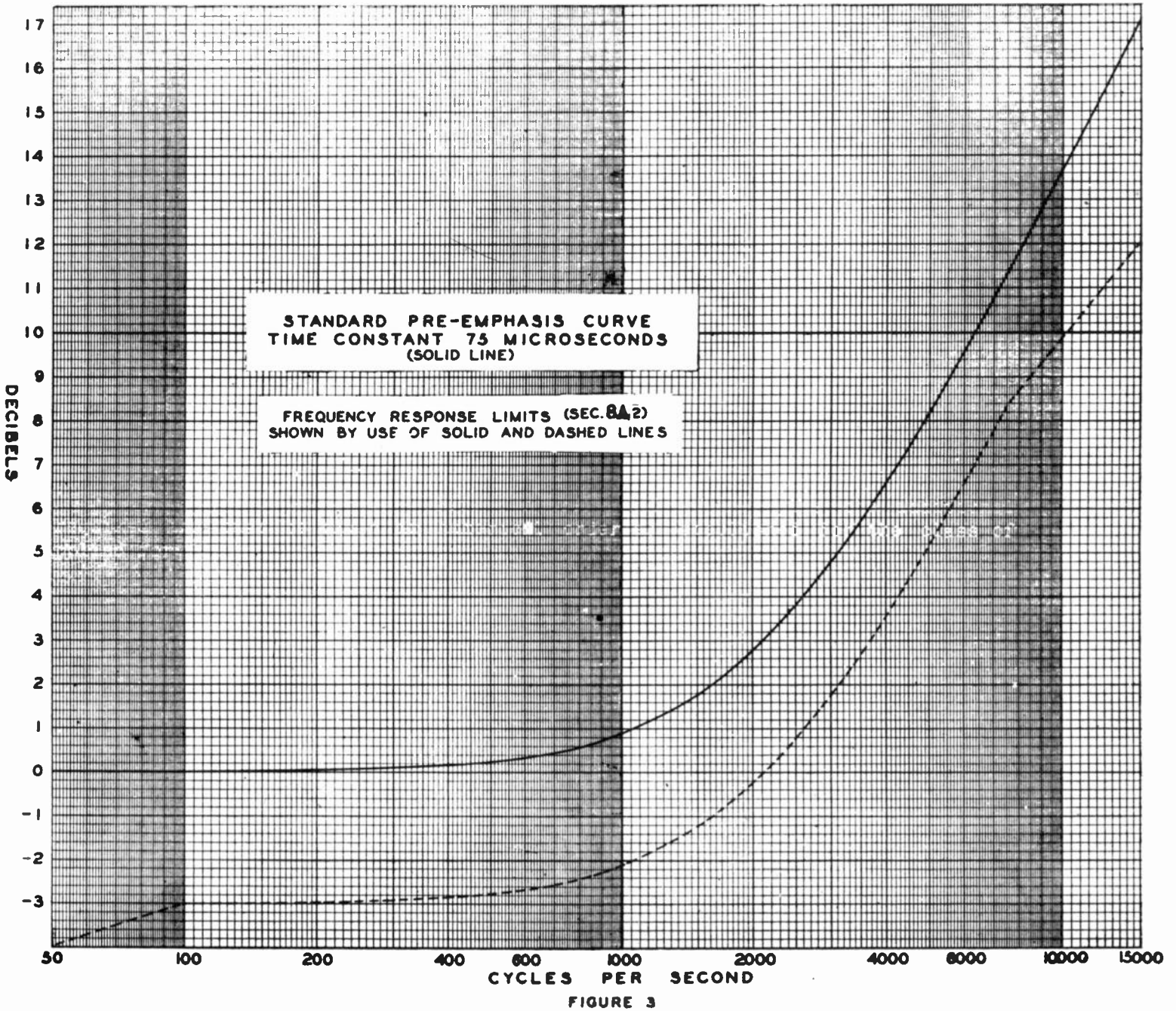
STANDARD PRE-EMPHASIS CURVE
TIME CONSTANT 75 MICROSECONDS
(SOLID LINE)
FREQUENCY RESPONSE LIMITS (SEC. 8A.2)
SHOWN BY USE OF SOLID AND DASHED LINES
DECIBELS
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
50
100
200
400
600
1000
2000
4000
6000
10000
15000
CYCLES PER SECOND

FIGURE 3

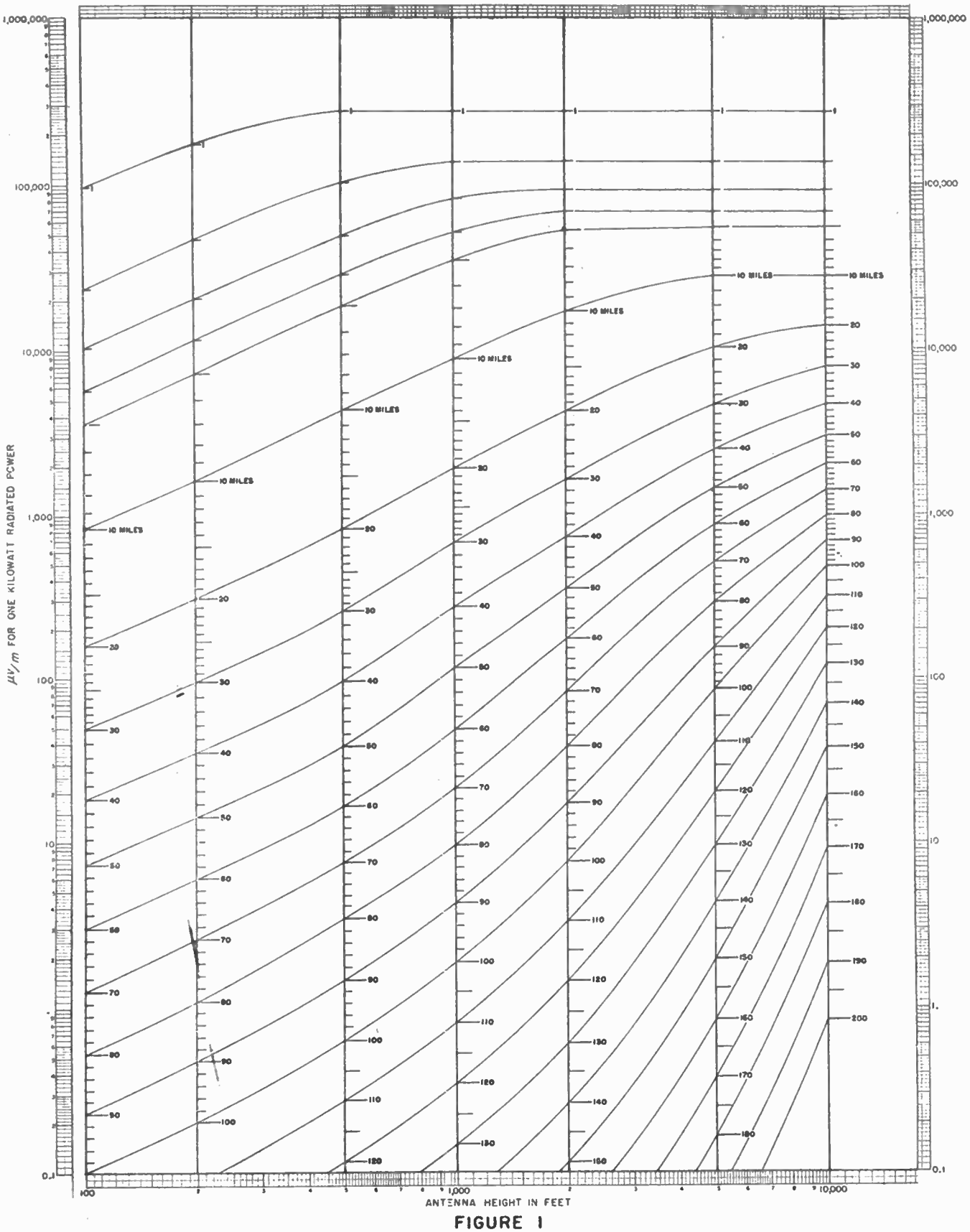

FIGURE 1

GROUND WAVE SIGNAL RANGE FOR FM BROADCASTING

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

Reprinted from Television Digest and F M Reports

STANDARDS OF GOOD ENGINEERING PRACTICE CONCERNING TV BROADCAST STATIONS

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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.

Sec. 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 megacycles 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 one 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 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 ten 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 transmission" 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 term "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 half-tones 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 attentuated 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.

Sec. 2. Transmission Standards and Changes of 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 synchronizing 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 per cent (with a tolerance of plus or minus 2.5 per cent) of the peak carrier amplitude.

13. The maximum white level shall be 15 per cent 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% or more than 150% 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% of the average synchronizing peak signal amplitude.

17.[1] *Black Level.*--The black should be made as nearly equal to the pedestal level as the state of 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;

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

(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 sub-paragraph (4) above.

Sec. 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:

TABLE I

Area	Median Field Intensity
City, business or factory areas	*5000 uv/m*
Residential and Rural areas	*500 uv/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 ten miles therefrom. Normally the radials are drawn for each 45^{0} 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 charts showing signal intensities. (Appendix IV)

The average elevation of the eight mile distance between two and ten 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% 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 5000 uv/m and 500 uv/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 two to ten 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 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 5000 uv/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.

Sec. 4. 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 rail-

road 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.

Sec. 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 Section 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% 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 uv/m contour of a station if a tropospheric signal from the co-channel station equals or exceeds 5 uv/m for at least ten percent of the time. The ten percent values for one 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 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 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 uv/m contour.

[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).

Sec. 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 non-directional 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 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 transmitter be operated at black level without synchronization peaks. Operation at a power somewhat less than black level is permissible but too great a reduction in power is not recommended due to the difficulty of recording weak signals. In any event, an appropriate factor shall be used to convert the readings obtained to the field strength that would exist on synchronization peaks while operating at the authorized power. If other means of measurements are to be used a request should be made to the Commission stating the reasons therefor 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 per cent 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 connected for a receiving antenna elevation of thirty 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 uv/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 uv/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 uv/m contour (as determined above) and the 500 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 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 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 of a type showing topography in the area). The 5000 and 500 uv/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 Section 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.

Sec. 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 5000 uv/m or greater field intensities in metropolitan areas, and inasmuch as signals below 500 uv/m may provide service in rural areas, considerable latitude in the geographical location of the transmitter is permitted; however, the necessity for a high elevation for the antenna may render this problem difficult. In general, the transmitting antenna of a station should be located at the most central point at the highest elevation available. In providing the best degree of service to an area, it is usually preferable to use a high antenna rather than a lower antenna with increased transmitter power. The location should be so chosen that line-of-sight can be obtained from the antenna over the principal city or cities to be served; in no event should there be a major obstruction in this path.

B. The transmitting location should be selected so that the 5000 uv/m contour encompasses the urban population within the area to be served and the 500 uv/m or the interference free contour coincides generally with the limits of the area to be served. It is recognized that topography, shape of the desired service area, and population distribution may make the choice of a transmitter location difficult. In such cases consideration may be given to the use of a directional antenna system, although it is generally preferable to choose a site where a non-directional 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 adjustments 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.

Sec. 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. Application 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% 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 non-directional 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 licensee 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 installation. 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.

Sec. 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 overall attenuation characteristics of the transmitter measured in the antenna transmission line after the vestigal 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.[4]

(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.

[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.

[4]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 overall field measurements. The "synchronizing signal" referred to in those paragraphs means either a standard synchronizing wave form or any pulse that will properly set the peak.

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 mid-characteristic operation.[3]

(4) The radio frequency signal, as radiated, shall have an envelope as would be produced by a modulating signal in comformity with Appendix I, as modified by vestigal 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 per cent 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 per cent 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% modulation. It is recommended, however, that the transmitter be designed to operate satisfactorily with a frequency swing of at least ± 40 kilocycles.

(2) The transmitting system (from input terminals of microphone preamplifier, through audio facilities at the studio, through telephone lines or other circuits between studio and transmitter, through audio facilities at a transmitter, and through the transmitter, but excluding equalizers for the correction of deficiencies in microphone response) shall be capable of transmitting a band of frequencies from 50 to 15,000 cycles. Pre-emphasis shall be employed in accordance with the impedance-frequency characteristic of a series inductance-resistance network having a time constant of 75 microseconds (See 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 deviations) from 50 to 15,000 cycles. The lower limit shall be uniform from 100 to 7500 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 (four db at 50 cycles); from 7500 to 15,000 cycles the lower limit shall fall from the three db limit at a uniform rate of two db per octave (five db at 15,000 cycles).

[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.

(3) At any modulating frequency between 50 and 15,000 cycles and at modulation percentages of 25%, 50% and 100%, 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
50 to 100	*3.5%*
100 to 7500 cycles	*2.5%*
7500 to 15000 cycles	*3.0%*

Measurements 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.[5]

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 distortion 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.[6]

(5) The transmitting system output noise level (amplitude modulation) in the band of 50 to 15000 cycles shall be at least 50 db below the level representing 100% amplitude modulation.[6]

(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. (±.002%)

(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.

D. Construction.

In general, the transmitters shall be constructed either on racks and panels or in totally enclosed frames protected

[5] Measurements of distortion using de-emphasis in the measuring equipment are not practical at the present time for the range 7500 to 15000 cycles for 25 and 50 percent modulation. Therefore, measurements should be made at 100% modulation and on at least the following modulating frequencies: 50, 100, 400, 1000, 5000, 10,000, and 15,000 cycles. At 25 and 50% modulation measurements should be made on at least the following modulating frequencies: 50, 100, 400, 1000 and 5000 cycles.

[6] 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.

as required by article 810 of the National Electrical Code[7] 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 AC 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.

[7]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."

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 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.

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.

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 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

An accurate circuit diagram and list of required spare tubes as furnished by the manufacturer of the equipment, shall be supplied and returned at the transmitter location.

H. Operation.

In addition to specific 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, shall be compatible with the required performance characteristics of television broadcast stations.

Sec. 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 transmitter 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 3/10 inches.

(2) Accuracy shall be at least 2 per cent 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 indicating instruments. If the records are to be used in any proceeding before the Commission, as representative of operation, the accuracy must be the equivalent of the indicating instruments and the calibration shall be checked at such intervals as to insure the retention of such accuracy.

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

Sec. 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 per cent above and 20 per cent 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 per cent above and 20 per cent below the authorized power except in emergencies.

(3) In the event it become 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 Inspector 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.[8]

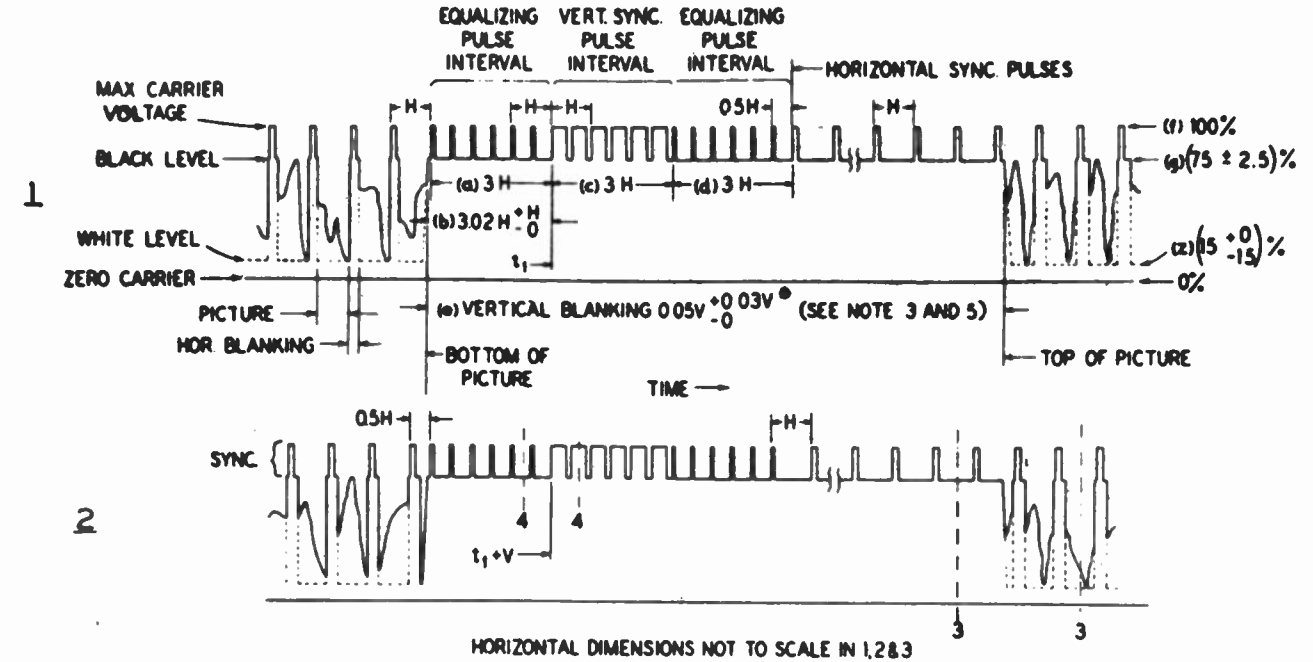
Sec. 12. Auxiliary Transmitters

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.

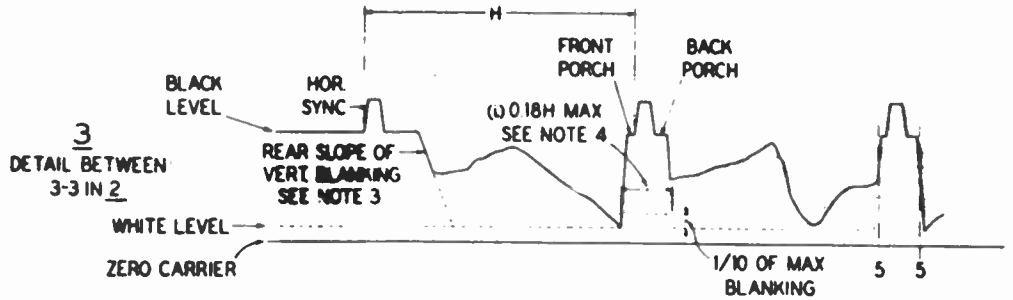
Sec. 13 to 20, inclusive. These sections to be supplied.

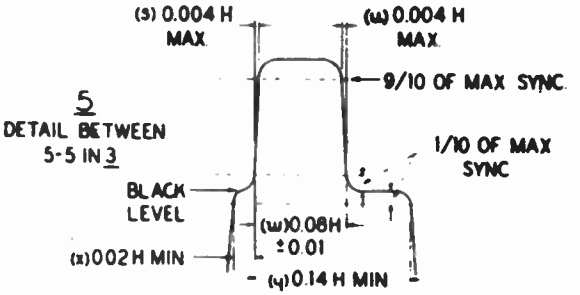
[8] See Appendix 3 of Part 1 of the Rules and Regulations for addresses of Field Offices.

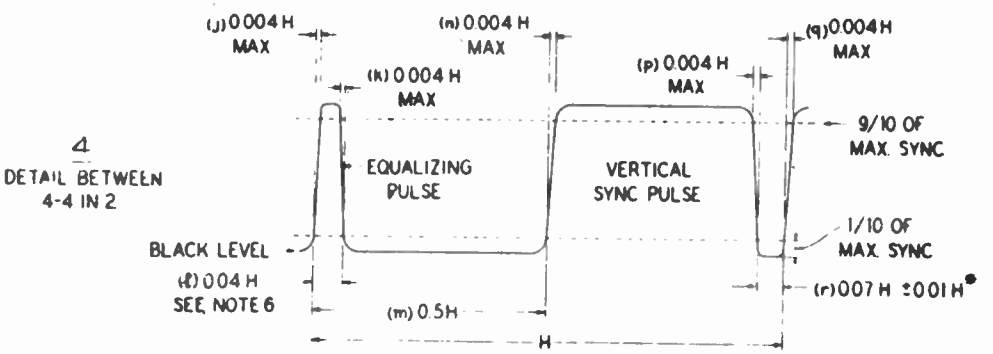
TELEVISION SYNCHRONIZING WAVEFORM



HORIZONTAL DIMENSIONS NOT TO SCALE IN 1, 2 & 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 0.1H.

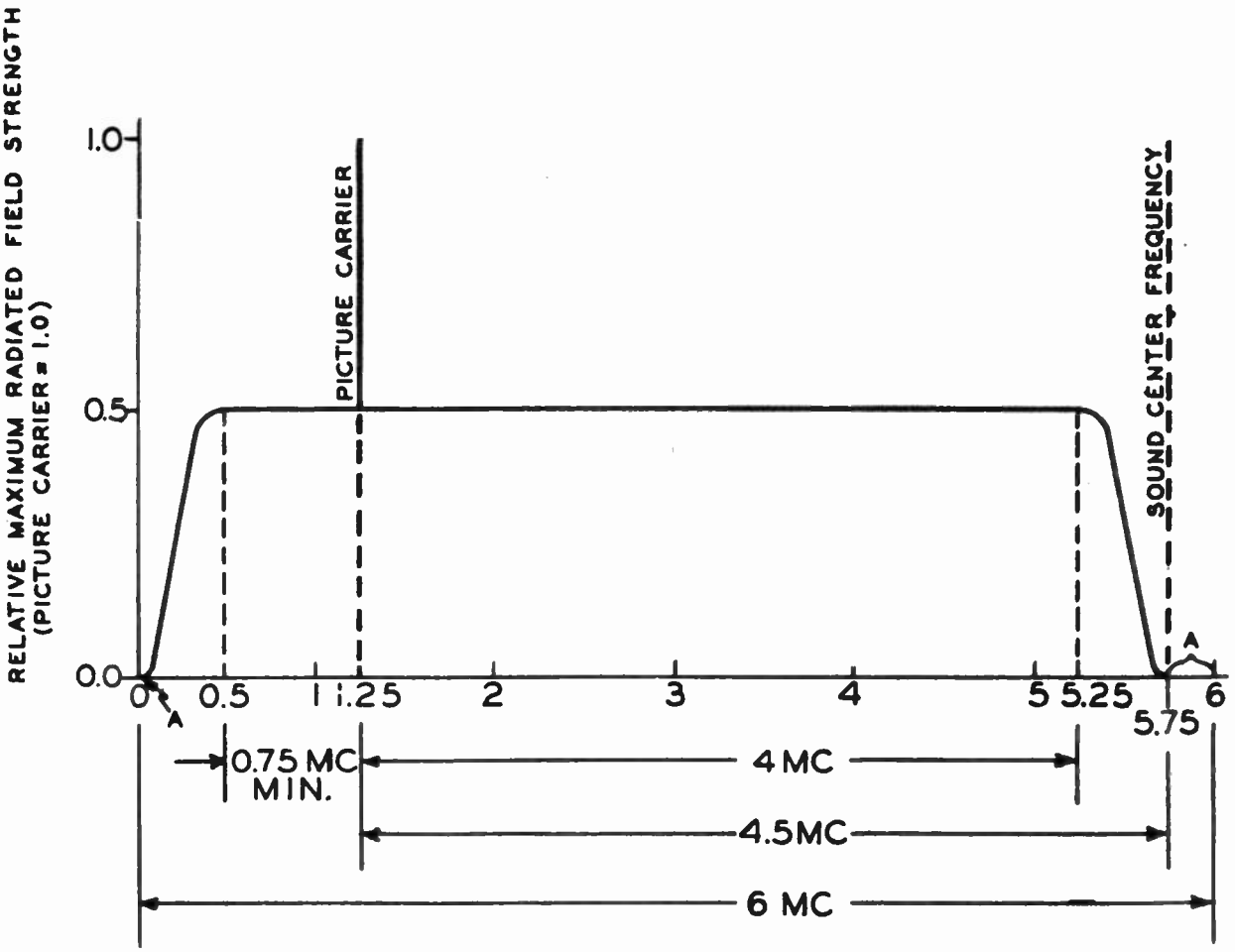
4 - LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MIN AND MAX VALUES OF (x + y) AND (i) UNDER ALL CONDITIONS OF PICTURE CONTENT.

*5 - DIMENSIONS MARKED WITH AN 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 THE AREA OF A HORIZONTAL SYNC PULSE.

7 - REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES.

IDEALIZED PICTURE TRANSMISSION AMPLITUDE CHARACTERISTIC

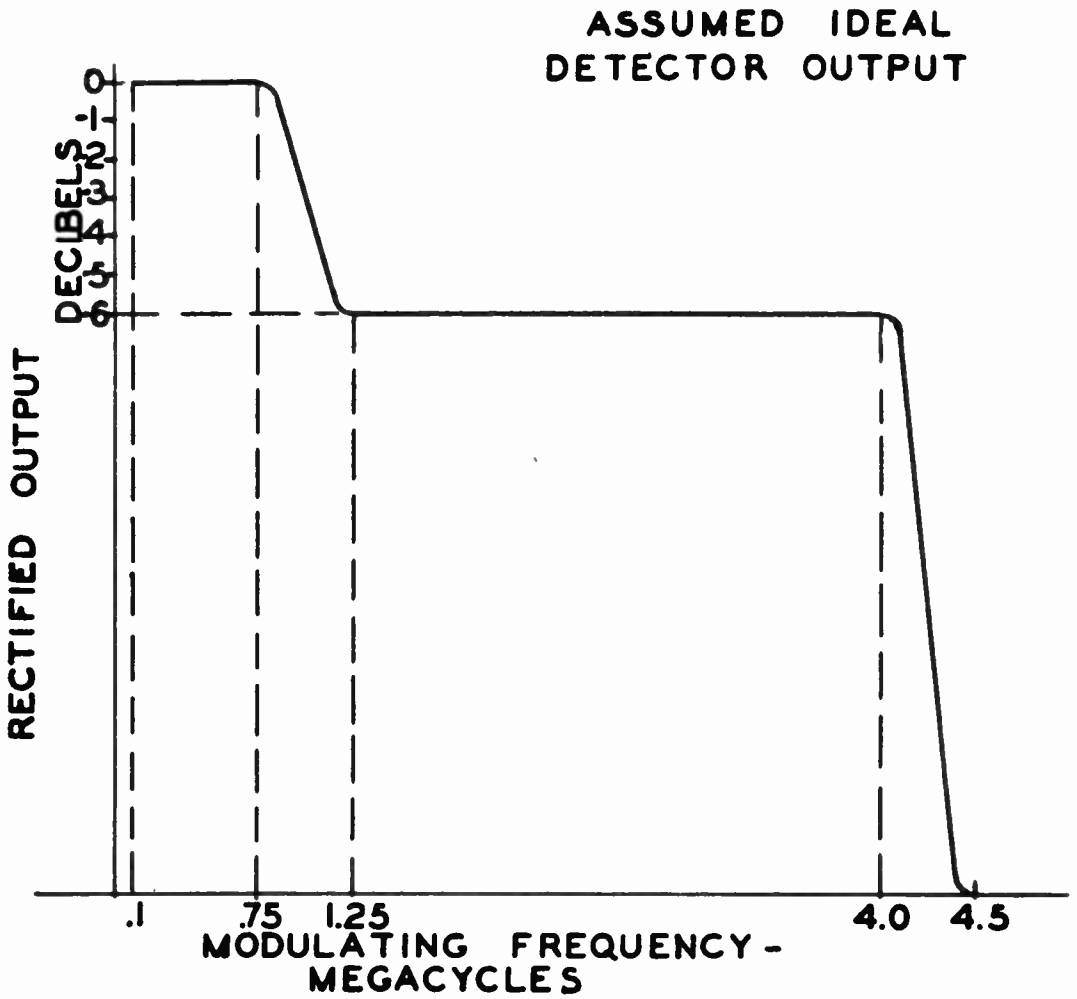


NOTES

A – SEE SECTION 9A(2) FOR FIELD STRENGTH AT THESE POINTS.

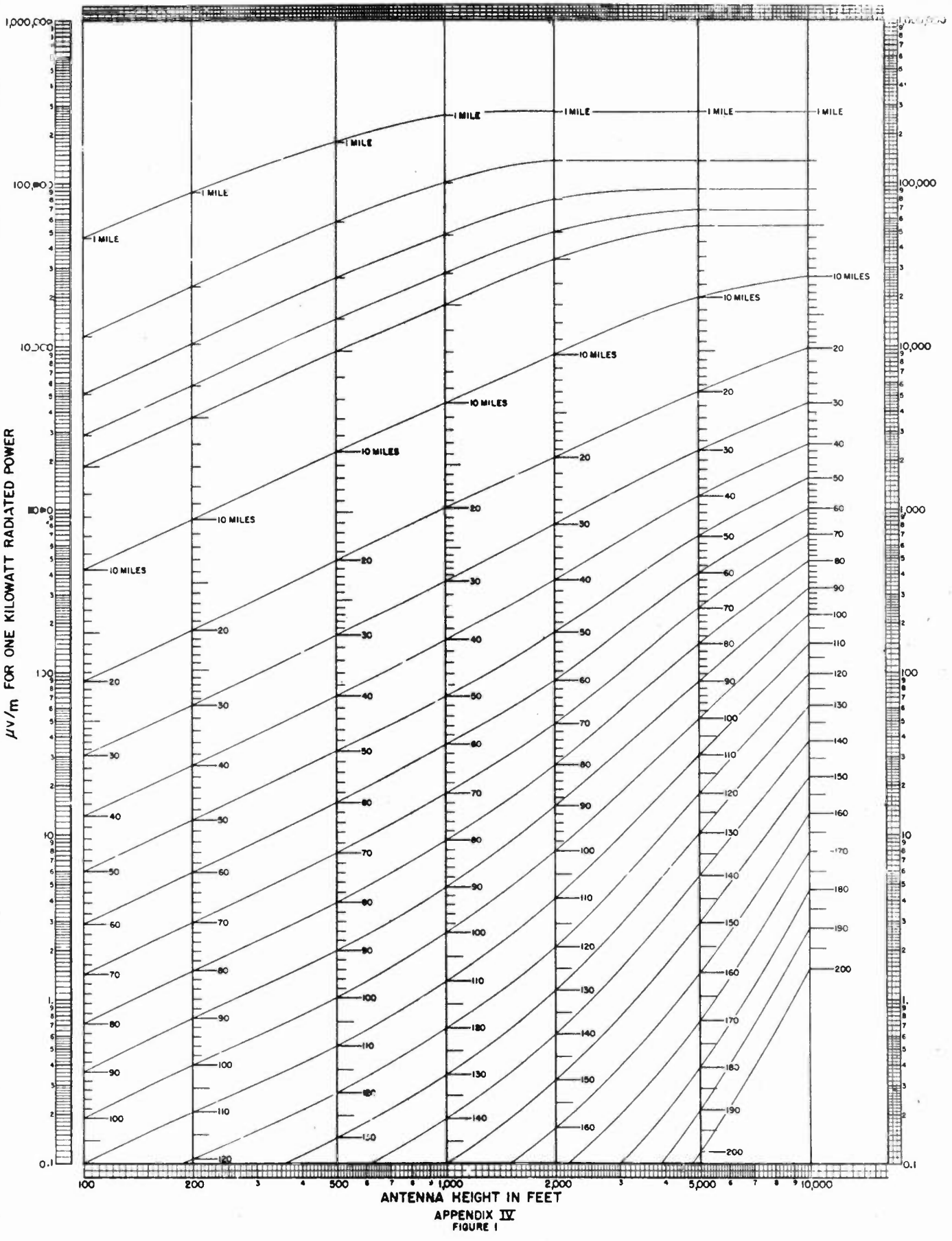
DRAWING NOT TO SCALE.

APPENDIX II



APPENDIX III

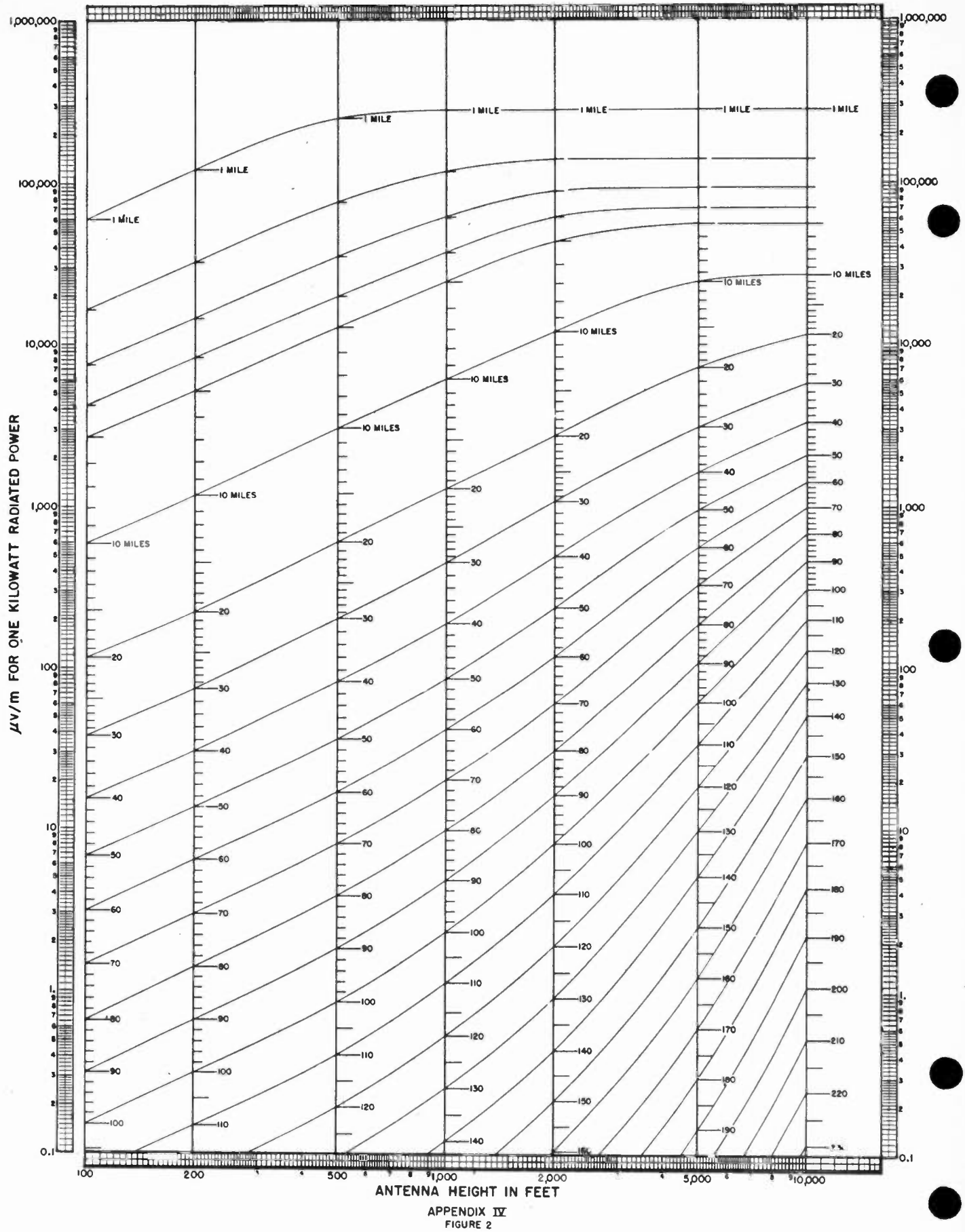
83787-1



APPENDIX IV
FIGURE 1

GROUND WAVE SIGNAL RANGE FOR TELEVISION

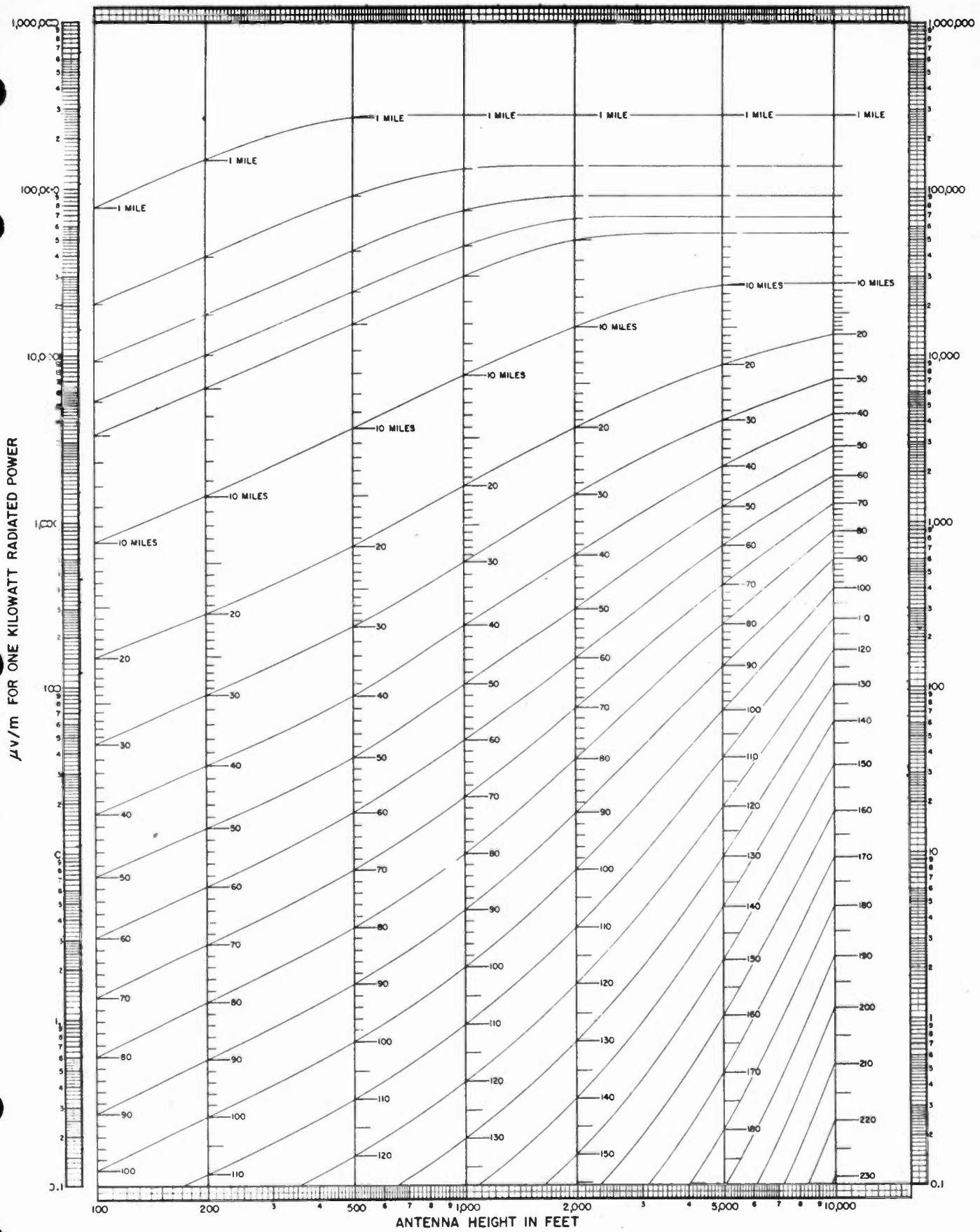
46 mc, $\sigma = 5 \times 10^{-14}$ e.m.u., $\epsilon = 15$, RECEIVING ANTENNA HEIGHT 30 FEET
FOR HORIZONTAL (AND APPROX. FOR VERTICAL) POLARIZATION



APPENDIX IV
FIGURE 2

GROUND WAVE SIGNAL RANGE FOR TELEVISION

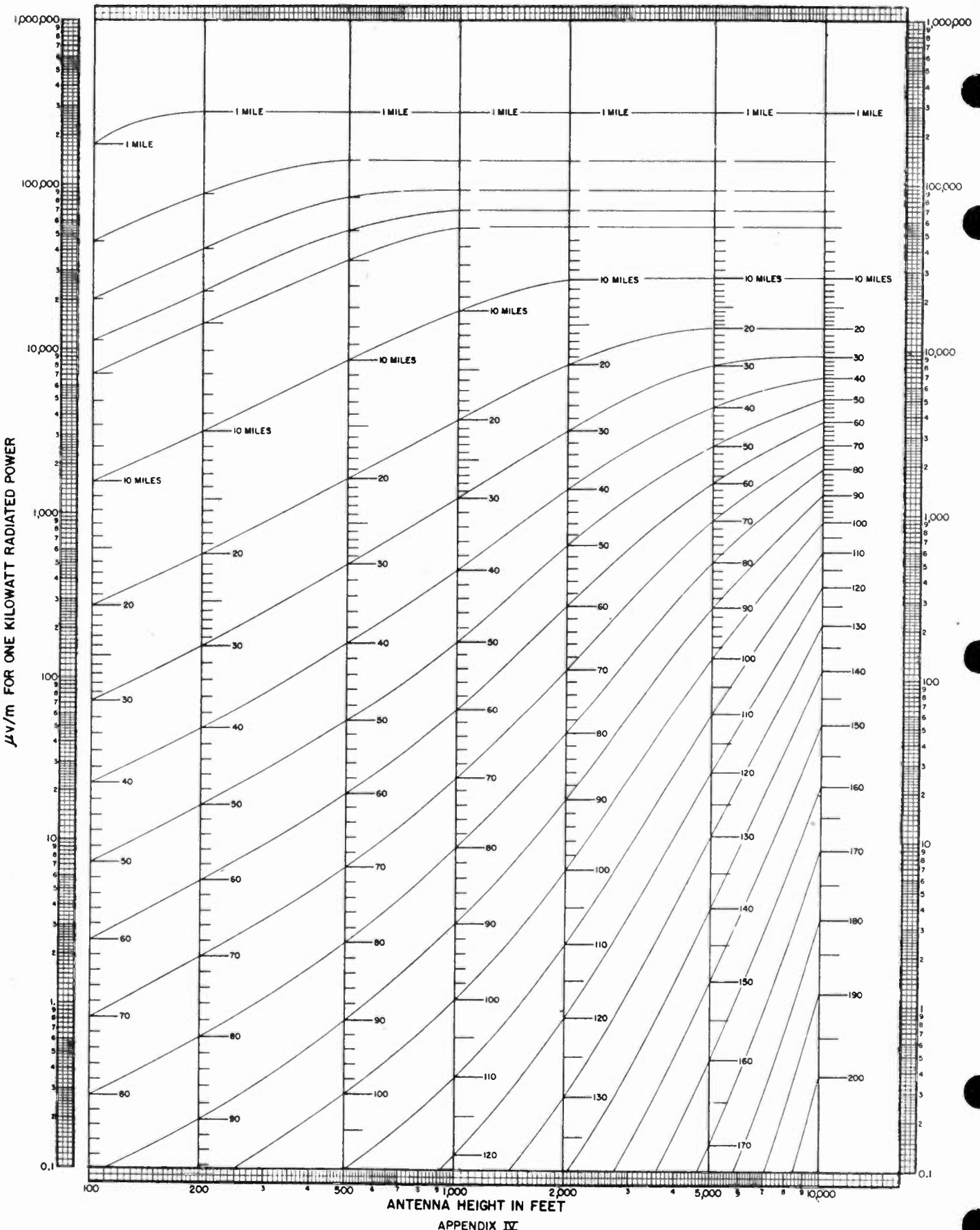
63 mc, $\sigma = 5 \times 10^{-14}$ e.m.u., $\epsilon = 15$, RECEIVING ANTENNA HEIGHT 30 FEET
FOR HORIZONTAL (AND APPROX. FOR VERTICAL) POLARIZATION



APPENDIX IV
FIGURE 3

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

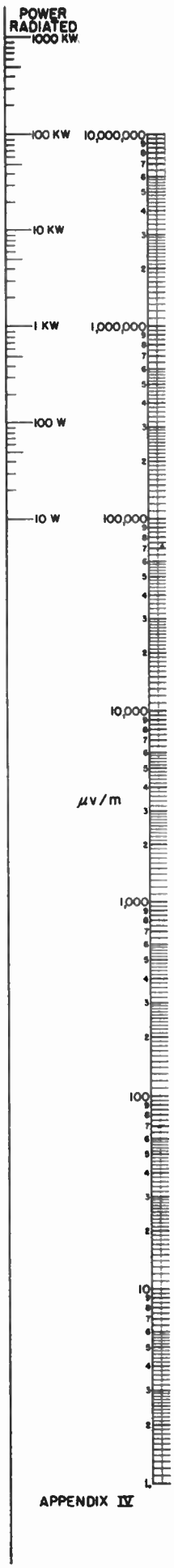


APPENDIX IV
FIGURE 4

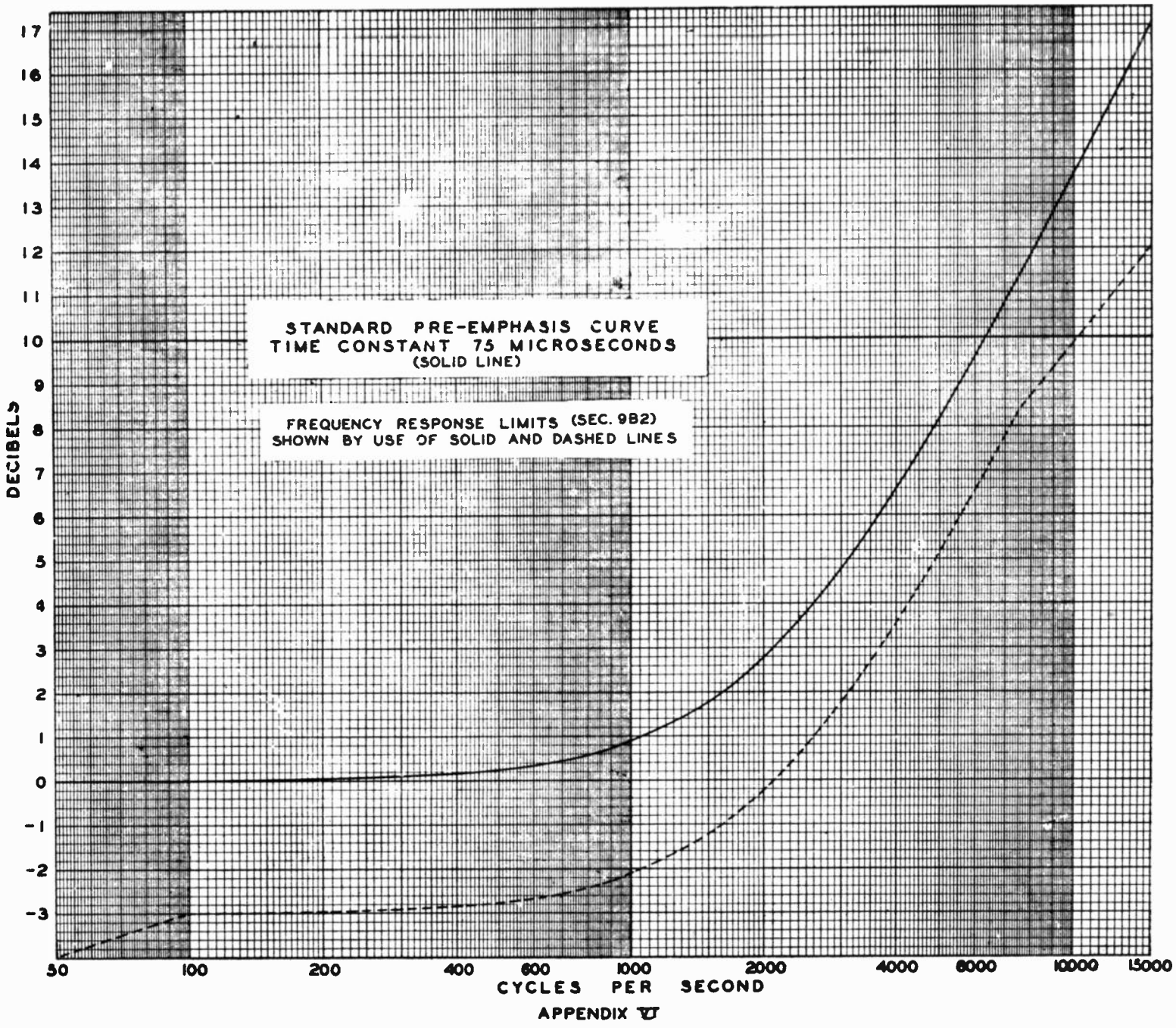
GROUND WAVE SIGNAL RANGE FOR TELEVISION

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

NOTE: This rule should be cut from the page and used as a sliding tape in connection with the curves on page H-41 to H-44 for radiated powers other than one kilowatt.



APPENDIX IV


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
10000
15000
CYCLES PER SECOND

APPENDIX VI

FCC STANDARDS OF GOOD ENGINEERING PRACTICE CONCERNING STANDARD BROADCAST STATIONS (550-1600 kc.)

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 Commissions 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.

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3. Data Required With Applications Involving Directional Antenna Systems.
4. Locations of Transmitters of Standard Broadcast Stations.
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6. Standard Lamps and Paints.
7. Further Requirements for Direct Measurement of Power.
8. Power Rating of Vacuum Tubes.
9. Requirements for Approval of Power Rating of Vacuum Tubes.
10. Plate Efficiency of Last Radio Stage.
11. Operating Power Tolerance.
12. Construction, General Operation and Safety of Life Requirements.
13. Indicating Instruments Pursuant to Section 3.58
14. Requirements for Type Approval of Broadcast Transmitters and Automatic Frequency Control Equipments.
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17. Use of Low Temperature Coefficient Crystals by Broadcast Stations.
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19. Use of Common Antenna by Standard Broadcast Stations or Another Radio Station.
20. Use of Frequency and Modulation Monitors at Auxiliary Broadcast Transmitters.
21. Approved Frequency Monitors.
22. Approved Modulation Monitors.
23. Approved Equipment.
24. Standard Broadcast Application Forms.
25. Field Offices of the Commission.
26. Average Sunrise and Sunset Times. Appendix I.

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 classification 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 ground wave contour. Protection is given this class of station to the 500 uv/m ground wave 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 sky wave contour and during daytime hours of operation to the 100 uv/m ground wave contour from stations on the same channel. Protection is given to the 500 uv/m ground wave 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 9,25 kw. or more than 50 kw. These stations are required to use a directional antenna or other means to avoid causing interference within the normally protected service areas of Class I stations or other Class II stations. These stations normally render primary service only, the area of which depends on the geographical location, power, and frequency. This may be relatively large but is limited by and subject to such interference as may be received from Class I stations. However, it is recommended that Class II stations be so located that the interference received from Class I stations will not limit the service area to greater than the 2500 uv/m ground wave 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

---

[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, in case of placing a station on an adjacent channel (10 kc. removed) to a Class I station which would substitute a primary service for the secondary service, the matter of the program service as well as the signal service of the two stations should be given consideration. That is, at the 0.5 mv/m 50 percent sky wave contour of a Class I station purely for the determination of comparative service, the area bound by 1 mv/m contour of a Class II, Class III or Class IV station 10 kc. removed may be taken as the area within which the secondary service of the Class I station is precluded. For higher values of 50 percent sky wave signal from a Class I station the ratio of the ground wave to sky wave shall be 2 to 1 and considered only within the 0.5 mv/m 50 percent sky wave contour of the Class I station.*

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 ground wave contour nighttime and the 500 uv/m ground wave 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 ground wave contour nighttime and 500 uv/m ground wave contour daytime.[2]

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 the 4000 uv/m ground wave contour nighttime and 500 uv/m ground wave contour daytime. On local channels the separation required for the daytime protection shall also determine the nighttime separation. 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 ground wave 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 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

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[2] *See tables IV and V.*

[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.

have in general three service areas;[1] namely, 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.

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.

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.

TABLE I

Primary Service

Area:	Field Intensity Ground Wave[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.*

TABLE II

Population:	Field Intensity Ground Wave
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*

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

[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 not being studied.*

[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.*

Secondary Service

Secondary service is delivered in the areas where the sky wave for 50 percent or more of the time has a field intensity of 500 uv/m or greater.[6] It is not considered that satisfactory secondary service can be rendered to cities unless the sky wave approaches in value the ground wave 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 ground wave 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, it shall be understood to apply in determining the interference between existing stations.[9] It is not considered that increased objectionable interference is caused when (in the case where interference is predominantly from a single station) a signal from another station is added which does not have an intensity greater than 70 percent of the value of the highest signal already causing interference. In case such highest value of signal cannot be determined separately then the maximum value of any signal that can be added without considering that an increase in objectionable interference results, should be determined as follows: For two interfering signals of approximately the same value the signal added should not exceed 85 percent of the computed value of a single signal from the estimated or measured RSS value. For more than two interfering signals of approximately the same value, the added signal should not exceed the value of a single signal computed from the RSS value. This formula should be used to compute the value of the single signal,

$$E = \sqrt{\frac{F^2}{N}}$$

where E is the value of a single signal.
F is RSS field intensity as measured by the usual field intensity meter.
N is the number of interfering signals of approximately the same value.

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

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[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.

[9] In computing interference to any station only the RSS value of all signals which are greater than 70 percent of the highest signal shall be considered.

intensity of the ground wave of an undesired station operating on an adjacent channel (or the root-sum-square value of the field intensities of two or more such undesired stations operating on the same adjacent channel) exceeds a value specified in 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 produce effective fields, for 1 kilowatt 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 horizontal and vertical field intensity patterns of the directional antenna must be calculated and compared with the appropriate vectors in the horizontal or vertical patterns of a nondirectional antenna having the same effective field. Thus the interfering signal toward any other station can be expressed in terms of kilowatts. This rating in kilowatts shall be applied in the use of mileage separation tables or in computing interference from the propagation curves.[10]

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 and Appendix I, or

(c) By reference to the distance tables set forth in Tables VI, VII, and VIII.

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 sky wave shall be made for a period of time not less than 10 days and an adequate check shall be made on the sky wave signal of other stations to determine the general conditions of propagation while such measurements are taken.[11]

In computing the distance to the 50 percent sky wave field intensity contour of a Class I station of a given power, and also in computing the 10 percent sky wave field intensity of an alleged interfering station, of any class and given power, at a specified distance, use shall be made of the appropriate graphs set forth in Figure 1 entitled "Average sky wave field intensity" (corresponding to the second hour after sunset at the recording station). The curves are drawn for an effective field of 100 millivolts per meter at 1 mile.

The distance to any specified ground wave field intensity contour may be determined from appropriate ground wave 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 "Ground wave field intensity," drawn for a frequency of 1000 kc., conductivity of 10^{-13}, dielectric constant 15, and an effective field of 100 millivolts per meter at 1 mile, may be employed when applicable.

Table VI gives the required day separation in miles between broadcast stations on the same channel. Table VII gives the required separation in miles between broadcast stations on adjacent channels during both daytime and nighttime. Table VIII gives the required night separation in miles between broadcast stations operating on the same channel. The assumed conditions of operation are given on the first page of the tables.

The tables are based upon the use of nondirective antennas but, in case a directive antenna is employed at a particular station, it will be necessary to consider the radiation distribution of the directional antenna involved and to modify the mileage separation accordingly.[12,13]

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

[11] See Annex III for detailed requirements and also section on 'Field Intensity Measurements in Allocation.'

[12] See Annex II for method of modification.

[13] The Commission will not authorize a directive antenna for a Class IV 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	Clear	10 kw. to 50 kw	SC 100 uv/m AC 500 uv/m	500 uv/m (50% sky wave).	5 uv/m	25 uv/m
II	Clear	0.25 kw. to 50 kw	500 uv/m	2500 uv/m [5] (ground wave).	25 uv/m	125 uv/m [5]
III-A	Regional	1 kw. to 5 kw	500 uv/m	2500 uv/m (ground wave).	25 uv/m	125 uv/m
III-B	Regional	0.5 to 1 kw. night and 5 kw. day.	500 uv/m	4000 uv/m (ground wave).	25 uv/m	200 uv/m
IV	Local [6]	0.1 kw. to 0.25 kw	500 uv/m	4000 uv/m (ground wave).	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] Ground wave.
[4] Sky wave 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 night separation tables for stations on the same frequency are computed from the sky wave curve given in Figure 1. These curves are based on extensive measurements of the sky wave produced by broadcasting stations and shall be considered as accurate in all cases unless proof to the contrary is supplied. Such proof must be based on field intensity measurements taken in accordance with requirements set out in Annex III and must show what condition prevails that causes the signal to depart from the average.

The mileage separation tables for the same channel during daytime and for adjacent channels day and night are computed from the ground wave curves in Figure 2. These tables apply only in case the frequency is 1000 kc. and the assumed soil conductivity and dielectric constant prevail. Since these values vary in every case, the tables for daytime and adjacent channel separation cannot be used except as a general guide. In any case under consideration an estimate of the mileage separation required may be made from the operating frequency and known or assumed soil conditions.-[14]

The undesired ground wave signal shall be determined at or within the 0.5 mv/m ground wave contour of the desired station. These values apply to all classes of stations both day and night and are based on ground waves which hold for an effective power up to 50 kw. Above this effective power, when an interfering sky wave signal for 10 percent or more of the time exceeds 5 times the desired signal 10 kc. removed in frequency (or undesired exceeds 25 times the desired signal 20 kc. removed in frequency), interference will be produced. This may result from the use of a directional antenna and in such cases the interference shall be determined from the 10 percent sky wave of an interfering station to the normally protected ground wave or to a sky wave of a desired station, on the basis of a ratio of 1 to 5 (or 1 to 25 for 20 kc.) for desired signal to the undesired sky wave signal for 10 percent or more of the time.

The mileages given in Table VII are based on ground waves only and do not apply for night operation where the 10 percent sky wave of an undesired station exceeds 5 times (or 25 times for 20 kc.) the normally protected field intensity of a desired station.

MILEAGE-SEPARATION TABLES

The required mileage separations between broadcasting stations as tabulated below are based upon the following conditions:

(1) The use of nondirectional antennas in the horizontal plane and the vertical pattern of a 0.311 wave-length antenna.

(2) Effective field in mv/m at 1 mile for 1 kilowatt.

[14] *See Annex I for a determination of interference from ground waves when actual measurements are not available.*

TABLE V

Adjacent Channel Interference

Channel Separation Between Desired and Undesired Stations:	Maximum Ground Wave Field Intensity of Undesired Station
10 kc	*0.25 mv/m*
20 kc	*5.0 mv/m*
30 kc	*25.0 mv/m*

Class I--225 mv/m
Class II and III--175 mv/m
Class IV--150 mv/m

(3) Frequency, 1000 kc.

(4) Soil conductivity, $s = 10^{-13}$.

(5) Soil dielectric constant, $e = 15$.

(6) Ground-wave transmission as shown on chart in Figure 2.

(7) Sky-wave transmission as shown on chart in Figure 1.

(8) Protection to service areas as shown in Table IV.

(9) Ratio of desired to undesired signal:

Channel Separation:	Ratio of Desired to Undesired
Same frequency	*20:1 ground wave or 10% sky wave*
Synchronized carriers	*4:1*[1]
10 kc	*2:1 ground wave*[2]
	1:5 sky wave
20 kc	*1:10 ground wave*
	1:25 sky wave
30 kc	*1:50*
40 kc. and above	*No restriction*[3]

[1]Two stations are considered to be operated synchronously when the carriers are maintained within one-fifth of a cycle per second of each other, either automatically or manually and they transmit the identical program. While observations have been made on several synchronized stations, no definite standards as to ratio of desired carrier to undesired carriers have been established, inasmuch as the methods of operations have not been standardized and results vary appreciably. From the observations it would appear that for most types of synchronous operation a ratio of about 4 to 1 between desired and undesired carriers is necessary to avoid distortion. This ratio holds only when the audio modulation is in sufficiently close time phase to avoid echo effects. In computing the interference in the primary service areas between the ground waves of two synchronously operated stations the ratio of 4 to 1 should be used. No complete information is available as to the required ratio between sky waves; however, it would appear that a ratio less than 4 to 1 can be tolerated without objectionable interference, first because the standard of acceptance of a signal as satisfactory is lower for secondary service, and second, because several waves with random relative phases usually make up each sky wave and the combination of two such synchronized waves generally causes less distortion. Synchronous operation of two or more stations may enable an extension of the coverage and service on a channel without any materially increased interference range beyond that one station would produce.

[2]This ratio of desired to undesired signal is not based on the characteristics of the average receiver but upon what the characteristics of an ideal receiver would be which would permit high-fidelity reception of a station in the high-fidelity primary service area (primary area where no interference would be caused to a receiver responding faithfully to a band 15 kc. wide or 7.5 kc. audio response). The ratio of desired to undesired (1 to 5 and 1 to 25) for interference from a sky wave 10 and 20 kc. removed in frequency respectively is based on the characteristics of most good receivers placed in operation since 1936 and operated as most listeners adjust variable selectivity receivers where the signal is one millivolt or less.

[3]Two stations, one with a frequency twice that of the other, should not be assigned in the same primary service area unless special precautions are taken to avoid interference from the second harmonic of the lower frequency.

(10) Service and interference radii—night:

Class—Power and field at mile	Service radii			Interference radii		
	2.5 mv/m G. W.	4.0 mv/m G. W.	500 uv/m 50% S. W.	200 uv/m 10% S. W.	125 uv/m 10% S. W.	25 uv/m 10% S. W.
Class IV						
100 w.: 47.5 mv/m		8.5		G. W.	190	
250 w.: 75 mv/m		11.5		G. W.	370	
Class III						
500 w.: 124 mv/m		15		380	590	
1000 w.: 175 mv/m	25	20		535	710	
5 kw.: 392 mv/m	39			840	1000	
Class II						
250 w.: 87.5 mv/m	17			210	440	1040
500 w.: 124 mv/m	21			380	590	1170
1000 w.: 175 mv/m	25			535	710	1325
5 kw.: 392 mv/m	39			840	1000	1340
10 kw.: 554 mv/m	42			960	1125	2120
25 kw.: 875 mv/m	56			1120	1320	2570
50 kw.: 1238 mv/m	65			1265	1510	
Class I						
10 kw.: 712 mv/m			345	1045	1225	2345
25 kw.: 1125 mv/m			575	1225	1460	
50 kw.: 1592 mv/m			715	1395	1685	

G. W.=Ground wave. S. W.=Sky wave.

TABLE VI.—*Required day separation in miles between broadcast stations on the same channel*[1]

Class and power	Class IV		Classes II and III							Class I		
	100 w.	250 w.	0.25 kw.	0.5 kw.	1 kw.	5 kw.	10 kw.	25 kw.	50 kw.	10 kw.	25 kw.	50 kw.
Class IV												
100 w	143	165	172	192	213	265	285	310	335	390	417	437
250 w	165	173	180	200	221	273	293	318	343	415	442	462
Classes II and III												
0.25 kw	172	180	183	203	224	276	296	321	346	418	446	465
0.5 kw	192	200	203	210	231	283	303	328	353	446	473	493
1 kw	213	221	224	231	239	291	311	336	361	467	494	514
5 kw	265	273	276	283	291	313	333	358	383	520	547	567
10 kw	285	293	296	303	311	333	345	370	395	540	567	587
25 kw	310	318	321	328	336	358	370	389	414	565	592	612
50 kw	335	343	346	353	361	383	395	414	430	587	614	634
Class I												
10 kw	390	415	418	446	467	520	540	565	587	556	585	605
25 kw	417	442	446	473	494	547	567	592	614	585	612	632
50 kw	437	462	465	493	514	567	587	612	634	605	632	652

[1] See discussion above before using in any specific case.

TABLE VII.—*Required day and night separation in miles between broadcast stations on adjacent channels* [1]

Class and power	Class IV						Classes II and III														
	0.1 kw.			0.25 kw.			0.25 kw.			0.5 kw.			1 kw.			5 kw.			10 kw.		
	10 kc.	20 kc.	30 kc.	10 kc.	20 kc.	30 kc.	10 kc.	20 kc.	30 kc.	10 kc.	20 kc.	30 kc.	10 kc.	20 kc.	30 kc.	10 kc.	20 kc.	30 kc.	10 kc.	20 kc.	30 kc.
Class IV																					
0.1 kw	73	37	32	82	45	40	86	47	42	94	55	50	105	63	58	133	84	79	149	98	93
0.25 kw	82	45	40	90	48	41	94	50	43	102	58	51	113	66	59	141	87	80	157	101	94
Classes II and III																					
0.25 kw	86	47	42	94	50	43	96	51	43	104	59	51	115	67	59	143	88	80	159	102	94
0.5 kw	94	55	50	102	58	51	104	59	51	112	62	52	123	70	60	151	91	81	167	105	95
1 kw	105	63	58	113	66	59	115	67	59	123	70	60	131	73	62	159	94	83	175	108	97
5 kw	133	84	79	141	87	80	143	88	80	151	91	81	159	94	83	180	104	87	196	118	101
10 kw	149	98	93	157	101	94	159	102	94	167	105	95	175	108	97	196	118	101	210	123	104
25 kw	172	115	110	180	118	111	182	119	111	190	122	112	198	125	114	219	135	118	233	140	121
50 kw	190	131	126	198	134	127	200	135	127	208	138	128	216	141	130	237	151	134	251	156	137
Class I																					
10 kw	162	107	102	170	110	103	172	111	103	180	114	104	188	117	106	209	127	110	223	132	113
25 kw	183	126	121	191	129	122	193	130	122	201	133	123	209	136	125	230	146	129	244	151	132
50 kw	203	144	139	211	147	140	213	148	140	221	151	141	229	154	143	250	164	147	264	169	150

[1] See discussion above before using in any specific case.

Class and power	Class II						Class I								
	25 kw.			50 kw.			10 kw.			25 kw.			50 kw.		
	10 kc.	20 kc.	30 kc.	10 kc.	20 kc.	30 kc.	10 kc.	20 kc.	30 kc.	10 kc.	20 kc.	30 kc.	10 kc.	20 kc.	30 kc.
Class IV															
0.1 kw	172	115	110	190	131	126	162	107	102	183	126	121	203	144	139
0.25 kw	180	118	111	198	134	127	170	110	103	191	129	122	211	147	140
Classes II and III															
0.25 kw	182	119	111	200	135	127	172	111	103	193	130	122	213	148	140
0.5 kw	190	122	112	208	138	128	180	114	104	201	133	123	221	151	141
1 kw	198	125	114	216	141	130	188	117	106	209	136	125	229	154	143
5 kw	219	135	118	237	151	134	209	127	110	230	146	129	250	164	147
10 kw	233	140	121	251	156	137	223	132	113	244	151	132	264	169	150
25 kw	250	149	125	268	165	141	242	145	123	261	160	136	281	178	154
50 kw	268	165	141	284	172	145	260	161	139	279	163	144	297	185	158
Class I															
10 kw	242	145	123	260	161	139	232	137	115	253	156	134	273	174	152
25 kw	261	160	136	279	168	144	253	156	134	272	163	139	292	181	157
50 kw	281	178	154	297	185	158	273	174	152	292	181	157	310	190	161

TABLE VIII.—*Required night separation in miles between broadcast stations on the same channels*

The following tables indicate the mileage protection each class must give all other classes:

TABLE VIII-A

Class Ia should protect Class II stations as shown:

	Class II--All Powers
Class Ia: 50 kw	*Not duplicated at night.*

TABLE VIII–B

Class Ib should protect other Class Ib stations as shown below:

Class Ib	Class Ib		
	10 kw.	25 kw.	50 kw.
10 kw	2665	3010	----------
25 kw	3010	(1)	(1)
50 kw	----------	(1)	(1)

[1] Cannot be duplicated without directional antenna and then this table does not apply.

TABLE VIII–C

Class II should protect other classes as shown below—nondirectional antenna.

Class II	Class II							Class Ib		
	0.25 kw.	0.5 kw.	1 kw.	5 kw.	10 kw.	25 kw.	50 kw.	10 kw.	25 kw.	50 kw.
0.25 kw	455	[1] 460	465	480	485	495	505	1,385	1,615	1,755
0.5 kw	605	610	615	630	635	645	655	1,515	1,745	1,885
1 kw	725	730	735	750	755	765	775	1,670	1,900	2,040
5 kw	1,015	1,020	1,025	1,040	1,045	1,055	1,065	2,185	2,415	2,555
10 kw	1,140	1,145	1,150	1,165	1,170	1,180	1,190	2,465	2,695	2,835
25 kw	1,335	1,340	1,345	1,360	1,365	1,375	1,385	2,915	3,145	--------
50 kw	1,525	1,530	1,535	1,550	1,555	1,565	1,575	--------	--------	--------

[1] The mileages in the upper right-hand half of this section of this table do not provide for protection to the lower power Class II station. Thus, if a 0.25 kw Class II station operated 460 miles from a 0.5 kw. Class II station, it would receive interference to greater than the 2.5 mv/m ground wave contour unless the 0.5 kw. Class II station used an appropriate directional antenna.

TABLE VIII–D

Class III–A should protect other classes as shown below:

Class III–A	Class III–A		Class III–B	
	1 kw.	5 kw.	0.5 kw.	1 kw.
1 kw	735	750 / [1] 1,025	550	555
5 kw	1,025	1,040	855	735 / 860

[1] Where double figures are given, the lower and larger figure is the mileage required to protect the station in the left-hand column to its normally protected contour.

TABLE VIII–E

Class III–B should protect other classes as shown below:

Class III–B	Class III–A		Class III–B	
	1 kw.	5 kw.	0.5 kw.	1 kw.
0.5 kw	615	630 / [1] 855	395	400 / 550
1 kw	735	750 / 860	550	555

[1] Where double figures are given, the lower and larger figure is the mileage required to protect the station in the left-hand column to its normally protected contour.

TABLE VIII–F

Class IV should protect other classes as shown below:

Class IV	Class III–A		Class III–B		Class IV	
	1 kw.	5 kw.[1]	0.5 kw.	1 kw.	0.1 kw.	0.25 kw.
0.1 kw	[2] 300	[2] 300	(3)	(3)	(3)	(3)
0.25 kw	395	410	(3)	(3)	(3)	(3)

[1] Where double figures are given, the lower and larger figure is the mileage required to protect the station in the left-hand column to its normally protected contour.
[2] The distance based on the minimum practical values.
[3] Daytime separation determines.

TABLE VIII–G

Distance Class II stations should be from Class Ib stations to obtain recommended protection to Class II station (2.5 mv/m ground wave contour):

Class II [1]	Class Ib		
	10 kw.	25 kw.	50 kw.
0.25 kw	1240	1475	1700
0.5 kw	1245	1480	1705
1 kw	1250	1485	1710
5 kw	1265	1500	1725
10 kw	1265	1505	1730
25 kw	1280	1515	1740
50 kw	1290	1525	1750

[1] The class II station should use a directional antenna to protect dominant station or stations with these separations.

TABLE VIII–H

Distance Class IV stations should be from Class III–A and III–B stations to obtain recommended protection to Class IV stations (4.0 mv/m ground wave contour):

Class IV	Class III–A or III–B		
	0.5 kw.	1.0 kw.	5.0 kw.
0.1 kw	388	543	850
0.25 kw	391	546	852

ANNEX I

Interference From Ground Wave Signals

Interference that may be caused by a proposed assignment or an existing assignment during daytime 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, interpolate 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 8, 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,[15] the ground wave intensity must be determined by means of the conductivity of the terrain and the ground wave 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.

If an interfering signal traverses areas for which more than one conductivity is given by the map, the conductivity for two-thirds the distance should be taken and in case this involves more than one value, then the highest predominating value should be assumed to prevail. Where the conductivity along a given path varies over wide limits, the previous method may give erroneous results, in which case the signal at any given point, for a given value of field intensity at 1 mile from the antenna in the direction concerned may be determined by determining and adding the attenuation

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

in decibels of each section of the intervening path.[16]

Figure 4 gives the ground wave 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[17] having such height as to produce an effective field for 1 kw. of 175 mv/m.[18] 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 ground wave contour of the 1 kw. station is determined by the use of the 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

$$\left(\frac{100 \times 500}{175} = 285\right)$$

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 250 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 sky wave 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. or 25 times when the frequency separation is 20 kc. In this case the interference must be estimated on the basis of the sky wave interference and the propagation curve in Figure 1 used to determine the interfering signals rather than Figure 4 for the ground wave signals.

[16] *For example, assuming three values of conductivity prevail such that for the frequency and distances concerned the signal is attenuated over the given conductivities 6, 8, and 14 db. respectively or a total of 28 db. over the entire path, then the signal at the point concerned for 100 mv/m at 1 mile would be*

$$\frac{100}{25.119 \text{ (voltage ratio for 28 db.)}}$$

or 3.98 mv/m.

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

[18] *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.*

ANNEX II

Computation on Interfering Signal From A Directional Antenna

In case of an antenna directional in the horizontal plane, the ground wave 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 ground wave curves set out in Annex I.

In case of determining sky wave interference from an antenna with a vertical pattern different from that on which Figure 1 is predicated (the basis of the night mileage separation tables), it is necessary to compare the appropriate vectors in the vertical plane.

The sky wave curves entitled "Average Sky Wave 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 wave length (112^0) 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 wave length 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 Sky Wave 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 15^0. Therefore, if the

vertical pattern of the proposed station in the direction of the other station is such that at 15^0 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

$$140 \times 1.30 \times \frac{124}{100} \text{ or } 225 \text{ uv/m}$$

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

When the distance is large, more than one reflection may be involved and due consideration must be given each appropriate vector in the vertical pattern, as well as the constants of the earth where reflection takes place between the transmitting station and the service area to which interference may be caused.

ANNEX III

Interference From Sky Wave Signals

Set out below is the detailed method of making measurements of the sky wave 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 characteristics. 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 information must be supplied as to why the signal measured has departed from the average. If the reason 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 ground wave signals were employed, as set out in Annex I. These methods of measurement should be used to determine skyway 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.-19

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 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

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19 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.

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.[20]

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 B5a, 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.

(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 definitely establish the pattern.

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 2d 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

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

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.[21]

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.[22]

(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

[21] *See 'Further Requirements for Direct Measurement of Power' and 'Construction, General Operation, and Safety of Life Requirements.'*

[22] *See 'Indicating Instruments Pursuant to Section 3.58.'*

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.

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 ground wave signal intensity or sky wave 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 sky wave 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.[23]

(2) Observations shall be made on other stations to determine whether sky wave 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.

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 ground wave 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.

[23] *See Annex III in section 'Engineering Standards of Allocation' for detailed requirements.*

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^{0} to 90^{0} above the ground plane, based on the ground wave 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 times 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, crosshatching, 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 clearly show 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.

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 millivolt per meter 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 millivolt per meter 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

TABLE A

Power of station	Population of city or metropolitan area [1]	Approximate radius of blanket area 250 mv/m [2]	Site—distance from center of city (business or geographical)	Maximum percentage of total population in blanket area [1]
		Miles	*Miles*	*Percent*
100 watts	5,000–50,000	0.15	½–1	1
100 watts	50,000 or more	0.15	([3])	
250–500 watts	5,000–150,000	0.3–0.5	1–3	1
250–500 watts	150,000 or more	0.3–0.5	([3])	
1 kilowatt	5,000 to 200,000	0.6–0.9	2–5	1
1 kilowatt	200,000 or more	0.6–0.9	([3])	
5–10 kilowatts	All	1.5–2.5	5–10	1
25–50 kilowatts	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.

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 is 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.

Careful consideration must be given to selecting a site so that the number of people in the blanket area is a minimum. The last

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.

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 a 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 millivolts per meter will be obtained over the business or factory areas of

the city.

(2) A minimum field intensity of 5 to 10 millivolts per meter 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[24] that the present antenna system meets the minimum 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[25] or a minimum effective field intensity of 150 mv/m for 1 kilowatt (100 watts 47.5 mv/m and 250 watts, 75 mv/m).

B. Class II and III stations, or a minimum effective field intensity of 175 mv/m for 1 kilowatt.

C. Class I stations, or a minimum effective field intensity of 225 mv/m for 1 kilowatt.

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 wave length long. There should be as many of these radials evenly spaced as practicable and in no event less than 90. (120 radials of 0.35 to 0.4 of a wave length in length and spaced 3^0 is considered an excellent ground system and in case of high base voltage, 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[24] 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

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[24] *See Field Intensity Measurements in Broadcast Allocation, section A.*

[25] *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.*

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 ground wave field which would be obtained from a perfect antenna of the height specified by Figure 7 for operation on frequencies below 1000 Kilocycles, and in the case of a Class II or III station less than 90 percent of the ground wave field which would be obtained from a perfect antenna of the height specified by Figure 7 for operation on frequencies below 750 Kilocycles.

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, color chip below.) 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.

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 1,000-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 ratio 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,

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[26] Specifications normally attached to authorization.

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, 1,000-watt aviation lighting service, clear, mogul bi-post base lamps shall be employed in all cases where rotating beacons with 1,000-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 milliameter 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.

[27] 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

[26] *Specifications normally attached to authorization.*

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[28] 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 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] *By Order No. 107, dated November 6, 1942, effective December 1, 1942, the provisions of this paragraph are suspended and there are substituted in lieu thereof: '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 value of the point on the ordinate where this curve intersects the operating frequency multiplied by the factor 1.26, gives the value of the antenna resistance.'*

[28] *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 Mc-Cullough	Federal Telegraph	General Electric Co.	Heintz & Kaufman	Hygrade Sylvania	RCA Mfg. Co.	Raytheon Production Corp.	Sheldon Electric Co.	United Electronics	Western Electric	Westinghouse Electric & Manufacturing Co.	Taylor Tubes, Inc.
50				35T 50T		GL-276-A	HK-54		808	RK-32 RK-35 RK-37 RK-47 RK-51 RK-52	35T		211D 211E 248A 276A		T55
75	HF-100 203-A 211 838 852 860	C-203A 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	203-A 211 838 850 852 860	RK-58		303-A 311 361-A 938 952	242A 242B 242C 260A 261A 284A 295A	WL-195 WL-196 WL-203-A WL-211 WL-469 WL-838 WL-850 WL-860	203A 211
100				100TH 100TL 75T	F-102-A F-108-A		254			RK-36 RK-38 RK-48	100TH			WL-460 WL-468	
125	HF-200 203-H 211-C 211-D 211-H 805 810	C-200 C-201 C-211-D		150-T	F-123-A	GL-803 GL-805 GL-810			803 805 810	RK-57 RK-28A		905		WL-463 WL-803 WL-805 WL-810	HD-203A
250	204-A HF-300 212-E	C-204-A C-300	504-A 561 571	152-TL 152-TH	F-127-A F-204-A F-212-E F-331-A	GL-204-A GL-806 GL-861	354 HK354A HK354C HK354D HK354E HK354F	204-A 212-D 831 861	204A 806 831 861	RK-63		304-A 312-E	212-D 212-E	WL-204-A WL-806 WL-861	T200 204A 814 822
350	270-A 849		549	250TH 250TL 300T	F-100-A F-849	GL-849		849	849		250TH	949	270-A	WL-849	
500	251-A			304TL 304TH 450TL 450TH		GL-833	255 654		833 833-A		450TH		251-A 357-A	WL-833 WL-833-A	

[1]See footnote on p. 33.

TABLE A.—*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	RCA Mfg. Co.	Raytheon Production Corp.	Sheldon Electric Co.	United Electronics	Western Electric	Westinghouse Electric & Manufacturing Co.	Taylor Tubes, Inc.
750	279-A 849-A 849-H 851	C-849-A C-849-H	551	500T	F-121-A F-351-A	GL-851	2054-A	851	851			951	279A	WL-851	
1,000	846			750TL 750TH	F-128-A F-346-A	GL-846	1554	846	846					WL-846	
2,500	228A 1652 HF3000		520-B 520-M	1500T	F-328-A F-328-B F-348 F-3652-A	GL-207 GL-889	3054	820-B	520B 1652				228A		
5,000	207 220-C 848 343A 863 891 892 892R		507 548 563	2000T	F-126-A F-307-A F-320-A F-320-B F-343-A F-348-A F-363-A F-892 F-892-R	GL-891 GL-892 GL-892-R		207 848 863	207 848 863 891 892 892R				220B 220C 343-A 220CA 343-AA	WL-207 WL-891 WL-892 WL-892-R	
10,000	232-B 342A				F-101-B F-110-A F-110-X F-116-A F-131-A F-332-A F-332-B F-332-C F-342-A F-358-A	GL-880 GL-893			858 893-R				232A 232B 342A	WL-858 WL-893 WL-893-R	
25,000					F-117-B F-124-A F-124-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	RCA Mfg. Co.	Raytheon Production Corp.	Sheldon Electric Co.	United Electronics	Western Electric	Westinghouse Electric & Manufacturing Co.	Taylor Tubes, Inc.
25				75T		GL-203-A	154		203A	RK-32 RK-35 RK-37 RK-47 RK-51				WL-203-A	203A 211 211C
50	HF-200 203-H 211-H 242-C			100TH 100TL 150-T 152-TH 152-TL	F-123-A	GL-242-C GL-803 GL-810	HK354 HK354A HK354C HK354D HK354E HK354F		803 806 810	RK-36 RK-38 RK-57 RK-58 RK-28A RK-48	100TH		242B 242C	WL-803 WL-810	HD203-A
75	HF300 212-E 204-A		504-A		F-127-A F-204-A F-212-E	GL-204-A		204-A 212-D	204A	RK-63		304-A 312-E	212D 212E	WL-204-A	T200 204A 814 822
125	270-A 849		549	250TH 250TL 300T 450TL 450TH	F-100-A F-849	GL-833 GL-849	654	849	833 833-A 849		250TH 450TH	949	270A	WL-833 WL-833-A WL-849	
250	251-A 849-A 849-H 851	C-849-A C-849-H	551	500-T	F-121-A F-128-A F-351-A	GL-851	255 1554	851	851			951	251A	WL-851	
350				750TL 750TH											
500	279-A 846			1000UHF 1500T	F-346-A	GL-846	2054-A 3054	846	846				279A 379A	WL-846	
1,000	228-A 1652 ZB3200		520-B 520-M	2000T	F-328-A F-328-B F-3652-A			820-B	520B 1652				228A		
1,250						GL-889									

[1] *See footnote on p. 33.*

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

Power rating (watts)	Amperex	Collins	De-Forest	Eitel Mc-Cullough	Federal Telegraph	General Electric Co.	Heintz & Kaufman	Hygrade Sylvania	RCA Mfg. Co.	Raytheon Production Corp.	Sheldon Electric Co.	United Electronics	Western Electric	Westinghouse Electric & Manufacturing Co.	Taylor Tubes, Inc.
2,500	207 220-C 343-A 863 892 892-R		507 569		F-126-A F-131-A F 307-A F-320-A F-320-B F-343-A F-363-A F-892 F-892-R	GL-207 GL-892 GL-892-R		207 863	207 863 892				220-B 220-C 220CA 343-A 343-AA	WL-207 WL-892	
5,000					F-358-A	GL-858			858					WL-858	
8,500	232-B 342-A				F-101-B F-110-A F-110-X F-116-A F-131-A F-332-A F-332-B F-332-C F-342-A								232-A 232-B 342-A		
10,000						GL-880 GL-893								WL-893 WL-893-R	
12,500					F-117-B F-124-A										
25,000					F-862 F-898	GL-862 GL-898			862 898				298-A	WL-862 WL-898	
75,000													320-A		

TABLE BC.[1]—*Power rating of vacuum tubes for low-level modulation in the last radio stage operating as linear power amplifier where efficiency approaches that of Class C operation*

Power rating (watts)	Amperex	Collins	De-Forest	Eitel Mc-Cullough	Federal Telegraph	General Electric Co.	Heintz & Kaufman	Hygrade Sylvania	RCA Mfg. Co.	Raytheon Production Corp.	Sheldon Electric Co.	United Electronics	Western Electric	Westinghouse Electric & Manufacturing Co.	Taylor Tubes, Inc.
250													357-A		
2,500													220-CA		

TABLE C.[1]—*Power rating of vacuum tubes for grid modulation in the last radio stage (operating efficiency 25 percent)*

Power rating (watts)	Amperex	Collins	De-Forest	Eitel Mc-Cullough	Federal Telegraph	General Electric Co.	Heintz & Kaufman	Hygrade Sylvania	RCA Mfg. Co.	Raytheon Production Corp.	Sheldon Electric Co.	United Electronics	Western Electric	Westinghouse Electric & Manufacturing Co.	Taylor Tubes, Inc.
25				75T											
50	212-E 241-B 270-A			250TH 250TL	F-212-E		354 HK354 A&C			RK-63	250TH		212-E 270-A		
100				300T			654								
125				450TL 500T 750TL			255				450TH				
250				1000UHF			1554								
350				1500T											
500				2000T			3054								

[1] *See footnote on p. 33.*

TABLE D.[1]—*Power rating of vacuum tubes for grid modulation in the last radio stage (operating efficiency 35 percent)*

Power rating (watts)	Amperex	Collins	De Forest	Eitel Mc-Cullough	Federal Telegraph	General Electric Co.	Heintz & Kaufman	Hygrade Sylvania	RCA Mfg. Co.	Raytheon Production Corp.	Sheldon Electric Co.	United Electronics	Western Electric	Westinghouse Electric & Manufacturing Co.	Taylor Tubes, Inc.
50					152-TL 152-TH	212-E							242-C		
250	849-A 849-H														
1,000					F-328-A								228-A		
2,500	343-R 892 892-R	C-892			F-307-A F-892 F-892R				892						
10,000														WL-895-R	

[1] These tables apply only to tube ratings for use in the last radio stage of broadcast transmitters and may not be applicable to any other service.

If in an application to the Commission a vacuum tube of a type number and power rating not given in the foregoing tables is specified for operation in the last radio stage, it may be accepted provided there is also submitted to and approved by the Commission the manufacturer's rating of the vacuum tube for the system of modulation or class of service contemplated. These data must be supplied by the manufacturer. (See section 3.42 and "Requirements for Approval of Power Rating of Vacuum Tubes.")

9. REQUIREMENTS FOR APPROVAL OF POWER RATING OF VACUUM TUBES

Section 3.42 (c) requires that only vacuum tubes of approved rating be employed in the last radio stages of standard broadcast transmitters and that such approved ratings will be given only upon submission of the ratings by the manufacturer.

These ratings shall be supplied under oath in the following table form.

The value of Epn and Ipn are those values that are recommended by the manufacturers for operation at the power rating specified. The values of Epmn and Ipmn are the maximum continuous operating values that the manufacturers will stand by their guarantee on the tube specified when used in the class of service above set out.

The power ratings given below are to apply when the following conditions and limitations as to operation prevail:

(1) The vacuum tubes are to be used in the last radio stage of standard broadcast transmitters.

(2) On the broadcast frequencies of 550 to 1,600 kilocycles, inclusive.

(3) The percentage of amplitude distortion or harmonic generation by the entire transmitter (from microphone terminals to antenna outputs) is not to be over 10 percent at 100 percent modulation. The radio harmonics are not to exceed the amount considered in accordance with good engineering practice. (See section 3.46 and "Construction, General Operation and Safety of Life Requirements" to comply with section 3.46.)

(4) The ventilation, cooling, general condition of circuits with respect to tuning, impedance match, and maintenance are to be those encountered in the average broadcast station and in accordance with good engineering practice. The operation, general maintenance, and adjustments are to be those ordinarily encountered in a broadcast station.

(5) The regulation of the power supply is to be that which has been found to exist throughout the United States where broadcast stations are located or may be located.

(6) Table A should give the power rating for use in transmitter employing plate modulation in last radio stage under the above specified conditions. (See section 3.52, Table A.)

(7) Table B should give the rating for use in transmitter employing low level modulation under the above specified conditions. (See section 3.52, Table B.)

(8) Tables C and D should give the power rating for use in transmitter employing grid modulation in the last radio stage under the above specified conditions and plate efficiencies of 25 and 35 percent, respectively. (Request for approval of ratings for grid modulation in the last radio stage should specify whether the operating efficiency is to be 25 percent or 35 percent. No tube will be approved for both efficiencies. See section 3.52, Table C.)

(9) The operating power of the transmitter is to be determined by sections 3.51, 3.52, 3.53, and 3.54.

(10) Due consideration will be given to the general standard of rating so that tubes manufactured by different firms but having practically the same absolute characteristics will have approximately the same power rating.

(11) The power rating should be an even power step as recognized by the Commission's plan of allocation (100 watts, 250 watts, 500 watts, 1,000 watts, 5 kw, 10 kw, 25 kw, 50 kw), or other ratings established in "Power Rating of Vacuum Tubes." If any other rating is desired,

TABLE (A, B, C, or D)—*Class of operation*

[State whether for plate modulation in the last radio stage, low level modulation, or grid modulation in the last radio stage. See section 3.52]

Type of tube	Epn	Epmn	Ipn	Ipmn	R_L	Ec	Power rating

it will be necessary to support the request with satisfactory reasons therefor.

10. PLATE EFFICIENCY OF LAST RADIO STAGE

Section 3.53 requires that in computing the operating power of standard broadcast stations by the indirect method the efficiency factors specified in section 3.52 shall apply in all cases and no distinction will be recognized due to the operating power being less than the maximum rated carrier power.[29]

In compliance with this rule, standard broadcast stations permitted to determine the operating power by the indirect method in accordance with section 3.51 (b) and to employ greater daytime power than nighttime power shall maintain the same operating efficiency for both daytime and nighttime operation.[30]

To determine whether this condition obtains, the following procedure should be used:

The apparent antenna resistance should be computed from the daytime (highest power) operating constants and then the nighttime power in the antenna determined from the I^2R, using the apparent resistance previously determined. If this computed antenna power agrees with the nighttime operating power determined by the indirect method within plus or minus 5 percent, the station is considered as complying with the requirement of maintaining the same operating efficiency. In case the antenna current is subject to variation due to weather or other conditions, an attempt should be made to arrive at an average value for the purpose of the computations referred to herein.

11. OPERATING POWER TOLERANCE

Section 3.57 requires that except in case of emergency beyond the control of the licensee, the operating power of each standard broadcast station shall be maintained within the prescribed limits of the licensed power.

Each station shall be operated at all times as near to the authorized power as practicable. However, in order to provide for variations in the power supply or other factors affecting the operating power which would necessitate continual adjustment to keep the operating power exactly the same as the authorized power, the operating power may be permitted to vary from 5 percent above to 10 percent below the authorized power for periods of short duration.

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

12. CONSTRUCTION, GENERAL OPERATION, AND SAFETY OF LIFE REQUIREMENTS

Section 3.46 requires that the transmitter proper and associated transmitting equipment of each broadcast station shall be designed, constructed, and operated in accordance with the Standards of Good Engineering Practice in addition to the specific requirements of the Rules and Regulations of the Commission.

The specifications deemed necessary to meet the requirements of the Rules and Regulations and good engineering practice with respect to design, construction, and operation of standard broadcast stations are set forth below. These specifications will be changed from time to time as the state of the art and the need arises for modified or additional specifications.

A. *Design* — The general design of standard broadcast transmitting equipment [main studio microphone (including telephone lines, if used, as to performance only[31]) to antenna output] shall be in accordance with the following specifications. For the points not specifically covered below, the principles set out shall be followed:

The equipment shall be so designed that:

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

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

(3) The total audio frequency distortion from microphone terminals, including microphone amplifier, to antenna output does not exceed 5 percent harmonics

[29] *See section 3.52, Table A.*

[30] *When different last radio stages with different systems of modulation are employed for the two powers, the same principle shall apply, that is, the power shall be determined by the plate input times the proper efficiency factor and the antenna current shall change in proportion to the square root of the change in power within 5 percent.*

[31] *In cases where telephone lines are not available to give the performance as required in these specifications a relay transmitter may be authorized to supersede the lines.*

(voltage measurements of arithmetical sum or r.s.s.) when modulated from 0 to 84 percent, and not over 7.5 percent harmonics (voltage measurements of arithmetical sum or r.s.s.) when modulating 85 percent to 95 percent (distortion shall be measured with modulating frequencies of 50, 100, 400, 1,000, 5,000 and 7,500 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 1,000 cycles between 100 and 5,000 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 5,000 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[32] 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[33] 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.

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 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[34] protected as required by article 810 of the National Electrical Code[35] 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

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

[33] See 'Use of Low Temperature Coefficient Crystals by Broadcast Stations.'

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

instances the place circuit of the tubes may provide such protection; however, individual approval of such shall be obtained by the manufacturer in case of standard equipment, and the licensee in case of composite equipment).

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

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. Lighting 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.[36]

(4) Metering equipment:[37]

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 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 overvoltage 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 neces-

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[35] *The pertinent sections of Article 810 of the National Electrical Code read as follows:*

'810 1. 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.'

[36] *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.*

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

sary for the operator to read) shall be so installed as to be easily and accurately read without the operator having to risk contact with circuits carrying high potential radio frequency energy.

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

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

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

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

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

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

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

(2) Since an operator must be on duty 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. 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*

F. *Operation* — In addition to the specific requirements of the rules governing standard broadcast stations, the following operating requirements shall be observed:

(1) The maximum percentage of modulation shall be maintained at as high level as practicable without causing undue audio frequency harmonics, which shall not be in excess of 10 percent when operating with 85 percent modulation.

(2) Spurious emissions, including radio frequency harmonics and audio frequency harmonics, shall be maintained at as low a level as practicable at all times in accordance with good engineering practice.

(3) In the event interference is caused to other stations by modulating frequencies in excess of 7,500 cycles or spurious emissions, including radio frequency harmonics and audio frequency harmonics outside the band plus or minus 7,500 cycles of the authorized carrier frequency, the licensee shall install equipment or make adjustments which limit the emissions to within this band or to such an extent above 7,500 cycles as to reduce the interference to where it is no longer objectionable.

(4) The operating power shall be maintained within the limits of 5 percent above and 10 percent below the authorized operating power and shall be maintained as near as practicable to the authorized operating power.

(5) Licensees of broadcast stations employing directional antenna systems shall maintain the ratio of the currents in the elements of the array within 5 percent of that specified by the terms of the license or other instrument of authorization.

(6) In case of excessive shift in operating frequency during warm-up periods, the crystal oscillator shall be operated continuously. The automatic temperature control circuits should be operated continuously under all circumstances.

G. *Studio equipment* — The studio equipment shall be subject to all the above requirements

where applicable except as follows:

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

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

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

13. INDICATING INSTRUMENTS PURSUANT TO SECTION 3.58

Section 3.58 requires that each standard broadcast station shall be equipped with suitable indicating instruments of accepted accuracy to measure the antenna current, direct plate circuit voltage, and the direct plate circuit current of the last radio stage.

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

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

(1) Length of scale shall be not less than 2-3/10 inches.

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

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

(4) Scale shall have at least 40 divisions.

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

B. Instruments indicating the antenna current shall meet the following specifications:

(1) Instruments having logarithmic or square law scales.

a. Shall meet same requirements as 1, 2, and 3 above for linear scale instruments.

b. Full scale reading shall not be greater than three times the minimum normal indication.

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

(2) Radio frequency instruments having expanded scales.

a. Shall meet same requirements as 1, 2, and 3 for linear scale instruments.

b. Full scale reading shall not be greater than five times the minimum normal indication.

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

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

(3) Remote reading antenna ammeters may be employed and the indications logged as the antenna current in accordance with the following:

a. Remote reading antenna ammeters may be provided by:

1. Inserting second thermocouple directly in the antenna circuit with remote leads to the indicating instrument.

2. Inductive coupling to thermocouple or other device for providing direct

current to indicating instrument.

3. Capacity coupling to thermocouple or other device for providing direct current to indicating instrument.

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

5. Using transmission line current meter at transmitter as remote reading ammeter. See paragraph (h) below.

6. Using indications of phase monitor for determining the ratio of antenna currents in the case of directional antennas, provided the indicating instruments in the unit are connected directly in the current sampling circuits with no other shunt circuits of any nature.

b. A thermocouple type ammeter meeting the above requirements shall be permanently installed in the antenna circuit. (This thermocouple ammeter may be so connected that it is short circuited or open circuited when not actually being read. If open circuited, a make-before-break switch must be employed.)

c. The remote ammeter shall be connected at the same point in the antenna circuit as the thermocouple ammeter and shall be so connected and calibrated as to read in amperes within 2 percent of this meter over the entire range above one-third or one-fifth full scale. See sections B1 (c) and B2 (c) above respectively.

d. The regular antenna ammeter shall be above the coupling to the remote meter in the antenna circuit so it does not read the current to ground through the remote meter.

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

f. Calibration shall be checked against the regular meter at least once a week.

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

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

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 an 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, 1,000 cycles).

   3. Data on audio frequency harmonics for 25-, 50-, 85-, and 100- percent modulation for the fundamental frequencies of 50, 100, 400, 1,000, 5,000, and 7,500 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[38] 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 at the Bureau of Standards. However, the Bureau of Standards does not approve or disapprove the monitor as this is entirely in the hands of the Commission. 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 request the Bureau of Standards to issue shipping instructions. The cost of tests as well as the shipping charges shall be paid by the manufacturer.

In approving a frequency monitor, based upon the tests at the Bureau of Standards, 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.[38]

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

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[38] *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.*

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.

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 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 accurately read within at least 1 cycle.

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

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 thermometer such that the temperature can be accurately measured within 0.025° C. for *X* or *Y* cut crystal or 0.25° C. for low temperature coefficient crystal.

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

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

C. Tests To Be Made By The Bureau of Standards

The tests to be made at the Bureau of Standards 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 Bureau of Standards all instructions or services which will be supplied to the purchaser of the equipment. The equipment, as submitted, shall be adjusted for operation in connection with broadcast stations operating on 1600 kilocycles.

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 at the Bureau of Standards. However, the Bureau of Standards does not approve or disapprove the monitor as this is entirely in the hands of the Commission. 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 request the Bureau of Standards to issue shipping instructions. The cost of tests, as well as the shipping charge, 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 ±1/2 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

Bellefonte Eng. Labs., Bellefonte, Pa.
Premier Crystal Labs, Inc., 53-63 Park Row, New York City.
RCA Mfg. Co., Camden, N.J.
Precision Piezo Service, Baton Rouge, La.
Scientific Research Laboratories, Hyattsville Md.
Commercial Radio Equipment Co., 216 East Seventy-fourth Street, Kansas City, Mo.
Hollister Crystal Co., Merriam, Kans.
Piezo Electric Laboratories, New Dorp, N.Y.
Collins Radio Co., Cedar Rapids, Iowa
Western Electric Co., New York, N.Y.
William W. L. Burnett, San Diego, Calif.
American Piezo Supply Co., Kansas City, Mo.
Bliley Electric Co., Union Station Building, Erie, Pa.
Hipower Crystal Co., 2035 West Charleston Street, Chicago, Ill.
Precision Crystal Laboratories, P.O. Box 326, Springfield, Mass.
Theodore S. Valpey, Holliston, Mass.

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) permits the simultaneous use of the same antenna or antenna structure by two standard broadcast stations or a standard broadcast station and a station of another service or class only when both are licensed to the same licensee.

Such simultaneous use may be authorized to the same licensee provided:

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

(2) The requirements of section 3.45 (a) and (b) are met 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 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 twenty 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 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.

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[39] independent of the frequency control of the transmitter.

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

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 specifica-

Manufacturer's name	Type	Approval No.
General Radio Co.	25-A	1461
RCA Victor Co.	311-A	1462
General Radio Co.	25-AB	1463
Western Electric Co.	1-C	1464

[39] *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.*

Manufacturer's name	Type No.	Approval No.
General Radio Co.	731-A or B	1551
RCA Manufacturing Co.	66-A	1552
Do.	66-B	1553

tions issued pursuant to section 3.55 (d):

23. APPROVED EQUIPMENT

Sections 3.41 to 3.64 govern the design, construction, and technical operation of standard broadcast equipment. There are listed below the equipments which have 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. BC 46T, automatic temperature control unit.

Collins Radio Co., Cedar Rapids, Iowa:

Type No. 10S-2, automatic frequency control unit.
Type No. 20H 1,000-watt broadcast transmitter.
Type No. 20HA, 1,000-watt broadcast transmitter.
Type No. 20J, 1,000-watt broadcast transmitter.
Type No. 20K, 1,000-watt broadcast transmitter.
Type No. 21A, 5,000-watt broadcast transmitter.
Type No. 21D, 5,000-watt broadcast transmitter.
Type No. 21DA, 5,000-watt broadcast transmitter.
Type No. 21DX, 5,000-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. 300G, 100-watt broadcast transmitter.
Type No. 300FA, 250-watt broadcast transmitter.

Doolittle Radio Inc., 7421 S. Loomis Blvd., 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, 1,000-watt broadcast transmitter.

Federal Telegraph Co., Newark, N.J.

Type No. 162-A, 50-kw. broadcast transmitter.
Type No. 163-A, 5-kw broadcast transmitter.

Gates American Corporation, Quincy, Ill.:

Type No. 25-A, automatic frequency control unit.
Type No. 100-A, 100-watt broadcast transmitter.
Type No. S-101, 100-watt broadcast transmitter.
Type No. 250-A, 250-watt broadcast transmitter.
Type No. S-251, 250-watt broadcast transmitter.
Type No. 250-C, 250-watt broadcast transmitter.
Type No. 500-A, 500-watt broadcast transmitter.
Type No. 1000-C, 1,000-watt broadcast transmitter.

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

Type No. 32 C 401-G 30, automatic temperature control unit.

Piezoelectric 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 AFCU or crystal).

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

Type No. 50-M, automatic temperature control unit.

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

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

RCA Victor, Inc., Camden, N.J.:

Type No. UL-4292, 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. 250-D, 250-watt broadcast transmitter.
Type No. 250-E, 250-watt broadcast transmitter.
Type No. 250-F, 250-watt broadcast exciter unit.
Type No. 250-G, 250-watt broadcast transmitter.
Type No. 250-K, 250-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. 5-D, 5-kw broadcast transmitter.
Type No. 5-D-1, 5-kw broadcast transmitter.
Type No. 5-D-2, 5-kw broadcast transmitter.
Type No. 5-E, 5-kw broadcast transmitter.
Type No. 5-DX, 5-kw broadcast transmitter.
Type No. 10-C-A, 10-kw broadcast transmitter.
Type No. 10-C-B, 10-kw broadcast transmitter.
Type No. 10-D, 10-kw broadcast transmitter.
Type No. 10-DX, 10-kw broadcast transmitter.
Type No. 10-E, 10-kw broadcast transmitter.
Type No. 50-D, 50-kw, broadcast transmitter.
Type No. 50-D, 50-kw, power amplifier.
Type No. 50-E, 50-kw, power amplifier.

Western Electric Co., 195 Broadway, New York City:

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 kw broadcast transmitter.
Type No. 403A-1, 1 kw broadcast transmitter.
Type No. 405A-1, 1 kw broadcast transmitter.
Type No. 405A-2, 5 kw broadcast transmitter.
Type No. 405B-1, 5 kw broadcast transmitter.
Type No. 405B-2, 5 kw broadcast transmitter.
Type No. 406A-1, 10 kw broadcast transmitter.
Type No. 406A-2, 10 kw broadcast transmitter.
Type No. 406A-3, 10 kw broadcast transmitter.
Type No. 406B-1, 10 kw broadcast transmitter.
Type No. 407-A-1, 50 kw broadcast transmitter.
Type No. 407-A-2, 50 kw broadcast transmitter.
Type No. 407-A-3, 50 kw broadcast transmitter.
Type No. 407-A-4, 50 kw broadcast transmitter.
Type No. 442-A-1, 500 watt broadcast transmitter.
Type No. 443-A-1, 1,000 watt broadcast transmitter.

Westinghouse Electric and Manufacturing Co., 2519 Wilkins Avenue, Baltimore, Md.

Type No. 50-HG, 50 kw broadcast transmitter.
Type No. 10HV, 10 kw broadcast transmitter.
Type No. 5HV, 5 kw broadcast transmitter.

2m. 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 is set out below the correct forms to be submitted in making application for various authorizations applicable to standard broadcast stations.

In general, these forms shall be completed in full, answering each specific section. The only exception is in the technical sections when in the case of standard equipment, which has been approved by type number by the Commission, or when no change in such equipment is involved, in which cases, the manufacturer's name and type number of the approved equipment may be stated, or should be answered "no change" in each section applicable. All applications involving actual operation, such as license to cover construction permit, renewal of license, etc., shall be completed in full, regardless of whether such information has been previously filed with the Commission.

F.C.C. Form 301, Application for new Standard Broadcast Station, Construction Permit, shall be used for all applications for authority to erect a new standard broadcast station.

F.C.C. Form 302, Application for Standard Broadcast Station License shall be used for all all applications for license:

(1) To cover construction permit.

(2) To use the former main transmitter as the auxiliary transmitter when no new construction is involved.

(3) For regular authorization covering special experimental authorization.

F.C.C. Form 303, Application for Renewal of Standard Broadcast Station License shall be used for all applications for renewal of regular licenses of all standard broadcast stations.

F.C.C. Form 304, Application for Construction Permit, Modification of Permit or License, shall be used for all applications for modification of any term of an existing regular license of a standard broadcast station:

(1) Change of frequency.

(2) Change of power where the equipment at present installed is capable of satisfactory operation at the proposed power.

(3) Change of time of operation.

(4) Change of location of main studio. (See Section 3.31)

(5) Change name of licensee where no change of ownership is involved.

(6) To change location of an existing transmitter or for approval of location previously authorized to be determined subject to Commission approval.

(7) To ihstall directional antenna system.

(8) For modification of any outstanding construction permit which has not been covered by license.

F.C.C. Form 305, Application for Authority to Install New Equipment or to Make Changes in equipment of an Existing Standard Broadcast Station, shall be used in making application for authority:

(1) To install new automatic frequency control equipment.

(2) To install new automatic temperature control chamber.

(3) Any other change affecting the accuracy or stability of the operating frequency of a standard broadcast station where an application for construction permit as above listed is not required.

(4) To install new transmitter.

(5) To make changes in existing equipment with respect to system of modulation.

(6) To change type of vacuum tubes in the last radio stage except to tubes of the same rating in accordance with release "Power Rating of Vacuum Tubes."

(7) To change number of vacuum tubes in the last radio stage.

(8) To make any other change affecting the maximum rated carrier power or type number of equipment.

F.C.C. Form 306, Application to Determine Operating Power of Broadcasting Station by Direct Measurement of Antenna Power, shall be used in making all applications for authority to determine power by the direct method.

F.C.C. Form 307, Application for Standard Broadcast Station Experimental Authorization or Extension Thereof, shall be used in making application for --

(1) Any special experimental authorization under Section 3.32.

(2) Any extension thereof.

NOTE -- Attention is invited to note 2 of FCC form 307, which reads: "Give detailed description by completing FCC forms 301, sections 17, 18, 19, and 20, or 305, sections 6 and 7, and any other form if more complete engineering description of proposed equipment can be given thereby."

F.C.C. Form 308, Application for Permit to Locate, Maintain, or use Studio or Apparatus

for Production of Programs to be Transmitted or Delivered to Foreign Radio Stations, shall be used in making application for all authorizations under section 325 (b) of the Communications Act of 1934.

F.C.C. Form 327, Supplemental Statement of Facts required under section 308 of the Communications Act of 1934 regarding station equipment, shall be submitted:

(1) Subsequent to the completion of any changes in automatic frequency control or devices.

(2) As may be required on other changes affecting frequency stability.

NOTE -- The information required under sections (e), (f), (g), and (h) shall be obtained from operation during the experimental period and no operation shall occur during the regular broadcast day until the Commission has approved this information, which may be submitted by telegram, provided, FCC form 327, properly completed and executed, has been deposited in the United States mail and the telegram so states.

F.C.C. Form 701, Application for Additional Time to Construct Radio Station, shall be submitted for all extensions of commencement and/or completion dates of construction permits.

F.C.C. Form 314, Application for Consent to Assignment of Radio Broadcast Station Construction Permit or License, shall be used in all such cases in accordance with section 1.364.

F.C.C. Form 315, Application for Consent to Transfer of Control of Corporation Holding Construction Permit or Station License, shall be used in all such cases in accordance with section 1.364.

F.C.C. Form 316, Inventory of Station property, shall be submitted with and as part of F.C.C. Forms 314 and 315 in accordance with the requirements of section 1.364.

F.C.C. Form 328, Income Statement, shall be submitted with F.C.C. Forms 314 and 315 in accordance with the requirements of section 1.364.

F.C.C. Form 329, Balance Sheet, shall be submitted with applications:

(1) For substantial changes for existing station.

(2) For consent to assignment of radio station construction permit or license by (a) the assignor and (b) the assignee.

(3) For consent to transfer of control of a licensed corporation by (a) the licensed corporation and (b) the transferee.

F.C.C. Form 317 Application for Standard Broadcast Station Special Service Authorization or Extension Thereof shall be submitted for all such authorizations in accordance with section 1.366.

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 inspector in charge	Territory within district	
		States	Counties
1	Customhouse, 7th floor, Boston, 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, 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, Greene, Kings, Nassau, New York, Orange, Putnam, Queens, Rensselaer, Richmond, Rockland, Schenectady, Suffolk, Sullivan, Ulster, and Westchester.

Radio district	Address of the inspector in charge	Territory within district	
		States	Counties
3	Room 1200, New U. S. Customhouse, 2d and Chestnut Sts., Philadelphia, 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 Falsway, Baltimore, Md.	Delaware	Kent and Sussex.
		District of Columbia	
		Maryland	All counties.
		Virginia	Arlington, Clarke, Fairfax, Fauquier, Frederick, Loudoun, Page, Prince William, Rappahannock, Shenandoah, and Warren.
5	Room 402, New Post Office Bldg., Norfolk, Va.	North Carolina	All except district 6.
		Virginia	All except district 4.
6	411 Federal Annex, Atlanta, Ga.	Alabama	All except district 8.
	Suboffice, P. O. Box 77 (214–218 Post Office Bldg.), Savannah, Ga.	Georgia	All counties.
		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, Fla.	Florida	All except district 8.
	Suboffice 203 Post Office Bldg., Tampa, Fla.		
8	400 Audubon Bldg., New Orleans, La.	Alabama	Mobile, Baldwin.
		Arkansas	All counties.
		Florida	Escambia.
		Louisiana	All counties.
		Mississippi	Do.
		Texas	City of Texarkana only.
9	Room 404, Federal Bldg., Galveston, Tex.	Texas	Aransas, Brazoria, Brooks, Calhoun, Cameron, Chambers, Fort Bend, Galveston, Goliad, Harris, Hidalgo, Jackson, Jefferson, Jim Wells, Kenedy, Kleberg, Matagorda, Nueces, Refugio, San Patricio, Victoria, Wharton, and Willacy.
	Suboffice, P. O. Box 1527 (329 Post Office Bldg.), Beaumont, Tex.		
10	P. O. Box 5238 (500 U. S. Terminal Annex Bldg.), Dallas, 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, Calif.	Arizona	All counties.
		California	Imperial, Inyo, Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, San Luis Obispo, Santa Barbara, and Ventura.
	Suboffice 307 U. S. Customhouse and Courthouse Bldg., Union and F Sts., San Diego, Calif.	Nevada	Clarke.
12	328 Customhouse, San Francisco, Calif.	California	All except district 11.
		Nevada	All except Clarke.
		Guam	
		Midway	
		Wake	
		American Samoa	
13	805 Terminal Sales Bldg., Portland, Oreg.	Idaho	All except district 14.
		Oregon	All counties.
		Washington	Wahkiakum, Cowlitz, Clark, Skamania, and Klickitat.
14	808 Federal Office Bldg., Seattle, Wash.	Idaho	Benewah, Bonner, Boundary, Clearwater, Idaho, Kootenai, Latah, Lewis, Nez Perce, and Shoshone.
		Montana	All counties.
		Washington	All except district 13.

Radio district	Address of the inspector in charge	Territory within district	
		States	Counties
15	504 Customhouse, Denver, Colo.	Colorado	All counties.
		Utah	Do.
		Wyoming	Do.
16	298 Uptown Post Office and Federal Courts Bldg., 5th and Washington Sts., St. Paul, Minn.	Minnesota	Do.
		Michigan	Alger, Baraga, Chippewa, Delta, Dickinson, Gogebic, Houghton, Iron, Keweenaw, Luce, Mackinac, Marquette, Menominee, Ontonagon, and Schoolcraft.
		North Dakota	All counties.
		South Dakota	Do.
		Wisconsin	All except district 18.
17	809 U. S. Courthouse, Kansas City, Mo.	Iowa	All except district 18.
		Kansas	All counties.
		Missouri	Do.
		Nebraska	Do.
18	246 U. S. Courthouse Bldg., Chicago, 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	Columbia, Crawford, Dane, Dodge, Grant, Green, Iowa, Jefferson, Kenosha, Lafayette, Milwaukee, Ozaukee, Racine, Richland, Rock, Sauk, Walworth, Washington, and Waukesha.
19	1029 New Federal Bldg., Detroit, Mich.	Kentucky	All counties.
		Michigan	All except district 16.
	Suboffice, 541 Old Post Office Bldg., Cleveland, Ohio.	Ohio	All counties.
		West Virginia	Do.
20	328 Federal Bldg., Buffalo, N. Y.	New York	All except district 2.
		Pennsylvania	All except district 3.
21	609 Stangenwald Bldg., Honolulu, T. H.	Territory of Hawaii	
22	P. O. Box 2987 (322-323 Federal Bldg.), San Juan, P. R.	Puerto Rico	
		Virgin Islands	
23	P. O. Box 1421, (7-8 Shattuck Bldg.), Juneau, Alaska.	Alaska	
Monitoring Station	Allegan Monitoring Station, P. O. Box 89, Allegan, Mich.		
Monitoring Station	Central Frequency Monitoring Station, P. O. Box 788, Grand Island, Nebr.		
Monitoring Station	Kingsville Monitoring Station, P. O. Box 632, Kingsville, Tex.		

26. AVERAGE SUNRISE AND SUNSET TIMES

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)

(A) Atlantic, (E) Eastern, (C) Central, (M) Mountain, (P) Pacific, Standard Times.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Aberdeen, S. Dak. (C):												
SR	9:15	8:45	7:45	6:45	6:00	5:45	6:00	6:30	7:15	7:45	8:30	9:00
SS	6:15	7:00	7:45	8:15	9:00	9:30	9:15	8:45	7:45	6:45	6:00	5:45
Abilene, Kans. (C):												
SR	8:45	8:15	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:15	8:45
SS	6:30	7:00	7:30	8:00	8:30	9:00	9:00	8:30	7:45	6:45	6:15	6:15
Akron, Ohio °(E):												
SR	8:45	8:15	7:45	6:45	6:15	6:00	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:30	9:00	9:00	8:30	7:30	6:45	6:15	6:00
Albany, Ga. (E):												
SR	8:45	8:15	7:45	7:15	6:45	6:30	6:45	7:00	7:15	7:45	8:00	8:30
SS	7:00	7:30	7:45	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:45	6:30
Albany, N. Y. °(E):												
SR	8:30	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:15	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:15	8:30	8:30	8:00	7:15	6:15	5:30	5:15
Albuquerque, N. Mex. (M):												
SR	8:15	8:00	7:15	6:30	6:00	5:45	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:00	8:15	8:15	8:00	7:15	6:30	6:00	6:00
Altoona, Pa. °(E):												
SR	8:30	8:15	7:30	6:30	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	6:45	7:15	7:45	8:15	8:45	8:45	8:15	7:30	6:30	6:00	5:45
Amarillo, Tex. (C):												
SR	9:00	8:30	8:00	7:15	6:45	6:30	6:45	7:00	7:30	8:00	8:15	8:45
SS	7:00	7:30	8:00	8:15	8:45	9:00	9:00	8:30	8:00	7:15	6:45	6:30
Ames, Iowa (C):												
SR	8:45	8:15	7:30	6:30	6:00	5:30	5:45	6:15	7:00	7:30	8:00	8:30
SS	6:00	6:45	7:15	8:00	8:30	8:45	8:45	8:15	7:30	6:30	6:00	5:45
Anderson, Ind. (C):												
SR	8:00	7:45	7:00	6:00	5:30	5:15	5:30	6:00	6:30	6:45	7:30	8:00
SS	5:45	6:15	6:45	7:15	7:45	8:15	8:15	7:45	7:00	6:00	5:30	5:15
Ardmore, Okla. (C):												
SR	8:30	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:30	8:00	8:30	8:45	8:45	8:15	7:30	7:00	6:30	6:15
Asheville, N. C. (E):												
SR	8:45	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:30	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:30	6:15
Ashtabula, Ohio (E):												
SR	8:45	8:15	7:45	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:30	9:00	9:00	8:30	7:30	6:45	6:00	6:00
Atlanta, Ga. °(E):												
SR	8:45	8:30	7:45	7:15	6:30	6:30	6:30	7:00	7:15	7:45	8:15	8:30
SS	6:45	7:15	7:45	8:15	8:30	8:45	8:45	8:30	7:45	7:00	6:30	6:30
Atlantic City, N. J. °(E):												
SR	8:15	7:45	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:00	7:45	8:15
SS	6:00	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:15	6:15	5:45	5:30
Aurora, Ill. (C):												
SR	8:15	7:45	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:30
Austin, Texas (C):												
SR	8:30	8:15	7:45	7:00	6:30	6:30	6:45	7:00	7:15	7:30	8:00	8:15
SS	6:45	7:15	7:45	8:00	8:15	8:30	8:30	8:15	7:45	7:00	6:30	6:30
Baker, Oreg. (P):												
SR	8:30	8:00	7:00	6:15	5:30	5:00	5:15	5:45	6:30	7:00	7:15	8:15
SS	5:30	6:15	7:00	7:30	8:15	8:45	8:30	8:00	7:00	6:15	5:30	5:15
Baltimore, Md. °(E):												
SR	8:30	8:00	7:15	6:30	6:00	5:45	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Bangor, Maine (E):												
SR	8:15	7:45	6:45	6:00	5:15	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	8:15	8:15	7:45	6:45	5:45	5:15	5:00
Baton Rouge, La. (C):												
SR	8:00	7:45	7:15	6:45	6:15	6:00	6:15	6:30	6:45	7:00	7:30	8:00
SS	6:30	6:45	7:15	7:30	7:45	8:15	8:15	7:45	7:15	6:30	6:15	6:00
Bay City, Mich. (E):												
SR	9:15	8:30	7:45	7:00	6:15	6:00	6:00	6:45	7:15	7:45	8:30	9:00
SS	6:30	7:00	7:45	8:15	9:00	9:15	9:15	8:45	7:45	7:00	6:15	6:30
Beaumont, Tex. (C):												
SR	8:15	8:00	7:30	6:45	6:30	6:15	6:30	6:45	7:00	7:15	7:45	8:00
SS	6:45	7:00	7:30	7:45	8:00	8:15	8:15	8:00	7:30	6:45	6:15	6:15
Beverly Hills, Calif. °(P):												
SR	8:00	7:45	7:00	6:30	5:45	5:45	5:45	6:15	6:30	7:00	7:30	7:45
SS	6:00	6:30	7:00	7:30	7:45	8:00	8:00	7:45	7:00	6:15	5:45	5:45
Billings, Mont. (M):												
SR	9:00	8:15	7:30	6:30	5:45	5:30	5:30	6:15	6:45	7:30	8:15	8:45
SS	6:00	6:45	7:15	8:00	8:30	9:00	9:00	8:30	7:30	6:30	5:45	5:30
Binghamton, N. Y. (E):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	8:00	8:30
SS	6:00	6:30	7:15	7:45	8:15	8:45	8:45	8:00	7:15	6:30	5:45	5:30

°Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Birmingham, Ala. *(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
Bismarck, N. D. (C):												
SR	9:30	8:45	8:00	7:00	6:15	5:45	6:00	6:45	7:15	8:00	8:45	9:15
SS	6:15	7:00	7:45	8:30	9:15	9:45	9:30	9:00	8:00	7:00	6:15	6:00
Bluefield, W. Va. (E):												
SR	8:45	8:15	7:45	6:45	6:15	6:00	6:15	6:45	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:15	6:15
Blytheville, Ark. (C):												
SR	8:15	7:45	7:15	6:30	6:00	5:45	6:00	6:15	6:45	7:00	7:30	8:00
SS	6:15	6:45	7:00	7:30	8:00	8:15	8:15	7:45	7:15	6:30	6:00	5:45
Boise, Idaho (M):												
SR	9:15	8:45	8:00	7:00	6:15	6:00	6:15	6:45	7:30	8:00	8:15	9:15
SS	6:30	7:15	7:45	8:30	9:00	9:30	9:30	8:45	8:00	7:00	6:15	6:15
Boone, Iowa (C):												
SR	8:45	8:15	7:30	6:30	6:00	5:45	5:45	6:15	7:00	7:30	8:00	8:30
SS	6:15	6:45	7:15	8:00	8:30	9:00	8:45	8:15	7:30	6:30	6:00	5:45
Boston, Mass. *(E):												
SR	8:15	7:45	7:00	6:00	5:30	5:00	5:15	5:45	6:30	7:00	7:30	8:00
SS	5:30	6:15	6:45	7:30	8:00	8:15	8:15	7:45	7:00	6:00	5:30	5:15
Brady, Tex. (C):												
SR	8:30	8:15	7:45	7:15	6:45	6:30	6:45	7:00	7:15	7:45	8:00	8:30
SS	7:00	7:30	7:45	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:45	6:30
Bridgeport, Conn. *(E):												
SR	8:15	7:45	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:30
Brookings, S. D. (C):												
SR	9:00	8:30	7:45	6:45	6:00	5:45	6:00	6:30	7:00	7:45	8:15	9:00
SS	6:15	7:00	7:30	8:15	8:45	9:15	9:15	8:30	7:45	6:45	6:00	5:45
Brooklyn, N. Y. *(E):												
SR	8:15	7:45	7:15	6:15	5:45	5:30	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:45	5:30
Brownsville, Tex. (C):												
SR	8:15	8:00	7:45	7:15	6:45	6:30	6:45	7:00	7:15	7:30	7:45	8:15
SS	7:00	7:30	7:45	8:00	8:15	8:30	8:30	8:00	7:30	7:00	6:45	6:45
Brunswick, Ga. (E):												
SR	8:30	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:15
SS	6:45	7:15	7:30	8:00	8:15	8:30	8:30	8:15	7:30	7:00	6:30	6:30
Buffalo, N. Y. *(E):												
SR	8:45	8:15	7:30	6:30	6:00	5:30	5:45	6:15	7:00	7:30	8:00	8:45
SS	6:00	6:45	7:15	8:00	8:30	9:00	9:00	8:15	7:30	6:30	6:00	5:45
Burlington, N. C. (E):												
SR	8:30	8:00	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:30	8:00	8:15
SS	6:30	7:00	7:30	7:45	8:15	8:30	8:30	8:15	7:30	6:45	6:15	6:00
Butler, Pa. (E):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	7:00	7:30	8:00	8:30	9:00	8:45	8:15	7:30	6:45	6:00	6:00
Butte, Montana (M):												
SR	9:15	8:30	7:45	6:45	6:00	5:45	6:00	6:30	7:00	7:45	8:30	9:00
SS	6:15	7:00	7:30	8:15	9:00	9:15	9:15	8:45	7:45	6:45	6:00	5:45
Camden, N. J.* (E):												
SR	8:15	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:00	7:45	8:15	8:30	8:30	8:00	7:15	6:30	5:45	5:30
Canton, N. Y. (E):												
SR	8:30	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:45	7:15	8:00	8:30
SS	5:45	6:30	7:00	7:45	8:15	8:45	8:45	8:00	7:15	6:15	5:30	5:15
Canton, Ohio* (E):												
SR	8:45	8:15	7:45	6:45	6:15	6:00	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:30	9:00	9:00	8:30	7:30	6:45	6:15	6:00
Carthage, Ill. (C):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	5:45	5:45
Cedar Rapids, Iowa (C):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	8:00	8:30
SS	6:00	6:45	7:15	7:45	8:15	8:45	8:45	8:15	7:15	6:30	5:45	5:30
Charleston, S. C. (E):												
SR	8:30	8:00	7:30	6:45	6:15	6:15	6:15	6:45	7:00	7:30	7:45	8:15
SS	6:30	7:00	7:30	7:45	8:15	8:30	8:30	8:00	7:30	6:45	6:15	6:15
Charleston, W. Va.* (E):												
SR	8:45	8:15	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:30	8:15	8:30
SS	6:30	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:15	6:15
Charlotte, N. C. (E):												
SR	8:30	8:15	7:30	7:00	6:15	6:15	6:15	6:45	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	8:00	8:15	8:45	8:45	8:15	7:30	6:45	6:15	6:15
Chattanooga, Tenn.* (C):												
SR	7:45	7:30	7:00	6:15	5:45	5:30	5:30	6:00	6:30	6:45	7:15	7:45
SS	5:45	6:30	6:45	7:15	7:30	8:00	8:00	7:30	6:45	6:15	5:30	5:30

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Cheyenne, Wyoming (M):												
SR	8:30	8:00	7:15	6:15	5:45	5:30	5:45	6:00	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:00	7:45	8:15	8:30	8:30	8:00	7:15	6:15	5:45	5:30
Chicago, Ill.* (C):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:15
Chico, Calif. (P):												
SR	8:30	8:00	7:15	6:30	6:00	5:45	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Cincinnati, Ohio* (E):												
SR	9:00	8:30	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:45	8:15	8:45
SS	6:45	7:15	7:45	8:15	8:45	9:00	9:00	8:30	7:45	7:00	6:30	6:15
Clayton, Missouri* (C):												
SR	8:15	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:45	7:00	7:30	8:00	8:30	8:30	8:00	7:15	6:30	5:45	5:45
Cleveland, Ohio* (E):												
SR	9:00	8:30	7:45	6:45	6:15	5:45	6:00	6:30	7:00	7:45	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:45	9:00	9:00	8:30	7:45	6:45	6:15	6:00
Coffeyville, Kans. (C):												
SR	8:30	8:15	7:30	6:45	6:15	6:00	6:15	6:45	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:15	6:00
Columbia, Mo. (C):												
SR	8:30	8:00	7:30	6:30	6:00	5:45	6:00	6:15	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Columbia, S. C. (E):												
SR	8:30	8:15	7:30	7:00	6:30	6:15	6:30	6:45	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	8:00	8:15	8:30	8:30	8:15	7:30	6:45	6:15	6:15
Columbus, Ohio* (E):												
SR	9:00	8:30	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:15	8:45
SS	6:30	7:00	7:45	8:15	8:45	9:00	9:00	8:30	7:45	7:00	6:15	6:15
Cordele, Ga. (E):												
SR	8:30	8:15	7:45	7:15	6:45	6:30	6:45	7:00	7:15	7:45	8:00	8:30
SS	7:00	7:15	7:45	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:30	6:30
Corpus Christi, Tex. (C):												
SR	8:30	8:15	7:45	7:00	6:45	6:30	6:45	7:00	7:15	7:30	7:45	8:15
SS	7:00	7:15	7:45	8:00	8:15	8:30	8:30	8:15	7:30	7:00	6:45	6:30
Corvallis, Oreg. (P):												
SR	8:45	8:15	7:30	6:30	5:45	5:30	5:45	6:15	6:45	7:30	8:15	8:45
SS	6:00	6:45	7:15	8:00	8:30	9:00	9:00	8:15	7:30	6:30	5:45	5:30
Cumberland, Md. (E):												
SR	8:30	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	6:45	7:15	7:45	8:15	8:45	8:45	8:15	7:30	6:30	6:00	5:45
Dallas, Tex.* (C):												
SR	8:30	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:30	8:00	8:15	8:30	8:30	8:15	7:30	7:00	6:30	6:15
Danville, Va. (E):												
SR	8:30	8:15	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	7:45	8:15	8:30	8:30	8:15	7:30	6:45	6:15	6:00
Davenport, Iowa* (C):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:15	7:45	8:15	8:45	8:30	8:00	7:15	6:15	5:45	5:30
Dayton, Ohio* (E):												
SR	9:00	8:30	7:45	7:00	6:30	6:15	6:15	6:45	7:15	7:45	8:15	8:45
SS	6:30	7:15	7:45	8:15	8:45	9:00	9:00	8:30	7:45	7:00	6:15	6:15
Decatur, Ala. (C):												
SR	8:00	7:30	7:00	6:15	5:45	5:30	5:45	6:15	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	5:45
Decatur, Ill. (C):												
SR	8:15	7:45	7:15	6:15	5:45	5:30	5:45	6:00	6:30	7:00	7:45	8:15
SS	6:00	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:45	5:30
Decorah, Iowa (C):												
SR	8:45	8:15	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	8:00	8:30
SS	6:00	6:30	7:15	7:45	8:30	8:45	8:45	8:15	7:15	6:30	5:45	5:30
Denver, Colo.* (M):												
SR	8:15	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:15	6:15	5:45	5:30
Des Moines, Iowa* (C):												
SR	8:45	8:15	7:30	6:30	6:00	5:45	5:45	6:15	7:00	7:30	8:00	8:30
SS	6:00	6:45	7:15	8:00	8:30	8:45	8:45	8:15	7:30	6:30	6:00	5:45
Detroit, Mich.* (E):												
SR	9:00	8:30	7:45	7:00	6:15	6:00	6:00	6:45	7:15	7:45	8:15	9:00
SS	6:30	7:00	7:45	8:15	8:45	9:15	9:15	8:30	7:45	6:45	6:15	6:00
Dodge City, Kans. (C):												
SR	9:00	8:30	8:00	7:00	6:30	6:15	6:30	7:00	7:15	7:45	8:15	8:45
SS	6:45	7:15	7:45	8:15	8:45	9:00	9:00	8:30	7:45	7:00	6:30	6:30
Dothan, Ala. (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

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Dublin, Tex. (C):												
SR	8:30	8:15	7:45	7:00	6:30	6:30	6:30	7:00	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:45	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:30	6:30
Dubuque, Iowa (C):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:30	6:15	6:45	7:15	8:00	8:30
SS	6:00	6:30	7:15	7:45	8:15	8:45	8:45	8:00	7:15	6:30	5:45	5:30
Duluth, Minn.* (C):												
SR	8:45	8:15	7:30	6:30	5:30	5:15	5:30	6:00	6:45	7:30	8:15	8:45
SS	5:45	6:30	7:15	8:00	8:30	9:00	9:00	8:15	7:15	6:30	5:30	5:15
East Lansing, Mich. (E):												
SR	9:00	8:30	8:00	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:30	9:00
SS	6:30	7:15	7:45	8:15	9:00	9:15	9:15	8:45	7:45	7:00	6:15	6:00
Eau Claire, Wis. (C):												
SR	8:45	8:15	7:15	6:30	5:45	5:15	5:30	6:00	6:45	7:15	8:00	8:30
SS	5:45	6:30	7:15	7:45	8:30	9:00	8:45	8:15	7:15	6:30	5:45	5:30
Elmira, N. Y. (E):												
SR	8:30	8:00	7:30	6:30	5:45	5:30	5:45	6:15	6:45	7:15	8:00	8:30
SS	6:00	6:45	7:15	7:45	8:15	8:45	8:45	8:15	7:15	6:30	5:45	5:30
El Paso, Tex.* (C):												
SR	9:00	8:45	8:15	7:45	7:15	7:00	7:15	7:30	7:45	8:15	8:30	9:00
SS	7:30	7:45	8:15	8:30	9:00	9:15	9:15	8:45	8:15	7:30	7:00	7:00
Erie, Pa.* (E):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	6:45	7:30	8:00	8:30	9:00	9:00	8:15	7:30	6:45	6:00	5:45
Eureka, Calif. (P):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	6:45	7:15	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:00	5:45
Evansville, Ind.* (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	8:00	8:15	8:15	7:45	7:00	6:15	5:45	5:30
Everett, Wash. (P):												
SR	9:00	8:15	7:30	6:15	5:30	5:15	5:30	6:00	6:45	7:30	8:15	8:45
SS	5:45	6:30	7:15	8:00	8:45	9:15	9:00	8:30	7:30	6:15	5:30	5:45
Fairmont, W. Va. (E):												
SR	8:45	8:15	7:30	6:45	6:15	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:00	6:00
Fall River, Mass.* (E):												
SR	8:15	7:45	7:00	6:00	5:30	5:15	5:15	5:45	6:30	7:00	7:30	8:00
SS	5:45	6:15	6:45	7:30	8:00	8:30	8:15	7:45	7:00	6:00	5:30	5:15
Fargo, N. Dak. (C):												
SR	9:15	8:30	7:45	6:45	6:00	5:30	5:45	6:30	7:00	7:45	8:30	9:00
SS	6:00	6:45	7:30	8:15	9:00	9:15	9:15	8:45	7:45	6:45	6:00	5:45
Fayetteville, N. C. (E):												
SR	8:30	8:00	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:15	7:45	8:15
SS	6:30	7:00	7:15	7:45	8:15	8:30	8:30	8:00	7:30	6:45	6:15	6:00
Fergus Falls, Minn. (C):												
SR	9:00	8:30	7:45	6:45	5:45	5:30	5:45	6:15	7:00	7:45	8:30	9:00
SS	6:00	6:45	7:30	8:15	8:45	9:15	9:15	8:30	7:45	6:45	5:45	5:45
Findlay, Ohio (E):												
SR	8:00	7:30	6:45	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:15	9:00
SS	6:30	7:15	7:45	8:15	8:45	9:15	9:00	8:30	7:45	7:00	6:15	6:00
Flint, Mich.* (E):												
SR	9:00	8:30	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:30	9:00
SS	6:30	7:00	7:45	8:15	8:45	9:15	9:15	8:45	7:45	7:00	6:15	6:00
Fort Wayne, Ind.* (C):												
SR	8:00	7:30	7:00	6:00	5:30	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	5:30	5:15
Fort Worth, Tex.* (C):												
SR	8:30	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:30	8:00	8:15	8:45	8:45	8:15	7:30	7:00	6:30	6:30
Frederick, Md. (E):												
SR	8:30	8:00	7:30	6:30	6:00	5:45	6:00	6:15	6:45	7:15	8:00	8:30
SS	6:15	6:45	7:15	7:45	8:15	8:45	8:30	8:00	7:15	6:30	6:00	5:45
Fredericksburg, Va. (E):												
SR	8:30	8:00	7:30	6:30	6:00	5:45	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Fremont, Nebr. (C):												
SR	8:45	8:30	7:45	6:45	6:15	5:45	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:30	9:00	9:00	8:30	7:45	6:45	6:15	6:00
Fresno, Calif. (P):												
SR	8:15	7:45	7:15	6:30	6:00	5:45	5:45	6:15	6:45	7:00	7:30	8:00
SS	6:00	6:45	7:00	7:30	8:00	8:15	8:15	7:45	7:15	6:30	5:45	5:45
Gainesville, Fla. (E):												
SR	8:30	8:15	7:45	7:00	6:30	6:30	6:45	7:00	7:15	7:30	8:00	8:15
SS	6:45	7:15	7:30	8:00	8:15	8:30	8:30	8:15	7:30	7:00	6:30	6:30
Gallup, N. Mex. (M):												
SR	8:30	8:00	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:15	7:45	8:15
SS	6:30	7:00	7:15	7:45	8:15	8:30	8:30	8:00	7:30	6:45	6:15	6:00

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Gary, Ind.* (C):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:15
Glendale, Calif.* (P):												
SR	8:00	7:45	7:00	6:30	5:45	5:45	5:45	6:15	6:30	7:00	7:30	7:45
SS	6:00	6:30	7:00	7:30	7:45	8:00	8:00	7:45	7:00	6:15	5:45	5:45
Grand Forks, N. Dak. (C):												
SR	9:15	8:45	7:45	6:45	5:45	5:30	5:45	6:15	7:00	7:45	8:30	9:15
SS	6:00	6:45	7:30	8:15	9:00	9:30	9:30	8:45	7:45	6:45	5:45	5:30
Grand Island, Nebr. (C):												
SR	9:00	8:30	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:15	8:45
SS	6:30	7:15	7:45	8:15	8:45	9:00	9:00	8:30	7:45	7:00	6:15	6:00
Grand Junction, Colo. (M):												
SR	8:30	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	6:45	7:15	7:45	8:15	8:45	8:45	8:15	7:30	6:30	6:00	6:00
Grand Rapids, Mich.* (E):												
SR	9:15	8:45	8:00	7:00	6:15	6:00	6:15	6:45	7:15	8:00	8:30	9:15
SS	6:30	7:15	7:45	8:30	9:00	9:30	9:15	8:45	8:00	7:00	6:15	6:15
Great Falls, Mont. (M):												
SR	9:15	8:30	7:45	6:45	5:45	5:30	5:45	6:15	7:00	7:45	8:30	9:00
SS	6:00	6:45	7:30	8:15	9:00	9:30	9:15	8:45	7:45	6:45	5:45	5:30
Greeley, Colo. (M):												
SR	8:15	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:15	6:15	5:45	5:30
Green Bay, Wis. (C):												
SR	8:30	8:00	7:15	6:15	5:30	5:00	5:15	6:00	6:30	7:00	7:45	8:15
SS	5:30	6:15	7:00	7:30	8:15	8:45	8:30	8:00	7:00	6:15	5:30	5:15
Greensburg, Pa. (E):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:00	6:00
Greensboro, N. C. (E):												
SR	8:30	8:15	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	7:45	8:15	8:30	8:30	8:15	7:30	6:45	6:15	6:00
Greenville, N. C. (E):												
SR	8:15	8:00	7:15	6:45	6:00	6:00	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:00	8:30	8:30	8:00	7:15	6:30	6:00	6:00
Greenville, S. C. (E):												
SR	8:45	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:30	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:30	6:15
Griffin, Ga. (E):												
SR	8:45	8:30	7:45	7:15	6:45	6:30	6:45	7:00	7:15	7:45	8:15	8:30
SS	6:45	7:15	7:45	8:00	8:30	8:45	8:45	8:30	7:45	7:00	6:30	6:30
Gulfport, Miss. (C):												
SR	8:00	7:45	7:15	6:30	6:00	6:00	6:00	6:30	6:45	7:00	7:15	7:45
SS	6:15	6:45	7:00	7:15	7:45	8:00	8:00	7:45	7:00	6:30	6:00	6:00
Hammond, Ind.* (C):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:15
Harrisburg, Pa.* (E):												
SR	8:30	8:00	7:15	6:30	6:00	5:30	5:45	6:15	6:45	7:15	8:00	8:30
SS	6:00	6:45	7:15	7:45	8:15	8:45	8:30	8:00	7:15	6:30	5:45	5:45
Harrisonburg, Va. (E):												
SR	8:30	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	7:00	7:15	7:45	8:15	8:45	8:45	8:15	7:30	6:45	6:00	6:00
Hartford, Conn.* (E):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:15
Hattiesburg, Miss. (C):												
SR	8:00	7:45	7:15	6:30	6:00	5:45	6:00	6:15	6:45	7:00	7:30	7:45
SS	6:15	6:45	7:00	7:30	7:45	8:00	8:00	7:45	7:00	6:30	6:00	6:00
Henderson, Ky. (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
Herrin, Ill. (C):												
SR	8:15	7:45	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:00	7:30	8:00
SS	6:00	6:30	7:00	7:30	8:00	8:15	8:15	7:45	7:00	6:15	5:45	5:45
Honolulu, T. H. (local):												
SR	7:45	7:30	7:15	6:45	6:30	6:15	6:30	6:45	6:45	7:00	7:15	7:30
SS	6:45	7:00	7:15	7:15	7:30	7:45	7:45	7:30	7:00	6:30	6:15	6:15
Hot Springs, Ark. (C):												
SR	8:15	8:00	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:15	7:45	8:15
SS	6:30	7:00	7:15	7:45	8:00	8:30	8:30	8:00	7:15	6:45	6:15	6:00
Houston, Tex.* (C):												
SR	8:15	8:00	7:30	7:00	6:30	6:15	6:30	6:45	7:00	7:30	7:45	8:15
SS	6:45	7:15	7:30	7:45	8:15	8:30	8:30	8:00	7:30	6:45	6:30	6:30

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Huntington, W. Va.* (E):												
SR	8:45	8:15	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:15	8:45
SS	6:30	7:00	7:30	8:00	8:30	9:00	9:00	8:30	7:45	7:00	6:15	6:15
Huntsville, Tex. (C):												
SR	8:15	8:00	7:30	7:00	6:30	6:15	6:30	6:45	7:00	7:30	7:45	8:15
SS	6:45	7:15	7:30	7:45	8:15	8:30	8:30	8:00	7:30	6:45	6:30	6:30
Idaho Falls, Idaho (M):												
SR	9:00	8:30	7:45	6:45	6:00	5:45	6:00	6:30	7:00	7:45	8:15	9:00
SS	6:15	7:00	7:30	8:15	8:45	9:15	9:15	8:30	7:45	6:45	6:00	5:45
Indianapolis, Ind.* (C):												
SR	8:00	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:30	8:00
SS	5:45	6:15	6:45	7:15	7:45	8:15	8:15	7:45	7:00	6:00	5:30	5:15
Iowa City, Iowa (C):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	8:00	8:30
SS	6:00	6:45	7:15	7:45	8:15	8:45	8:45	8:00	7:15	6:30	5:45	5:30
Ithaca, N. Y. (E):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	8:00	8:30
SS	6:00	6:30	7:15	7:45	8:15	8:45	8:45	8:15	7:15	6:30	5:45	5:30
Jackson, Miss. (C):												
SR	8:00	7:45	7:15	6:30	6:00	6:00	6:00	6:30	6:45	7:00	7:30	8:00
SS	6:30	7:00	7:15	7:30	8:00	8:15	8:15	7:45	7:15	6:30	6:15	6:00
Jackson, Tenn. (C):												
SR	8:00	7:45	7:15	6:30	5:45	5:45	5:45	6:15	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	5:45
Jacksonville, Fla.* (E):												
SR	8:30	8:15	7:45	7:00	6:30	6:30	6:30	7:00	7:15	7:30	7:45	8:15
SS	6:45	7:15	7:30	8:00	8:15	8:30	8:30	8:15	7:30	7:00	6:30	6:30
Jacksonville, Ill. (C):												
SR	8:15	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:00	7:45	8:00	8:30	8:30	8:00	7:15	6:30	5:45	5:45
Jersey City, N. J.* (E):												
SR	8:15	7:45	7:15	6:15	5:45	5:30	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:45	5:30
Johnson City, Tenn. (C):												
SR	7:45	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	6:45	6:00	5:15	5:15
Johnstown, Pa.* (E):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	6:45	7:15	8:15	8:30	8:45	8:45	8:15	7:30	6:30	6:00	5:45
Joliet, Ill. (C):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:30
Jonesboro, Ark. (C):												
SR	8:15	7:45	7:15	6:30	6:00	5:45	6:00	6:15	6:45	7:15	7:45	8:00
SS	6:15	6:45	7:15	7:30	8:00	8:15	8:15	8:00	7:15	6:30	6:00	5:45
Kalamazoo, Mich. (E):												
SR	7:15	8:45	8:00	7:00	6:15	6:00	6:15	6:45	7:15	8:00	8:30	9:00
SS	6:30	7:15	7:45	8:15	9:00	9:15	9:15	8:45	8:00	7:00	6:15	6:15
Kalispell, Mont. (M):												
SR	9:30	8:45	8:00	6:45	6:00	5:30	5:45	6:30	7:15	8:00	8:45	9:15
SS	6:15	7:00	7:45	8:30	9:15	8:45	9:30	9:00	7:45	6:45	6:00	5:45
Kansas City, Mo.* (C):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:00	6:00
Knoxville, Tenn.* (C):												
SR	7:45	7:30	6:45	6:00	5:30	5:15	5:30	6:00	6:15	6:45	7:15	7:45
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
LaCrosse, Wis. (C):												
SR	8:45	8:00	7:15	6:30	5:45	5:15	5:30	6:15	6:45	7:15	8:00	8:30
SS	5:45	6:30	7:15	7:45	8:30	8:45	8:45	8:15	7:15	6:30	5:45	5:30
Lawrence, Kansas (C):												
SR	8:45	8:15	7:30	6:45	6:15	6:00	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:15	6:00
Lawrence, Mass.* (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
Lawton, Okla. (C):												
SR	8:45	8:15	7:45	7:00	6:45	6:15	6:30	7:00	7:15	7:45	8:00	8:30
SS	6:45	7:15	7:45	8:00	8:30	8:45	8:45	8:30	7:45	7:00	6:30	6:30
Lexington, Ky. (C):												
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
Lihue, T. H. (L):												
SR	6:45	6:45	6:15	5:45	5:30	5:30	5:30	5:45	6:00	6:00	6:15	6:45
SS	5:45	6:00	6:15	6:30	6:45	6:45	7:00	6:45	6:15	5:45	5:30	5:30
Little Rock, Ark.* (C):												
SR	8:15	8:00	7:15	6:45	6:00	6:00	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:00	8:30	8:30	8:00	7:15	6:30	6:00	6:00

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Lincoln, Nebr. (C):												
SR	8:45	8:30	7:45	6:45	6:15	6:00	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:30	7:00	7:30	8:00	8:30	9:00	9:00	8:30	7:45	6:45	6:15	6:00
Logan, W. Va. (E):												
SR	8:45	8:15	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:30	8:15	8:30
SS	6:30	7:00	7:30	8:00	8:30	8:45	8:45	8:30	7:45	7:00	6:15	6:15
Long Beach, Calif. (P):												
SR	8:00	7:45	7:00	6:30	6:00	5:45	6:00	6:15	6:30	7:00	7:45	8:00
SS	6:00	6:30	7:00	7:30	8:00	8:30	8:15	7:45	7:00	6:15	5:45	5:30
Longview, Tex. (C):												
SR	8:15	8:00	7:30	6:45	6:15	6:15	6:15	6:45	7:00	7:30	7:45	8:15
SS	6:30	7:00	7:30	7:45	8:15	8:30	8:30	8:00	7:30	6:45	6:15	6:15
Los Angeles, Calif.* (P):												
SR	8:00	7:45	7:00	6:30	5:45	5:45	5:45	6:15	6:30	7:00	7:30	7:45
SS	6:00	6:30	7:00	7:30	7:45	8:00	8:00	7:45	7:00	6:15	5:45	5:45
Louisville, Ky.* (C):												
SR	8:00	7:30	7:00	6:15	5:30	5:15	5:30	6:00	6:30	6:45	7:30	8:00
SS	5:45	6:15	6:45	7:15	7:45	8:15	8:00	7:45	7:00	6:00	5:30	5:30
Lubbock, Tex. (C):												
SR	9:00	8:30	8:00	7:15	6:45	6:30	6:45	7:15	7:30	7:45	8:15	8:45
SS	7:00	7:30	8:00	8:15	8:45	9:00	9:00	8:30	8:00	7:15	6:45	6:45
Lufkin, Tex. (C):												
SR	8:15	8:00	7:30	7:00	6:30	6:15	6:30	6:45	7:00	7:15	7:45	8:15
SS	6:45	7:00	7:30	7:45	8:15	8:30	8:30	8:00	7:30	6:45	6:15	6:15
Macon, Ga. (E):												
SR	8:45	8:15	7:45	7:00	6:30	6:30	6:30	7:00	7:15	7:45	8:00	8:30
SS	6:45	7:15	7:45	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:30	6:30
Madison, Wis. (C):												
SR	8:30	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:15	7:45	8:30
SS	5:45	6:30	7:00	7:45	8:15	8:45	8:30	8:00	7:15	6:15	5:30	5:30
Manchester, N. H. (E):												
SR	8:15	7:45	7:00	6:00	5:30	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	5:30	5:15
Manhattan, Kans. (C):												
SR	8:45	8:15	7:45	6:45	6:15	6:00	6:15	6:45	7:00	7:30	8:15	8:45
SS	6:30	7:00	7:30	8:00	8:30	9:00	8:45	8:30	7:30	6:45	6:15	6:00
Mansfield, Ohio (E):												
SR	9:00	8:30	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:15	8:45
SS	6:30	7:00	7:30	8:15	8:45	9:00	9:00	8:30	7:45	6:45	6:15	6:00
Marinette, Wis. (C):												
SR	8:30	8:00	7:00	6:15	5:15	5:00	5:15	5:45	6:30	7:00	7:45	8:30
SS	5:30	6:15	7:00	7:30	8:15	8:45	8:30	8:00	7:00	6:15	5:30	5:15
Martinsville, Va. (E):												
SR	8:30	8:15	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	8:00	8:15	8:45	8:45	8:15	7:30	6:45	6:15	6:00
Mason City, Iowa (C):												
SR	8:45	8:15	7:30	6:30	5:45	5:30	5:45	6:15	6:45	7:15	8:00	8:30
SS	6:00	6:45	7:15	8:00	8:30	9:00	8:45	8:15	7:30	6:30	5:45	5:45
Mayaguez, P. R. (A):												
SR	8:00	8:00	7:30	7:15	7:00	6:45	7:00	7:15	7:15	7:15	7:30	7:45
SS	7:15	7:30	7:45	7:45	8:00	8:00	8:15	8:00	7:30	7:00	6:45	7:00
Medford, Oreg. (P):												
SR	8:45	8:15	7:30	6:30	5:45	5:30	5:45	6:15	6:45	7:30	8:00	8:30
SS	6:00	6:45	7:15	7:45	8:30	8:45	8:45	8:15	7:30	6:30	5:45	5:45
Memphis, Tenn.* (C):												
SR	8:15	7:45	7:15	6:30	6:00	5:45	6:00	6:15	6:45	7:00	7:30	8:00
SS	6:15	6:45	7:00	7:30	8:00	8:15	8:15	7:45	7:15	6:30	6:00	5:45
Merced, Calif. (P):												
SR	8:15	8:00	7:15	6:30	6:00	5:45	6:00	6:15	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:30	8:00	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Meridian, Miss. (C):												
SR	8:00	7:45	7:00	6:30	6:00	5:45	6:00	6:15	6:45	7:00	7:30	7:45
SS	6:15	6:45	7:00	7:30	7:45	8:00	8:00	7:45	7:00	6:30	6:00	5:45
Miami, Fla.* (E):												
SR	8:15	8:00	7:30	7:00	6:30	6:30	6:30	7:00	7:00	7:15	7:45	8:00
SS	6:45	7:15	7:30	7:45	8:00	8:15	8:15	8:00	7:30	7:00	6:30	6:30
Milwaukee, Wis.* (C):												
SR	8:30	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:15	7:00	7:30	8:15	8:30	8:30	8:00	7:00	6:15	5:30	5:15
Minneapolis, Minn.* (C):												
SR	8:45	8:15	7:30	6:30	5:45	5:30	5:45	6:15	6:45	7:30	8:15	8:45
SS	6:00	6:45	7:15	8:00	8:30	9:00	9:00	8:15	7:30	6:30	5:45	5:30
Minot, N. Dak. (C):												
SR	9:30	9:00	8:00	7:00	6:00	5:45	6:00	6:45	7:15	8:00	8:45	9:30
SS	6:15	7:00	7:45	8:30	9:15	9:45	9:45	9:00	8:00	7:00	6:15	5:45
Missoula, Mont. (M):												
SR	9:15	8:45	7:45	6:45	6:00	5:45	6:00	6:30	7:15	8:00	8:45	9:15
SS	6:15	7:00	7:45	8:30	9:00	9:30	9:30	8:45	7:45	6:45	6:00	5:45

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mobile, Ala. (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	6:45	7:00	7:15	7:45	8:00	8:00	7:30	7:00	6:15	6:00	6:00
Modesto, Calif. (P):												
SR	8:15	8:00	7:15	6:30	6:00	5:45	6:00	6:15	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:00	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Montgomery, Ala. (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	7:30	8:00	8:00	7:30	7:00	6:15	5:45	5:45
Nashville, Tenn.* (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
Newark, N. J.* (E):												
SR	8:15	7:45	7:15	6:15	5:45	5:30	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:45	5:30
New Britain, Conn.* (E):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:15
Newburgh, N. Y. (E):												
SR	8:15	8:00	7:15	6:15	5:45	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:15	8:30	8:30	8:00	7:15	6:15	5:45	5:30
New Castle, Pa. (E):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:30	9:00	9:00	8:15	7:30	6:45	6:00	6:00
New Haven, Conn.* (E):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:30
New Kinsington, Pa.* (E) (Pittsburgh Metropolitan District):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:00	6:00
New Orleans, La.* (C):												
SR	8:00	7:45	7:15	6:30	6:15	6:00	6:15	6:30	6:45	7:00	7:30	7:45
SS	6:15	6:45	7:15	7:30	7:45	8:00	8:00	7:45	7:00	6:30	6:00	6:00
New York, N. Y.* (E):												
SR	8:15	7:45	7:15	6:15	5:45	5:30	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:45	5:30
Niagara Falls, N. Y.* (E):												
SR	8:45	8:15	7:30	6:30	6:00	5:30	5:45	6:15	7:00	7:30	8:00	8:45
SS	6:00	6:45	7:15	8:00	8:30	9:00	9:00	8:15	7:30	6:30	6:00	5:45
Norfolk, Nebr. (C):												
SR	9:00	8:30	7:45	6:45	6:15	5:45	6:00	6:30	7:15	7:45	8:15	8:45
SS	6:15	7:00	7:30	8:15	8:45	9:00	9:00	8:30	7:45	6:45	6:15	6:00
Norfolk, Va.* (E):												
SR	8:15	8:00	7:15	6:30	6:00	5:45	6:00	6:15	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:00	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Norman, Okla. (C):												
SR	8:45	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:30	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:30	6:15
Northfield, Minn. (C):												
SR	8:45	8:15	7:30	6:30	5:45	5:30	5:45	6:15	6:45	7:30	8:15	8:45
SS	6:00	6:45	7:15	8:00	8:30	9:00	9:00	8:15	7:30	6:30	5:45	5:30
North Platte, Nebr. (C):												
SR	9:15	8:45	8:00	7:00	6:30	6:15	6:30	6:45	7:30	8:00	8:30	9:00
SS	6:45	7:15	7:45	8:15	9:00	9:15	9:15	8:45	8:00	7:00	6:30	6:15
Oakland, Calif.* (P):												
SR	8:30	8:00	7:30	6:30	6:00	5:45	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Ogden, Utah (M):												
SR	9:00	8:30	7:45	6:45	6:15	6:00	6:00	6:30	7:15	7:45	8:15	8:45
SS	6:30	7:00	7:30	8:00	8:45	9:00	9:00	8:30	7:45	6:45	6:15	6:00
Oklahoma City, Okla.* (C):												
SR	8:45	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:30	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:30	6:15
Olean, N. Y. (E):												
SR	8:45	8:15	7:30	6:30	6:00	5:30	5:45	6:15	7:00	7:30	8:00	8:30
SS	6:00	6:45	7:15	8:00	8:30	8:45	8:45	8:15	7:30	6:30	6:00	5:45
Olympia, Wash. (P):												
SR	9:00	8:15	7:30	6:30	5:30	5:15	5:30	6:00	6:45	7:30	8:15	8:45
SS	5:45	6:30	7:15	8:00	8:45	9:15	9:00	8:30	7:30	6:30	5:45	5:15
Omaha, Nebr.* (C):												
SR	8:45	8:15	7:45	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:30	9:00	9:00	8:30	7:30	6:45	6:00	6:00
Opelika, Ala. (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	5:30

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Orlando, Fla. (E):												
SR	8:15	8:00	7:30	7:00	6:30	6:30	6:30	7:00	7:15	7:30	7:45	8:15
SS	6:45	7:15	7:30	7:45	8:15	8:30	8:30	8:00	7:30	7:00	6:30	6:30
Palestine, Tex. (C):												
SR	8:30	8:00	7:30	7:00	6:30	6:15	6:30	6:45	7:00	7:30	7:45	8:15
SS	6:45	7:15	7:30	7:45	8:15	8:30	8:30	8:00	7:30	6:45	6:30	6:15
Panama City, Fla. (E):												
SR	8:45	8:30	8:00	7:15	6:45	6:45	6:45	7:15	7:30	7:45	8:15	8:30
SS	7:00	7:30	7:45	8:15	8:30	8:45	8:45	8:30	7:45	7:15	6:45	6:45
Paterson, N. J.* (E):												
SR	8:15	7:45	7:15	6:15	5:45	5:30	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:45	5:30
Pensacola, Fla. (C):												
SR	7:45	7:30	7:00	6:30	6:00	5:45	6:00	6:15	6:30	6:45	7:15	7:45
SS	6:15	6:30	7:00	7:15	7:30	7:45	8:00	7:30	7:00	6:15	5:45	5:45
Peoria, Ill.* (C):												
SR	8:15	8:00	7:15	6:15	5:45	5:30	5:45	6:00	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:00	7:30	8:15	8:30	8:30	8:00	7:15	6:15	5:45	5:30
Petersburg, Va. (E):												
SR	8:30	8:00	7:30	6:45	6:00	5:45	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	6:00
Philadelphia, Pa.* (E):												
SR	8:15	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:00	7:45	8:15	8:30	8:30	8:00	7:15	6:30	5:45	5:30
Phoenix, Ariz. (M):												
SR	8:30	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:30	8:00	8:15	8:45	8:45	8:15	7:30	7:00	6:30	6:15
Pierre, S. Dak. (C):												
SR	9:15	8:45	8:00	7:00	6:15	6:00	6:15	6:45	7:15	8:00	8:30	9:15
SS	6:30	7:15	7:45	8:30	9:00	9:30	9:30	8:45	8:00	7:00	6:15	6:00
Pittsburg, Kans. (C):												
SR	8:30	8:15	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	8:00	8:15	8:45	8:45	8:15	7:30	6:45	6:15	6:00
Pittsburgh, Pa.* (E):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:00	6:00
Plainview, Tex. (C):												
SR	9:00	8:30	8:00	7:15	6:45	6:00	6:45	7:00	7:30	7:45	8:15	8:45
SS	7:00	7:30	8:00	8:15	8:45	9:00	9:00	8:30	8:00	7:15	6:15	6:15
Pocatello, Idaho (M):												
SR	9:00	8:30	7:45	6:45	6:15	5:45	6:00	6:30	7:15	7:45	8:15	9:00
SS	6:15	7:00	7:30	8:15	8:45	9:15	9:00	8:30	7:45	6:45	6:15	6:00
Ponce, P. R. (A):												
SR	8:00	8:00	7:30	7:15	7:00	6:45	7:00	7:15	7:15	7:15	7:30	7:45
SS	7:15	7:30	7:30	7:45	7:45	8:00	8:00	8:00	7:30	7:00	6:45	7:00
Pontiac, Mich.* (E):												
SR	9:00	8:30	7:45	7:00	6:15	6:00	6:00	6:45	7:15	7:45	8:15	9:00
SS	6:30	7:00	7:45	8:15	8:45	9:15	9:15	8:30	7:45	6:45	6:15	6:00
Port Arthur, Tex. (C):												
SR	8:15	8:00	7:30	6:45	6:15	6:15	6:15	6:45	7:00	7:15	7:30	8:00
SS	6:30	7:00	7:15	7:30	8:00	8:15	8:15	8:00	7:15	6:45	6:15	6:15
Portland, Maine (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	5:00
Portland, Oreg.* (P):												
SR	8:45	8:15	7:30	6:30	5:45	5:15	5:30	6:15	6:45	7:30	8:15	8:45
SS	5:45	6:30	7:15	8:00	8:30	9:00	9:00	8:15	7:30	6:30	5:45	5:30
Portsmouth, N. H. (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
Providence, R. I.* (E):												
SR	8:15	7:45	7:00	6:00	5:30	5:15	5:15	5:45	6:30	7:00	7:30	8:00
SS	5:45	6:15	6:45	7:30	8:00	8:30	8:15	7:45	7:00	6:00	5:30	5:15
Pueblo, Colo. (M):												
SR	8:15	7:45	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:00	7:45	8:15
SS	6:00	6:30	7:00	7:30	8:00	8:30	8:15	8:00	7:15	6:15	5:45	5:45
Pullman, Wash. (P):												
SR	8:30	8:00	7:00	6:00	5:15	5:00	5:15	5:45	6:30	7:00	7:45	8:30
SS	5:30	6:15	7:00	7:30	8:15	8:45	8:45	8:00	7:00	6:00	5:15	5:00
Quincy, Ill. (C):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	5:45	5:45
Racine, Wis.* (C):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:15	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:15
Raleigh, N. C. (E):												
SR	8:30	8:00	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:15	7:45	8:15
SS	6:30	7:00	7:15	7:45	8:15	8:30	8:30	8:00	7:30	6:45	6:15	6:00

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rapid City, S. Dak. (M):												
SR	8:30	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:15	7:00	7:30	8:15	8:45	8:30	8:00	7:00	6:15	5:30	5:15
Reading, Pa.* (E):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	5:45	5:45
Reno, Nev. (P):												
SR	8:15	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:15	6:15	5:45	5:30
Rice Lake, Wis. (C):												
SR	8:45	8:15	7:30	6:30	5:45	5:15	5:30	6:00	6:45	7:15	8:00	8:45
SS	5:45	6:30	7:15	7:45	8:30	9:00	9:00	8:15	7:15	6:30	5:45	5:30
Richmond, Va.* (E):												
SR	8:30	8:00	7:30	6:30	6:00	5:45	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	6:00
Roanoke, Va.* (E):												
SR	8:30	8:15	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	8:00	8:15	8:45	8:45	8:15	7:30	6:45	6:15	6:00
Rochester, N. Y.* (E):												
SR	8:45	8:15	7:30	6:30	5:45	5:30	5:45	6:15	6:45	7:30	8:00	8:30
SS	6:00	6:45	7:15	7:45	8:30	8:45	8:45	8:15	7:15	6:30	5:45	5:30
Rockford, Ill.* (C):												
SR	8:30	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:15	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:15	8:30	8:30	8:00	7:15	6:15	5:30	5:30
Rock Island, Ill. (C):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:15	7:45	8:15	8:45	8:30	8:00	7:15	6:15	5:45	5:30
Roseburg, Oreg. (P):												
SR	8:45	8:15	7:30	6:30	5:45	5:30	5:45	6:15	6:45	7:30	8:00	8:45
SS	6:00	6:45	7:15	8:00	8:30	9:00	8:45	8:15	7:30	6:30	5:45	5:45
Rutland, Vt. (E):												
SR	9:00	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:45	7:15	8:00	8:30
SS	6:00	6:30	7:00	7:30	8:00	8:15	8:15	7:45	7:00	6:15	5:45	5:30
Sacramento, Calif.* (P):												
SR	8:30	8:00	7:15	6:30	6:00	5:45	6:00	6:15	5:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Saginaw, Mich. (E):												
SR	9:15	8:30	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:30	9:00
SS	6:30	7:00	7:45	8:15	9:00	9:15	9:15	8:45	7:45	7:00	6:15	6:00
St. Paul, Minn.* (C):												
SR	8:45	8:15	7:30	6:30	5:45	5:30	5:45	6:15	6:45	7:30	8:15	8:45
SS	6:00	6:45	7:15	8:00	8:30	9:00	9:00	8:15	7:30	6:30	5:45	5:30
St. Petersburg, Fla.* (E):												
SR	8:30	8:15	7:45	7:00	6:45	6:30	6:45	7:00	7:15	7:30	7:45	8:15
SS	7:00	7:15	7:45	8:00	8:15	8:30	8:30	8:15	7:30	7:00	6:30	6:30
Salem, Oreg. (P):												
SR	8:45	8:15	7:30	6:30	5:45	5:30	5:45	6:15	6:45	7:30	8:15	8:45
SS	6:00	6:45	7:15	8:00	8:30	9:00	9:00	8:15	7:30	6:30	5:45	5:30
Salina, Kansas (C):												
SR	8:45	8:30	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:15	8:45
SS	6:30	7:00	7:30	8:00	8:30	9:00	9:00	8:30	7:45	7:00	6:15	6:15
Salt Lake City,* Utah (M):												
SR	8:45	8:30	7:45	6:45	6:15	6:00	6:15	6:30	7:15	7:45	8:15	8:45
SS	6:30	7:00	7:30	8:00	8:30	9:00	9:00	8:30	7:45	6:45	6:15	6:00
San Antonio, Tex.* (C):												
SR	8:30	8:15	7:45	7:15	6:45	6:30	6:45	7:00	7:15	7:30	8:00	8:15
SS	7:00	7:30	7:45	8:00	8:15	8:30	8:30	8:15	7:45	7:00	6:45	6:30
San Diego, Calif.* (P):												
SR	7:45	7:30	7:00	6:15	5:45	5:45	5:45	6:15	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	5:45
San Francisco, Calif.* (P):												
SR	8:30	8:00	7:30	6:30	6:00	5:45	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	5:45
San Jose, Calif.* (P):												
SR	8:30	8:00	7:15	6:30	6:00	5:45	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	5:45
San Juan, P. R. (A):												
SR	8:00	8:00	7:30	7:15	6:45	6:45	7:00	7:00	7:15	7:15	7:30	7:45
SS	7:15	7:30	7:30	7:45	7:45	8:00	8:00	7:45	7:30	7:00	6:45	6:45
Santa Barbara, Calif. (P):												
SR	8:00	7:45	7:15	6:30	6:00	5:45	6:00	6:15	6:45	7:00	7:30	8:00
SS	6:15	6:45	7:00	7:30	8:00	8:15	8:15	7:45	7:15	6:30	6:00	5:45
Saranac Lake, N. Y. (E):												
SR	8:30	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:15	7:45	8:30
SS	5:45	6:30	7:00	7:45	8:15	8:45	8:45	8:00	7:15	6:15	5:30	5:15
Sarasota, Fla. (E):												
SR	8:30	8:15	7:45	7:00	6:45	6:30	6:45	7:00	7:15	7:30	7:45	8:15
SS	7:00	7:15	7:45	8:00	8:15	8:30	8:30	8:15	7:30	7:00	6:45	6:45

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Sault Ste. Marie, Mich. (C):												
SR	8:15	7:45	7:00	6:00	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	6:00	5:00	4:45
Savannah, Ga.* (E):												
SR	8:30	8:15	7:30	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:15
SS	6:45	7:15	7:30	8:00	8:45	8:30	8:30	8:15	7:30	7:00	6:30	6:15
Schenectady, N. Y.* (E):												
SR	8:30	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:15	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:15	8:30	8:30	8:00	7:15	6:15	5:30	5:15
Scranton, Pa.* (E):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:15	7:45	8:15	8:45	8:30	8:00	7:15	6:30	5:45	5:30
Seattle, Wash.* (P):												
SR	9:00	8:15	7:30	6:30	5:30	5:15	5:30	6:00	6:45	7:30	8:15	8:45
SS	5:45	6:30	7:15	8:00	8:45	9:15	9:00	8:30	7:30	6:30	5:30	5:15
Sharon, Pa.* (E):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:30	9:00	9:00	8:15	7:30	6:45	6:00	6:00
Sheboygan, Wis. (C):												
SR	8:30	7:45	7:00	6:15	5:30	5:15	5:15	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:15	7:00	7:30	8:15	8:30	8:30	8:00	7:00	6:15	5:30	5:15
Shenandoah, Iowa (C):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:30	9:00	8:45	8:15	7:30	6:45	6:00	6:00
Sherman, Tex. (C):												
SR	8:30	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:30	8:00	8:15	8:45	8:45	8:15	7:30	7:00	6:30	6:15
Shreveport, La. (C):												
SR	8:15	8:00	7:30	6:45	6:15	6:00	6:15	6:45	7:00	7:15	7:45	8:15
SS	6:30	7:00	7:15	7:45	8:00	8:30	8:30	8:00	7:30	6:45	6:15	6:15
Siloam Springs, Ark. (C):												
SR	8:30	8:15	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:30	8:00	8:15
SS	6:30	7:00	7:30	7:45	8:15	8:30	8:30	8:15	7:30	6:45	6:15	6:00
Sioux City, Iowa (C):												
SR	9:00	8:30	7:45	6:45	6:00	5:45	6:00	6:30	7:00	7:45	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:45	9:00	9:00	8:30	7:45	6:45	6:00	6:00
Sioux Falls, S. Dak. (C):												
SR	9:00	8:30	7:45	6:45	6:00	5:45	6:00	6:30	7:00	7:45	8:15	9:00
SS	6:15	7:00	7:30	8:15	8:45	9:15	9:00	8:30	7:45	6:45	6:00	5:45
South Bend, Ind.* (C):												
SR	8:15	7:45	7:00	6:00	5:30	5:15	5:15	5:45	6:30	7:00	7:30	8:00
SS	5:45	6:15	6:45	7:30	8:00	8:15	8:15	7:45	7:00	6:00	5:30	5:15
Spartanburg, S. C. (E):												
SR	8:30	8:15	7:45	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:30
SS	6:45	7:15	7:30	8:00	8:30	8:45	8:45	8:15	7:30	7:00	6:30	6:15
Spokane, Wash.* (P):												
SR	8:30	8:00	7:00	6:00	5:15	4:45	5:00	5:45	6:30	7:15	8:00	8:30
SS	5:30	6:15	7:00	7:45	8:15	8:45	8:45	8:00	7:00	6:00	5:15	5:00
Springfield, Mass.* (E):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:15	7:00	7:30	8:00	8:30	8:30	7:45	7:00	6:15	5:30	5:15
Springfield, Mo. (C):												
SR	8:30	8:00	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:30	6:45	6:00	6:00
Springfield, Vt. (E):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:15	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:15	7:00	7:30	8:00	8:30	8:30	8:00	7:00	6:15	5:30	5:15
St. Albans, Vt. (E):												
SR	8:30	8:00	7:15	6:15	5:30	5:00	5:15	6:00	6:30	7:00	7:45	8:30
SS	5:30	6:15	7:00	7:30	8:15	8:45	8:30	8:00	7:00	6:15	5:30	5:15
St. Joseph, Mo. (C):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:00	6:00
St. Louis, Mo.* (C):												
SR	8:15	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:45	7:00	7:30	8:00	8:30	8:30	8:00	7:15	6:30	5:45	5:45
Stevens Point, Wis. (C):												
SR	8:30	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:15	8:00	8:30
SS	5:45	6:30	7:00	7:45	8:15	8:45	8:45	8:00	7:15	6:15	5:30	5:15
Stockton, Calif. (P):												
SR	8:15	8:00	7:15	6:30	6:00	5:45	6:00	6:15	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:00	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Suffolk, Va. (E):												
SR	8:15	8:00	7:15	6:30	6:00	5:45	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:00	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Sumter, S. C. (E):												
SR	8:30	8:15	7:30	7:00	6:15	6:15	6:15	6:45	7:00	7:30	7:00	8:15
SS	6:30	7:00	7:30	7:45	8:15	8:30	8:30	8:15	7:30	6:45	6:15	6:15

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Syracuse, N. Y.* (E):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:30	6:15	6:45	7:15	8:00	8:30
SS	6:00	6:30	7:15	7:45	8:15	8:45	8:45	8:15	7:15	6:30	5:45	5:30
Tacoma, Wash.* (P):												
SR	9:00	8:15	7:30	6:30	5:30	5:15	5:30	6:00	6:45	7:30	8:15	8:45
SS	5:45	6:30	7:15	8:00	8:45	9:15	9:00	8:30	7:30	6:30	5:30	5:15
Tallahassee, Fla. (E):												
SR	8:30	8:15	7:45	7:15	6:45	6:30	6:45	7:00	7:15	7:45	8:00	8:30
SS	7:00	7:30	7:45	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:45	6:45
Tampa, Fla.* (E):												
SR	8:30	8:15	7:45	7:00	6:45	6:30	6:45	7:00	7:15	7:30	7:45	8:15
SS	7:00	7:15	7:45	8:00	8:15	8:30	8:30	8:15	7:30	7:00	6:30	6:30
The Dalles, Oreg. (P):												
SR	8:45	8:15	7:15	6:15	5:30	5:15	5:30	6:00	6:45	7:15	8:00	8:45
SS	5:45	6:30	7:15	7:45	8:30	9:00	8:45	8:15	7:15	6:15	5:30	5:15
Toledo, Ohio* (E):												
SR	9:00	8:30	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:30	9:00
SS	6:30	7:00	7:45	8:15	8:45	9:15	9:15	8:30	7:45	7:00	6:15	6:00
Topeka, Kansas (C):												
SR	8:45	8:15	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:15	6:00
Trenton, N. J. (E):												
SR	8:15	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:15	6:15	5:45	5:30
Troy, N. Y.* (E):												
SR	8:30	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:15	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:15	8:30	8:30	8:00	7:15	6:15	5:30	5:15
Tucson, Ariz. (M):												
SR	8:30	8:15	7:30	7:00	6:30	6:15	6:30	6:45	7:15	7:30	8:00	8:15
SS	6:45	7:15	7:30	8:00	8:15	8:30	8:30	8:15	7:30	7:00	6:30	6:15
Tulsa, Okla.* (C):												
SR	8:30	8:15	7:30	7:00	6:15	6:00	6:15	6:45	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:15	6:15
Tuscaloosa, Ala. (C):												
SR	8:00	7:30	7:00	6:15	5:45	5:45	5:45	6:15	6:30	7:00	7:15	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	5:45
Tuscola, Ill. (C):												
SR	8:15	7:45	7:00	6:15	5:45	5:30	5:30	6:00	6:30	7:00	7:30	8:00
SS	5:45	6:30	7:00	7:30	8:00	8:15	8:15	7:45	7:00	6:15	5:45	5:30
Twin Falls, Idaho (M):												
SR	9:00	8:30	8:00	7:00	6:15	6:00	6:15	6:45	7:15	7:45	8:30	9:00
SS	6:30	7:15	7:45	8:15	8:45	9:15	9:15	8:45	7:45	7:00	6:15	6:00
Uniontown, Pa. (E):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:00	8:30
SS	6:15	7:00	7:30	8:00	8:30	8:45	8:45	8:15	7:30	6:45	6:00	6:00
Urbana, Ill. (C):												
SR	8:15	7:45	7:15	6:15	5:45	5:30	5:30	6:00	6:30	7:00	7:45	8:15
SS	5:45	6:30	7:00	7:30	8:00	8:30	8:15	7:45	7:00	6:15	5:45	5:30
Valdosta, Ga. (E):												
SR	8:30	8:15	7:45	7:00	6:45	6:30	6:45	7:00	7:15	7:30	8:00	8:30
SS	7:00	7:15	7:45	8:00	8:15	8:30	8:45	8:15	7:45	7:00	6:30	6:30
Vancouver, Wash.* (P):												
SR	8:45	8:15	7:30	6:30	5:45	5:15	5:30	6:15	6:45	7:30	8:15	8:45
SS	5:45	6:30	7:15	8:00	8:30	9:00	9:00	8:15	7:30	6:30	5:45	5:30
Vermillion, S. Dak. (C):												
SR	9:00	8:30	7:45	6:45	6:00	5:45	6:00	6:30	7:00	7:45	8:15	8:45
SS	6:15	7:00	7:30	8:15	8:45	9:15	9:00	8:30	7:45	6:45	6:00	6:00
Vicksburg, Miss. (C):												
SR	8:00	7:45	7:15	6:30	6:00	6:00	6:00	6:30	6:45	7:00	7:30	8:00
SS	6:15	6:45	7:15	7:30	8:00	8:15	8:15	7:45	7:15	6:30	6:00	6:00
Victoria, Tex. (C):												
SR	8:30	8:15	7:45	7:00	6:30	6:30	6:45	7:00	7:15	7:30	7:45	8:15
SS	7:00	7:15	7:30	8:00	8:15	8:30	8:30	8:15	7:30	7:00	6:30	6:30
Visalia, Calif. (P):												
SR	8:15	7:45	7:15	6:30	5:45	5:45	5:45	6:15	6:45	7:00	7:30	8:00
SS	6:00	6:45	7:00	7:30	8:00	8:15	8:15	7:45	7:00	6:30	5:45	5:45
Wallace, Idaho (P):												
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	5:00
Washington, D. C.* (E):												
SR	8:30	8:00	7:15	6:30	6:00	5:45	6:00	6:15	6:45	7:15	7:45	8:15
SS	6:15	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	6:00	5:45
Washington, N. C. (E):												
SR	8:15	8:00	7:15	6:30	6:00	5:45	6:00	6:30	6:45	7:15	7:45	8:15
SS	6:15	7:00	7:15	7:45	8:00	8:15	8:00	8:00	7:15	6:30	6:00	6:00
Waterbury, Vt. (E):												
SR	8:30	8:00	7:00	6:15	5:30	5:00	5:15	5:45	6:30	7:00	7:45	8:15
SS	5:30	6:15	7:00	7:30	8:15	8:30	8:30	8:00	7:00	6:15	5:30	5:30

*Metropolitan district.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Watertown, N. Y. (E):												
SR	8:30	8:00	7:15	6:30	5:45	5:15	5:30	6:00	6:45	7:15	8:00	8:30
SS	5:45	6:30	7:15	7:45	8:15	8:45	8:45	8:15	7:15	6:15	5:45	5:30
West Lafayette, Ind. (C):												
SR	8:15	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:30	8:00
SS	5:45	6:15	7:00	7:30	8:00	8:15	8:15	7:45	7:00	6:15	5:30	5:30
Wenatchee, Wash. (P):												
SR	8:45	8:15	7:15	6:15	5:30	5:00	5:15	6:00	6:30	7:15	8:00	8:45
SS	5:30	6:30	7:00	7:45	8:30	9:00	9:00	8:15	7:15	6:15	5:30	5:15
Wheeling, W. Va.* (E):												
SR	8:45	8:15	7:30	6:45	6:15	6:00	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:30	9:00	8:45	8:15	7:30	6:45	6:15	6:00
Wichita, Kans.* (C):												
SR	8:45	8:15	7:45	7:00	6:15	6:00	6:15	6:45	7:15	7:30	8:15	8:45
SS	6:30	7:00	7:30	8:00	8:30	8:45	8:45	8:30	7:45	7:00	6:15	6:15
Wichita Falls, Tex. (C):												
SR	8:45	8:15	7:45	7:00	6:30	6:15	6:30	7:00	7:15	7:45	8:00	8:30
SS	6:45	7:15	7:45	8:00	8:30	8:45	8:45	8:15	7:45	7:00	6:30	6:30
Wilmington, Del.* (E):												
SR	8:30	8:00	7:15	6:30	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	5:45	5:45
Wilmington, N. C. (E):												
SR	8:15	8:00	7:30	6:45	6:15	6:00	6:15	6:30	7:00	7:15	7:45	8:15
SS	6:30	7:00	7:15	7:45	8:00	8:30	8:30	8:00	7:15	6:45	6:15	6:00
Winston-Salem, N. C. (E):												
SR	8:30	8:15	7:30	6:45	6:15	6:00	6:15	6:45	7:00	7:30	8:00	8:30
SS	6:30	7:00	7:30	8:00	8:15	8:45	8:45	8:15	7:30	6:45	6:15	6:15
Wisconsin Rapids, Wis. (C):												
SR	8:30	8:00	7:15	6:15	5:30	5:15	5:30	6:00	6:30	7:15	8:00	8:30
SS	5:45	6:30	7:00	7:45	8:15	8:45	8:45	8:00	7:15	6:15	5:30	5:15
Wolf Point, Mont. (M):												
SR	8:45	8:15	7:15	6:15	5:30	5:00	5:15	6:00	6:45	7:15	8:15	8:45
SS	5:30	6:30	7:00	7:45	8:30	9:00	9:00	8:15	7:15	6:15	5:30	5:15
Worcester, Mass.* (E):												
SR	8:45	7:45	7:00	6:15	5:30	5:15	5:30	6:00	6:30	7:00	7:30	8:15
SS	5:45	6:15	7:00	7:30	8:00	8:30	8:30	7:45	7:00	6:00	5:30	5:15
Yakima, Wash. (P):												
SR	8:45	8:15	7:15	6:15	5:30	5:00	5:15	6:00	6:45	7:15	8:00	8:45
SS	5:45	6:30	7:00	7:45	8:30	9:00	9:00	8:15	7:15	6:15	5:30	5:15
Yankton, S. Dak. (C):												
SR	9:00	8:30	7:45	6:45	6:15	5:45	6:00	6:30	7:15	7:45	8:15	9:00
SS	6:15	7:00	7:30	8:15	8:45	9:15	9:00	8:30	7:45	6:45	6:15	6:00
York, Pa. (E):												
SR	8:30	8:00	7:15	6:30	6:00	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:45	7:15	7:45	8:15	8:30	8:30	8:00	7:15	6:30	5:45	5:45
Youngstown, Ohio* (E):												
SR	8:45	8:15	7:30	6:45	6:00	5:45	6:00	6:30	7:00	7:30	8:15	8:45
SS	6:15	7:00	7:30	8:00	8:30	9:00	9:00	8:15	7:30	6:45	6:00	6:00
Yuma, Ariz. (M):												
SR	8:45	8:30	7:45	7:15	6:45	6:30	6:45	7:00	7:15	7:45	8:15	8:30
SS	7:00	7:30	7:45	8:15	8:30	8:45	8:45	8:30	7:45	7:00	6:45	6:30
Zarephath, N. J. (E):												
SR	8:15	8:00	7:15	6:15	5:45	5:30	5:45	6:15	6:45	7:15	7:45	8:15
SS	6:00	6:30	7:00	7:30	8:00	8:30	8:30	8:00	7:15	6:15	5:45	5:30

*Metropolitan district.

APPENDIX I

Ground Wave Field Intensity Charts

Graphs 1-20 show the computed values of ground wave field intensity as a function of the distance from the transmitting antenna. The ground wave 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 X 10^{14} or expressed in mhos per meter X 10^{3}) given on the curves. The curves show the variation of the ground wave field intensity with distance to be expected for transmission from a short vertical antenna at a 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 ground wave 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 ground wave 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 ground wave 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 earch 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) $2/3 = 1.21$. The amount of this refraction varies from day to day and from season to season, depending on the air mass conditions in the lower atmosphere. If k denotes the ratio between the equivalent radius of the earth and the true radius, the following table gives the values of k for several typical air masses encountered in the United States.

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

Air mass type	k	
	Summer	Winter
Tropical Gulf—T_c	1.53	1.43
Polar Continental—P_c	1.31	1.25
Superior—S	1.25	1.25
Average	1.33	

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 ground wave 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 1/3 mc 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.

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 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.

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

$(R/\lambda)_1$ = 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.

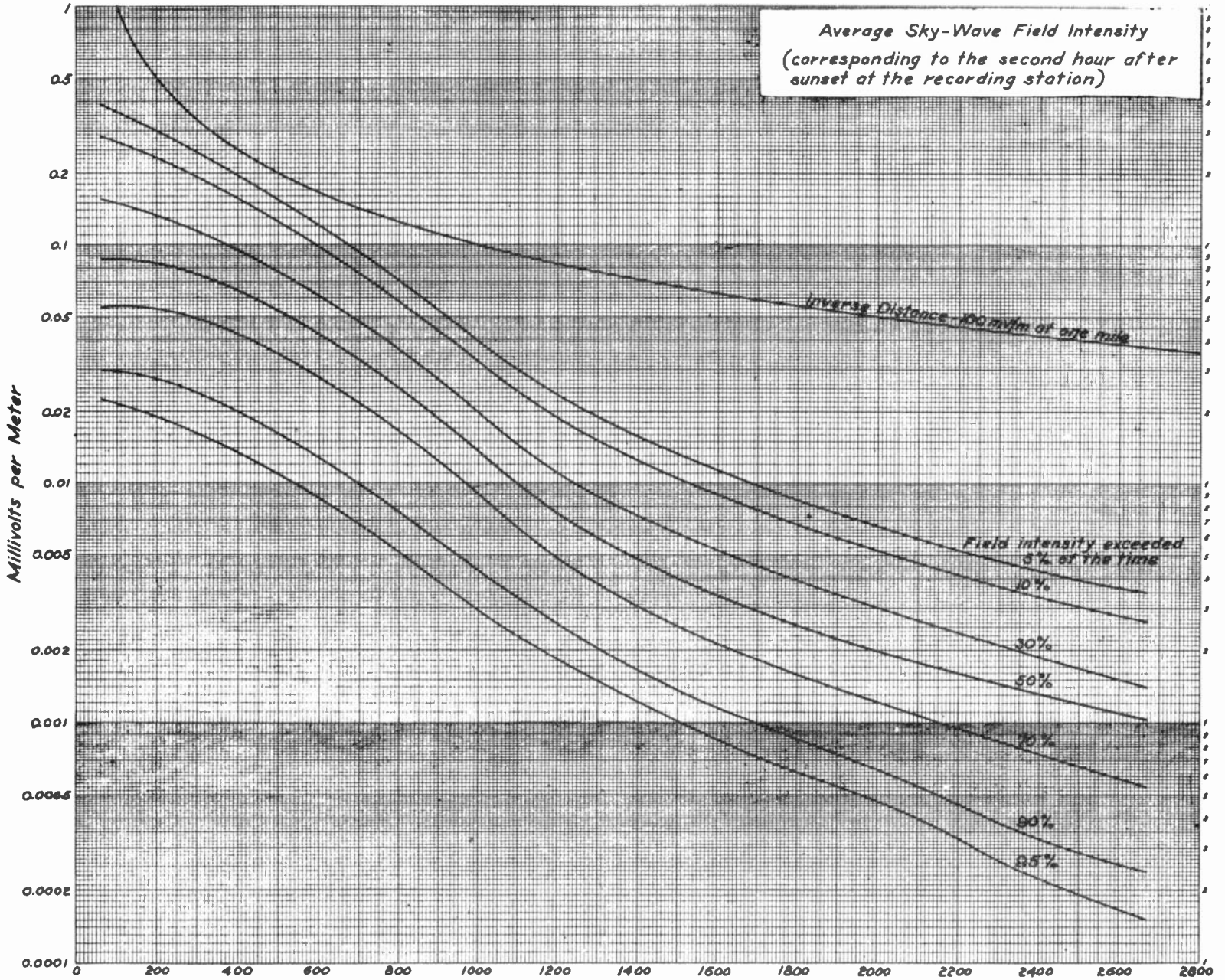
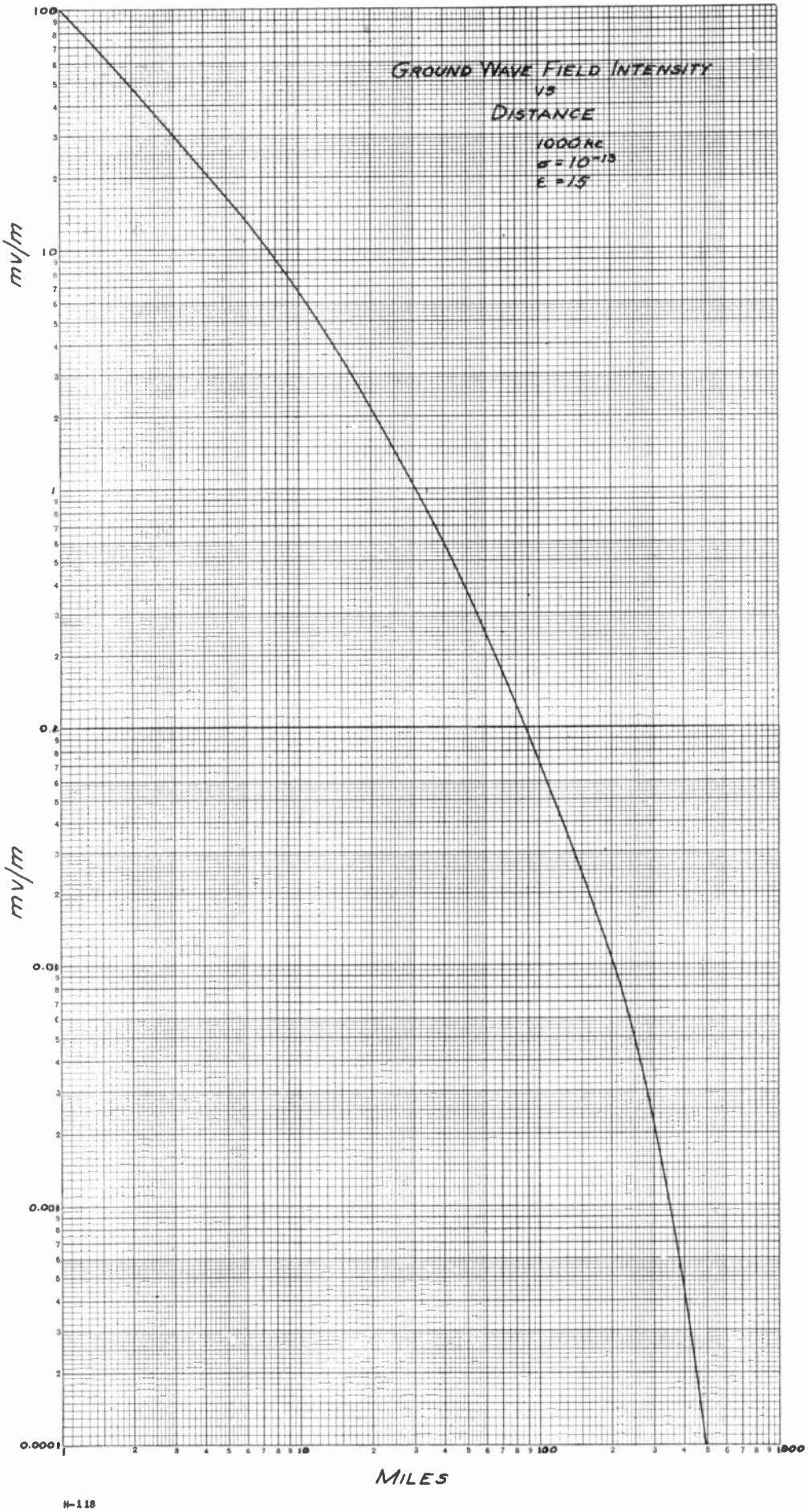


Figure 1

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


GROUND WAVE FIELD INTENSITY
VS
DISTANCE
1000 Kc
σ = 10⁻¹³
ε = 15
mv/m
mv/m
MILES

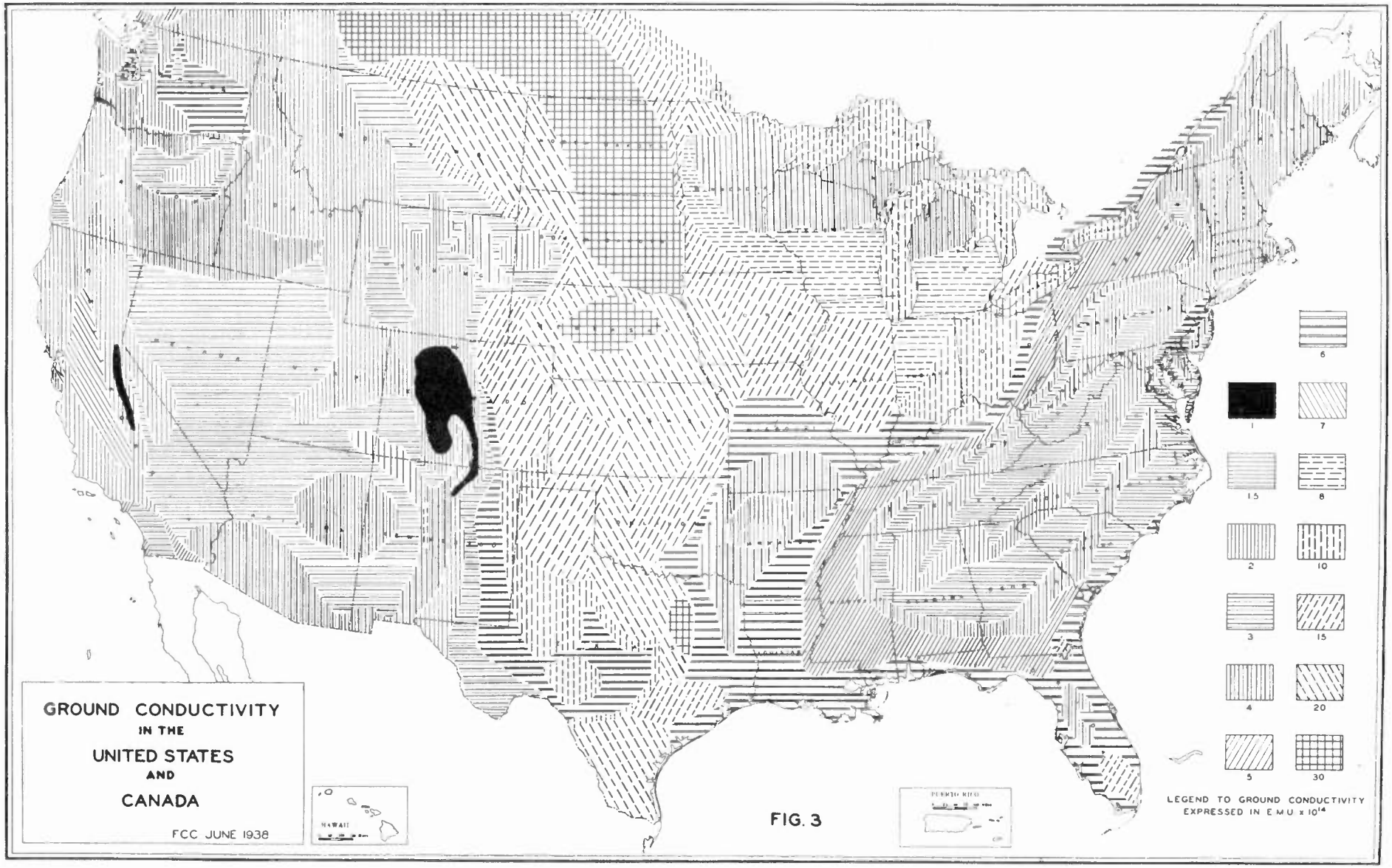

GROUND CONDUCTIVITY
IN THE
UNITED STATES
AND
CANADA
FCC JUNE 1938
HAWAII
PUERTO RICO
6
1
7
15
8
2
10
3
15
4
20
5
30
LEGEND TO GROUND CONDUCTIVITY
EXPRESSED IN E.M.U. x 10^14

FIG. 3

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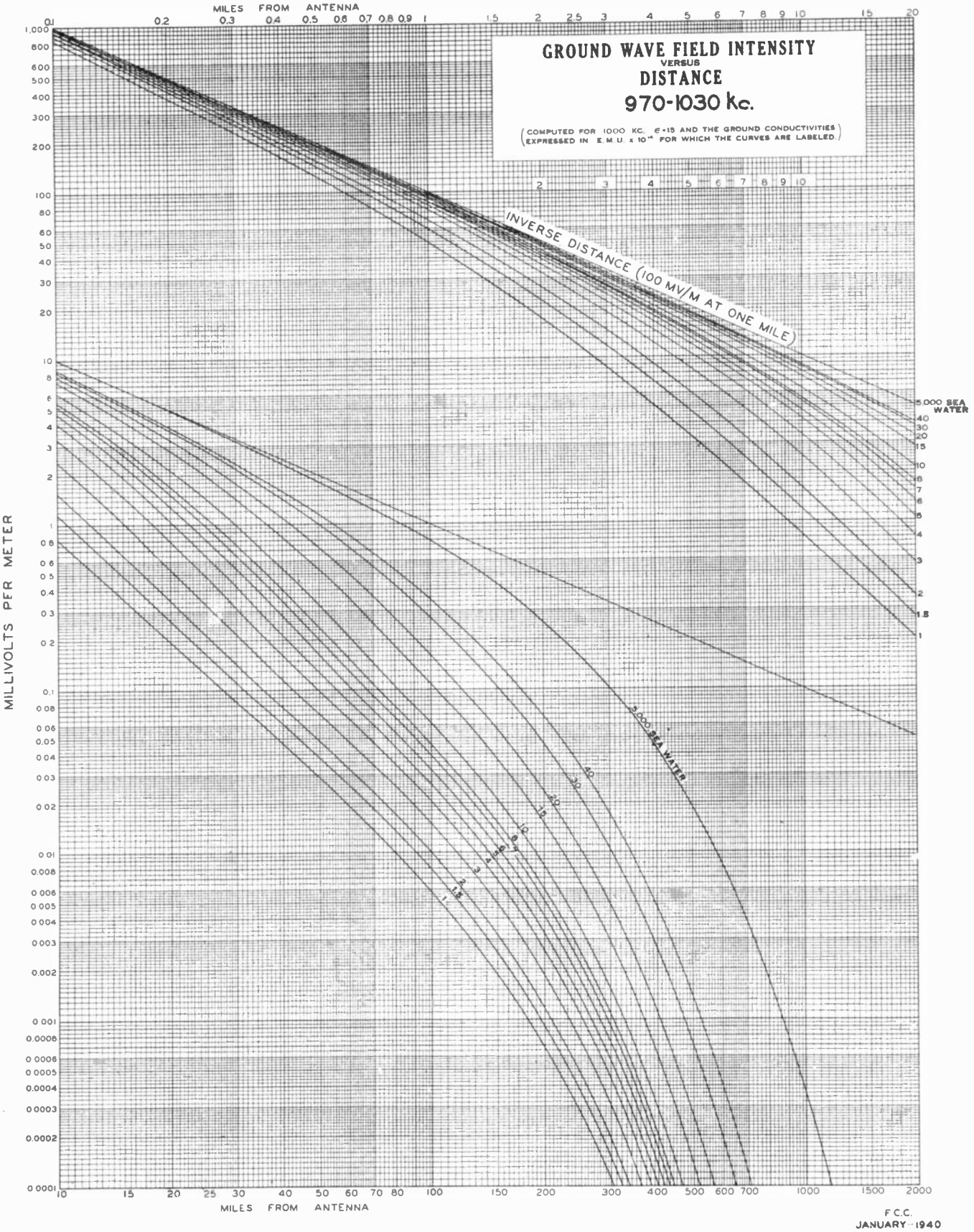
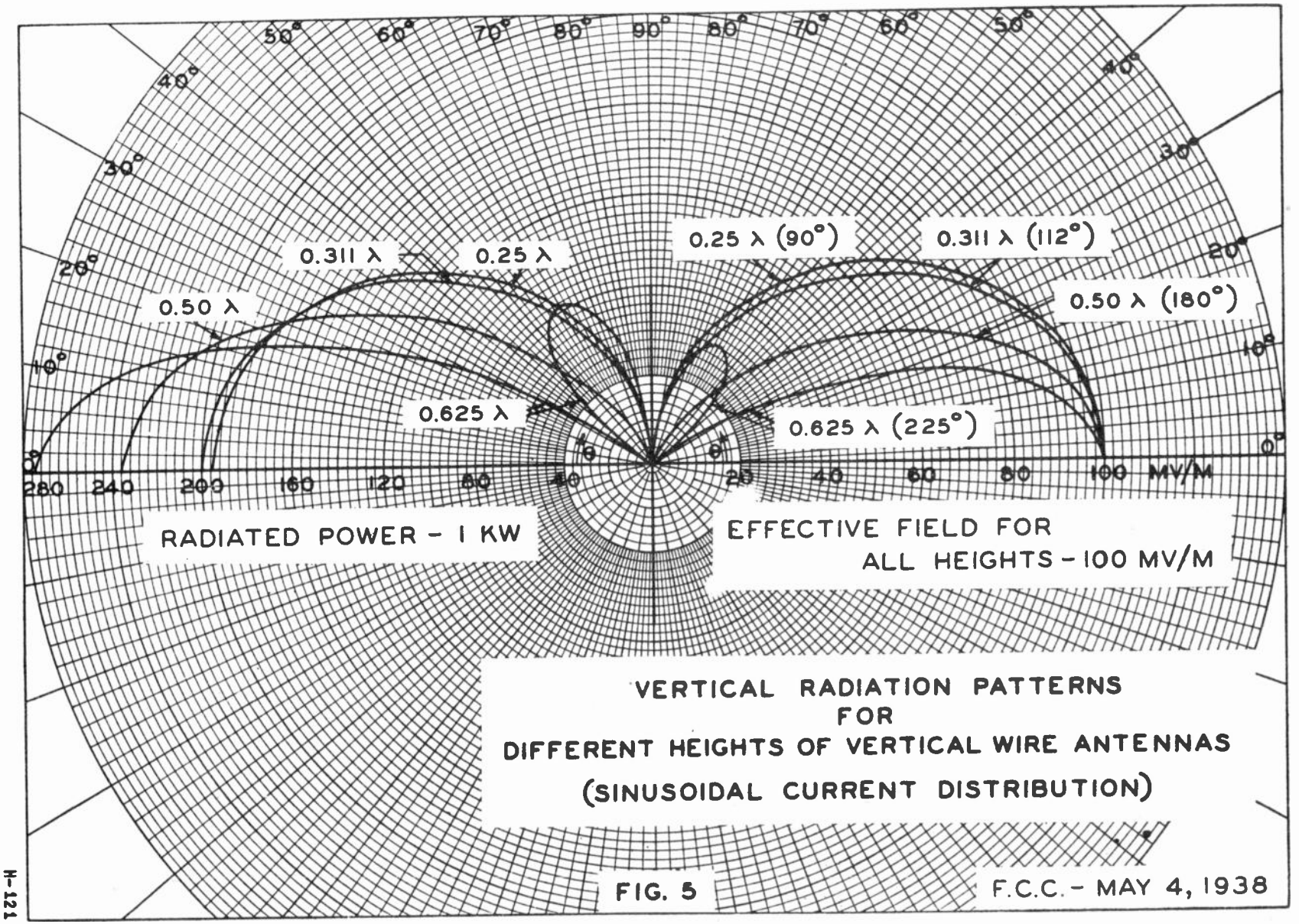


H-120

FIGURE 4



VERTICAL RADIATION PATTERNS
FOR
DIFFERENT HEIGHTS OF VERTICAL WIRE ANTENNAS
(SINUSOIDAL CURRENT DISTRIBUTION)

FIG. 5

F.C.C. - MAY 4, 1938

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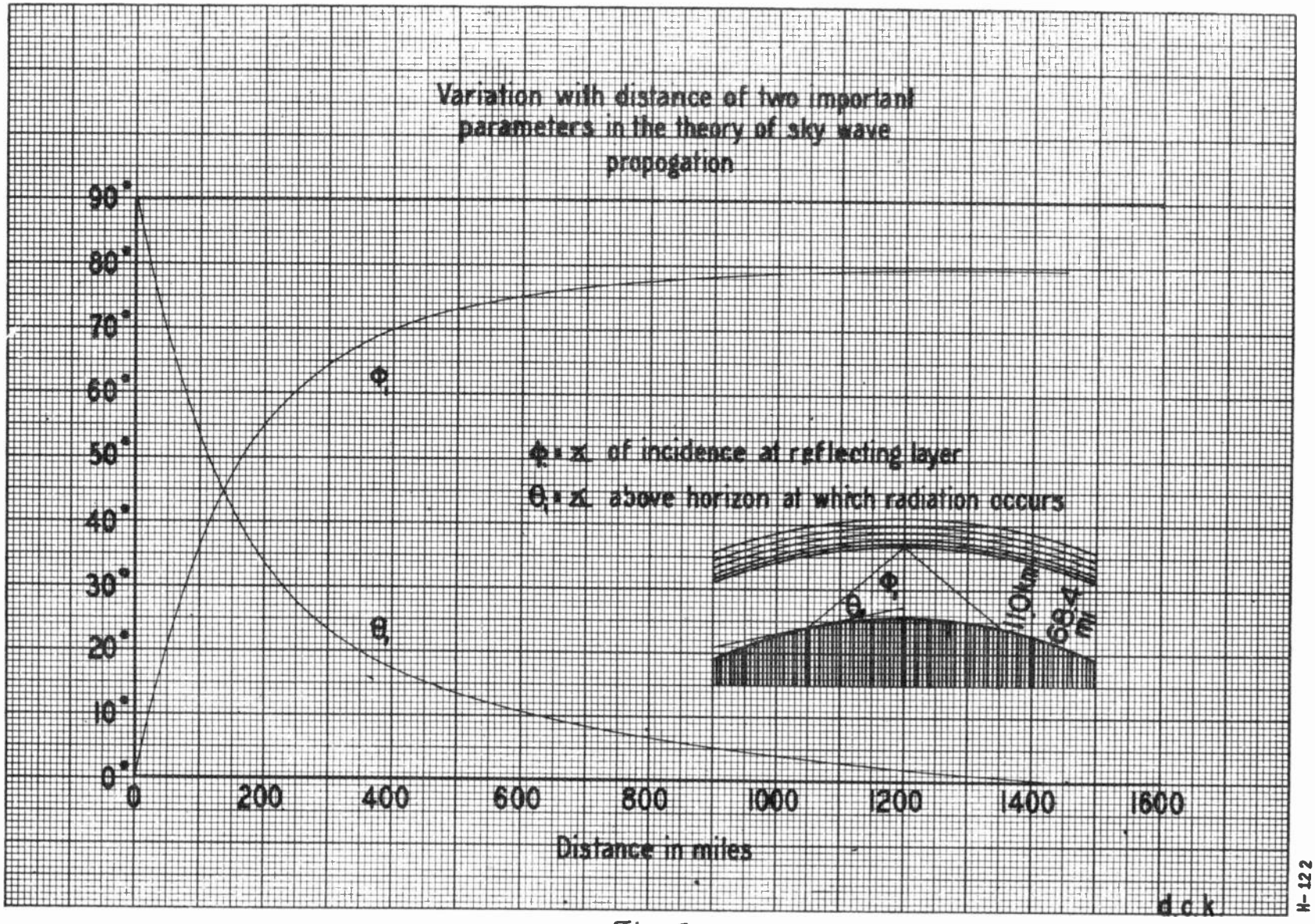
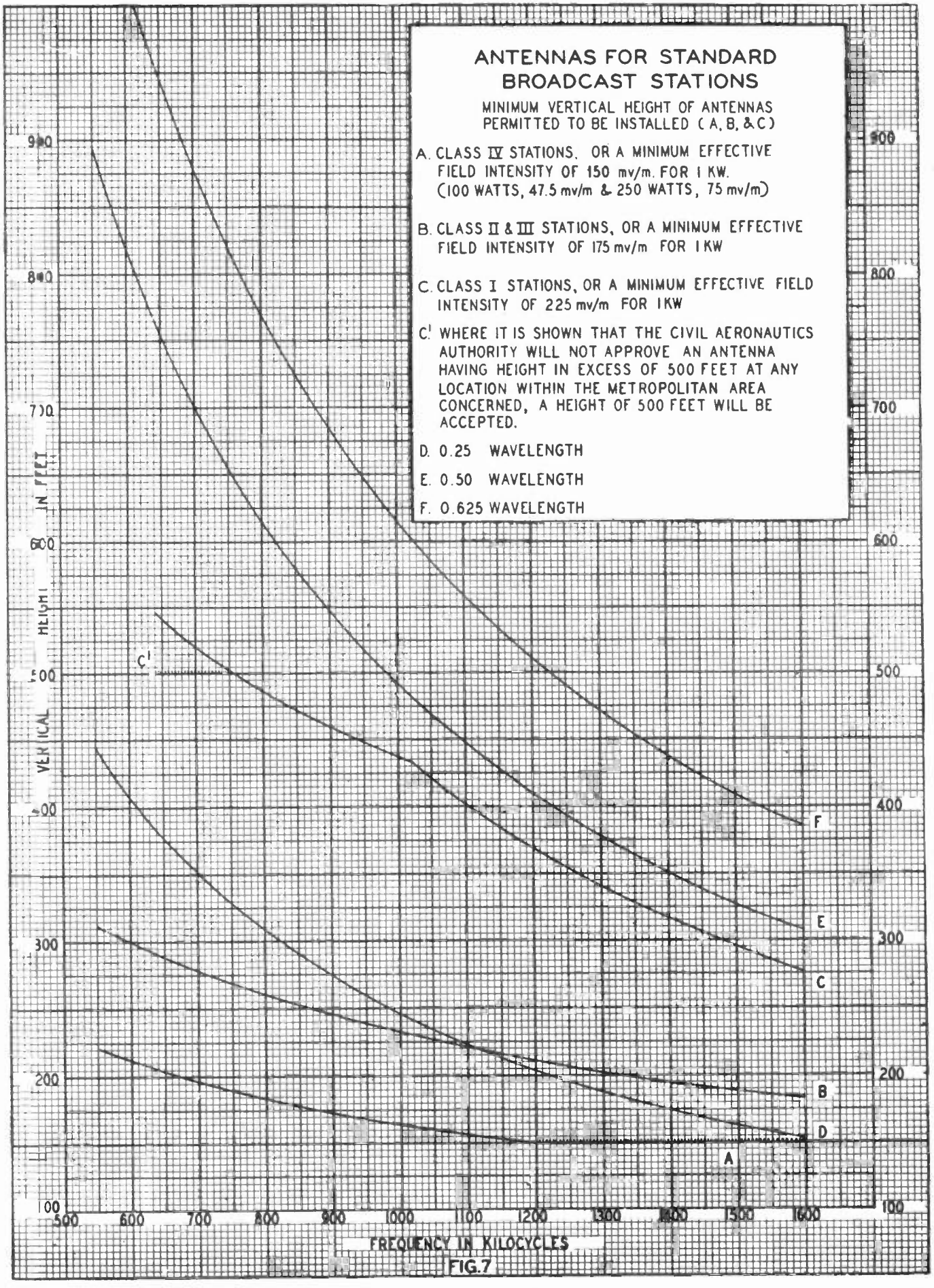
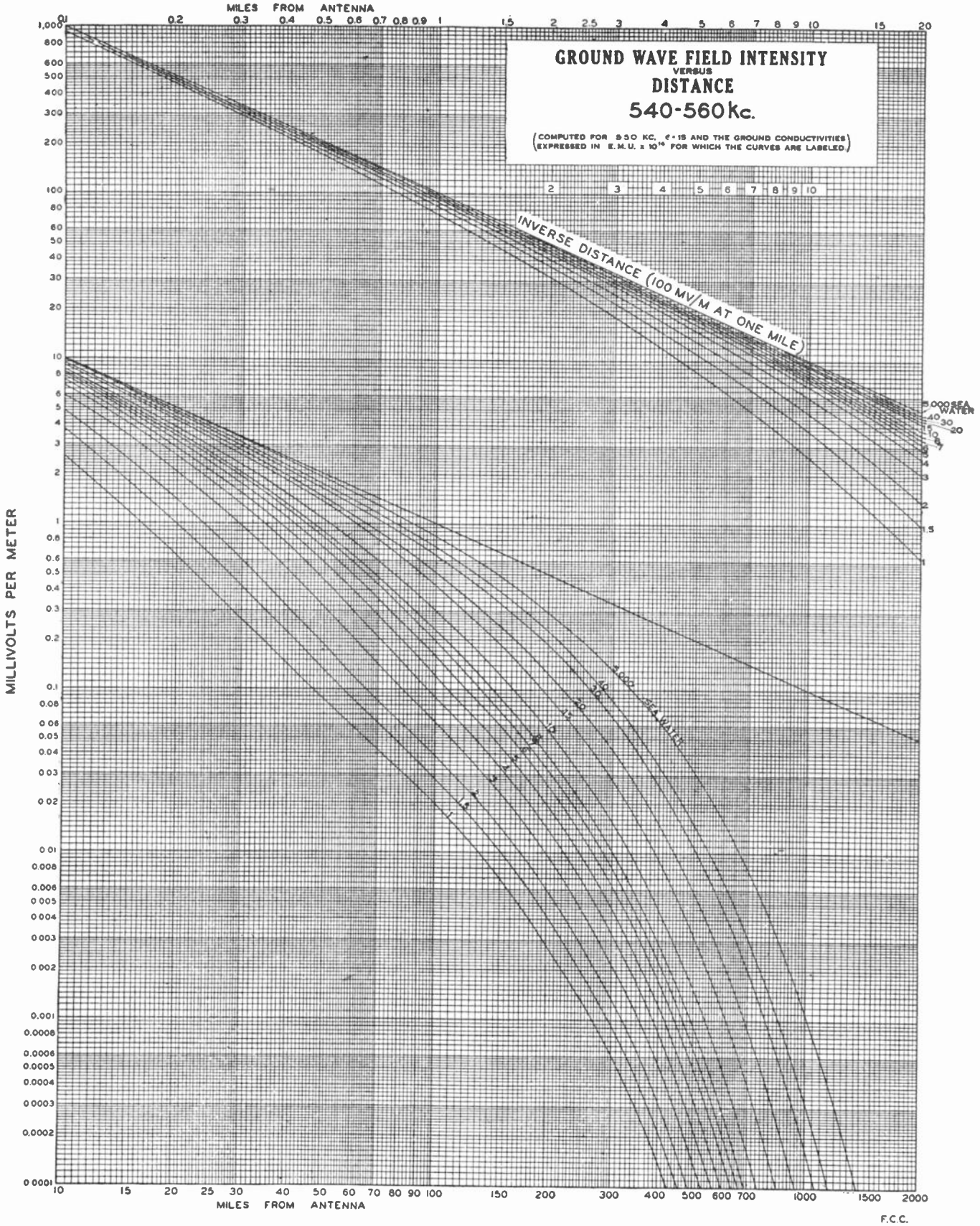

Variation with distance of two important parameters in the theory of sky wave propogation
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
0
200
400
600
800
1000
1200
1400
1600
Distance in miles
Φ
θ
Φ = ∠ of incidence at reflecting layer
θ = ∠ above horizon at which radiation occurs
110 miles
68.4 miles
d.c.k.
H-122

Fig. 6


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



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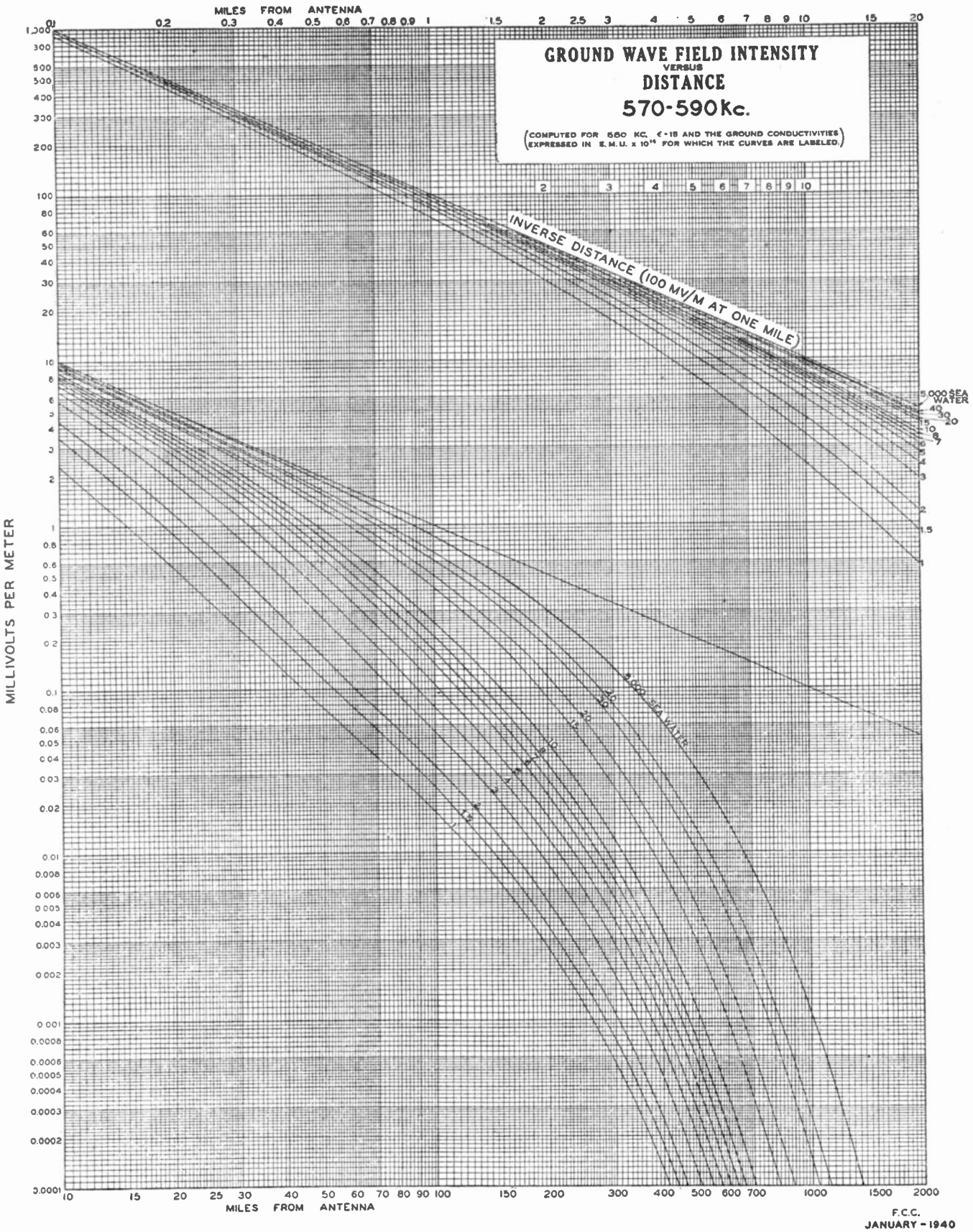
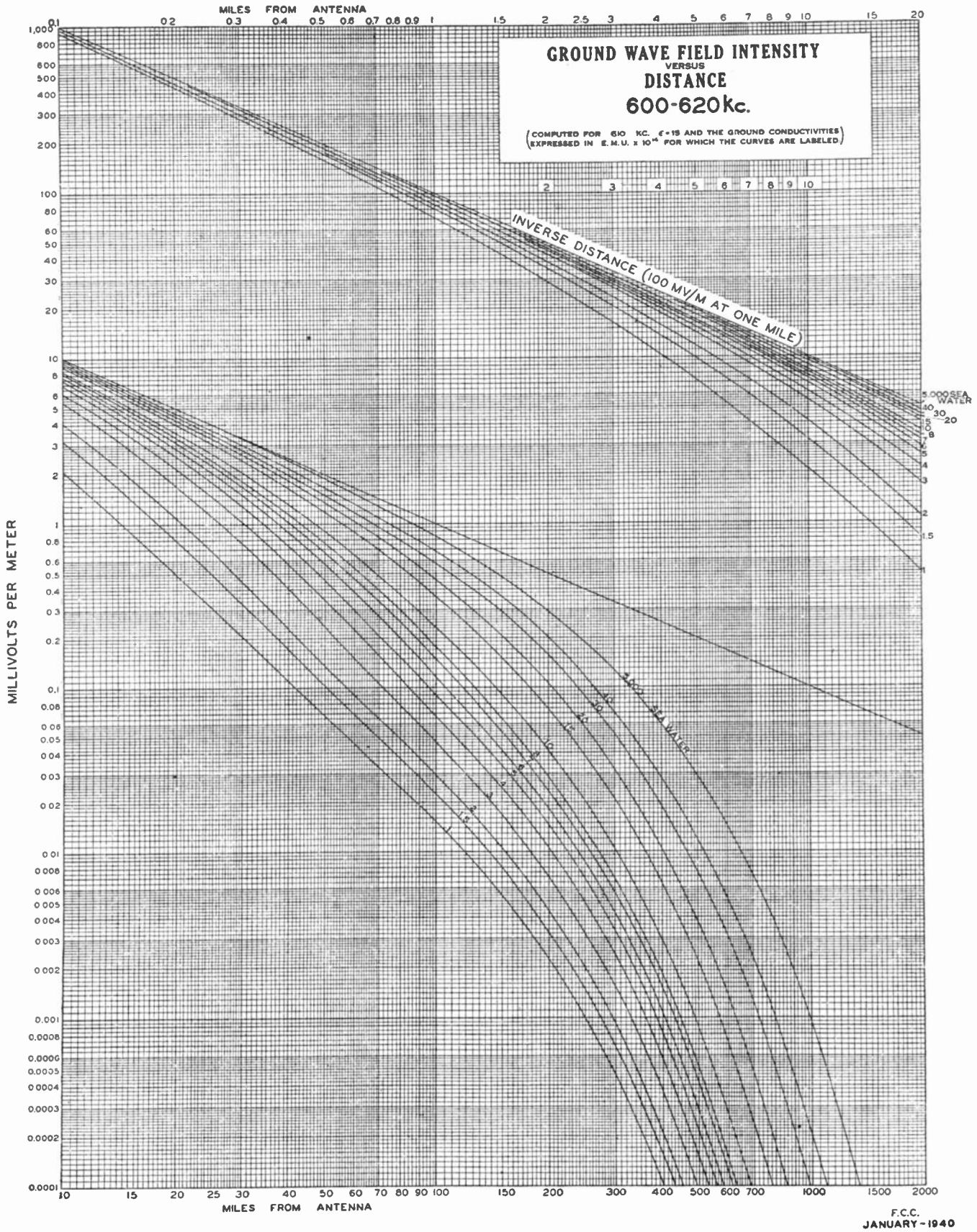
APPENDIX I - GRAPH 1



APPENDIX 1 - GRAPH 2



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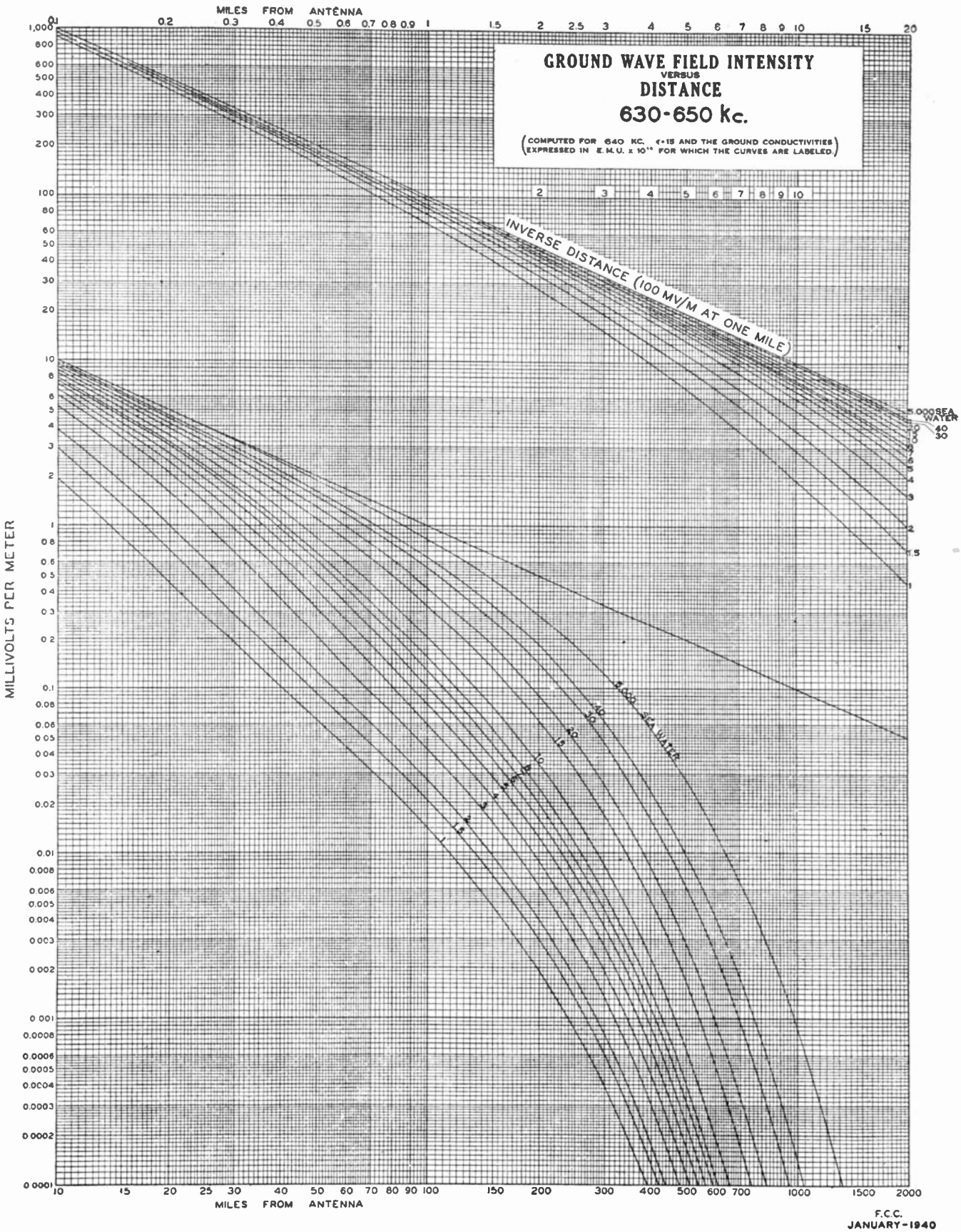
APPENDIX I - GRAPH 3



F.C.C.
JANUARY-1940

APPENDIX I - GRAPH 4

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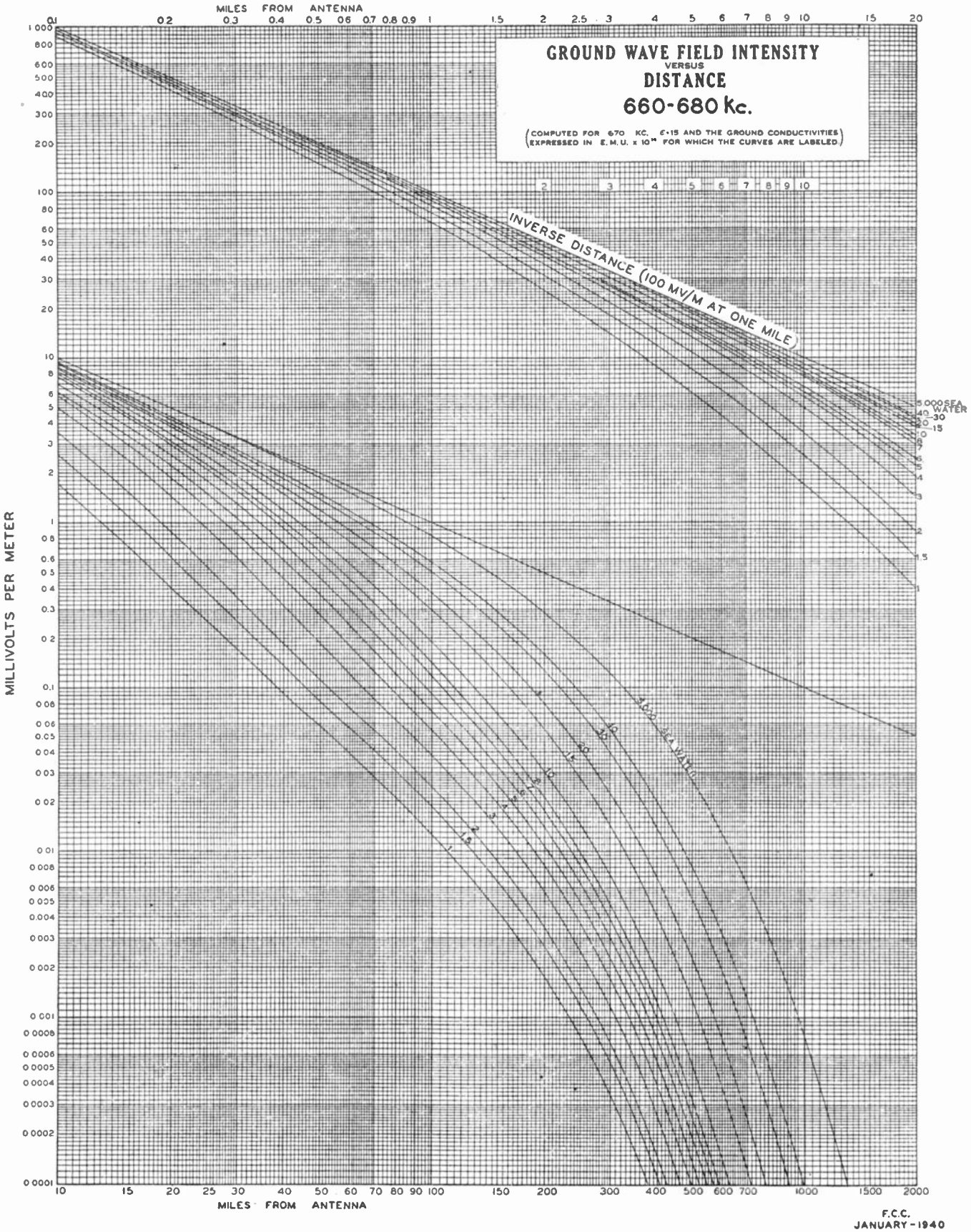
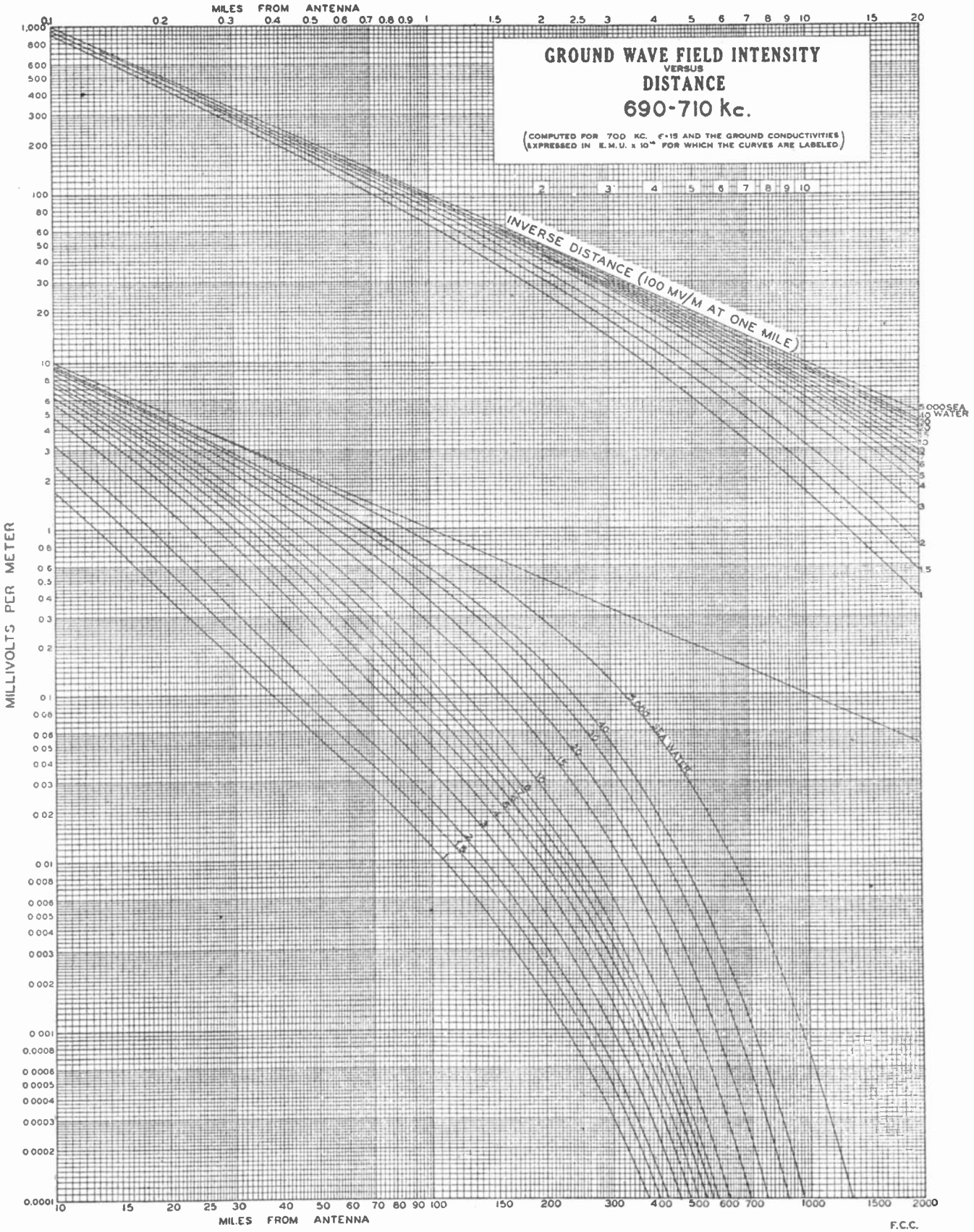
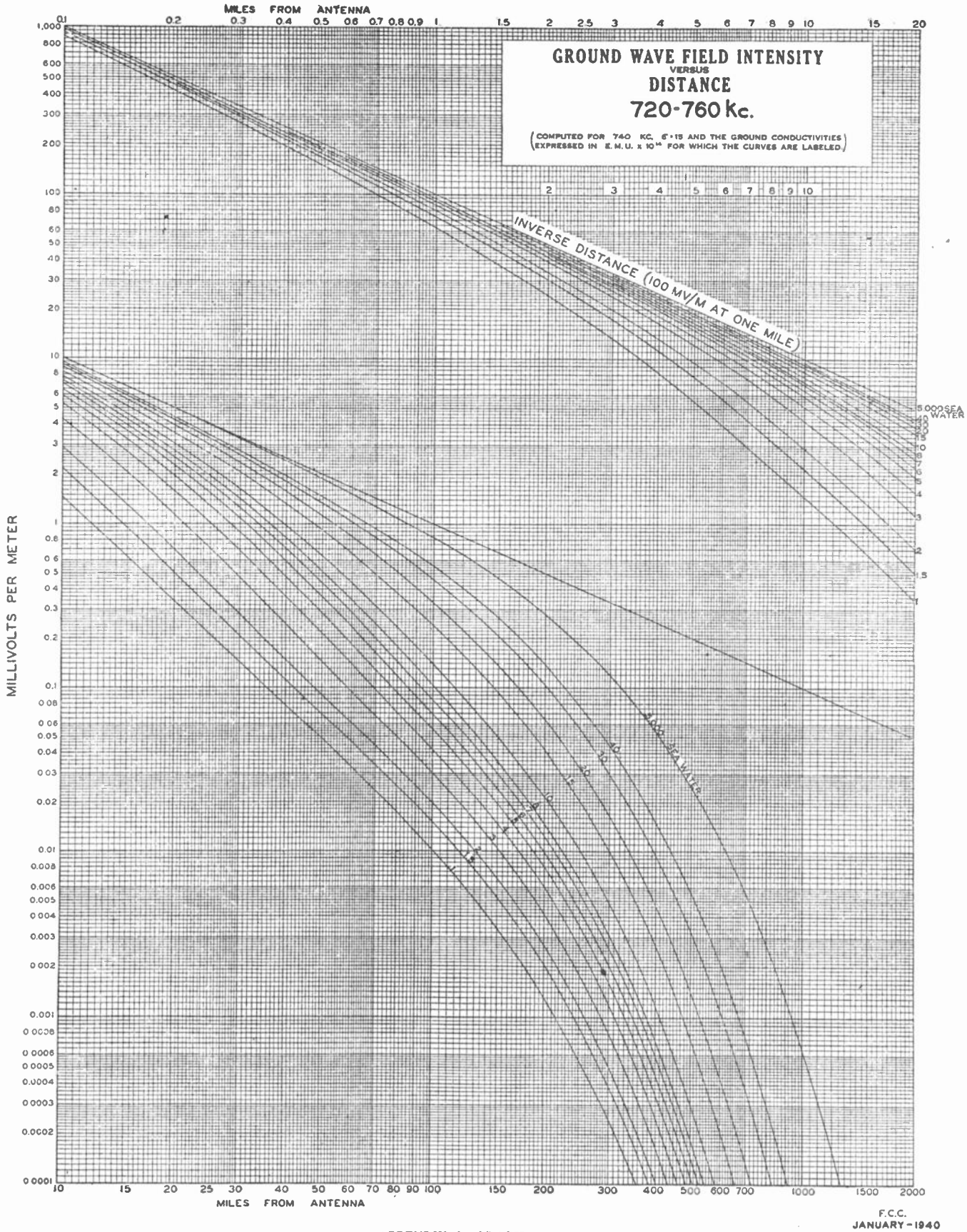


APPENDIX 1 - GRAPH 5

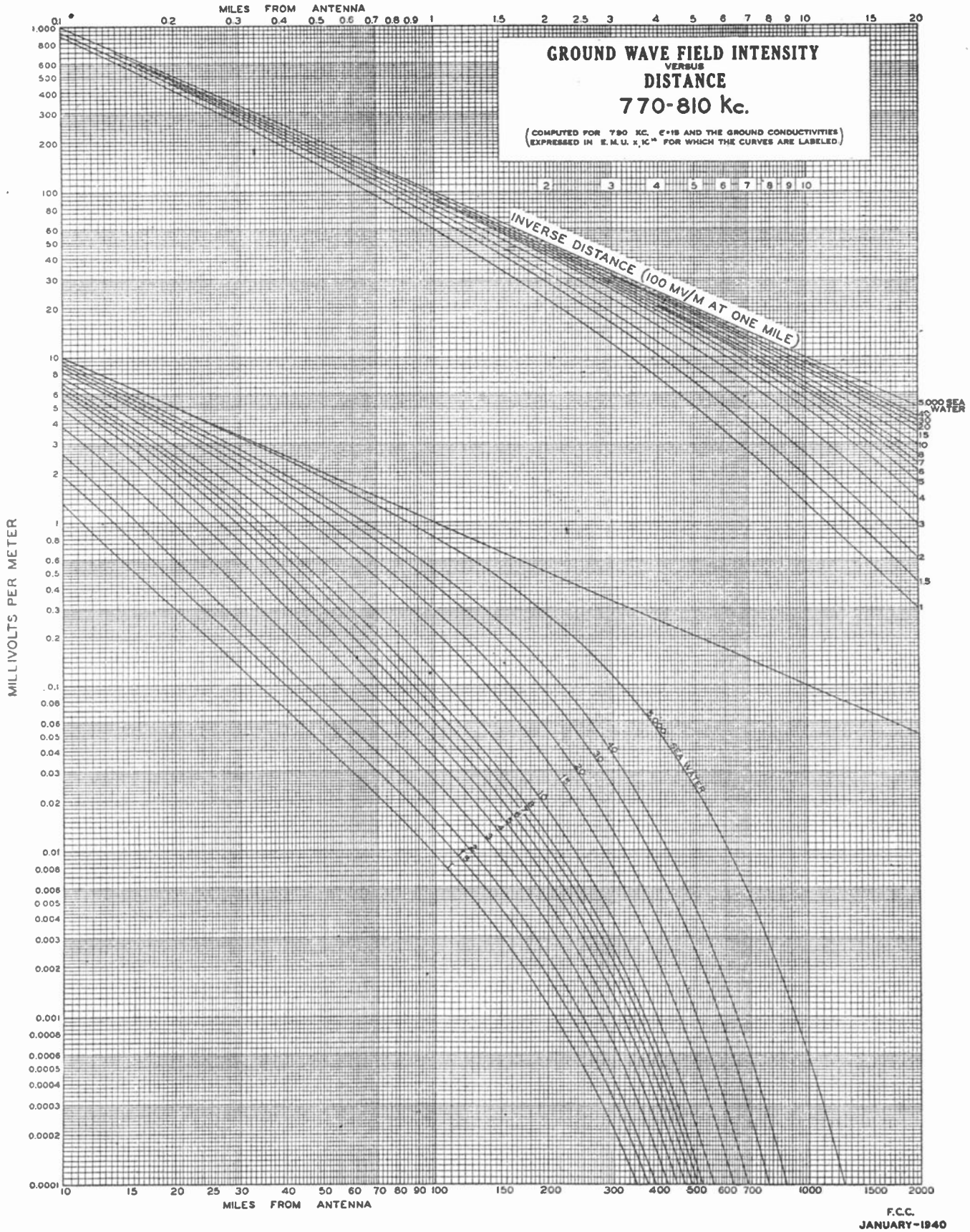


APPENDIX I - GRAPH 6

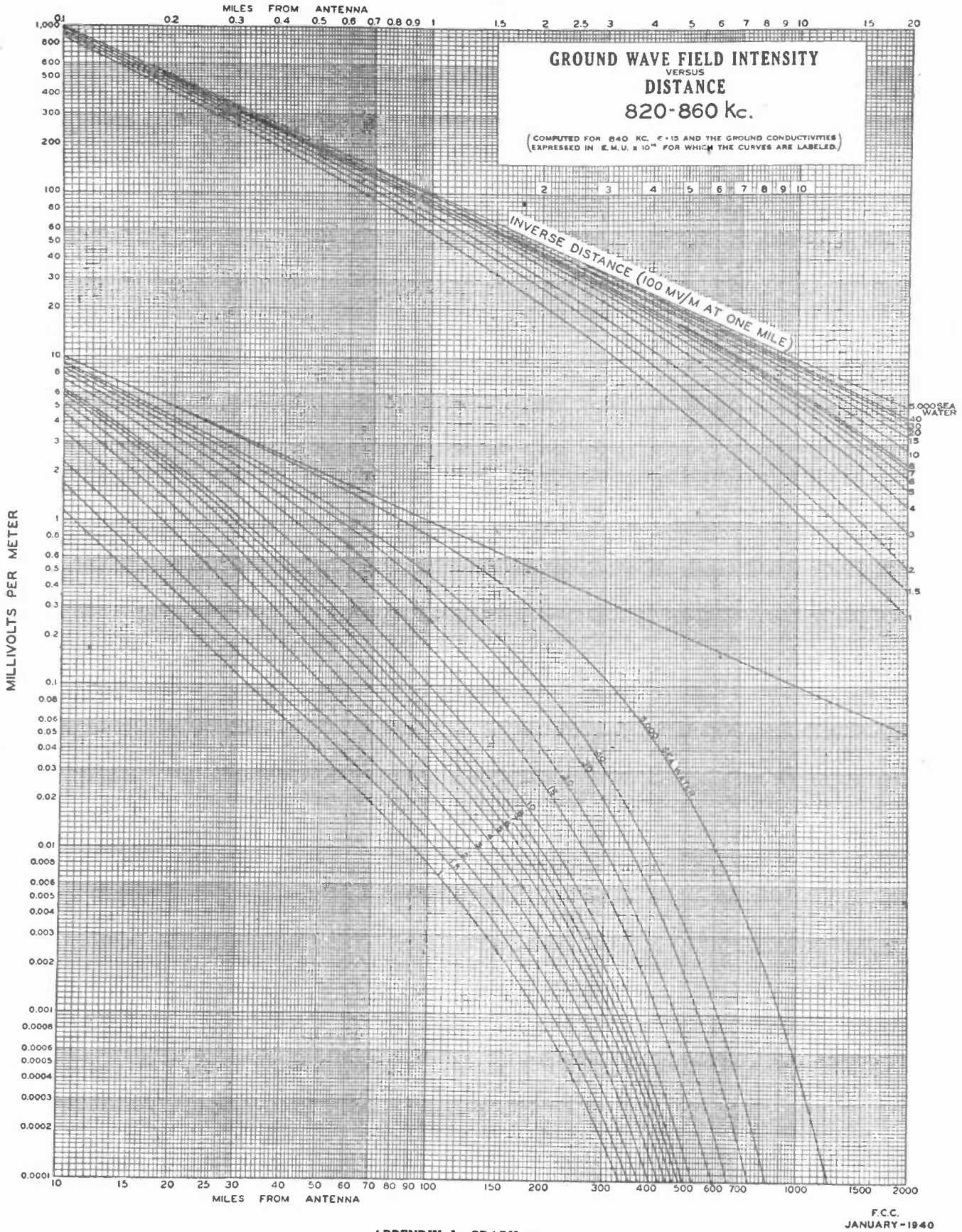


H-130

APPENDIX I - GRAPH 7



APPENDIX 1 - GRAPH 8



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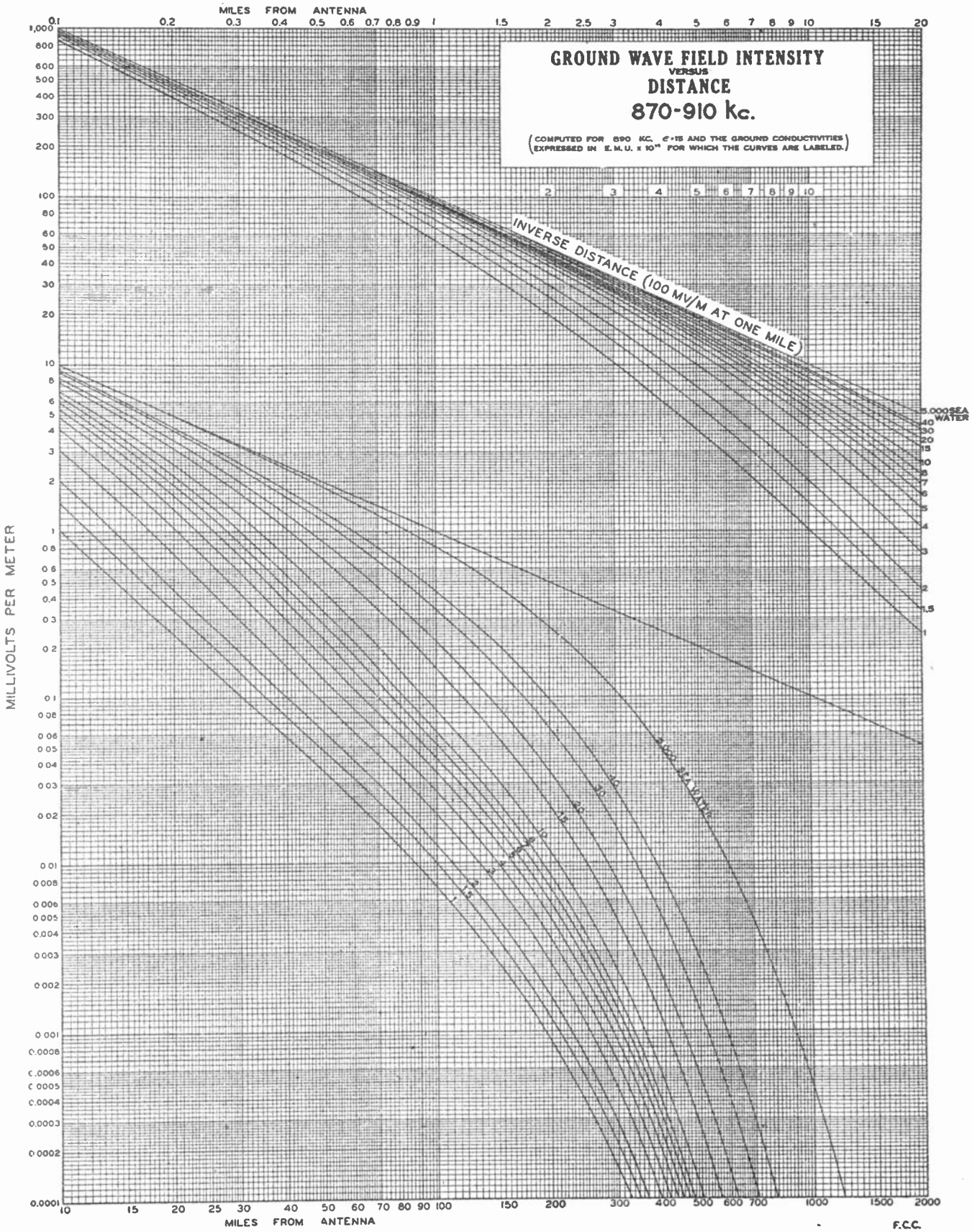
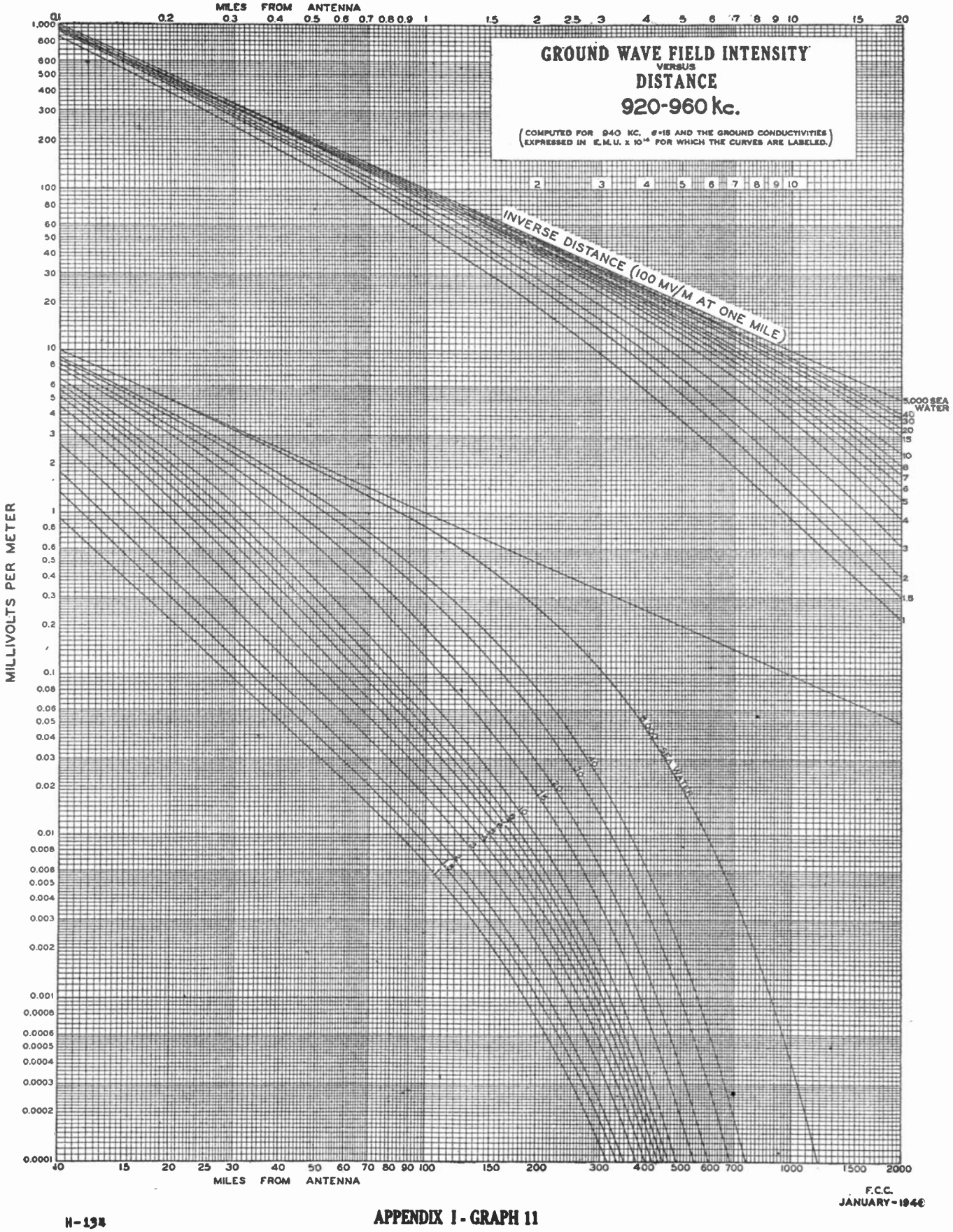
APPENDIX I - GRAPH 9



APPENDIX 1 - GRAPH 10



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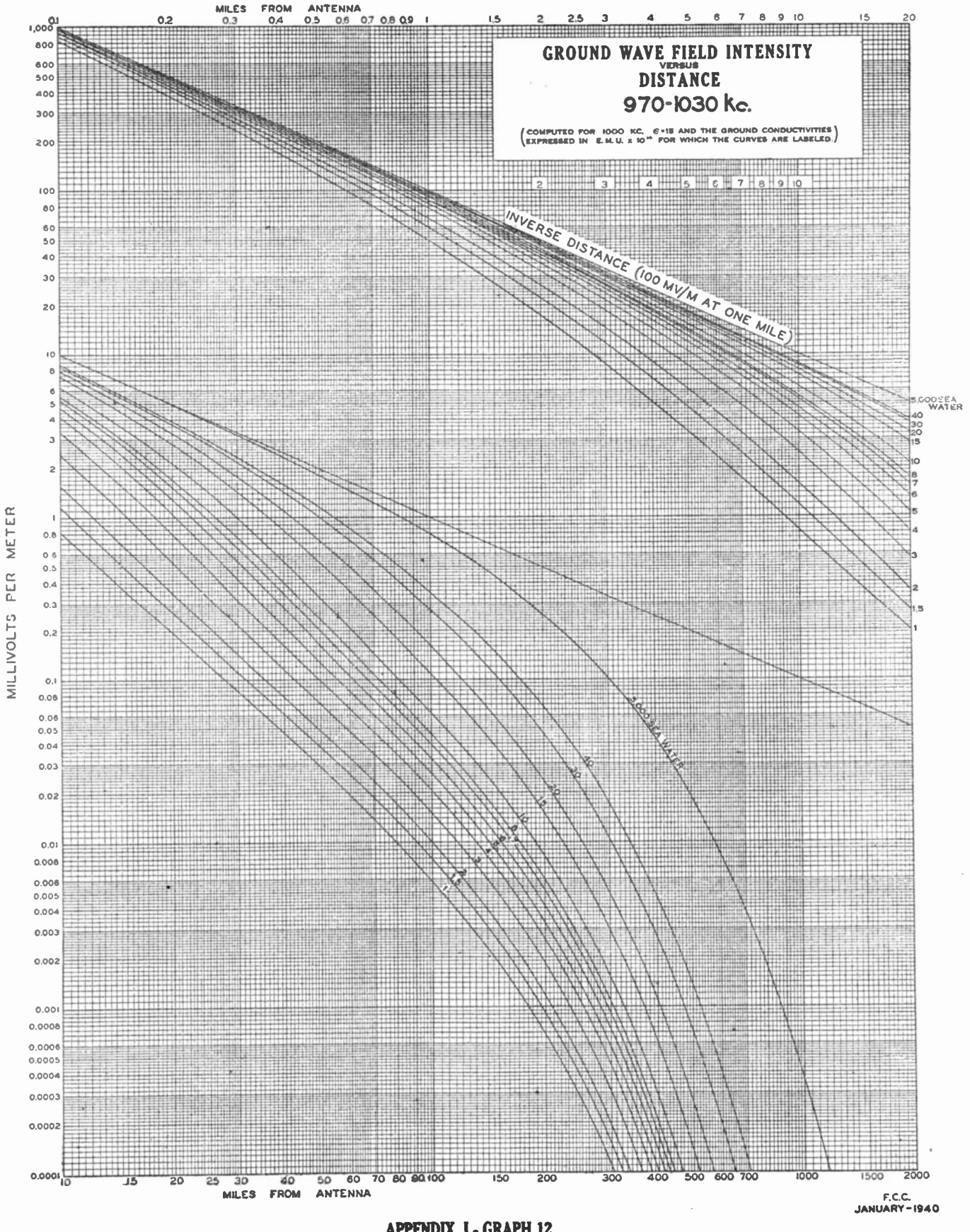
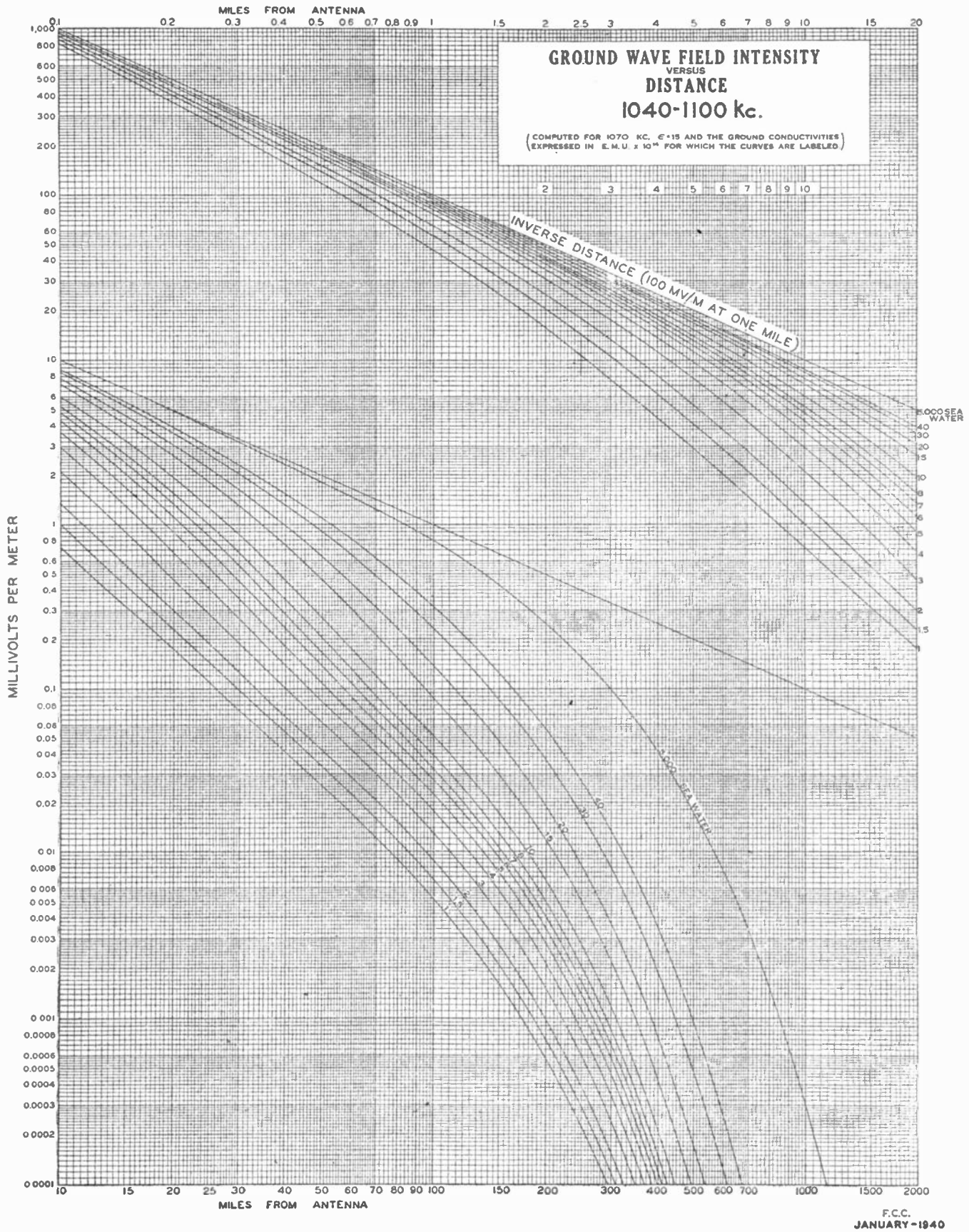
APPENDIX I - GRAPH 11

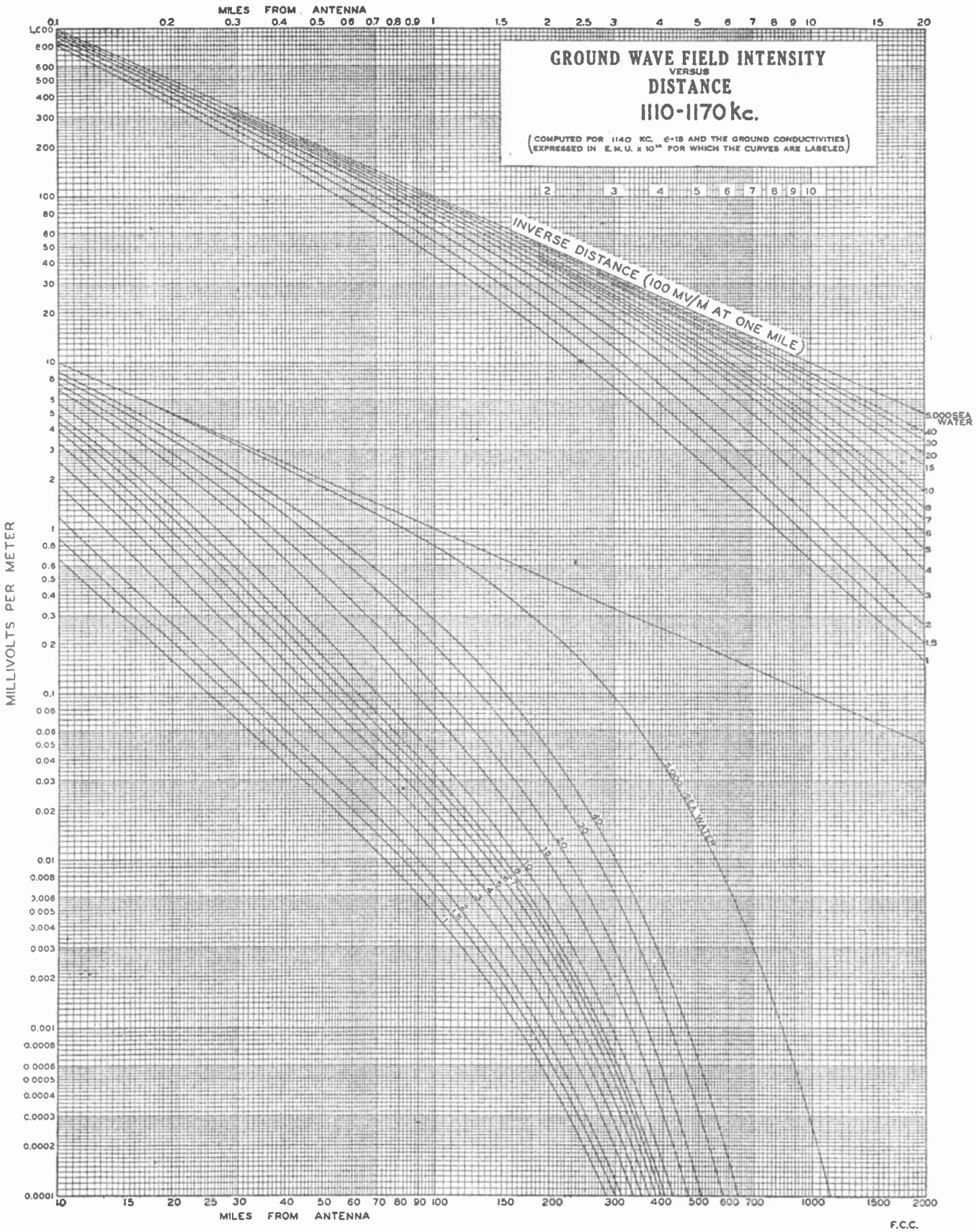


APPENDIX I - GRAPH 12



APPENDIX I - GRAPH 13

H-196



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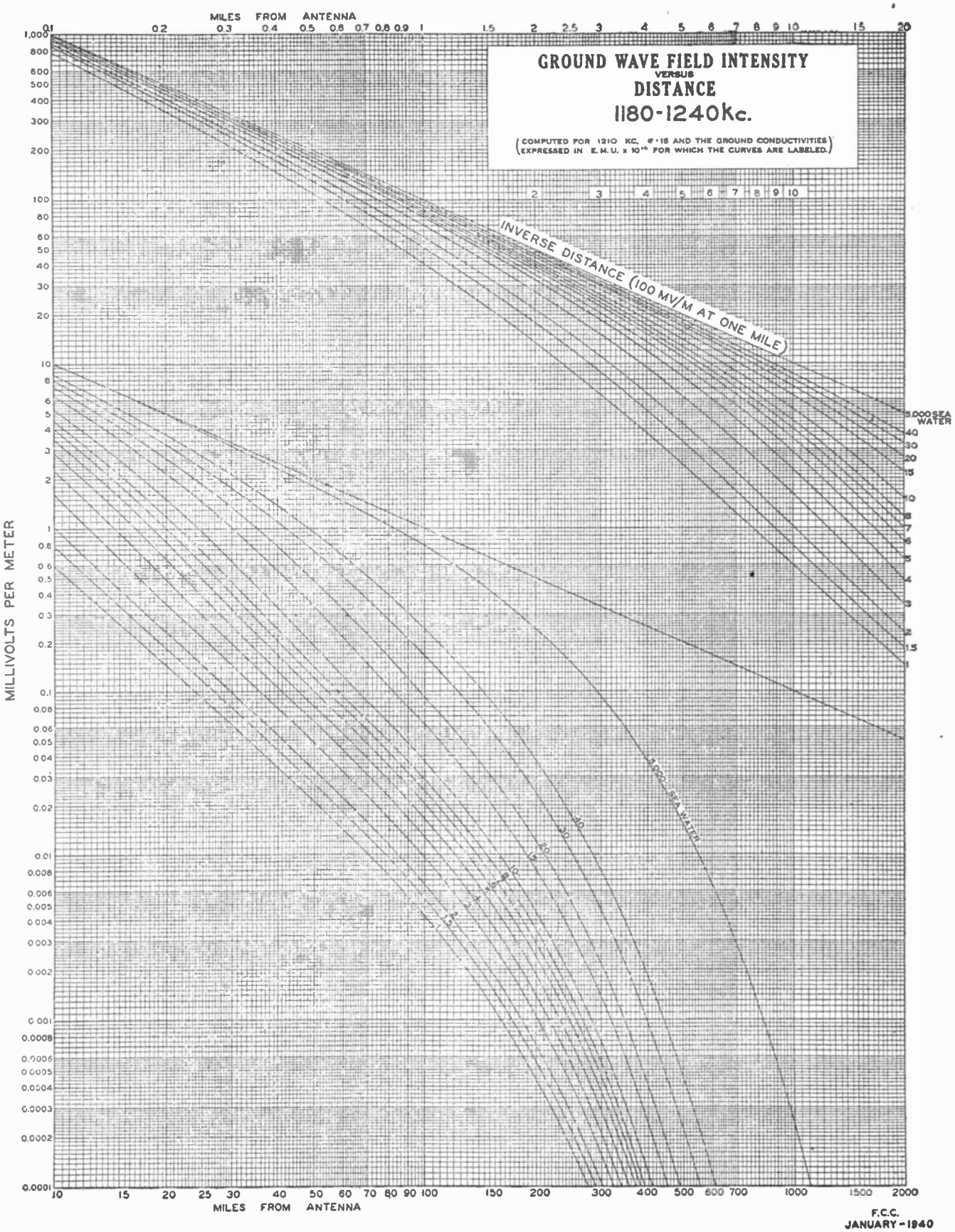
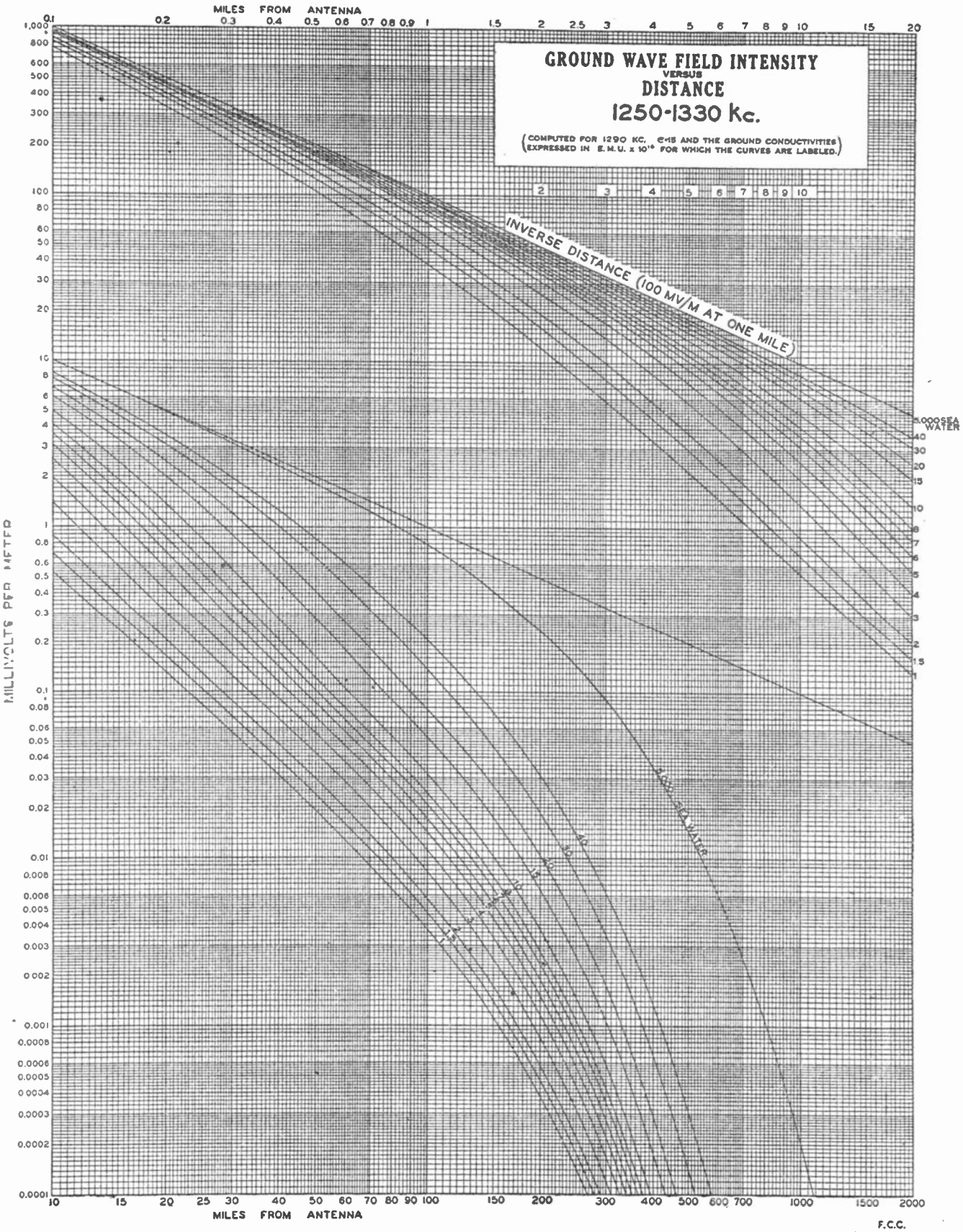
APPENDIX I - GRAPH 14

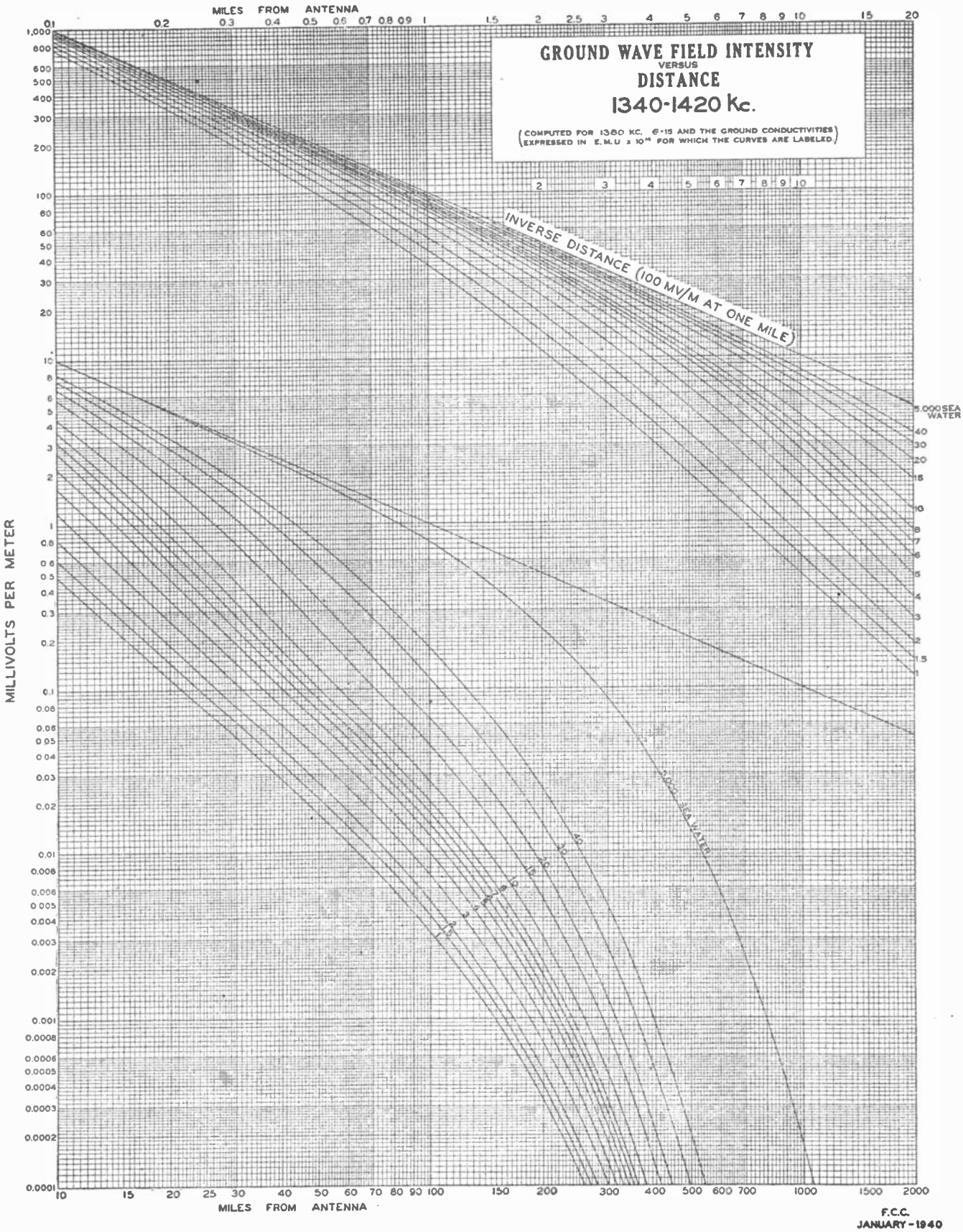


APPENDIX I - GRAPH 15

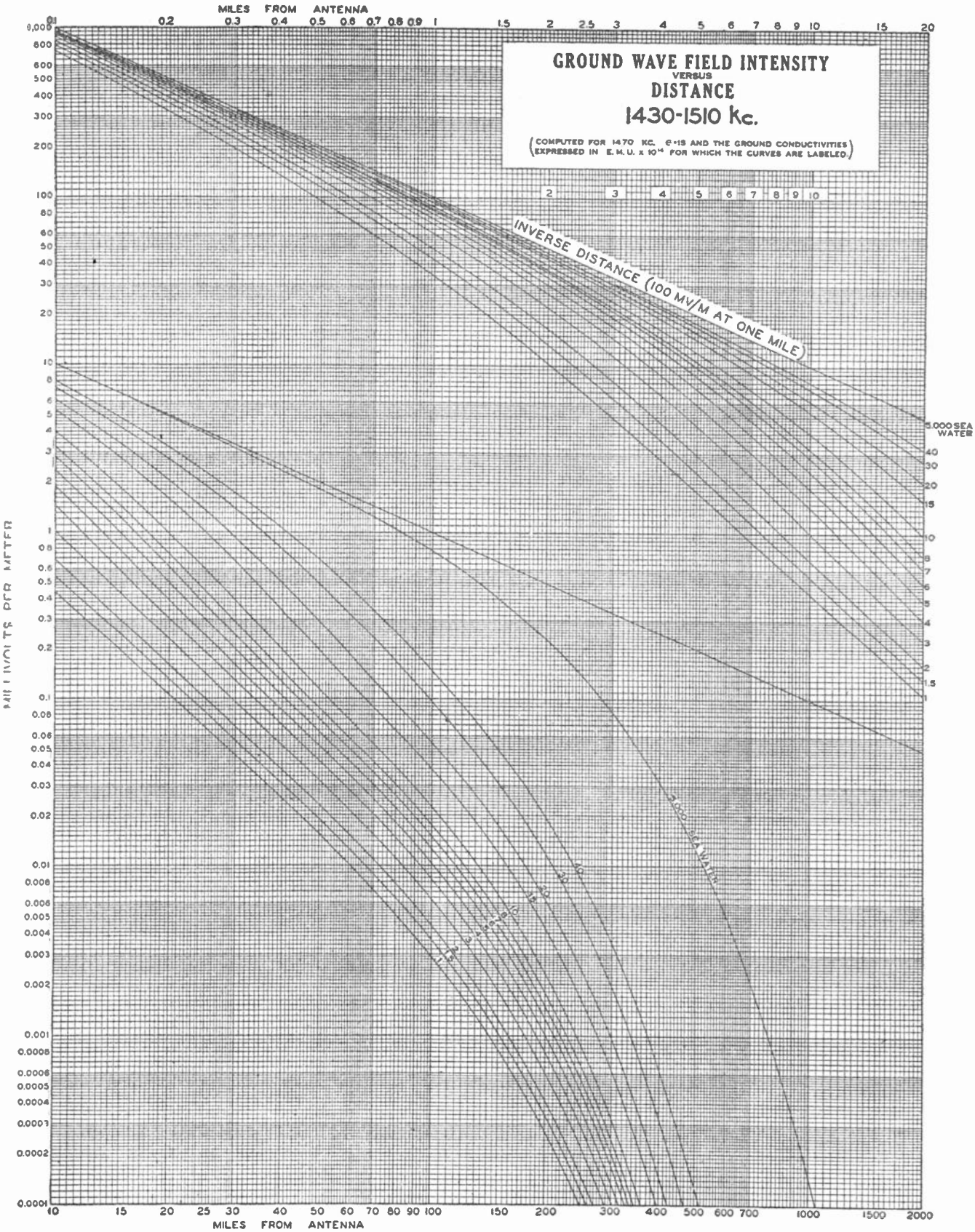


F.C.C.
JANUARY-1940

APPENDIX I - GRAPH 16

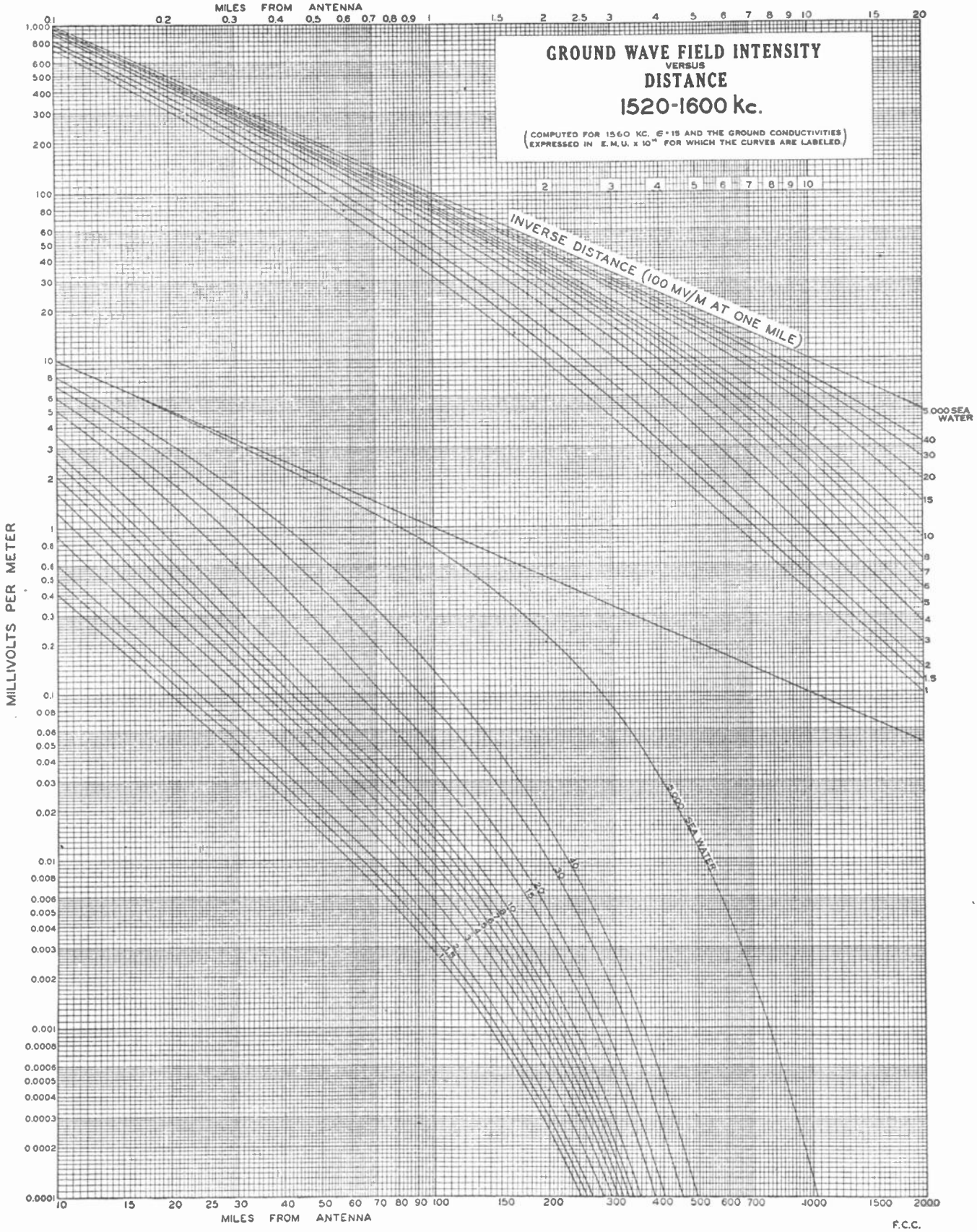


APPENDIX 1 - GRAPH 17



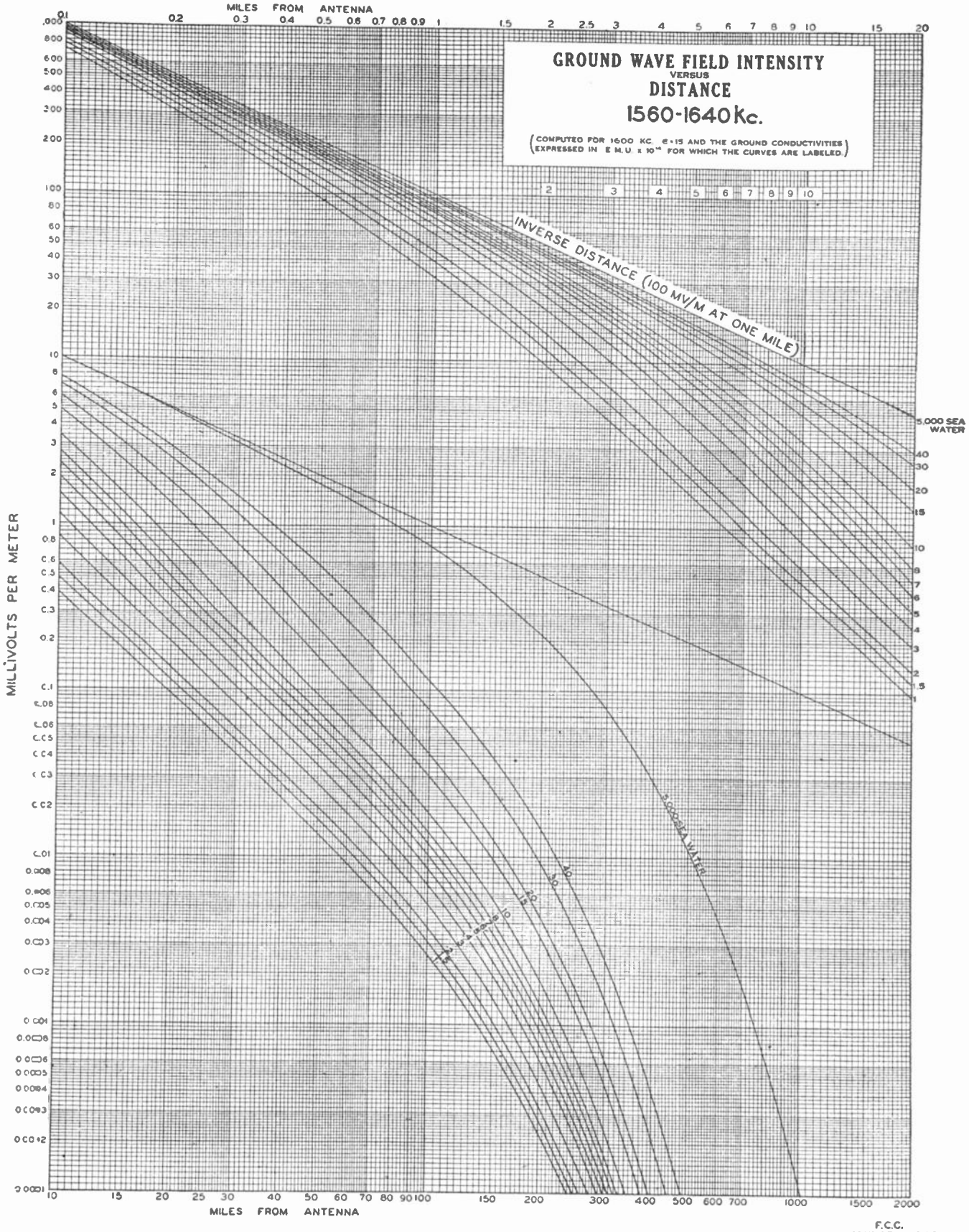
F.C.C.
JANUARY - 1940

APPENDIX I - GRAPH 18



APPENDIX I - GRAPH 19

H-142



APPENDIX I - GRAPH 20

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GROUND WAVE FIELD INTENSITY VERSUS NUMERICAL DISTANCE OVER A PLANE EARTH

$$p = \frac{\pi}{x}\frac{R}{\lambda}\frac{\cos^2 b''}{\cos b'} \cong \frac{\pi}{x}\frac{R}{\lambda}\cos b$$
$$b = 2b'' - b' \cong \tan^{-1}\frac{\epsilon+1}{x}$$
} Vertical Polarization.

$$p = \pi\frac{R}{\lambda}\frac{x}{\cos b'}$$
$$b = 180° - b'$$
} Horizontal Polarization.

$$x = \frac{1.79731\cdot 10^{15}\,\sigma \text{ e.m.u.}}{fmc}$$

$\frac{R}{\lambda}$ = distance expressed in wavelengths.

σ = ground conductivity expressed in e.m.u.

f = frequency expressed in megacycles

ϵ = dielectric constant of the ground referred to air as unity.

$$\tan b'' = \frac{\epsilon}{x}$$
$$\tan b' = \frac{\epsilon-1}{x}$$

INVERSE DISTANCE ($1/p$)

$b = 0°$, 15°, 30°, 45°, 60°, 75°, 90°, 180°

RELATIVE FIELD INTENSITY $\frac{f(p)}{p}$

100, 50, 20, 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02, 0.01, 0.005, 0.002, 0.001, 0.0005, 0.0002, 0.0001, 0.00005, 0.00002, 0.00001, 0.000005, 0.000002, 0.000001

0.001, 0.002, 0.005, 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200

p

NUMERICAL DISTANCE

APPENDIX I - GRAPH 21

PROPOSED REVISION OF PART 1, STANDARDS OF GOOD ENGINEERING PRACTICE CONCERNING STANDARD BROADCAST STATIONS

The revised version of Part 1, Standards of Good Engineering Practice Concerning Standard Broadcast Stations, which the Federal Communications Commission is considering for adoption, is reprinted below.

At a hearing held August 5, 1946, this proposed revision was submitted to the FCC by members of the Commission's Engineering Department as Exhibit #325, Clear Channel Hearing, Docket 6741.

The Commission has not indicated when these new Standards would be adopted to replace the present ones. Some minor revisions will probably be made before the new Standards are formally adopted.

This Bulletin is being distributed in order that you may have advance information available regarding the proposed changes.

The bracketed numbers appearing alongside many of the sectional headings indicate the page numbers of corresponding sections in the present Standards. When no number is shown, there is no section of the present Standards which is directly comparable.

NOTE: This exhibit was evolved from Exhibit #264 as the result of an engineers' conference held on July 15, 16, and 17, 1946, pursuant to Public Notice 95546 of July 3, 1946. In general, this revision reflects the view of the majority of the engineers present. It was made clear at that conference that minority reports would be accepted at the August 5, 1946 session.

NOTE: The procedures set forth herein are not intended to supplant those of Exhibit #109. The latter give methods of describing the coverage of radio stations in terms of quality of signal as related to interferences of various sorts and are intended to be used for showing such coverages in these proceedings. The procedures set forth herein are intended for use in allocation matters before the Commission to replace the present Standards (Part 1) at some future date yet to be decided upon. They will serve as the basis of this government's recommendations to the parties of the North American Regional Broadcasting Agreement for engineering changes in the new agreement to be drawn up in 1947. The results of those negotiations might indicate the advisability of some revisions of these procedures. As written they are intended for application to the present domestic set-up of channel assignments, station classification and power limitations, and some revisions may also be required depending upon the findings of these proceedings.

Curves and figures referred to herein are either in the present Standards or attached.

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1. ENGINEERING STANDARDS OF ALLOCATION

A. GENERAL

(1) Introductory [1-4-6]

Section 3.28 of the Commission's Rules requires that individual standard 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. Section 3.24 sets out the showing required of an applicant for new or increased facilities and sub-section (b) of this section concerns the matter of interference that may be caused by a new assignment or increase in facilities of an existing assignment. The Commission's Standards, which set forth in detail the methods of determining service areas and interference areas of the various classes of stations are contained in this document.

A definition of service area which is useful from an engineering point of view is the area bounded by a contour where the signal has the same technical value as regards freedom from interference from all sources. The extent of this area depends on many variables, such as power and frequency and type of transmitting antenna of the station, ground conductivity in the vicinity of the station, atmospheric noise level, man-made noise level, time of day, of year, and of sunspot cycle, latitude of the transmitter (for skywave service), interference from other stations on the same and adjacent channels, the listener's tolerance of interference, and the nature of the listener's receiver. A certain position of this varying area may be established as representative by selecting a certain value of each of the variables as representative, but it must be remembered that within the contour so established there will be areas of service of better quality than the representative value at the contour, and in areas beyond the contour there will be areas of useful service, even though of lesser quality than the chosen representative value. The area in which the station actually enjoys regular reception by a substantial portion of the population may not necessarily coincide with the service area defined by engineering considerations since certain other factors may be contributory, such as the availability of other signals in the area and the relative and absolute desirability of the program service, which are not amenable to quantitative engineering determination, and are hence not considered herein.

(2) Groundwaves and Skywaves [1]

The radiated energy which follows close to the earth, called the groundwave, is characterized by:

(a) High field intensities near the transmitter.

(b) Attenuation to low values within a few tens of miles, depending upon the character of the ground, the power and frequency of the transmitted signal and the type of transmitting antenna.

(c) Relatively steady values.

The energy which is reflected back from the ionosphere (chiefly evident after sunset), called the skywave is characterized by:

(a) Considerable field intensity at distances of hundreds of miles from the transmitter.

(b) Wide variation in field intensity from moment to moment, from night to night, and from year to year.

(c) Considerable variation with latitude of the transmission path and the earth characteristics in the vicinity of the transmitter, and some variation with frequency.

(3) Groundwave Service

Because of its steady nature and the strong signals obtainable in areas near the transmitter, the preferable service of any station is that obtained from groundwaves. (See Rule 3.11). The extent of the areas of groundwave service is determined not only by the transmitter power, frequency and type of antenna, and by the ground conductivity in the area, but also by the interference to the desired signal caused by atmospheric noise, man-made noise, other stations on the same or adjacent channels,

or, under certain conditions at night, by the fading and distortion caused by a mixture of groundwave and skywave. Since the intensity of these limiting factors varies widely from moment to moment and from night to night, the area of satisfactory service also varies. For allocation purposes a standard grade of groundwave service is defined in paragraph 1A(9). The method of determining the extent of the service area so defined is described in section 1D.

(4) Skywave Service [5-6]

Since the strong steady groundwave service is in general available only within a relatively short distance of the transmitter, a considerable part of the country lies outside such areas. This is particularly true at night, when strong skywave signals from distant stations on the same channel cause considerable interference in many instances and thus reduce the effective service area from its daytime value. At night in these areas use can be made of any interference-free skywave signals for service, but because of its wide variation in intensity and occasional periods of signal distortion, such service is considered in general less desirable than groundwave service. (See Rule 3.11). Only Class I stations are designed to render this type of service. The extent of the area of satisfactory skywave service depends upon the interference to the desired signal caused by atmospheric and man-made noise, other stations on the same and adjacent channels and under certain conditions by the fading and distortion caused by a mixture of the station's own ground and skywave signals. In view of the wide variation in skywave signal level from night to night, the area in which satisfactory listening can be had on any one night will vary greatly. In order to arrive at a definition of skywave service, as a reasonable basis for allocation purposes, it has been decided to consider signal levels obtainable on 50% of the nights. This does not give directly the number of nights per year on which service of a particular quality may be expected, since the problem of determining that is quite complex, but it is used in determining the amount of interference from other stations which can be permitted. (See paragraph 1C(3)). For the purpose of convenience in these standards, those Class 1 stations which operate on the channels listed in Rule 3.25(a) are called Class 1a stations, and those which operate on the channels listed in Rule 3.25(b) are called Class 1b stations. Under the rules, Class 1a stations do not share the channel with another station operating at night within the continental United States (excluding Alaska), while Class 1b stations may share the channel with one or more other stations. A degree of protection from interference is provided the latter class by limiting the value of the permissible interfering signal. In the case of Class 1a stations, a relatively small degree of interference can be expected, since other nighttime use of the channel is restricted to stations outside the continental United States (excluding Alaska) and the permissible skywave signal at the border is small.

(5) Atmospheric Noise [5]

In rural areas where man-made noise is low, and in the absence of interference from other radio stations, the minumum useful field intensity is determined in most areas of the United States by the strength of atmospheric noise or "static". This, of course, varies greatly with time of day, being generally lower in the daytime than at night, and lower in the morning than in the afternoon. It varies greatly with season, being generally lower in winter than in summer. The intensity of the atmospheric noise has been recorded at a number of locations throughout the United States and corrected to a value corresponding to a receiver effective band width of 4 kc. Then, by means of U. S. Weather Bureau records of thunderstorm incidence, a reasonable estimate was made of the value which was exceeded for 50% of the year in any area of the United States. This determination was done separately for daytime (counting all hours from sunrise-plus-one to sunset-minus-one) and for nighttime (using for second hour after sunset as representative). Separate determination was made for the low frequency and high frequency ends of the standard broadcast band, and a method evolved to permit estimating the values at intermediate frequencies. The result of this procedure is only roughly accurate, but, is considered to be the best estimate obtainable from the available data. The ratio of signal to noise to give standard acceptable service (See paragraph 1A(9) for discussion of standard ratio) was applied to the calculated noise intensities and thus was obtained the minimum signal level for day and for night, required to render standard acceptable service for 50% of the year in the absence of other kinds of interference. This signal level, called the 50% atmospheric-noise-free signal, is shown on a map of the United States; figure 12-3 for daytime conditions and figure 14-4 for night. These maps are used to determine, in certain instances outlined in paragraph 1C(1), the field intensity which may be protected from interference.

(6) Man-made Noise

By this term is meant the radio frequency noise originating in such devices as motor commutators, sparking trolleys, welding equipment, electric razors, dial telephones. Extensive tests in cities of various sizes have confirmed a general trend to higher noise intensity in cities of greater population. Variations from

the mean value are large, however, and it does not appear warranted to derive a more accurate method of estimating population than is indicated in the table in paragraph 1C(5).

(7) Interference From Other Stations

The engineering factor which measures the amount of interference caused by other radio stations is the ratio of field intensity of desired to undesired signals. A rather wide range of ratios can be considered satisfactory, depending on the relative degree of modulation of the desired and undesired signals, the type of program on each, the critical attitude of the listener, and, in the case of adjacent channel interference, the selectivity of the receiver. Based on listener reaction tests and on experience, a certain ratio (e.g., 20 to 1 for steady signals or for the instantaneous value of fading signals on the same channel) has been adopted as being the minimum for acceptable service. It has been experimentally determined that where two or more steady interfering signals exist, their electrical resultant is very close in value to the square root of the sum of the squares of the component voltages. This is called the RSS value. For convenience in computations, the modified RSS rules specified in paragraph 1E(2), permits the omission of signals of negligibly small value from the calculation of RSS. For fading skywave signals, which follow a "Rayleigh distribution" of intensity with time, the value exceeded for 10% of the hour by a resultant wave is the RSS of the corresponding values for the component waves. The same rule applies for average values, median values and to some other statistics. The Rayleigh distribution describes the fading of signals during a particular hour and has not been found to hold for the night-to-night variation of median signal strength. However, the modified RSS rule will prove reasonably accurate and is certainly the most practical rule now available. The question as to whether the electrical value of a mixture of interfering signals is a direct measure of their objectionability has not yet been determined, except that in the case of a test with two equal steady interfering signals, tabulation of listener's votes indicated the objectionability will in fact be the same as for one interfering signal of equal RSS value.

(8) Definition of Interference [7-8]

When used in the broad sense "interference" may be considered to include the effect on acceptability of a received program due to any kind of extraneous signal, such as atmospheric noise, man-made noise, the distortion due to the mixture of the desired station's own skywave and groundwave, as well as signals from other radio stations. Ordinarily it is used in a more restricted sense to apply to the latter case only. "Objectionable interference" is defined as the degree of interference produced when the field intensity of an undesired station exceeds for 10% or more of the time the values determined by the interference ratios of paragraph 1C(4). Note that in the case of skywave interference to groundwave service, the interfering signal is taken to be the modified RSS value of two or more interfering 10% skywaves.

(9) Listener's Opinions on the Ratio of Signal to Interference

Studies were made in 1945 and 1946 as to what ratio of desired signal to interference (noise or other-signal) will be considered objectionable by the listener. As a result it is concluded that no change is required in the 20 to 1 ratio heretofore used for the minimum desired to undesired signal ratio for groundwave interfering with groundwave. This value was found to be satisfactory by approximately two-thirds of the listeners polled for the average of several types of programs, involving both speech and music. (The range of the ratio for the various types of programs was rather large; for speech interfered with by speech the required ratio was nearly double the average value, and for music interfered with by music the ratio was half the average value or even less, depending on the type of music used in the test). Studies involving fading signals were inconclusive but it is considered that the same 20 to 1 ratio may be applied to instantaneous values when it is desired to calculate the percent-of-time during which satisfactory service will be obtained in any given case. For man-made noise, the radio which similarly satisfied approximately two-thirds of the listeners was applied to the urban noise measurements in arriving at the figures in paragraph 1D(5) for signals required in various urban areas. For atmospheric noise, the ratio which satisfied approximately two-thirds of the listeners was used in making the maps (Figures 12-3 and 14-4)* showing the required signal level for service for 50% of the year, day and night.

*NOTE: These figures are actually drawn using a preliminary estimate of the ratio. Tests now in progress indicate the preliminary estimate for daytime signal was probably half the proper value. Pending completion of the tests and final revision of the maps, the contour values of figure 12-3 may be multiplied by two.

(10) Extent of Groundwave Service Determined By Time Variations in Signal Intensity, Noise, and Other-Station Interference

Having accepted as a standard that minimum ratio of desired signal to undesired interference will satisfy two-thirds of the listeners the determination of the percent-of-time for which the minimum ratios exist at any location involves the correlation of the variations in desired signal strength, and the variations in the interference intensity. In the absence of other-station interference, and outside the areas of high man-made noise, the limit of the service area is normally governed by the intensity of atmospherics. Thus the atmospheric noise-free signal derived from the maps (Figures 12-3 and 14-4) in accordance with paragraph 1C(1)., is the signal level which will provide the standard signal to noise ratio for 50% of the day or night hours during the year. The contour thus defined in some circumstances becomes the protected groundwave contour of the station: See Section 1C. Note that all the population within the groundwave service area does not necessarily receive satisfactory service since the signal level in urban areas may be insufficient to override man-made noise. See paragraph 1C(5) for required urban signals.

(11) Distortion Zone

Class I stations at night will usually have interference-free contours which provide a serviceable groundwave signal out to a distance from the transmitter where its own skywave signal is of comparable magnitude. In such an area, service may be greatly deteriorated due to audio distortion resulting from the mixture of the skywave and groundwave signals. Because of the wide variation in skywave signal intensity from night to night the distance at which the distortion appears will vary considerably. No standards have been established for determining the location or extent of this zone because no study has yet been made to correlate the relative signal levels of the skywave and groundwave with the opinion of listeners as to the objectionability of the resulting distortion.

B. CLASSES OF STATIONS

(1) General [1]

Sections 3.21 to 3.34 inclusive of the Commission's Rules govern the allocation of facilities in the Standard Broadcast Band. These sections contain the definitions of Clear, Regional and Local channels and Class I, II, III and IV stations. For the purpose of convenience Class I Stations assigned to channels allocated by section 3.25(a) will be termed Class I-a and those assigned to channels allocated by section 3.25(b) will be termed Class I-b.

(2) Class I-a Stations [1-2]

(a) Power. See Rule 3.25(a).*

(b) Channel Assignment. Clear Channels as prescribed in Rule 3.25(a).*

(c) Service Areas. Class I-a stations are designed to render skywave service as well as groundwave service.

(d) Protection. Class I-a stations are afforded protection as set out in paragraph 1C(2) and 1C(3) below. The only station licensed for nighttime operation in the continental U. S. (excluding Alaska), on each of these channels is the one Class I-a station.

(3) Class I-b Stations [1-2-4]

(a) Power. See Rule 3.22(a).*

(b) Channel Assignment. Clear channels as prescribed in Rule 3.25(b).*

(c) Service Areas. Class I-b stations are designed to render skywave service as well as groundwave service.

(d) Protection. Protection is provided to the service areas of the Class I-b station as determined by the method set forth in paragraphs 1C(2) and 1C(3) below.

(4) Class II Stations [2-4]

(a) Power. See Rule 3.22(b).*

(b) Channel Assignment. Clear channels as prescribed in Rule 3.25.* (The Class II Stations assigned to channels listed in Rule 3.25(a)* operate limited time or daytime only).

(c) Service Areas. Class II stations normally render groundwave service only.

(d) Protection. Class II stations are not protected from interference from Class I stations. They are protected from interference from other classes of stations in accordance with paragraph 1C(2).

(5) Class III Stations [2-3-4-5]

(a) Power. See Rule 3.22(c).*

(b) Channel Assignment. Class III stations

operate on regional channels (Rule 3.26) as prescribed in Rule 3.22(c).*

(c) Service Areas. Class III stations normally render groundwave service only.

(d) Protection. Class III stations are normally protected in accordance with paragraph 1C(2) below.

(6) Class IV Stations [3-4-5]

(a) Power. See Rule 3.22(d).*

(b) Channel Assignment. Class IV stations operate on local channels (Rule 3.27)* as prescribed in Rule 3.22(d).*

(c) Service Areas. Class IV stations normally render groundwave service only, over an area restricted by the low power and the assigned frequencies.

(d) Protection. Class IV stations are normally protected from groundwave interference in accordance with paragraph 1C(2) below. Protection from skywave interference at night is not afforded. For the purpose of estimating coverage the nighttime limitation should be determined as set forth in paragraph 1E(2) below.

C. COVERAGE AND PROTECTION REQUIREMENTS [10]

(1) Normally Protected Groundwave Contour And Atmospheric-Noise-Free Contour

The "normally protected" groundwave field intensity is defined as that value of field intensity beyond which any interference as determined in accordance with paragraph 1C(4) will normally not be considered objectionable, from an allocation standpoint.

(Note that useful service may be rendered beyond these contours, in the absence of interference from other stations, and that under special circumstances the Commission may afford protection to such service in accordance with paragraph 1C(2).)

The normally protected contours are set forth in the following table:

TABLE I - NORMALLY PROTECTED GROUNDWAVE SERVICE CONTOURS

Class Of Station	Class Of Channel	Normally Protected Groundwave Service Contour Day	Night
I-A	*Clear*	*SC 0.1 mv/m*	*SC not duplicated*
		AC 0.5 mv/m	*AC 0.5 mv/m*
I-B	*Clear*	*SC 0.1 mv/m*	*SC 0.5 mv/m*[1]
		AC 0.5 mv/m	*AC 0.5 mv/m*
II	*Clear*	*0.5 mv/m*	*2.5 mv/m*[2]
III	*Regional*	*0.5 mv/m*	*2.5 mv/m*
IV	*Local*	*0.5 mv/m*	*not protected*

SC - for interference on same channel
AC - for interference on adjacent channel

*NOTE: Rules for Power and Channel Assignments are subject to possible revision as the result of the findings in Docket No. 6741.

[1]The nighttime groundwave signal of a Class I-b station is usually protected from same channel interference automatically to a lower contour than 0.5 mv/m by virtue of the protection afforded to the skywave service area.

[2]This value is with respect to interference from all stations except Class I, which stations may cause interference to a field intensity contour of higher value. However, it is recommended that a Class II station be so located that the interference received from Class I stations will not be within this contour.

The atmospheric-noise-free signal is defined as that value of field intensity which, if limited only by atmospheric noise, would give service for 50% of the year. It is determined from maps, Figures 12-3 and 14-4 for daytime and nighttime conditions respectively. The contours on the maps show the locus of points where a particular field intensity is required to give service for 50% of the year for a frequency of 1000 kc. For points between the contours, the value may be determined by linear interpolation along the shortest straight line through the point and connecting adjacent contours. The value for other frequencies is determined from the 1000 kc value by applying the factor determined from the curves of Figure 4-1, "Relative Signal Intensities for Atmospherics-free Reception versus Frequency." The value of atmospheric-noise-free groundwave field intensity determined for the location of the transmitter will be considered as the value throughout the service area. As an example, computation of the daytime atmospherics-noise-free groundwave field intensity for a station on 1380 kc in Reno, Nevada, would be as follows: From Figure 12-3, Reno is found to be 0.5 the distance from the 0.01 to the 0.02 mv/m atmospherics-noise-free signal contour for 1000 kc, giving a value of 0.015 mv/m. From Figure 4-1 the value for 1380 kc is 0.76 as great, giving a resultant of 0.0113 mv/m.* As a second example, computation of the nighttime atmospherics-noise-free groundwave field intensity for a station on 620 kc in New Orleans would be as follows: From Figure 14-4, New Orleans would be found to be 0.1 the distance between the 0.7 and the 0.8 mv/m atmospherics-noise-free signal contour for 1000 kc, giving a value of 0.71 mv/m. From Figure 4-1 the value for 620 kc is 1.27 times as great, giving a resultant value of 0.90 mv/m.

(2) Protection Of Groundwave Service [4]

Ordinarily the field intensities listed in Table I are protected from interference in accordance with the signal ratios established in paragraph 1C(4). When a station is at present limited to a higher groundwave contour than the normally protected contour, additional interference will be permissible in the area where interference already exists. That is, in the case of groundwave interference additional interfering signals will be permitted in existing interference areas without regard to the cumulative effect of such signals, and in the case of skywave interference, the additional signal must be less than the smallest value which, under the prescribed method of computing the RSS value (paragraph 1E(2)), will increase the calculated RSS limitation. When it is shown that groundwave service is rendered beyond the normally protected contour, and when groundwave service to approximately 90% of the population (population served with adequate signal) of the area between the normally protected contour and the contour to which such station actually serves, is not supplied by any other station or stations carrying the same general program service, the contour to which protection may be afforded in such cases will be determined from the individual merits of the case. However, in no event will protection be afforded to signal intensities less than 0.1 mv/m or less than the atmospheric-noise-free signal.

The nighttime groundwave service of Class IV stations on local channels is not protected against skywave interference, although the limitation may be estimated by the method described in paragraph 1E(2). Class II stations are not protected from interference from Class I stations on the same channel. Skywave interference from any one adjacent channel will be considered only if the highest single signal limitation from that channel is in excess of the RSS co-channel limitation.

(3) Permissible Interference To Skywave Service [10]

The value of 50% skywave field intensity of a Class I station which is used as a reference in establishing the value of interfering 10% skywave signal permitted in that value calculated as in paragraph 1E(1), which would be obtained at 700 miles distance from the station if it were operating at 50 kw with a standard non-directional antenna (see note, paragraph 1E(1), using the latitude of the transmitter for the calculation. For example, the reference 50% skywave contour of a 50 kw Class I station at latitude 38^0 would be determined as follows: The pertinent angle for 700 miles is 8.5^0; the corresponding radiated field is 96% of the horizontal radiated field or $0.96 \times 225 \times \sqrt{50} = 1527$ mv/m; the 50% skywave field at 700 miles is then 0.57 mv/m.

The reference contour applies to co-channel skywave interference to Class I-b stations and adjacent channel interference to both Class I-a and Class I-b stations. The permissible interfering signal at the specified contour is determined from the table of desired to undesired signal ratios in paragraph 1C(4). (While skywave service is not protected against interference from adjacent channel signals, provision is made for determining the area in which adjacent channel groundwaves will interfere.) Two or more interfering skywave signals at a reference skywave contour are considered individually

*In accordance with the footnote on paragraph 1A(9) this figure should be multiplied by two, giving 0.0226 mv/m.

and are not combined as in the case of skywave interference to a groundwave signal where the RSS value is used. The existence of interfering signals in excess of the recommended value at the reference 50% skywave contour of a Class I station will not be considered as decreasing the protection required from proposed stations.

(4) Interference Ratios and Frequency Separation [1-4-10-11-12]

The following table is to be used for determining the ratio of field intensity of a desired to an undesired signal. In the case of desired groundwave interfered with by two or more skywave signals, the RSS value of the latter is used.

Stations in the same area may be licensed for operation on channels as close as 30 kc separation. However, due consideration will be given to the possibility of cross modulation between the two transmitters if the field from one is very strong at the antenna location of the other. In case objectionable interference results because of such assignment, the permittee of the new station will be held responsible for making necessary adjustments. The licensee of the existing station will be expected to cooperate in every way possible.

Frequency Separation of Desired & Undesired Signals	Desired Groundwave To Undesired Groundwave	Desired Groundwave To Desired 10% Skywave	Desired 50% Skywave To Undesired 10% Skywave
0 kc	20:1	20:1	20:1
10 kc	1:2	1:5	*
20 kc	1:30		

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 and carrying the identical program will have their groundwave service subject to some distortion in areas where the signals from the two stations are of comparable intensity. For the purpose of estimating coverage of such stations areas in which the signal ratio is between 1 to 2 and 2 to 1 will not be considered as having satisfactory service.

(5) Signals Required in Urban Areas [5]

The minimum field intensity which a station is required to provide to the city in which its main studio is located is given in Part 4 of these Standards, "Locations of Transmitters of Standard Broadcast Stations." In estimating population served by a station's interference-free-groundwave signal, the following table gives the percentage of the city to include if the field intensity in the city lies between the values indicated. (For this purpose the field intensity in the city is considered as that value of contour which bisects the city area.)

When a station delivers a large range of field intensities over a city, the population may be estimated by summing the populations of those precincts or other subdivisions for which

---

*NOTE: The skywave service area of a Class I station is not protected from adjacent channel interference. However, in case of placing a station on an adjacent channel (10 kc. removed) to a Class I station which would substitute a groundwave service for the skywave service, the matter of program service as well as the signal service of the two stations should be given consideration. That is, within the reference 50% skywave contour of the Class I station, purely for the determination of comparative service the area within which the ratio of the desired skywave to the undesired groundwave of a Class II, Class III or Class IV station 10 kc. removed as 1 to 4 may be taken as the area in which the secondary service of the Class I station is precluded.

population statistics are available, where the required field intensity is obtained in at least 50% of the precinct area.

D. CALCULATION OF GROUNDWAVE SIGNALS

(1) Determination of Distances to Field Intensity Contours [9-16-17-18]

In any case, the best method of determining groundwave contour distances is by measurement. These must be made in accordance with Part 2, "Field Intensity Measurements in Allocation." In case of proposed operation these distances may be calculated by use of the 20 graphs of the Appendix I showing "groundwave field intensity versus distance" covering the frequencies of the standard broadcast band. These assume a ground dielectric constant of 15 and show the field for ground conductivities from 1 to 5000 x 10^{-14} e.m.u. The conductivity of a given terrain may be determined by measurements of broadcast signals traversing the terrain, made in accordance with Section 2 of these Standards. In case this is not possible, then conductivity may be taken from the map of ground conductivities in the US, Figure 3. This map shows the conductivity throughout the entire US by general areas of reasonably uniform conductivity. In areas of limited size, or over a particular path, the conductivity may vary widely from the value given. The set of 20 graphs in Appendix I. are calculated on the basis of 100 mv/m unattenuated field at one mile.

TABLE II - PERCENT OF URBAN POPULATION SERVED

Population of City Lies Between*	Field Intensity Contour Bisecting City Area Lies Between (mv/m): 0.5-1	1-2	2-5	5-10	10-25	Over 25
2,500-10,000	70	80	100	100	100	100
10,000-50,000	60	70	80	90	100	100
50,000-250,000	40	60	70	80	90	100
250,000-1,000,000	30	40	60	70	80	100
Over 1,000,000	0	30	50	60	70	100

As an example, calculate the distance to the 0.5 mv/m contour from a 5 kw station operating on 990 kc; station located in central Nevada. Suppose the 5 kw station to have a radiated field of 391 mv/m at one mile*. From Figure 3, the conductivity in the vicinity of central Nevada is 3 x 10^{-14} e.m.u. Graph 12 includes the frequency 990 kc in the block of frequencies. Since the curves are based on 100 mv/m radiated field, and the radiated field from the station used as an example is 391 mv/m, any value shown on the curve should be multiplied by 3.91 to give the actual value. In order to find the actual distance to the 0.5 mv/m contour the distance to the 0.127 mv/m contour must be read (i.e., 3.91 x 0.127 = 0.5), which gives a value of 38.5 miles for conductivity of 3 x 10^{-14}.

In case there are several values of conductivity for the path an acceptable estimate of the distance to a given contour may be made by adding the attenuation in decibels (or multiplying the field ratios) across each section of the path with constant conductivity. As an example, assume that the first 15 miles of the path being investigated has a conductivity of 3, the next 8 miles 1.5, and the next 20 miles 4. Also assume a radiated field of 100 mv/m at 1 mile and a frequency of 990 kc. From the curves it will be noted that a signal with a radiated field of 100 mv/m for conductivity 3 x 10^{-14} will have been attenuated to 1.07 mv/m at 15 miles from the transmitter. Then on the 1.5 x 10^{-14} curve it will be determined that a signal traversing the distance between 15 and 23 miles will be attenuated by a field ratio of 0.5 to 0.195 or 2.56. From the 4 x 10^{-14}

*NOTE: The population to be used in determining the field intensity required is the total population of contiguous cities, which would constitute a unit as a source of man-made noise. Cities will be considered as contiguous for this purpose if their boundaries are within one mile of each other.

*NOTE: The radiated field at one mile of vertical antennas is determined in accordance with Section 5 of these Standards. In the absence of sufficient data to determine the radiated field, the following values may be used for computations:

Class of Station	Horizontally Radiated Field For 1 kw Input:
I	225 mv/m
II and III	185 mv/m
IV	175 mv/m

curve the attenuation in traversing the distance between 23 miles and 43 miles gives a field ratio of 0.58 to 0.138 or 4.2. The product of these two is then 2.56 x 4.2 = 10.7. That is, a signal traversing the path between 15 miles and 43 miles will be attenuated by a field ratio of 10.7. Since the signal at 15 miles was 1.07 mv/m, the signal at 43 miles will equal 1.07/ 10.7 = 0.100 mv/m.

(2) Determination of Groundwave Interference To Groundwave Service [9-16-17-18]

The problem of calculating interference of an undesired groundwave signal on the same or adjacent channel to a desired groundwave signal is one of calculating the locus of points where the signals have the standard ratio specified in paragraph 1C(4). Plot the normal protected groundwave service contour and the corresponding interference contour on a map of suitable scale. The points where the contours cross are the starting points for the interference contour. Other points may be similarly determined by using contours of different field intensities.

In cases involving interference from two or more groundwave signals, the largest undesired signal will be considered to determine the existence or absence of interference at any point. For the method used to calculate skywave interference to groundwave signals refer to paragraph 1E(2).

E. CALCULATION OF SKYWAVE SIGNALS

(1) General Description of Method [8-9-18]

For the sake of simplification and uniformity of nomenclature, the following definitions are made of certain abbreviated terms used in these Standards:

"Hourly median value" (of skywave field intensity, atmospheric noise intensity, or any other function varying with time). That value which is exceeded for a total of 30 minutes in an hour.

"50% skywave signal." The hourly median skywave field intensity which is exceeded at a given receiving location on 50% of the nights of the year (or any other long period).

"Radiated field." The inverse distance field at one mile from a transmitting antenna in a particular direction.

The value of a skywave field at any receiving location may be determined by measurements made in accordance with Part 2 of these Standards. However, it is pointed out that the period over which the measurements must be made is quite extensive in order to minimize the effect of seasonal and annual variations. It is considered that usually a more accurate value will be obtained by the use of the skywave curves and the measured (or calculated) radiated field from the antenna.

Figure 2, "50% Skywave Signal Range Chart," shows the 50% 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 pertinent angle is the angle described in Figure 6, "Variation With Distance of Two Important Parameters in the Theory of Skywave Propagation." The latitude of the transmission path is defined as the geographic latitude of the midpoint between the transmitter and the receiver. Latitude 35° should be used in case the midpoint of the path lies below 35° North and latitude 50° should be used in case the midpoint of the path lies above 50° North, pending accumulation of additional information to extend the curves beyond the present limits.

To determine the 50% field at any distance required therefore determination of the radiation at the pertinent angle. In the case of non-directional vertical antennas the vertical distribution of relative fields for several heights, assuming sinusoidal distribution of current along the antenna, is shown in Figure 5. 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 point, the angle θ is determined from Figure 6. The ratio of the value of radiated field at that value of angle θ, to 100 mv/m (for which the 50% skywave signal range chart is drawn) is then used as the multiplying factor for the value of the field read from the curves of Figure 2. Note that the accuracy of the curves is not well established by measurements for distances less than 250 miles. However,

*NOTE: The effective field of non-directional vertical antennas is determined in accordance with Section 5 of these Standards. In the absence of sufficient data to determine the effective field, the following values may be assumed for computations:

Class of Station	Effective Field	Ht. of Antenna
I	*225 mv/m*	*0.5*
II and III	*185 mv/m*	*0.25*
IV	*175 mv/m*	*0.25*

pending accumulation of additional data to establish firm standards for skywave calculations in this range, the curves may be used.

(NOTE: The Engineering Department of the FCC is preparing sets of skywave curves peculiar to transmission by one, two, three or more hops, for use in two cases: First, where the vertical field intensity pattern departs radically from that of a 0.311 antenna, and the second, where the transmission path has sea water reflection points or sea water takeoff. Also under preparation is a method for determining skywave fields at distances beyond 2800 miles.)

(2) Skywave Interference to Groundwave Service; RSS [7-8]

For stations on the same channel this is based on a minimum ratio of 20 to 1 desired to undesired field intensities for 90% of the time. Thus the undesired 10% skywave field, multiplied by 20 will give the limitation to the desired signal. 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, California, which is radiating a signal of 392 mv/m unattenuated at one mile in the direction of Portland, using a 0.5 wavelength antenna. The distance is 825 miles. From Figure 6 the pertinent angle is 6^0 and from Figure 5 the radiated field at the pertinent angle is 97.5% or 382 mv/m at 1 mile. The latitude of the midpoint of the path is 39.8^0 and, from Figure 1, the 10% skywave field at 825 miles is 0.050 mv/m for 100 mv/m radiated. Multiplying by 392/100 to adjust the value to the actual radiation gives 0.196 mv/m. At 20 to 1 ratio, the limitation to the Portland station is to the 3.9 mv/m contour.

When two or more interfering 10% skywave signals of the same frequency exist at a point, their effective value is considered to be the Root-sum-square (RSS) value of the components. Except in the case of Class IV stations on local channels, calculation is accomplished by considering the signals in order of decreasing magnitude, adding the squares of the values and extracting the square root of the sum, excluding those signals which are less than 50% of the RSS value of the higher signals previously included. If the interfering skywave signals are on any one adjacent channel to the desired groundwave signal, interference will be produced if the ratios given in the table of paragraph 1D(6) are exceeded; however, in this case the highest interfering signal is used instead of the RSS value. The limitation to a station from signals on each channel is considered channel by channel, and the highest value from any one channel determines the limitation.

In the case of Class IV stations on local channels, the relatively large number of signals of approximately the same magnitude greatly increases the inaccuracy of the above RSS method. On this account all interfering signals will be included in the RSS except those less than 50% of the maximum interfering signal.

(3) Skywave Interference to Skywave Service [18]

The problem of determining at any receiving location the actual number of nights per year on which it may be expected that skywave signals from a particular Class I station will be free of interference from atmospheric noise or skywave signals from other stations (as distinguished from signals of a specified field intensity) is extremely involved. For allocation purposes this is not attempted and instead a specified field strength contour (which varies with the latitude of the transmitter) is called a "reference" contour and the maximum permissible interfering skywave field intensity from any other station is specified at that contour.

For stations on the same channel, this is based on a minimum 20 to 1 ratio of the 50% skywave value of the desired to the 10% skywave value of the undesired signal. Paragraph 1C(3) specifies the reference contour of the skywave service of a Class I station at which the ratio is to be determined. For example, if the reference contour of a station located at latitude 38^0 is its 0.57 mv/m 50% contour, the maximum permissible interfering signal at contour is 0.0285 mv/m (10% value). If for geographical reasons, (e.g., protection to a border of the country), the service contour to be considered is higher than normal, the 20 to 1 ratio will determine the permissible value of interfering signal at that contour. Suppose in the foregoing example it is desired to determine the permissible radiation from a Class II station at latitude 45^0 located 1500 miles from the nearest point on the reference contour of the Class I-b station, and further suppose that a plot of the 0.57 mv/m contour shows the nearest point to the Class II station to be at latitude 39^0. Suppose further that the midpoint of the path of the interfering signal will then be 42.2^0. From Figure 1, the 10% value at 1500 miles will be 0.0087 mv/m for a radiation of 100 mv/m. Thus the permissible radiation is 0.0285/0.0087 x 100 = 328 mv/m. For allocation purposes, each interfering signal is considered without reference to others. This means that even though, by previous assignment, one interfering signal at a point on the reference skywave contour is in excess of the prescribed value, other interfering signals are nevertheless required to remain below the prescribed value.

F. SPECIAL CONSIDERATIONS FOR STATIONS OUTSIDE THE CONTINENTAL UNITED STATES

In general, the procedures set out in the preceding stations apply to stations located outside the continental United States (e.g., Alaska, Hawaii, Puerto Rico). However, the following special considerations apply:

In the case of Clear Channels on which a Class I-a station is assigned in the continental US, Class II stations for nighttime operation may be assigned elsewhere provided the assignment is consistent with the provisions of the current North American Regional Broadcasting Agreement for Class II stations in other countries.

The value of atmospheric noise at broadcast frequencies is not sufficiently well established in these areas to use it as a basis for establishing the atmospheric-noise-free contours as a limit to the specially protected contour described in paragraph 1C(2).

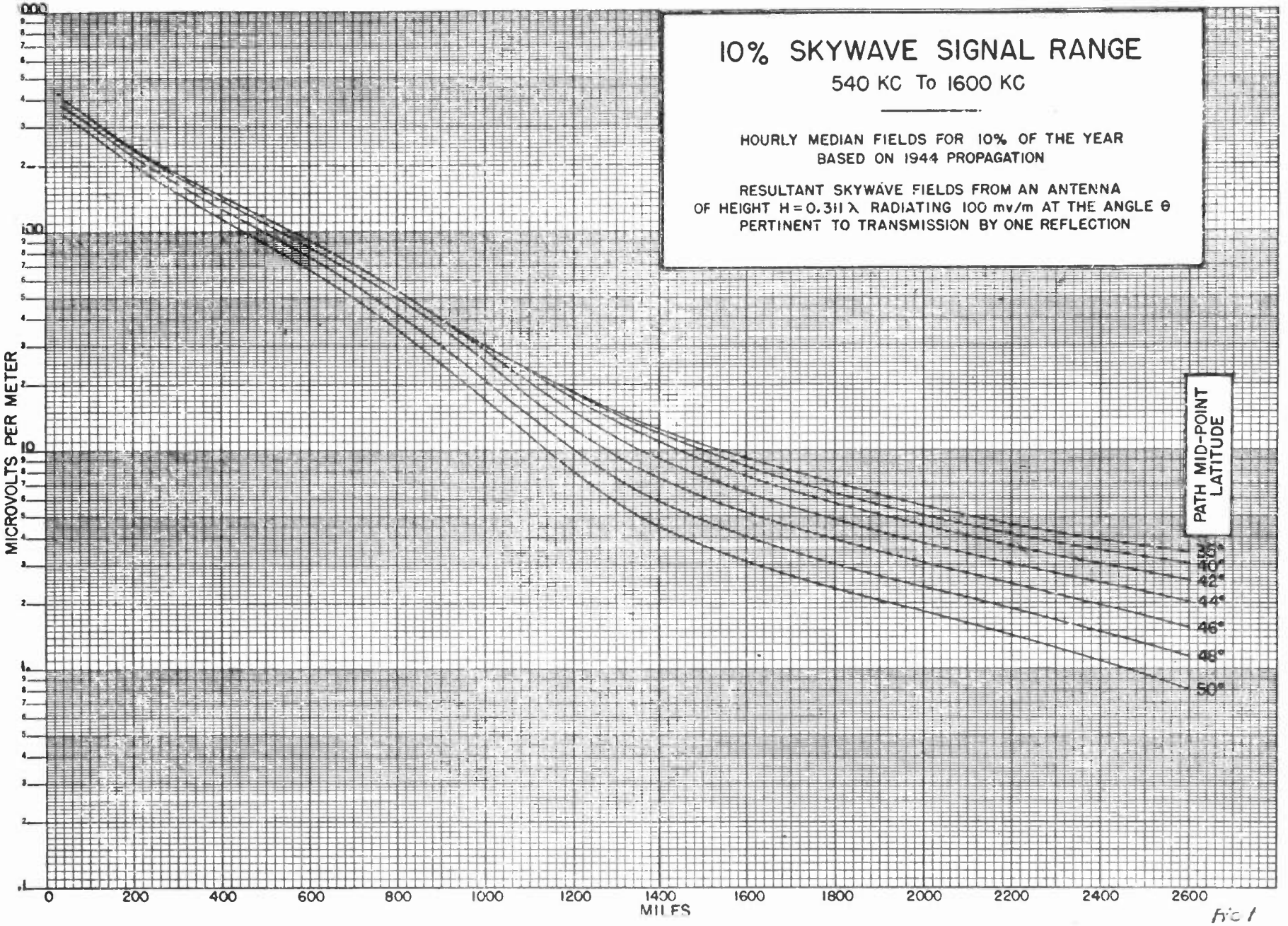
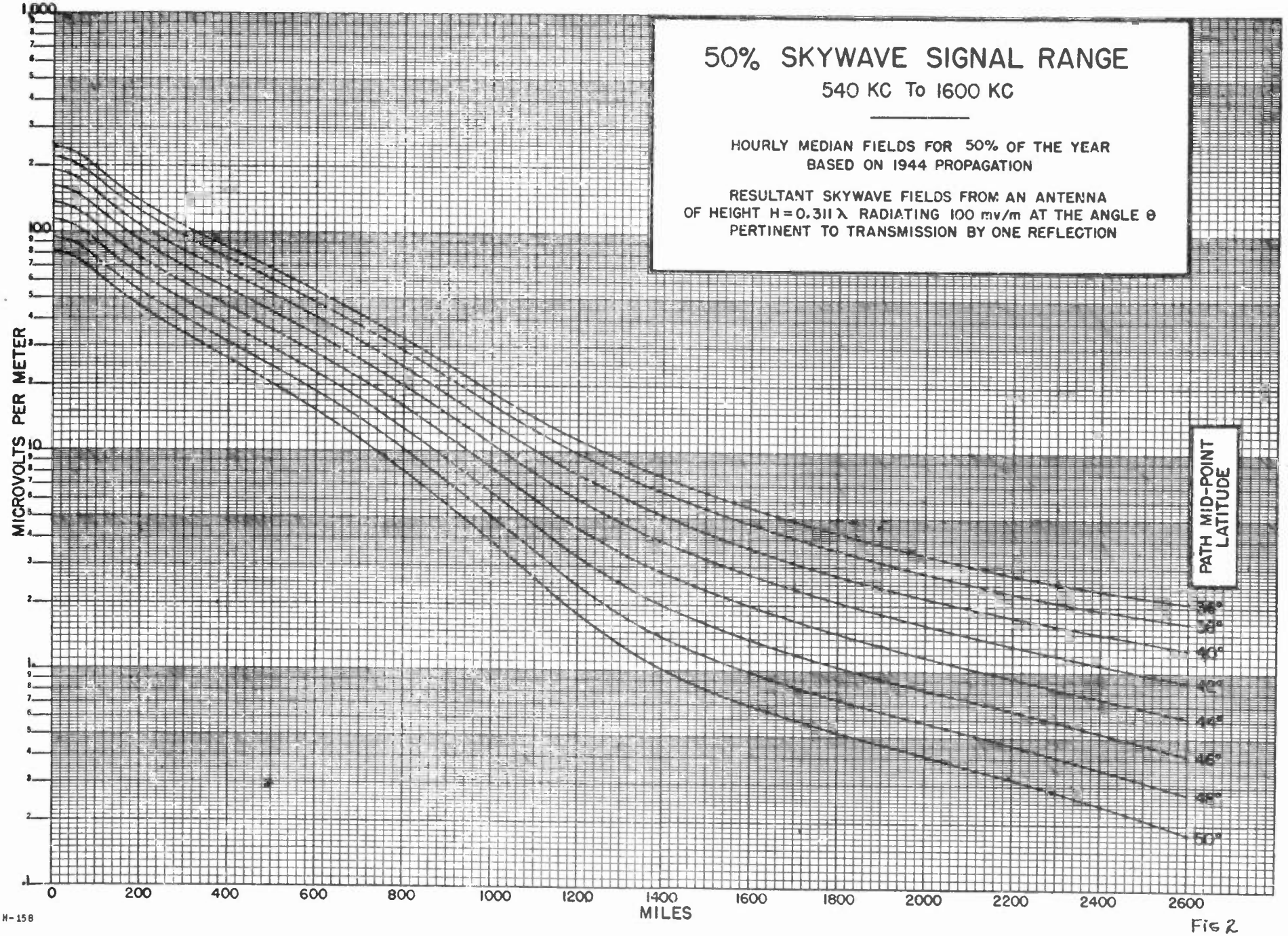

10% SKYWAVE SIGNAL RANGE
540 KC To 1600 KC
HOURLY MEDIAN FIELDS FOR 10% OF THE YEAR
BASED ON 1944 PROPAGATION
RESULTANT SKYWAVE FIELDS FROM AN ANTENNA
OF HEIGHT H = 0.311 λ RADIATING 100 mv/m AT THE ANGLE θ
PERTINENT TO TRANSMISSION BY ONE REFLECTION
MICROVOLTS PER METER
MILES
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
PATH MID-POINT LATITUDE
40°
42°
44°
46°
48°
50°

Fig 1


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
1000
100
10
1
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
MILES
PATH MID-POINT LATITUDE
36°
38°
40°
42°
44°
46°
48°
50°

H-158

Fig 2

UNITED STATES

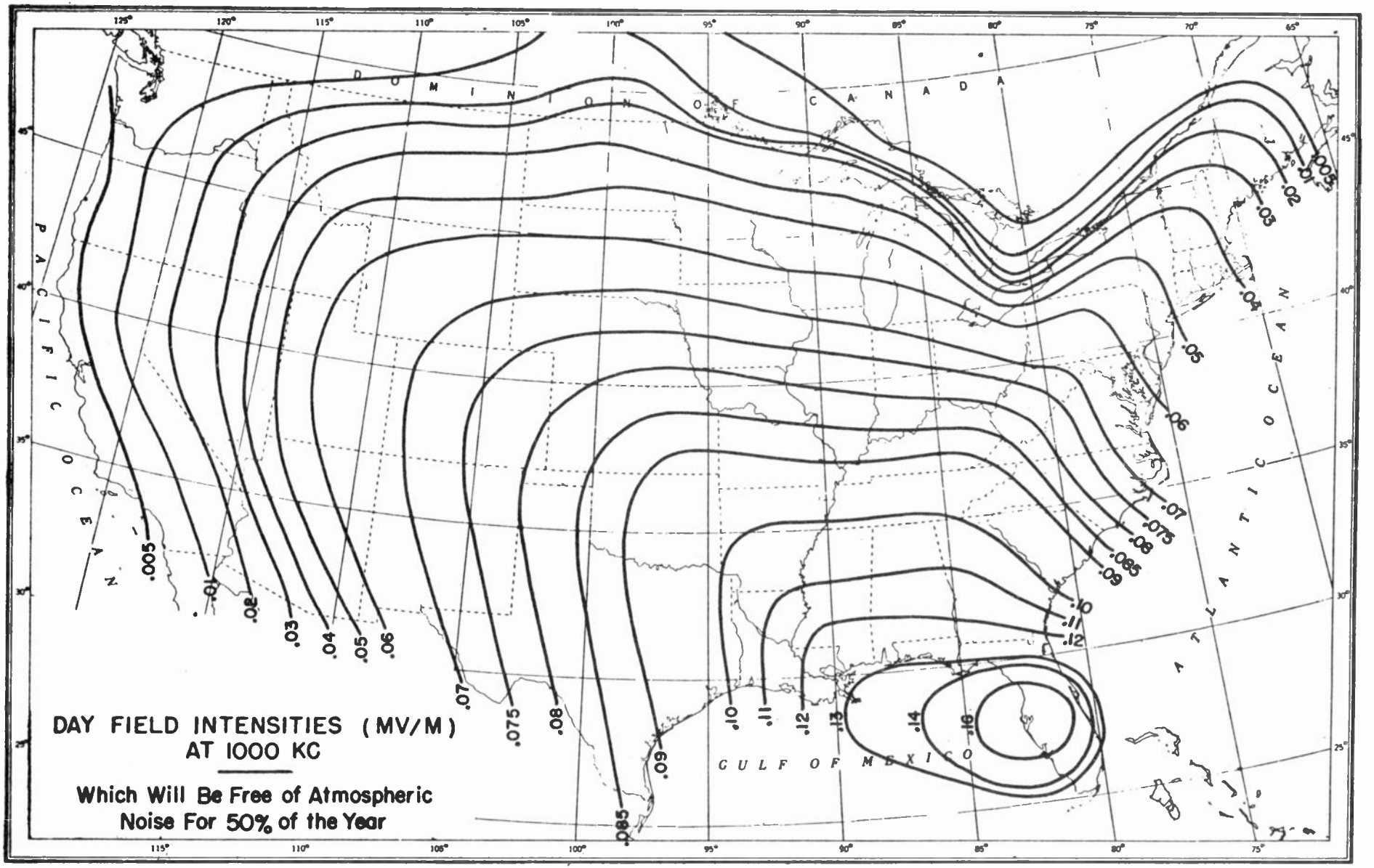


Fig. 12-3

UNITED STATES

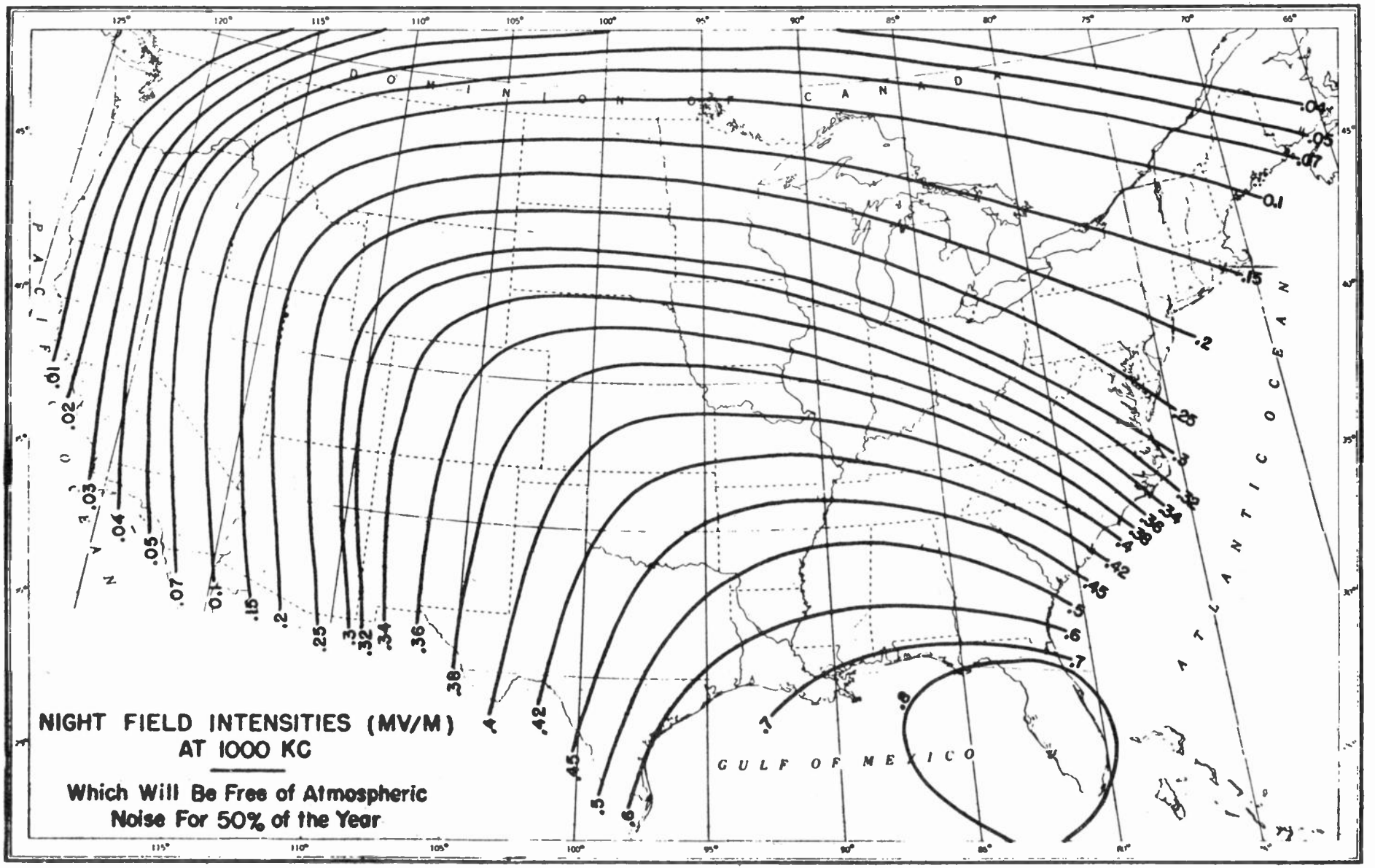


Fig. 14-4

RELATIVE SIGNAL INTENSITIES FOR ATMOSPHERICS-FREE RECEPTION

VS

FREQUENCY

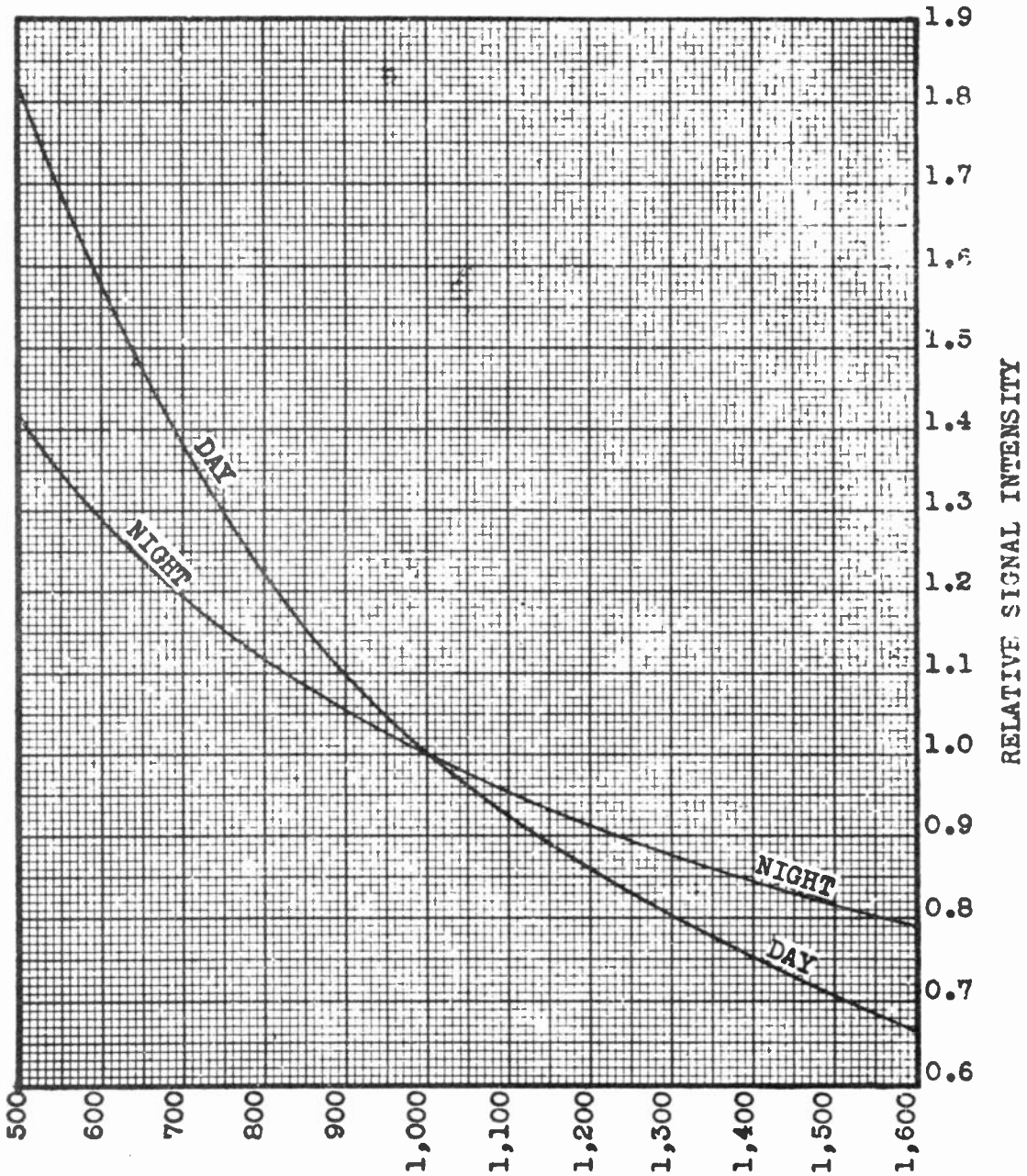


FIGURE 4-1

DIRECTIONAL ANTENNAS

FOREWORD

A new book titled "Directional Antennas" which presents in simple language the necessity for directional antennas, the underlying properties thereof and methods of designing same, has just been written by Carl E. Smith and published by the Cleveland Institute of Radio Electronics. In addition to the texts and formulas, there are included over 15,000 two and three element directional antenna patterns. Each pattern is completely defined in regard to orientation and spacing of elements, current ratios, phasings and root-mean-square value. Mr. Smith and the publisher have granted permission to NAB to include excerpts from the above named book in this engineering handbook.

The NAB Director of Engineering recommends that those engineers who desire to become better acquainted with this subject include in their library the complete volume* as outlined in the table of contents on the following pages.

. . . . . .

* *This book, "Directional Antennas" by Carl E. Smith, E. E., (1946), contains over 300 pages 8½ x 11", more than 15,000 patterns, and is published by Cleveland Institute of Radio Electronics, Terminal Tower, Cleveland, Ohio. Price, $15.00 per single copy, $25.00 for two copies; quantity order discounts upon request.*

DIRECTIONAL ANTENNAS

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DIRECTIONAL ANTENNAS

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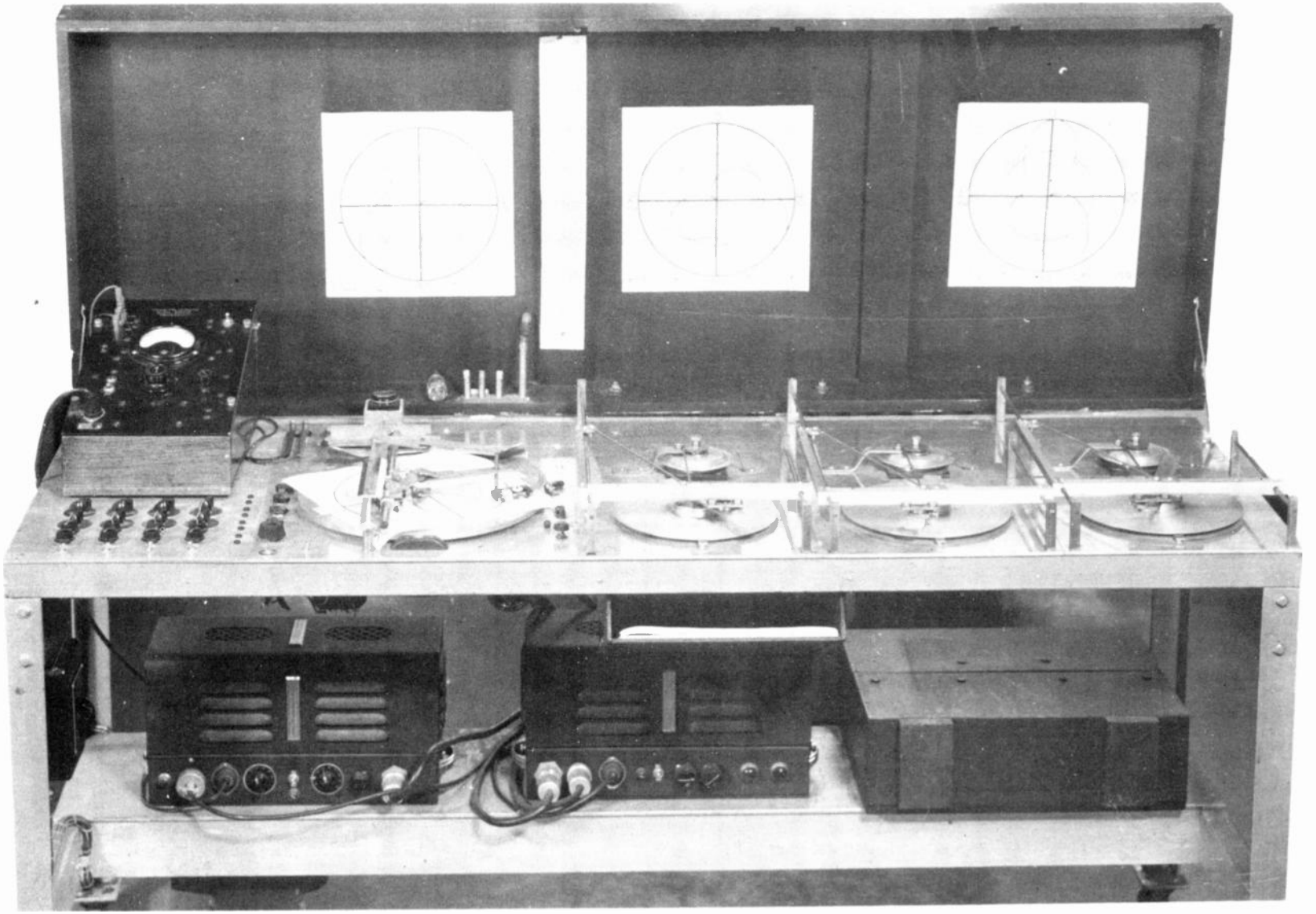
Part II - Systematization of Two Tower Patterns out to 1440° Spacing.

In this section there are 568 patterns. 256 of these patterns are general patterns with spacings out to four wavelengths, while 312 are detailed patterns for spacings out to one wavelength.

Part III - Systematization of Three Tower patterns out to 360° spacing.

In this section there are 14,592 patterns. Briefly, there are 228 placements of three towers and for each placement there are 64 different phasings presented.



ELECTRO-MECHANICAL DIRECTIONAL ANTENNA PATTERN CALCULATOR

DIRECTIONAL ANTENNAS

PART I

THEORY AND APPLICATION

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CL[illegible]ND INSTITUTE OF RADIO ELECTRONICS
[illegible]INAL TOWER, CLEVELAND 13, OHIO.

1. 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.

(3) Eliminate multiple ownership problems by controlling one or more of the directional antenna patterns of radio stations owned by the same company.

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 tow-

ers. 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 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 a long period of time. This material is under almost constant revision as the art progresses.

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.

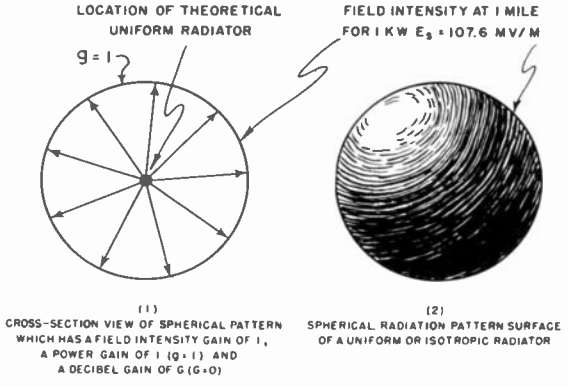
d. *DETERMINATION OF PATTERN SIZE*. – Pattern size is determined by the class of station and efficiency of the antenna system. The power for the class of station is regulated by the Federal Communicat ns Commission as outlined in Good Engineering Practice. In general, the power ranges from 50 kilowatts for clear channel stations to 5 kilowatts for regionals down to 250 watts for local stations. The predominance of directional antenna designs are for regional stations which have to protect radio stations in other regions of the country. A few are used on clear, but none on local channels.

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. 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 of 175 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 an 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 accoustic waves, this standard is represented by a sphere pulsating radially.



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 World War II antenna work. With this information, the figure of merit of other antennas can be compared with this basic standard. 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 per-

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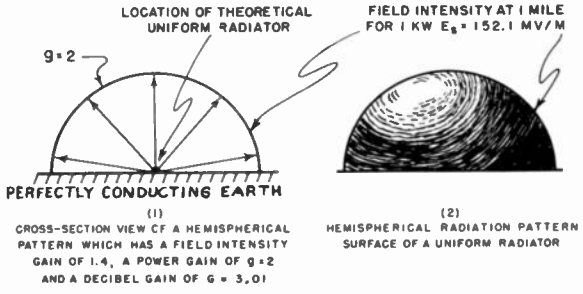
fectly conducting earth, all of the power must be radiated in the hemisphere above the surface of the earth as shown in Fig. 2. For a given power source, the power flow will have twice the intensity of a uniform radiator in free space, hence the power gain is said to be 2. For this case, the field intensity 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



PATTERN OF A UNIFORM RADIATOR AT THE SURFACE OF A PERFECT REFLECTING 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:

$$E = \frac{60\pi}{d\lambda} I (\delta h) \cos\theta \qquad (3)$$

or

$$= \frac{60\pi f}{dc} I (\delta h) \cos\theta$$

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

δh = 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 –

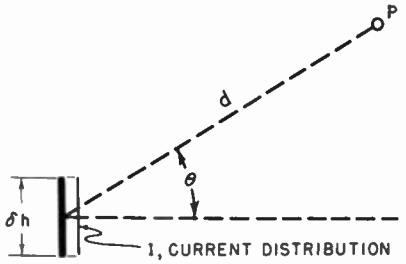
$$E = E_o \cos\theta \qquad (4)$$

$$= 131.8 \cos\theta$$

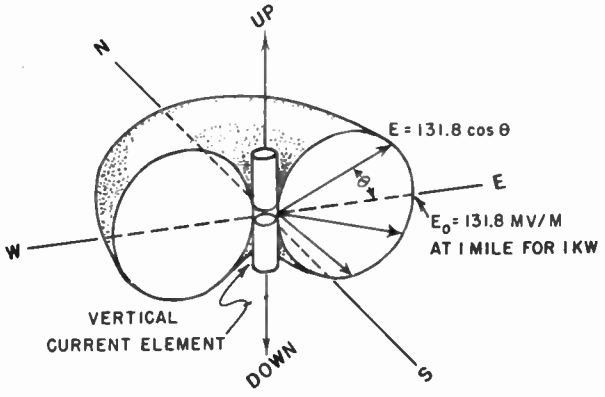
where E = millivolts per meter unattenuated field intensity at one mile for one kilowatt

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

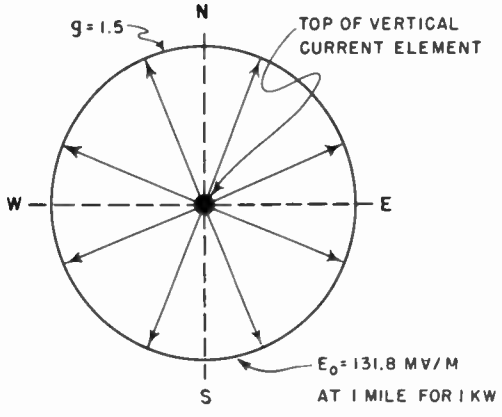
θ = elevation angle as shown in Fig. 3(a).



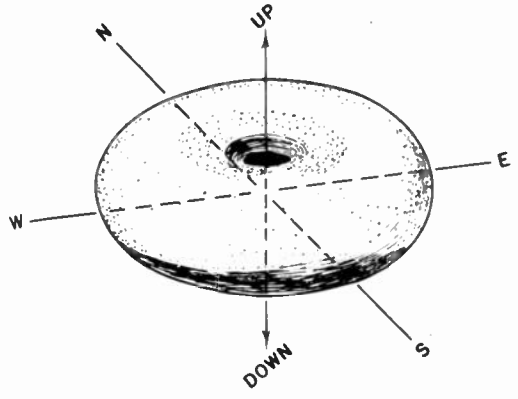
(a) ELECTRIC CURRENT ELEMENT OF LENGTH δh AND CARRYING CURRENT I



(b) SIDE CROSS-SECTION VIEW OF THE TOROIDAL RADIATION PATTERN SHOWING THE VERTICAL DIRECTIVITY.



(c) HORIZONTAL CROSS-SECTION VIEW OF TOROIDAL RADIATION PATTERN SHOWING ZERO HORIZONTAL DIRECTIVITY



(d) SURFACE PATTERN SHOWING TOROIDAL OR DOUGHNUT SHAPE

THE RADIATION PATTERN OF A VERTICAL ELECTRIC CURRENT ELEMENT IN FREE SPACE

FIG. 3

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.

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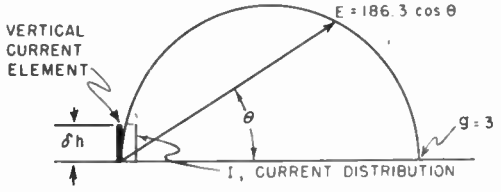
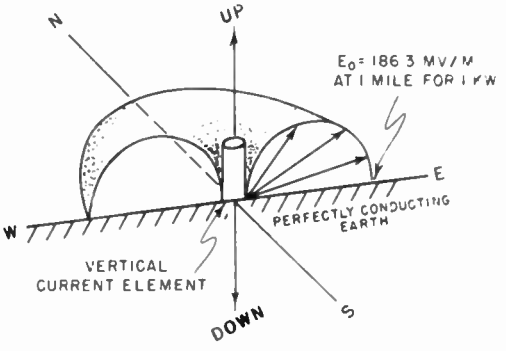
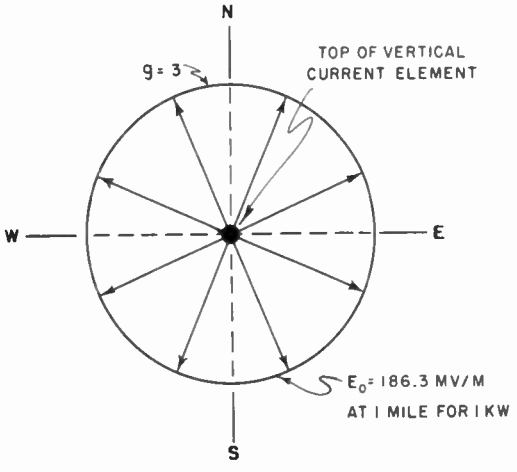
(4) Vertical Current Element Antenna Over a Perfectly Conducting Earth. – If a vertical current element antenna is located at the surface of a perfect earth, the radiation will be hemispherical as shown in Fig. 4.



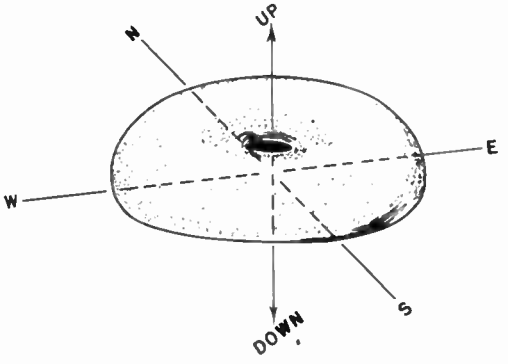
(a) VERTICAL RADIATION PATTERN



(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 ZERO 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

When this vertical current element radiates 1 kw of power the field intensity at one mile is

$$E = 186.3 \cos \theta \qquad (5)$$

where E and θ are defined in Eq. (4) and Fig. 4(a).

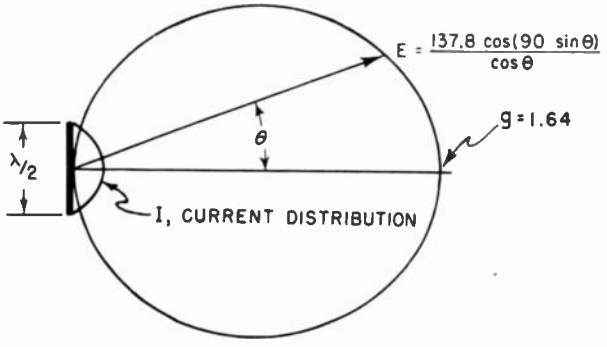
This vertical current element antenna is sometimes used as a secondary reference antenna. It gives the vertical pattern of a zero height antenna. See Eq.(10). While one of these infinitesimal antennas itself is of no practical value it is useful in summing up the radiation effects of antennas having 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

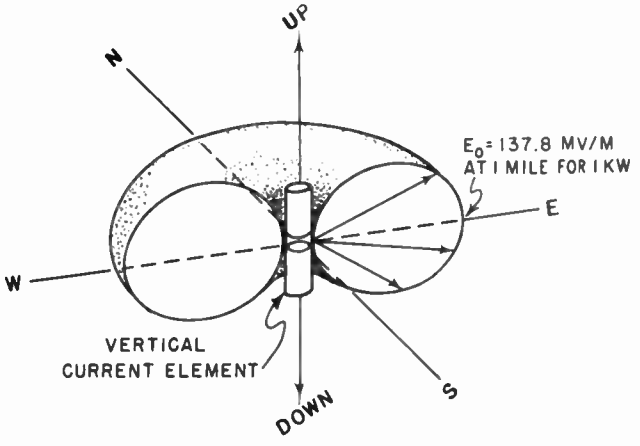
$$E = \frac{137.6 \cos (90 \sin \theta)}{\cos \theta} \qquad (6)$$

where E and θ are defined in Eq.(3) and Fig. 5(a).

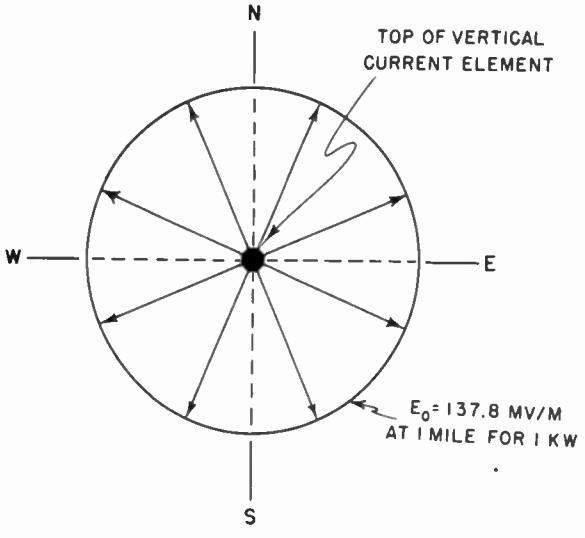
This type of antenna is often used as a secondary standard reference antenna because it is a practical type of antenna that is easy to set up experimentally. For example, the Federal Communications Commission uses this standard for FM and TV Broadcast Stations.



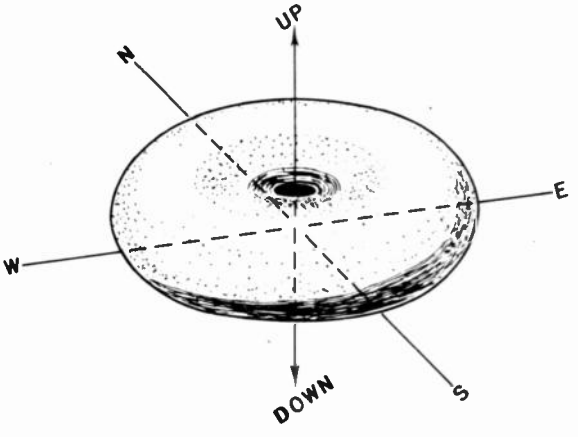
(a) VERTICAL RADIATION PATTERN



(b) SIDE CROSS-SECTION VIEW OF THE RADIATION PATTERN SHOWING THE VERTICAL DIRECTIVITY



(c) HORIZONTAL CROSS-SECTION VIEW OF RADIATION PATTERN SHOWING ZERO HORIZONTAL DIRECTIVITY



(d) SURFACE PATTERN SHOWING DOUGHNUT SHAPE

THE RADIATION PATTERN OF A VERTICAL HALF WAVE RADIATOR IN FREE SPACE

FIG. 5

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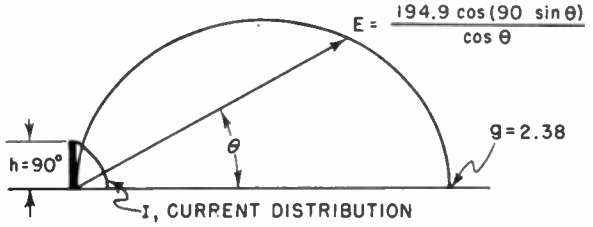
(6) Quarter-Wave Vertical Antenna over a Perfectly Conducting Earth. - This type of antenna is very common and is often used as a secondary standard reference antenna. With a sinusoidal current distribution as shown in Fig. 6(a) the radiation pattern is given by

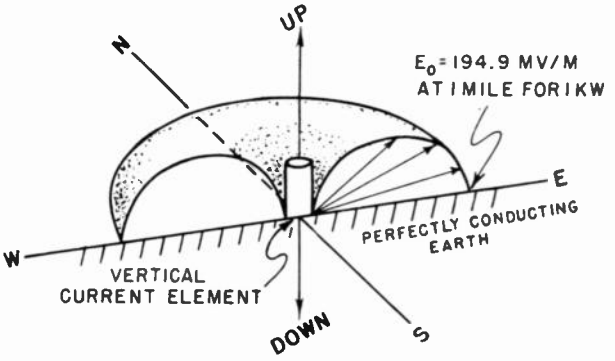
$$E = \frac{194.9 \cos (90 \sin \theta)}{\cos \theta} \qquad (7)$$

where E and θ are defined in Eq. (3) and Fig. 6(a).

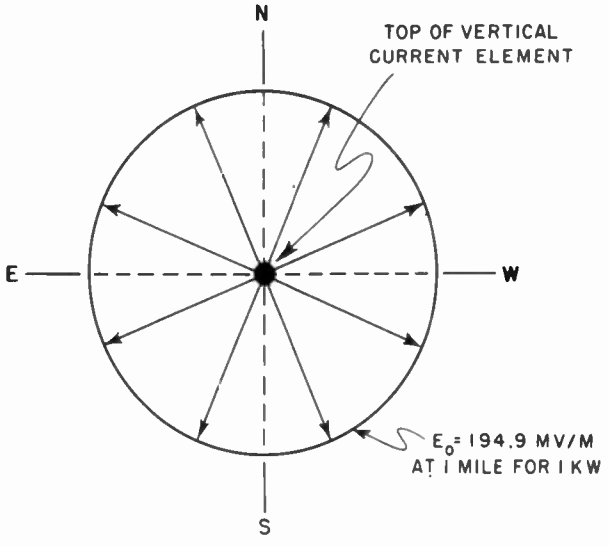
Many directional antenna arrays are designed with quarter wave elements because of the ease of making computations in design and adjustments during the proof of performance.



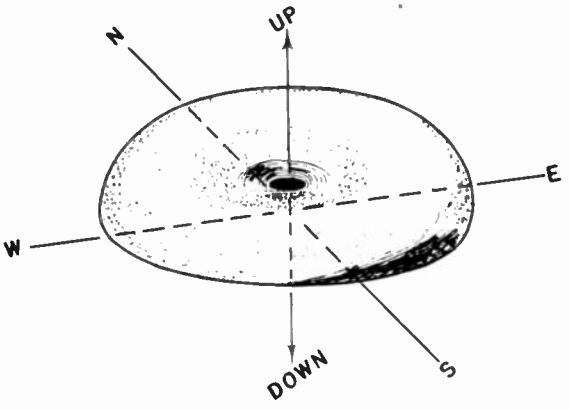
(a) VERTICAL RADIATION PATTERN



(b) SIDE CROSS-SECTION VIEW OF THE RADIATION PATTERN SHOWING THE VERTICAL DIRECTIVITY



(c) HORIZONTAL CROSS-SECTION VIEW OF RADIATION PATTERN SHOWING ZERO HORIZONTAL DIRECTIVITY



(d) SURFACE PATTERN SHOWING DOUGHNUT SHAPE

THE RADIATION PATTERN OF A VERTICAL QUARTER WAVE RADIATOR OVER A PERFECTLY CONDUCTING EARTH

FIG. 6

(7) 0.311λ Vertical Antenna Over a Perfectly Conducting Earth. - The Federal Communications Commission at the present time uses this height antenna ($h = 111.96^\circ$) 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 -

$$E = 200 \frac{\cos (h \sin \theta) - \cos h}{(1 - \cos h) \cos \theta} \quad (8)$$

$$= 319.5 \frac{\cos (111.96 \sin \theta) - 0.3740}{\cos \theta}$$

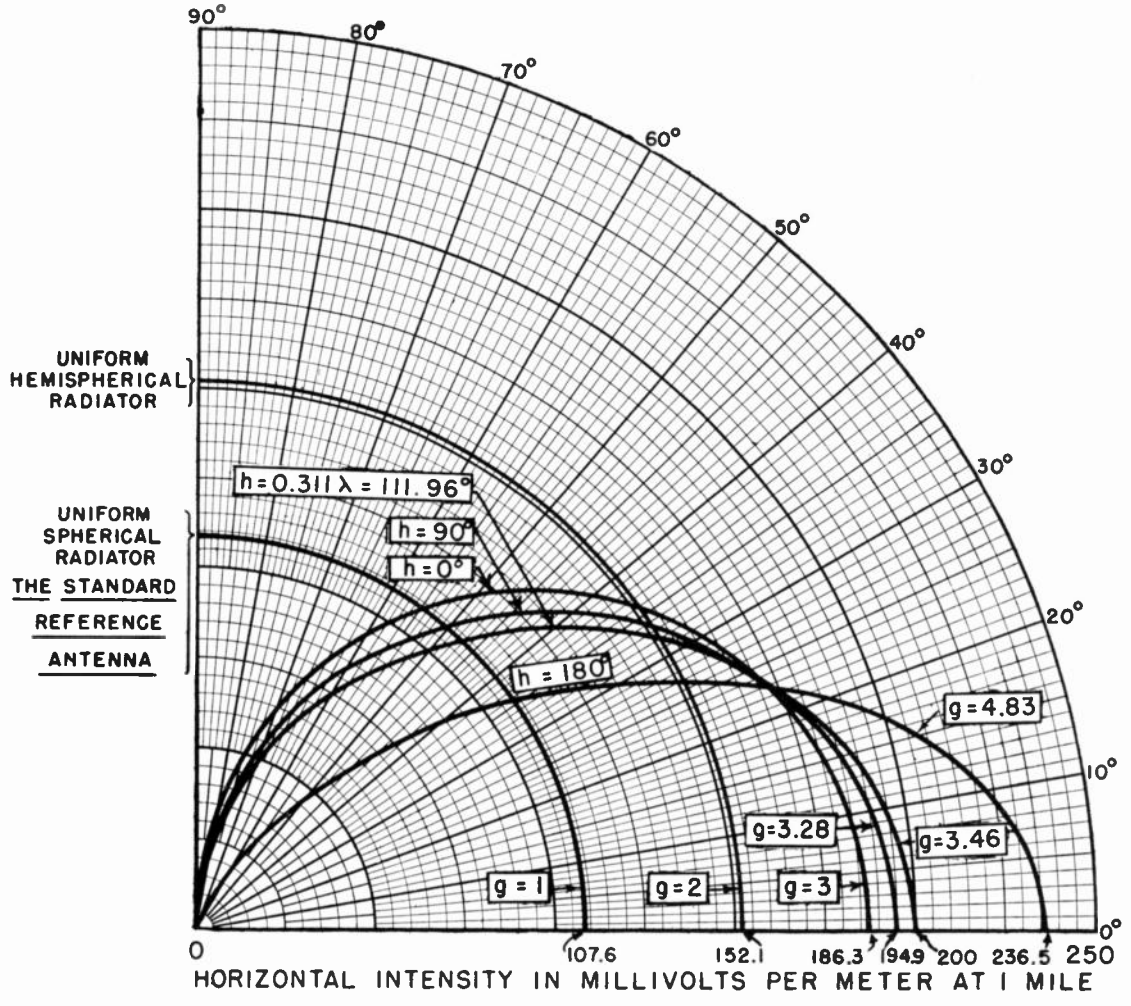
where E and θ are defined in Eq. (3) and $h = 111.96^\circ$ the height of the antenna in electrical degrees.

(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

$$E = 236.5 \frac{\cos (h \sin \theta) - \cos h}{(1 - \cos h) \cos \theta} \quad (9)$$

$$= 118.25 \frac{\cos (180 \sin \theta) + 1}{\cos \theta}$$

where E and θ are defined in Eq. (3) and $h = 180^\circ$ the height of the antenna in electrical degrees.



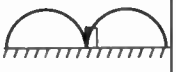
COMPARISON OF VERTICAL RADIATION PATTERN OF STANDARD REFERENCE ANTENNAS WITH A RADIATED POWER OF 1 KILOWATT

FIG. 7

(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.

TABLE I
SUMMARY OF STANDARD REFERENCE ANTENNAS

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

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

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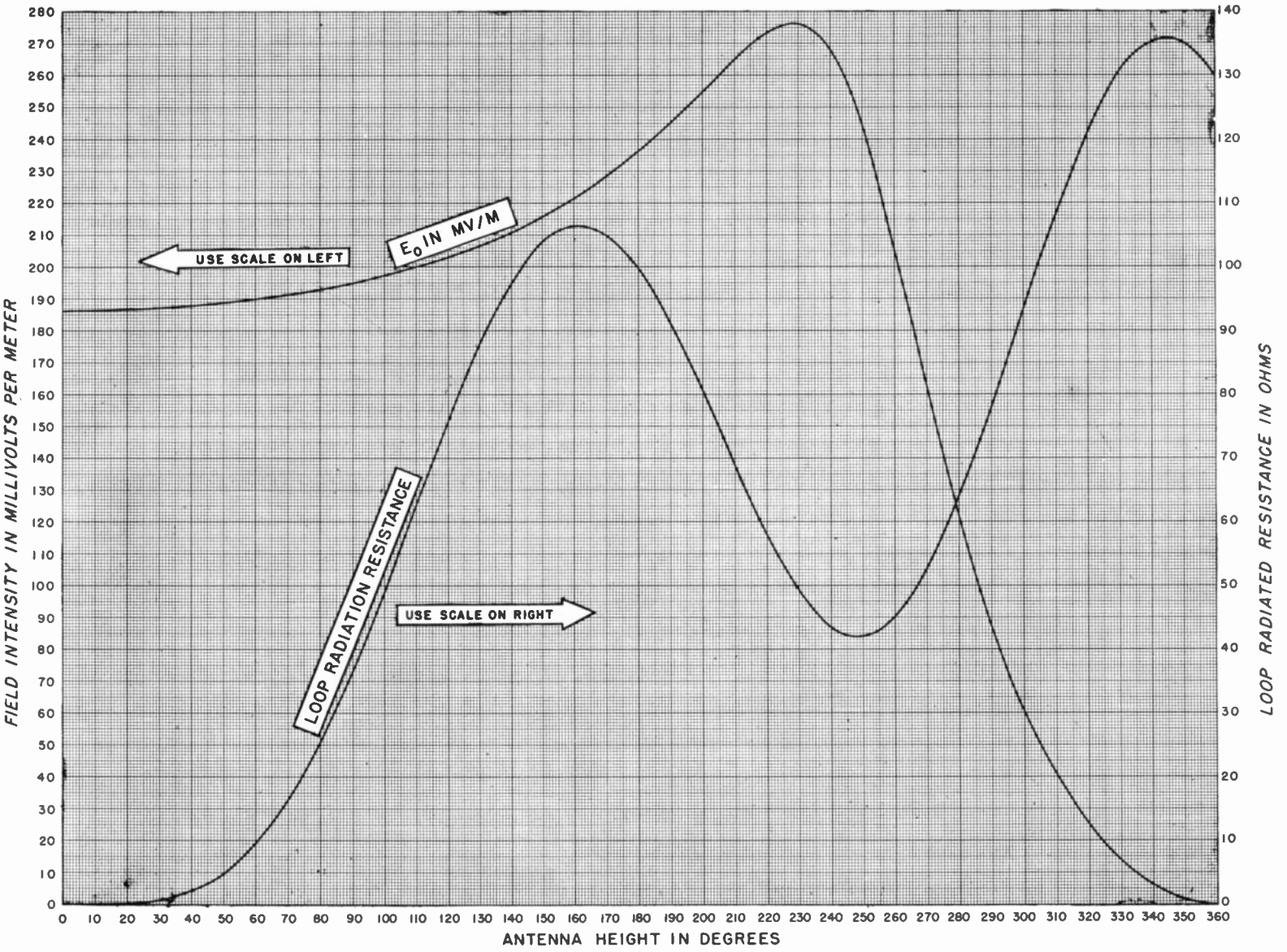

UNATTENUATED FIELD INTENSITY AT ONE MILE FOR ONE KILOWATT
AND THE LOOP RADIATION RESISTANCE AS A FUNCTION OF ANTENNA HEIGHT
OVER A PERFECTLY CONDUCTING EARTH

FIG. 8

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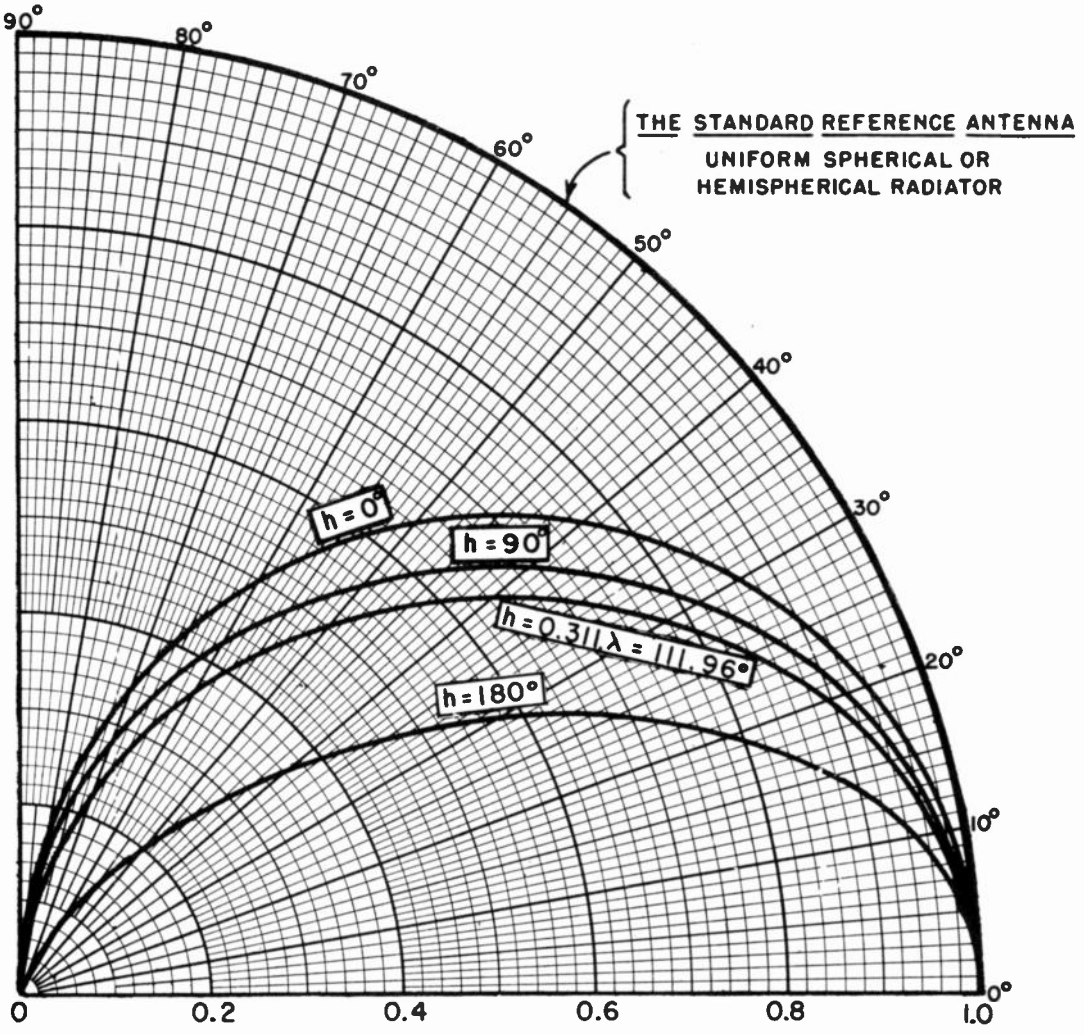

COMPARISON OF THE VERTICAL RADIATION CHARACTERISTICS FOR SEVERAL STANDARD REFERENCE ANTENNAS

FIG. 9

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

$$f(\theta) = \frac{\cos(h \sin\theta) - \cos h}{(1 - \cos h)\cos\theta} \qquad (10)$$

where $f(\theta)$ = vertical radiation characteristic

h = electrical height of the antenna in electrical degrees

θ = elevation angle of the observation point measured up from the horizon in degrees

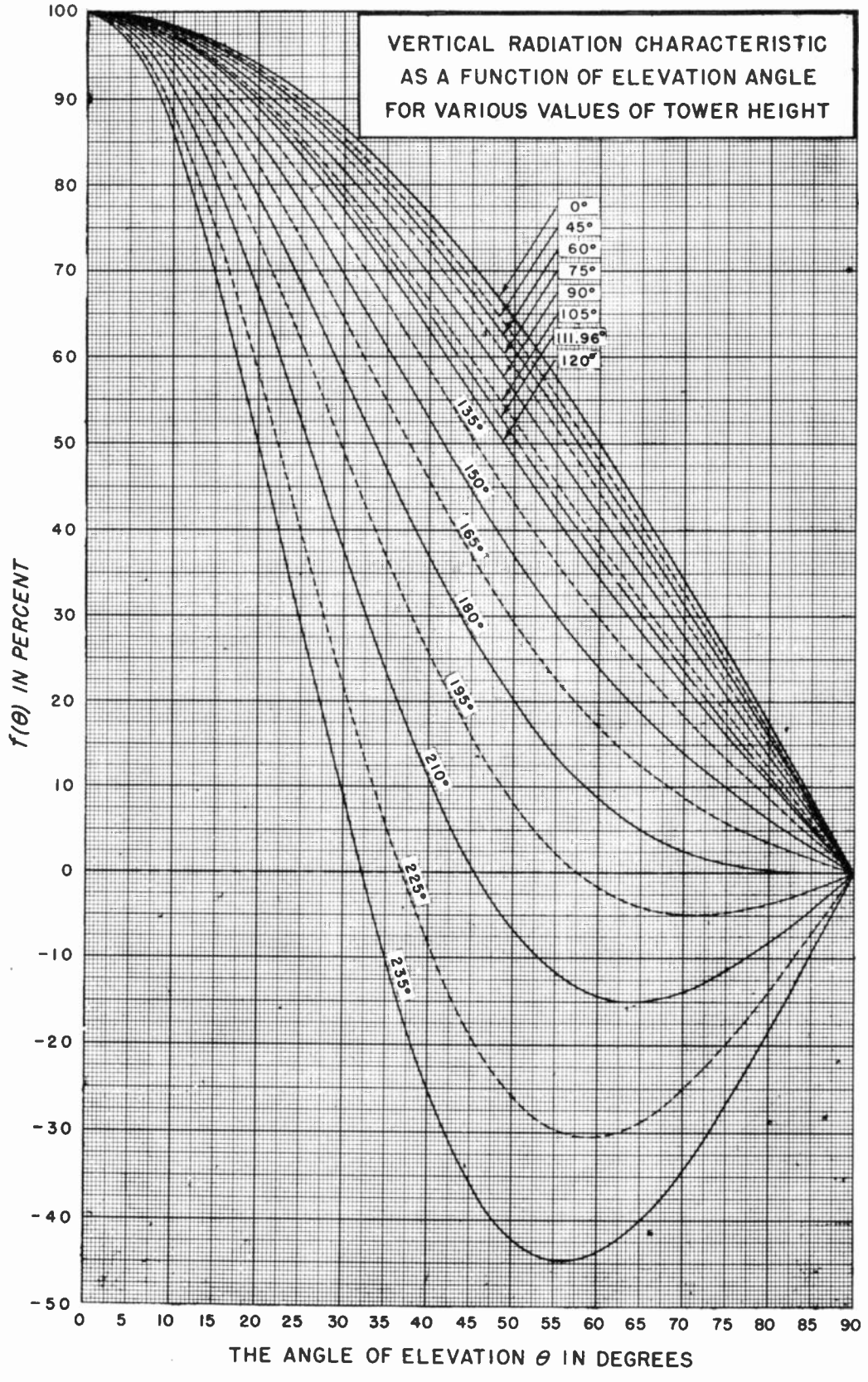
VERTICAL RADIATION CHARACTERISTIC
AS A FUNCTION OF ELEVATION ANGLE
FOR VARIOUS VALUES OF TOWER HEIGHT
0°
45°
60°
75°
90°
105°
111.96°
120°
135°
150°
165°
180°
195°
210°
225°
235°
f(θ) IN PERCENT
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
THE ANGLE OF ELEVATION θ IN DEGREES

FIG. 10

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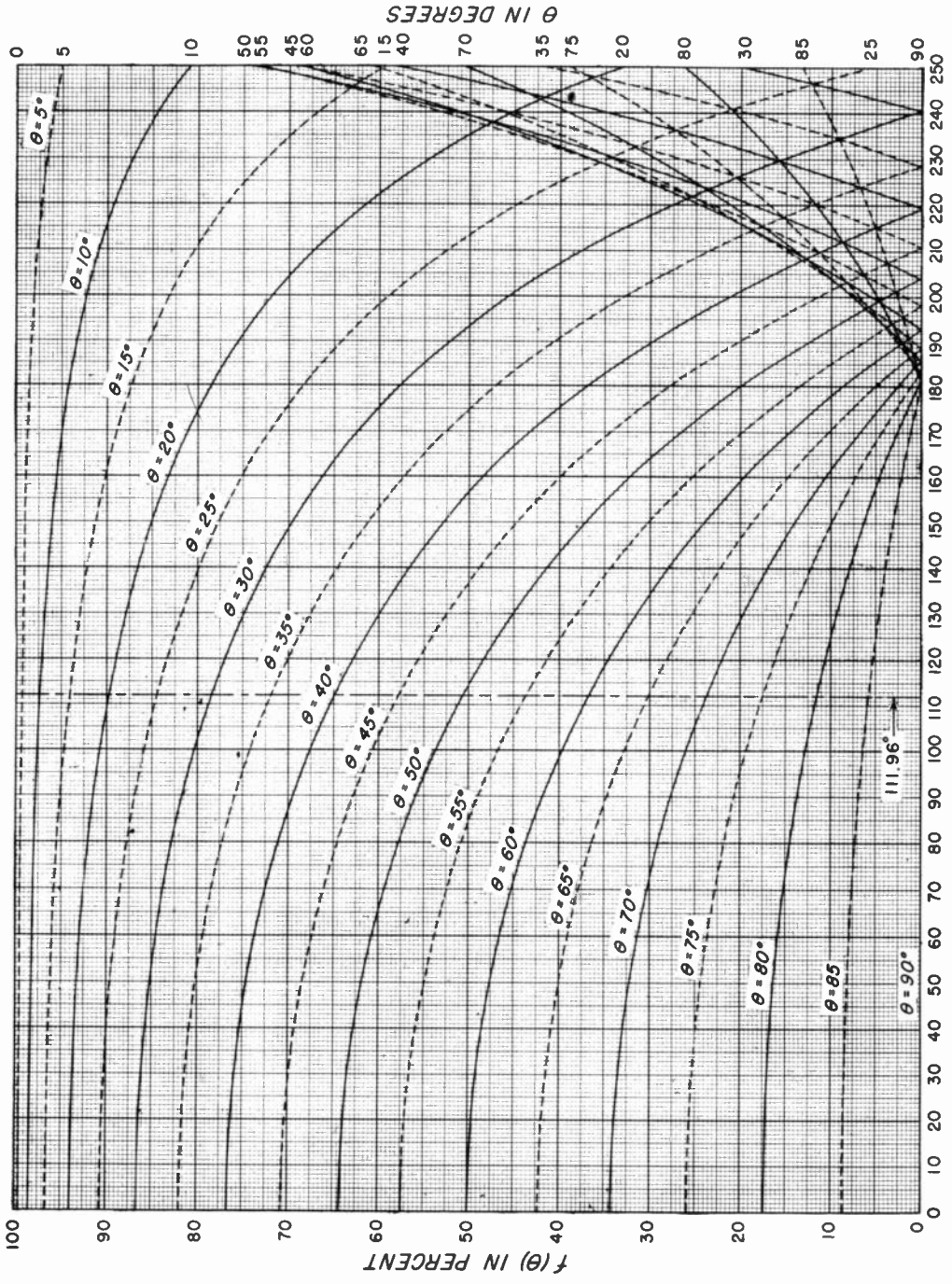
The curves in Fig. 10 represent the solution of this equation over the most useful range of antenna heights. The vertical radiation characteristic is plotted as a function of elevation angle for various values of tower height. A representative set of tower heights have been selected for Fig. 10. Fig. 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 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. (15). In the horizontal plane this function reduces to unity and simplifies the design equation.



VERTICAL RADIATION CHARACTERISTIC AS A FUNCTION OF ELECTRICAL TOWER HEIGHT FOR VARIOUS VALUES OF ELEVATION ANGLE

FIG. 11

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.

(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,

$$g = \frac{P_s}{P_r} \quad \text{(equal field intensities)} \qquad (13)$$

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_m (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,

$$G = 10 \log g \qquad (14)$$

where G = decibels directive gain
g = directivity or power gain.

d. *GENERALIZED EQUATION TO DETERMINE PATTERN SHAPE.* – The generalized equation for a directional antenna array as given here is based upon the following assumptions:

(1) That the antennas are over a perfectly conducting plane earth surface
(2) that the distance from the space reference point to the observation point is great in comparison to the physical dimensions of the directional antenna array.

The generalized equation for n antennas in the directional antenna array is –

$$E = E_1 f_1(\theta) \angle\beta_1 + E_2 f_2(\theta) \angle\beta_2 \; E_k f_k(\theta) \angle\beta_k + \cdots + E_n f_n(\theta) \angle\beta_n \qquad (15a)$$

By using the summation sign this equation can be written

$$E = \sum_{k=1}^{k=n} E_k f_k(\theta) \angle\beta_k \qquad (15b)$$

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where E = the total effective field-intensity vector at unit distance for the antenna array with respect to the voltage reference axis

k = the k^{th} antenna in the system

n = the total number of antennas in the directional-antenna array

E_k = the horizontal magnitude of the field intensity at unit distance produced by the k^{th} antenna

$f_k(\theta)$ = vertical radiation characteristic of the k^{th} antenna - see Eq.(10, for a vertical thin conductor.

θ = elevation angle of the observation point measured up from the horizon

$$\beta_k = S_k \cos(\phi_k - \phi) \cos\theta + \psi_k \quad (16)$$

= phase relation of the voltage (or current in the k^{th} antenna with respect to the voltage reference axis

$S_k \cos(\phi_k - \phi) \cos\theta$ = space phasing portion of the β_k due to location of of the k^{th} antenna

S_k = electrical length of spacing of the k^{th} antenna from the space reference point.

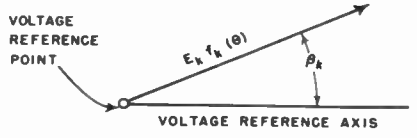
ϕ_k = true horizontal azimuth, orientation of the k^{th} antenna, with respect to the space reference axis

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 electrical phase angle of the voltage (or current) in the k^{th} antenna with respect to the voltage reference axis

The generalized equation for n antennas as given in Eq. (15a) and (15b) treats only the k^{th} antenna. All of the antennas in the directional antenna array can be handled in a similar fashion and the vectors finally added together as indicated by the summation sign. It will be noted in this equation that the field intensity vector for the k^{th} antenna has a *magnitude* of E_k in all directions in the horizontal plane. This magnitude is modified by the *vertical radiation characteristic* $f_k(\theta)$ which corrects the magnitude of the field intensity vector E_k to give the correct value of the elevation angle being considered. For simple vertical antennas Eq. (10), Figs. 10 and 11 or Appendix I can be used to determine the value of $f_k(\theta)$.

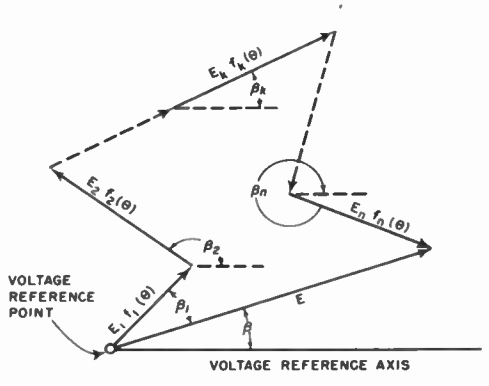
The vector field intensity from the k^{th} antenna in any direction is illustrated in Fig. 12.



VECTOR REPRESENTATION OF THE MAGNITUDE $E_k f_k(\theta)$ AND PHASE ANGLE β_k OF THE FIELD INTENSITY FROM THE k^{th} ANTENNA

FIG. 12

It has a magnitude of $E_k f_k(\theta)$ and makes an angle of the β_k with respect to the voltage reference axis. The summation of these vectors for the n antennas in the directional antenna array, as indicated in Eq. (15), is illustrated in Fig. 13. The vector angles, as will be noted in the figure, are all measured from the voltage reference axis.

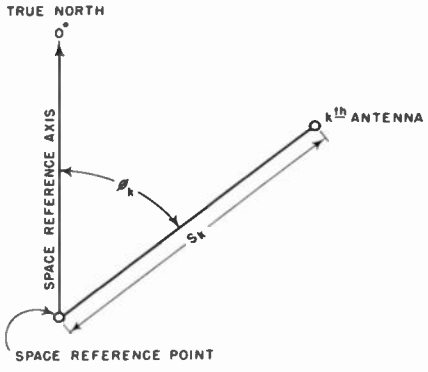


SUMMATION OF FIELD INTENSITY VECTORS FOR n ANTENNAS IN THE DIRECTIONAL ANTENNA ARRAY

FIG. 13

The angle θ_k, of the field intensity vector, as defined in Eq. (16), is a function of

space phasing and time phasing. The space phasing parameters for the k^{th} antenna are illustrated in Fig. 14.

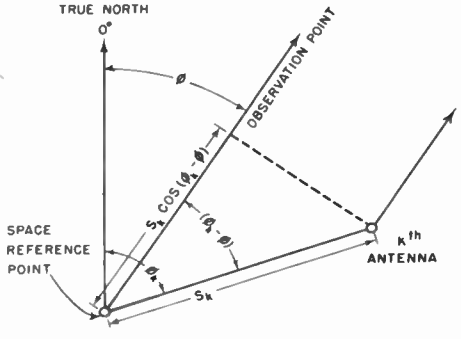


PLAN VIEW OF THE TRUE ORIENTATION AND SPACING OF THE k^{th} ANTENNA

FIG. 14

This figure illustrates that any antenna in the directional antenna array can be located with respect to the space reference axis by the true orientation angle ϕ_k, and with respect to the space reference point by the distance S_k.

In the space phasing portion of Eq. (16) 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 to the k^{th} antenna and the space reference point as shown in Fig. 15.

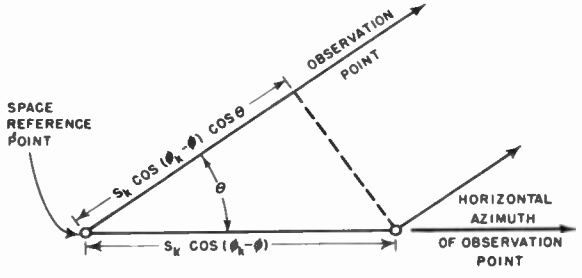


PLAN VIEW OF k^{th} ANTENNA SHOWING SPACE PHASING IN THE HORIZONTAL PLANE

FIG. 15

Since the observation point is assumed to be at a great distance, a perpendicular dropped from the k^{th} antenna to the straight line connecting the observation and reference points creates a right triangle, the side of which is $S_k \cos(\phi_k - \phi)$. This space phasing quantity is the required difference distance 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 Eq. (16) and Fig. 16, a right triangle can be formed by dropping a perpendicular to the line connecting the space reference point and the observation point.



ELEVATION ANGLE θ SHORTENS THE SPACING S_k TO THE VALUE $S_k \cos\theta$

FIG. 16

The k^{th} antenna then appears to have a space phasing of $S_k \cos(\phi_k - \phi) \cos\phi$ 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 in the hemisphere.

The direction of the observation point P in terms of the true orientation ϕ and elevation angle θ is illustrated in Fig. 17. The magnitude of the total effective field intensity E. as given in Eq. (15), is represented along the direction of the line from the space reference point toward the observation point P. This is for convenience in drawing polar charts.

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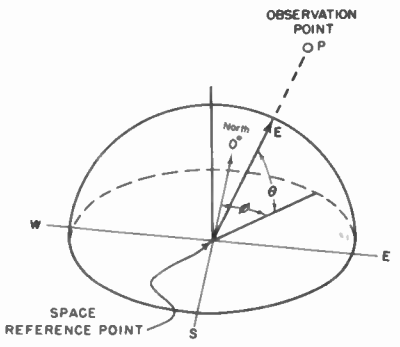


VECTOR REPRESENTATION OF THE TOTAL FIELD NTENSITY IN SPACE

FIG. 17

Referring again to Eq. (16), it is seen that the phase angle of the voltage vector is a function of space phasing and time phasing. The space phasing, as discussed above, varies with the position of the observer, while the time phasing is a constant that is set by the phase angle of the voltage (or current) in the k^{th} antenna.

It is of interest to note that a pattern can be calculated for a given elevation angle which is equivalent to a horizontal pattern that has field intensity vector magnitudes of the respective antennas equal to $E_k f_k(\theta)$ and spacings reduced to $S_k \cos \theta$. This scheme of drawing patterns at the various elevation angles is a useful method for determining the vertical pattern of an equivalent non-directional antenna. All that is required to make this computation is to determine the root-mean-square value of the pattern for each elevation angle.

e. *DIRECTIONAL ANTENNA PARAMETERS*. – In general this system specifies all of the parameters required to determine the shape and size of the directional antenna pattern. To be specific the system specifies:

(1) The number of antennas in the directional antenna array,
(2) The true orientation of each antenna from the space reference axis,

TABLE II

DIRECTIONAL ANTENNA PARAMETERS

Antenna No.	True Orientation $\emptyset^o$	Spacing S^o	Phasing ψ^o	Horizontal Field Intensity $E_{mv/m}$	Electrical Height h^o
1					
2					
.					
.					
.					
k					
.					
.					
.					
n					
P =		E_s =		E_o =	

(3) The spacing of each antenna from the space reference point,
(4) The time phasing of the voltage (or current) in each antenna with respect to the voltage reference axis,
(5) The horizontal field intensity of each antenna,
(6) The electrical height of each antenna, if a uniform cross-section tower, or the vertical radiation characteristic if it cannot be determined from Eq. (10),
(7) The rated input power to the directional antenna array, (92.5 % of P_i the input power as specified by FCC),
(8) The solid root-mean-square field intensity or the radiated power from the directional antenna array,
(9) The horizontal root-mean-square field intensity.

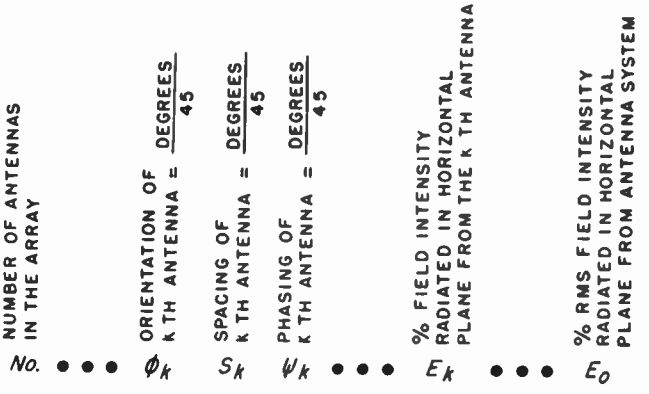
The general scheme for specifying the parameters of a directional antenna system can be tabulated as shown in TABLE II.

where k = k^{th} antenna in the array
n = total number of antennas in the array
ϕ^o = true orientation in degrees
S^o = spacing in degrees
ψ^o = phasing in degrees
Emv/m = horizontal field intensity in millivolts per meter
h^o = electrical height in degrees
P = watts rated input power to the directional antenna system (92.5% of the input power as specified by FCC)
E_s = mv/m unattenuated field intensity from an equivalent hemispherical *standard* reference antenna (Solid rms field intensity)
E_o = mv/m rms unattenuated field intensity in the horizontal plane (horizontal rms field intensity)

f. *SYSTEMATIZATION OF DIRECTIONAL ANTENNA*

(1) General. – A pattern numbering system has been devised which furnishes the antenna parameters in an orderly fashion. The first digit specifies the number of antennas in the directional antenna array. Succeeding sequences of three digits specify the orientation, spacing and phase of each antenna in the array. To simplyfy this numbering system, the orientation, spacing, and phase of each antenna is shifted in steps of 45 degrees. Rather than specify these steps directly in degrees, the number of degrees is divided by 45 to produce small whole numbers that can be used more conveniently in the pattern numbering system. The orientation, spacing, and phasing sequence are followed by two digit figures to specify, in percent, of the maximum lobe field intensity. the horizontal field intensity from each antenna and finally the last two digits specify in percent. the rms field intensity in the horizontal plane for the directional antenna array.

The basic idea of the pattern numbering system is illustrated in Fig. 18. Referring to this figure the first digit specifies the number of antennas and will require only 1 digit for 9 or less antennas.



PATTERN NUMBERING SYSTEM

FIG. 18

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Each antenna in the array will require 3 digits to specify its orientation, spacing and phase plus 2 digits to specify its field intensity in percent. Finally, the rms field intensity will require 2 digits.

On this basis the pattern number will require,

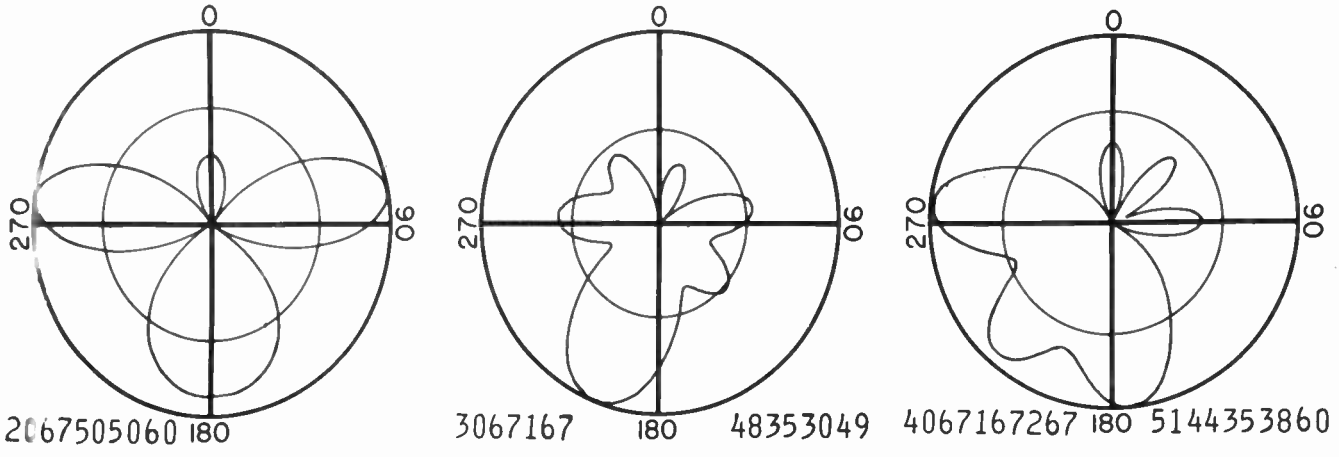
$$\text{Total number of digits in the pattern number} = 1 + 3n + 2n + 2 = 5n + 3 \quad (17)$$

where n = number of antennas in the array. However, if No. 1 antenna is placed at the space reference point and the phase is held at zero, the first set of three digits will always be zero. Therefore, the pattern number can be reduced by three digits if No. 1 antenna is used as the reference antenna. The first set of 3 digits will then specify the orientation, spacing and phase of No. 2 antenna with respect to No. 1 antenna. Using this modification the number of digits required will be,

$$\text{Total number of digits in modified pattern number} = 1 + 3(n-1) + 2n + 2 = 5n \quad (18)$$

where n is defined in Equation (17). On this basis a two tower systematization will require 10 digits, a three tower systematization will require 15 digits and a four tower systematization will require 20 digits. Fig. 19 illustrates respectively a two, three and four tower directional antenna array using this pattern numbering system.

(2) Sample Patterns. – In order to illustrate the application of this pattern nomenclature the following 6 pages have been lifted from the directional antenna book. On page 1.20 we have complete specifications for a directional antenna system giving both pattern size and shape. Page 1.21 is a sample page of the general two tower patterns; pages 1.22 and 1.23 are sample pages of the detailed two tower patterns, and finally, pages 1.24 and 1.25 are samples of the three tower systematization.

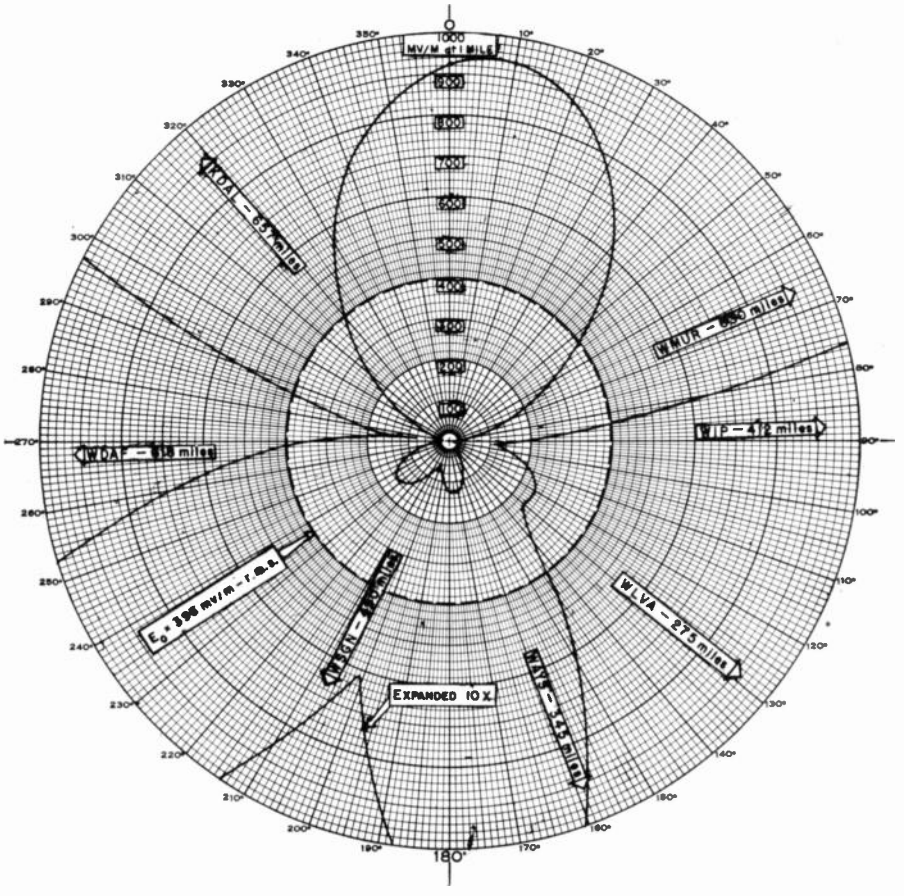


(a) TWO TOWER PATTERN (b) THREE TOWER PATTERN (c) FOUR TOWER PATTERN

HORIZONTAL PLANE DIRECTIONAL ANTENNA PATTERNS
USING THE PATTERN NUMBERING SYSTEM

FIG. 19

3. Sample Specifications for a Directional Antenna System.



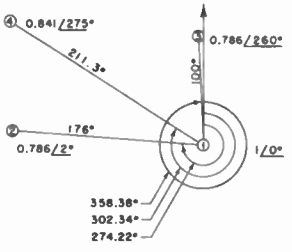
DIRECTIONAL ANTENNA PARAMETERS FOR

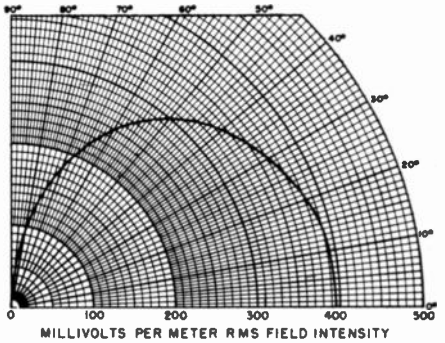
CALL LETTERS WHKC — LOCATION COLUMBUS, OHIO

FREQUENCY 610 KC — RATED POWER 5 KW

ANTENNA No.	TRUE ORIENTATION $\phi°$	SPACING $S°$	PHASING $\psi°$	FIELD RATIO	HORIZONTAL FIELD INTENSITY E mv/m	ELECTRICAL HEIGHT $h°$	DETERMINATION OF PATTERN SIZE: ELEVATION ANGLE $\theta°$	DETERMINATION OF PATTERN SIZE: RMS FIELD INTENSITY E_θ
1	0	0	0	1.0	276.1	90	0	396.4
2	274.22	176	2	0.786	217.0	90	10	395.4
3	358.38	100	260	0.786	217.0	52	20	381.7
4	302.34	211.3	275	0.841	232.2	52	30	362.2
5							40	334.2
6							50	300.0
7							60	248.2
8							70	181.4
9							80	86.5
							E_p = 341.9 MV/M	
							P_r = 5052.9 WATTS	

ANTENNA PLACEMENT SKETCH





HORIZONTAL PLANE PATTERN, PARAMETERS, SKETCH AND PATTERN SIZE DATA

4. Sample Two Tower Patterns.

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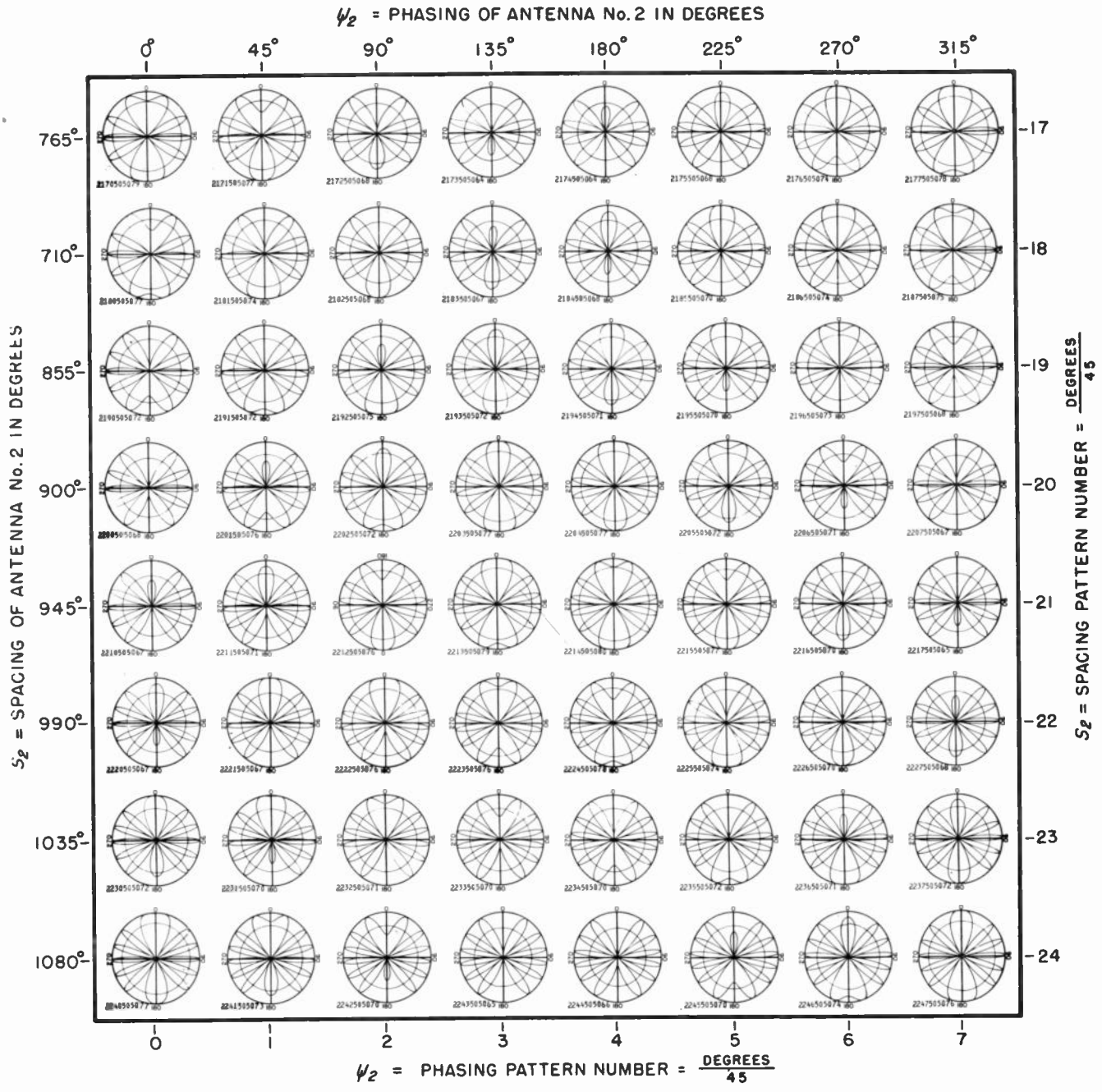
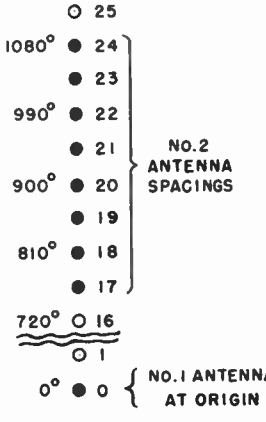


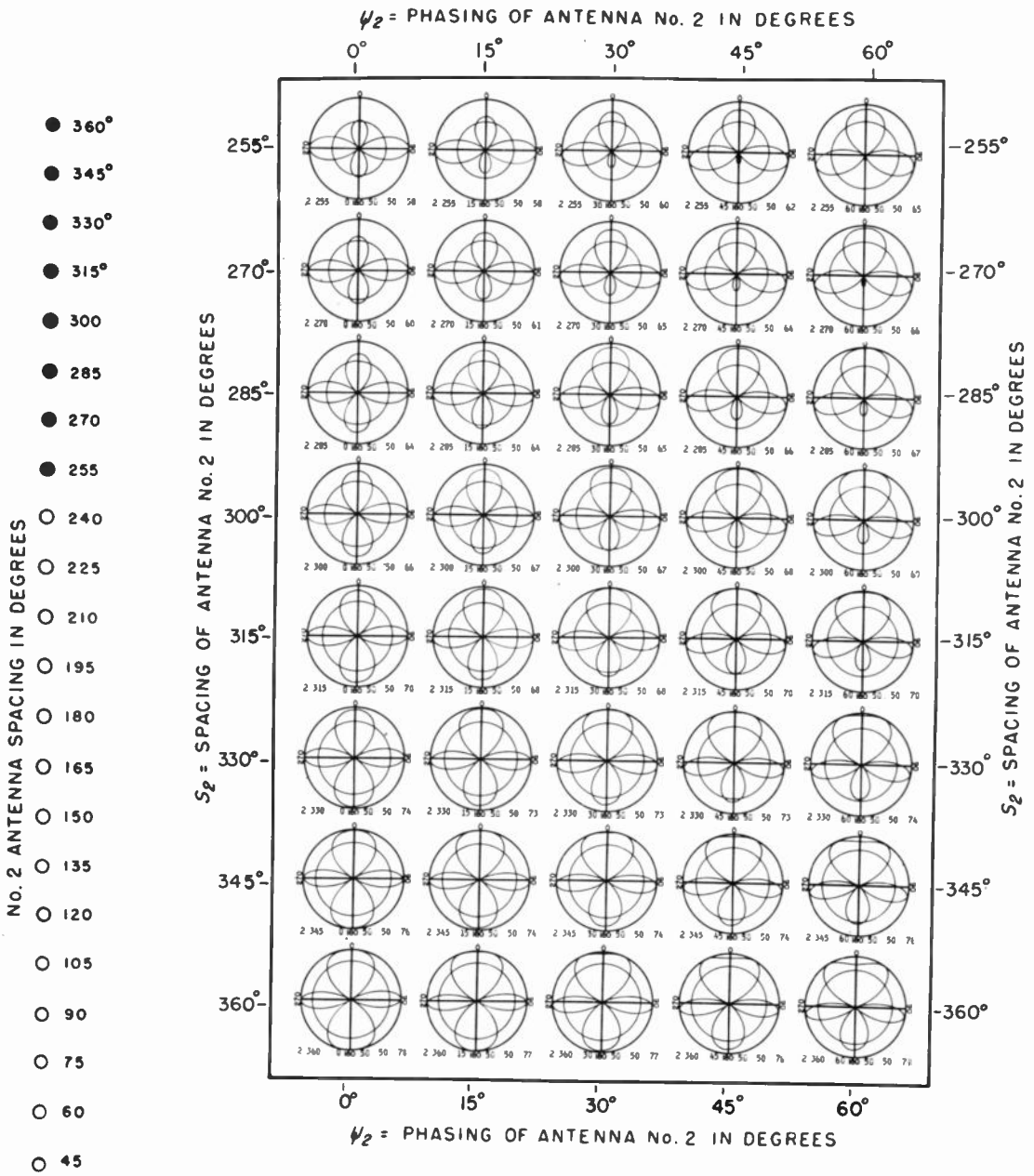


SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS.

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	17	0	50	50	79

DIRECTIONAL ANTENNAS



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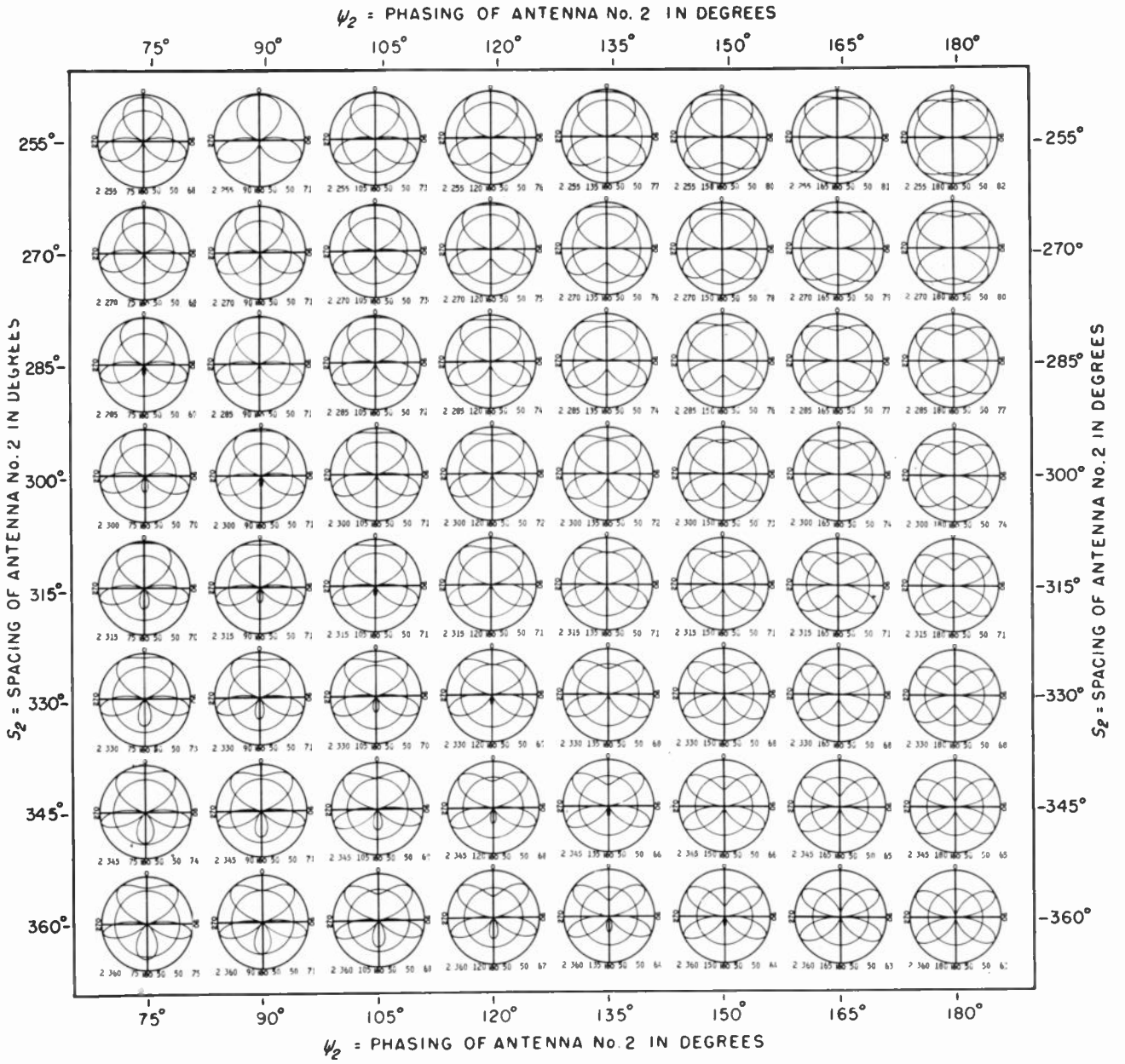
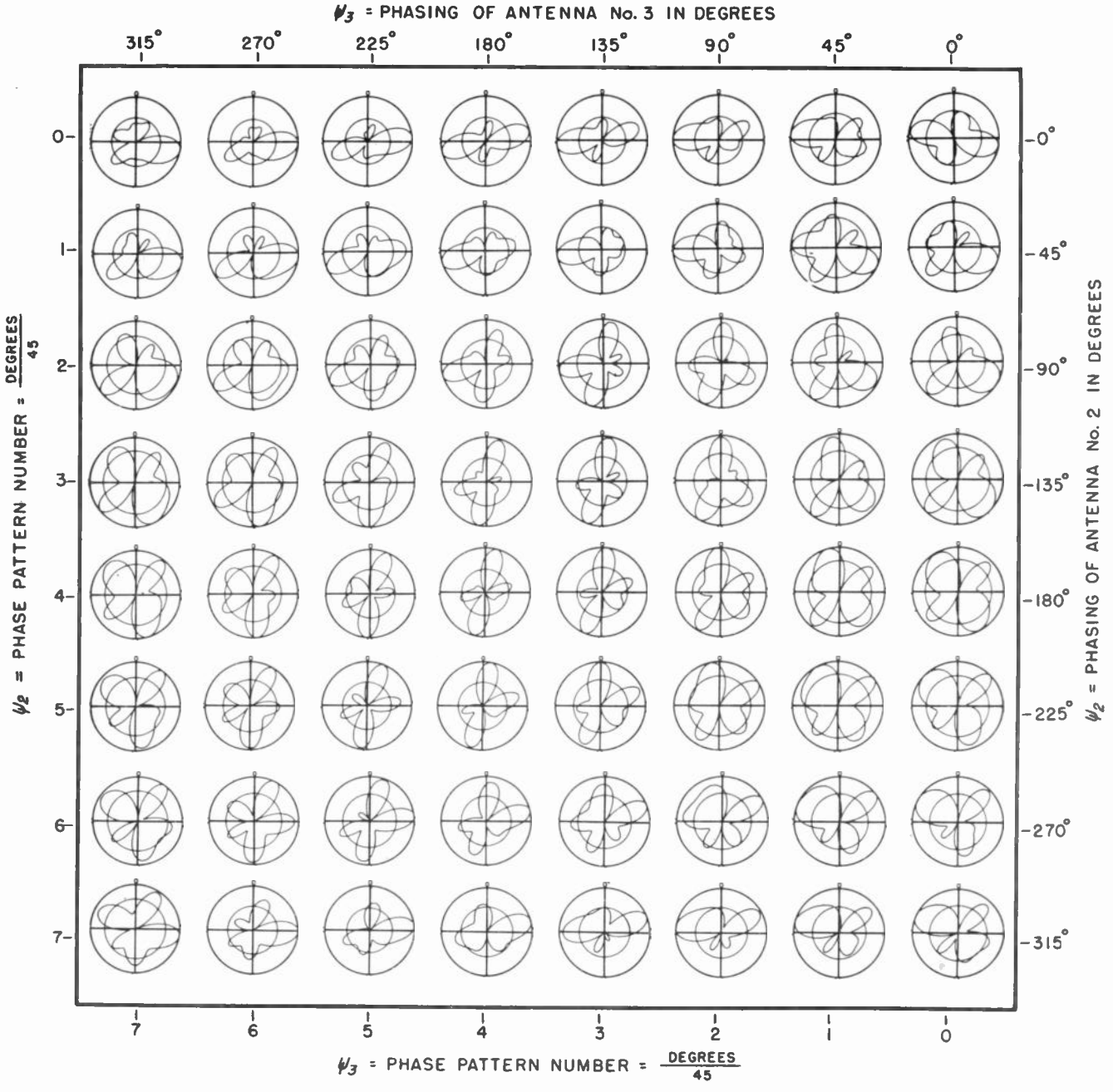


NUMBER OF ANTENNAS IN THE SYSTEM	SPACING OF NO. 2 ANTENNA IN DEGREES	PHASING OF NO.2 ANTENNA IN DEGREES	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 1 ANTENNA	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 2 ANTENNA	% RMS FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM
No.	S_2	ψ_2	E_1	E_2	E_0
2	255	75	50	50	68

PATTERN NOMENCLATURE

DIRECTIONAL ANTENNAS

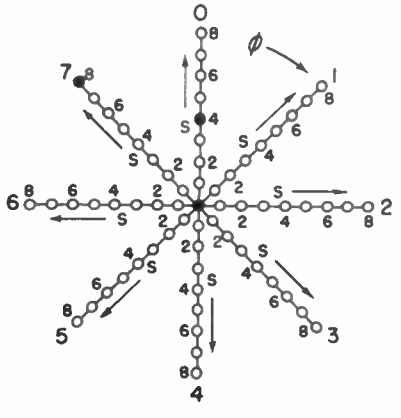
5. Sample Three Tower Patterns.



NUMBER OF ANTENNAS IN THE SYSTEM	ORIENTATION OF NO.2 ANTENNA = DEGREES/45	SPACING OF NO.2 ANTENNA = DEGREES/45	PHASING OF NO.2 ANTENNA = DEGREES/45	ORIENTATION OF NO.3 ANTENNA = DEGREES/45	SPACING OF NO.3 ANTENNA = DEGREES/45	PHASING OF NO.3 ANTENNA = DEGREES/45	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 1 ANTENNA.	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 2 ANTENNA.	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 3 ANTENNA.	% RMS FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM.
No.	ϕ_2	S_2	ψ_2	ϕ_3	S_3	ψ_3	E_1	E_2	E_3	E_0
3	0	4	0	7	8	0	31	63	24	61

LEFT HAND PATTERN NUMBER GIVES ANTENNA PLACEMENT AND PHASING DATA.

RIGHT HAND PATTERN NUMBER GIVES ANTENNA FIELD INTENSITY DATA IN PERCENT.



SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS IN THE SYSTEMATIZATION PLACEMENT CHART.

PATTERN NOMENCLATURE

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ψ_3 = PHASING OF ANTENNA No. 3 IN DEGREES

0° 45° 90° 135° 180° 225° 270° 315°

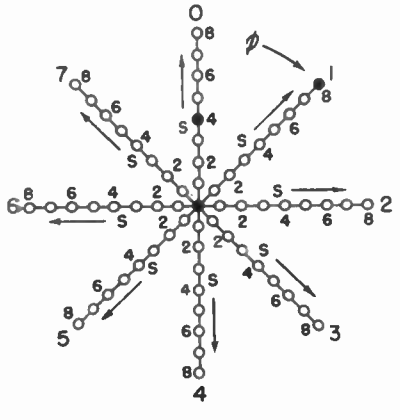
ψ_2 = PHASING OF ANTENNA No. 2 IN DEGREES

0° 45° 90° 135° 180° 225° 270° 315°

ψ_2 = PHASE PATTERN NUMBER = $\frac{\text{DEGREES}}{45}$

0 1 2 3 4 5 6 7

ψ_3 = PHASE PATTERN NUMBER = $\frac{\text{DEGREES}}{45}$



SPOTS LOCATE THE ANTENNAS FOR THIS PAGE OF PATTERNS IN THE SYSTEMATIZATION PLACEMENT CHART.

NUMBER OF ANTENNAS IN THE SYSTEM	ORIENTATION OF NO. 2 ANTENNA = $\frac{\text{DEGREES}}{45}$	SPACING OF NO. 2 ANTENNA = $\frac{\text{DEGREES}}{45}$	PHASING OF NO. 2 ANTENNA = $\frac{\text{DEGREES}}{45}$	ORIENTATION OF NO. 3 ANTENNA = $\frac{\text{DEGREES}}{45}$	SPACING OF NO. 3 ANTENNA = $\frac{\text{DEGREES}}{45}$	PHASING OF NO. 3 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.	% FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM NO. 3 ANTENNA.	% RMS FIELD INTENSITY RADIATED IN HORIZONTAL PLANE FROM ANTENNA SYSTEM.
No.	ϕ_2	S_2	ψ_2	ϕ_3	S_3	ψ_3	E_1	E_2	E_3	E_0
3	0	4	0	1	8	0	31	63	24	61

LEFT HAND PATTERN NUMBER GIVES ANTENNA PLACEMENT AND PHASING DATA.

RIGHT HAND PATTERN NUMBER GIVES ANTENNA FIELD INTENSITY DATA IN PERCENT.

PATTERN NOMENCLATURE

6. Bibliography

In this bibliography no attempt has been made to give all references dealing with the subject. The bibliography on directional antennas has been divided into various groupings so associated topics will be found together.

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General consideration of tower antennas

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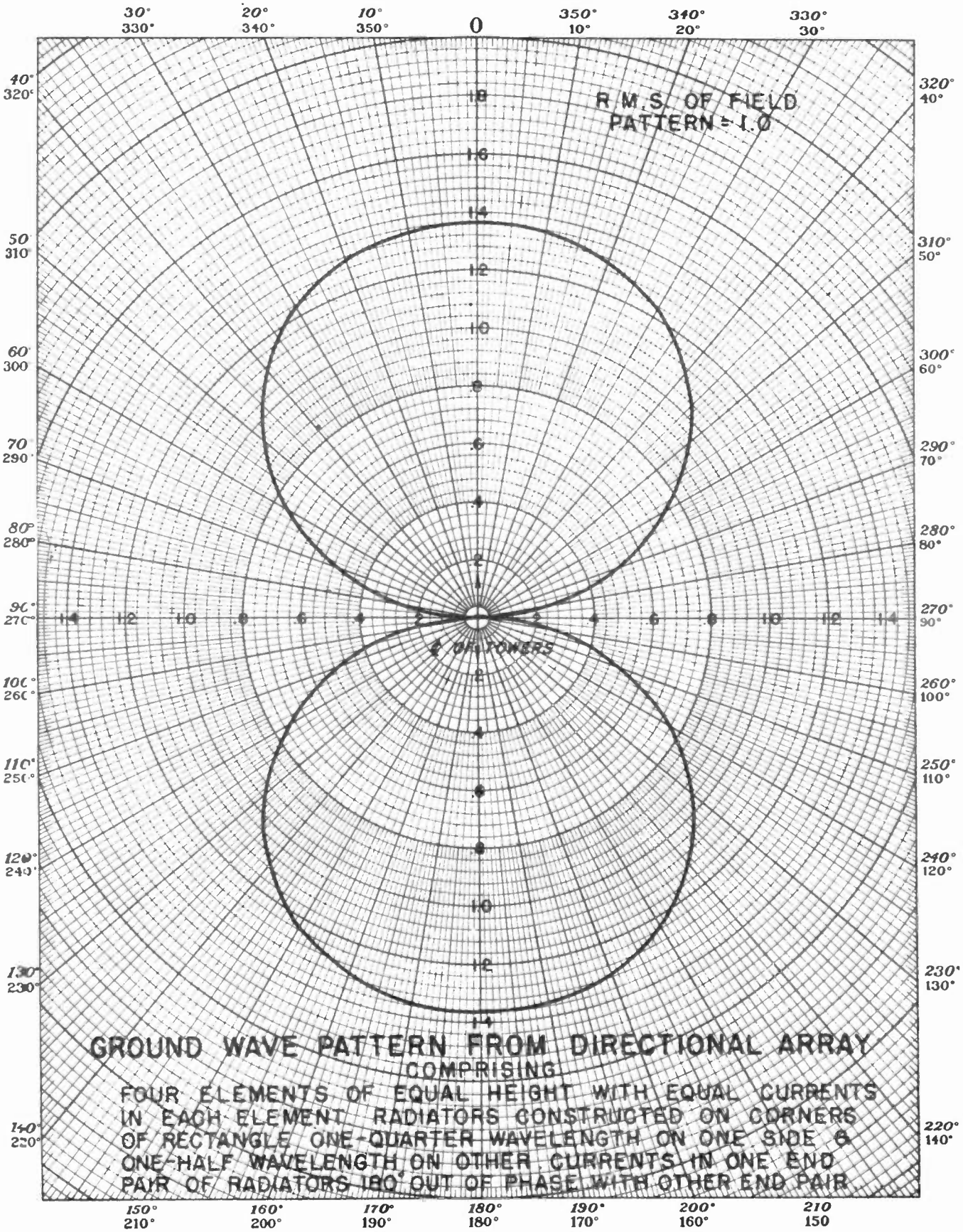
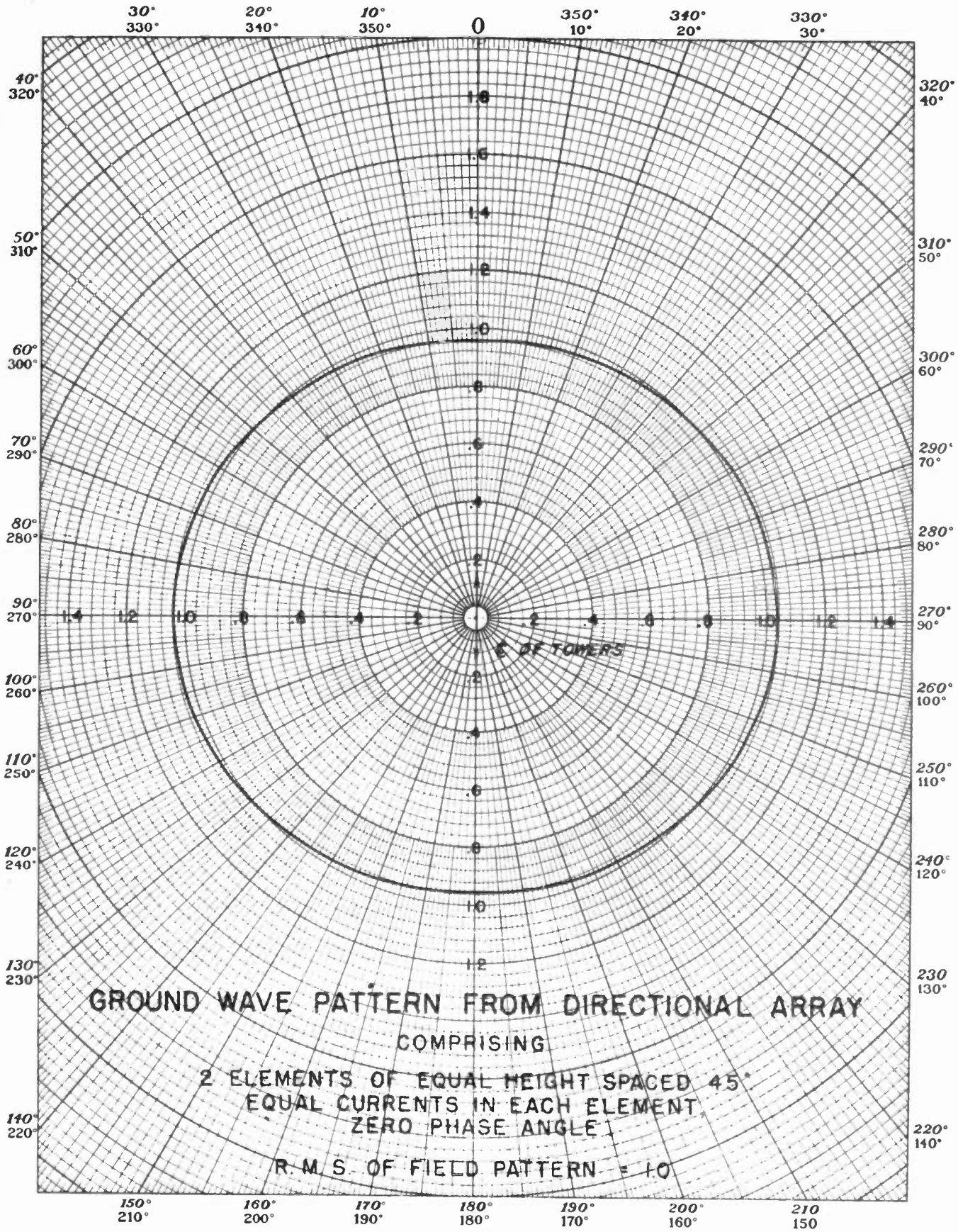


GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
FOUR ELEMENTS OF EQUAL HEIGHT WITH EQUAL CURRENTS IN EACH ELEMENT. RADIATORS CONSTRUCTED ON CORNERS OF RECTANGLE ONE-QUARTER WAVELENGTH ON ONE SIDE & ONE-HALF WAVELENGTH ON OTHER. CURRENTS IN ONE END PAIR OF RADIATORS 180° OUT OF PHASE WITH OTHER END PAIR

2.1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240° 120°
230 130°
220° 140°
150° 210°
160° 200°
170° 190°
180° 180°
190° 170°
200° 160°
210 150
1.8
1.6
1.4
1.2
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.8
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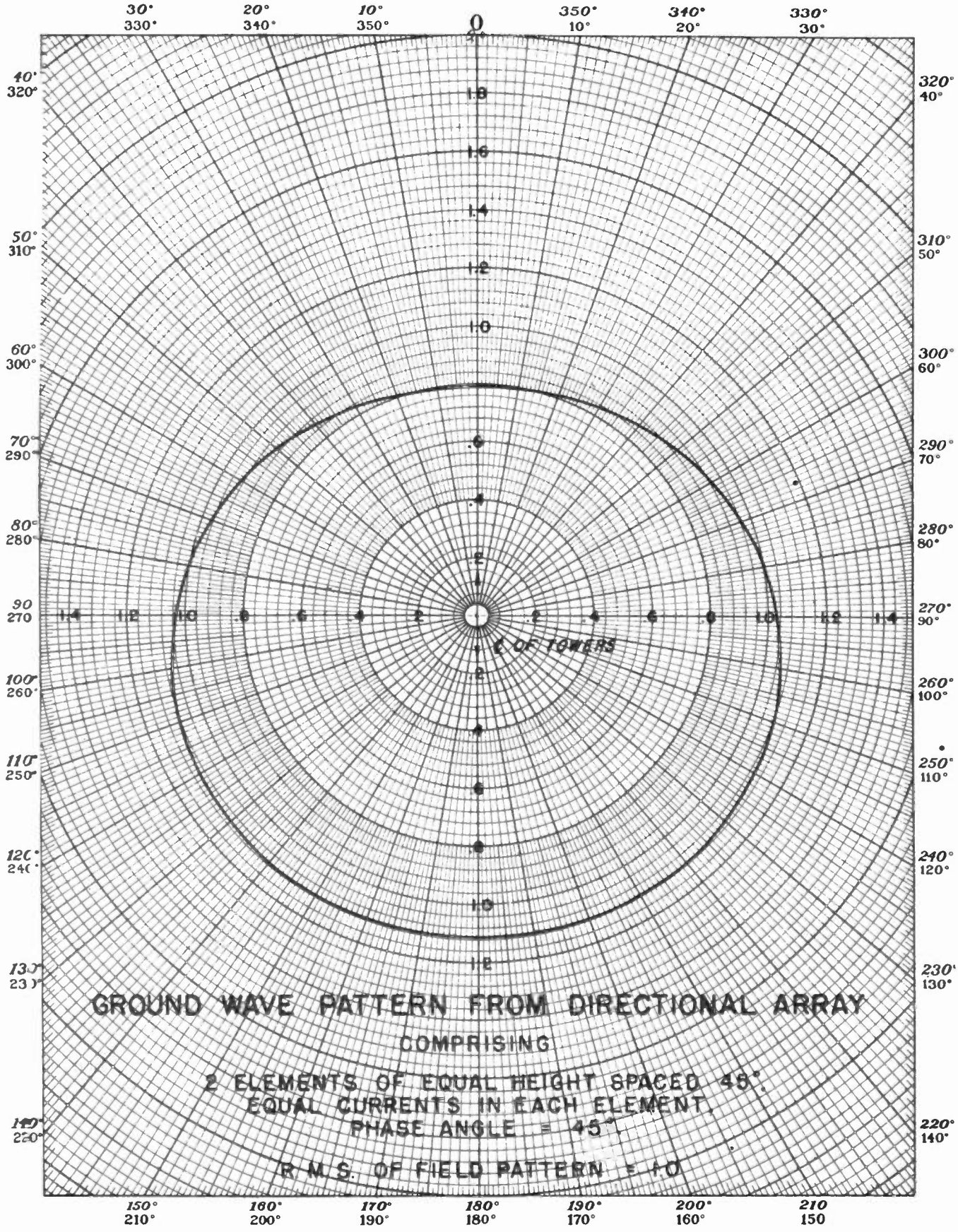
.2
℄ OF TOWERS
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 45°
EQUAL CURRENTS IN EACH ELEMENT
ZERO PHASE ANGLE
R.M.S. OF FIELD PATTERN = 1.0

2.2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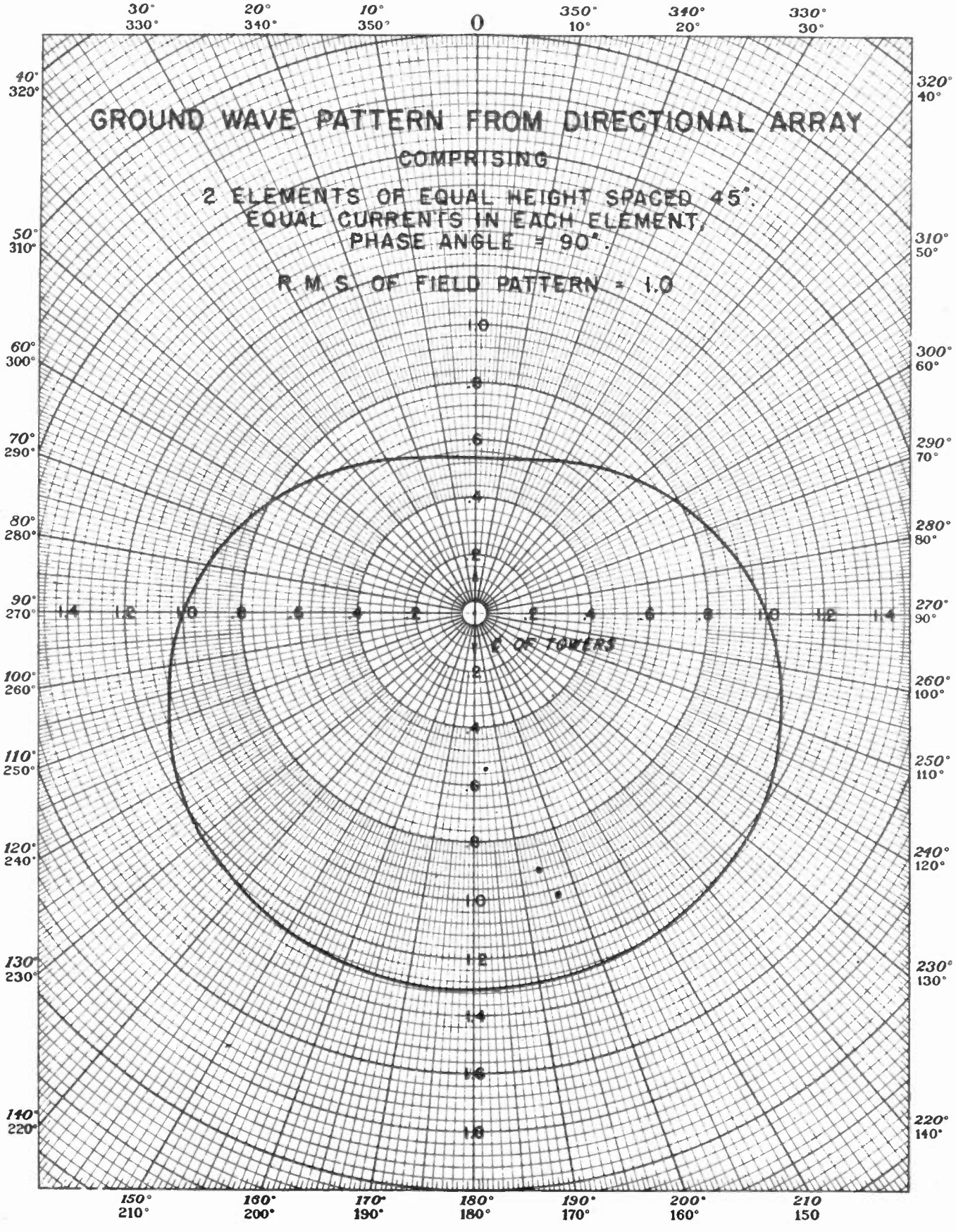
1.4 1.2 1.0 .8 .6 .4 .2 .2 .4 .6 .8 1.0 1.2 1.4
℄ OF TOWERS
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 45°.
EQUAL CURRENTS IN EACH ELEMENT.
PHASE ANGLE = 45°
R.M.S. OF FIELD PATTERN = 1.0


GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 45°.
EQUAL CURRENTS IN EACH ELEMENT.
PHASE ANGLE = 90°.
R. M. S. OF FIELD PATTERN = 1.0
E OF TOWERS
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30° 330°
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340° 20°
330° 30°
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50° 310°
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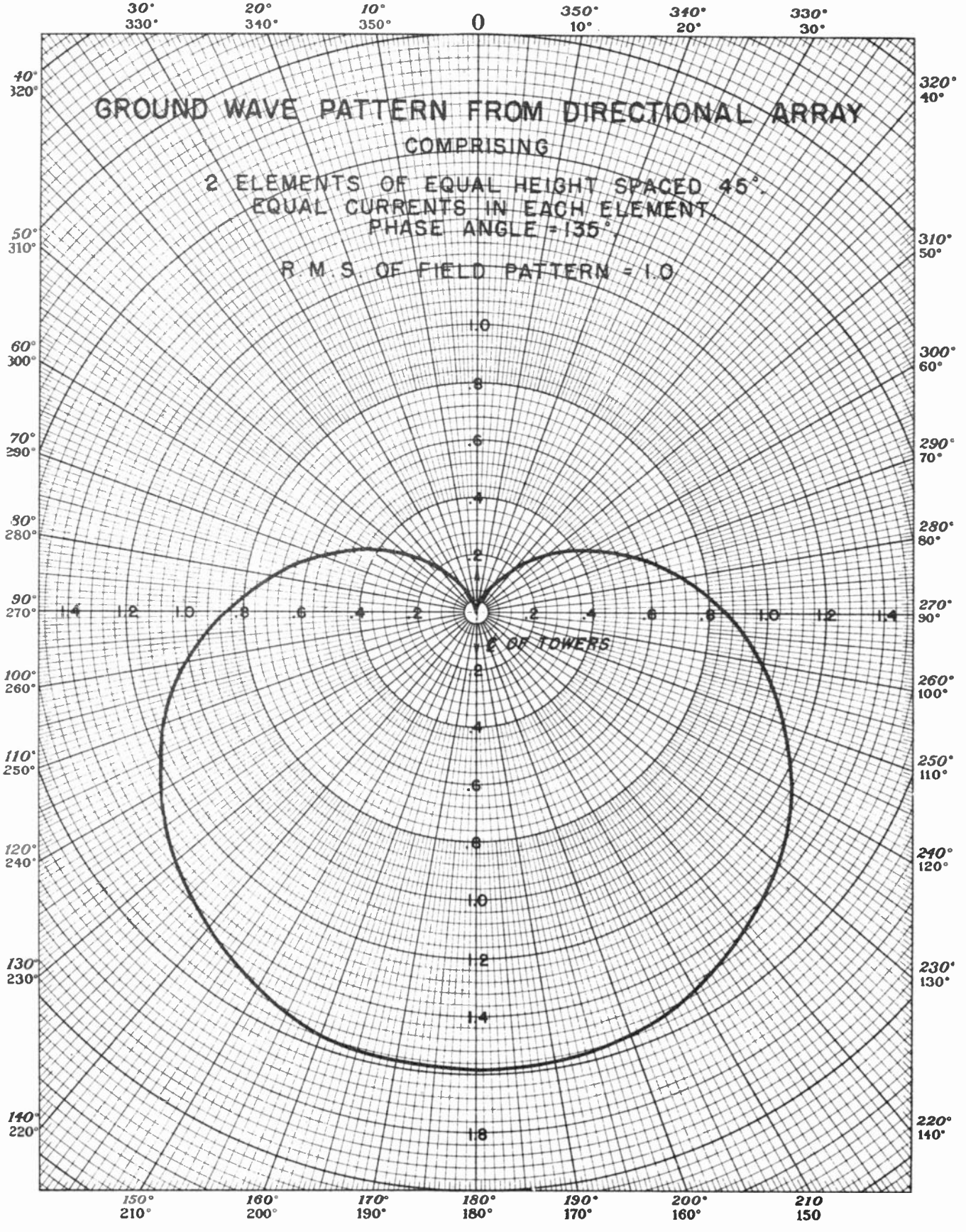
2.4


GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 45°.
EQUAL CURRENTS IN EACH ELEMENT.
PHASE ANGLE = 135°.
R.M.S. OF FIELD PATTERN = 1.0
0
30° 330°
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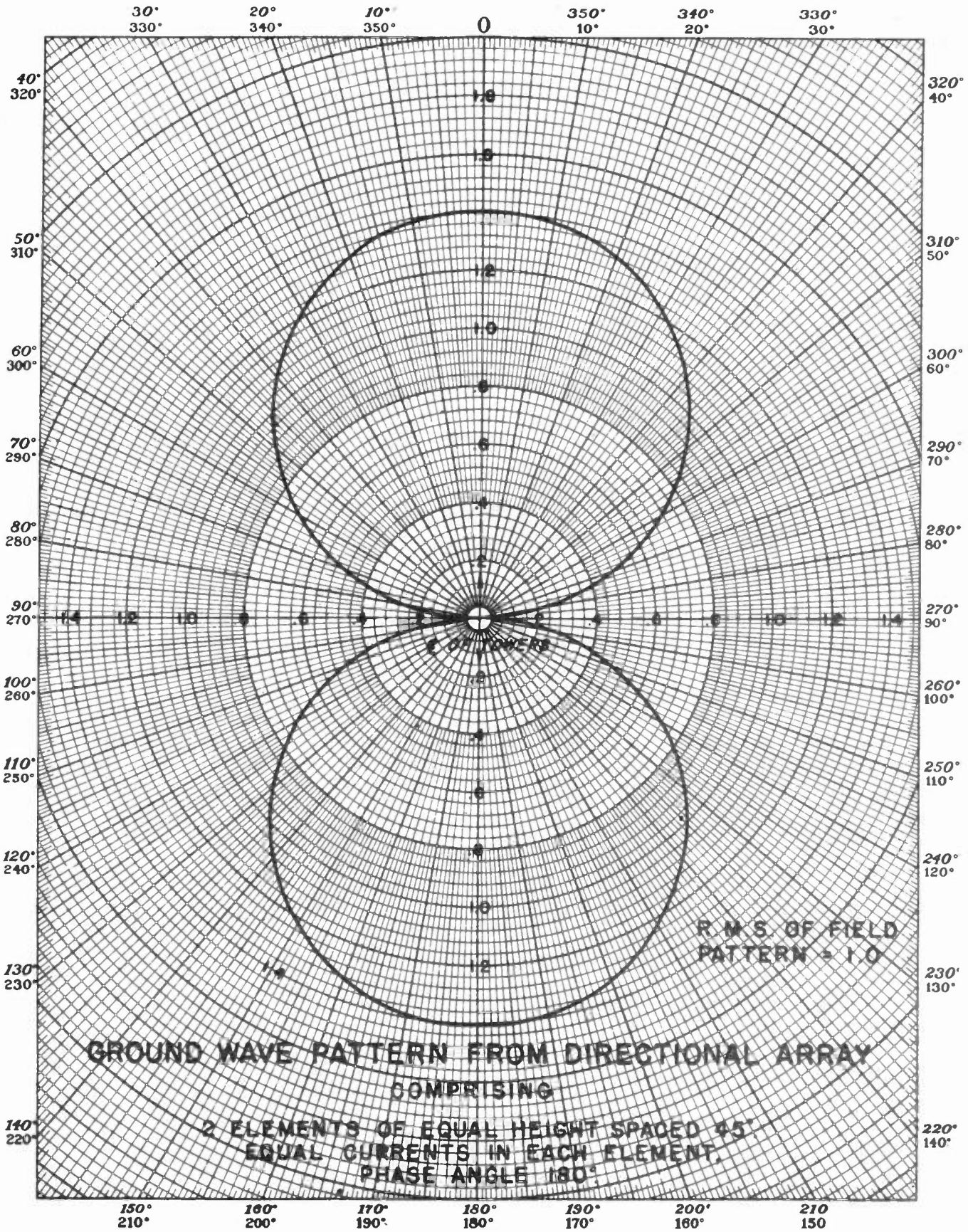
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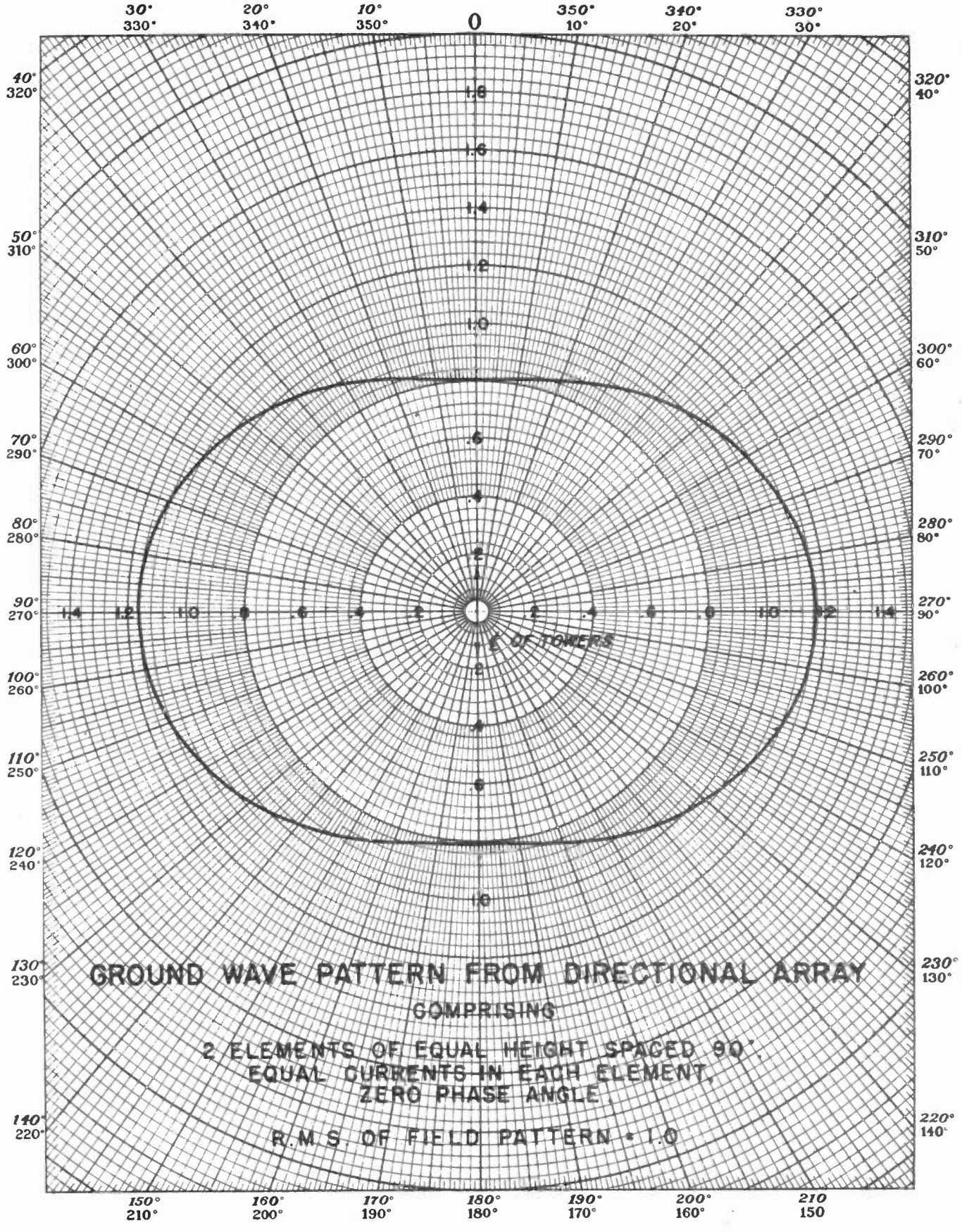
.4
.2
R.M.S. OF FIELD PATTERN = 1.0
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 45°
EQUAL CURRENTS IN EACH ELEMENT.
PHASE ANGLE 180°

2.6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℄ OF TOWERS
.2
.4
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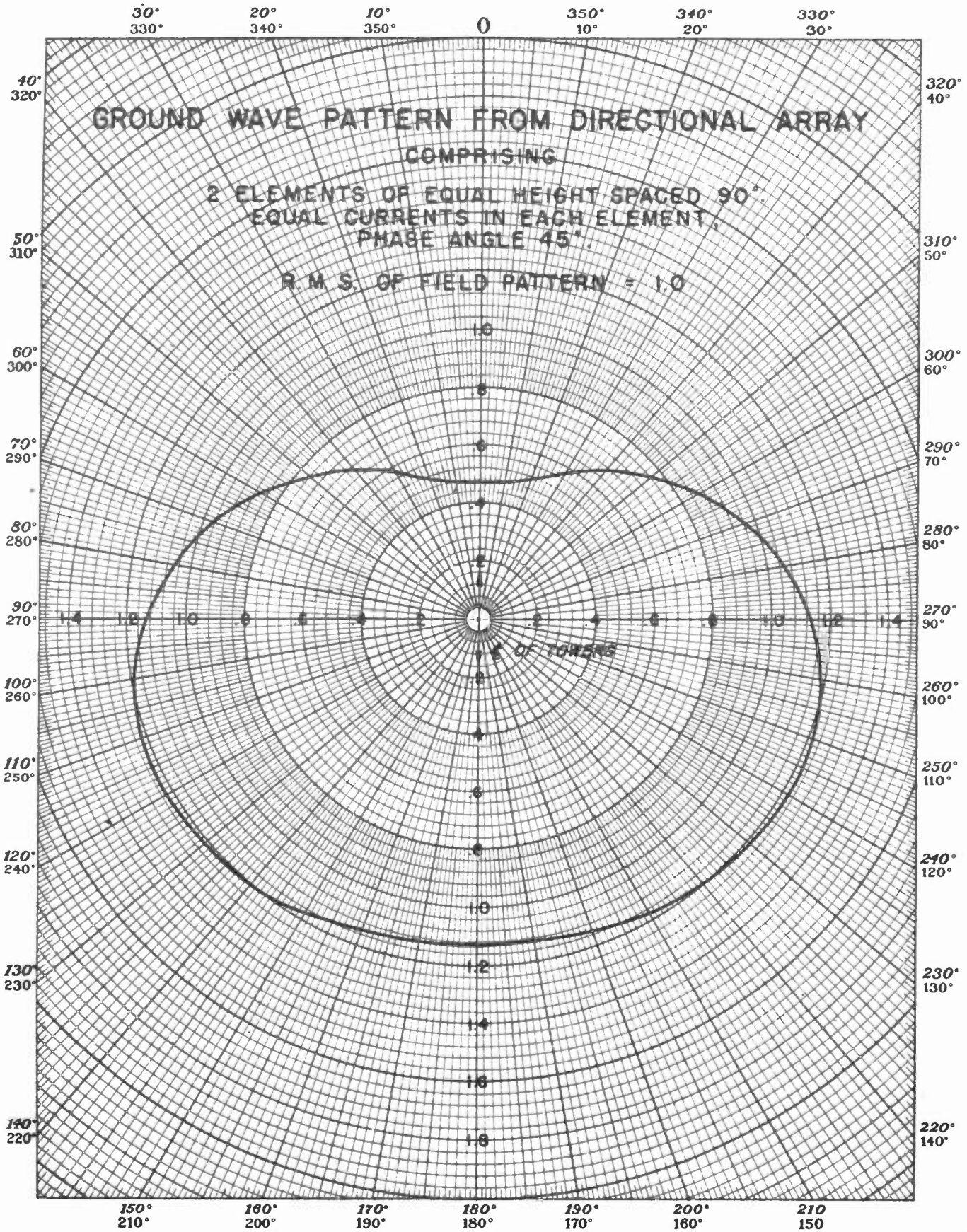
1.0
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 90°.
EQUAL CURRENTS IN EACH ELEMENT,
ZERO PHASE ANGLE.
R.M.S. OF FIELD PATTERN = 1.0


GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 90°.
EQUAL CURRENTS IN EACH ELEMENT,
PHASE ANGLE 45°.
R.M.S. OF FIELD PATTERN = 1.0
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30° 330°
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190° 170°
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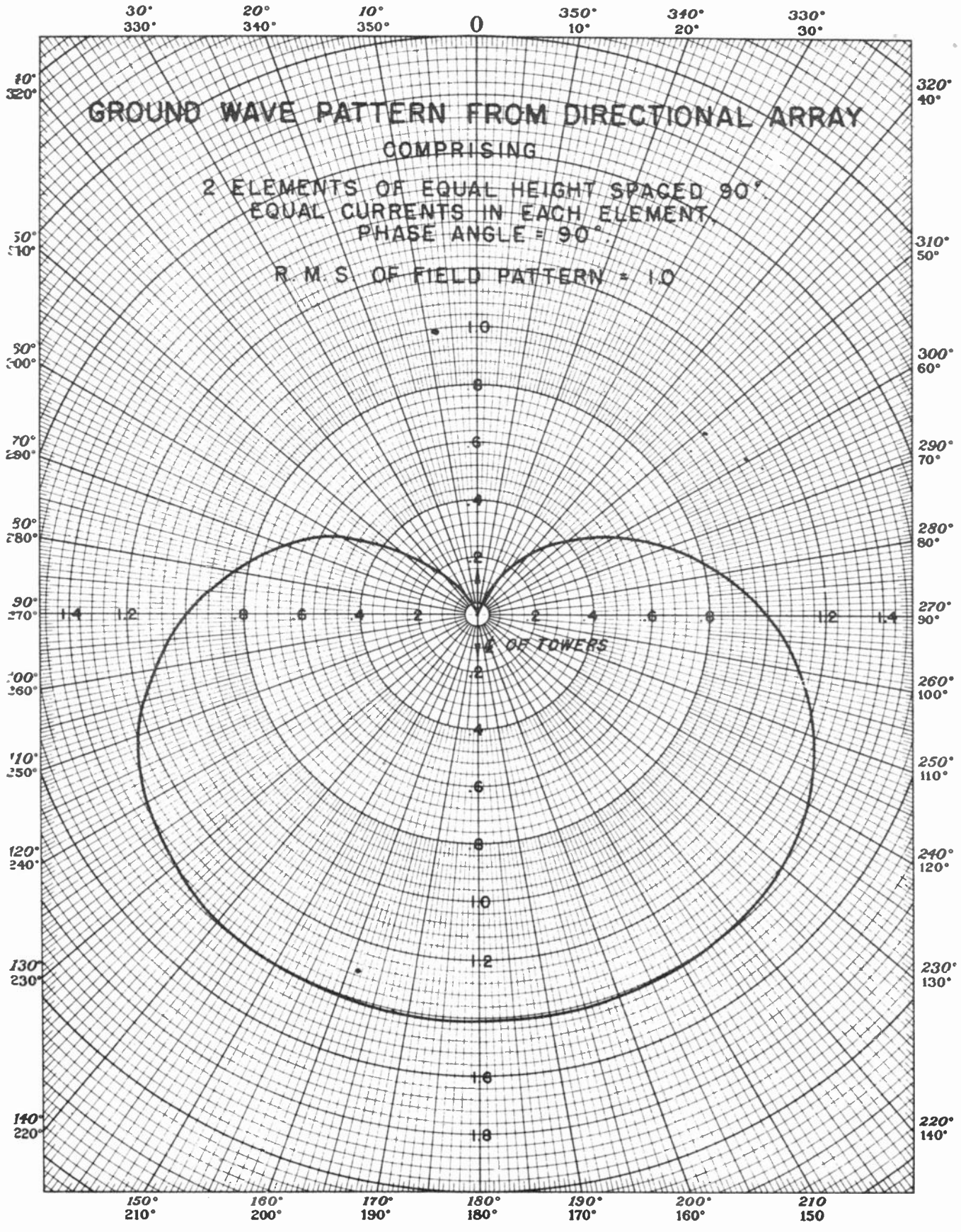
.1
OF TOWERS

2.8


GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 90°.
EQUAL CURRENTS IN EACH ELEMENT.
PHASE ANGLE = 90°.
R.M.S. OF FIELD PATTERN = 1.0
1/4 OF TOWERS
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10° 350°
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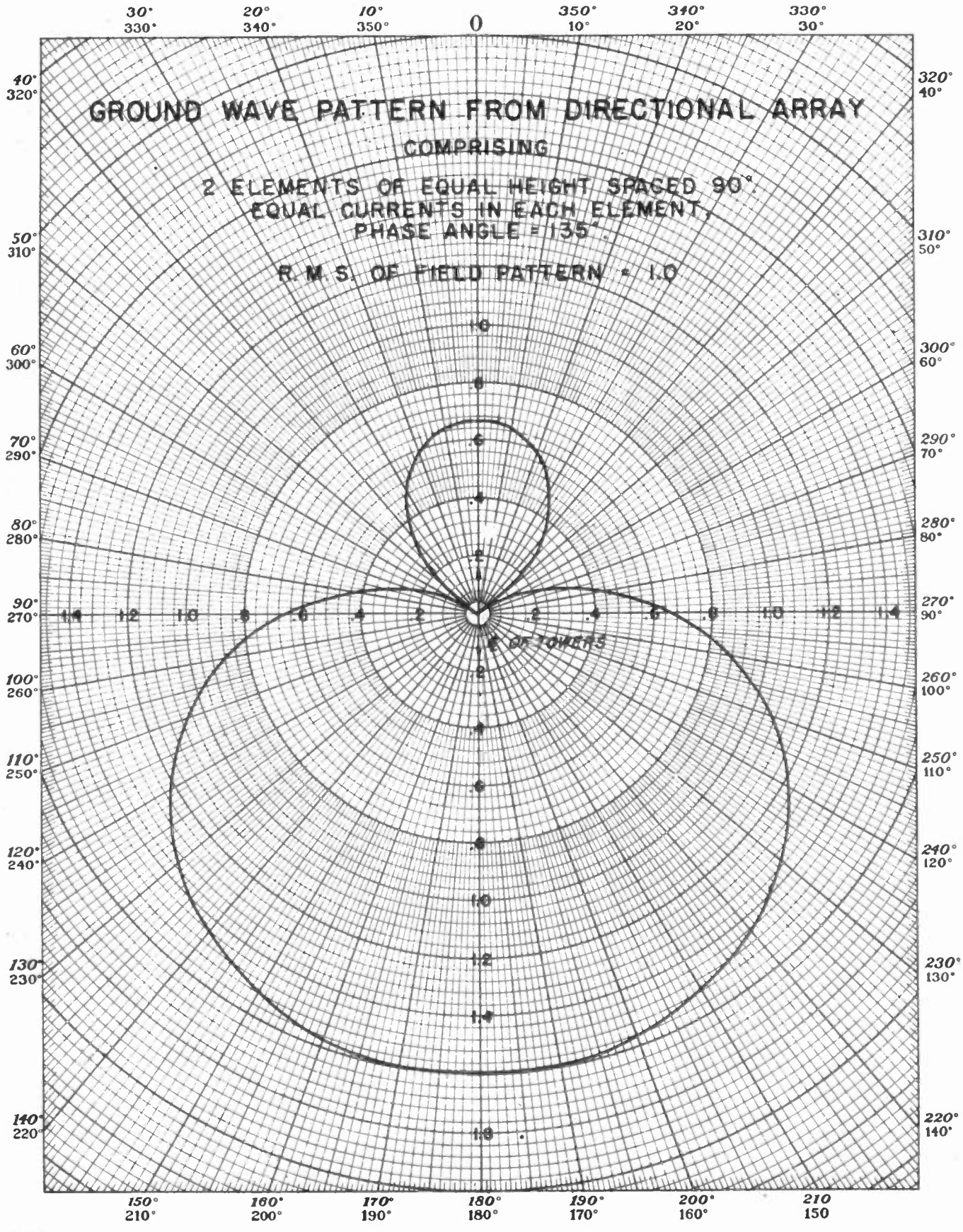
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 90°.
EQUAL CURRENTS IN EACH ELEMENT,
PHASE ANGLE = 135°.
R. M. S. OF FIELD PATTERN = 1.0
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30° 330°
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340° 20°
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40° 320°
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240° 120°
230° 130°
220° 140°
150° 210°
160° 200°
170° 190°
180° 180°
190° 170°
200° 160°
210 150
1.6
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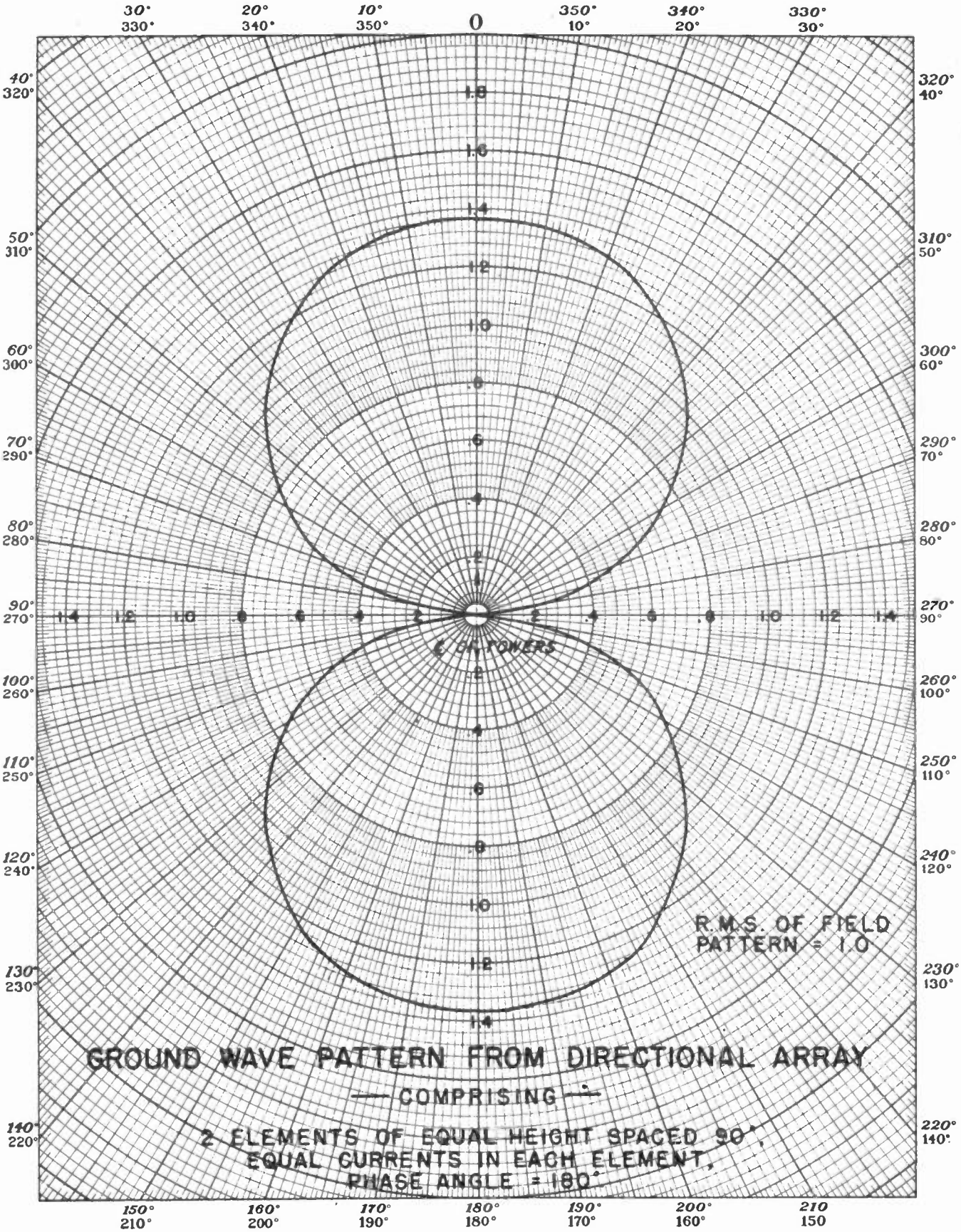
.2
2 OF TOWERS

2.10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160° 200°
170° 190°
180° 180°
190° 170°
200° 160°
210 150
1.8
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1.4
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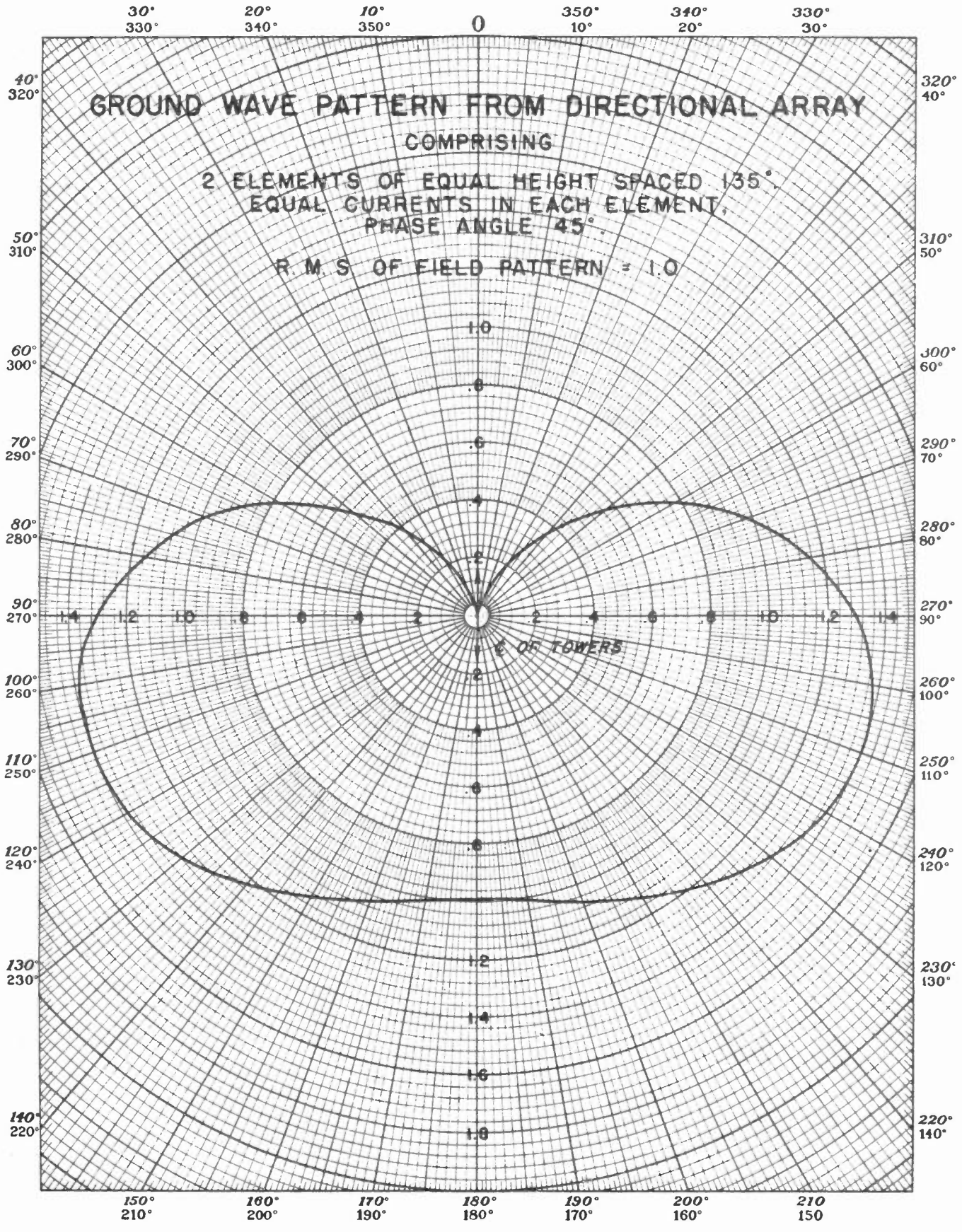
E ON TOWERS
R.M.S. OF FIELD PATTERN = 1.0
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
— COMPRISING —
2 ELEMENTS OF EQUAL HEIGHT SPACED 90°,
EQUAL CURRENTS IN EACH ELEMENT,
PHASE ANGLE = 180°


GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 135°,
EQUAL CURRENTS IN EACH ELEMENT,
PHASE ANGLE 45°.
R M S OF FIELD PATTERN = 1.0
1.0
.8
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℄ OF TOWERS
30° 330°
20° 340°
10° 350°
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350° 10°
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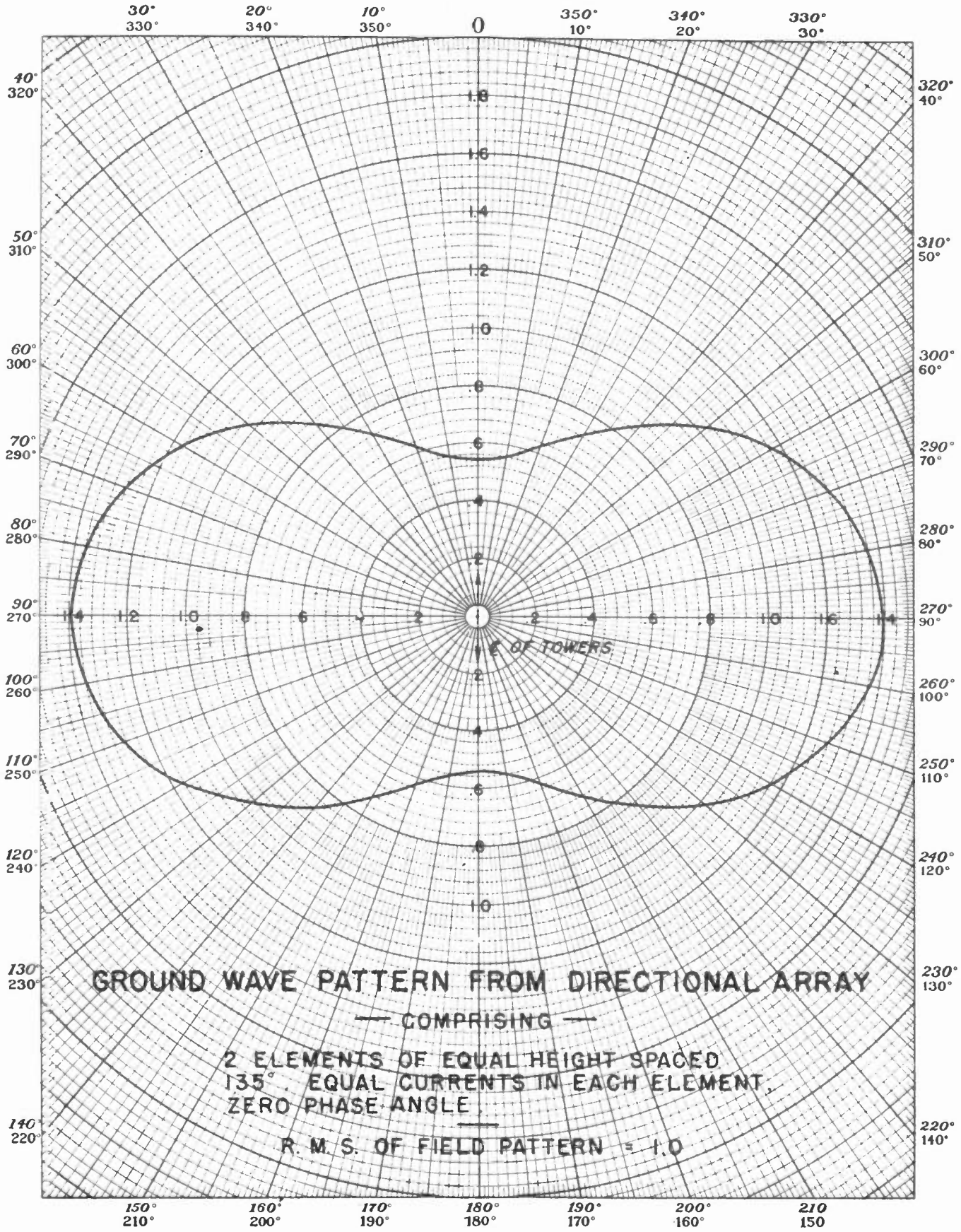
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200° 160°
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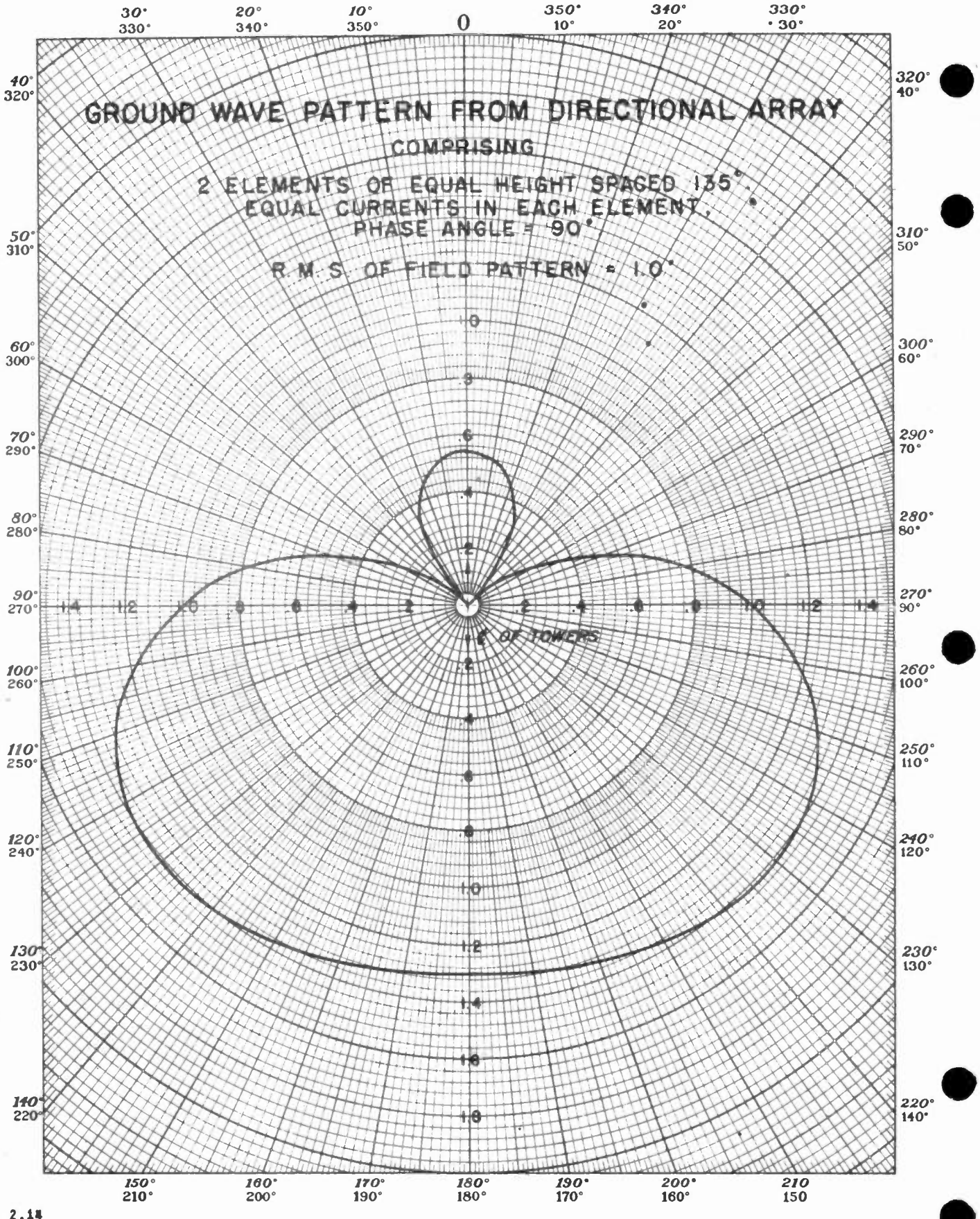
℄ OF TOWERS
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
— COMPRISING —
2 ELEMENTS OF EQUAL HEIGHT SPACED
135°. EQUAL CURRENTS IN EACH ELEMENT,
ZERO PHASE ANGLE.
R. M. S. OF FIELD PATTERN = 1.0

2.13


GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 135°.
EQUAL CURRENTS IN EACH ELEMENT.
PHASE ANGLE = 90°
R.M.S. OF FIELD PATTERN = 1.0°
0
30° 330°
20° 340°
10° 350°
350° 10°
340° 20°
330° 30°
40° 320°
50° 310°
60° 300°
70° 290°
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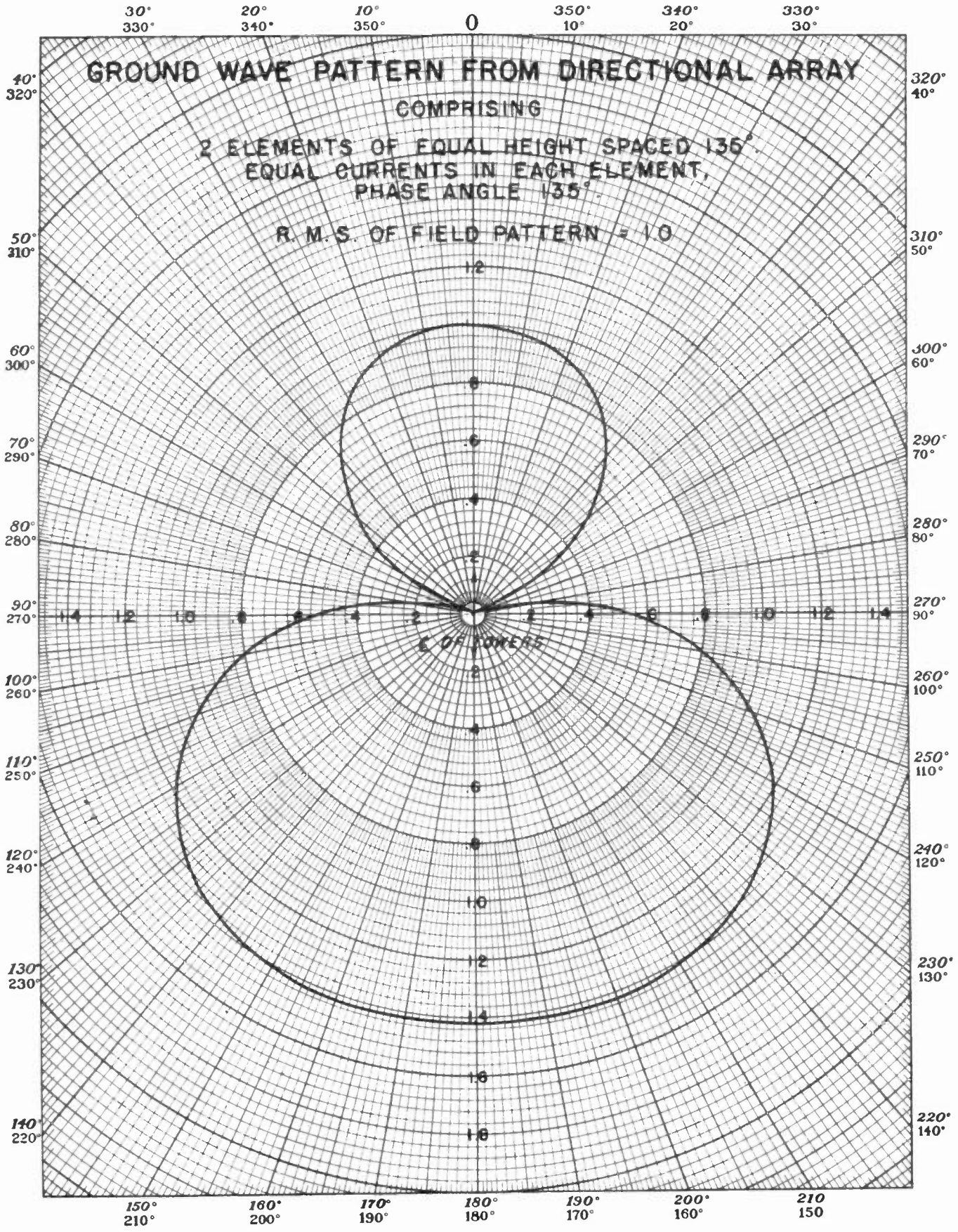
1.8
C OF TOWERS

2.14


GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 135°.
EQUAL CURRENTS IN EACH ELEMENT,
PHASE ANGLE 135°.
R. M. S. OF FIELD PATTERN = 1.0
E OF TOWERS
0
30° 330°
20° 340°
10° 350°
350° 10°
340° 20°
330° 30°
40° 320°
50° 310°
60° 300°
70° 290°
80° 280°
90° 270°
100° 260°
110° 250°
120° 240°
130° 230°
140° 220°
320° 40°
310° 50°
300° 60°
290° 70°
280° 80°
270° 90°
260° 100°
250° 110°
240° 120°
230° 130°
220° 140°
150° 210°
160° 200°
170° 190°
180° 180°
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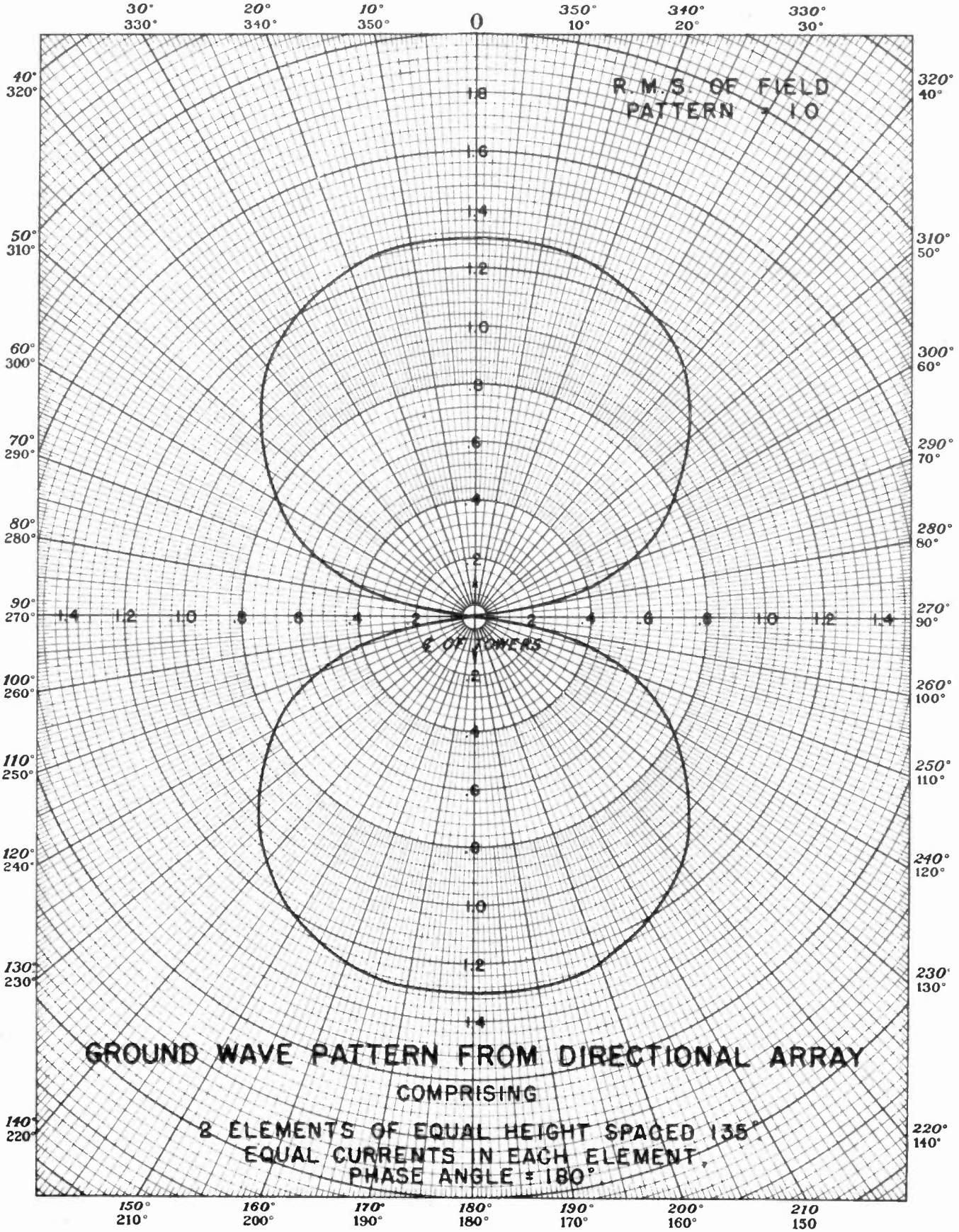
200° 160°
210 150
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8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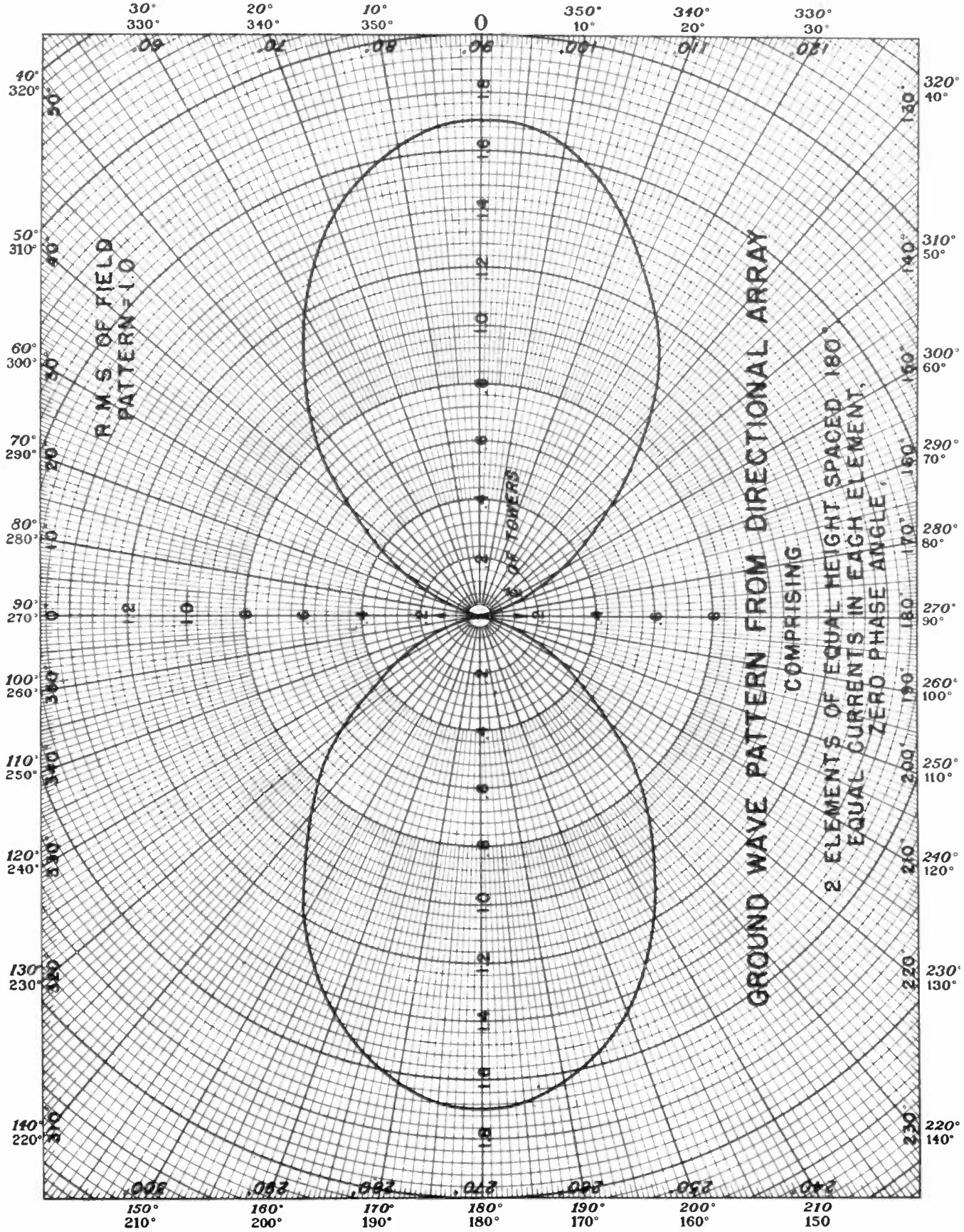
℄ OF TOWERS
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 135°
EQUAL CURRENTS IN EACH ELEMENT
PHASE ANGLE ± 180°

2.16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COMPRISING
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EQUAL CURRENTS IN EACH ELEMENT,
ZERO PHASE ANGLE
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PATTERN=1.0
OF TOWERS
0
30° 330°
20° 340°
10° 350°
350° 10°
340° 20°
330° 30°
40° 320°
50° 310°
60° 300°
70° 290°
80° 280°
90° 270°
100° 260°
110° 250°
120° 240°
130° 230°
140° 220°
150° 210°
160° 200°
170° 190°
180° 180°
190° 170°
200° 160°
210 150
320° 40°
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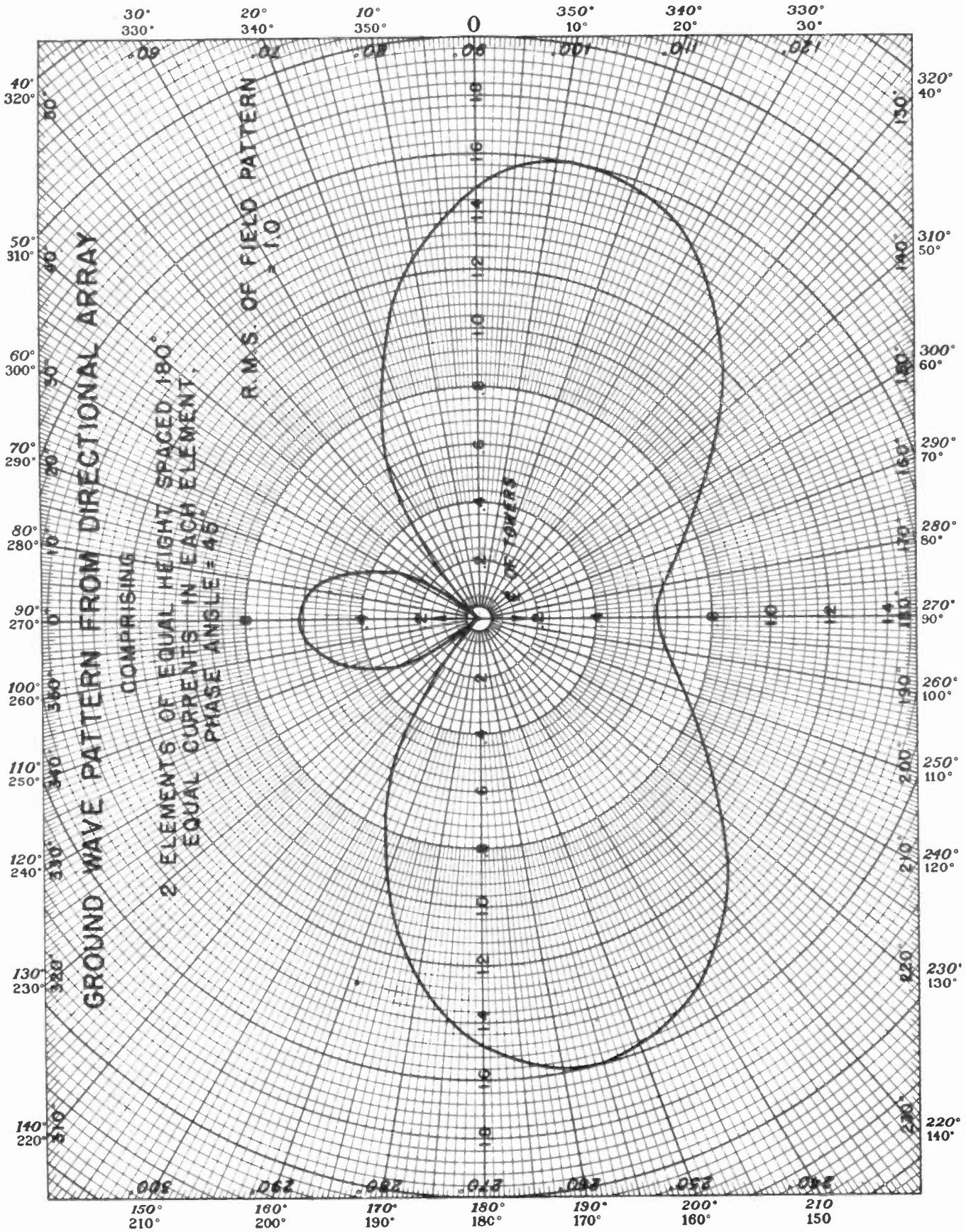
230° 130°
220° 140°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COMPRISING
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EQUAL CURRENTS IN EACH ELEMENT
PHASE ANGLE = 45°
R.M.S. OF FIELD PATTERN
= 1.0
OF TOWERS
0
30° 330°
20° 340°
10° 350°
350° 10°
340° 20°
330° 30°
40° 320°
50° 310°
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90° 270°
100° 260°
110° 250°
120° 240°
130° 230°
140° 220°
150° 210°
160° 200°
170° 190°
180° 180°
190° 170°
200° 160°
210 150
320° 40°
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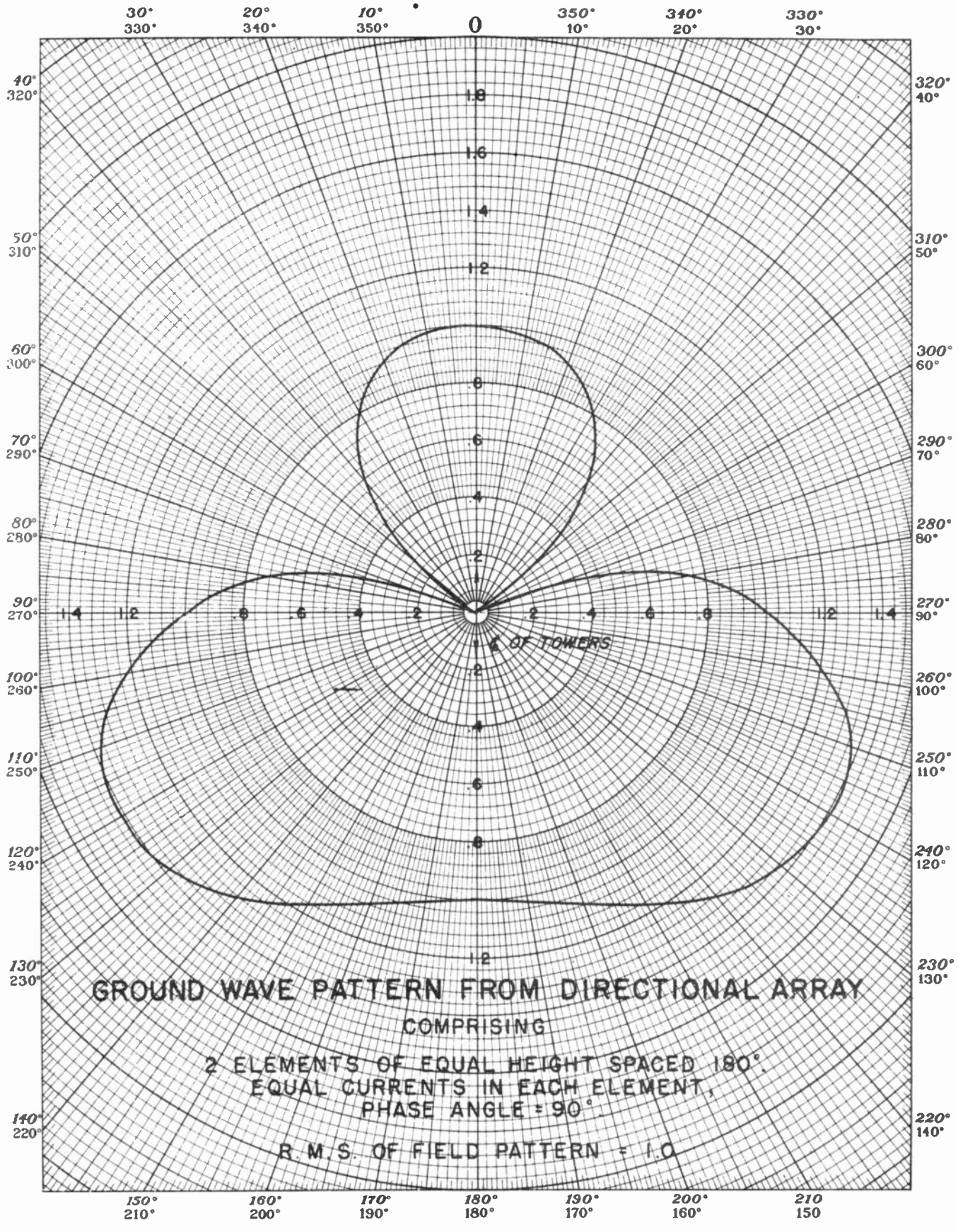
2.18


0
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20° 340°
10° 350°
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110° 250°
120° 240°
130° 230°
140° 220°
320° 40°
310° 50°
300° 60°
290° 70°
280° 80°
270° 90°
260° 100°
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240° 120°
230° 130°
220° 140°
150° 210°
160° 200°
170° 190°
180° 180°
190° 170°
200° 160°
210 150
1.8
1.6
1.4
1.2
.8
.6
.4
.2
1.4 1.2 .8 .6 .4 .2 .2 .4 .6 .8 1.2 1.4
1.2
.2
.4
.6
.8
1.2
OF TOWERS
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
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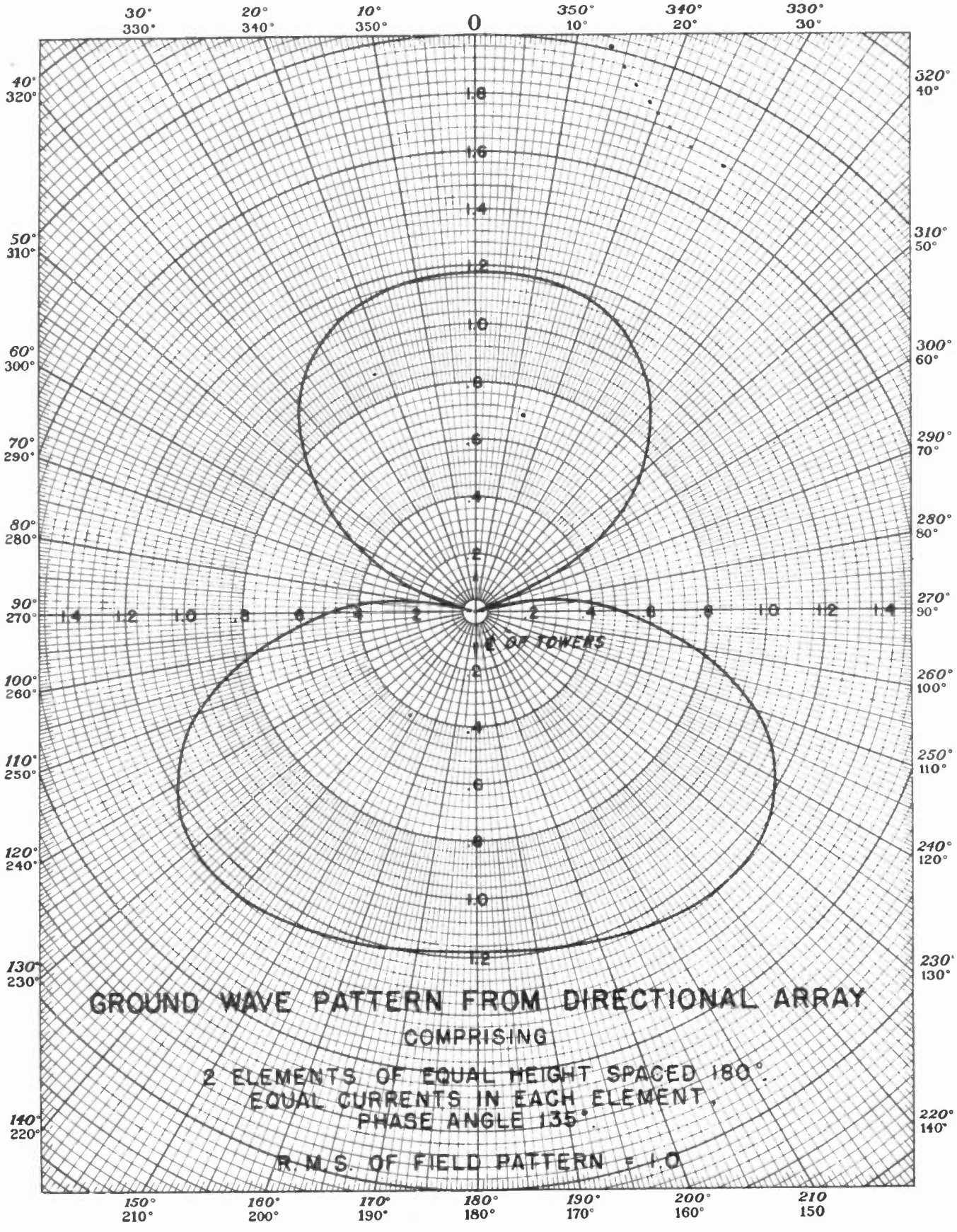
EQUAL CURRENTS IN EACH ELEMENT.
PHASE ANGLE = 90°.
R.M.S. OF FIELD PATTERN = 1.0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20° 340°
10° 350°
350° 10°
340° 20°
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40° 320°
50° 310°
60° 300°
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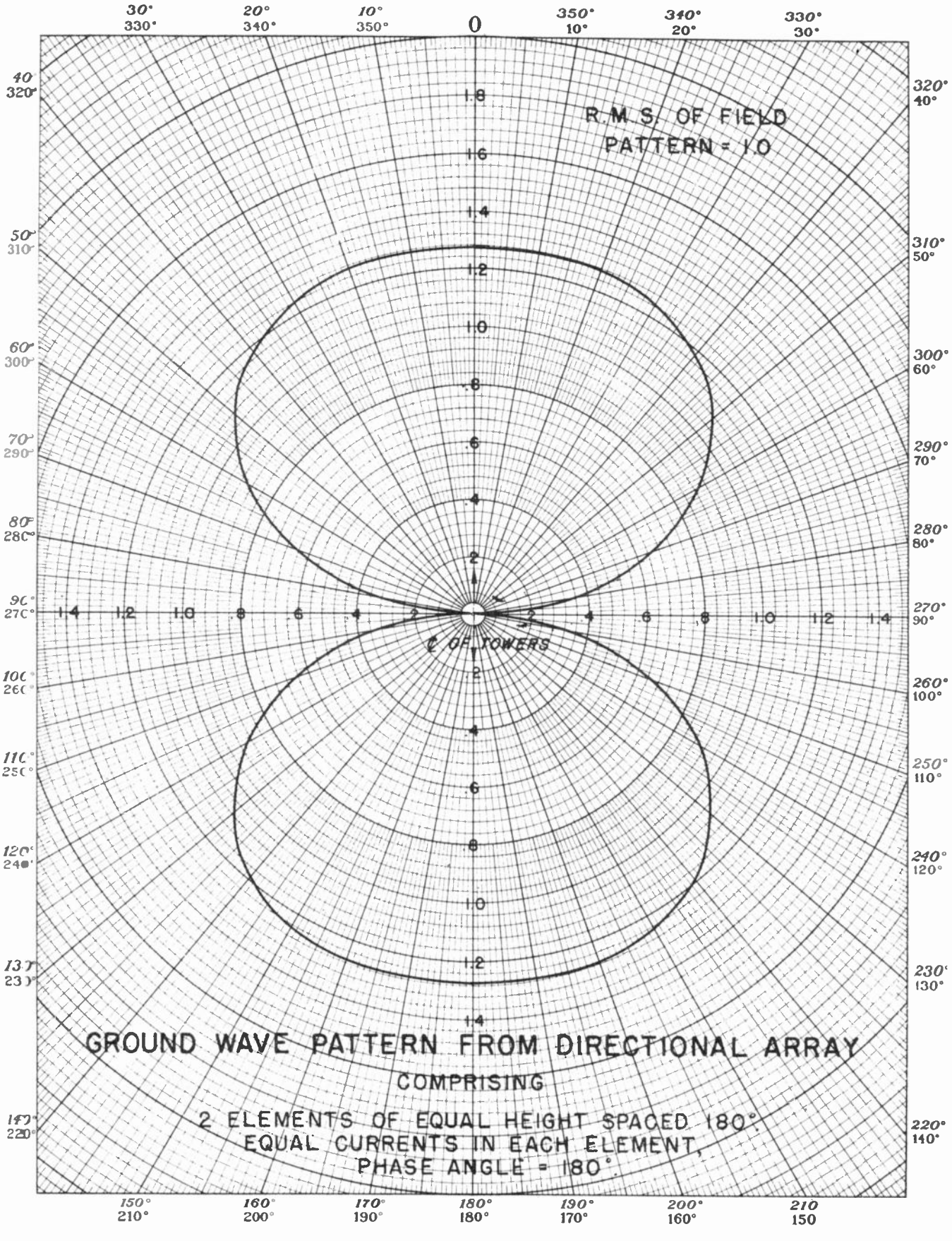
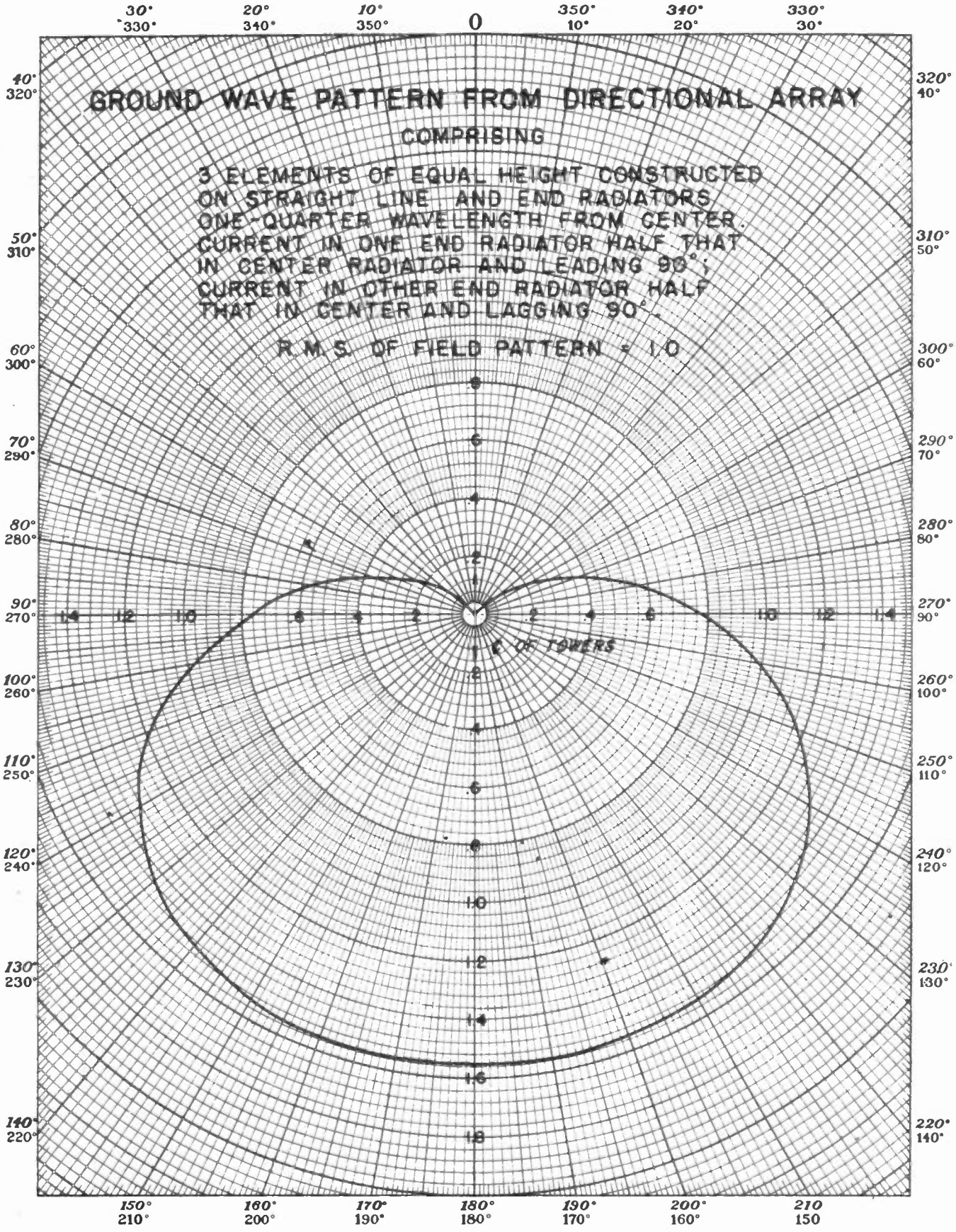
80° 280°
90° 270°
100° 260°
110° 250°
120° 240°
130° 230°
140° 220°
320° 40°
310° 50°
300° 60°
290° 70°
280° 80°
270° 90°
260° 100°
250° 110°
240° 120°
230° 130°
220° 140°
150° 210°
160° 200°
170° 190°
180° 180°
190° 170°
200° 160°
210 150
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
℄ OF TOWERS
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 180°.
EQUAL CURRENTS IN EACH ELEMENT,
PHASE ANGLE 135°.
R.M.S. OF FIELD PATTERN = 1.0


R.M.S. OF FIELD PATTERN = 1.0
℄ OF TOWERS
GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
2 ELEMENTS OF EQUAL HEIGHT SPACED 180°
EQUAL CURRENTS IN EACH ELEMENT,
PHASE ANGLE = 180°


GROUND WAVE PATTERN FROM DIRECTIONAL ARRAY
COMPRISING
3 ELEMENTS OF EQUAL HEIGHT CONSTRUCTED ON STRAIGHT LINE AND END RADIATORS ONE-QUARTER WAVELENGTH FROM CENTER. CURRENT IN ONE END RADIATOR HALF THAT IN CENTER RADIATOR AND LEADING 90°; CURRENT IN OTHER END RADIATOR HALF THAT IN CENTER AND LAGGING 90°.
R.M.S. OF FIELD PATTERN = 1.0
℄ OF TOWERS
0
30° 330°
20° 340°
10° 350°
350° 10°
340° 20°
330° 30°
40° 320°
50° 310°
60° 300°
70° 290°
80° 280°
90° 270°
100° 260°
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120° 240°
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300° 60°
290° 70°
280° 80°
270° 90°
260° 100°
250° 110°
240° 120°
230° 130°
220° 140°
150° 210°
160° 200°
170° 190°
180° 180°
190° 170°
200° 160°
210 150

2.22

RECOMMENDED PRACTICE FOR FIELD INTENSITY SURVEYS FOR THE PURPOSE OF ESTIMATING FIELD STRENGTH CONTOURS OF A BROADCAST STATION IN THE REGULAR BROADCAST BAND

I. INTRODUCTION

Thru the medium of field measurements we determine the *potential coverage* of a broadcast station. In order that the interpretation and presentation of such measurements might be such that the work of one engineer might readily be compared with that of another, and the claims of one station compared with those of another, it is desirable to have a uniform practice of procedure for doing this work. It is hoped that the "Recommended Practice For Field Intensity Surveys" will be adopted in order that uniformity of measurements and of interpreting them will be achieved.

A field strength survey, in order to be reliable, should be made by an engineer who has had a substantial amount of experience in making field measurements. The following "Recommended Practice For Field Intensity Surveys" is written as a guide for those who already know how to take properly field measurements, and interpret the results.

The *potential service area* of a broadcast station is that area in which the station can be generally received free and clear of objectionable interference. This *potential service area* is composed of two parts; the *primary area* over which the service can be considered as being highly satisfactory, and the *secondary area* over which the conditions of good service obtained partially. The term *potential service area* deals with the ability of the listener in an area to receive a given station and does not take into account program considerations and the presence of other usable signals.

The *potential service area* of a station is limited by the ratio of the strength of the desired signal to that of the undesired noise or interference from other stations. Satisfactory service can be rendered only when the signal is substantially stronger than the other electrical disturbances that cause "noise." Although the noise level between points close together may vary over a wide range, it is common practice to take certain values of signal as satisfactory to overcome the noise in certain types of localities.

The values of signals recommended for satisfactory service given in "Standards of Good Engineering Practice of the Federal Communications Commission" which became effective on August 1, 1939, are as follows:

TABLE I

Type of Territory	Recommended Field Strength Ground Wave
City Business or Factory Areas	*10 to 50 milli-volts per meter*
City Residential Areas	*2 to 10*
Rural-All Areas During Winter or Northern Areas During Summer	*0.1 to 0.5*
Rural-Southern Areas During Summer	*0.25 to 1.0*

TABLE II

SIGNALS REQUIRED IN TOWNS

Population	Field Intensity Ground Wave
Up to 2,500	*0.5 milli-volts per meter*
2,500 to 10,000	*2.0*
10,000 and up	*Values in Table I*

The values given in Tables I and II are based on an absence of objectionable fading either in changing intensity or selective fading, the usual noise level in the area and an absence of limiting interference from other broadcast stations.

In populated areas it may be found that the field strength will vary greatly; the field on one side of a street may be many times that on the other. It may sometimes vary to as great an extent in the country, where there are obstructions to radio waves, such as metal structures, wire lines, etc. In the open country the field strength may also vary on account of hills, rivers, variations in the conductivity of the ground, etc., but in these cases the variations are comparatively small, being seldom greater than 2 to 1 (or 6 db) from the general average. A map showing the field contours of a station is intended to indicate the average field at sites free from obstructions. *Each contour is a closed curve traversing points at which the average field at such open sites is of the same intensity.* The contours showing the limits of the various service areas represent an average distance from the station, for the service indicated, and it should be kept in mind however, that some listeners inside a certain indicated area will not receive that service and some listeners outside the area will receive it.

The accuracy of a contour depends, to a large extent, on the proper selection of sites at which measurements are made in order to obtain a true "average" value. There are several possible ways of selecting sites. All these ways would give the same results, if a sufficiently large number of measurements were taken. Since, in order to keep the cost of a survey down to a reasonable amount, the number of measurements made must be limited, it is desirable, in order to compare different surveys with one another, to use as far as possible, the same general methods. A uniform procedure such as that described below, is therefore, desirable.

One of the most important factors in the proper measurement of the field contours of a station is the personnel, not only in making the measurements and selecting the sites, but also in interpreting the results. *An important principle of such interpretations is that all deductions should be based on a sufficiently large number of measurements for the "average" to be reasonably accurate.* For instance, substantial and sudden variations of a contour should not be based on a few measurements, but should be supported by a substantial number of measurements. In the case of a directional antenna, comparatively abrupt variations of the field pattern may be found. In this case fewer measurements need be made to accept such variations as true, if they are supported by theoretical calculations based on the design of the antenna, then if no apparent or calculable reason could be found.

The accuracy of field measuring work is affected by the number of measurements made, the usual errors in measuring distances and directions and in locating sites on maps, variations in transmitting antenna current, errors in plotting the measurements, errors in drawing an average curve thru the plotted points, errors in transposing the results to a map, errors in the measuring equipment and personal errors of the observer. The equipment and personal errors are somewhat greater in the field than they would be if the measurements were made in the laboratory, so that some allowance must be given over the accuracy obtainable in the laboratory with the same equipment.

II. RECOMMENDED PROCEDURE FOR ESTIMATING AVERAGE DAYTIME CONTOURS

1. Accuracy of Field Set

The field set used should be accurate under laboratory conditions of measurements within plus or minus 10%. At the higher signal levels, such as those encountered in determining the effective field at one mile, the set should have an accuracy of plus or minus 5%.

2. Calibration of Field Set

The field set used is assumed to comprise:

(a) A standard antenna or loop.

(b) A calibrating source of signal fed into the antenna or loop circuit.

(c) Means, which will not vary with time, for measuring the amount of signal so fed.

(d) An attenuator.

(e) An amplifier.

(f) Output meter.

The accuracy of each measurement is assumed to be independent of the stability of the amplifier over long periods of time, since the amplification is adjusted for each measurement. The accuracy of the set usually depends on there being no variations in the antenna or loop, in the means of measuring the amount of signal fed from the calibrating oscillator, in the attenuator, in the output meters and

sometimes in the linearity of the state operating the output meter.

Such a field set does not have to be calibrated more than once, unless a major change is made in any of the essential parts which might affect its calibration. After any such change the set should be recalibrated. These calibrations should be made by the National Bureau of Standards or other reliable laboratory, and the laboratory should state the accuracy with which the calibration was made.

The elements which are most likely to change should be calibrated immediately before and immediately after each survey. It is usual to use for this purpose, a Standard Signal Generator of reliable accuracy. Such a signal generator should be checked at one point with a vacuum tube voltmeter, which in turn may be checked with an accurate alternating current meter.

If the procedure is not followed because of special design of the set or other reason, the engineer should explain the reason in his report.

3. Calibration in Field

It is not usually necessary to carry out calibrations in the field with instruments other than those incorporated in the field set. Measurements of a number of stations should be made, however, each day of the survey at a suitable open site, which can be readily and accurately identified. Should these measurements made on one day of the survey indicate substantial difference from the measurements of another day, the cause of the difference should be found before continuing the survey. It may then be necessary to repeat some of the measurements made previously in the course of the survey, if the cause of the discrepancy indicates some uncertainty about their accuracy.

4. Time of Measurement

No measurements should be taken when there is measurable fading. The signals in general will be free of fading if they are measured during the daytime hours between one hour after sunrise and one hour before sunset. It should be pointed out that night conditions sometimes prevail during more than these daytime hours, particularly during the winter. Near the station, where ground signals are strong, there may be no fading either day or night, under these conditions the measurements can be made at any time.

5. Selection of Radials

The sites should be selected as nearly as possible along straight lines radiating from the transmitter. In general there should be not less than eight radials, spaced as uniformly as possible. If the topography of the country or the type of transmitting antenna used indicates that there may be sharp variations in certain directions, additional radials should be taken in these directions. If fewer than eight (8) radials are taken because of special conditions, the engineer should explain the reason in his report.

6. Selection of Sites

Each site should be selected as far as possible from obvious obstructions. When there is an obstruction such as overhead telephone lines, the field meter should be watched as the field set is moved away from the obstruction until it reaches a steady value and the measurement made after the steady value has been reached. If it is not possible to follow this procedure, it is good practice in most cases to keep at least one-half wave from overhead wires and at a distance of not less than five times the height of the wires. Where other large objects, such as metal tanks and buildings are present, a greater distance should be taken. In a densely populated area, the measurements should be made in as many open spaces as possible. In a park or large square, several measurements should be made and the average value taken.

At each site the residual signal, when the loop is turned to minimum, should be sharp. When the minimum is greater than 10% of the maximum, the measurements should be discarded, unless a satisfactory reason is given in the report for retaining it.

7. Number of Sites on a Radial

The number of sites selected on each radial in order to determine the "average" value of the field strength should not be less than is indicated in the following table:

TABLE III

Distance From Station	Average Distance Between Sites
0 - 10 miles	*1 mile*
10 - 30 miles	*2 to 5 miles*
30 - 100 miles	*5 to 10 miles*
Over - 100 miles	*10 to 20 miles*

When the measurements are to be used to estimate the performance of the antenna, the number of measurements in the first ten miles

should be increased to correspond to the following minimum:

TABLE IV

Distance From Station	Average Distance Between Sites
*Up to 2 miles**	*0.1 mile*
2 to 6 miles	*0.5 mile*
6 to 10 miles	*1 mile*
10 to 20 miles	*2 miles*

**"Measurements should start as close to the antenna as possible without including the induction field and yet far enough away to provide for the fact that an antenna system is not a point source. In the case of a single antenna; i.e. non-directional, the first measurement should be taken at a distance of approximately one wave length or five times the verticle height of the antenna, whichever is the greater. In the case of a directional antenna the first measurement should be taken at a distance of approximately ten times the spacing between the elements of the directional antenna."*

In cases where it is not possible to obtain accurate measurements at close distances to the antenna due to the character of the intervening terrain, the measurements at greater distances should be made at closer intervals than is indicated above. If fewer measurements are made than indicated in Tables III and IV the engineer should explain the reason in his report.

When the terrain is such that the measurements vary substantially from the average value of the field, or where a desired contour falls within the ten mile circle, more measurements than indicated in Table III should be made.

8. Length of each Radial

Each radial should start at a point where the average signal is at least twice the highest signal contour to be determined and each radial should be extended at least to a point where the average signal has dropped to one half the value of the lowest contour to be determined.

9. Estimate of Interference

If, within the contours being measured another station causes objectionable interference estimated in accourance with the standards of interference of the Standards of Good Engineering Practice adopted on August 1, 1939 by the Federal Communications Commission, the strength of the field of the interfering station should be measured at a sufficient number of sites to be able to estimate the contour within which reception is free from objectionable interference.

If such measurements cannot be made, an estimate of this contour should be made, based on calculations, or calculations combined with measurements. In his report the engineer should explain his method of calculation and state all the assumptions he has made. He should also explain why calculations were used instead of measurements.

10. Estimate of Contour

All the measurements on each radial should be plotted on log-log paper with the field strength as ordinate and the distance in miles as abscissa. An average smooth curve should be drawn through the measured points. This curve should be used to indicate the average field strength against distance.

If measurements have been made of the field strength of interfering stations, they should be indicated on the same sheet. A smooth curve should be drawn indicating the estimated (measured or calculated) average field of the interfering station. The point where the average field of the stations is free from objectionable interference from the average field of the interfering station, should be clearly marked.

III. RECOMMENDED PROCEDURE FOR ESTIMATING AVERAGE NIGHT-TIME CONTOURS

1. Strength of Sky-Wave

The strength of sky-waves at night should be calculated in accordance with the procedure given in the Standards of Good Engineering Practice of the Federal Communications Commission, which became effective on August 1, 1939, based on the Average Sky-Wave Field Intensity Curve for the second hour after sunset.

No measurements should be used as a basis for estimating the strength of sky-waves unless it is shown that the measurements are superior in accuracy to the measurements used in obtaining the Average Sky-Wave Intensity Curve which is the result of several months of field intensity recording during the Spring of 1935.

2. Sky-Wave Service

The estimated strength of the sky-wave should be used to estimate the field strength contours at night in the sky-wave service area. The contours should correspond to the field strength exceeded 50% of the time. A description of the method used in making such estimates should be included in the report.

3. Field Free From Interference

The estimated strength of sky-waves should be used with the standards of interference

given in the Standards of Good Engineering Practice of the Federal Communications Commission which became effective on August 1, 1939 to estimate the contours free from interference. A description of the method used in making such estimates should be included in the report.

4. Rapid Fading Zone

The rapid fading zone starts where the ratio of the ground wave to the 10% sky-wave becomes less than two to one. The curves on the attached chart for the various antennas have been plotted for twice the sky-wave for convenience.

The curves may be used to estimate where the rapid fading zone starts. The signal strength of the ground wave radial of the station should be converted to 1,000 mv/m at one mile and plotted on the chart. The rapid fading zone starts where the ground wave radial intersects the curve for the antenna in use.

IV. ESTIMATE OF POPULATION COVERAGE

1 Calculation of Population Coverage

The calculation of the population served should be based on the population given in the most recent United States census of population.

2. Limits of Coverage

The population served should not include any population in an area which is subject to objectionable interference from other radio stations, either on the same channel or adjacent channels. The population served should not include any population in an area subject to objectionable interference from noise. In view of the lack of detailed information on noise levels, however, the following arbitrary values of signals may be considered as satisfactory for a service signal to overcome noise.

The service areas should be divided as follows:

A - *Daytime Primary Service Area* is the area free from objectionable interference from other stations and limited by the contours given in the second column of Table V.

B - *Daytime Secondary Service Area* is the area free from objectionable interference from other stations outside the primary service area and limited by the contours given in the third column of Table V.

C - *Night-time Primary Service Area* is the area free from objectionable interference from other stations and limited by the inner contour of the rapid fading zone.

D - *Night-time Secondary Service Area* is the area free from objectionable interference from other stations limited on the inside by the inner boundary of the rapid fading zone and extending to where the sky-wave for 50% of the time exceeds 0.5 mv/m; except for towns and cities of more than 2500 population where the signal does not exceed 2 mv/m 50% of the time.

V. PRESENTATION OF DATA

The report on the measurements and the presentation of the data should be put in the *form of an affidavit* and should include the following:

1. Name of engineer and his qualifications.
2. Purpose and limits of survey.
3. General description of method used in survey.
4. Description of final results.
5. Map or maps, preferably of the clear type, and made by a government agency, should be used for showing clearly the contours free from interference. As far as possible, the government typographical maps should be used for the one-mile surveys. For large surveys the use of the proper size filtered photostatic copy of the U. S. Alber's Equal Area projection map is recommended. A scale should be drawn on the map, prior to the taking of the photo-

TABLE V

Type of Territory	Primary	Secondary
Rural Areas	*0.5 milli-volts per meter*	*0.1*
Towns and Cities of 2500 population and up	*2 milli-volts per meter*	*0.5*

static copy, so that the scale will be correct after photostating. It is recommended that sufficient contours be shown so as to indicate how rapidly the signal varies with distance. For instance, for a complete survey, the following contours may be shown and properly labeled; 50, 25, 10, 5, 2, 1, 0.5, 0.25 and 0.1 mv/m. If contours of any other value bound a certain coverage area, they should also be shown and properly labeled. The source of the map should be stated. The date, frequency, and power of the station and other pertinent data about the station should be shown on the map along with the signature of the engineer making the survey.

6. Statement of causes limiting service in different directions (e.g. field strength, interference from other stations, noise level, rapid fading, etc.)

7. Other pertinent conclusions.

The description of the measurements, which shall form part of the affidavit, shall include:

1. Name of manufacturer, type and serial number of field set used.

2. A statement on the accuracy of the set and the procedure used to calibrate the set, stating when and by whom or under whose direction the field set was last calibrated for establishment of its constants, the accuracy with which these constants were determined and how the set was checked during the course of the survey.

3. Map or maps showing the location of each site where the measurements were made. Each location should be properly numbered.

4. Plot of field strength along each radial with all measured points properly numbered shown. (See Section II-10 above).

5. Field strength measured at each site, the date and time of the measurement, the distance and direction from the transmitter, together with notes, if necessary, on the reliability of the measurement and the antenna current at the time of each measurement as indicated by the station's log.

6. Explanation or reasons for adopting variations in the recommended procedure, as requested for instance, under Sections II-2, II-5, IV-2.

7. Explanation of any calculations used and assumptions made, as requested, for example, in Sections II-9, III-3, III-4, IV-2.

8. If other maps are used than those made by a government agency, a statement of how their accuracy was checked and what errors were found.

9. Any other pertinent information.

RADIO FREQUENCY NETWORKS

(By Arthur C. Stewart, Station KFAB)

"T" and "Pi" networks, having impedance arms composed of reactances are widely used to obtain impedance matches. Such networks, being made up of three variables, can control three characteristics, namely the resistance and the reactance of the input impedance and the phase shift introduced by the network. The attached charts -- R. F. NETWORK DATA Nos. 1, 2, 3, 4 and 5 -- give values of "a", "b" and "c", which can be substituted in the formulas on the DIAGRAM page of the NETWORK DATA, to determine the reactances that should be used in the various network configurations shown. In the charts, "a", "b" and "c" are plotted vs. "r" for various values of B. "r" is the transformation ratio and is equal to R_1/R_2 where R_1 is the image impedance at one end of the network and R_2 is the impedance at the other end. B is the phase angle by which the phase at the output terminal differs from the phase at the input terminal of the network.

In CHARTS 1 and 2, it will be noted that values of "a" are plotted against "r" for various phase shift angles B. CHART 1 is used for phase shifts of less than 90^0; CHART 2 for phase shifts of greater than 90^0.

In CHART 3, "b" is plotted against "r" for various phase angles B. CHART 3 covers all phase shifts from 0^0 to 180^0.

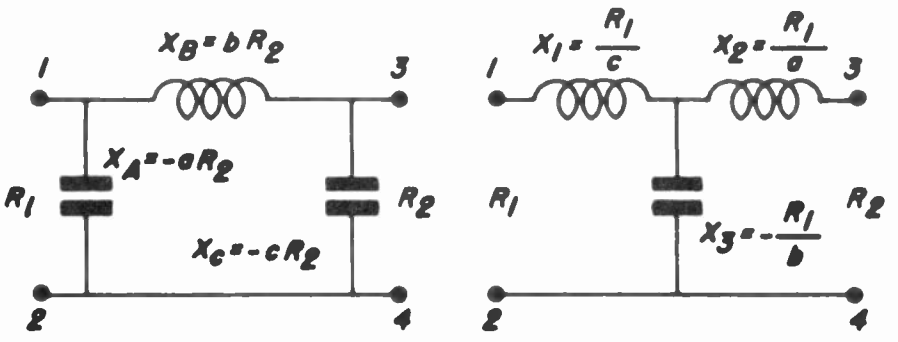
CHARTS 4 and 5 give values of "c" plotted against "r" for various phase angles B. It will be noted that "c" is a positive number on CHART 4 and negative on CHART 5, the sign of "c" being the determining factor as to whether X_1 and X_C on the DIAGRAM sheet will be inductive or capacitive reactances, and whether the network used will be a Type 1 or a Type 3 network (when "c" is positive) or a Type 2 or a Type 4 network which is used when "c" is negative. Note that Type 1 and Type 2 networks are used for negative or lagging phase shifts, while Type 3 and 4 networks are used for positive or leading phase angles. Thus a network with a leading phase shift calls for a Type 3 network if the value of "c" is obtained from CHART 4 and is therefore positive, or a Type 4 network if "c" is obtained from CHART 5 and is thus negative. It should be pointed out that it will not be possible to find a value of "c" for a given transformation ratio "r" and a given phase shift B on both CHARTS 4 and 5, hence there is no question as to whether a Type 3 or 4 network is indicated, after the value of "c" has been obtained from the CHART. Note that "r" is always greater than 1. This is no limitation since terminals 1 and 2 can be placed at either end of the network and the transformation ratio will thereby always be greater than 1. An interesting special case of the three element network is the "L" network, in which "c" is made equal to infinity. When this is the case, X_C in the Pi network becomes infinite, the network thus becoming an "L" network. When "c" becomes infinite, X_1 in the "T" network becomes zero, and this network also reduces to an "L". This type of network can be used to transform a given resistance into a desired resistance, but since there are only two variables, the phase shift cannot be controlled. Values of "a" and "b" for the "L" type networks are plotted on CHART 1 and 3, the phase shift for the network being determined by interpolation between the curves on CHART 3. A phase shift of more than 90^0 is impossible with the "L" network. In designing a network, the reactive component of the terminating impedance is neglected and the assumption made that pure resistances are being matched. After the network has been designed, the reactive component of the terminating impedance may be combined with one arm of the network. This is a very simple procedure when the terminating impedance is a series circuit of R and X and the network has a "T" configuration. When a "Pi" network is desired and there is a reactive component in the terminating impedance, it is much simpler to design a "T" network and then transform it to a "Pi" network by means of the following formulas:

$$X_A = \frac{\Sigma X}{X_2} \qquad X_B = \frac{\Sigma X}{X_3} \qquad X_C = \frac{\Sigma X}{X_1}$$

$$\Sigma X = X_1X_2 + X_2X_3 + X_1X_3$$

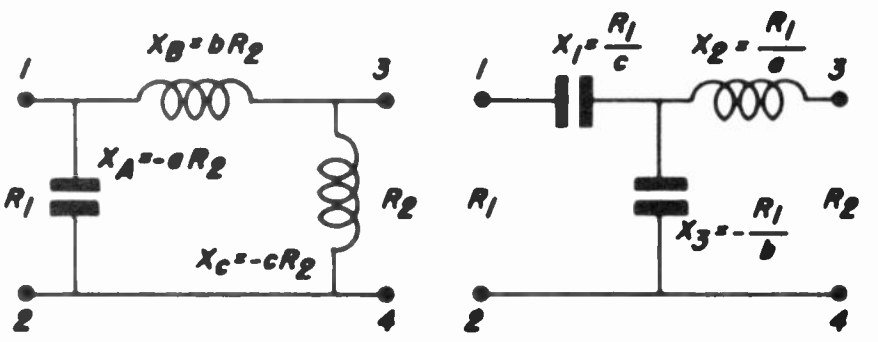
where the X's must be considered as vector quantities.

TYPE 1



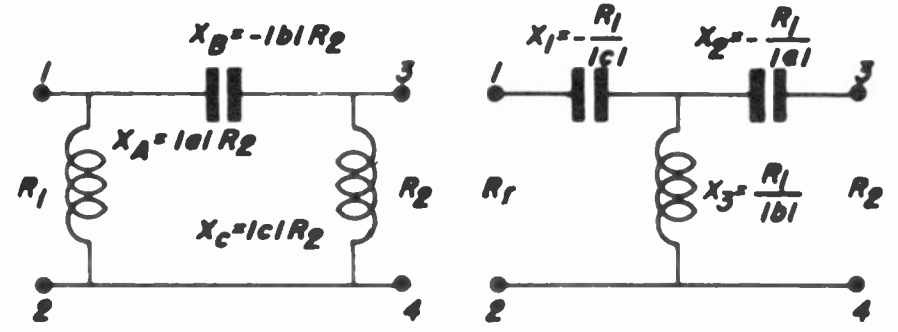
Phase retarded by large angle (c positive)

TYPE 2



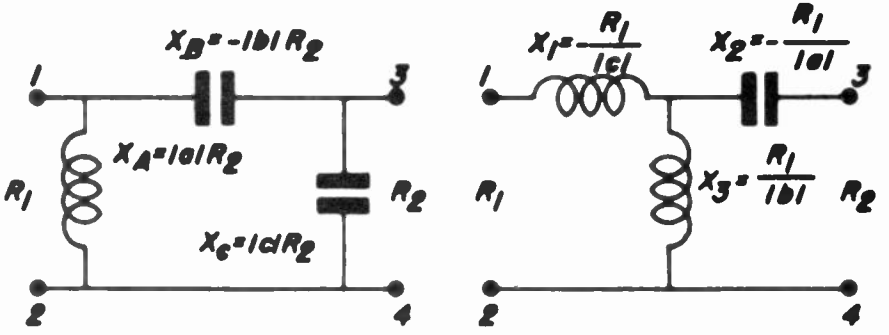
Phase retarded by small angle (c negative)

TYPE 3



Phase advanced by large angle (c positive)

TYPE 4



Phase advanced by small angle (c negative)

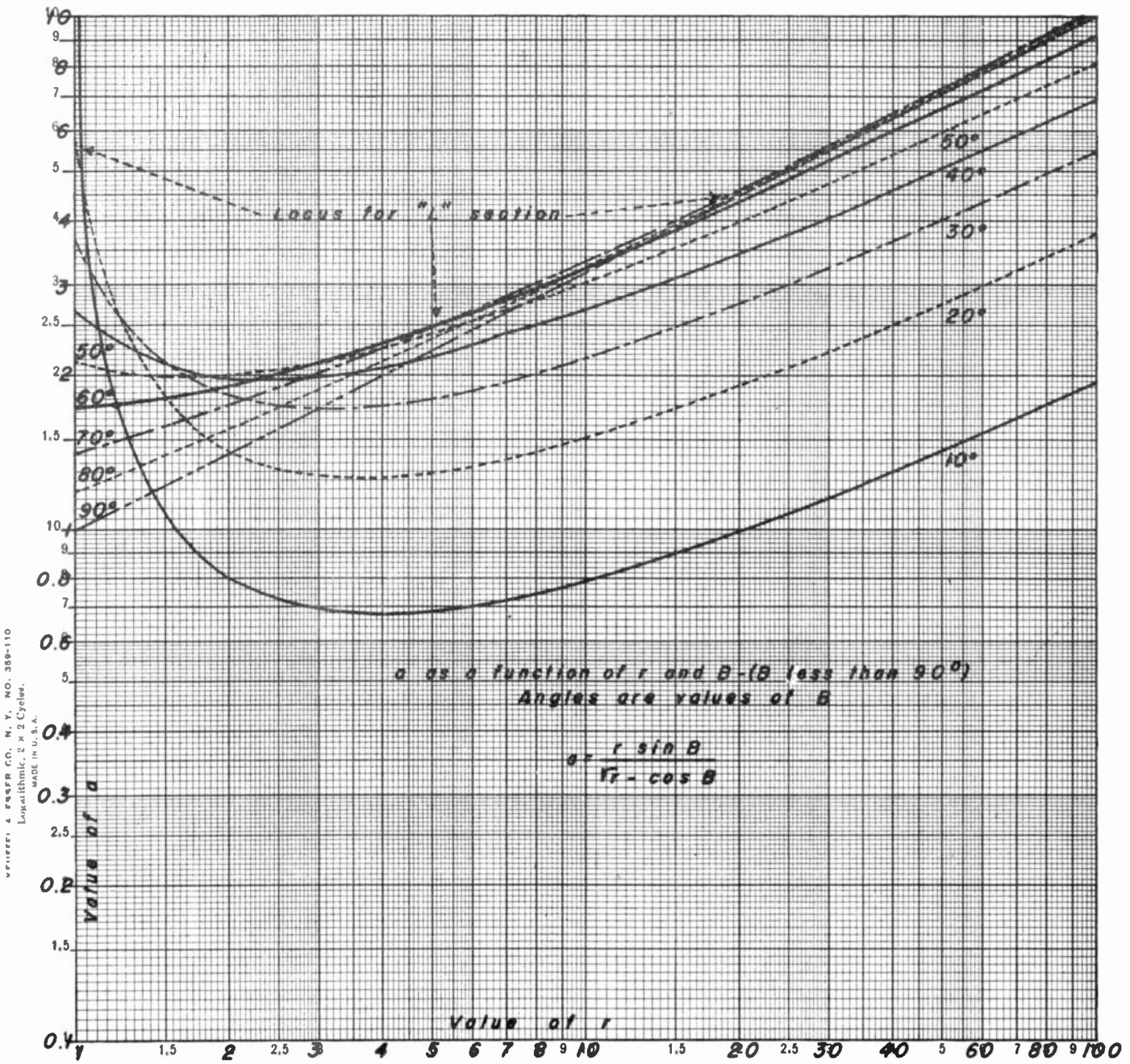
R.F. NETWORK DATA

Three element reactance networks for transformation of resistance

Arthur C. Stewart

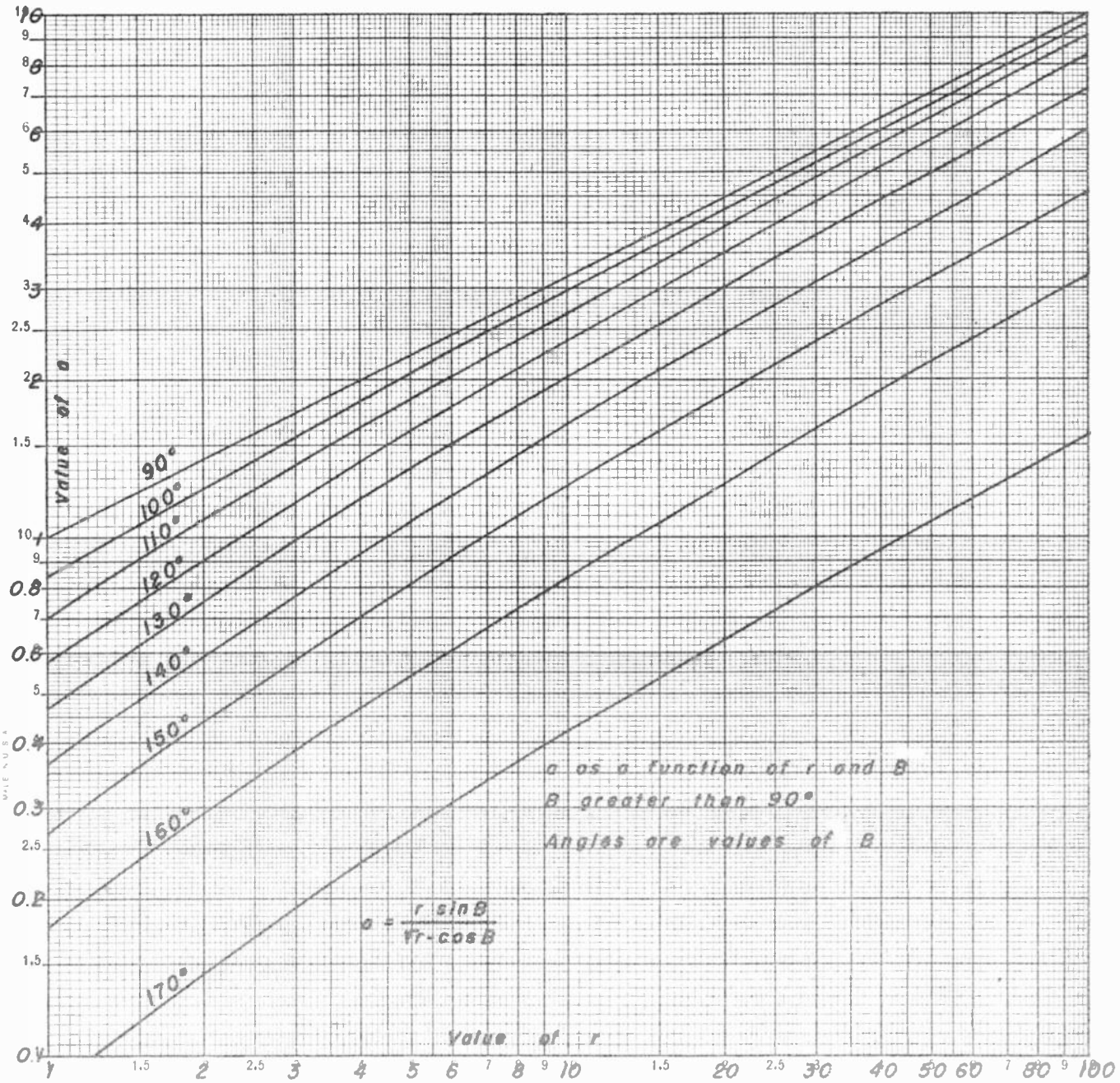
July 18, 1944

R.F. NETWORK DATA NO. 1



Arthur C. Stewart
7-3-44

R. F. NETWORK DATA NO. 2



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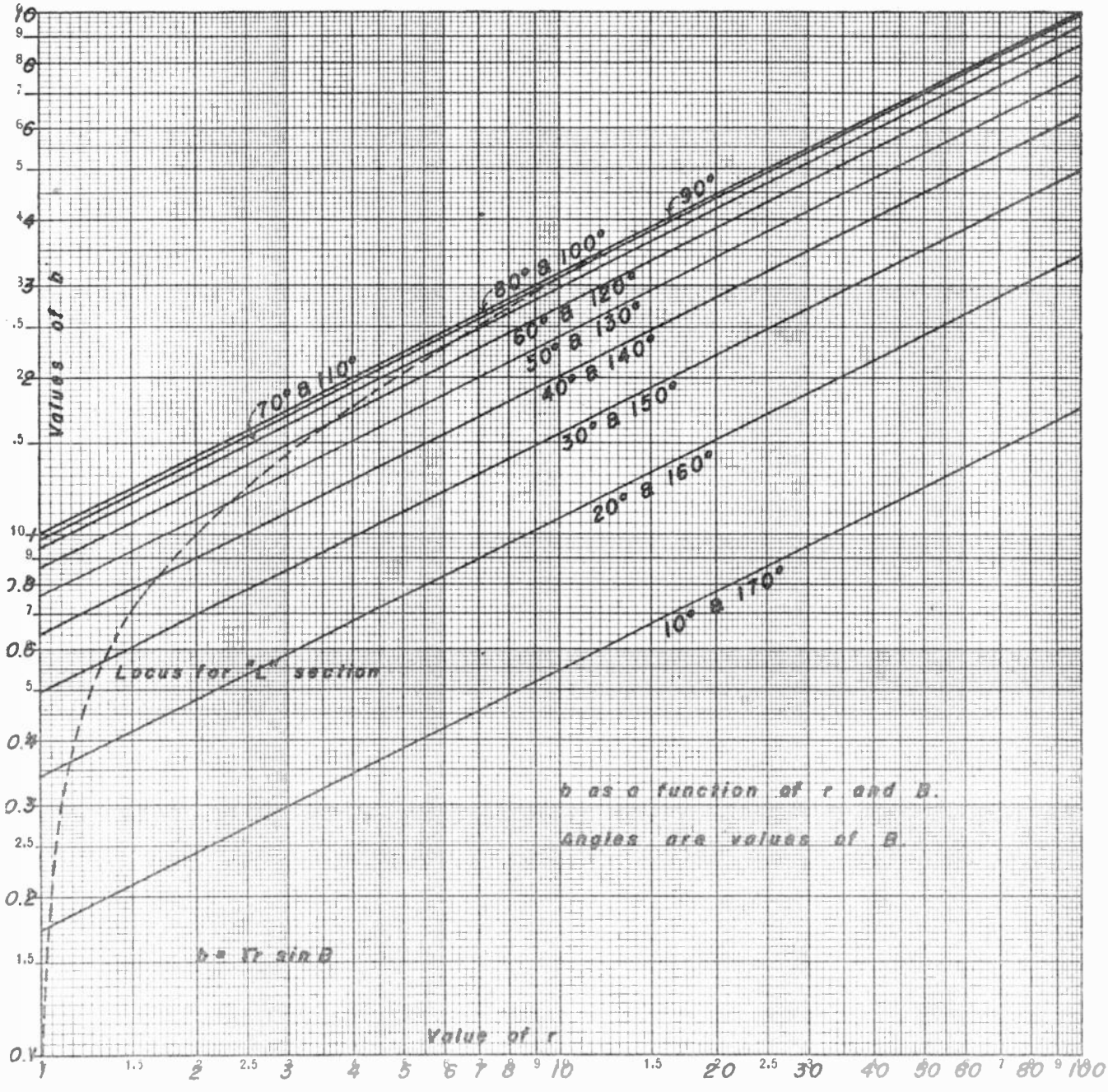
Arthur C. Stewart

7-11-44

N. R.

R.F. NETWORK DATA NO. 3



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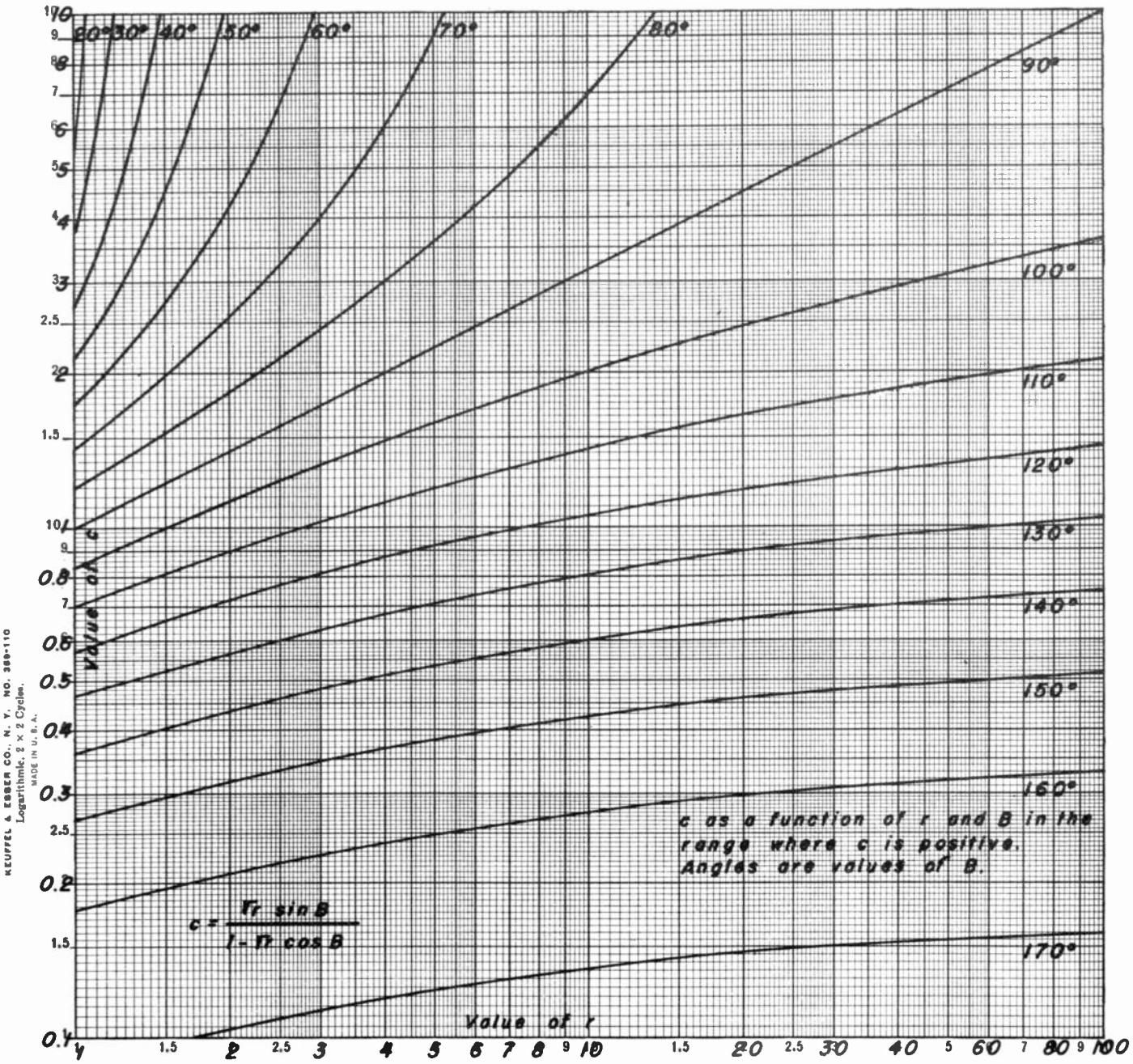
R.F. NETWORK DATA NO. 4



Arthur C. Stewart

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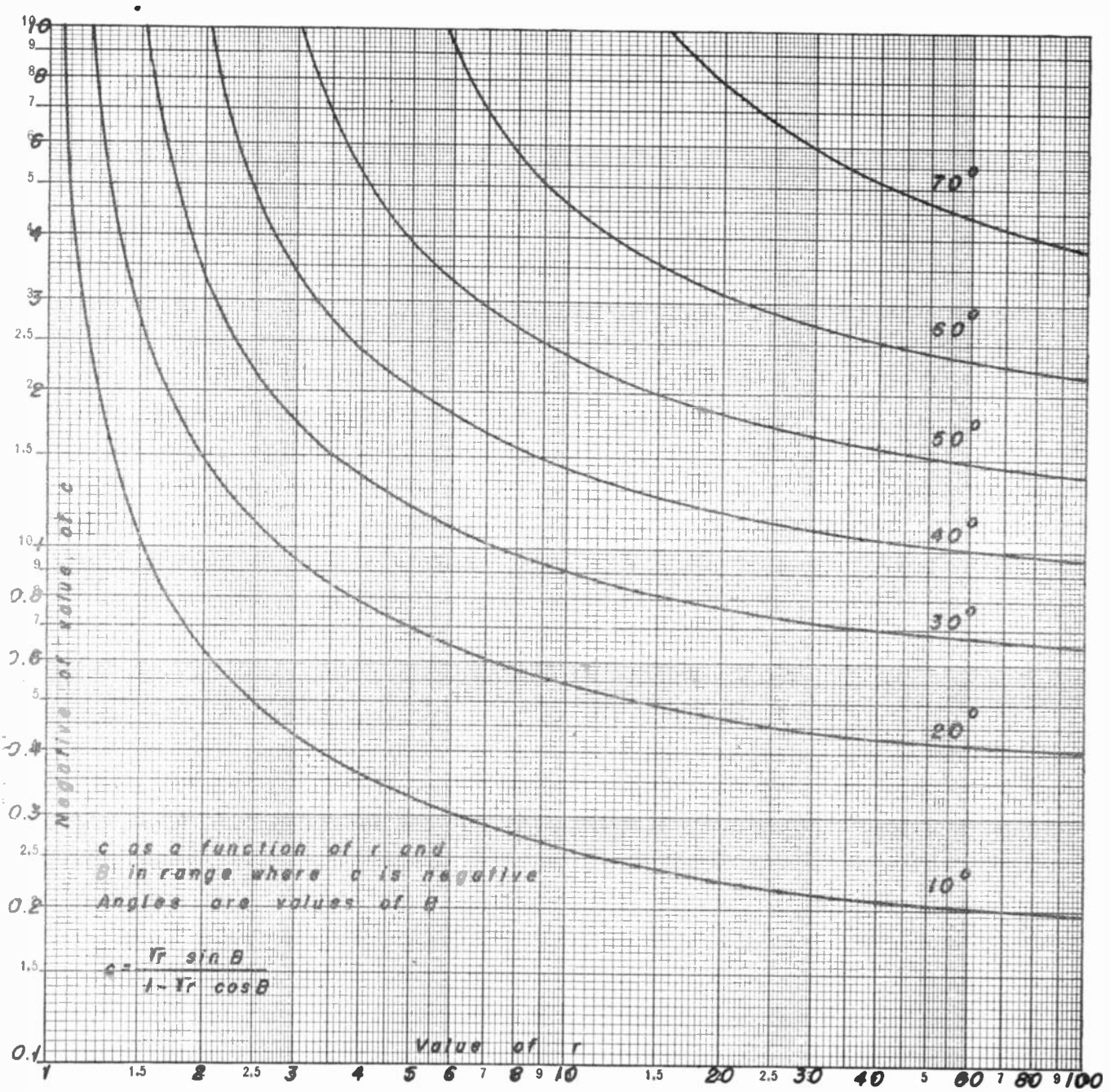
R.F. NETWORK DATA NO. 5



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Arthur C. Stewart
6-29-44

EXAMPLE

Design a 30^0 leading network to match an antenna load of 14.9 - j 18 to a transmission line with a characteristic impedance of 70 + j 0.

For the moment, neglect the reactive component of the antenna, and we find "r" = R_1/R_2 = 70/14.9 = 4.7. In CHART 1, from "r" = 4.7, proceed upwards in the chart to the curve for B = 30^0 and find "a"= 1.78. In CHART 3, from "r" = 4.7, proceed upwards in the chart to the curve for B = 30^0 and find "b" = 1.07. In CHART 5 (Note that CHART 4 will not supply us with a value for "c" since the 30^0 curve does not intersect the "r" = 4.7 line) from "r" = 4.7, proceed upwards in the chart to the curve for B = 30^0 find "c" = -1.25. Since we have a positive 30^0 phase shift specified for the problem, and since "c" is negative, a Type 4 network is indicated and,

$$X_1 = -70/-1.25 = 56 \text{ ohms}$$

$$X_2 = -70/1.78 = -39.3 \text{ ohms}$$

$$X_3 = 70/1.07 = 65.4 \text{ ohms}$$

Now, since we already have -j18 ohms reactance in the antenna, we can include this in the X_2 arm of network and the X_2 arm will become -39.3 -(-18) = -21.3 ohms.

If we had wanted to use an "L" network to match the 14.9 -j18 ohm antenna to the 70 + j0 transmission line, from CHART 1 we would find that "a" = 2.43, from CHART 3, "b" = 1.95. Since "c" = infinity, from the Type 4 network diagram we have,

$$X_1 = 0 \qquad X_2 = -70/2.43 = -28.8 \text{ ohms}$$

$$X_3 = 70/1.95 = 35.9$$

Since we have -j18 ohms in the antenna, X_2 becomes -10.8 ohms. Note, from CHART 3, that in this case the phase shift through the network is + 65^0, and that we have no control over the phase shift.

In practical networks, the condensers have negligible loss, but the resistance of the inductances is not negligible. Assuming that the Q or X/R of the inductances remains constant for all inductances, we can write:

$$\frac{\text{Power Lost in Network}}{\text{Power Delivered to the Network}} = \frac{\text{Loss Function}}{Q}$$

where the Loss Function can be obtained from CHARTS 7 and 8. CHART 7 applies when "c" is negative, and CHART 8 is used when "c" is positive. Note from these curves that the minimum loss occurs for "L" type networks, and for three element networks in the neighborhood of 90^0. Note also that there is no choice between leading or lagging networks, or between "T" or "Pi" networks insofar as losses are concerned. In cases where the phase shift desired or the transformation ratio is very large, it is often possible to obtain an increase in efficiency by dividing the total phase shift between two networks, and by making the impedance transformation in two steps.

CHART 6 gives values of "a", "b" and "c" plotted against phase-shift for the special case where $R_1/R_2 = 1$. This network could be used as a phase shifting network only.

Networks that call for an inductance in the series arm and/or a capacity in the shunt arm can be readily arranged to provide discrimination against harmonics. To suppress the harmonic, the series arm inductance could be supplied with a parallel resonant network tuned to the harmonic. The shunt capacity could be supplied with a series circuit which is tuned to resonance at the harmonic.

EXAMPLE

Consider the case where it is desired to connect a 230 + j0 transmission line to the output coil of a transmitter, and where it is desired to use 155 ohms of inductive reactance contained in the output coil as one arm of the network, and where the network is to be used for suppression of the second harmonic output of the transmitter. This last function can be performed by making the shunt arm of the network series resonant at the harmonic frequency and hence act as a harmonic shunt.

From the DIAGRAM sheet for Type 1 "T" networks, we have the following formulas:

$$X_1 = R_1/c \qquad X_2 = R_1/a \qquad X_3 = -R_1/b$$

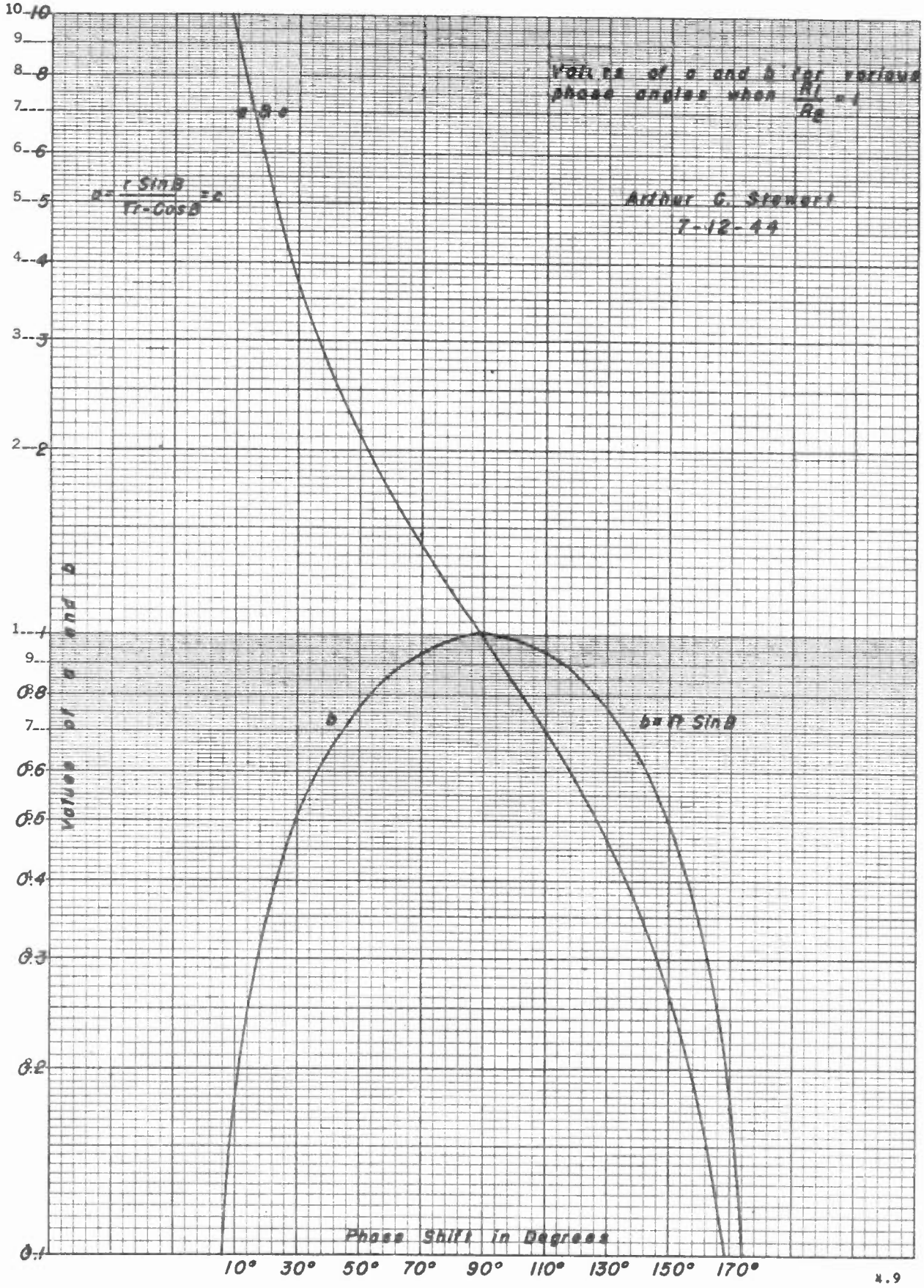
Since we wish the inductive reactance of the output coil to be the X_2 arm of the network, we can substitute the known values in the formula for X_2 and get:

$$155 = 230/a \qquad a = 1.48$$

On CHART 6, opposite "a" = 1.48, we find that the phase shift through the network will be 67^0, and that "c" will be equal to "a", and hence X_1 will be equal to 155 ohms of inductive reactance. In CHART 6, find "b" = .915, substituting in the formula for X_3:

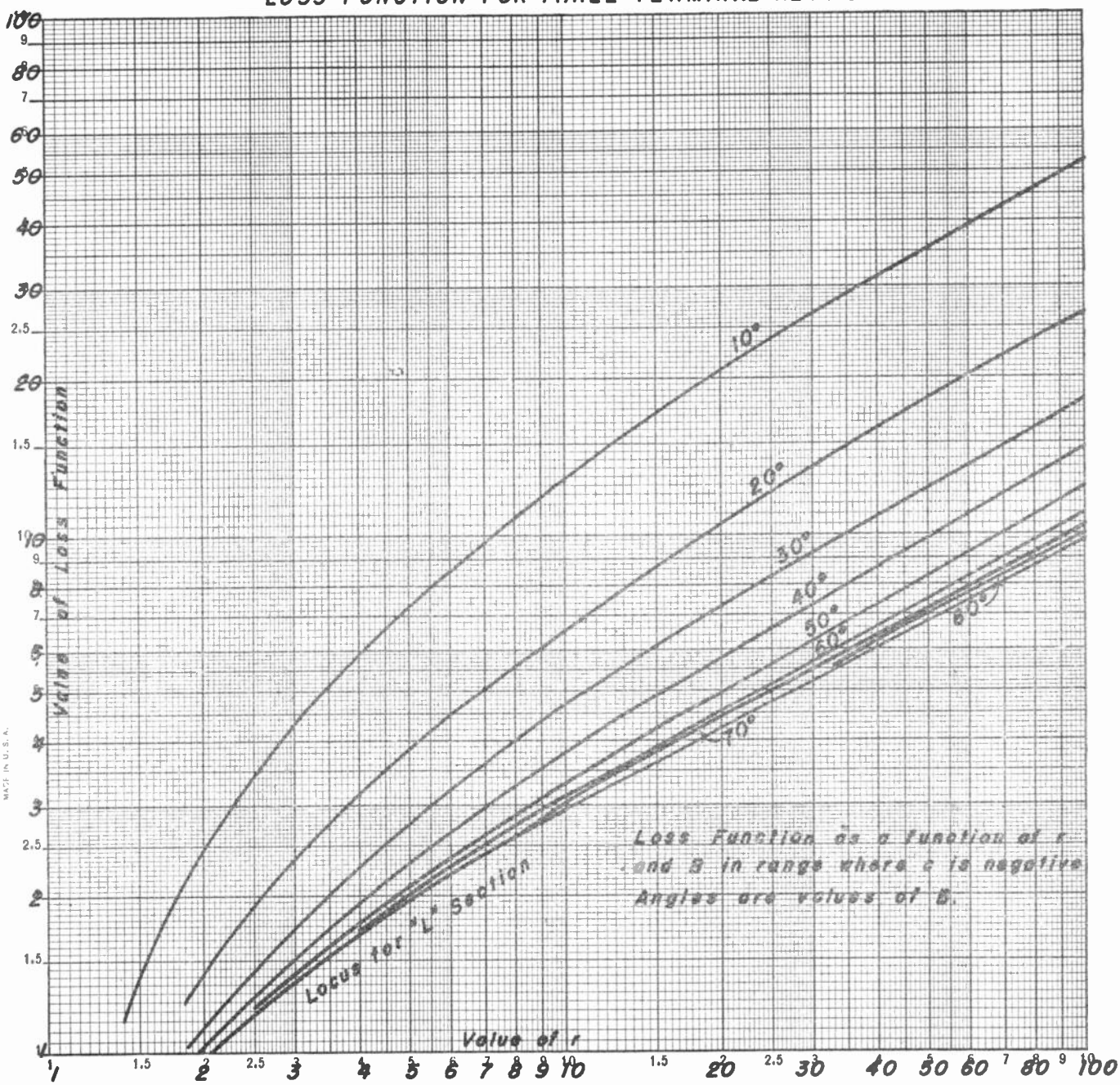
$$X_3 = -230/.915 = -256 \text{ ohms}$$

R.F. NETWORK DATA NO. 6



KEUFFEL & ESSER CO., N. Y., NO. 359-61
Semi-Logarithmic, 2 Cycles × 10 to the inch
MADE IN U.S.A.

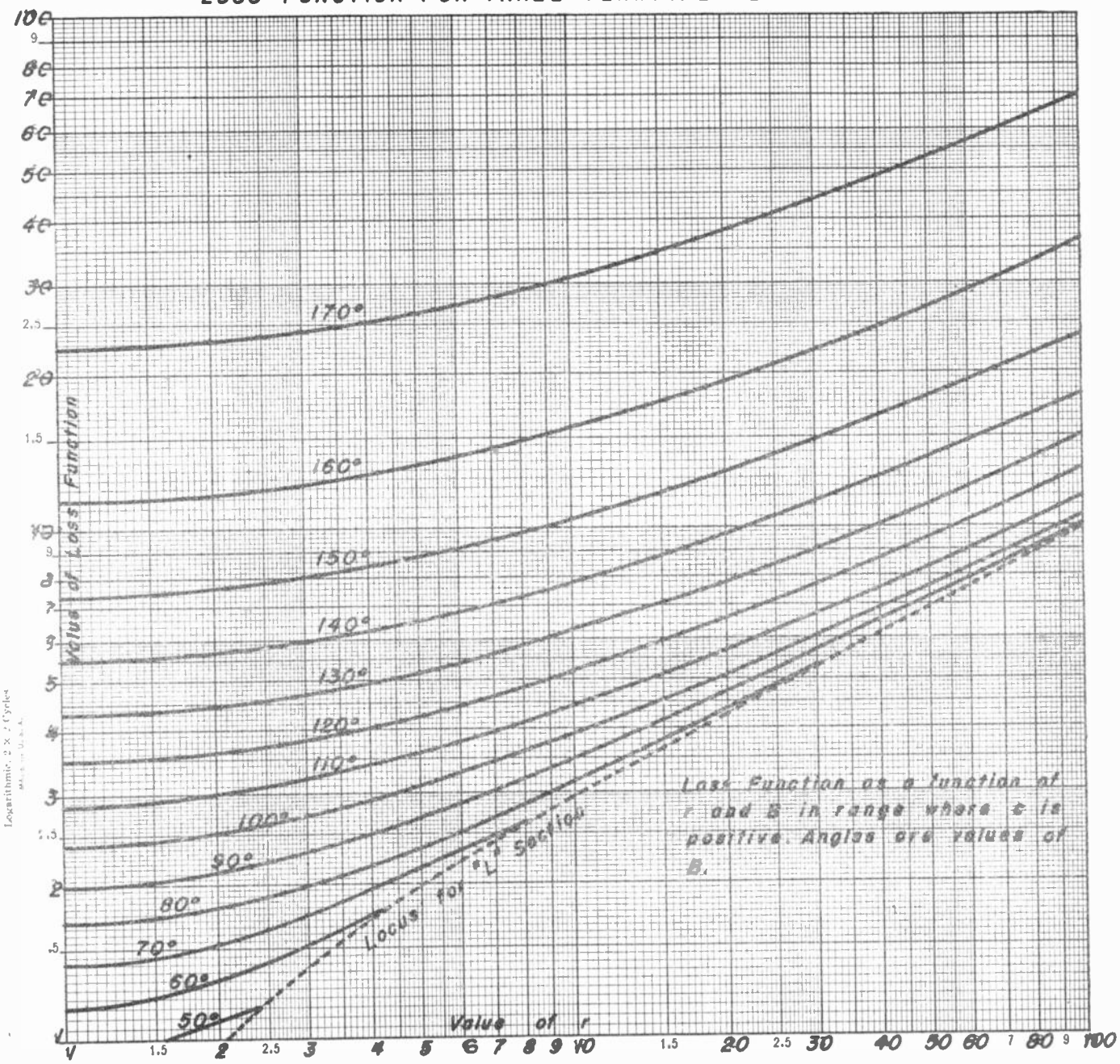
LOSS FUNCTION FOR THREE TERMINAL NETWORK



KEUFFEL & ESSER CO., N. Y. NO. 359-110
Logarithmic 2 X 2 Cycles.
MADE IN U.S.A.

Arthur C. Stewart
8-30-44

LOSS FUNCTION FOR THREE TERMINAL NETWORK



KEUFFEL & ESSER CO., N. Y. NO. 359-110
Logarithmic 2 X 7 Cycles

Arthur C. Stewart
8-30-44

Since we wish X_3 to consist of an "L" and "C" that are resonant at the harmonic frequency, which we will assume is 2220 kc., and since this series combination must have 256 ohms of capacitive reactance at the fundamental frequency -- or 1110 kc. -- we can write two simultaneous equations:

$$LC_{(2220\ kc.)} = 5.12 \times 10^{-15}$$

$$wL_{(1110\ kc.)} - 1/wC_{(1110\ kc.)} = -256$$

Solving these equations simultaneously gives us:

$$C = 416\ mmf$$

$$L = 12.3\ micro\text{-}hy.$$

After we have arrived at the values of reactance that are necessary to give the desired impedance match and phase shift in the network, the next design consideration is the determination of the currents that will flow in the various components and the voltages to which they will be subjected. These values can be obtained rather easily by plotting the VECTOR DIAGRAM of the network, since the elements are assumed to be pure reactances and the currents will be 90° out of phase with the voltages across them. Consider first the case of the "T" network. If we consider this network in the form where two pure resistances are being matched, the determination of the input current and voltage and the output current and voltage becomes a simple problem in Ohms Law, once the power to be handled is known. Also the input current and voltage will be in phase, as will the output current and voltage. Draw the input and output current vectors to scale, with the phase shift through the network as the angle between them. Completing the triangle will give the current through X_3 which can be scaled from the diagram or computed from the "law of cosines":

$$a = \sqrt{b^2 + c^2 - 2cb\ Cos\ A}$$

Draw E_I in phase with I_I and construct a perpendicular to it at its terminal end. Draw E_L in phase with I_L and erect a perpendicular to it at its terminal end. The intersection of these perpendiculars will determine the two vectors E_2 and E_1. Connecting the origin with the end of E_2 will give the voltage E_3. An example of the VECTOR DIAGRAM of a "T" network is given on page 13.

In the case of the "Pi" network, E_I, I_I, E_L and I_L can be computed as was outlined above for the "T" network. Draw E_L and E_I separated by an angle equal to the phase shift through the network. Connecting the ends of E_L and E_I gives the value of E_B. Draw I_I and I_L in phase with E_I and E_L respectively. Erect a perpendicular to I_I at its terminal end and draw a line through the origin perpendicular to E_B. The intersection of these lines will determine I_B and I_A -- where I_B will be perpendicular to E_B and I_A will be perpendicular to E_I. Directions should be assigned to these vectors, such that vectorially $I_B + I_A = I_I$. Erect a perpendicular to I_L at its terminal end and this vector should pass through the intersection of I_A and I_B and will be equal to I_C. Directions should be assigned such that $I_L + I_C = I_B$. As an example, convert the "T" network on page 8 to a "Pi" network, and we will plot the VECTOR DIAGRAM for this "Pi" network. The formulas for conversion of "T" networks to "Pi" networks are given on page 1.

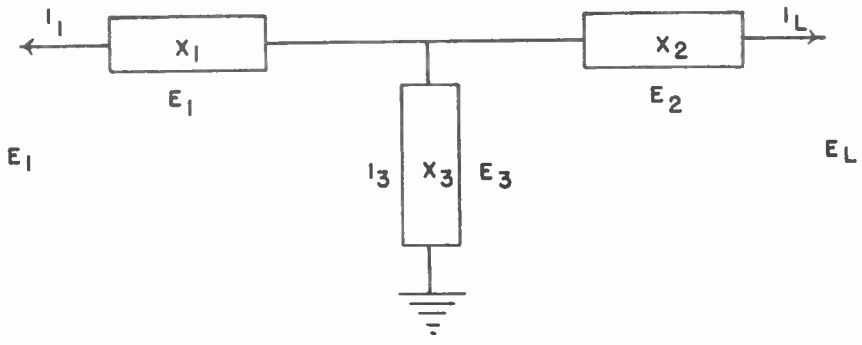
$$\Sigma X = 56\angle 90 \times 21.3\angle -90 + 21.3\angle -90 \times 65.4\angle 90 + 56\angle 90 \times 65.4\angle 90$$

$$= 1193\angle 0 + 1393\angle 0 + 3662\angle 180 = -1077$$

$$X_A = \frac{+1077\angle 180}{21.3\angle -90} = 50.5\angle -90 = -j50.5$$

$$X_B = \frac{+1077\angle 180}{65.4\angle 90} = 16.5\angle 90 = +j16.5$$

$$X_C = \frac{1077\angle 180}{56\angle 90} = 19.2\angle 90 = +j19.2$$



Assume a power of 10 kw. is to be handled by the network

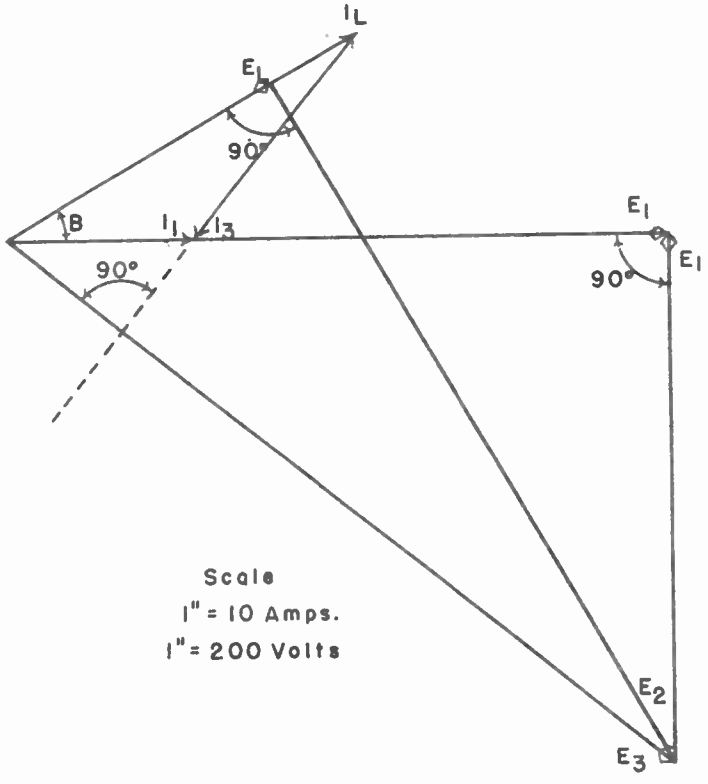
Then: $I_I = \sqrt{P/R_I} = \sqrt{10000/70} = 11.96$ amperes

$E_I = I_I \times R_I = 11.96 \times 70 = 837.2$ volts

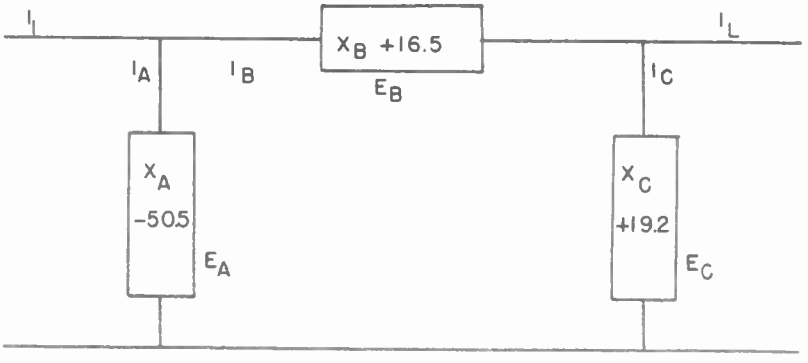
$I_L = \sqrt{P/R_L} = \sqrt{10000/14.9} = 25.85$ amperes

$E_L = I_L \times R_L = 25.85 \times 14.9 = 385.5$ volts

B (from page 1) equals 30^o



Vector Diagram "pi" Network



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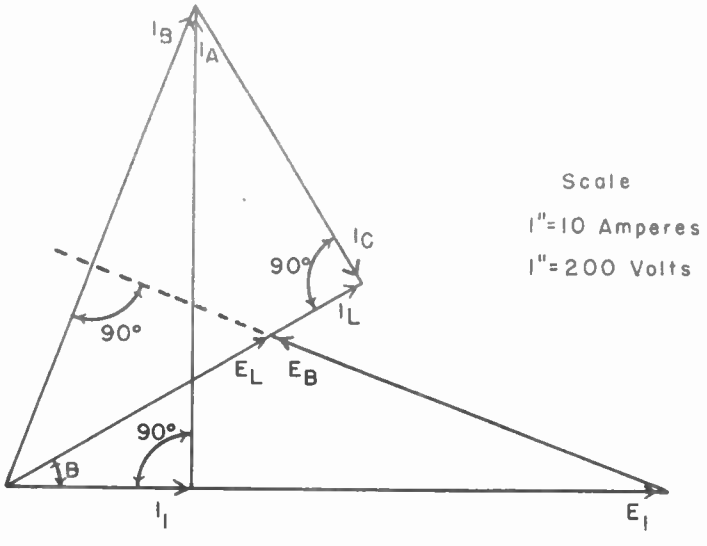
Then: $I_I = \sqrt{P/R_I} = \sqrt{10000/70} = 11.96$ amperes

$E_I = I_I \times R_I = 11.96 \times 70 = 837.2$ volts

$I_L = \sqrt{P/R_L} = \sqrt{10000/14.9} = 25.85$ amperes

$E_L = I_L \times R_L = 25.85 \times 14.9 = 385.5$ volts

$B = 30^0$



Scale

1"=10 Amperes

1"=200 Volts

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Communications	W. L. Everitt	Sept., Oct., 1938
Broadcast News	E. A. LaPort	January, 1939
Broadcast News	A. Vollenweider	July, 1938

COUPLING AND TUNING CAPACITOR FOR VARIOUS ANTENNAS

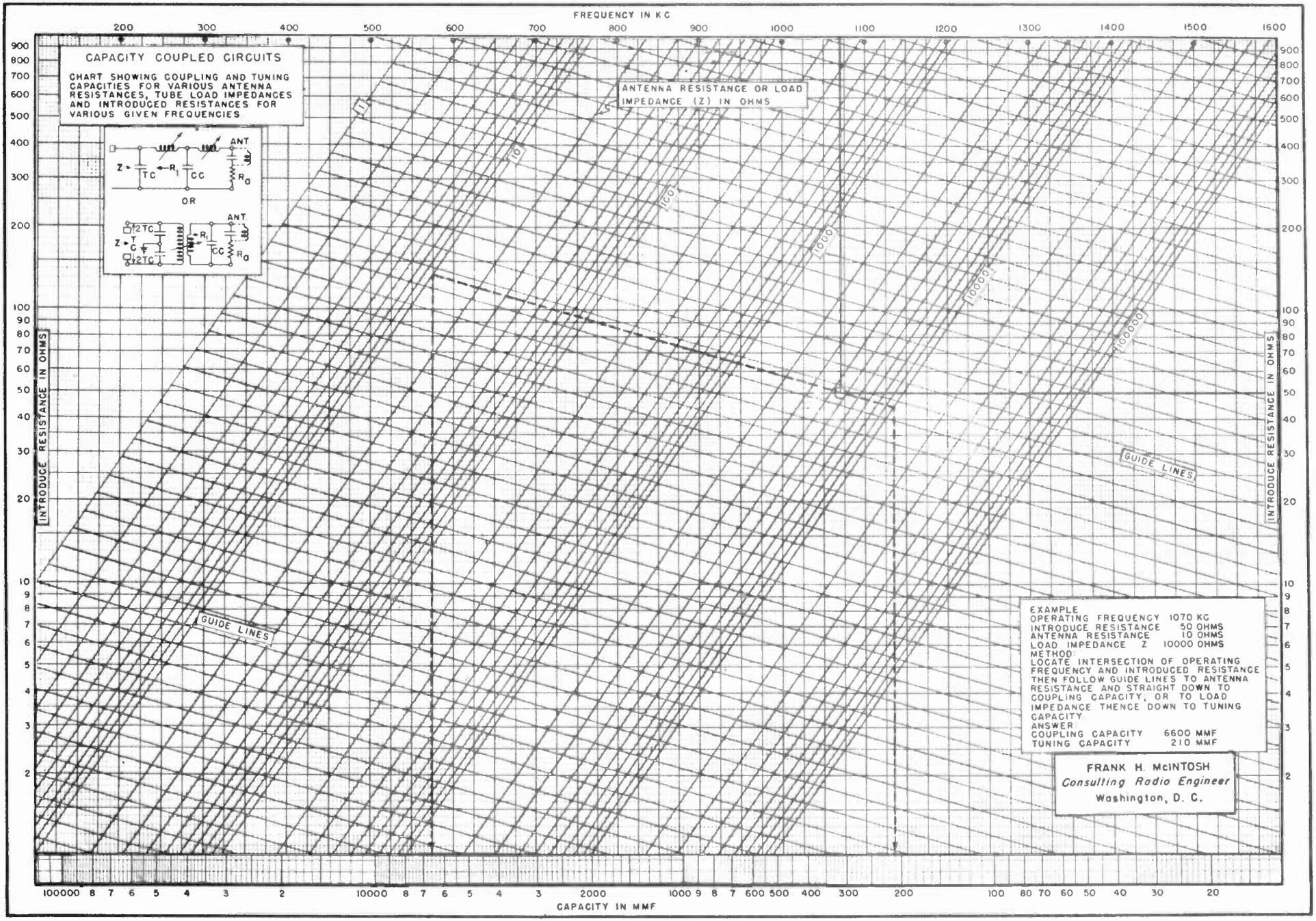
The attached chart has been found to be a useful tool for adjusting the transmitter output circuit using capacity coupling to the antenna or transmission line. The values of capacity shown are approximate but sufficiently close for practical purposes, since stray capacity of leads and components has 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.

WRH


CAPACITY COUPLED CIRCUITS
CHART SHOWING COUPLING AND TUNING CAPACITIES FOR VARIOUS ANTENNA RESISTANCES, TUBE LOAD IMPEDANCES AND INTRODUCED RESISTANCES FOR VARIOUS GIVEN FREQUENCIES
ANT
Z
TC
R1
CC
Ra
OR
2TC
ANTENNA RESISTANCE OR LOAD IMPEDANCE (Z) IN OHMS
FREQUENCY IN KC
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600
INTRODUCE RESISTANCE IN OHMS
900 800 700 600 500 400 300 200 100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2
GUIDE LINES
CAPACITY IN MMF
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
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.

OPERATION AND MAINTENANCE OF TRANSMITTER POWER TUBES

(Reprinted from the engineering notes of the Columbia Broadcasting System.)

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 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.

Detailed information on this subject has appeared from time to time in vacuum tube bulletins prepared for the industry by the Western Electric Company, RCA Manufacturing Company, Federal Telegraph Company and other tube manufacturers.

It is possible to lengthen appreciably the life of water-cooled tubes (bright tungsten filaments) by operating the tube at a filament voltage below the normal rating. These tubes, used both in amplifiers and rectifiers, should be operated at the lowest possible filament voltage consistent with satisfactory operation -- power output, tolerable distortion, and carrier shift. All broadcast transmitters should be operated in accordance with good engineering practice. However, this does not mean that it is 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. A bit of common sense in this regard will pay dividends and should not produce objectionable or noticeable distortion.

The following tabulation 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
Normal	100	100	100
	105	50	200
	110	26	415

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 from the operation of such tubes much below or above 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.

Power Tube Maintenance

Initial operation of power tubes, which have been kept on the shelf for extended periods, may be improved by conditioning treatment before they are placed in service.

1. Water-cooled Amplifier Tubes

Inasmuch as broadcasting stations are now required to maintain a complement of 100% spares, some tubes may deteriorate on the shelf before being placed in service. Before a tube that has stood for several months is put into operation, it should 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 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 in; that is, adjusted for the 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 voltage, 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.

It is recommended that tubes held as spares be conditioned periodically to insure continuity of service when the tubes are inserted for use.

2. *Rectifier Tube Conditioning*

High vacuum rectifier tubes may be conditioned in the same manner as amplifier tubes shown above.

Mercury vapor rectifiers should be preheated and tested under standard operating conditions to determine that there is no vacuum leak and that all of 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 a resistance bank of approximately 1 megohm, such as 20 - 20 watt, 50,000 ohm "Red Devil" resistance units, manufactured by the Ohmite Manufacturing Company, 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.

3. *Air-cooled Amplifier 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.

Consult your vacuum tube bulletins for more detailed information.

A SIMPLE TEST FOR DEFECTS OR DAMAGE TO VACUUM TUBES

By Paul M. Reyling
Manager of Production and Engineering
Freeland & Olschner Products, Inc.

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 Kv. source, operated from a 110 volt a.c. plug, completely portable, and small enough to hold with one hand.

In use, the tip of the coil is placed against the external bulb surface of the tube in question, far enough away from all external metal parts so that no arc can be struck externally. Any glow observed within 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.

These simple tests, performed prior to placing a tube in service, will prevent serious damage to the tube, save much time and trouble in making the actual tube replacements, and allow rebuilding of the tube much more readily by competent manufacturers. This is particularly true of large water-cooled tube types.

The outlined 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 defects. It is highly desirable to follow this procedure *immediately* on receipt of all tubes to facilitate handling of possible damage claims.

This 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.

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

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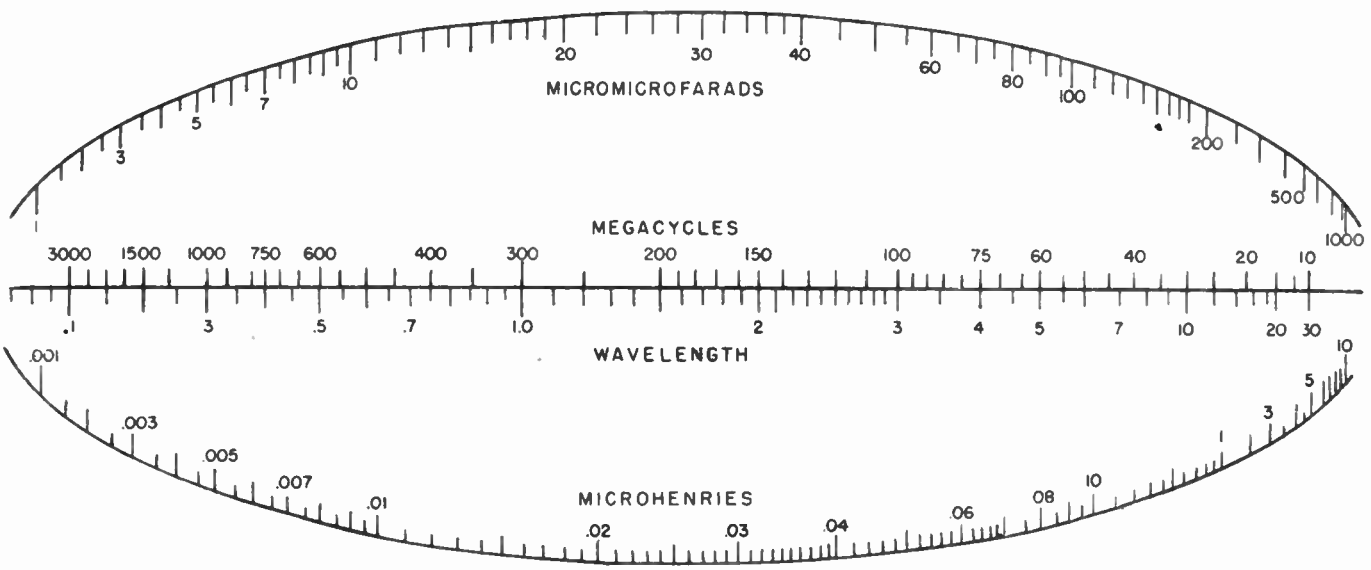
CHART I -- Nomographic chart of LC values in the short wave range



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.

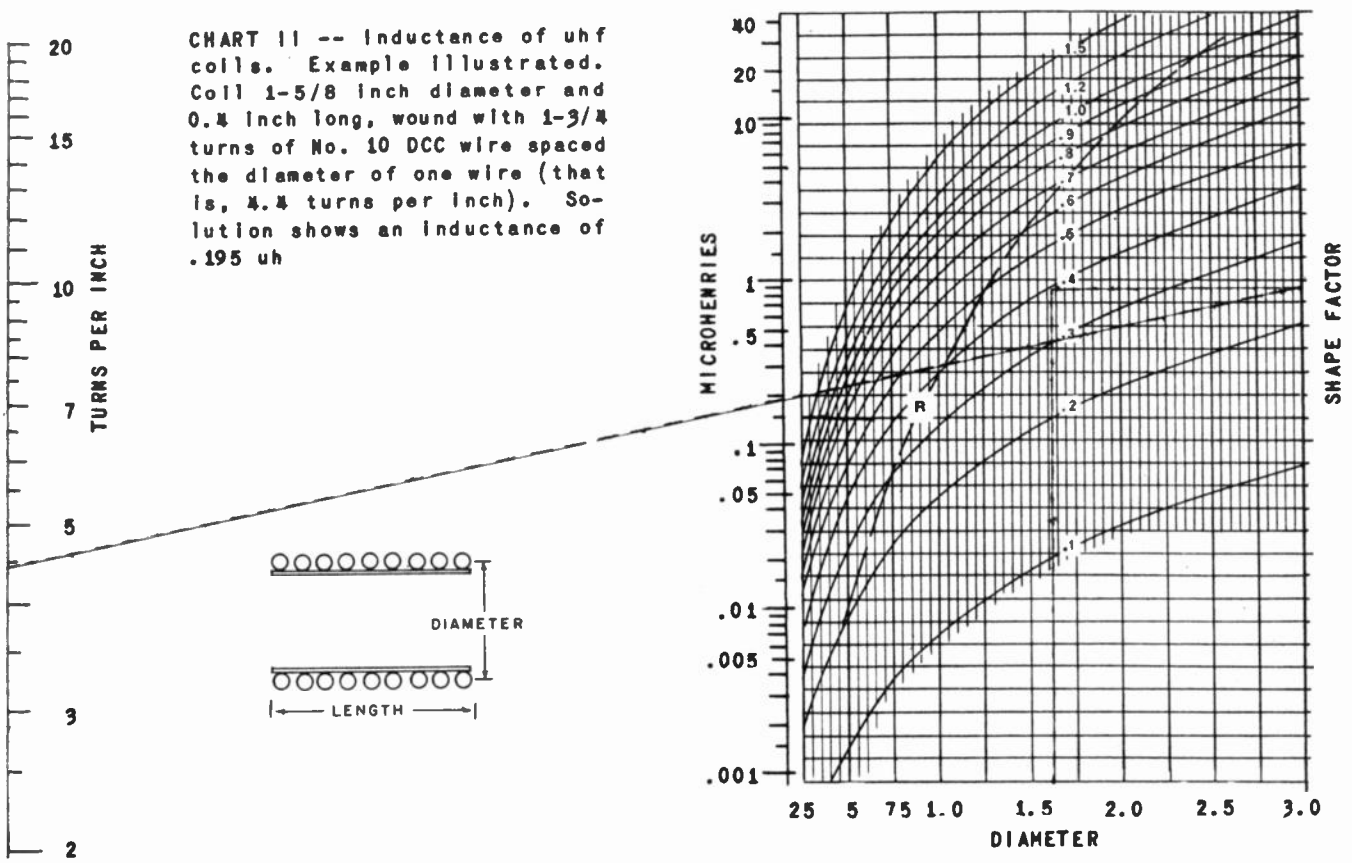
Coil Dimension Factors

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 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/1 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.

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



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,

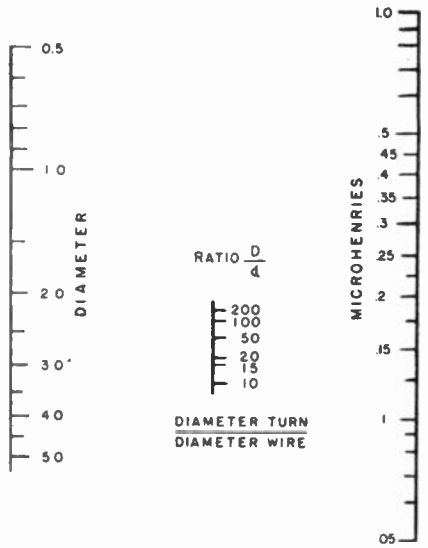


CHART III -- Nomographic charts showing inductance of single turn loops

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.

PRACTICAL ANALYSIS OF UHF, TRANSMISSION LINES, RESONANT SECTIONS, RESONANT CAVITIES & WAVE GUIDES

By J. R. Meagher & H. J. Markley
Field Engineers

(Reprinted by permission of RCA Service Company, Inc.)

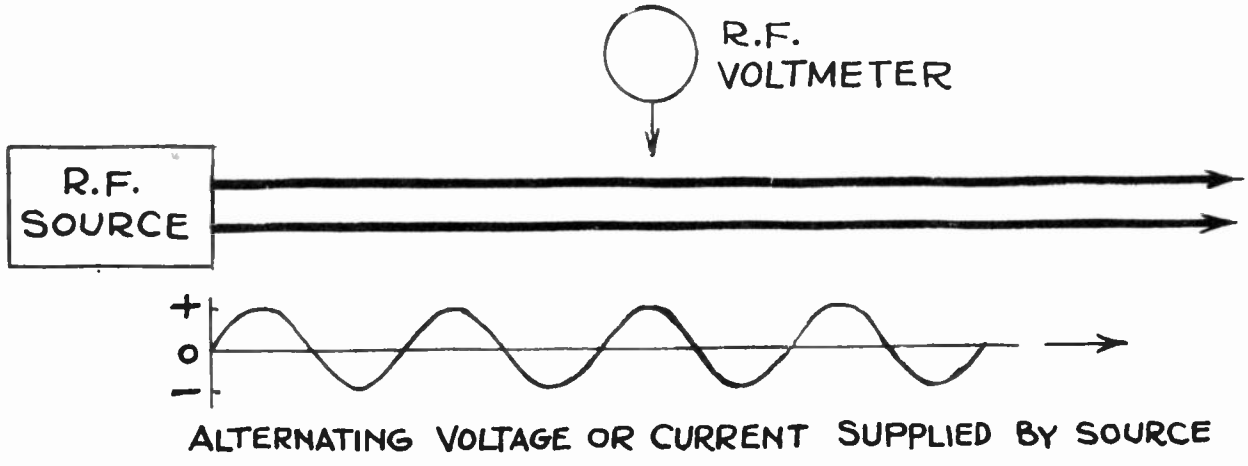
PREFACE

The purpose of this paper is to cover some practical aspects of transmission lines, resonant sections, wave guides and resonant cavities, without becoming involved mathematically. This material is intended as an aid in bridging the gap between the low frequency and ultra-high frequency spectrums, and to give the reader at least a "discussion knowledge" of the subject covered. This data has been compiled for the most part from practical field experience. Additional data on these subjects may be found in numerous books covering these subjects in greater or less detail. Several curves that are in common usage have been included.

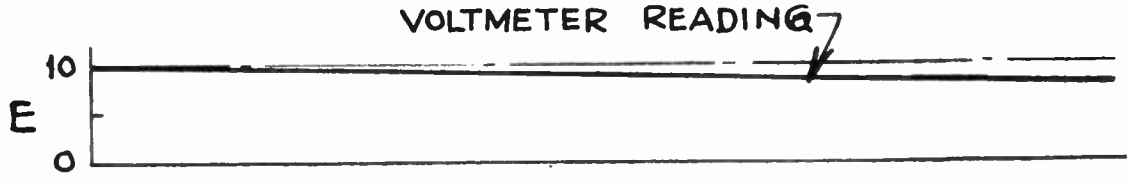
For simplicity, most of the illustrations show parallel wire transmission lines. The information, however, also applies to coaxial lines.

TRANSMISSION LINES AND TUNED RESONANT SECTIONS

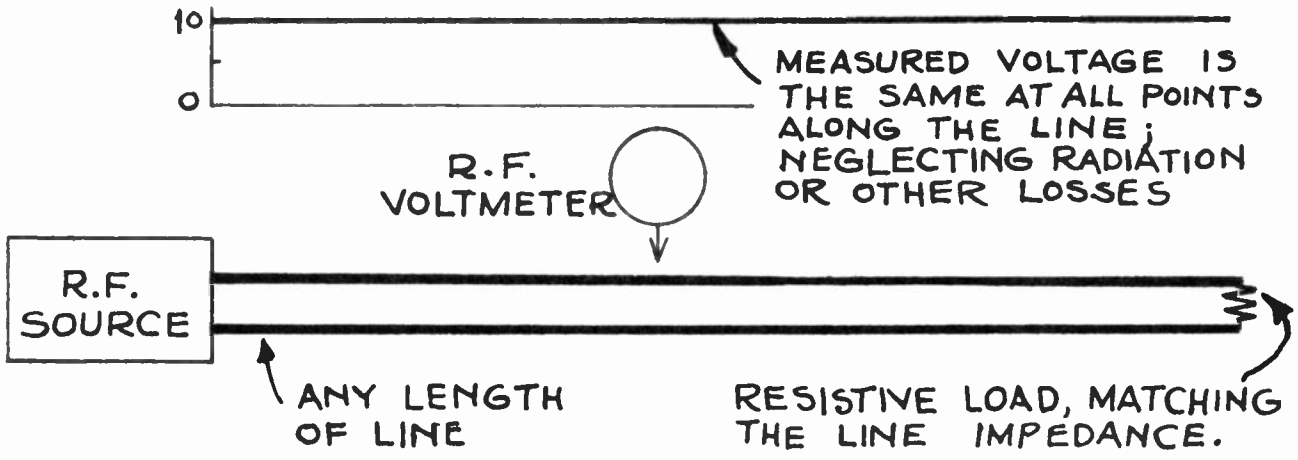
STANDING WAVES



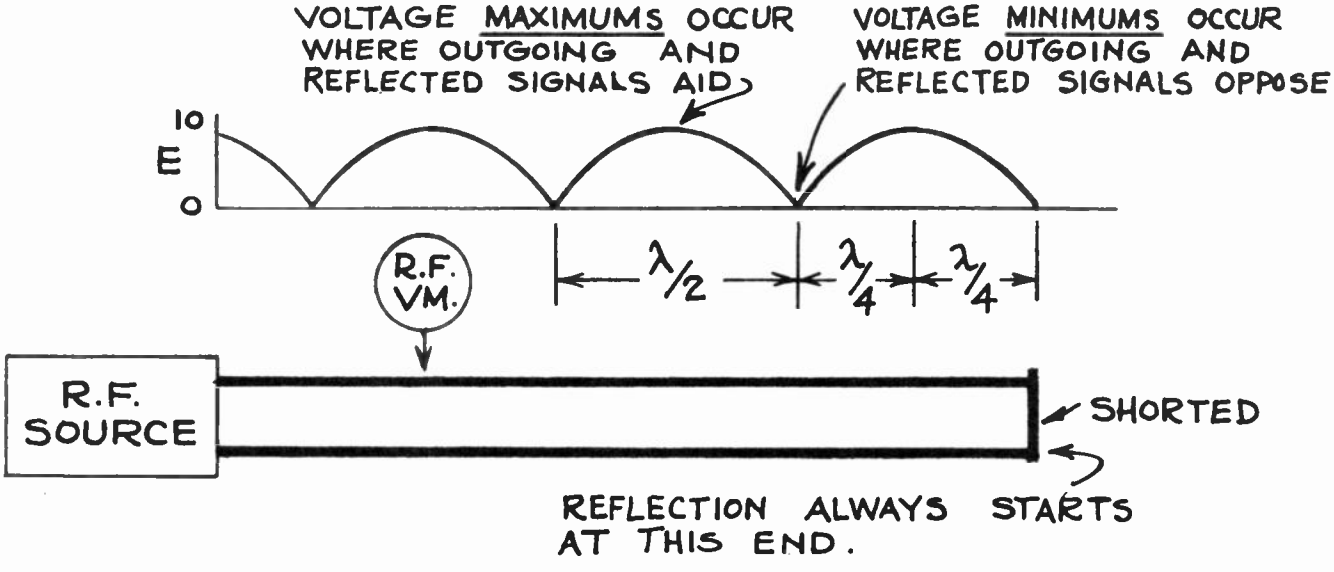
On an infinitely long line, a rapid succession of peaks and nodes passes the RF voltmeter, (which indicates some average value) which will fall off in magnitude slowly due to the attenuation (loss) of the line as the distance from the source increases.



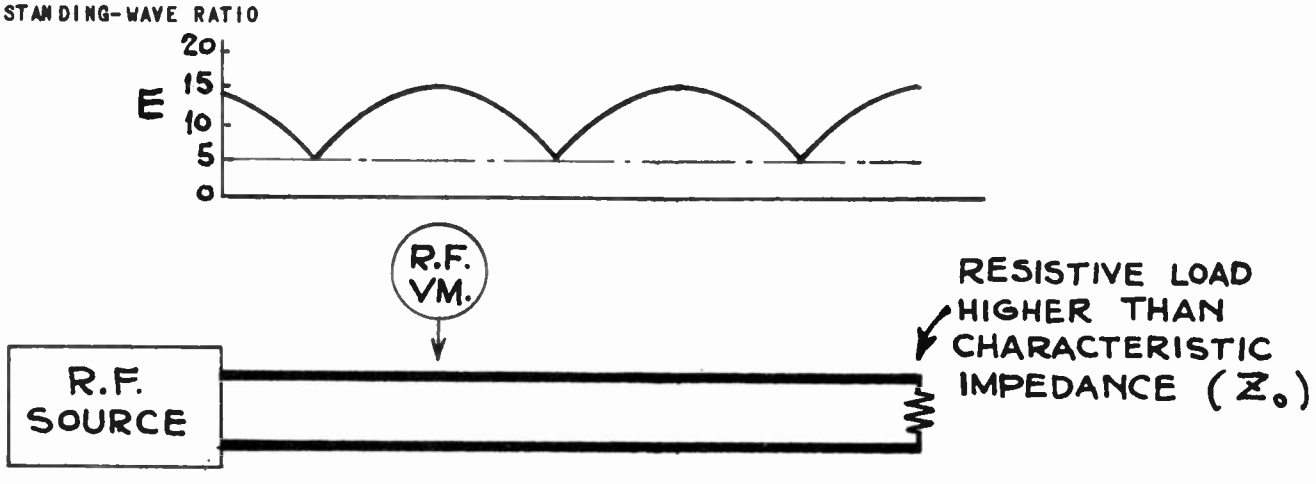
If the line is infinitely long, the signal never reaches the end, and therefore cannot be reflected, so there are no "standing waves". The RF voltage measured along the line gradually decreases due to losses in the line.



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.



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*, as shown above.



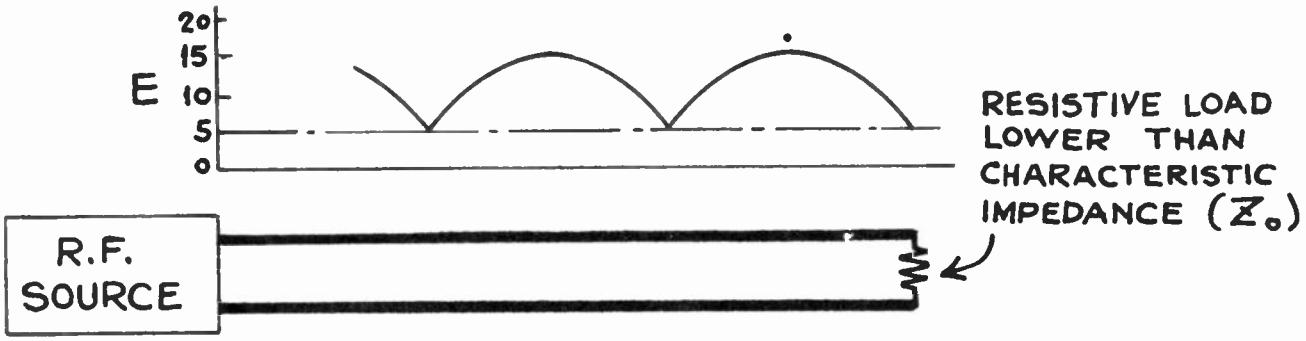
The standing-wave ratio = $\frac{\text{Maximum Voltage}}{\text{Minimum Voltage}}$

this ratio indicates the ratio of mismatch of the load impedance (or line to load).

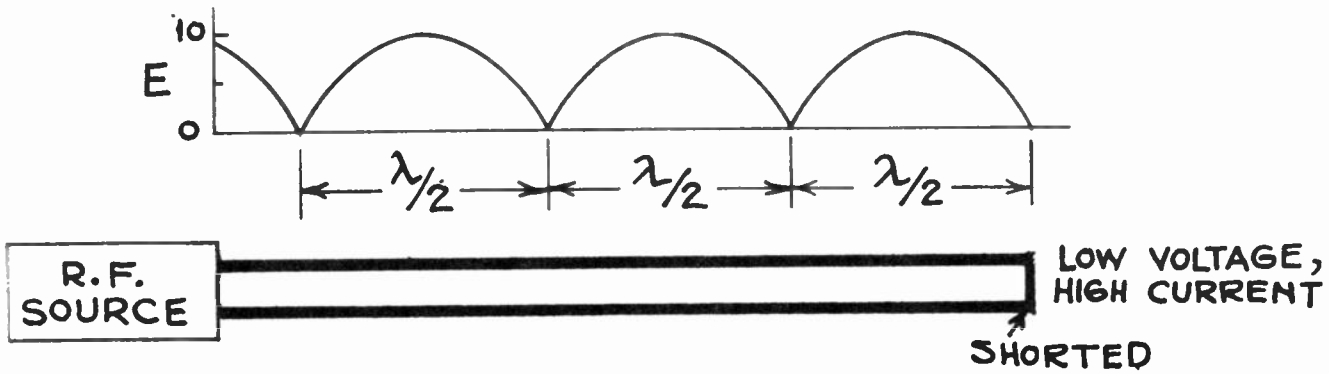
In the example shown above, the voltage at minimum's is 5, and the voltage at maximum's is 15. The ratio is $\frac{15}{5}$ or 3 to 1.

Therefore, the load impedance is either 3 times larger than the line impedance, or one-third of the line impedance. (In this particular example, the voltage at the load is maximum, so the load impedance is higher than the line impedance.)

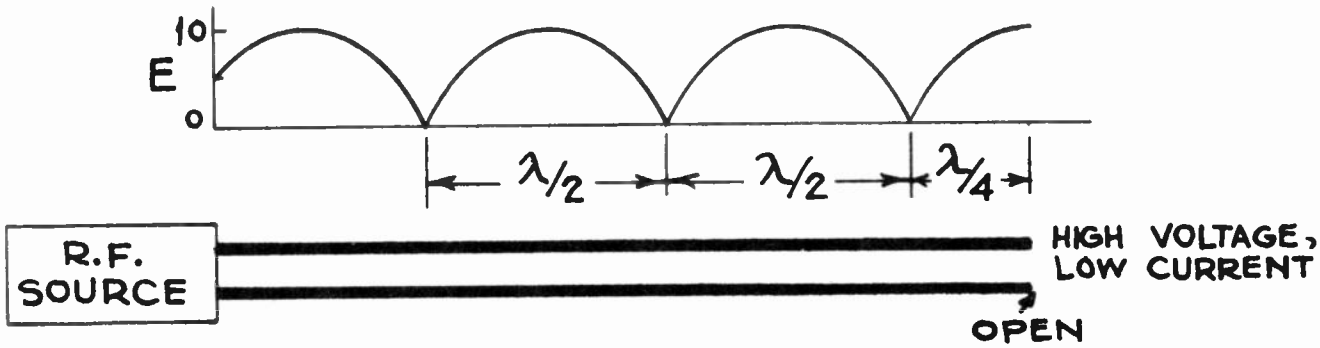
If the standing-wave ratio is 2 to 1, the ratio of load and line impedance is 2 to 1, etc.



POSITION OF VOLTAGE MINIMUM'S AND MAXIMUM'S

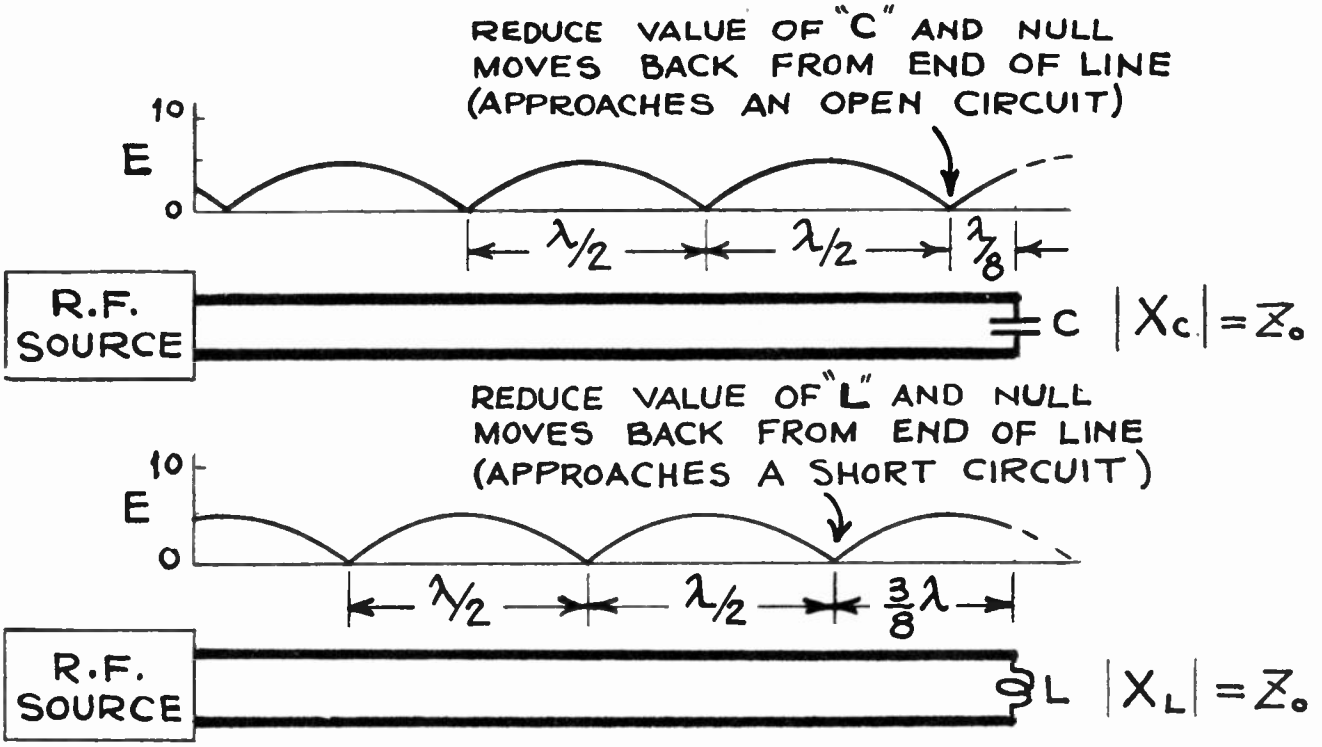


If the end of the line is shorted, the voltage at the short is low and the current is high. The first voltage minimum occurs one-half-wave back from the end of the line.



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 one-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.

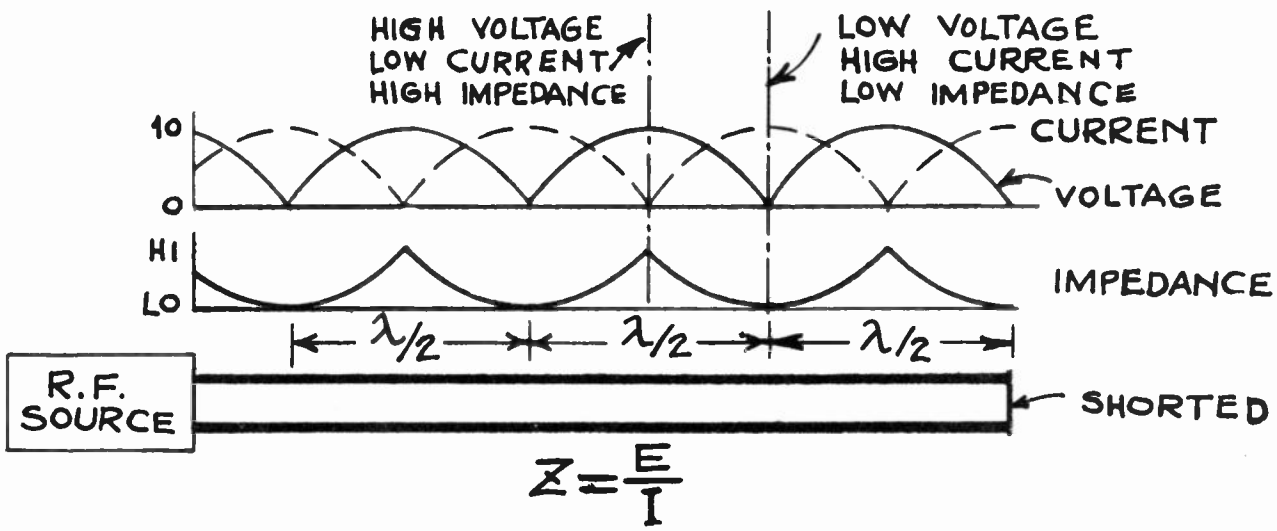


Often it is desirable to speak of electrical degrees rather than fractions of a wavelength:

$\lambda/8 = 45°$	$\lambda/2 = 180°$	$7/8\lambda = 315°$
$\lambda/4 = 90°$	$5/8\lambda = 225°$	$\lambda = 360°$
$3/8\lambda = 135°$	$3/4\lambda = 270°$	

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

(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.

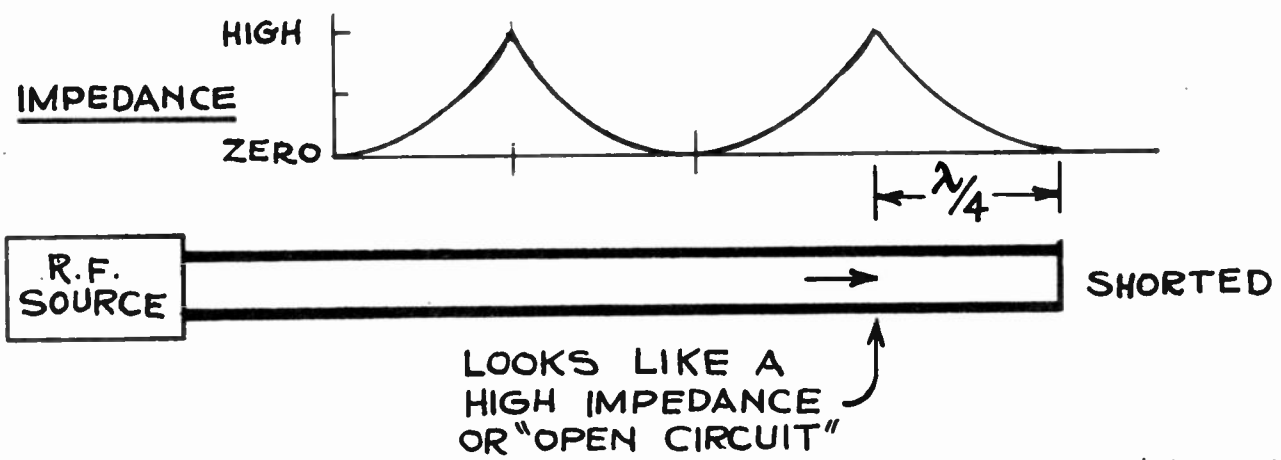
In most applications where a line is used to connect a signal source to a load (for instance, to connect a transmitter to an antenna) it is generally desirable to make the load match the line. *If the load is not matched, the length of the line becomes critical,* and incorrect length may affect the power output and frequency of the source. *When the load is matched to the line, the line may be cut to any reasonable length.*

USING LINES AS TUNED CIRCUITS

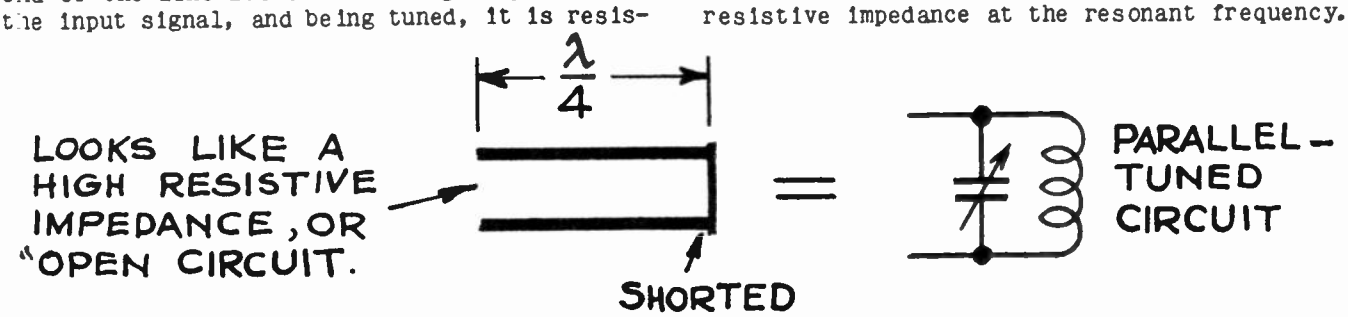
When sections of line are used as tuned circuits, their action depends on the existance of reflections and standing-waves to produce the effect of high-impedance and low-impedance tuned circuits. Therefore, sections of lines, when used as tuned circuits or transformers are either effectively shorted 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.

We will now consider one-quarter-wave and one-half-wave sections, and their action as tuned circuits. This can be explained on the basis of the change in impedance produced by standing-waves along an opened or shorted line.

QUARTER-WAVE SHORTED SECTION

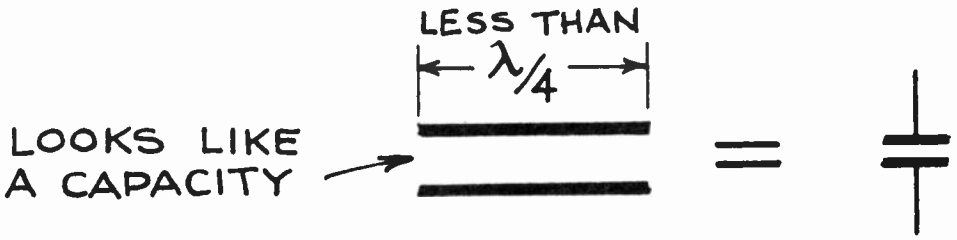


The quarter-wave shorted section at the end of the line looks like a high-impedance to the input signal, and being tuned, it is resistive. The equivalent conventional circuit is a parallel-tuned circuit for it also has high resistive impedance at the resonant frequency.

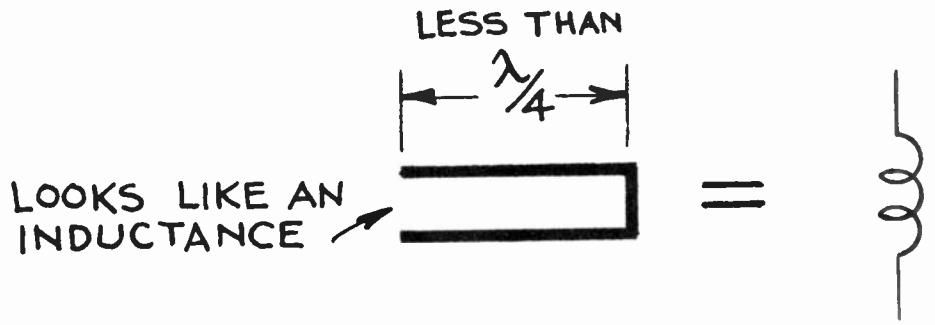


The action of this section may also be explained as follows:

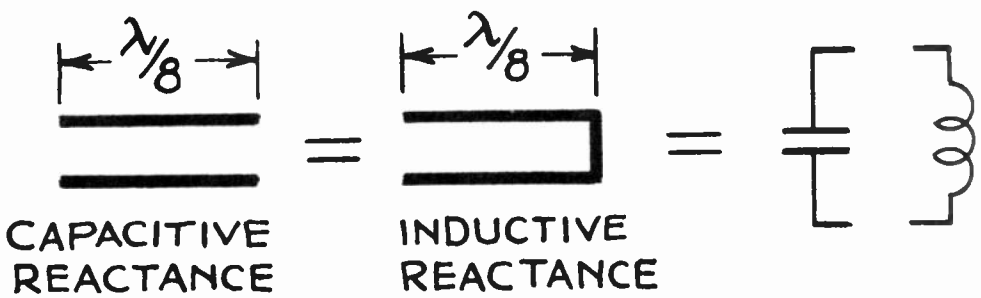
A section of line open at each end and less than one-quarter wave long acts like a capacity:



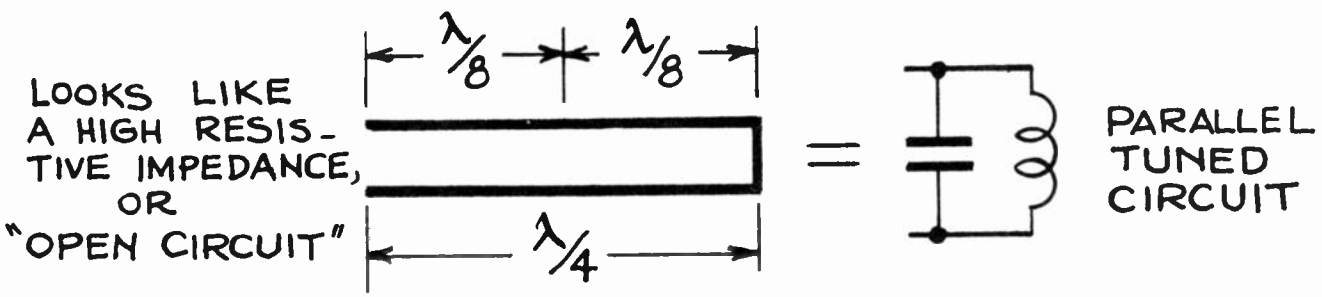
A section of line shorted at one end and less than one-quarter wave long acts like an inductance:



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. And the values of these reactances are equal to the characteristic (based on size of conductor and spacing) impedance.

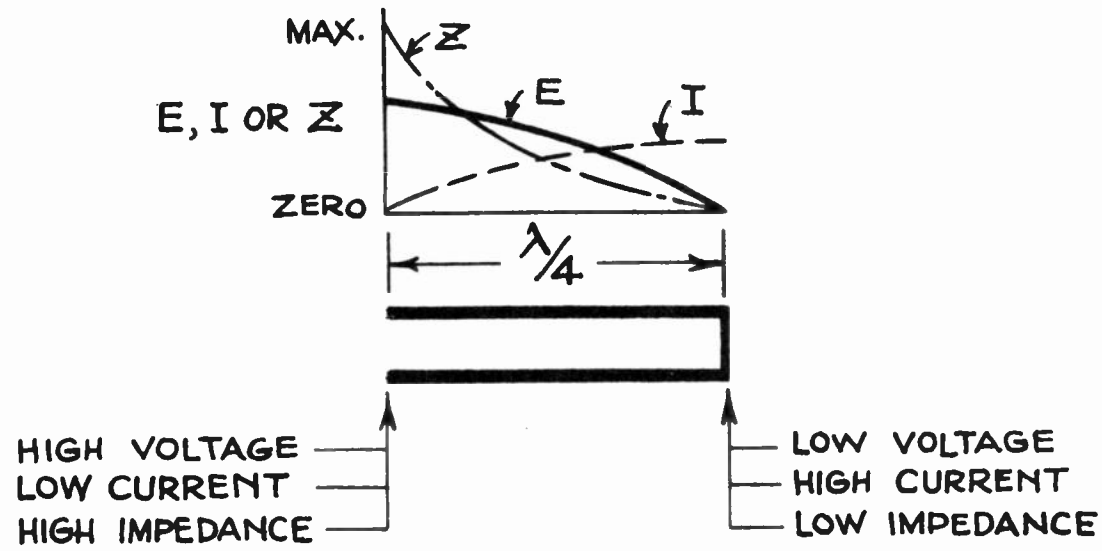


If the two sections are combined, the result is a resonant circuit that has high-resistive impedance, like a parallel-tuned circuit:

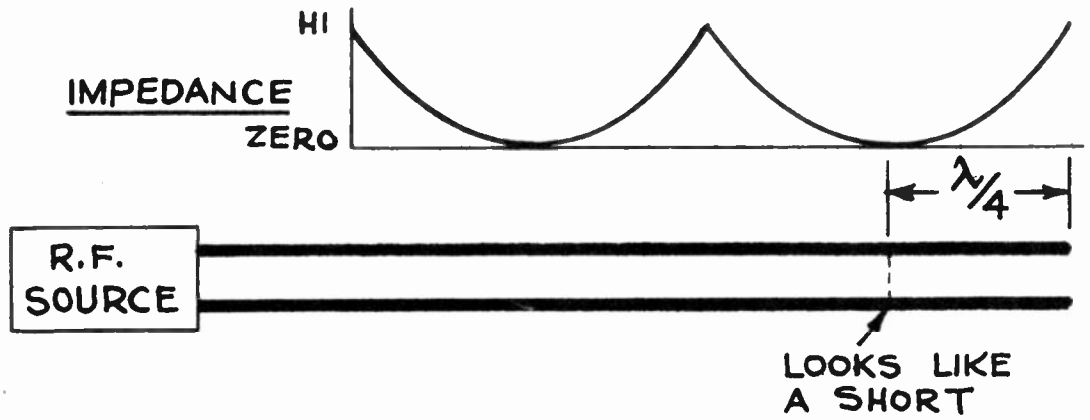


(This example is given because it is simple to visualize. Naturally, any two sections that add in length to equal one-quarter-wave electrically will have equal reactance and will produce the same result.)

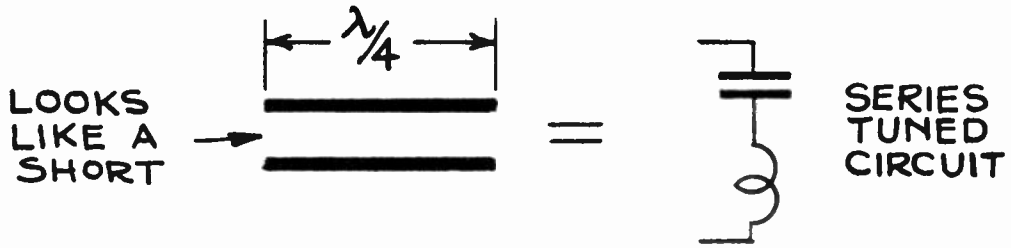
The voltage, current, and impedance relations for a quarter-wave section are shown below:



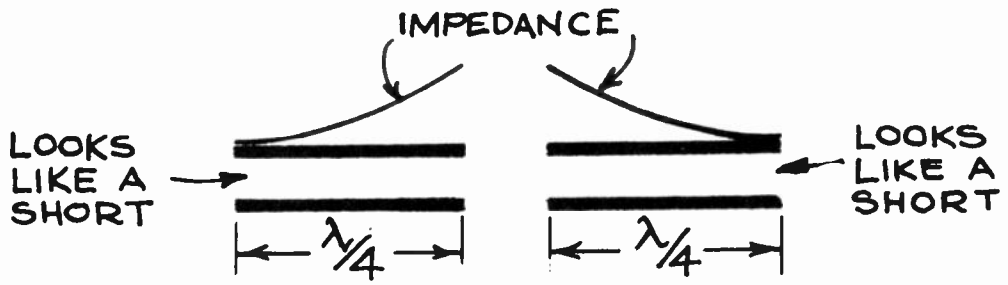
QUARTER-WAVE OPEN SECTION



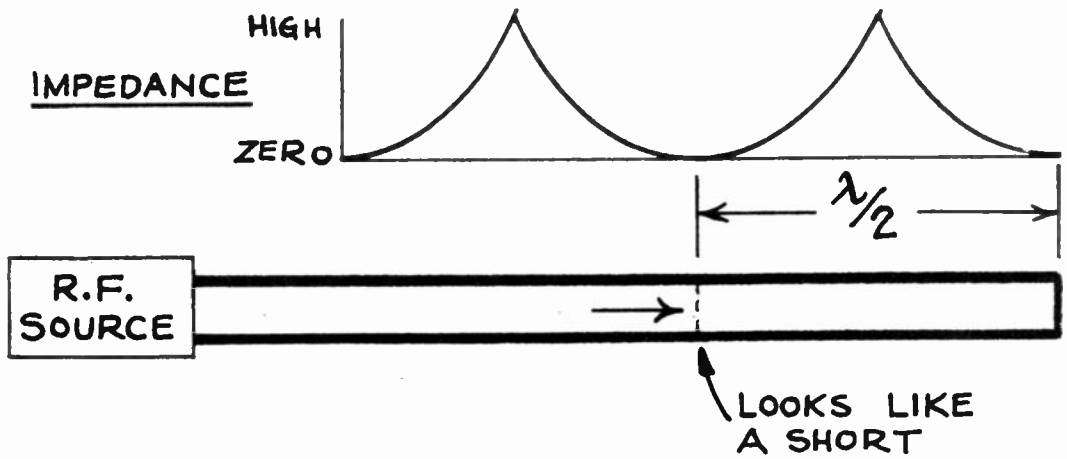
The quarter-wave section at the end of the line has very low input impedance, and, being tuned, it is resistive. It is equivalent to a conventional series-tuned circuit.



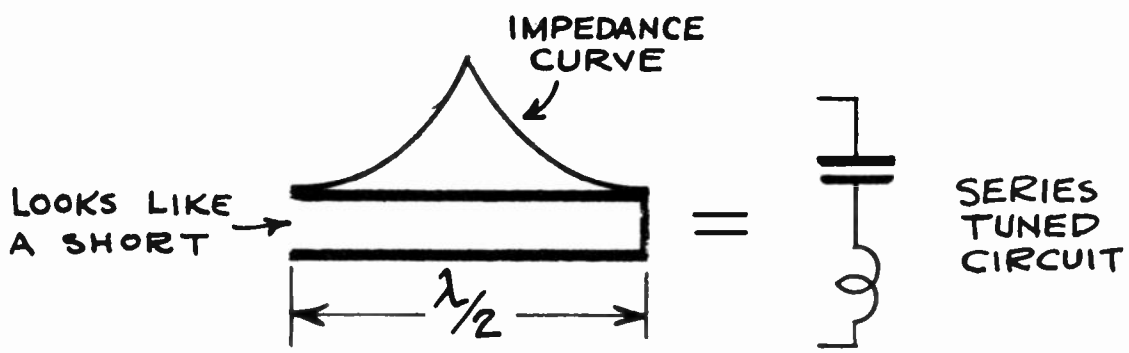
The question may be asked, "Does this quarter-wave open section look like a high-impedance on the other end?" The answer is that it looks like a short *to the input*, regardless of which end the input is applied to:



HALF-WAVE SHORTED SECTION



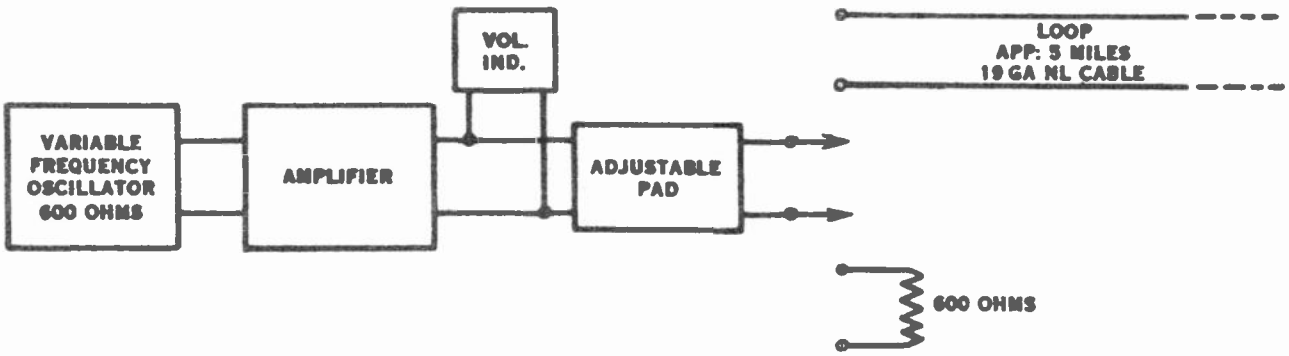
The half-wave shorted section at the end of the line also has low resistive input impedance. It corresponds to a series-tuned circuit.



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.

TESTING ARRANGEMENT



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.

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

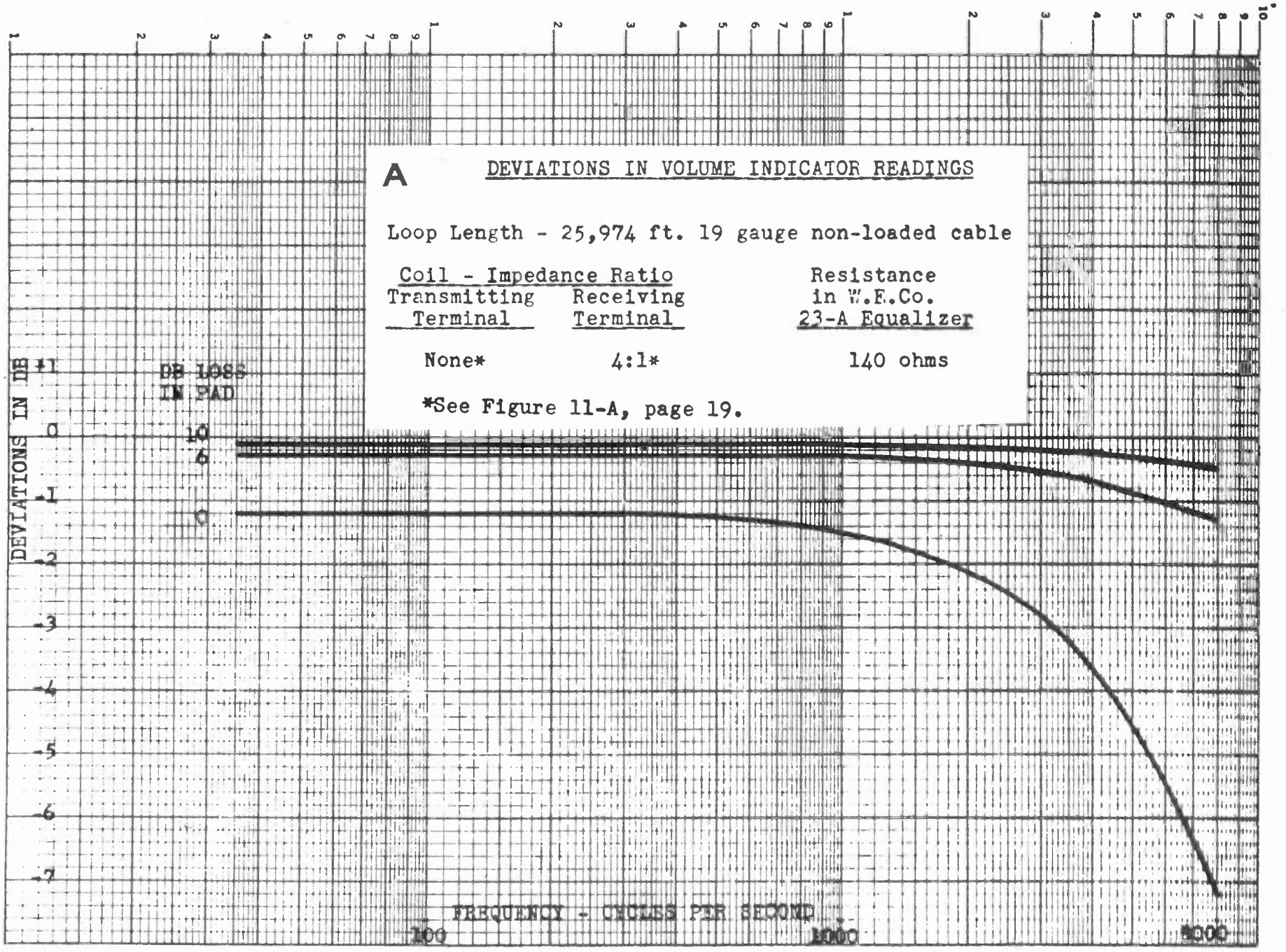
The results of these tests are shown by the four accompanying sets of curves. Deviations identified by (+) indicate that the readings were higher for the loop than for the 600-ohm termination. It can be seen that the deviation can be reduced to a small amount (about .3 db) by use of a 6 db transmitting 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.

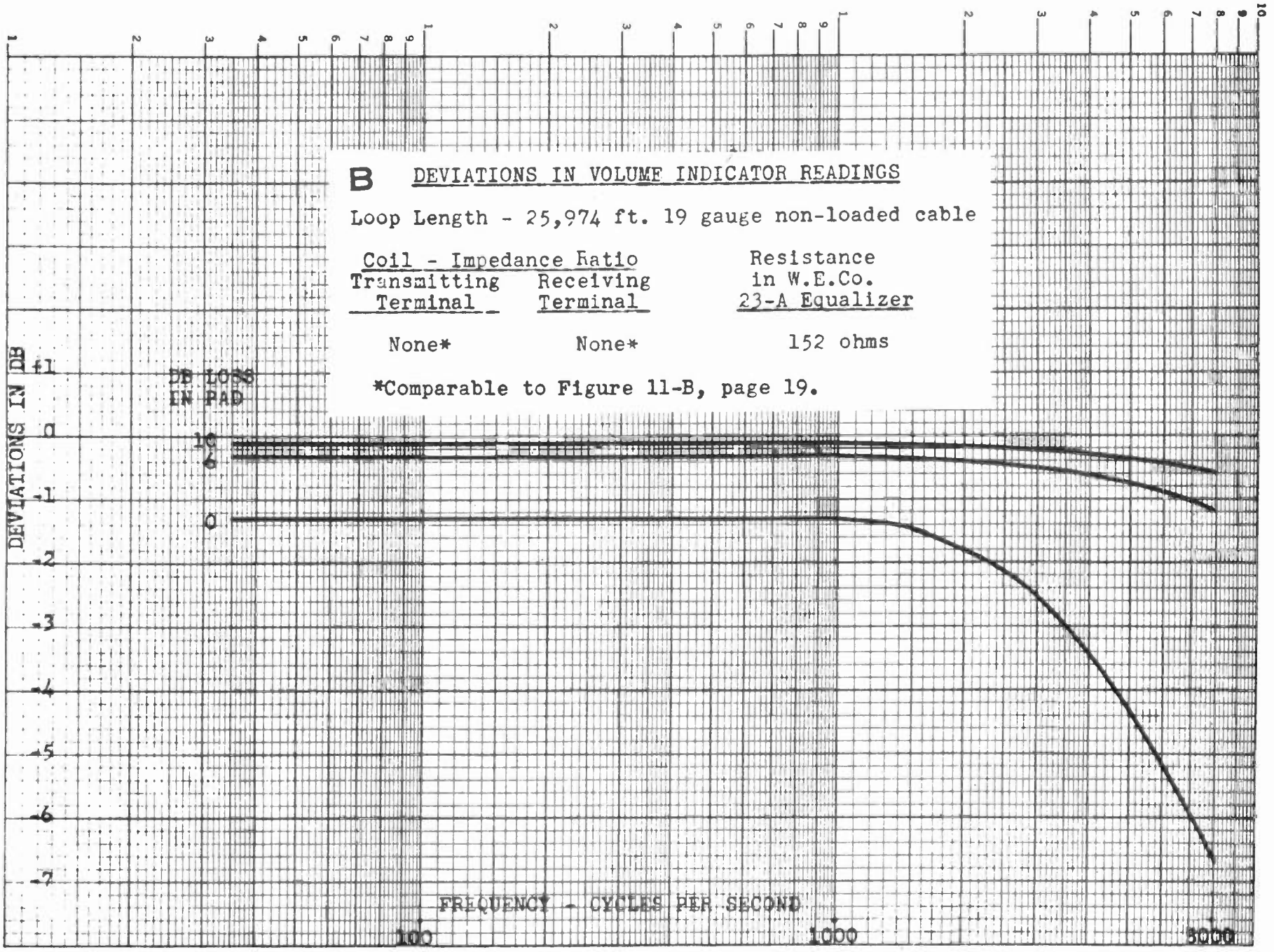
Note: The data obtained from these tests apply strictly to the specific loop tested. Loops of other makeups would show the same tendencies but the magnitudes of the effects might be different. For example, a loop of considerable length containing smaller than 19 gauge conductors would normally produce volume indicator readings greater than the 600-ohm termination, even with the transmitting coil omitted.

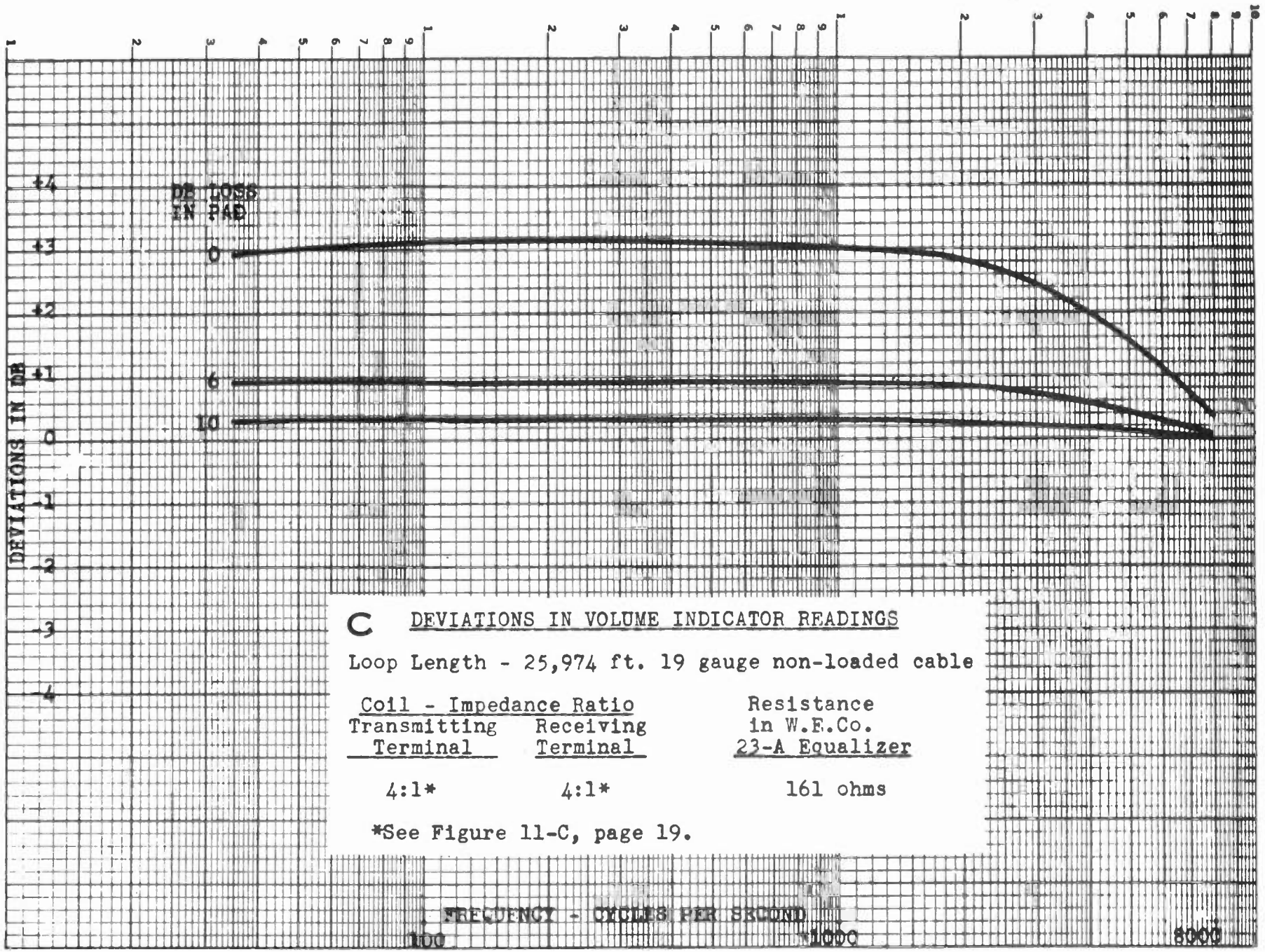
APPENDIX

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


A
DEVIATIONS IN VOLUME INDICATOR READINGS
Loop Length - 25,974 ft. 19 gauge 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 11-A, page 19.
DEVIATIONS IN DB
+1
0
-1
-2
-3
-4
-5
-6
-7
DB LOSS IN PAD
10
6
0
FREQUENCY - CYCLES PER SECOND
100
1000
5000


B DEVIATIONS IN VOLUME INDICATOR READINGS
Loop Length - 25,974 ft. 19 gauge 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 11-B, page 19.
DEVIATIONS IN DB
+1
0
-1
-2
-3
-4
-5
-6
-7
DB LOSS IN PAD
10
6
0
FREQUENCY - CYCLES PER SECOND
100
1000
5000

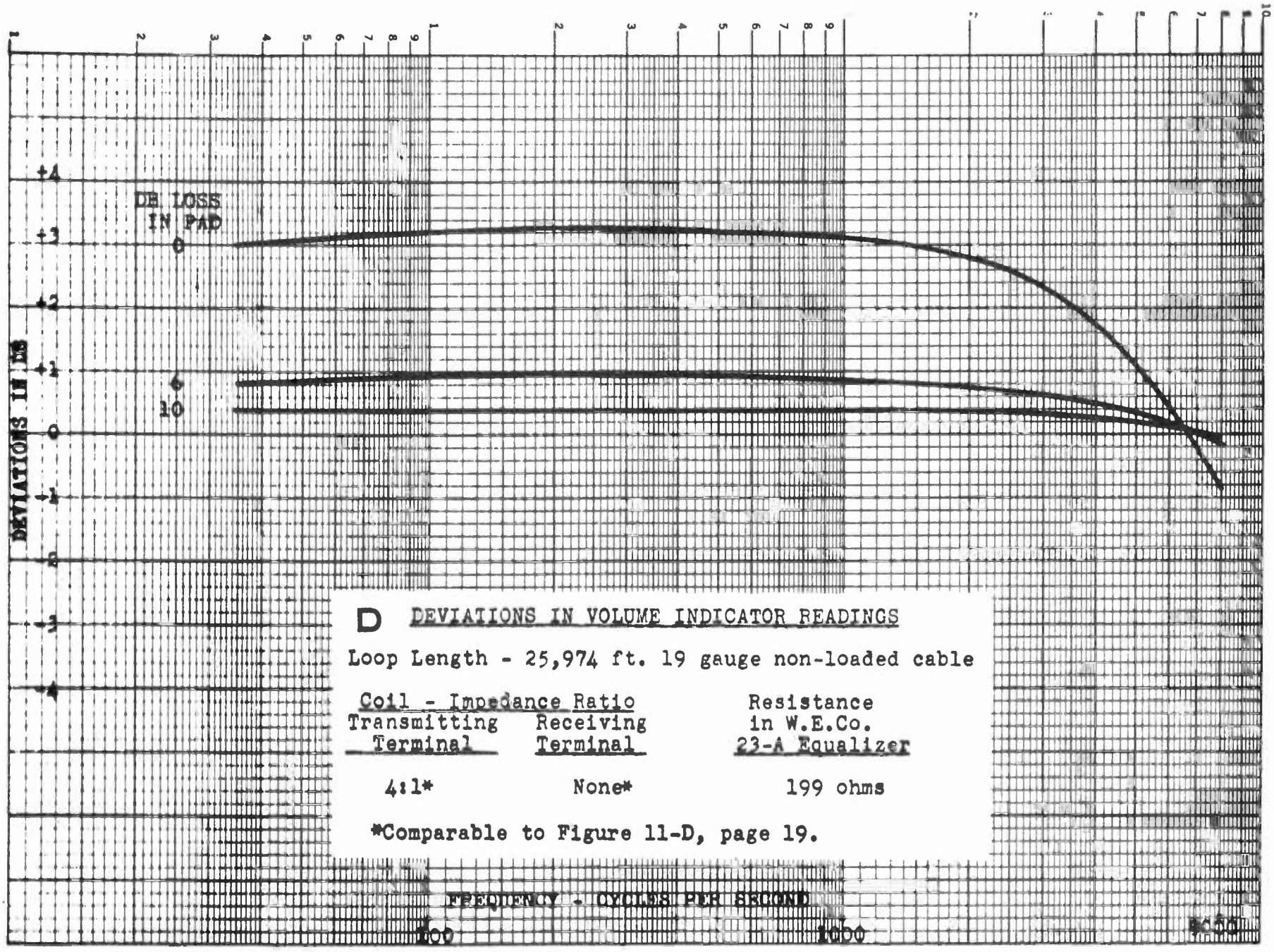


C DEVIATIONS IN VOLUME INDICATOR READINGS

Loop Length - 25,974 ft. 19 gauge 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 11-C, page 19.



D DEVIATIONS IN VOLUME INDICATOR READINGS

Loop Length - 25,974 ft. 19 gauge non-loaded cable

Coil - Impedance Ratio		Resistance
Transmitting Terminal	Receiving Terminal	in W.E.Co. 23-A Equalizer
4:1*	None*	199 ohms

*Comparable to Figure 11-D, page 19.

THE MEASUREMENT OF AUDIO DISTORTION

By H. H. Scott, Technology Instrument Corporation

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 as generally used 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 annoying in real high-quality reproduction.

The conventional practice has been to measure non-linear distortion in terms of the harmonic components added to a single frequency test-tone 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 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 $\pm$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 circuit, 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 $\pm$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 rss 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 push-button operated R-C feedback type, 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 oscillators of this type the standard push-button 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. This is the only commercial oscillator with a low enough distortion 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 continuously tunable R-C type as commercially produced generally has a somewhat higher distortion through the medium-frequency range than the better grades of beat-frequency oscillators. 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 generally available two-tone distortion tests will become quite generally used, particularly in cases where high amounts of distortion are encountered, since it is generally 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. 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 on 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. Need-

less 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.

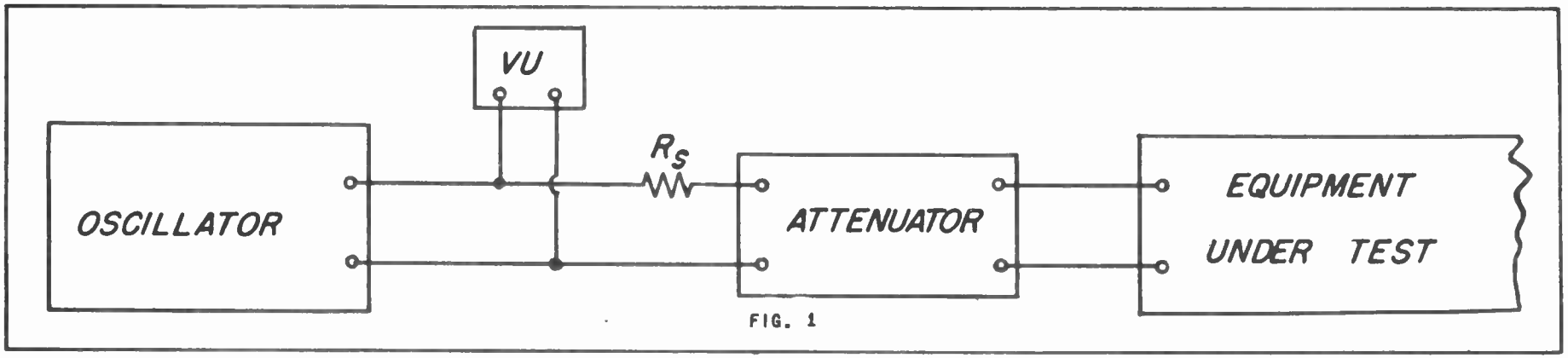


FIG. 1

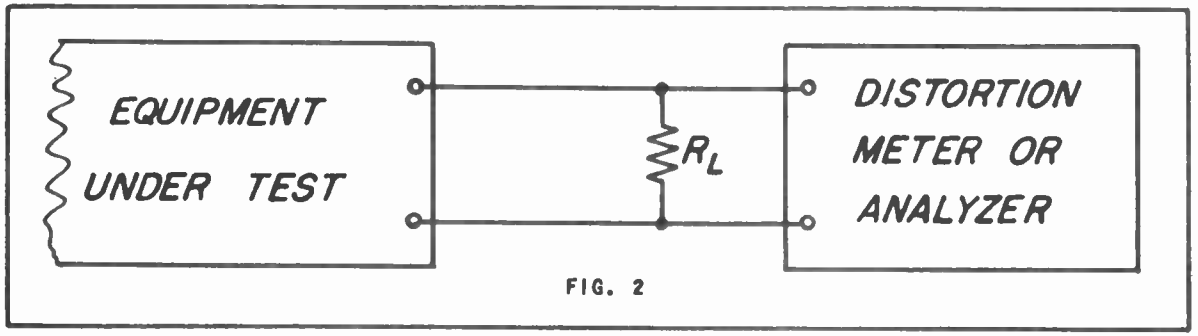


FIG. 2

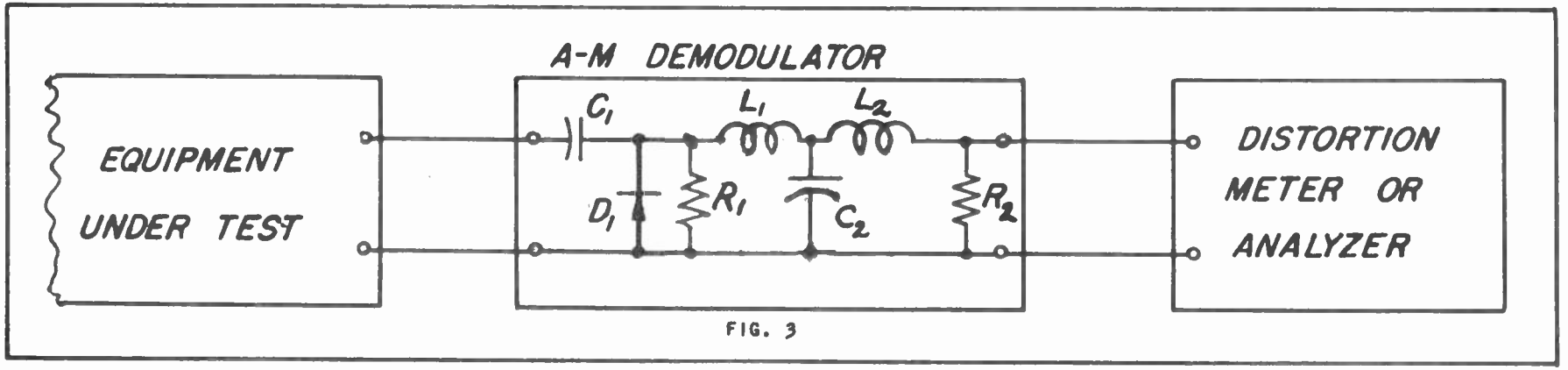


FIG. 3

GLOSSARY OF DISK-RECORDING TERMS

By Howard A. Chinn,
General Engineering Dept., Columbia Broadcasting System
(Reprinted from the Proceedings of the Institute of Radio Engineers, November, 1945)

INTRODUCTION

During 1941 the Engineering Committee of the National Association of Broadcasters formed a Recording and Reproducing Standards Committee for the purpose of formulating standards for electrical transcription and recordings made for radio broadcasting. Sixteen technical standards and good engineering practices were adopted[1] and are now followed by the industry.

A number of other items were under study by subcommittees and one additional item was completed before the war interrupted all activity in this field. The item in question is a glossary of disk-recording terms prepared by Subcommittee III and approved by the Executive Committee. This material has never been published, however, and in view of the potential post-war interest in recording, it seems opportune that the glossary be made available generally, particularly since it is not believed that material of this type exists elsewhere in the literature.

The members of the subcommittee which prepared the glossary consisted of H. A. Chinn, Columbia Broadcasting System, Inc., Chairman; E. J. Content, WOR; C. Lauda, World Broadcasting System; and G. E. Stewart, National Broadcasting Company.

GLOSSARY OF TERMS PERTAINING TO CONSTANT-ROTATIONAL-SPEED DISK RECORDING

Abrasive: The grinding material sometimes incorporated in record stock for the purpose of shaping the needle point to fit the groove properly.

Acetate disks: Various acetate compounds used for solid and laminated (which see) disks. The term is often erroneously used to describe cellulose-nitrate discs (which see).

Advance ball: A rounded support (often sapphire) attached to the recording head which rides on the discs to maintain a uniform mean depth of cut by correcting for small variations in the plane of the disc surface.

Angle of groove: The angle from wall to wall of an unmodulated groove in a radial plane perpendicular to the surface of the disk.

Backed stampers: A thin, metal matrix (which see) which is attached to a backing material, generally a metal sheet 1/8 inch to 1/4 inch thick.

Binder: A resinous material which causes the various materials of a record compound to adhere to one another.

Biscuit: A small slab of the stock material, from which records are pressed, as it is prepared for use in the presses.

Blank groove: A groove upon which no modulation is inscribed.

Burnishing surface (of cutting stylus): The portion of the cutting stylus directly behind the cutting edge which smooths the groove.

Burnishing tool: The stylus sometimes used to smooth the groove of a recording.

Cake wax: A thick disk of wax (which see) upon which an original recording is inscribed.

Capacitor pickup: A phonograph pickup which depends for its operation upon the variation of its capacitance.

Carbon-contact pickup: A phonograph pickup which depends for its operation upon the variation in the resistance of carbon contacts.

Cellulose-nitrate disks: See lacquer disks.

Center hole: The hole in the center of the record, which fits the center pin of the turntable.

Center pin: The shaft protruding from the center of the turntable used for centering the record.

Chip: The material removed from the disk by the recording stylus in cutting the groove.

Christmas-tree pattern: A term sometimes used in referring to the optical pattern (which see).

Condenser pickup: See capacitor pickup.

Constant amplitude: Recordings wherein all frequencies of the same intensity are inscribed at the same amplitude.

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[1] L. C. Smeby, "Recording and reproducing standards," Proc. I.R.E., vol. 30, pp.355-356; August, 1942.

Constant velocity: Recordings wherein frequencies of a given intensity are inscribed with the same maximum velocity of the cutting stylus.

Core: The central layer or basic support of certain types of laminated disks. (See laminated and lacquer disks.)

Crossover frequency: See transition frequency.

Crossover spiral: Same as spread groove (which see).

Crystal pickup: A pickup which depends for its operation on the piezoelectric effect of certain (generally Rochelle salt) crystals.

Cutter: An electromechanical transducer which transforms electric energy into mechanical motion which is inscribed into the original record by the cutting stylus. Also known as recording head.

Cut double (triple, etc.): Make two (three, etc.) original recordings simultaneously.

Cutting stylus: The cutting tool which cuts the groove into the original record.

Damping: See mechanical damping.

Drive pin: A pin similar to the center pin, but located to one side thereof, which is sometimes used to prevent the record from slipping on the turntable.

Drive-pin hole: A hole in the record which fits over the turntable drive pin.

Dubbing (in a cutting stylus): Same as burnishing surface (which see).

Dubbing (in recording): A recording made by re-recording from one or more records.

Dulling: Forming the burnishing surface of the cutting stylus.

Duping: To make duplicates by re-recording.

Dynamic pickup: A phonograph pickup in which the electrical output results from the motion of a conductor in a magnetic field.

Eccentric circle: A blank, locked groove (which see) whose center is other than that of the record (generally used in connection with mechanical control of phonographs).

Eccentricity: The eccentricity of the recording spiral with respect to the record center hole.

Fast spiral: A blank, spiral groove having a pitch that is much greater than that of the recorded grooves.

Feedback cutter: A cutter provided with a feedback circuit (separate from the driving circuit) in which a voltage, for inverse feedback to the driving amplifier, is induced by the movement of the cutting stylus.

Filler: The bulk material of a record compound as distinguished from the binder (which see).

Flowed-wax platter: Disk base (usually metal) upon which wax is flowed.

Flutter: Frequency modulation caused by spurious variations in groove velocity.

Frequency record: A record upon which have been recorded various frequencies throughout the desired frequency spectrum.

Groove: The track cut in the record by the stylus.

Groove contour: The shape of the groove in a radial plane perpendicular to the surface of the record.

Groove speed: See groove velocity.

Groove velocity: The linear velocity of the groove with respect to the stylus.

Grouping: Nonuniform spacing between grooves.

Guard circle: An inner concentric groove inscribed on a record to prevent reproducer from being damaged by being thrown to the center of the record.

Hill-and-dale recording: See vertical recording.

Hot plate: A heated table used for (a) softening the biscuits of record material prior to placing them in the press or (b) making flowed waxes.

Instantaneous recording: A recording which may be used without further processing.

Label: The identification markings on paper or similar material, at the center of the record.

Lacquer disks: Disks, usually of metal, glass, or paper, which are coated with a lacquer compound (often containing cellulose nitrate) and used either for "instantaneous" recordings or lacquer masters.

Lacquer master: A term improperly applied to a "lacquer original" (which see).

Lacquer original: An original recording on a lacquer disk which is intended to be used for the

making of a metal master.

Laminated record: A disk composed of several layers of material. Normally used with one thin facer on each side of a core.

Land: The record surface between two grooves.

Lateral compliance: The ability of a reproducing stylus to move laterally with respect to the record groove while in the reproducing position in a record.

Lateral recording: A recording in which the groove modulation is in the plane of the record and along a radius.

Lead screw: The threaded rod which leads the cutter or reproducer across the surface of the disc.

Lead-in spiral: A blank, spiral groove at the beginning of a record, generally having a pitch that is much greater than that of the recorded grooves.

Locked groove: A concentric, blank groove at the end of modulated grooves whose function is to prevent further travel of the reproducer.

Magnetic pickup: A reproducer employing an armature placed in a magnetic field and coupled mechanically to the reproducing stylus. An electric potential is generated in a coil placed in this field when the stylus is actuated by the modulated groove of a record.

Master: The negative produced from the original recording (which see).

Master stamper: A master used as a stamper to make pressings.

Matrix: The negative from which duplicate records are molded. (See also stamper.)

Mechanical damping: The mechanical resistance which is generally associated with the moving parts of a cutter or a reproducer.

Metal master: The metal negative produced directly from the original recording.

Metal negative: Same as metal master (which see).

Metal mold: Same as matrix (which see).

Mother: A positive produced directly from the metal master or negative.

Needle (reproducing needle): A replaceable reproducing stylus (which see).

Needle drag: Same as stylus drag (which see).

Needle pressure: Same as stylus pressure (which see).

Optical pattern: The pattern which is observed when the surface of a record is illuminated by a beam of parallel light.

Orange peel: Mottled surface of a defective disc having an appearance similar to the skin of an orange.

Original recording: See lacquer original and wax original.

Overcutting: Excessive level in recording to an extent that one groove cuts through into an adjacent one.

Pickup: A mechanicoelectrical transducer which is actuated by the undulations of the record groove and transforms this mechanical energy into electrical energy.

Pinch effect: A pinching, or in some cases a lifting of the reproducing stylus, twice each cycle in the reproduction of lateral recordings, caused by the recording stylus cutting a narrower groove when moving across the record while swinging from a negative to a positive peak.

Playback: An expression used to denote the immediate reproduction of a recording.

Pold: The curve that the center of a sphere traces when the surface of the sphere is rolling along a sine wave.

Postemphasis: The complement in reproduction of pre-emphasis (which see).

Pre-emphasis: A method of recording whereby the relative recorded level of some frequencies is increased with respect to other frequencies.

Pressing: A record produced in a record-molding machine from a matrix or stamper.

Processing: Making the master, mother, and matrix (which see).

Recording head: Same as cutter (which see).

Re-recording: A recording made from the reproduction of a recording. (See also dubbing.)

Reference recording: Recording of a program or other material made for the purpose of checking same.

Reproducing stylus: The "needle" or jewel which follows the undulations in the record groove and transmits the mechanical motion thus derived to the pickup mechanism.

Rumble: Low-frequency vibration mechanically

transmitted to the recording or reproducing turntable and superimposed on the reproduction.

Safety: A second recording, made simultaneously with the original, to be used for duplication should the original be damaged.

Shaving: Process of removing material from a wax disc of recording material to obtain a plane surface.

Shell or shell stamper: A thin metal matrix (generally 0.015 to 0.020 inch thick).

Spew: The excess record material which is ejected from the record press in the manufacture of pressed records.

Spread groove: A groove, with greater than normal pitch, cut between recordings of short-time duration, thus separating the recorded material into bands while still enabling the reproducing stylus to travel from one band to the next.

Sputtering: A process sometimes used in the production of the metal master, wnerein the wax or lacquer original is coated with an electrical conducting layer by means of an electrical discharge in a vacuum. Sometimes called cathode sputtering.

Stamper: A negative (generally made of metal) produced from the mother (which see) and from which the finished pressings are molded. (See also matrix.)

Stylus drag: The expression used to denote the effect of the friction between the record surface and the reproducing stylus.

Stylus force: Effective weight of reproducer or force in vertical direction on stylus when it is in operating position.

Stylus pressure: Term sometimes erroneously used to denote effective weight of reproducer or stylus force (which see).

Stylus weight: Actually stylus force (which see).

Surface noise: The noise reproduced in playing a record due to rough particles in the record material and/or irregularities in the walls of the groove left by the cutting stylus.

Throw-out spiral: A blank spiral groove at the end of a recording, generally at a pitch that is much greater than that of the recorded grooves.

Throw-out tail: End of throw-out spiral (which see).

Tracing distortion: A harmonic distortion introduced in the reproduction of records because of the fact that the curve traced by the center of the tip 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" (which see).

Tracking error: The angle (in a lateral recording) between the vertical plane containing the vibration axis of the mechanical system of the reproducer and a vertical plane containing the tangent to the record groove.

Transition frequency: The frequency at which the change-over from constant-amplitude recording to constant-velocity recording takes place.

Translation loss: The loss in high-frequency reproduction which occurs as the groove velocity decreases.

Turnover frequency: Same as transition frequency (which see).

Vertical compliance: The ability of a reproducing stylus to move in a vertical direction while in the reproducing position on a record.

Vertical recording (hill-and-dale recording): A recording wherein the groove modulation is in a plane tangent to the groove and normal to the surface of the record.

Vertical stylus force: See stylus force.

Wax: A blend of waxes with metallic soaps (also see cake wax).

Wax master: A term improperly applied to a "wax original" (which see).

Wax original: An original recording on a wax surface for the purpose of making a metal master.

William (or willy): A negative produced from a mother to produce still another mother.

Wow: A low-frequency flutter (which see).

(A) Has a minimum dimension of half a wave-length (in order to propogate a signal) but it may be greater.

(B) Is not critical except for voltage breakdown or the possibility of operation in a wrong "mode".

For this particular wave-guide, the electrostatic lines of force, and density of distribution of the E & H fields are shown in the center above. The voltage (electrostatic field) being maximum at the center and minimum at the ends. The electro-magnetic lines of force may be thought of as "whirlpools" in a plane, perpendicular to the electro-static line of force, traveling down the tube in the direction of propogation. Comparison with a quarter-wave shorted stub may clarify this picture. 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.

TYPES OF PROPAGATION

Electro-magnetic fields may be propagated down a hollow metal tube provided:

(1) The frequency is high enough.

(2) The fields have certain definite distributions.

"TM" propagation refers to transverse-magnetic propagation, and is applied to the fact there is no magnetic field (H) in the direction of propagation down the tube. The electric field (E) does have a longitudinal component in the direction of propagation. There are numerous modes of operation (or oscillation) depending upon the cross section of the hollow metal tube and how it is excited from the R.F. source. Different modes of operation are identified by sub-numerals after the letters "TM".

"TE" propagation refers to transverse-electrostatic, and is applied to the fact that the magnetic (H) field is in the direction of propagation and the electric (E) field is transverse. There are numerous modes of operation; identified as mentioned in the paragraph above. It may be of interest to note that "TEo" mode has the lowest "cut off" frequency of any, that can be transmitted through a given tube.

Wave Guides are essentially ultra-high frequency devices since the frequency must be high before a field can be transmitted (from a practical point of view) through a wave guide. A wave guide has a definite cut-off frequency as determined by the cross section of the hollow tube, and will not operate at a frequency lower than the cut-off frequency. When the guide is half a wave-length in width, the wave reflects back and forth across the guide making no progress at all (hence cut-off frequency).

Speed of propagation or "group velocity" is slower in a wave-guide than in air. It is dependent on the frequency, and the tube dimensions (width in the case of a rectangular wave guide).

Velocity of propagation (group velocity) in a given size of rectangular wave-guide:

(a) Increases as the wave-length becomes shorter since there are fewer reflections from the wave-guide walls for a given amount of forward travel (see illustration "A" below) but is always less than the speed of light.

(b) Decreases as the wave-length becomes longer (up to the cut-off frequency) since there are more reflections from the wave-guide walls for a given amount of forward travel (see illustration "B" below).

Phase Velocity (apparent speed) is greater than the speed of propagation; or the speed of travel in an unrestricted medium.

$$\text{Apparent speed} = \frac{\text{(true speed)}}{(\cos \alpha \text{ between wall and direction of travel})}$$

Thus the apparent speed is great since the waves are striking the wall at an angle.

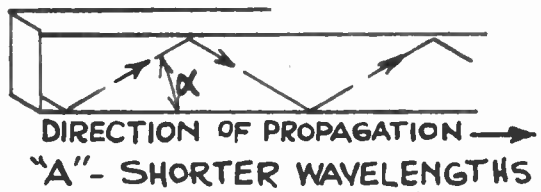
The wave-length in a hollow wave-guide is always greater than, or at the limit equal to, the wave-length in air (as measured on a slotted wave guide).

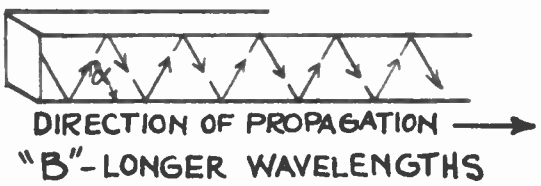
Attenuation in a given size of wave-guide (rectangular):

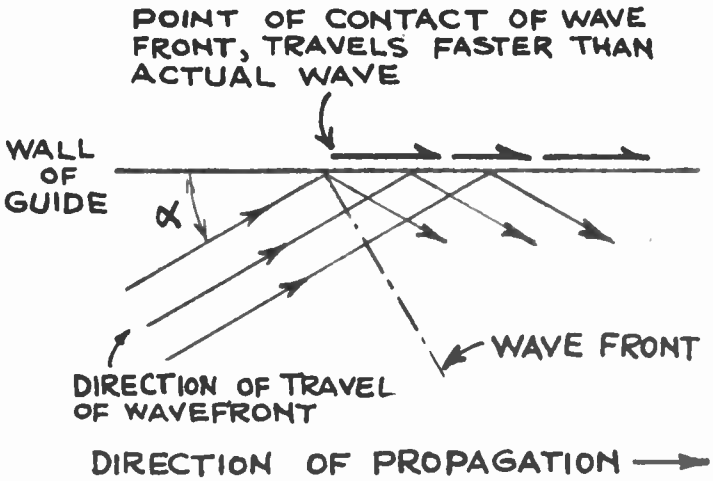
(a) As the wave-length of the signal increases toward the cut-off value, the attenuation increases since there are more reflections resulting in higher losses due to R.F. currents in the "skin" of the inside wall.

(b) At a much shorter wave-length, attenuation again increases due to increased "skin effect" at higher frequencies.

(c) There is an OPTIMUM frequency of least attenuation; however, this is usually not used because of economy reasons.







There is a different "characteristic impedance" for every mode of OPERATION. In a round wave guide the lowest characteristic impedance is about 350 ohms. In a rectangular wave guide the characteristic impedance may be any value as both dimensions are varied. The impedance is directly proportional to the narrow dimension and if the other dimension and frequency is fixed, the impedance may be anything between approximately 0 and 465 ohms.

PRACTICAL FACTS

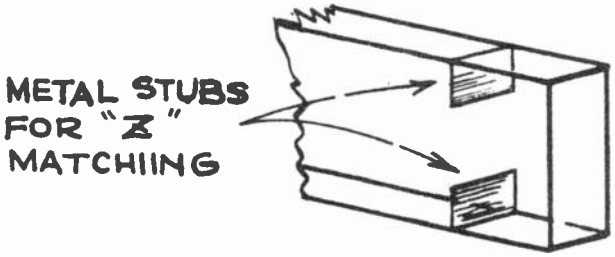
1. A quarter-wave length or odd multiples of a quarter-wave length wave guide SHORTED, reflects an "OPENING" where it joins another wave guide.

2. A half wave-length or multiples of a half wave-length, SHORTED reflects a "SOLID WALL" where it joins another wave guide.

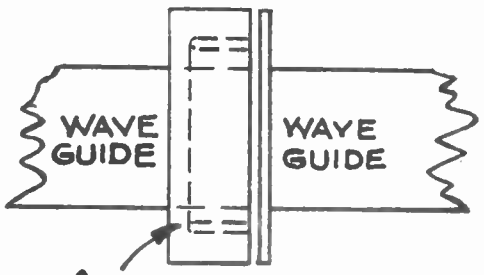
3. A quarter-wave section of wave guide inverts the impedance as with ordinary forms of transmission line.

4. A wave guide has a "characteristic impedance" which is usually rather high compared with the impedance of coaxial lines.

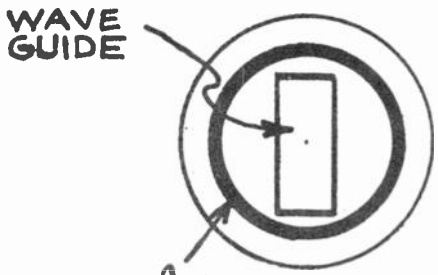
5. Impedance matching may be accomplished by using "shorting stubs". For instance, in matching to a dipole radiator. The stubs constrict the opening; may be used to "filter" out certain modes of operation.



6. Usually where two wave-guide sections are joined in such a fashion, as to be quickly removable, an R.F. choke is used:



SLOT $\lambda/4$ DEEP (CLOSED AT BOTTOM) ACTS AS R.F. CHOKE FOR R.F. SIGNAL WHICH MIGHT TRY TO "GET OUT" IN A DIRECTION PERPENDICULAR TO THE AXIS OF WAVE GUIDE.

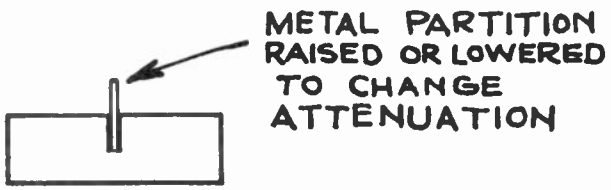


$\lambda/4$ DEEP SLOT MILLED IN CIRCULAR PIECE OF METAL BRAZED TO WAVE GUIDE.

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; in general, the larger the flare, the sharper the R.F. Signal is beamed.

8. A wave-guide attenuator, may consist of a movable metal partition as shown below; the attenuation increasing as the partition is lowered.



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 a "Littel 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 a much higher frequency, measurements are considerably more delicate.

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-wave length (about a s small as can be used.

THICKNESS - about 44% of the width.

WAVE LENGTH - 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.

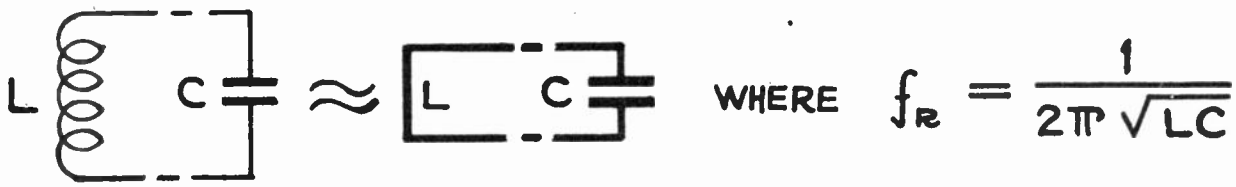
Additional wave-guide theory may be found in the books "ULTRA HIGH FREQUENCY TECHNIQUE" Chapter #14, and "MICRO WAVE TRANSMISSION", Chapter #3, etc.

CAVITY RESONATORS

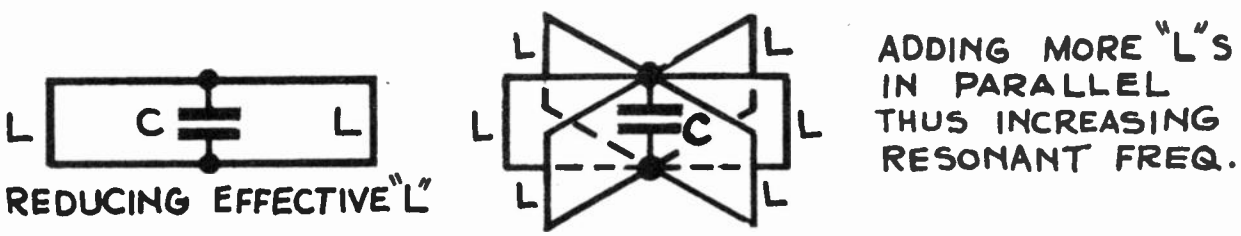
Cavity resonators are tuned resonant circuits for extremely high frequencies where it becomes impossible or impractical to use tuned lined or lumped circuits.

No unique definition of L, C, and R can be found in a cavity resonator. They are, in a sense, similar to wave-guides in that electromagnetic 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.

DEVELOPING A SIMPLE RESONANT CAVITY

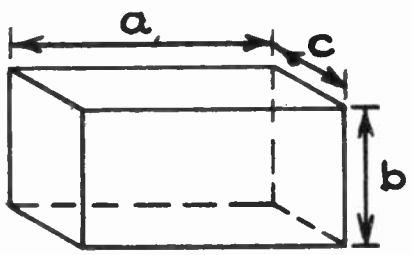


If it is desired to increase the resonant frequency, we can parallel the inductances "L", thus making the equivalent "L" quite small. There are limits as to how small "C" may be made practically, so the only thing left to do is to decrease the effective "L" of the circuit in order to tune to a higher frequency. See diagram at left below:



As shown to 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



Consider a rectangular section. The description of the "Mode" would be given in terms of electro-magnetic fields and various frequencies. Various frequencies of oscillation (different modes) are possible, because wave energy may be propogated 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.

RESONANT FREQUENCY, "Q" AND "Ro"

The resonant frequency can be calculated from the shape of the cavity for very simple types possessing symmetry.

The "Q" can be determined through knowledge of the rate at which energy is lost. A large "Q" may be obtained when the ratio of volume to surface is large. Approximate values of "Q" may be 28,000; 31,000 and 26,000, for a

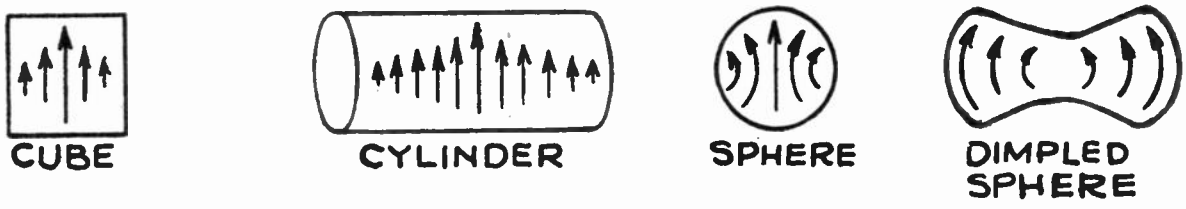
cube, cylinder, and sphere, respectively, when not loaded.

High "Q" does not necessarily imply high shunt resistance ("Ro") in a resonant cavity.

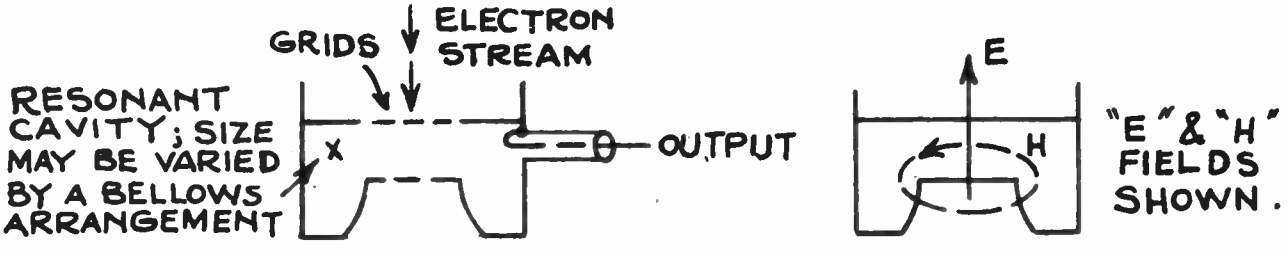
FORMS OF ACTUAL CAVITY RESONATORS

Cavity resonators may take various shapes such as, cube, sphere, cylinder, sphere dimpled on top and bottom, cylinder "dented" in one end (with ends forming grids as in a HF-tube, for instance), etc.

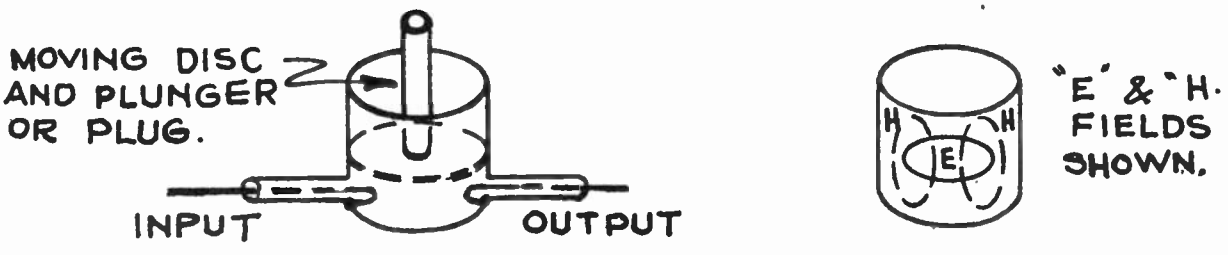
Several possible types of cavity resonators are shown below with "E" lines of force shown for one possible mode of operation:



Several practical cavities are shown below:



TUBE RESONATOR



ECHO BOX

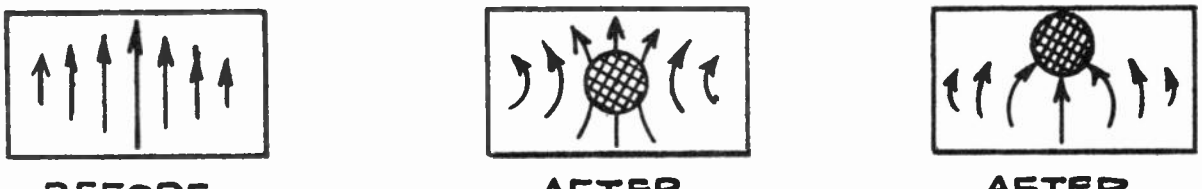
TUNING SLUGS

For the purposes of explanation, a metal sphere is shown in a rectangular resonant cavity, with the "E" lines of force for this particular operation as shown below:

(1) The slug shortens electrostatic (E) lines of force, hence the capacity is said to *increase*.

(2) The magnetic (H) lines of force are normally weak at the center and are not appreciably affected.

(3) The wave-length *increases* (frequency lower).



If the slug is inserted at one side or the other the result is as follows:

(1) The slug shortens the magnetic lines of force (H), hence the effective inductance is said to *decrease*.

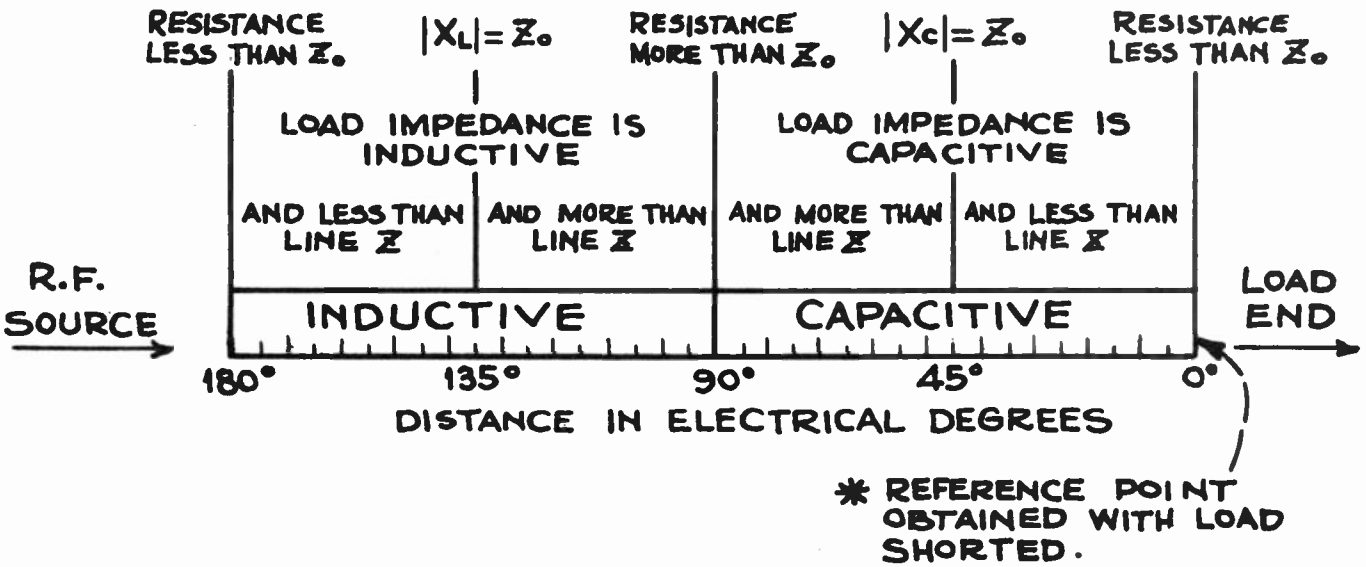
(2) The electrostatic lines of force (E) are normally weak at the side and are not appreciably affected.

(3) The wave-length *decreases* (frequently higher).

Since the two positions of the slug, namely, in the maximum (E) field, and maximum (H) field, change the resonant frequency in opposite directions, it would be expected that a position where no change in wave-length would result might be found.

APPENDIX ON MEASURING LINES

DETERMINING REACTIVE AND RESISTIVE COMPONENTS OF LOAD FROM *POINT OF VOLTAGE MINIMUM* - MEASURED BACK FROM REFERENCE POINT.



The above table summarizes the data given on pages 3, 4, and 5, and may be used to indicate the resistive and reactive nature of the load when the load is composed of both components (as it usually is).

**NOTES:*

(a) If the measuring line is long enough, it will be less confusing to use the reference point obtained with the load shorted and the chart as illustrated above. However, it is desirable to be aware of the following points:

(b) If the load is connected directly to the end of the line, (such as a resistor), the point of connection may be considered to be the reference point.

(c) If a quarter-wave, matching or phase inverter section is used with the load, and the reference point is chosen as the point at which the phase inverter connects to the measuring line, a shift of 90^0 in the above chart must be made. This is made by moving the "INDUCTIVE" section as is, to the right of the "CAPACITIVE" section (between the capacitive part of the chart and the load).

CHARTS FOR USE WITH SLOTTED LINES

The following charts, in conjunction with measurements on a slotted line, make it possible to determine the impedance and phase angle of a load. To use the accompanying charts, it is necessary to know:

1. The standing wave ratio $\frac{\text{I min.}}{\text{I max.}}$ or $\frac{\text{E min.}}{\text{E max.}}$

2. The distance in electrical degrees (KX^0) from the load (or reference point with load shorted) to the first I minimum or E maximum. A voltage maximum corresponds to a current minimum.

$$KX^0 = \frac{(360^0)\,(\text{distance back from the reference point})}{(\text{one wave-length on the slotted line})}$$

THE PROCEDURE IS AS FOLLOWS:

(1) Connect the UHF generator, and the load with or without its transmission line, to the slotted measuring line (of the same impedance as that of the transmission line).

(2) Short-circuit the far end of the line at the load. The short must be as direct and effective as possible for accurate results.

(3) With the line shorted, accurately locate the voltage minimum point on the slotted line nearest the load. This is the "Reference Point".

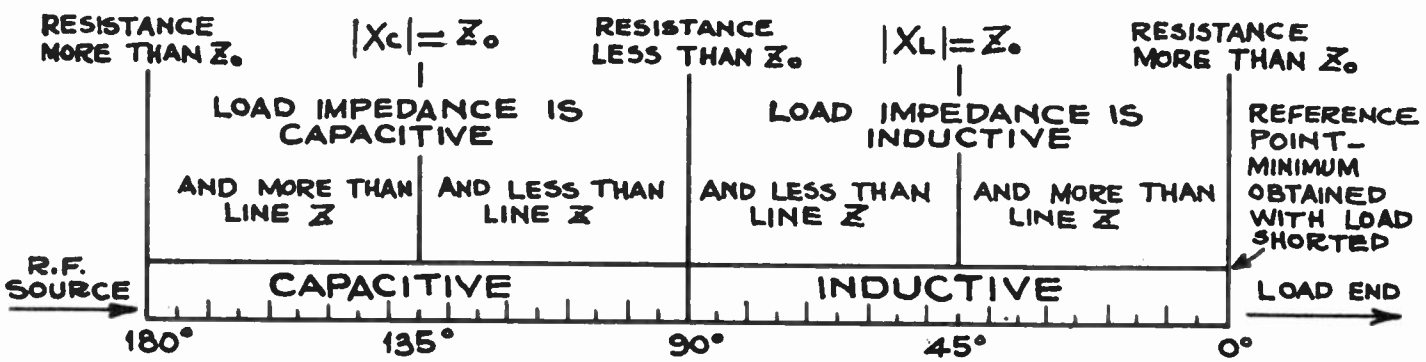
(4) Remove the short-circuit.

(5) Determine the standing-wave ratio, $R = \frac{\text{Minimum Voltage}}{\text{Maximum Voltage}}$

(6) Move the Voltmeter probe from the reference point toward the generator and accurately locate the first voltage maximum from the reference point.

(7) Express the distance from the reference point to the first maximum in degrees. Call this KX^0. It is convenient to make a scale as shown and place it under the probe pointer with 0^0 at the reference mark, and extending toward the generator, when a single frequency is involved. Otherwise, the distance may be calculated as indicated above.

DETERMINING REACTIVE AND RESISTIVE COMPONENTS FROM *POINT OF VOLTAGE MAXIMUM* -- MEASURED BACK FROM REFERENCE POINT.



MAKE SCALE LENGTH = ½ WAVE LENGTH AT OPERATING FREQ. (AS MEASURED BETWEEN TWO MINIMUM POINTS ON THE SLOTTED LINE)

$$\text{½ WAVE IN INCHES} = \frac{5908}{\text{FREQ. IN MC.}}$$ (MAY BE SLIGHTLY SHORTER ON LINE THAN IN AIR)

This scale is arranged for a slotted line with the generator feed at left end of voltmeter probe scale and based on using first *maximum* voltage point (on generator side) from reference point.

THERE ARE FOUR CHARTS:

Use #1 if KX^0 is between 0 and 45^0, or 135^0 and 180^0.

Use #2 if KX^0 is between 45^0 and 135^0.

(Charts #3 and #4 are enlargements of #1 and #2, respectively, for greater accuracy when the standing-wave ratio is between 0.7 and 1.0).

As an example, if -

R, the standing-wave ratio, $\frac{(E\text{-Minimum})}{(E\text{-Maximum})} = 0.5$

KX^0, the distance in degrees, $= 60^0$

Zc the line impedance, = 40 ohms.

As KX^0 is 60^0, use chart #2

Locate R=0.5 on top of #2 chart and follow this line around until it crosses the $KX=60^0$ line. Mark this point and from it go straight across the chart to find that the ratio of the $\frac{\text{load impedance}}{\text{line impedance}} = 0.75$

As the line impedance is 40 ohms, the load impedance is 40 x 0.75 or 30 ohms.

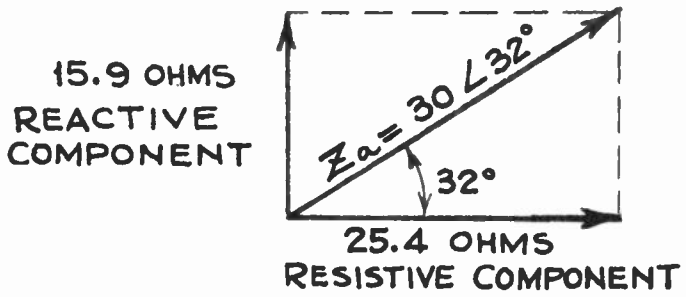
From the marked point (where R crosses KX^0, drop straight down and note that the angle of the load is 32^0 (inductive).

The load impedance (Za) may be expressed in terms of resistive and reactive components:

$$\bar{Z}a = 30 \cos 32^0 + J\ 30 \sin 32^0$$

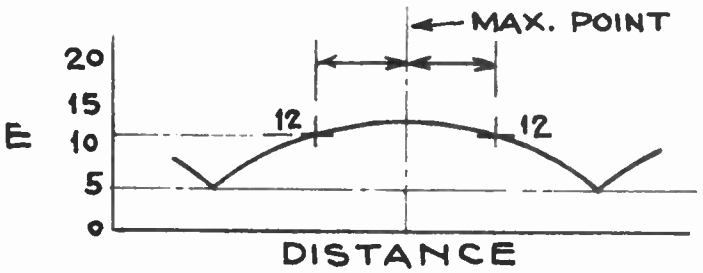
$$= 25.4 + J15.9 \text{ ohms.}$$

Expressed vectorially:



NOTE ON OBTAINING *MAXIMUM VOLTAGE* POINT:

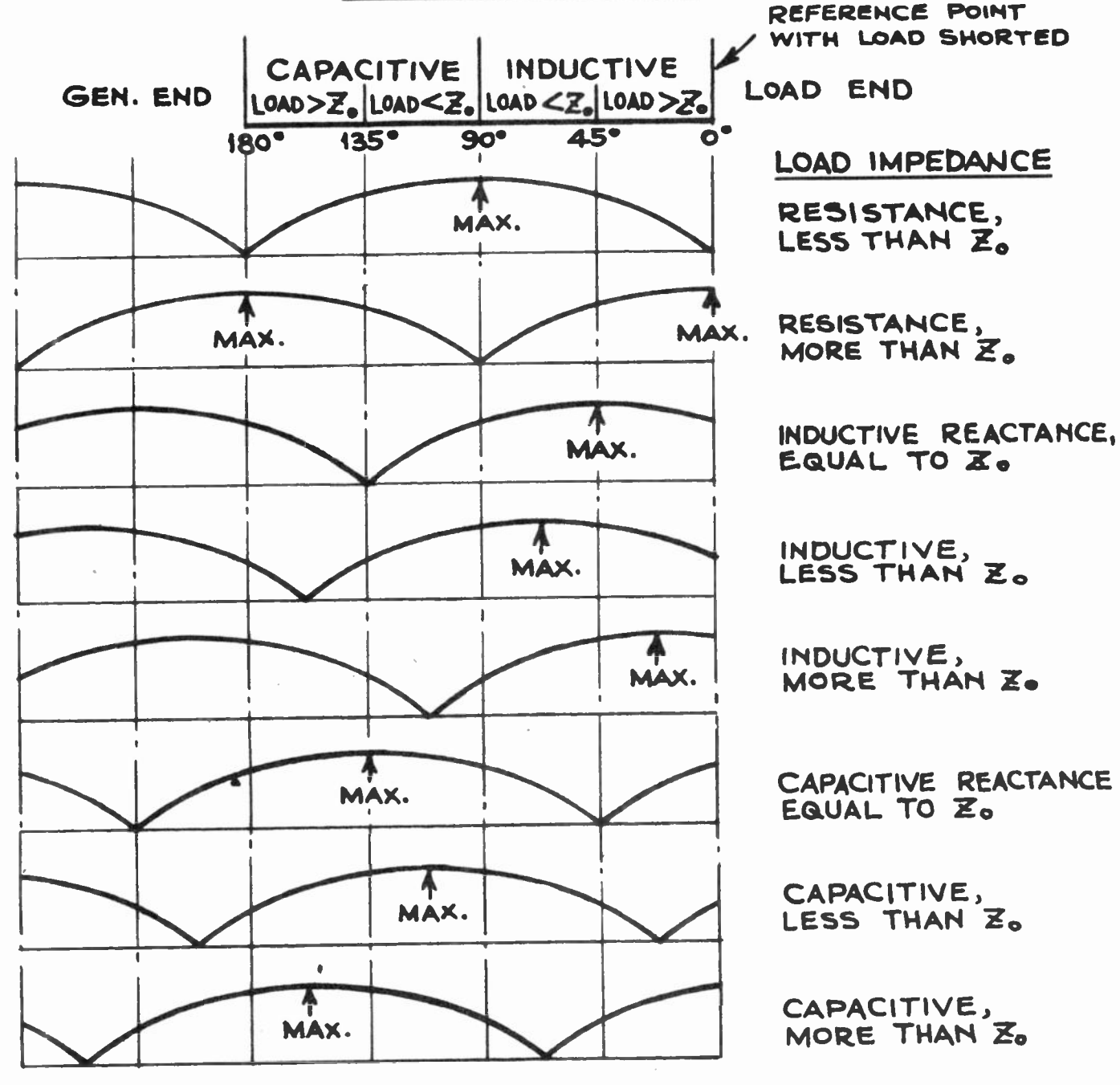
As an aid in obtaining accurate maximum voltage points, it is suggested that two voltage points of equal magnitude be selected, one on each side of the maximum point, then choose the distance half way between these two points as the maximum point.

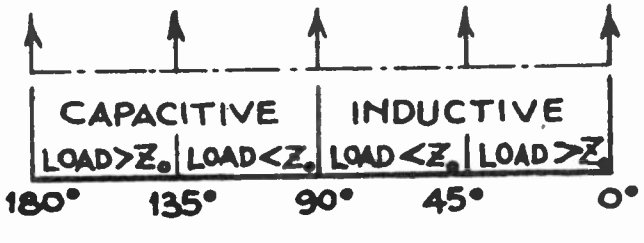


NOTE ON USING *MINIMUM VOLTAGE* POINT:

If it is desired to use the *minimum voltage* point with charts 1, 2, 3, and 4, set 90^0 on scale at the reference point and use the scale reading as KX^0.

EXAMPLES AND INTERPRETATION OF VARIOUS POSSIBLE STANDING WAVE PATTERNS, USING FIRST MAXIMUM POINT BACK TOWARD GENERATOR, FROM REFERENCE POIINT.





TO USE VOLTAGE MINIMUM POINT WITH CHARTS 1, 2, 3 AND 4, MOVE ABOVE SCALE FOR PROBE SO 90° CORRESPONDS TO REFERENCE POINT (OR 180° FROM REFERENCE POINT AS SHOWN)

Z_c = CHARACTERISTIC IMPEDENCE (SURGE IMP.) OF CONCENTRIC TRANSMISSION LINE OR PARALLEL WIRE LINE.

Z_a = MAGNITUDE OF LOAD IMPEDENCE (TERM. IMP.) AT END OF TRANSMISSION LINE.

θ_a = ANGLE OF LOAD IMPEDENCE.

KX° = DISTANCE FROM LOAD TO FIRST CURRENT MINIMUM OR VOLTAGE MAXIMUM.

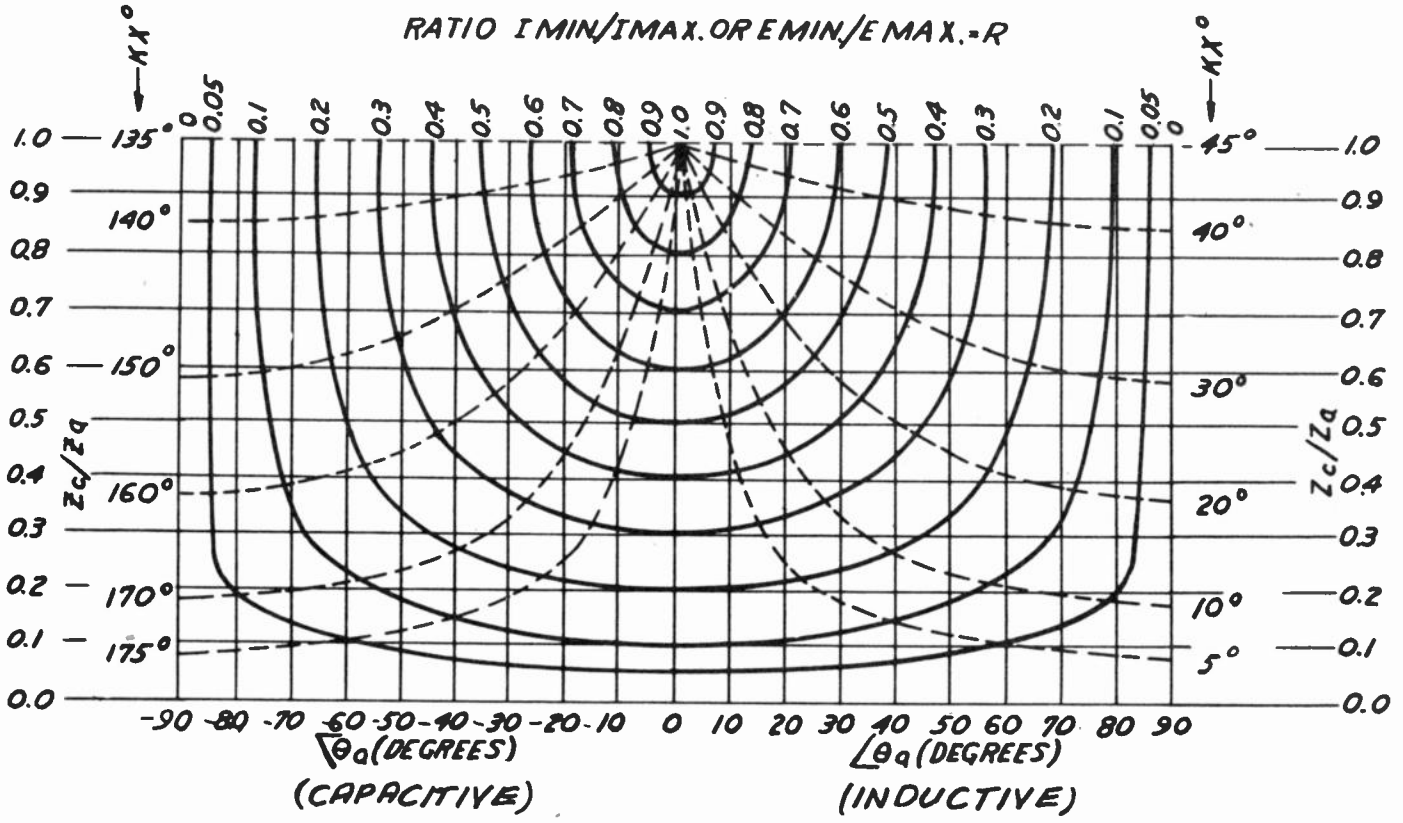


CHART Nº 1

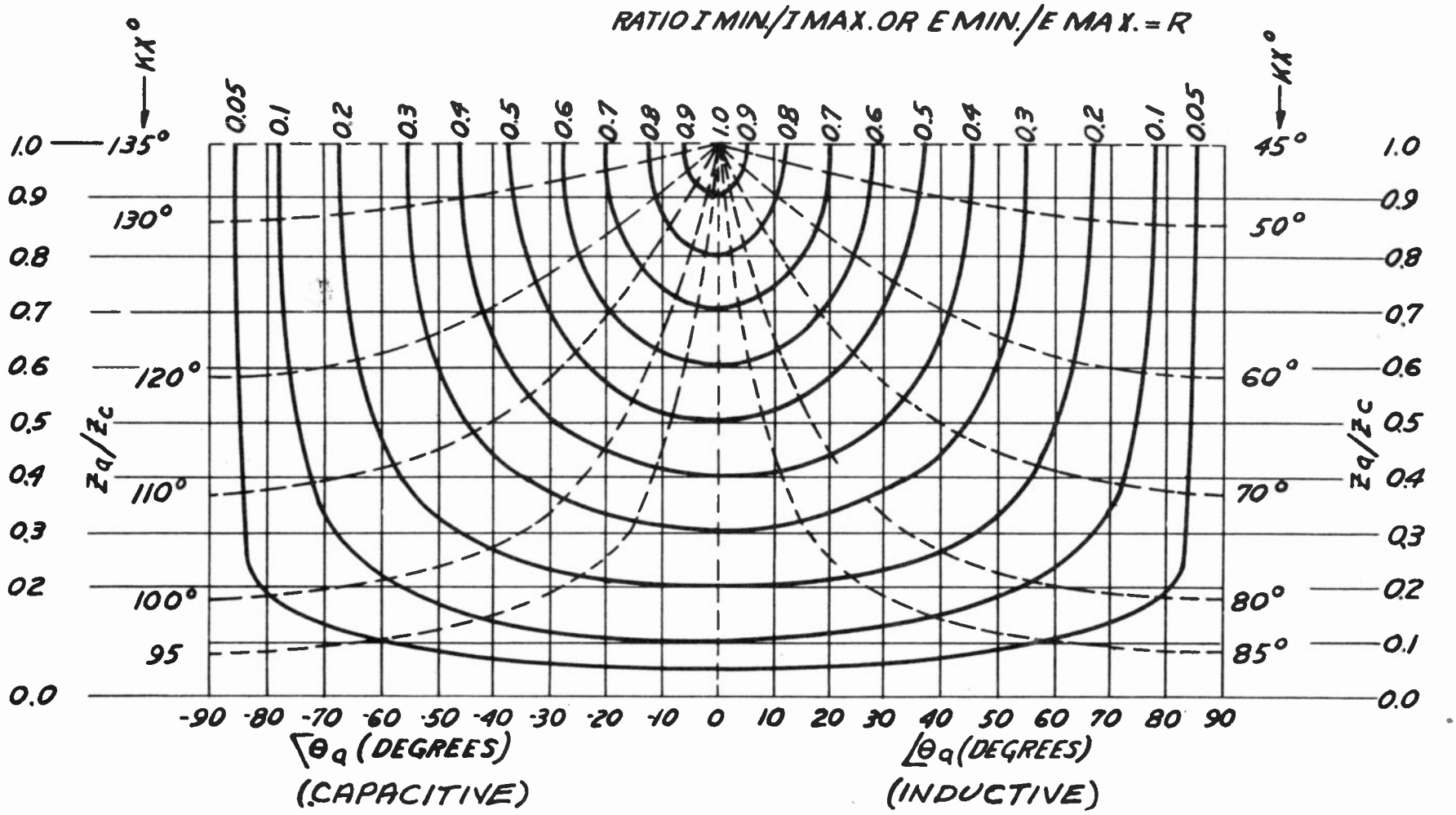

RATIO I MIN./I MAX. OR E MIN./E MAX. = R
KX°
135°
130°
120°
110°
100°
95
45°
50°
60°
70°
80°
85°
Zq/Zc
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.05
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
∠θq (DEGREES)
(CAPACITIVE)
∠θq (DEGREES)
(INDUCTIVE)

CHART Nº 2

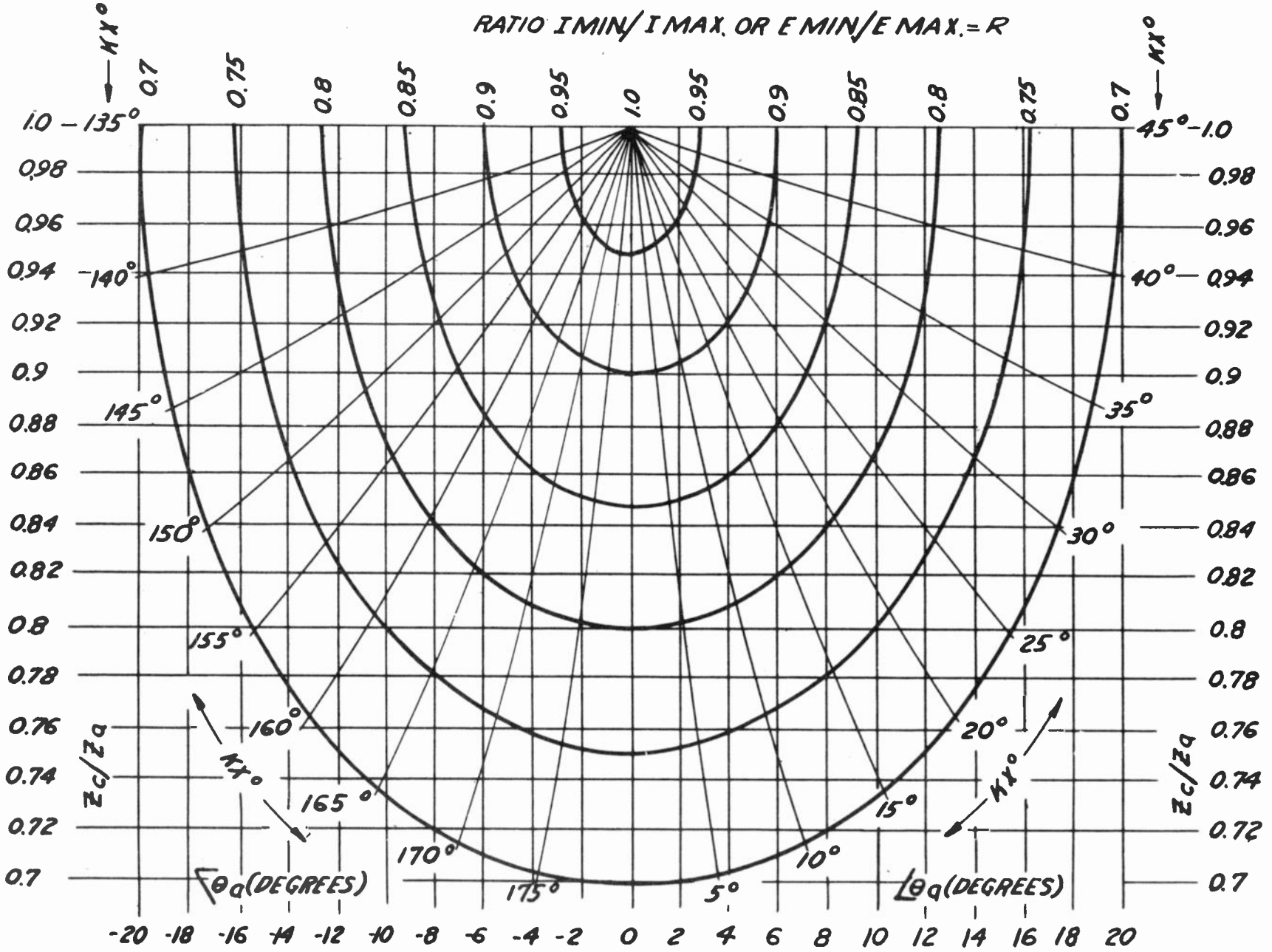


CHART Nº 3 – ENLARGEMENT OF PART OF CHART Nº 1

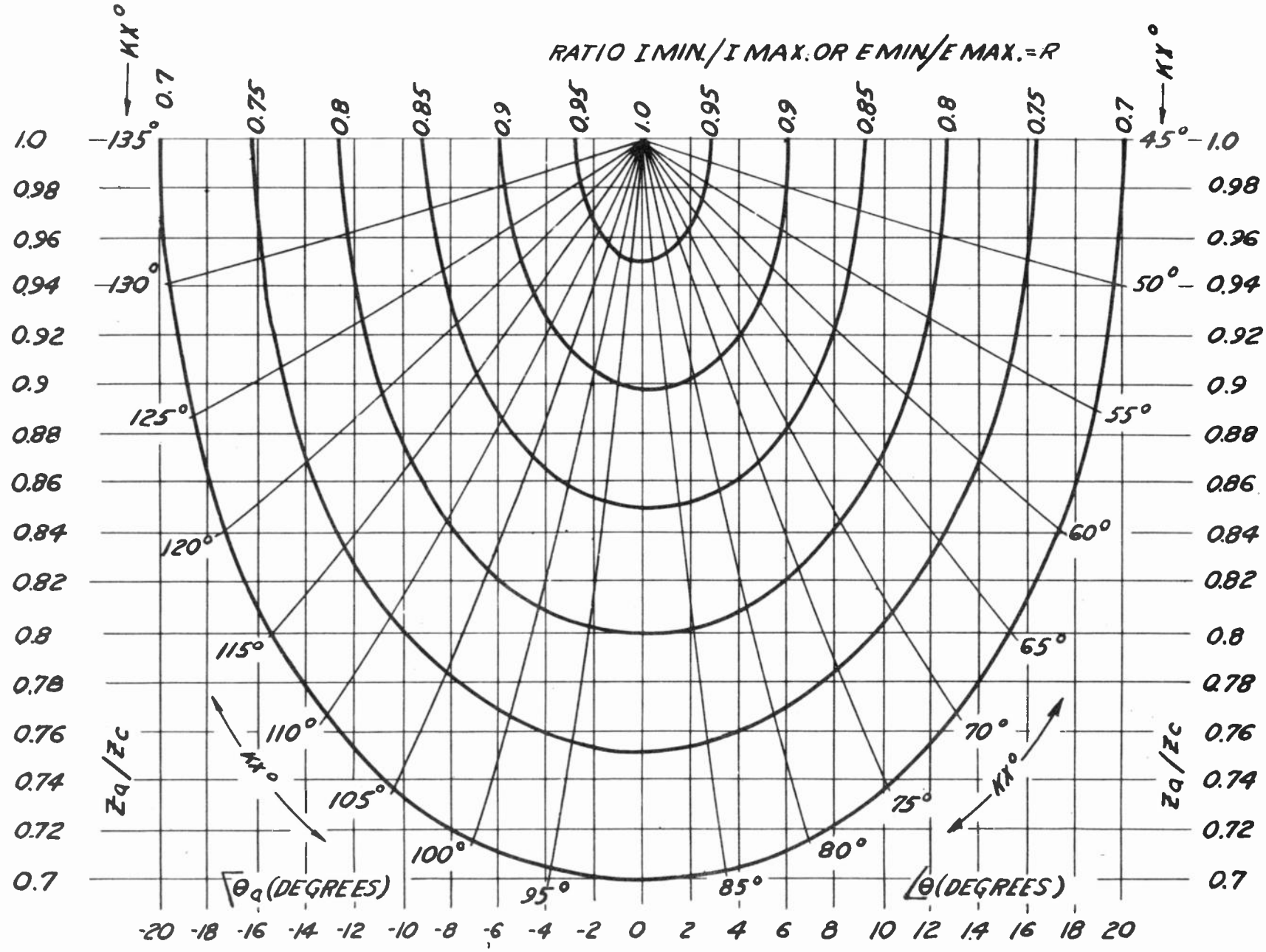
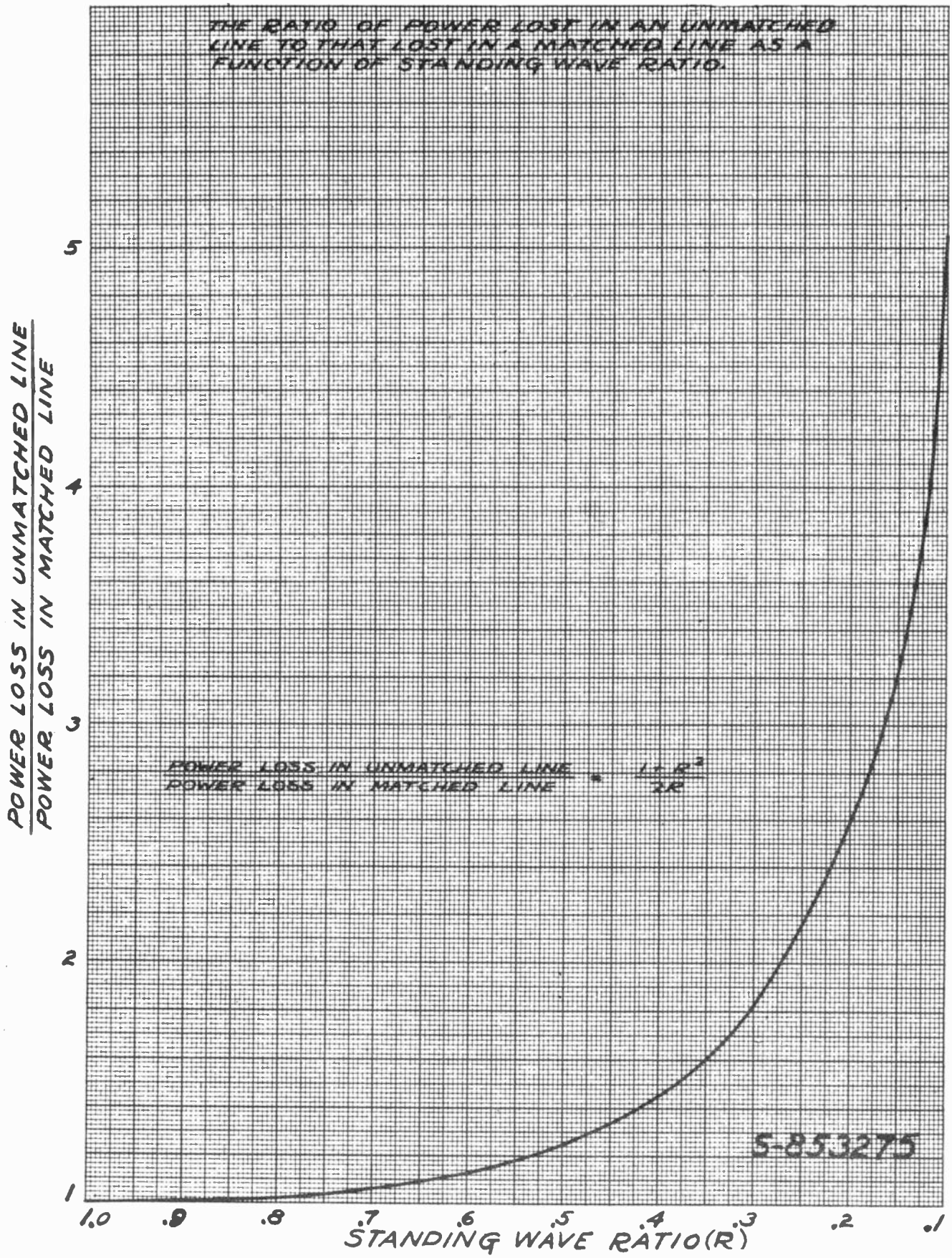


CHART Nº 4 - ENLARGEMENT OF PART OF CHART Nº 2


THE RATIO OF POWER LOST IN AN UNMATCHED LINE TO THAT LOST IN A MATCHED LINE AS A FUNCTION OF STANDING WAVE RATIO.
POWER LOSS IN UNMATCHED LINE / POWER LOSS IN MATCHED LINE
5
4
3
2
1
POWER LOSS IN UNMATCHED LINE / POWER LOSS IN MATCHED LINE = (1+R²)/2R
5-853275
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
STANDING WAVE RATIO (R)

AUTOMATIC CONTROL CIRCUITS FOR BROADCAST TRANSMITTERS

By W.R. Sloat

Transmitter Engineer, Station KMOX, St. Louis

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Probably the most important criterion by which a broadcast station is judged is dependability. Of course, audio quality and program content are important, but it is the primary obligation of the entire staff to keep the station on the air.

Dependability may be considered a measure of how much program time is lost. Accident and error are the contributing factors to lost time; error is failure of the personnel to function properly, and accident is an equivalent failure of equipment. Both may be, and usually are, unpreventable. Time lost through both causes may nevertheless be minimized to a large extent through use of certain automatic devices designed to aid the operator in clearing temporary faults, locating trouble, quickly restarting the transmitter after over or underload, and in general supplementing the human hand.

It is the purpose of this article to present four automatic devices, three of which were designed by the author and the fourth, the carrier restoring device, by the transmitter staff of WABC under the supervision of Mr. R. W. Newby. All have been in use at KMOX for some time, giving excellent service.

The four devices are independent of one another, and each self-sufficient for its purpose. Collectively they provide comprehensive and measureable improvement in station dependability. All contain only small standard components that are ordinarily at hand.

Carrier Protective Device

Under certain conditions, radio-frequency arcs become established at a transmitting antenna by electric storms or static discharges and are sustained by the transmitter output. These arcs may be of insufficient magnitude to operate the transmitter overload relays, although capable of damaging parts of the equipment. Two methods of stopping these arcs are momentarily cutting the carrier or reducing the output of the transmitter to a point where it will not maintain the arc.

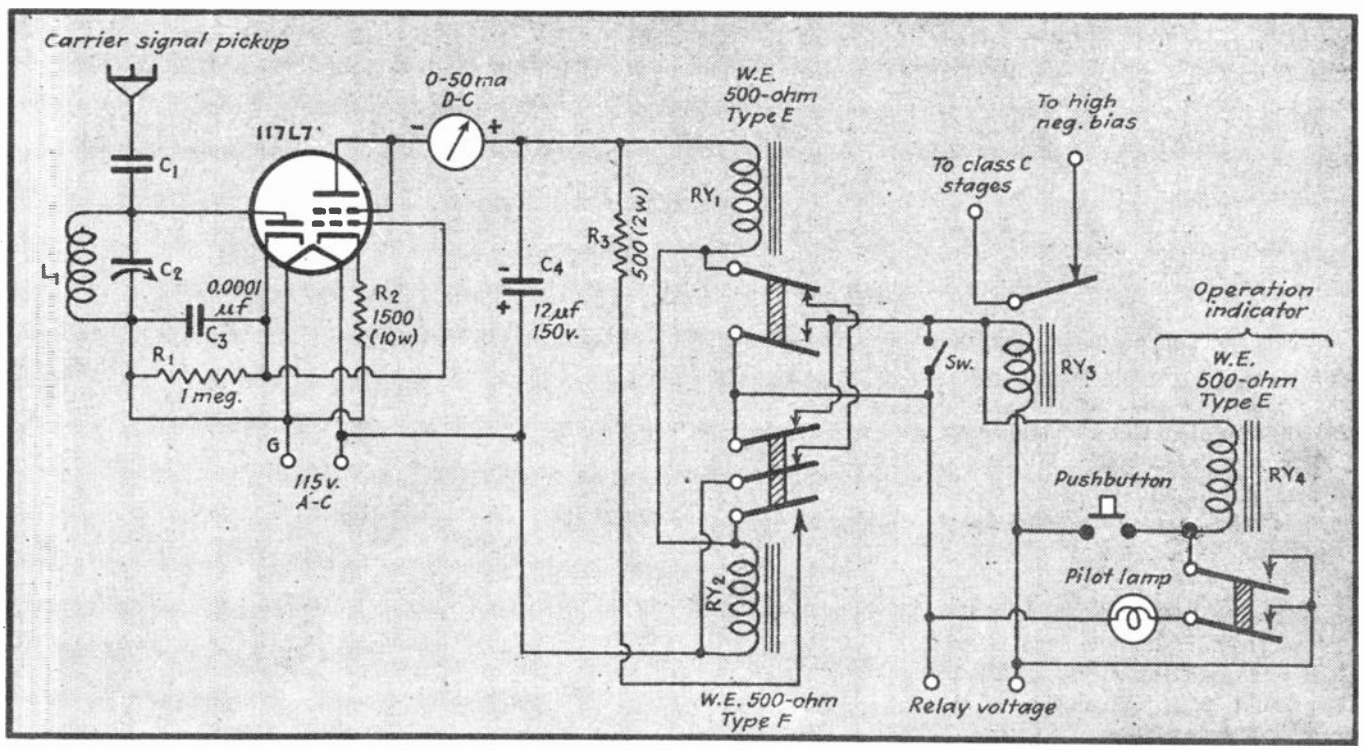

FIG. 1—If an r-f arc becomes established and is sustained by the transmitter output without drawing enough current to trip overload relays, this carrier-actuated protective circuit automatically reduces the transmitter output momentarily to about 15 percent of normal to kill the arc. If RY_2 is inherently slow enough, the interlock with RY_1 may be omitted

Initiating devices to achieve one of these methods fall into several classes. One comparatively complicated type, usually difficult to handle, balances out-of-phase components of the r-f energy in one stage or the transmission line against that in the preceeding stage. Another method, applicable only to a case where the arcs occur repeatedly at the same point, uses a phototube to actuate the system. A third method uses the arc itself as a conducting path for relay current.

A fourth method, in use at KMOX, is one operating directly from a portion of the radiated carrier power. It can be used with low-level modulated transmitters without any restarting equipment. An independent restarting device, having no tubes and only one relay, can be used in conjunction with the device for protecting high-level systems.

The circuit of the KMOX carrier-protective device for low-level systems is shown in Fig. 1. The instrument is controlled by carrier energy picked up by a short antenna and fed to the diode section of the 1f7L7. The diode develops positive bias for the tetrode section of the tube, which is also cathode-biased.

When normal energy is radiated, two relays, RY_1 and RY_2, are energized by the tetrode plate current by virtue of positive grid bias from the diode and RY_3 is also energized. Under this condition, the coil of RY_1 is paralleled by R_3, and only a slight drop in plate current will cause RY_1 to open. An abnormal condition anywhere in the transmitter resulting in a moderate drop in radiated energy will cause such a drop in plate current, and RY_1 will release RY_3, applying high negative bias to the buffer and modulated amplifier stages.

RY_3, may, of course, have any contact arrangement desired for the application of this bias, which must be determined to suit the individual transmitter. This bias should be sufficient to reduce the carrier power to about 15 percent of normal, which will not sustain arcs unless there has been some damage to equipment. When the power drops to this low value, RY_2 will not have sufficient current to hold and will drop out, picking up RY_3 through a set of de-energized contacts, removing the high bias and returning the carrier to normal. These de-energized contacts on RY_2 also perform the useful function of protecting the device against tube failure, since the relay cannot pick up without plate current, and these contacts hold in RY_3.

When RY_2 opens two other functions occur: R_3 is removed from its position in parallel with the coil of RY_1, and RY_2 is locked out through its remaining de-energized contact and a similar one on RY_1. Thus, RY_1 is subjected to the full plate current, and will now pick up on a smaller current than is present when it opens, and RY_2 is prevented from picking up until after RY_1 has closed. RY_1 closes at about 25 percent normal power, and RY_2 at about 80 percent when the tetrode plate current is large enough to keep RY_1 energized as the paralleling resistor R_3 is reconnected. The instrument is now recycled. If damage has occurred to the transmitter or other trouble is present to prevent the carrier from returning to full power, the device will remain static, with RY_2 open, RY_1 open or closed, and transmitter bias normal (RY_3 closed).

The contacts of RY_1 should make before break and the springs should have about half the tension of those on RY_2. C_4 is provided to avoid relay chatter on the rectified alternating current in the plate circuit of the 117L7. A switch SW is provided in parallel with the energized contacts of RY_1 in order to hold in RY_3 when adjusting the device or taking it out of service for some other reason. C_1 must be used to isolate the antenna from the power system, so that in the event the power source becomes reversed, the antenna will not be at line potential. C_1 also provides a convenient means of limiting the r-f input to the instrument. Enough r-f energy, however, should be fed to L_1C_2 so that this tank may be operated somewhat detuned from the station frequency, and C_2 used as a control of the tetrode bias and the dropout point of RY_1. When properly adjusted for dropout at 75 percent of full carrier, the plate current should be about 22 ma, and about 7 ma when the high bias is applied to the transmitter during an overload.

For use with high-level systems, where power reduction by means of high bias is more difficult to achieve, the contacts of RY_3 would be placed in series with the plate OFF button or in series with the series-overload circuit of the transmitter, both generally arranged as normally closed circuits. Operation of the device would then result in an interruption of the plate-contactor holding circuit, shutting off the high voltage. As previously pointed out, a carrier-restoring device will be necessary for this method of operation, unless manual restoring of the carrier is to be depended upon.

An operation indicator is a desirable accessory to the carrier protective device. The one in use at KMOX is shown at the right in Fig. 1, and is so simple that very little explanation will be needed. Under normal conditions (RY_1, RY_2 and RY_3 closed), RY_4 is energized by the push button, seals itself in through RY_4, and lights the pilot lamp. When

RY_1 is opened, RY_2 will drop out and put out the pilot light, which will remain out until the operator resets it with the pushbutton. The protective device will continue to operate when called upon to do so, regardless of conditions in the indicator.

WABC Carrier-Restoring Device

Overloads are probably the most common cause of carrier interruptions in broadcast stations. These result in operation of the protective relays and removal of the plate voltages. Where a manual operation is necessary to restore plate voltages, there is usually a delay of at least several seconds before the operator can reach the switch to restore the carrier to the air.

The carrier reset to be described cannot be praised too highly. It has been in service at WABC and then at KMOX since 1933, and has proven itself thoroughly dependable. The author does not know of a single case of trouble due to failure of this device. It is probably the simplest gadget yet designed that is capable of performing the standard three-shot and lockout cycle of reclosing devices. This unit, shown in Fig. 2, needs only as many relay contacts as there are protected plate circuits in the transmitter. It will operate within 0.3 second on the first attempt to restore the carrier, and within 0.6 second on the two subsequent attempts. Under these conditions, instead of a definite program interruption, a simple overload results in a momentary break of such short duration that only the most attentive listeners will be aware of it. In addition to its electrical and mechanical simplicity, it has no buttons to push to recycle it after a lockout. It is completely automatic in every respect. Its contacts never break a circuit and consequently never need attention.

This reclosing device consists essentially of a relay with one set of de-energized contacts for each protected plate circuit, and a pendulum associated with the relay armature. Most transmitters have only two protected plate circuits, a medium voltage for the exciter and driver stages, and a high voltage for the buffer and final amplifiers. This is the case at KMOX, as represented in Fig. 2. The relay contacts are paralleled with the plate ON control buttons, so that the high-voltage circuit breakers are closed by operation of the relay. The relay is energized by current flowing through auxiliary contacts Ax and Bx on the plate voltage primary

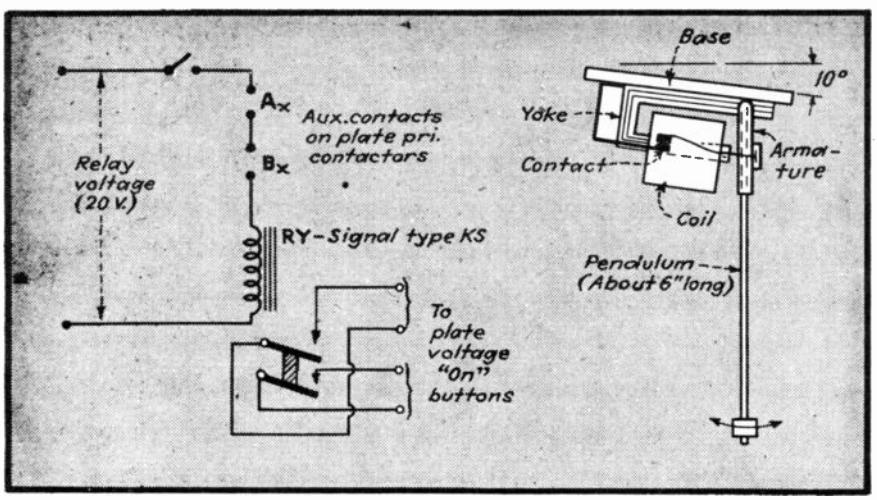

FIG. 2—In the event of carrier failure due to overload, this simple relay arrangement performs the standard three-shot and lockout cycle of reclosing devices. It makes three attempts to restore power, working so fast that listeners are not aware of trouble

contactors. Thus, when either contactor is opened as a result of an overload, the reset relay becomes de-energized and the pendulum-yoke arrangement is released. The contacts will close at the end of the first half swing of the pendulum and the plate voltage will be reapplied.

If the overload has cleared, the contactor will remain closed, energizing the reset relay and restoring conditions to normal. If the overload still exists, the plate contactor will reopen by action of the protective relays, and the reset relay pendulum will continue to swing. If the overload has not cleared by the time the third application of plate voltage has been made, lockout will occur as the reset pendulum has lost its kinetic energy and will come to rest in a neutral position. The carrier must

now be restored manually. As soon as the plate contactors remain closed simultaneously long enough to energize the reset relay, the device is ready for another operation cycle.

Nearly any type of clapper relay is suitable for conversion into a pendulum reset device. The relay voltage source may be chosen to fit the relay, or vice versa. The relay used at KMOX is a Signal Electric and Manufacturing Co. type KS, operating from the 20-volt filament supply. Connections are made to the moving contact arms by means of flexible leads. The pendulum is of such a length that three full swings take place, resulting in three contact closures before the arc of the swing has become too short to close the contacts. A complete swing of the pendulum requires about 0.6 second, but the first closure occurs in half that time since only a half swing is required.

A quarter-inch rod of any material will suffice for the pendulum, and several nuts may be threaded on the end to provide weighting for energy storage. The relay is mounted approximately 10 deg. from the horizontal so that the contacts are open when the relay is not energized and the pendulum is at rest.

If no auxiliary contacts are available on the plate contactors, they can usually be installed without great difficulty. However, where this is utterly impossible, auxiliary relays in parallel with the plate transformer primaries could be used.

Automatic Starting Device

An automatic time-delay starting device is particularly useful in two ways, for getting back on the air after a breakdown with a minimum of lost time, and for locating trouble where the fault cannot be expeditiously located without the power on and it is impossible to keep it on without damaging equipment.

The device in use at KMOX will give a start in 10 seconds, providing the interlocking

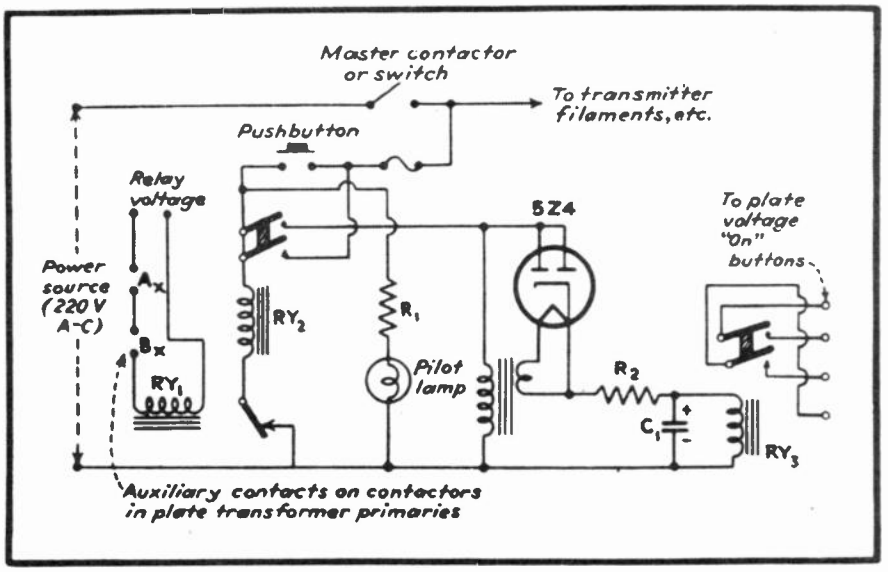

FIG. 3—Automatic starting circuit for getting back on the air after a breakdown with a minimum of lost time

grid and filament relays are all clear, otherwise the start will wait until they do clear. This 10-seconds can be utilized by the operator in getting the studio on the order wire, or in proceeding to the point where trouble is suspected, so that he may observe the equipment at the moment the plate voltage is applied. For example, in the latter situation, the operator is enabled to locate readily a bad tube in a parallel installation when the only indication of trouble is a flash inside the tube.

Electrical details of this device are shown in Fig. 3. If either plate voltage is off, RY_1 will be de-energized and its contact closed. The method of energizing RY_1 is the same as for the reset relay. RY_2 may now be picked up by means of the pushbutton, and it will seal itself in through its lower contacts. The pilot lamp will go on and remain on until the starting action is completed. The upper contacts of RY_2 then excite the filament transformer of the rectifier tube, and apply alternating voltage to the plates of the tube. When the cathode has reached conduction temperature, RY_3 will be energized, closing its contacts

across the plate ON buttons. As soon as the plate contactors close, RY_1 will operate, opening its contacts and releasing RY_2. Thus the transmitter has been given one starting impulse. Subsequent starts will not require a full 10 seconds if the tube has not fully cooled. Obviously, RY_2 cannot be picked up when the plates are on or the master control off, eliminating the possibility of accident through a "stored up" start.

Resistors R_1 and R_2 are for dropping the pilot lamp and RY_3 voltages to the proper values from the 220-volt relay circuit used at KMOX. C_1 is shown across RY_3 coil for removing the chatter if RY_3 is a d-c relay. It will not be necessary if an a-c relay is used.

Carrier-Interruption Timing Device

This auxiliary device records the time at which a transmitter breakdown occurs, as well as its duration, permitting the operator to give his entire attention to the cause and repair of the failure without having to note the time both before and after the repair period. It is, like most automatic instruments, capable of greater accuracy than can be obtained by mere observation.

The KMOX timer is shown diagramatically in Fig. 4. Its operation is similar to that of the carrier-protective device described above. The control element is the carrier wave, a bit of which is rectified and used to develop positive grid voltage for the tetrode section of the 117L7 tube, also cathode biased. When the carrier is on, RY_1 and RY_2 are energized, and clocks CL_1 and CL_2 are running, while CL_3 is stopped. All three clocks are self-starting. CL_1 keeps correct time, running continuously.

When the carrier is interrupted, RY_1 and RY_2 are de-energized, CL_2 is stopped, and CL_3 is started. CL_2, therefore, determines the time that the interruption occurred. When the carrier is restored, RY_2 is picked up, stopping CL_3. This clock thus determines the duration of the interruption. RY_1 is not picked up by the carrier, for its coil is shorted through its own de-energized contact and the reset button. After the operator has noted the time of the breakdown, the reset button is pushed, allowing RY_1 to become energized and returning the instrument to its original condition.

The clocks may be set by means of switches

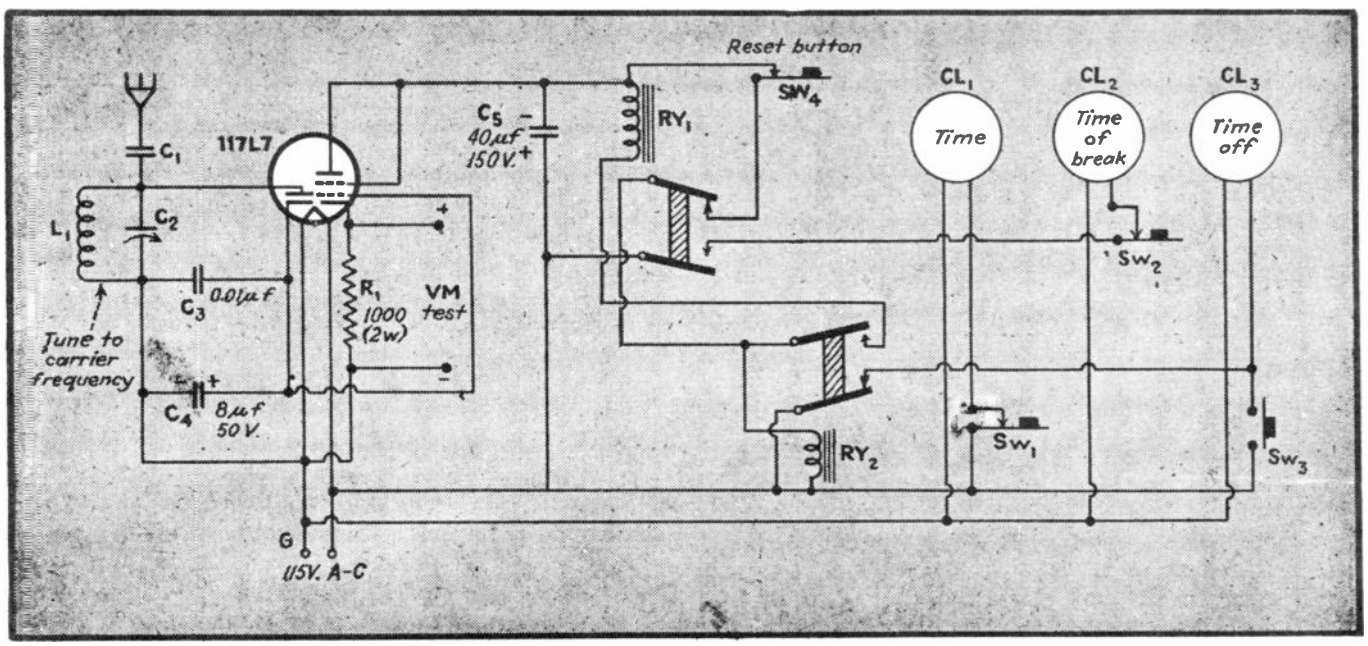

FIG. 4—Arrangement for securing automatically a record of the time that carrier failure occurred and the duration of the failure

1, 2, and 3, at the operator's convenience. CL_2, normally running, keeps correct time until the carrier is stopped, and CL_3 is set at 12:00, ready to time any interruption in terms of hours, minutes, and seconds by direct reading.

Coil Is Interlocked

The coil of RY_1 is interlocked through an energized contact on RY_2 to insure simultaneous opening of both relays. This interlock may

not be necessary in all cases, depending on the characteristics of the relays used.

The diode circuit is similar to that of the carrier-protective device, with two notable exceptions. C_2L_1 is tuned exactly to the carrier frequency, C_2 being fixed if desired and the tank tuned by removing turns from L_1. The other, and major exception, is the substitution of C_4, an 8-μf capacitor, for the tetrode grid leak. This provides a time delay of about one second, the time required for C_4 to discharge to the point where the bias limits the plate current to the point where it will no longer energize RY_1 and RY_2. The delay is incorporated to keep the instrument from operating on a normal reset due to overload, since this is not considered an interruption.

A grid leak is not necessary because of the conduction through the electrolyte of C_4. Cathode bias resistor R_1, being 1000 ohms, will bias the tube to a value numerically equal in volts to the plate current in ma. This provides a convenient test consideration, and leads are incorporated for measuring the bias with a voltmeter. When properly adjusted, the bias should be about 15 v with the carrier on and about 8 v with no signal. The circuit C_2L_1 may be tuned by adjusting for maximum bias voltage. Capacitor C_1 isolates the antenna and limits the r-f input. The circuit arrangement operates all the clocks on a 117L7 tube failure, and this calls the attention of the operator to the failure.

As pointed out in the introduction, these four devices are now in actual use at KMOX and are continuing to prove themselves to be well worth while in preventing damage from arcs resulting from static discharges, in saving time and trouble when breakdowns do occur, and in adding to operating convenience. Their use at stations not having similar equipment is highly recommended.

RADIO INTERFERENCE IN AREAS OF HIGH FIELD INTENSITY

- *By P. A. Young*
Propagation Engineer, Crosley Broadcasting Corporation

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]:

---

[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.*

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.

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

TABLE II

550 + 1360 = 1910	550 + 2720 = 3270	1100 + 1360 = 2460
550 - 1360 = 810	550 - 2720 = 2170	1100 - 1360 = 260

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.

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LOCATING THE TELEVISION TRANSMITTER

(Reprinted through the courtesy of the RCA Victor Division, Radio Corporation of America.)

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 purpose of the transmitting station is to provide signals to the population in the area which the station is to serve. The location of the transmitting station is likely to determine, to a marked degree, how well that station serves its territory.

FACTORS GOVERNING CHOICE OF A SITE

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. For this reason, as well as because of their importance, they form a logical starting point.

TECHNICAL REQUIREMENTS

The technical requirements governing the location of a television transmitter are basically 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.

(c) The location must meet practical requirements as to accessibility, space, service facilities, etc. (These requirements are not listed in order of importance, since, in fact, all are equally important, but rather in the order of logical consideration.)

IMPORTANCE OF CENTRAL LOCATION

The search for a site can be immediately narrowed down by noting that the site should--very preferably--be near the center of the area to be served. 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.

In many cases, however, the city in question will--because of irregularities or 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 2. Again, because of availability 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 3, can be designed, and some of these have actually been built, for television broadcast purposes. They are common, of course, in point-to-point communication service. It is difficult, however, to combine in one design both high gain and special directivity. Moreover, such designs involve complicated mechanical arrangements and almost preclude standardized manufacture (since each one would be different). That directive antennas will in the future be used to some extent seems fairly certain; however, at the present stage of the art, most engineers prefer not to recommend them.

What, then, should be done? The answer, as far as it can be given now, seems to be (a) to use non-directive transmission, (b) to locate as near the center of the area as is practical, (c) to cover as much of the area as possible under the circumstances. In some cases (Figure 4) it will simply not be economical, and perhaps not even possible to cover the whole area.

IMPORTANCE OF HEIGHT

Height of antenna above prevailing ground level will determine the "horizon" for the station as well as the ability to avoid shadows from obstructions. While high frequency signals travel somewhat beyond the mathematical horizon, the attenuation beyond it is so much greater that for practical purposes the horizon may be used as a criterion when considering service coverage. The higher the antenna, the better the results 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

WRH

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 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.

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 rather than after the construction permit is granted and the use thereof becomes almost a necessity.

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.

THE 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 and an FM transmitter, with the television antenna and the FM antenna mounted on the same tower.

Some of the advantages and disadvantages of the five 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. 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 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 5).

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 height have been known to cause shadow patterns. Another common drawback is that it is often not possible to erect a multi-layer antenna, so that desirable *antenna gain* must be sacrificed. 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 7 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.

(c) Use of AM 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. An installation of this type consists of a turnstile mounted on the top of one of the towers which form the antenna system for the AM station.

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 to erect, no extra cost for running in power lines, etc. Operating costs are lower because of the centralization of operating and maintenance facilities.

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 turnstile 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 per cent or 30 per cent of the transmitter output. Finally, the AM band lies completely within the range of video frequencies; therefore, special shielding or other installation precautions will undoubtedly be necessary in order to prevent interference with the video signal.

(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. 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.

The disadvantage of this type of installation is the added cost of the steel tower which must be erected. In most cases, the roof 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.

(e) Dual Location. Television and FM Transmitters at the Same Site

A site that is favorable to the location of a television transmitter may also be favorable for a location for an FM transmitter. The consideration of the dual use of space may prove well worth while to a station that plans to provide both television and FM service. In such a case, a single tower can be used to support both the FM and the television turnstile antennas.

CALCULATION OF COVERAGE

For purposes of filing an application for construction permit with the Federal Communications Commission, it is 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 bulletin 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 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 band-width. 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. This sometimes enables the audience in these locations to see two pictures simultaneously and, unfortunately, not in register. The problem of location in rough terrain is one which demands individual study.

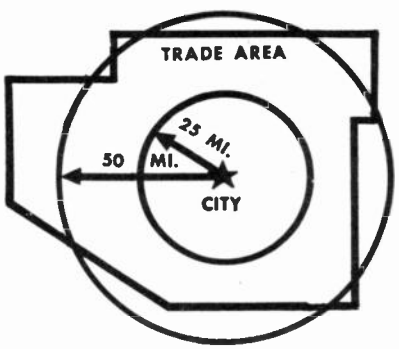
Noise level at the receiving location is not within the control of the transmitting station, but the location of the transmitting antenna can be planned to produce maximum signal strength at points where noise level is highest. High receiving noise level will generally be experienced in densely populated 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. Rural and suburban areas can ordinarily be served successfully with signal intensities considerably lower than in metropolitan localities.

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.

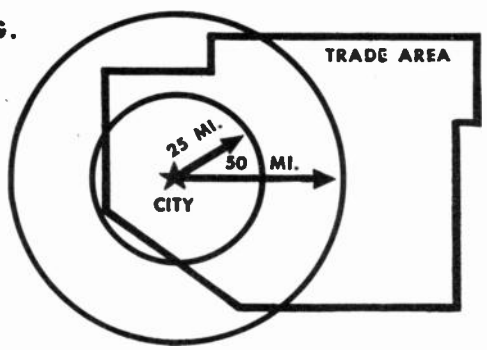
Speaking in general, the problems inherent in locating a television transmitter are capable of solution, but they must be approached with intelligence based on some technical experience.

FIG. 1



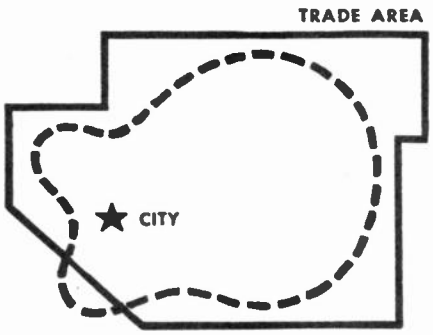
Where the trade area of a city is more or less symmetrical, a site near the city will give the most uniform coverage.

FIG. 2



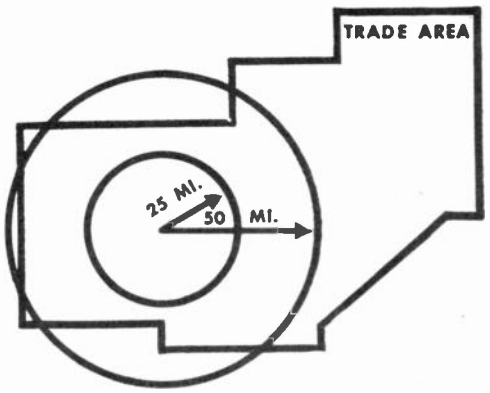
Where the area is not symmetrical about the city, it will usually not be possible to cover the whole area with a non-directive antenna.

FIG. 3



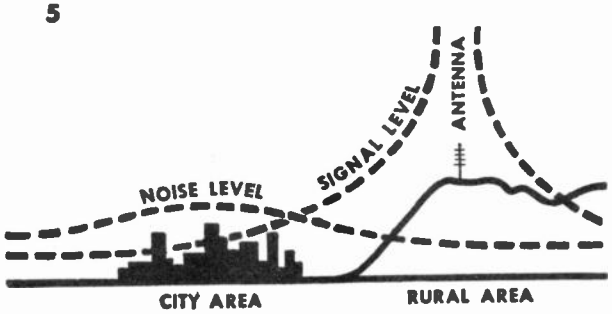
Directional antennas are a possibility, but usually involve non-standard designs which should be avoided when possible.

FIG. 4



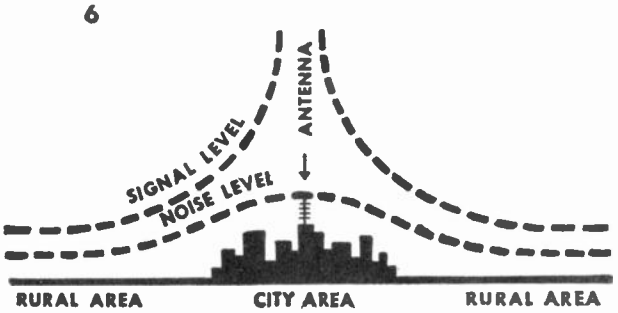
Where the trade area is very large or of irregular contour it will probably not be possible to provide coverage of the whole area.

FIG. 5



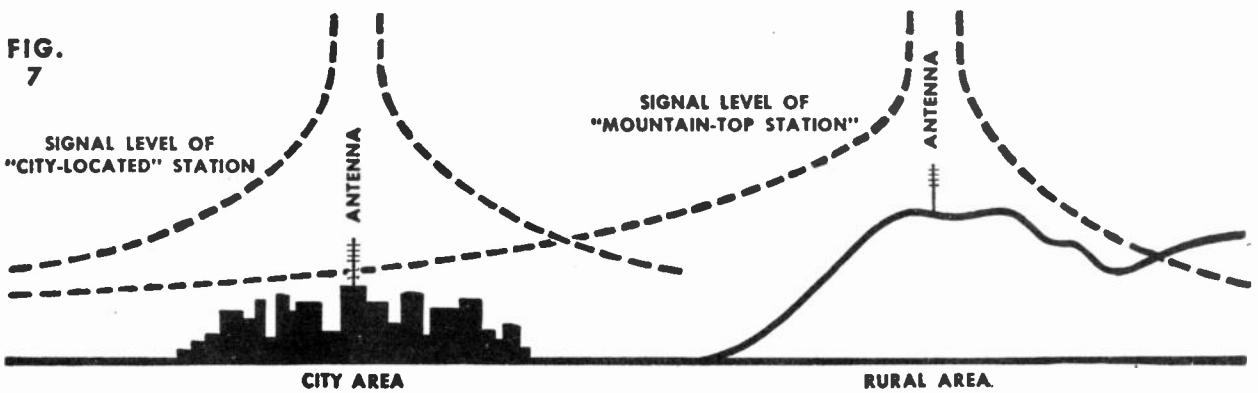
A "mountain-top" station has its highest signal where least needed; i.e., where noise level is lowest.

FIG. 6

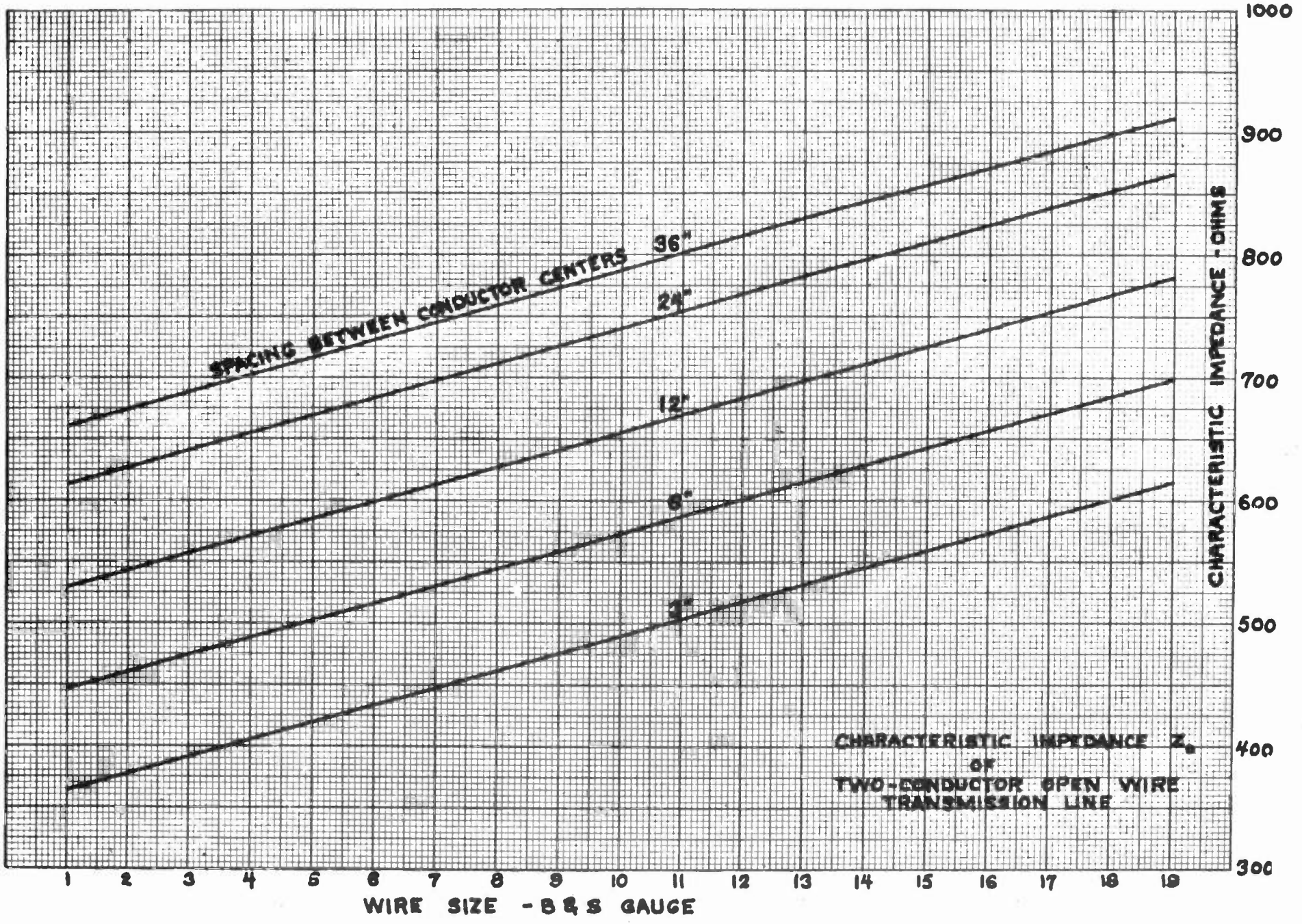


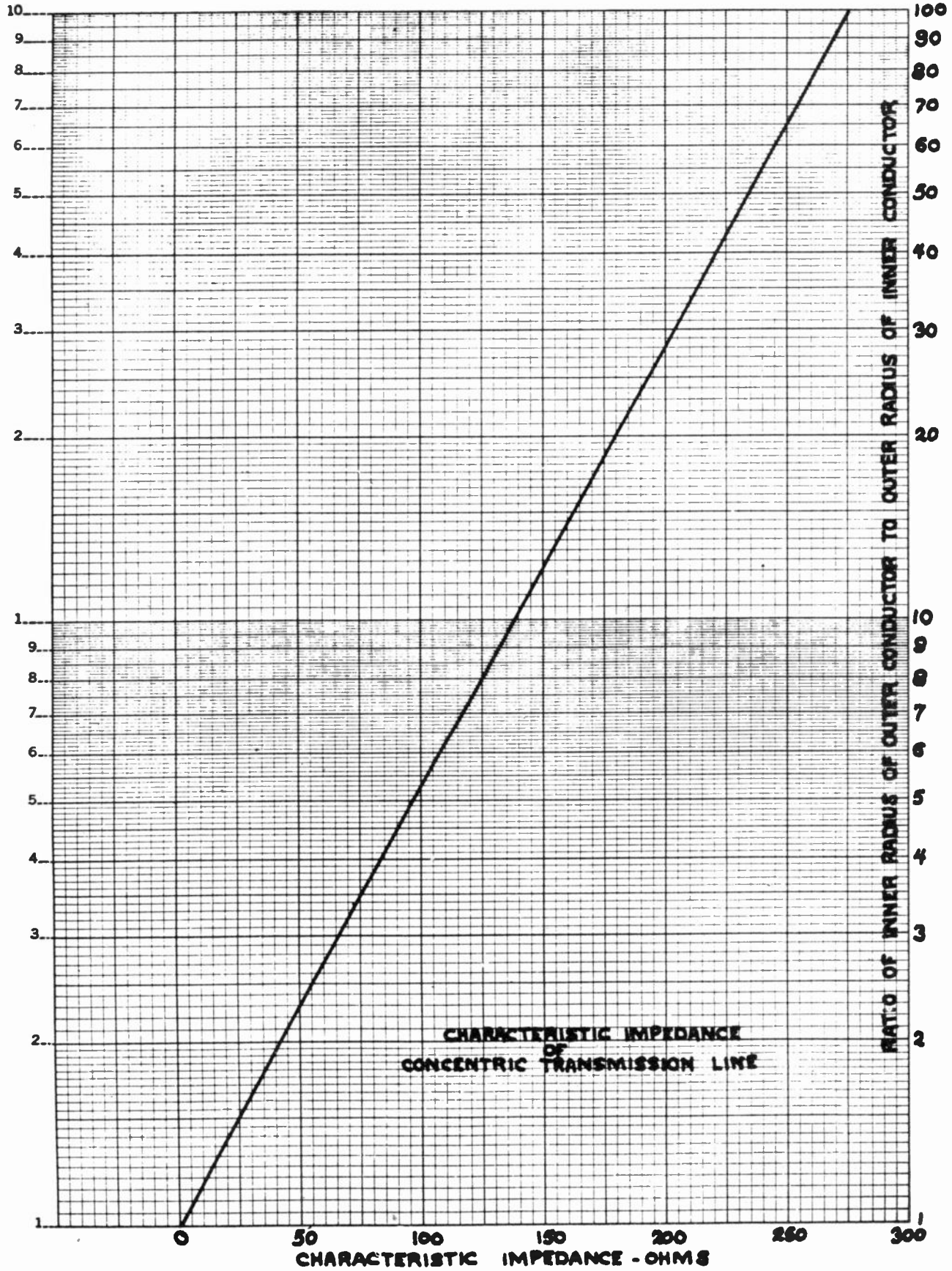
A "city-located" station has its highest signal where most needed; i.e., where noise level is highest.

FIG. 7



The signal of a "mountain-top" station may suffer by comparison with that of a competitive "city-located" station.


SPACING BETWEEN CONDUCTOR CENTERS
36"
24"
12"
6"
3"
CHARACTERISTIC IMPEDANCE Z₀
OF
TWO-CONDUCTOR OPEN WIRE
TRANSMISSION LINE
CHARACTERISTIC IMPEDANCE - OHMS
1000
900
800
700
600
500
400
300
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
WIRE SIZE - B & S GAUGE


CHARACTERISTIC IMPEDANCE
OF
CONCENTRIC TRANSMISSION LINE
RATIO OF INNER RADIUS OF OUTER CONDUCTOR TO OUTER RADIUS OF INNER CONDUCTOR
CHARACTERISTIC IMPEDANCE - OHMS
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50
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250
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8
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4
3
2
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90
80
70
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50
40
30
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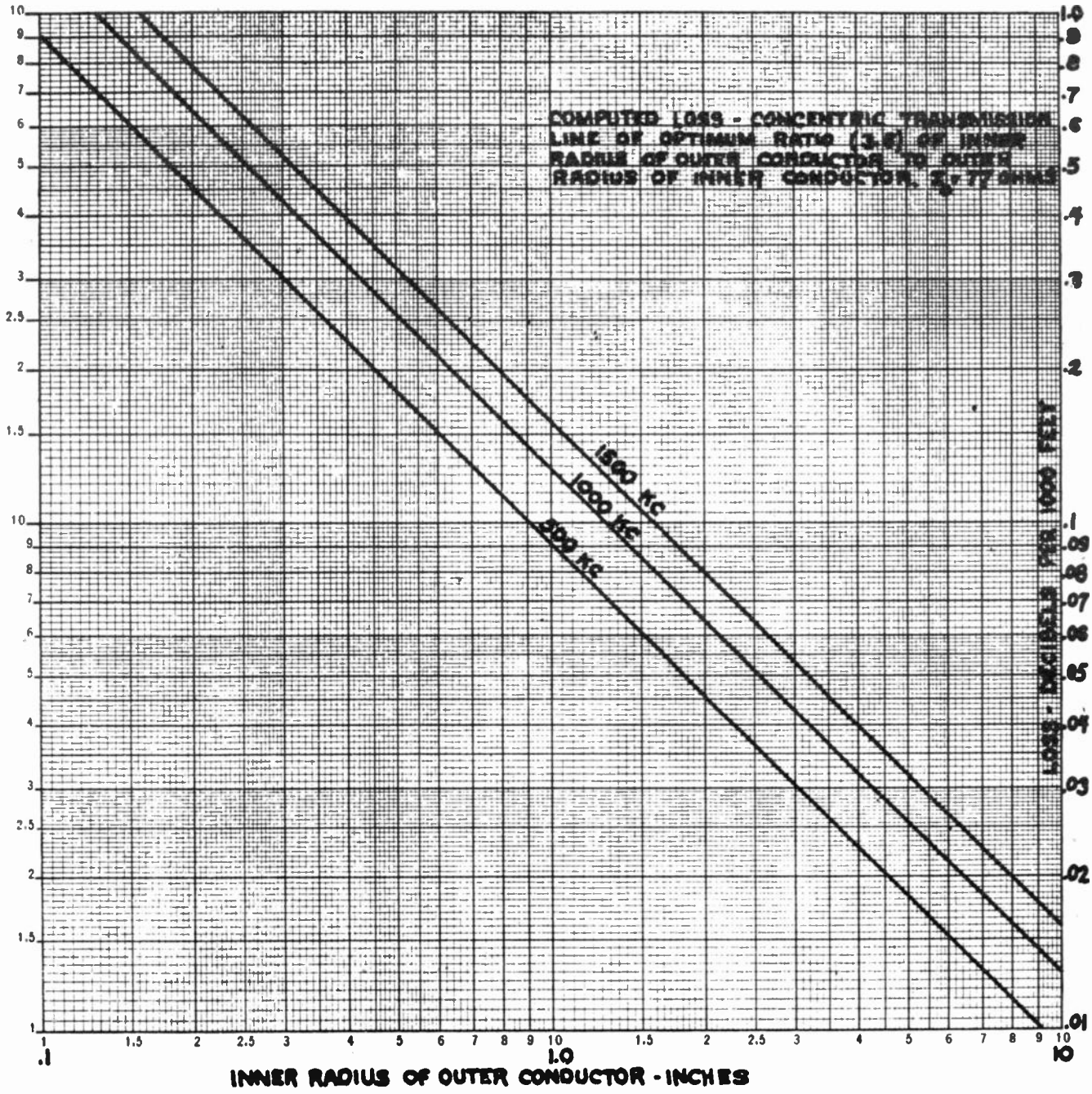
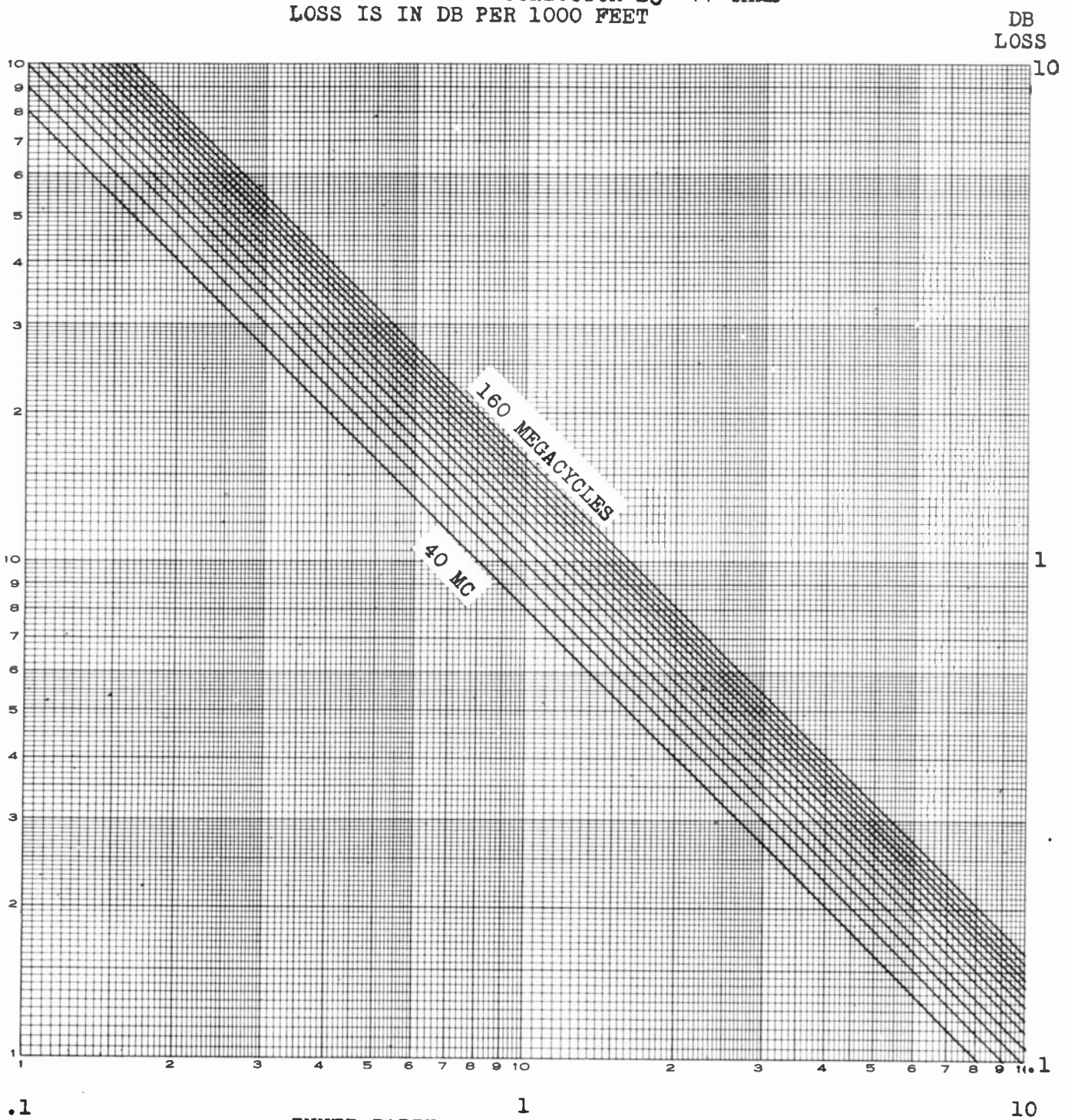
10


COMPUTED LOSS - CONCENTRIC TRANSMISSION LINE OF OPTIMUM RATIO (3.6) OF INNER RADIUS OF OUTER CONDUCTOR TO OUTER RADIUS OF INNER CONDUCTOR, Z = 77 OHMS
1500 MC
1000 MC
300 MC
LOSS - DECIBELS PER 1000 FEET
INNER RADIUS OF OUTER CONDUCTOR - INCHES

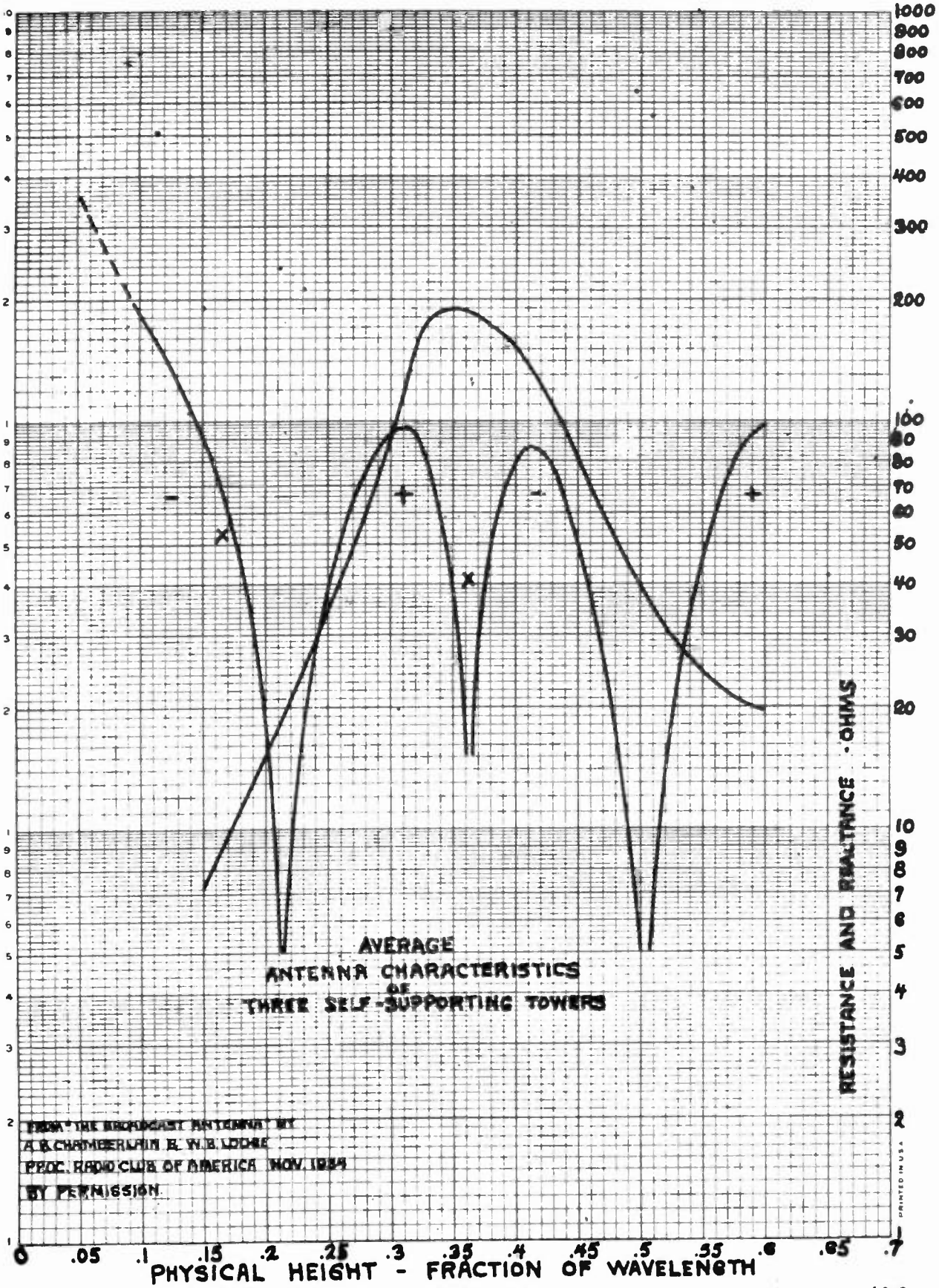
COMPUTED LOSS-CONCENTRIC TRANSMISSION LINE OF OPTIMUM RATIO (3.6) OF INNER RADIUS OF OUTER CONDUCTOR TO OUTER RADIUS OF INNER CONDUCTOR-Z_o=77 OHMS LOSS IS IN DB PER 1000 FEET



POWER LOSS IN DB IS PROPORTIONAL TO LENGTH OF LINE

13.4

NAB 1940


RESISTANCE AND REACTANCE - OHMS
1000
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700
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300
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100
90
80
70
60
50
40
30
20
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9
8
7
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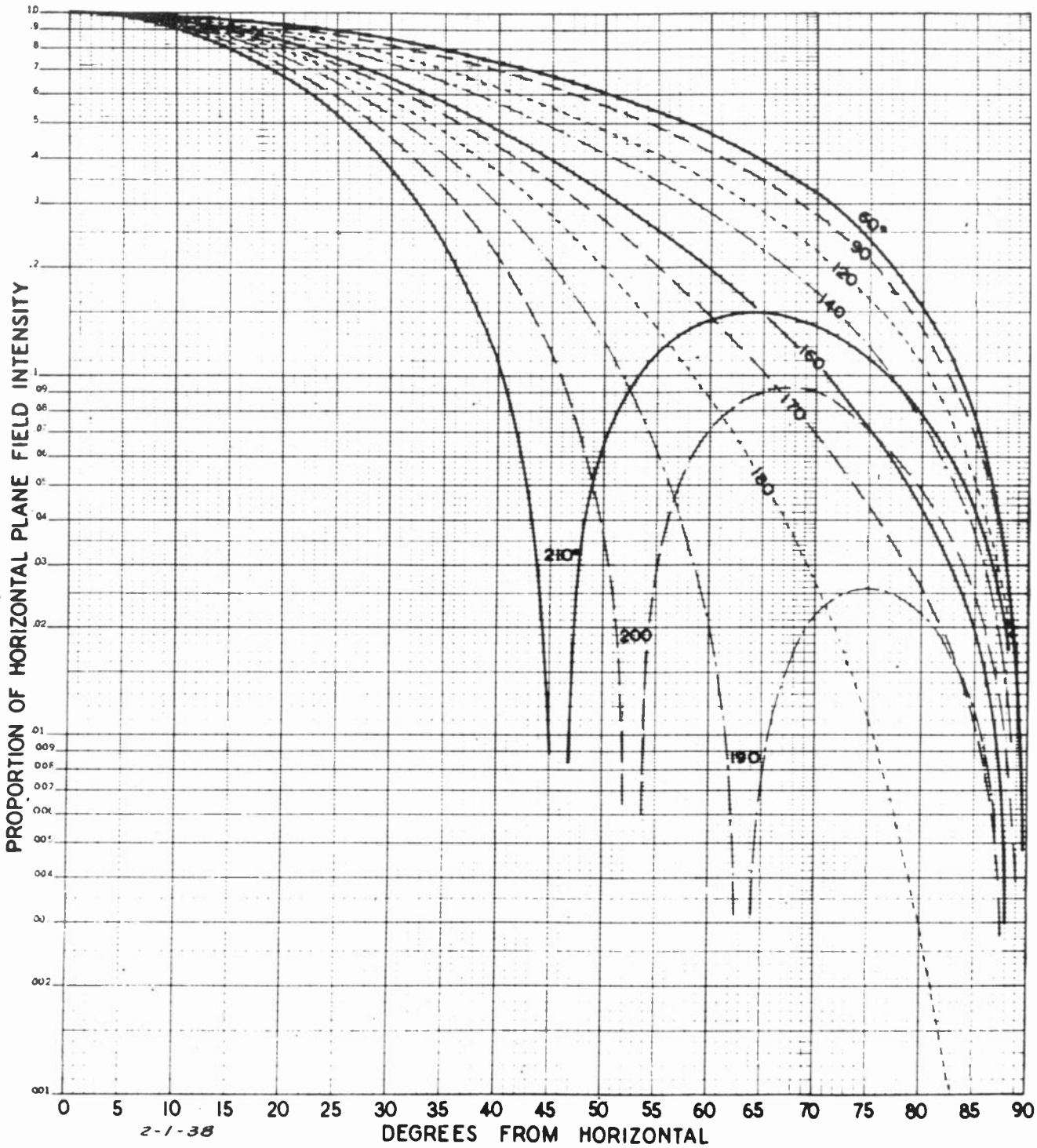
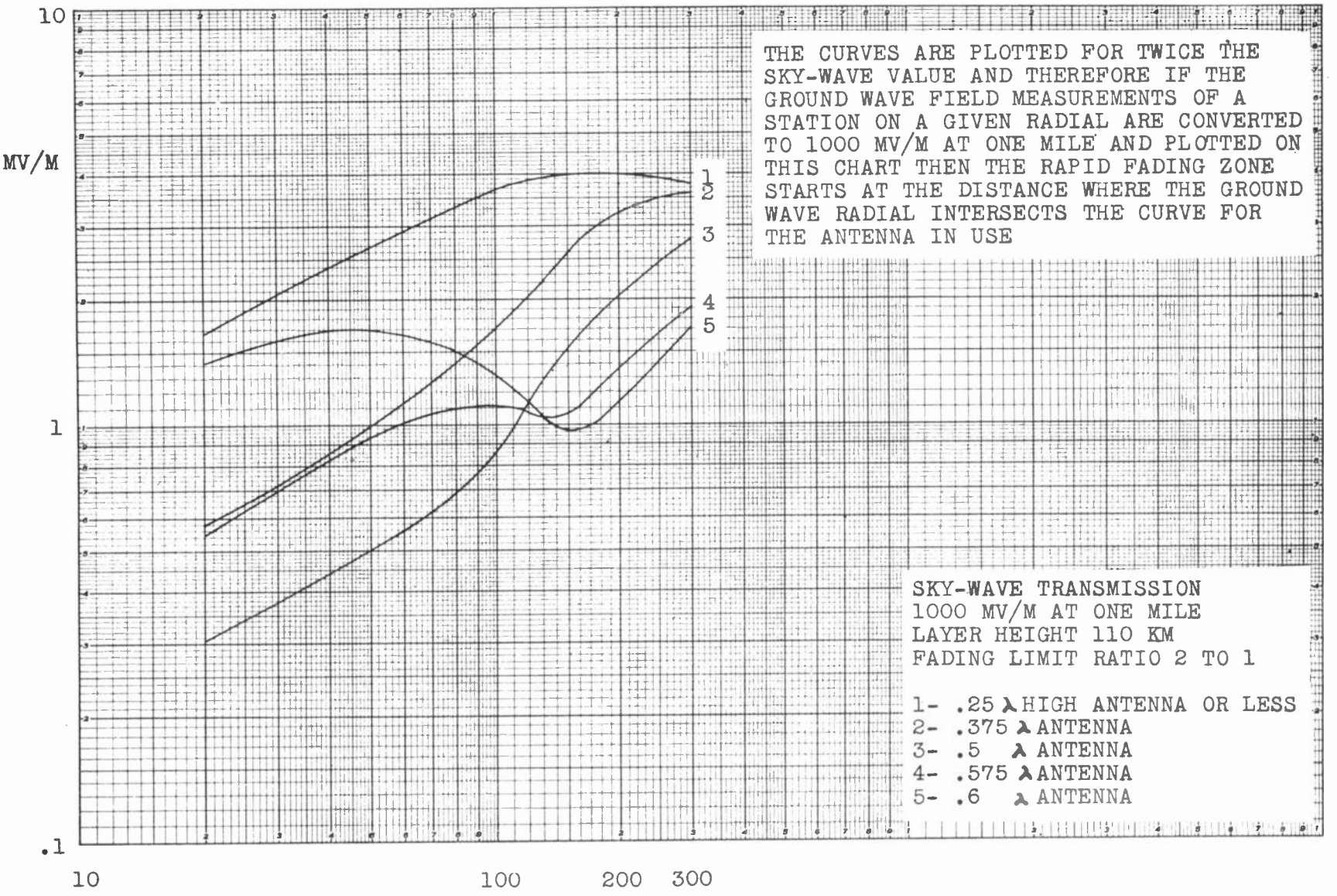
5
4
3
2
1
0
.05
.1
.15
.2
.25
.3
.35
.4
.45
.5
.55
.6
.65
.7
PHYSICAL HEIGHT - FRACTION OF WAVELENGTH
AVERAGE
ANTENNA CHARACTERISTICS
OF
THREE SELF-SUPPORTING TOWERS
FROM "THE BROADCAST ANTENNA" BY
A.B. CHAMBERLAIN & W.B. LODGE
PROC. RADIO CLUB OF AMERICA NOV. 1934
BY PERMISSION
PRINTED IN U.S.A.

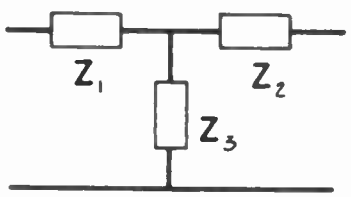
VERTICAL PLANE RADIATION CHARACTERISTICS OF CONSTANT CROSS SECTION VERTICAL RADIATORS 60° TO 210° HEIGHT



CURVES FOR CALCULATION OF START OF RAPID FADING ZONE



SERIES IMPEDANCE of "T" PHASE SHIFTING NETWORK



$$Z_1 = Z_2 = jZ_o \text{ TAN } \frac{B}{2}$$

where Z_o = characteristic impedance

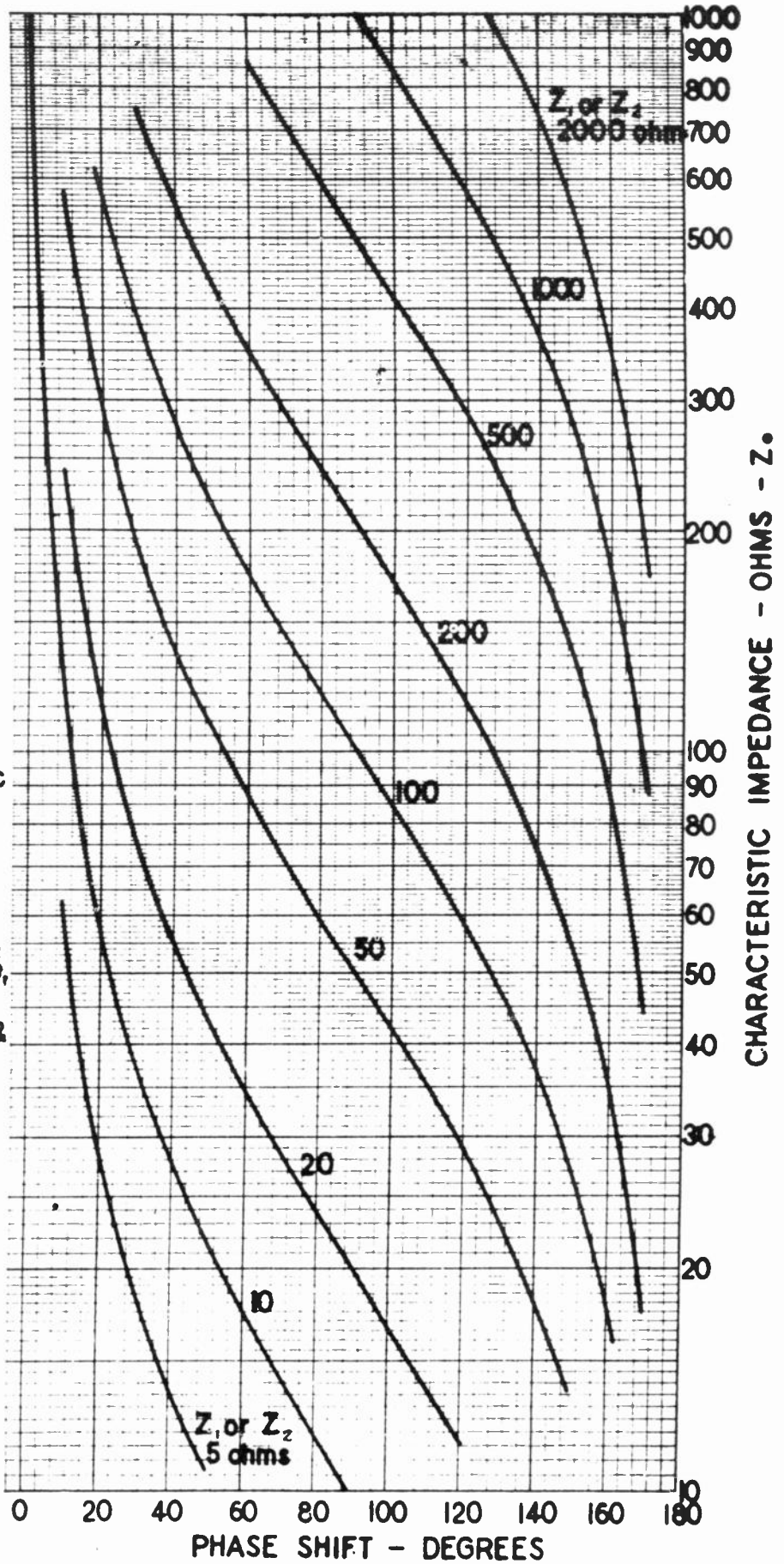
B = phase shift

Z_1 - Z_2 - Z_3 & Z_o measured in ohms

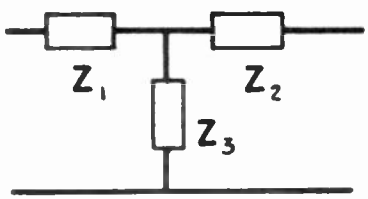
For phase delay, Z_1 & Z_2 are positive, or inductive, reactance.

For phase advance, Z_1 & Z_2 are negative, or capacitive, reactance.

2-1-38



SHUNT IMPEDANCE of "T" PHASE SHIFTING NETWORK



$$Z = -j \frac{Z_o}{\sin B}$$

where Z_o = characteristic impedance

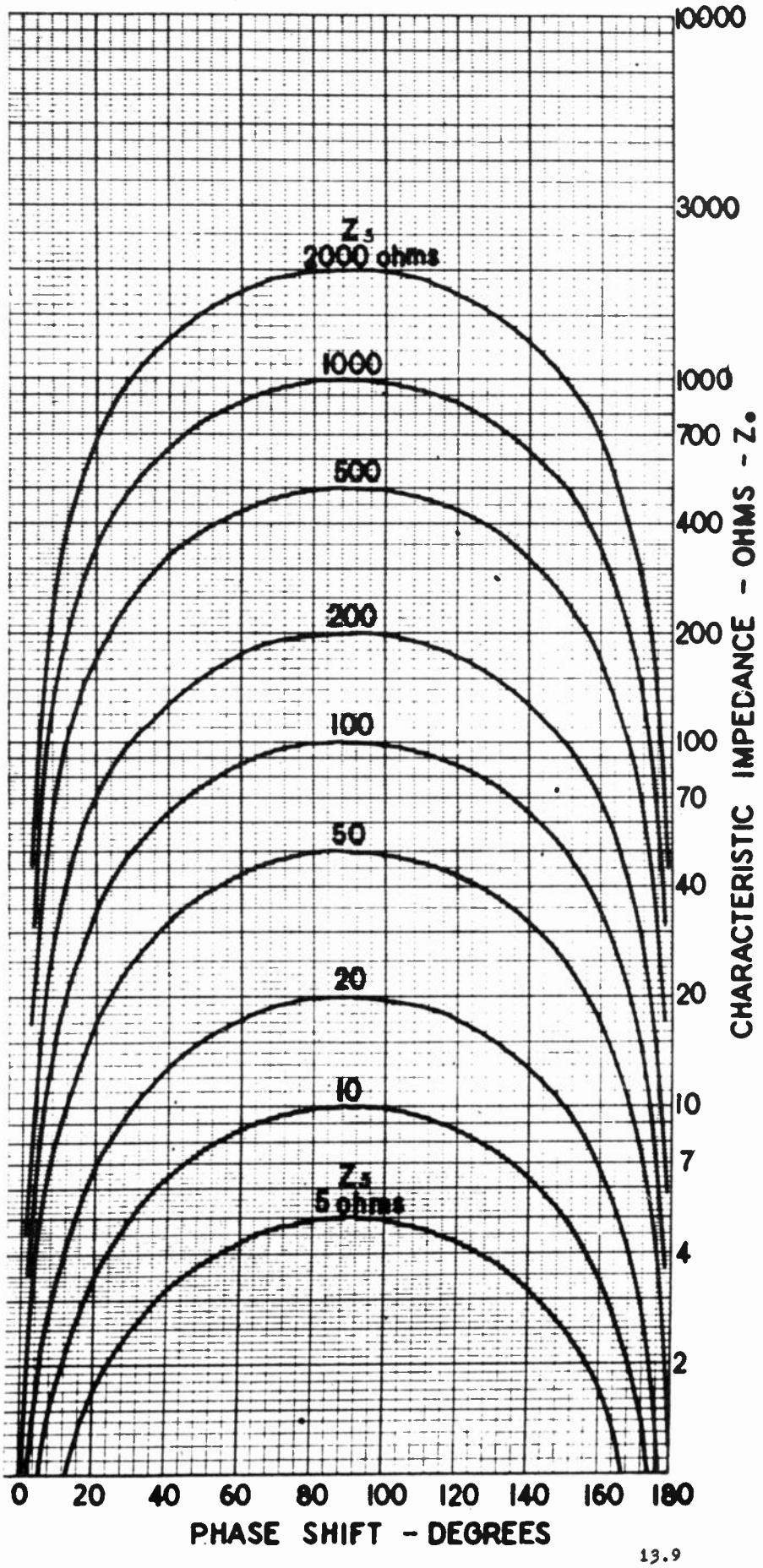
B = phase shift

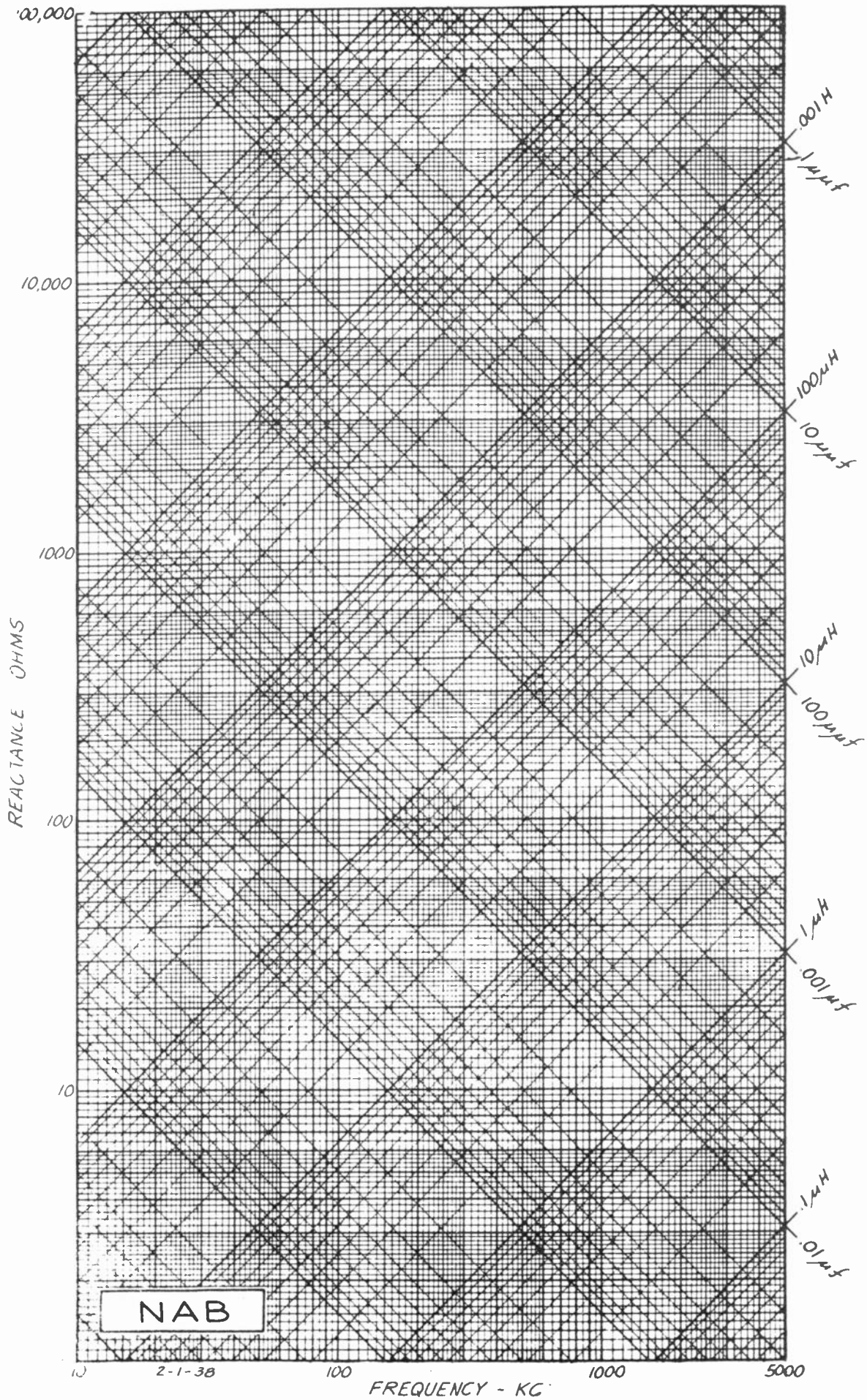
Z_1 - Z_2 - Z_3 & Z_o measured in ohms

For phase delay, Z_3 is negative, or capacitive, reactance.

For phase advance, Z_3 is positive, or inductive, reactance.

2-1-38.




100,000
10,000
1000
100
10
REACTANCE OHMS
.001 H
1 μμf
100 μH
10 μμf
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.01 μf
NAB
10
2-1-38
100
1000
5000
FREQUENCY - KC

BROADCAST STATION AUDIO AND CONTROL CIRCUITS

By Warren E. McDowell
Naval Research Laboratory
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 was 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.

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 range from holding a piece of stiff paper against a needle, hoping to catch a tiny vibration indicative of the start of the sound, or the almost equally impractical use of headphones, to the method herein described. The first method obviously lacks dependability, the second is inconvenient at best. It is much more effective to make use of a simple relay method which has been installed with great success in a number of stations.

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 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 feedback 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. All common wires should be tied together at one point in the mixer console. An external ground is connected to this same terminal. Low level circuits are carried in #19 lead cable and higher level circuits in copper braid. If a noise level of 60 DB below reference is to be reached, extreme care must be taken with all wiring. In some instances very high level circuits are run in lead cable to decrease cross-talk.

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

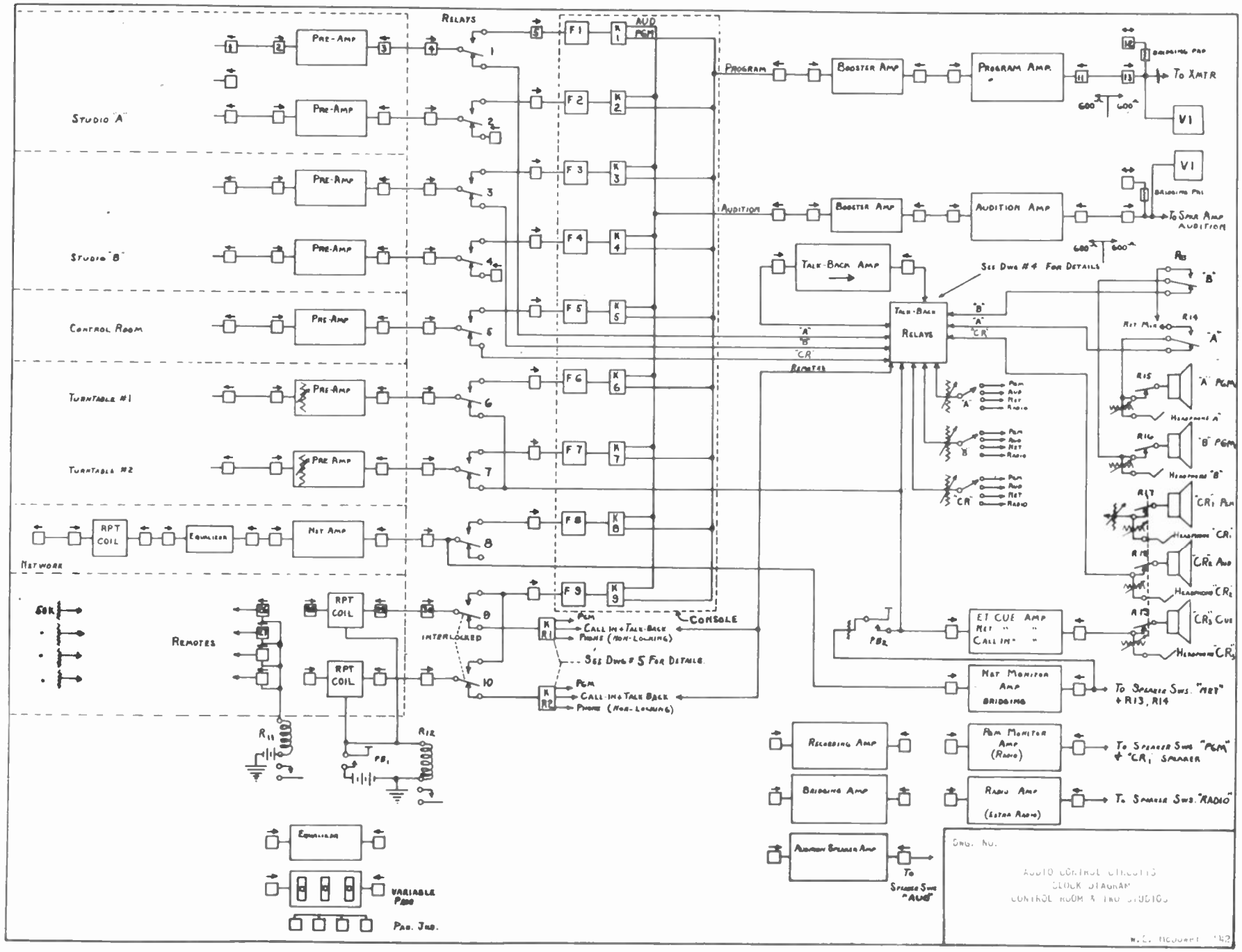
The manufacturer of equipment or components is not specified since each engineer will have his own preference. Satisfactory operation will depend, of course, upon the care with which the selection is made. This choice of high quality relays, pushbuttons and key switches will more than repay the cost 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. Layout 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 author acknowledges the assistance in the development of these circuits from the following: David W. Jefferies, Radio Station W T B O, Cumberland, Maryland; Otis L. Atherton, Radio Station W H D L, Olean, New York; John T. Dowdell, Radio Station W I B X, Utica, New York.

The author's home address is 3953 First Street, Southwest. Washington, D.C.


Relays
Aud
Pgm
Studio "A"
Pre-Amp
Studio "B"
Control Room
Turntable #1
Turntable #2
Rpt Coil
Equalizer
Net Amp
Network
Remotes
Program
Booster Amp
Program Amp
To Xmtr
Audition
Audition Amp
To Spkr Amp Audition
Talk-Back Amp
See Dwg # 4 For Details
Talk-Back Relays
Console
See Dwg # 5 For Details
Interlocked
Call In & Talk-Back
Phone (Non-Loading)
Pbm
Net Monitor Amp Bridging
To Speaker Sws. "Net" & R13, R14
Et Cue Amp
Recording Amp
Bridging Amp
Pbm Monitor Amp (Radio)
Radio Amp (Extra Radio)
To Speaker Sws. "Pbm" & "CR1 Speaker
To Speaker Sws. "Radio"
To Speaker Sws. "Aud"
Variable Pbm
Pbm. Jnd.
Dwg. No.
Audio Control Circuits
Block Diagram
Control Room & Two Studios

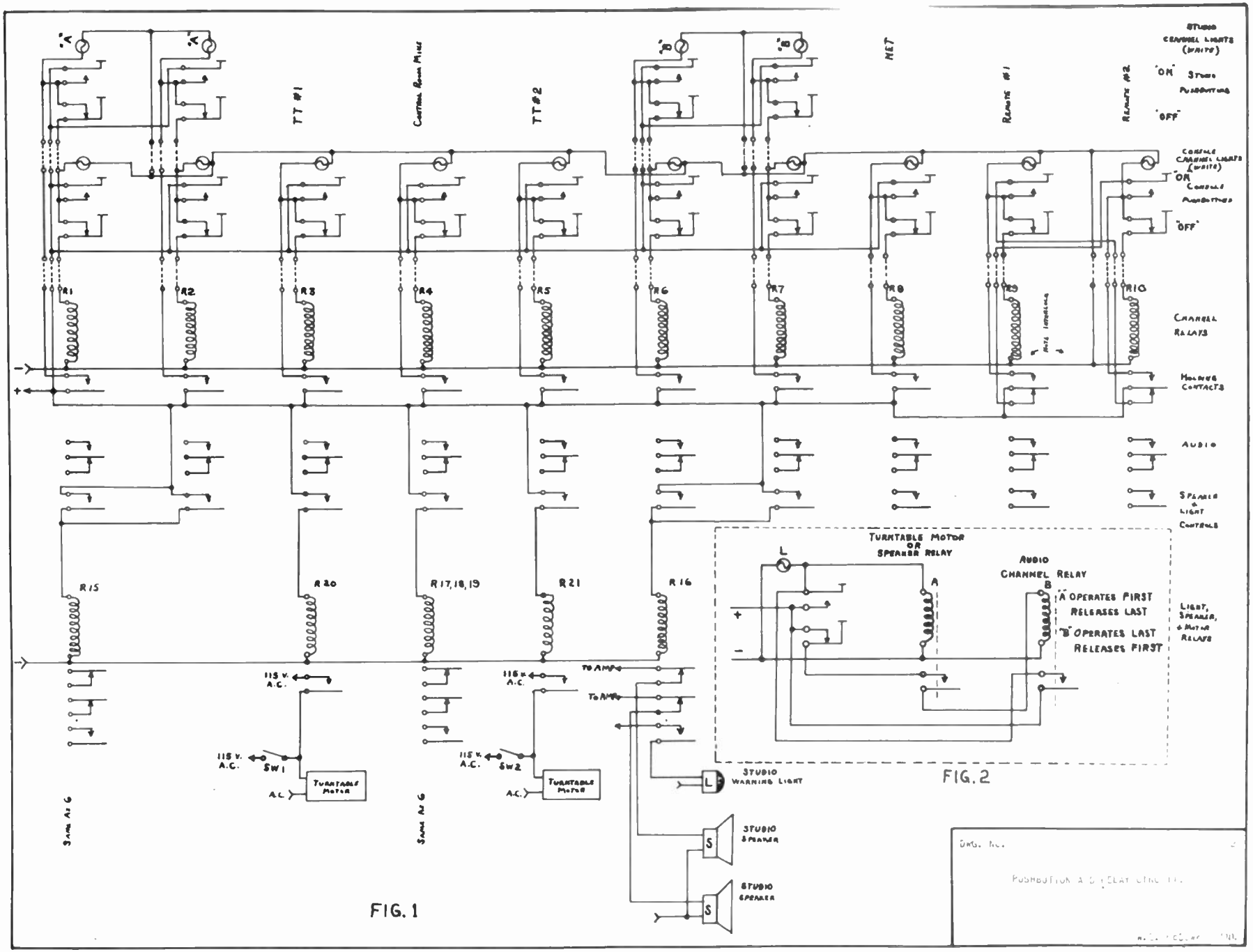


FIG. 1

FIG. 2

Dwg. No.

Pushbutton A & B Relay Ckt. ??

12.5

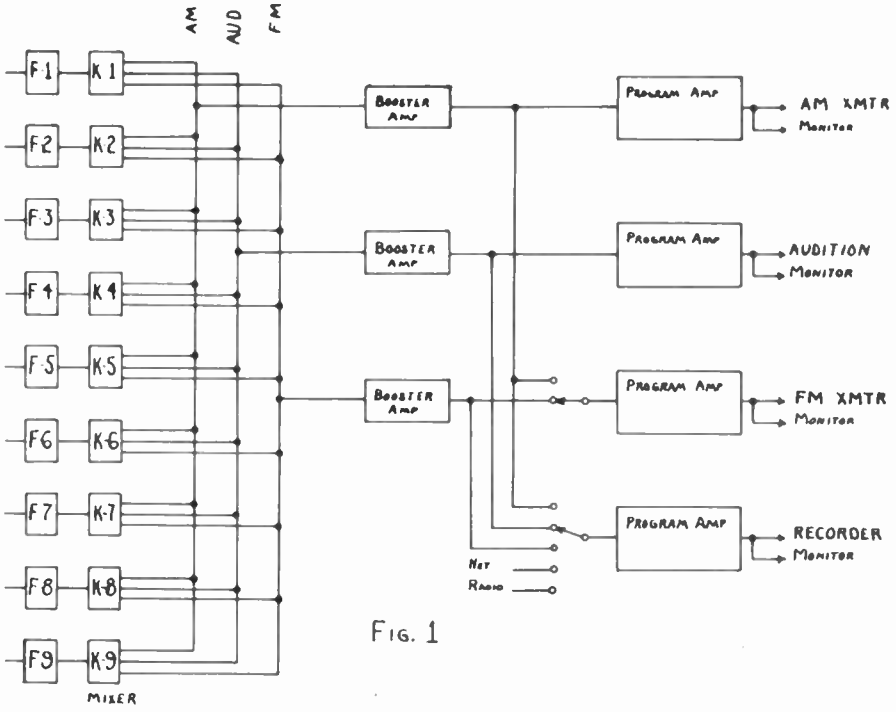
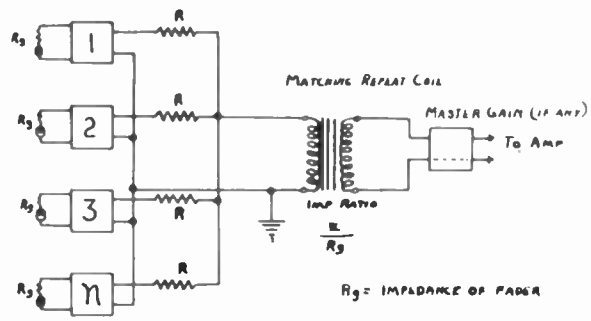


FIG. 1



CIRCUIT CONSTANTS	NUMBER OF MIXING CHANNELS, n							
MINIMUM LOSS $= 10\log_{10}(2n-1)$ DB	2	3	4	5	6	7	8	9
	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

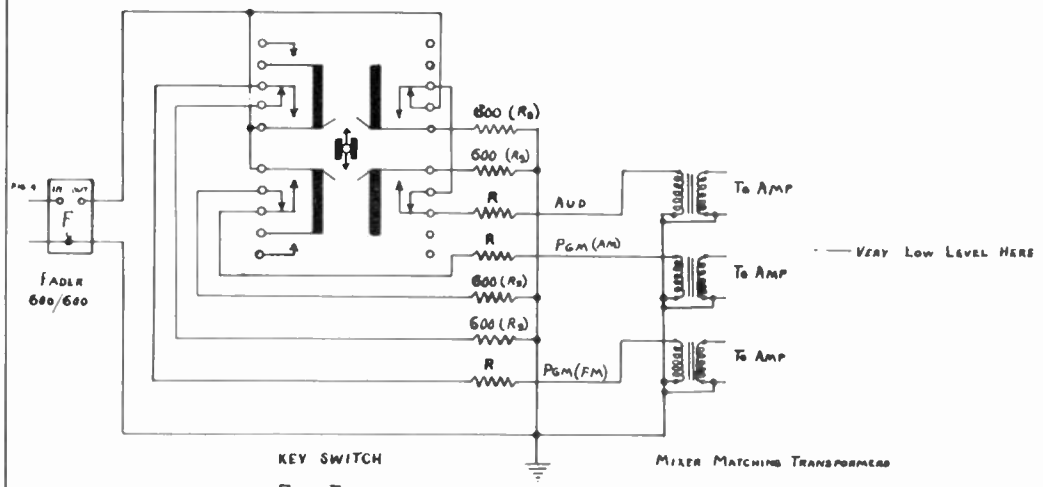
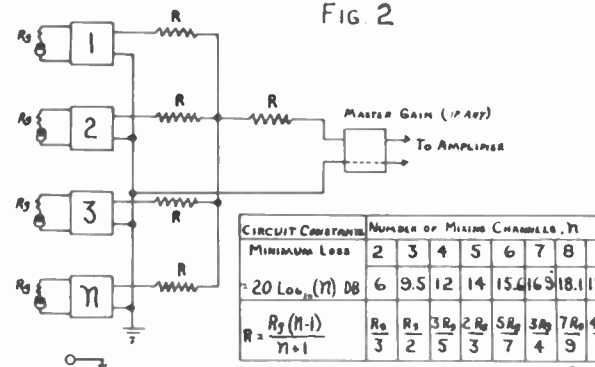


FIG. 3



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
$R = \frac{R_g(n-1)}{n+1}$	$\frac{R_g}{3}$	$\frac{R_g}{2}$	$\frac{3R_g}{5}$	$\frac{2R_g}{3}$	$\frac{5R_g}{7}$	$\frac{3R_g}{4}$	$\frac{7R_g}{9}$	$\frac{4R_g}{5}$

*PICKUPS 9-37

FIG. 5

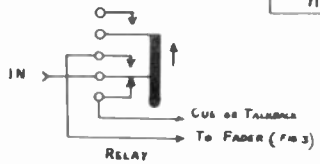
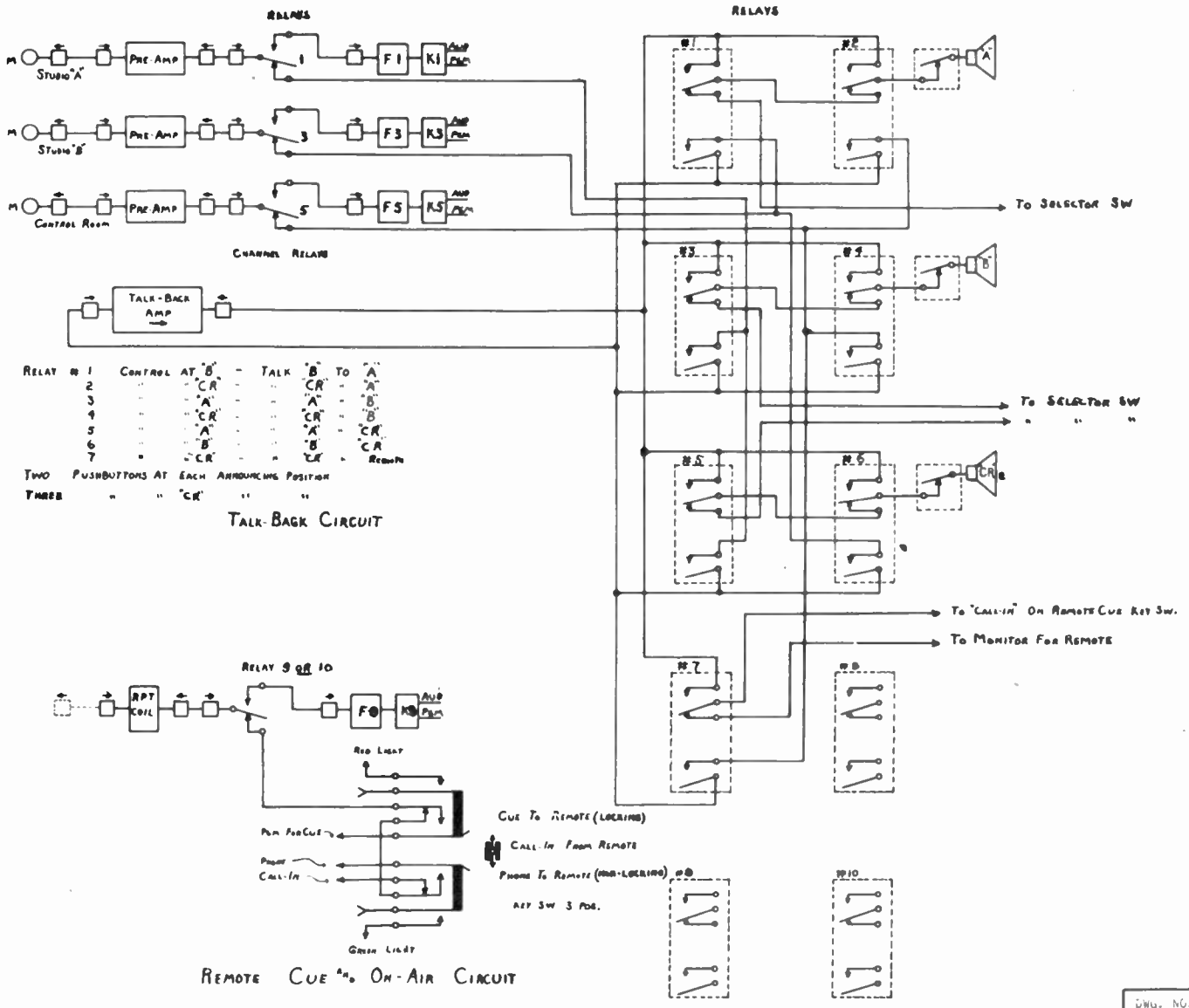


FIG. 4

DWG. NO. 3

MIXER SYSTEMS

W.E. McDowell '44



Relay # 1	Control at	"B"	-	Talk	"B"	to	"A"
2	"	"CR"	-	"	"CR"	-	"A"
3	"	"A"	-	"	"A"	-	"B"
4	"	"CR"	-	"	"CR"	-	"B"
5	"	"A"	-	"	"A"	-	"CR"
6	"	"B"	-	"	"B"	-	"CR"
7	"	"CR"	-	"	"CR"	-	Remote

Two Pushbuttons at each announcing position
Three " " "CR" " "

Talk-Back Circuit

Remote Cue and On-Air Circuit

Dwg. No.	4
Remote Cue Circuit Talk-Back Circuit	
W.E. Hodgell '41	

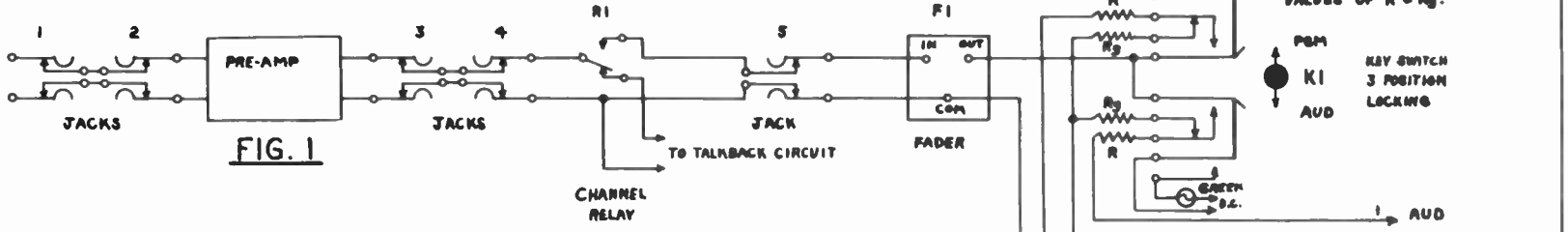
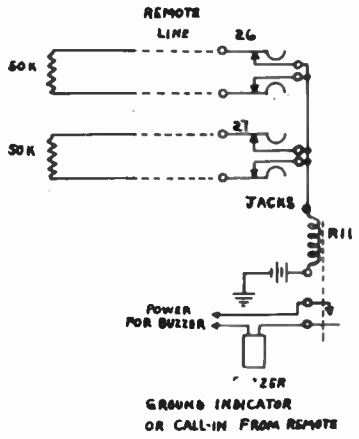


FIG. 1



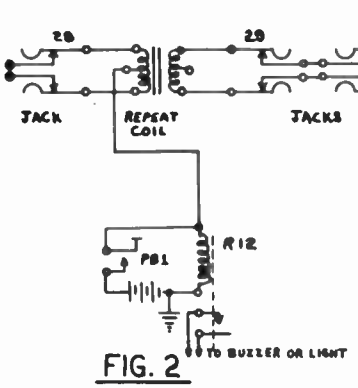
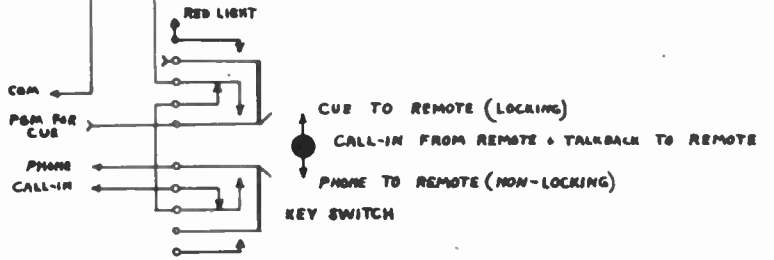


FIG. 2



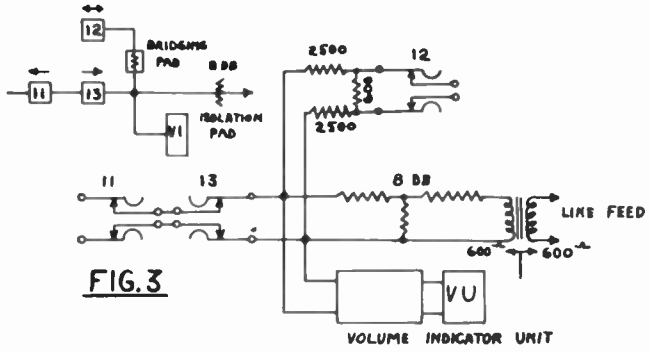


FIG. 3

DWG. NO.	5
WIRING DETAIL JACKS, KEY SWITCHES & RELAYS REMOTE CUE KEY SWITCH	
W.E. McDowell '48	

ROOM ACOUSTICS*
GENERAL CONSIDERATIONS FOR GOOD ROOM ACOUSTICS

(Reprinted from Reference Data for Radio Engineers, Second Edition, by permission of the publisher, Federal Telephone and Radio Corporation.)

ROOM ACOUSTICS*

General Considerations for Good Room Acoustics

The following information is intended primarily to aid field engineers in appraising acoustical properties of existing structures and not as a complete treatise on the subject.

1. Good Acoustics - Governing Factors

A. *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.

B. *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.

2. 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.

Limits for reasonable freedom of standing waves:

width to height = 1.2 to 1.35
length to width = 1.5 to 1.7

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.

Minimum sizes and desirable dimensions for broadcast music studios are given in Fig. 1.

3. Optimum Reverberation Time.

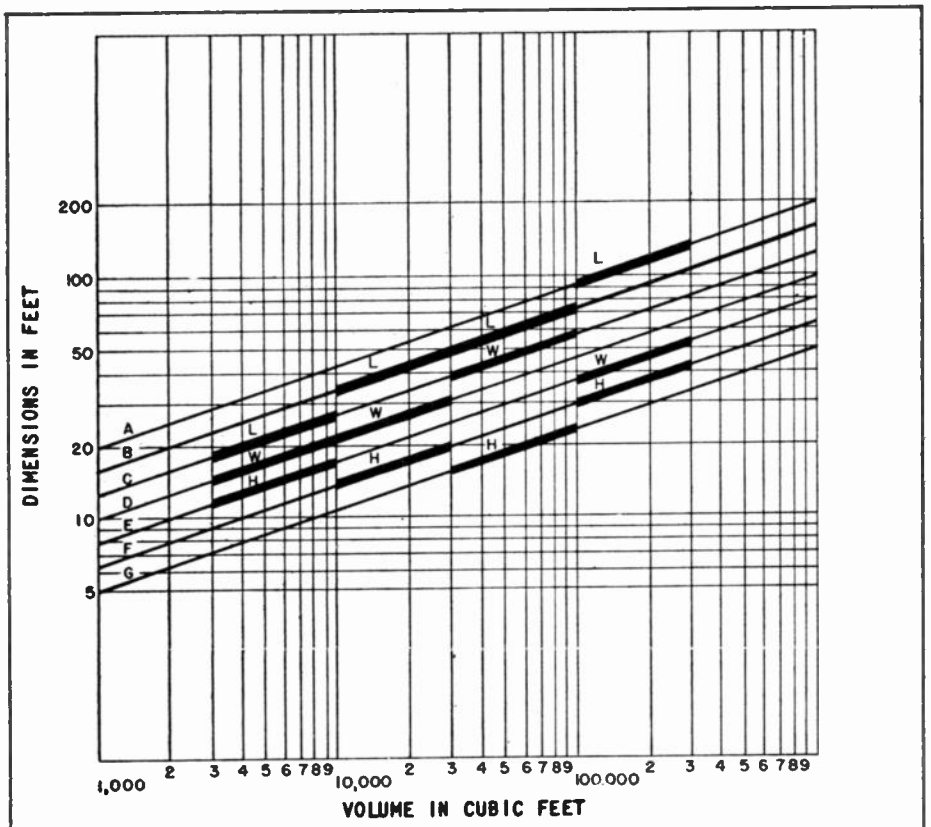
Optimum, or most desirable reverberation-time, varies with (1) room sizes and (2) use, such as music, speech, etc. (see Figs. 2 and 3).

A small radio studio for speech broadcasts represents a special case. The acoustic studio design should be such that the studio neither adds nor detracts from the speaker's voice, which on reproduction in the home should sound as though he were actually present.

For optimum characteristics of a speech studio, the reverberation time should be about one-half a second throughout the middle and lower audio frequency range. At high frequencies, the reverberation time may be 20 percent to 25 percent greater than at 512 cycles. This rise at the higher frequencies enhances intelligibility and allows for the presence in the studio of one or two extra persons without materially affecting the reverberation-time/frequency curve.

Speech sounds above about 1000 cycles pro-

* Compiled by Edward J. Content, Consulting Engineer.



Courtesy Acoustical Society of America and RCA Manufacturing Co.

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. 1 -- Preferred room dimensions based on 2 1/3 ratio. Permissable deviation ± 5%.

mote intelligibility. Apparent intensity of speech sounds is provided by frequencies below this value.

Preponderance of low bass reverberation and standing waves tends to make the voice sound "boomy" and impairs speech intelligibility.

4. Computation of Reverberation Time.

Reverberation time at different audio frequencies may be computed from room dimensions 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

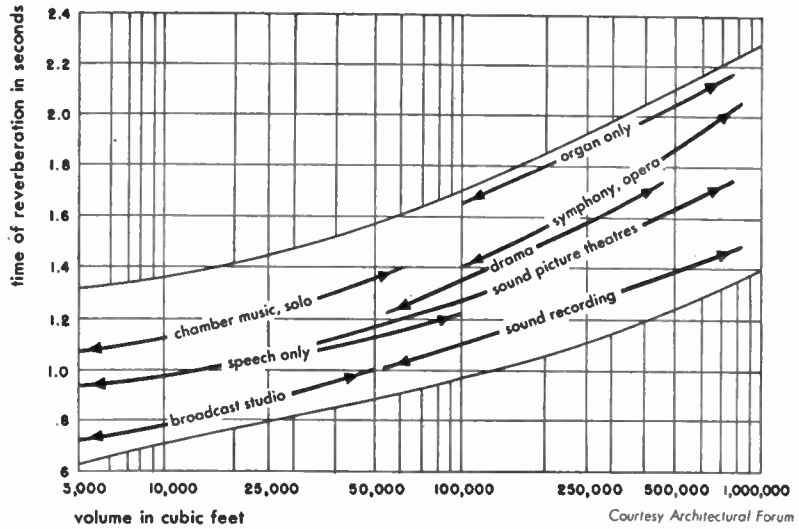


Fig. 2—Optimum reverberation time in seconds for various room volumes at 512 cycles per second.

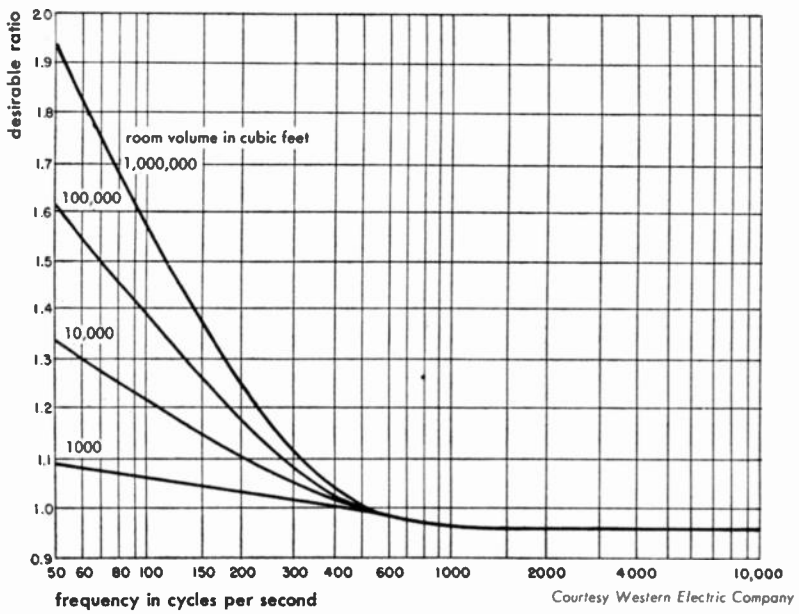


Fig. 3—Desirable relative reverberation time versus frequency for various structures and auditoriums.

Note: 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. 2) by the number in the vertical scale which corresponds to the frequency chosen.

referred to as "open window" or "OW" units.

$$T = \frac{.05V}{-S \log_e (1-a_{av})}$$

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 Table I. As an aid in using the formula for reverberation time, Fig. 4 may be used for obtaining $[-\log_e (1-a_{av})]$ from known values of (a_{av}).

Table II shows absorption coefficients for some of the more commonly used materials for acoustical correction.

Considerable variation of sound-absorption in air at frequencies above 1000 cycles occurs at high relative humidities (see Fig. 5). Calculation of reverberation time, therefore, should be checked at average relative humidities applicable to the

TABLE I

ACOUSTICAL COEFFICIENTS OF MATERIALS AND PERSONS

Description	Sound Absorption Coefficients *Cycles per 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	.012	.013	.017	.02	.023	.025	"
Plaster Finish Coat Wood lath-wood studs	.020	.022	.032	.039	.039	.028	P. E. Sabine
Plaster + Finish Coat on Metal lath	.038	.049	.060	.085	.043	.056	V. O. Knudsen
Poured Concrete Unpainted	.010	.012	.016	.019	.023	.035	"
Poured Concrete Painted and Varnished	.009	.011	.014	.016	.017	.018	"
Carpet, pile on concrete	.09	.08	.21	.26	.27	.37	Building Research Station
Carpet, pile on 1/8" felt	.11	.14	.37	.43	.27	.25	"
Draperies, Velour, 18 oz. per sq. yard in contact with wall	.05	.12	.35	.45	.38	.36	P. E. Sabine
Ozite 3/8"	.051	.12	.17	.33	.45	.47	"
Rug, Axminster	.11	.14	.20	.33	.52	.82	Wente and Bedell
Audience, seater per sq. ft. of area	.72	.89	.95	.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	.05	.04	.03	.025	.022	.02	Estimated

Courtesy Architectural Acoustics

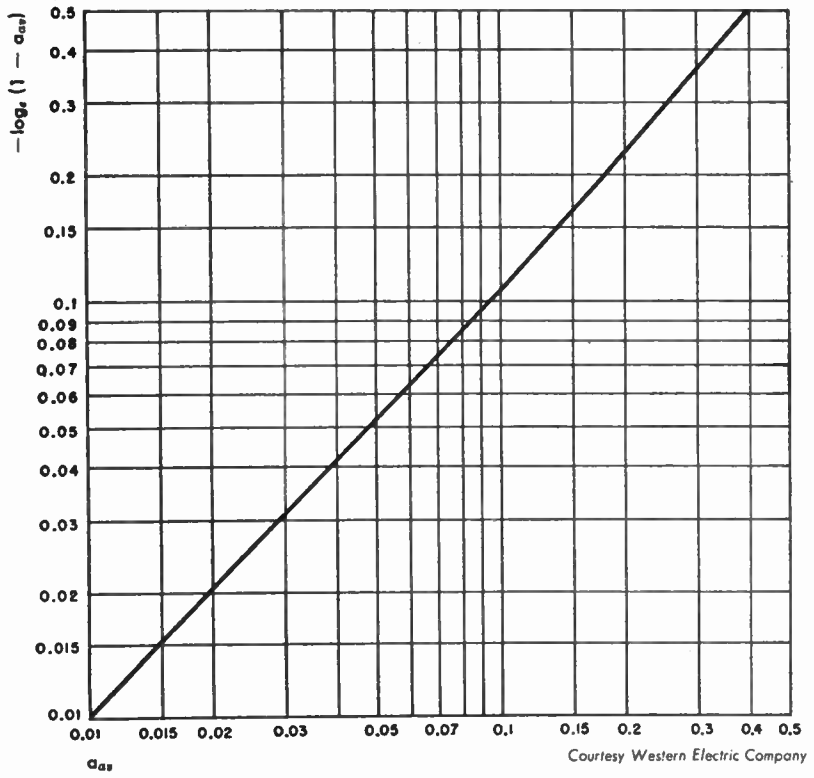


Fig. 4.

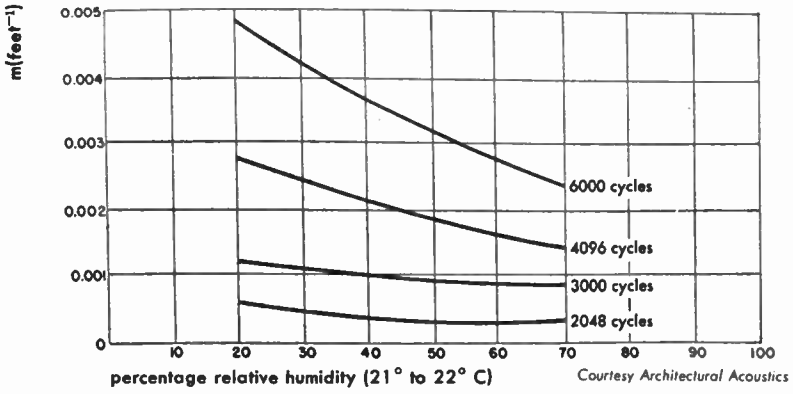


Fig. 5—Value of attenuation constant m at different frequencies and relative humidities.

particular location involved. For such check calculations the following formula may be used:

$$T = \frac{.05V}{-S \log_e (1-a_{av}) + 4m V}$$

where "m" is the coefficient in feet $^{-1}$ as indicated in Fig. 5.

5. **Electrical Power Levels Required For Public Address Requirements.**

   A. *Indoor:* See Fig. 6.

   B. *Outdoor:* See Fig. 7.

6. **General**

   A. *Loudspeaker Wire Sizes:* See Fig. 8.

   B. *Acoustical Sound Levels:* See Fig. 9.

   C. *Acoustical Musical Ranges and Levels:* See Fig. 10.

   D. *Acoustical Speech Levels and Ranges of Other Sounds:* See Fig. 11.

   E. *Noise Levels:* See Fig. 13.

TABLE II

ACOUSTICAL COEFFICIENTS OF MATERIALS USED FOR ACOUSTICAL CORRECTION

Material	*Cycles per second*						*Noise *Red. Coef.*	*Manufactured By*
	128	256	512	1024	2048	4096		
Corkoustic-B4	.08	.13	.51	.75	.47	.46	.45	Armstrong Cork Co.
" B6	.15	.28	.82	.60	.58	.38	.55	"
Cushiontone A-3	.17	.58	.70	.90	.76	.71	.75	"
Koustex	.10	.24	.64	.92	.77	.75	.65	David E. Kennedy Inc.
Sanacoustic (Metal) Tiles	.25	.56	.99	.99	.91	.82	.85	Johns-Manville Sales Corp.
Permacoustic Tiles 3/4"	.19	.34	.74	.76	.75	.74	.65	"
Low Frequency Element	.66	.60	.50	.50	.35	.20	.50	"
Triple Tuned Element	.66	.61	.80	.74	.79	.75	.75	"
High Frequency Element	.20	.46	.55	.66	.79	.75	.60	"
Absorbatone A	.15	.28	.82	.99	.87	.98	.75	Luse Stevenson Co.
Acoustex 60R	.14	.28	.81	.94	.83	.80	.70	National Gypsum Co.
Econacoustic 1"	.25	.40	.78	.76	.79	.68	.70	"
Fiberglas Acoustical Tiletype TW-PF 9D	.22	.46	.97	.90	.68	.52	.75	Owens-Corning Fiberglas Corp.
Acoustone D 11/16"	.13	.26	.79	.88	.76	.74	.65	U.S. Gypsum Co.
Acoustone F 13/16"	.16	.33	.85	.89	.80	.75	.70	"
Acousti-Celotex Type C-6 1¼"	.30	.56	.94	.96	.69	.56	.80	The Celotex Corp.
Absorbex Type A 1"	.41	.71	.96	.88	.85	.96	.85	"
Acousteel B Metal Facing 1 5/8"	.29	.57	.98	.99	.85	.57	.85	"

* 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 Acoustics Materials Association

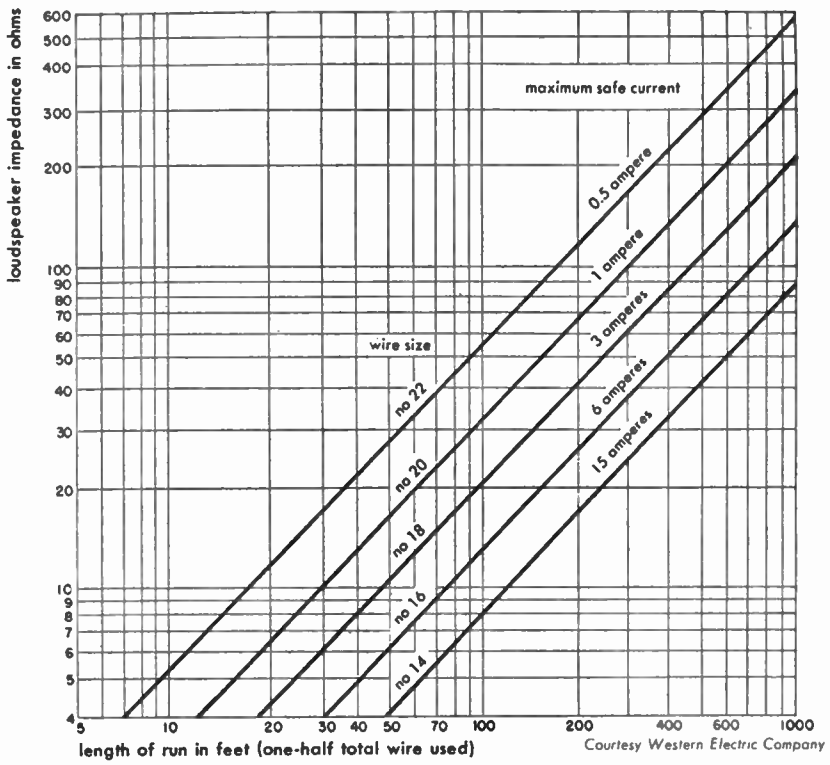


Fig. 6—Wire sizes for loudspeaker circuits assuming maximum loss of 0.5 decibel.

F. *Equal Loudness Contours:* Fig. 12 gives average hearing characteristics of the human ear at audible frequencies and at loudness levels of zero to 120 db versus intensity levels expressed in decibels above 10^{-16} watts per square centimeter. Ear sensitivity varies considerably over the audible range of sound frequencies at various levels. A loudness level of 120 db is heard fairly uniformly throughout the entire audio range but, as indicated in Fig. 12, a frequency of 1000 cycles at a 20 db level will be heard at very nearly the same intensity as a frequency of 60 cycles at a 60 db 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 80 to 100 db (see Fig. 10).

ROOM ACOUSTICS

Note on Illustration Credits:

Table 1, and Fig. 5, Architectural Acoustics; by V. O. Knudsen, published by John Wiley and Sons; Fig. 2, Architectural Forum, September, 1939; Fig. 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, Western Electric Co.; Table 11, Bulletin No. VIII, Acoustics Materials Association, Fig. 1, Acoustical Society of America and RCA Manufacturing Co.

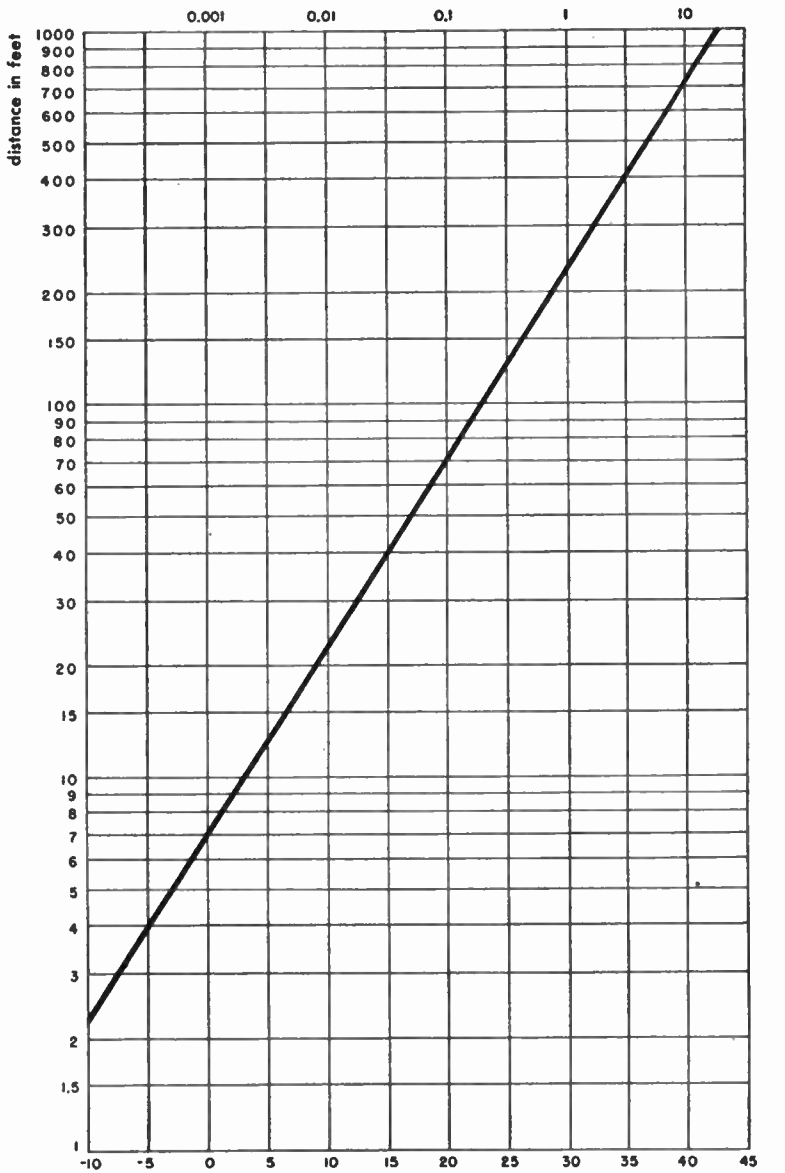


Fig. 8—Distance from loudspeaker and relative amplifier power capacity required for speech, average for 30° angle of coverage. For angles over 30°, more loudspeakers and proportional output power are required. Depending on loudspeaker efficiency, a correction factor must be added to the indicated power level, varying approximately from 4 to 7 decibels for the more-efficient type of horn loudspeakers.

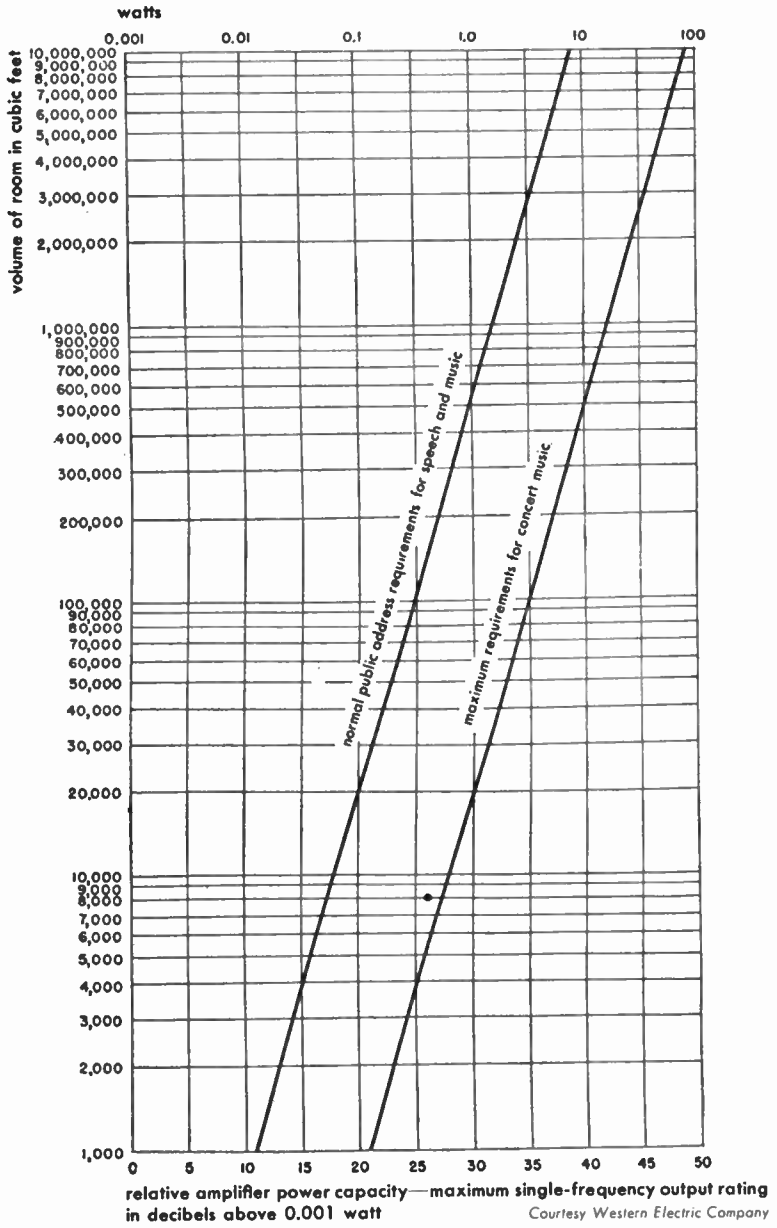


Fig. 7—Room volume and relative amplifier power capacity. To the indicated power level depending on loudspeaker efficiency, there must be added a correction factor which may vary from 4 decibels for the most efficient horn-type reproducers to 20 decibels for less efficient cone loudspeakers.

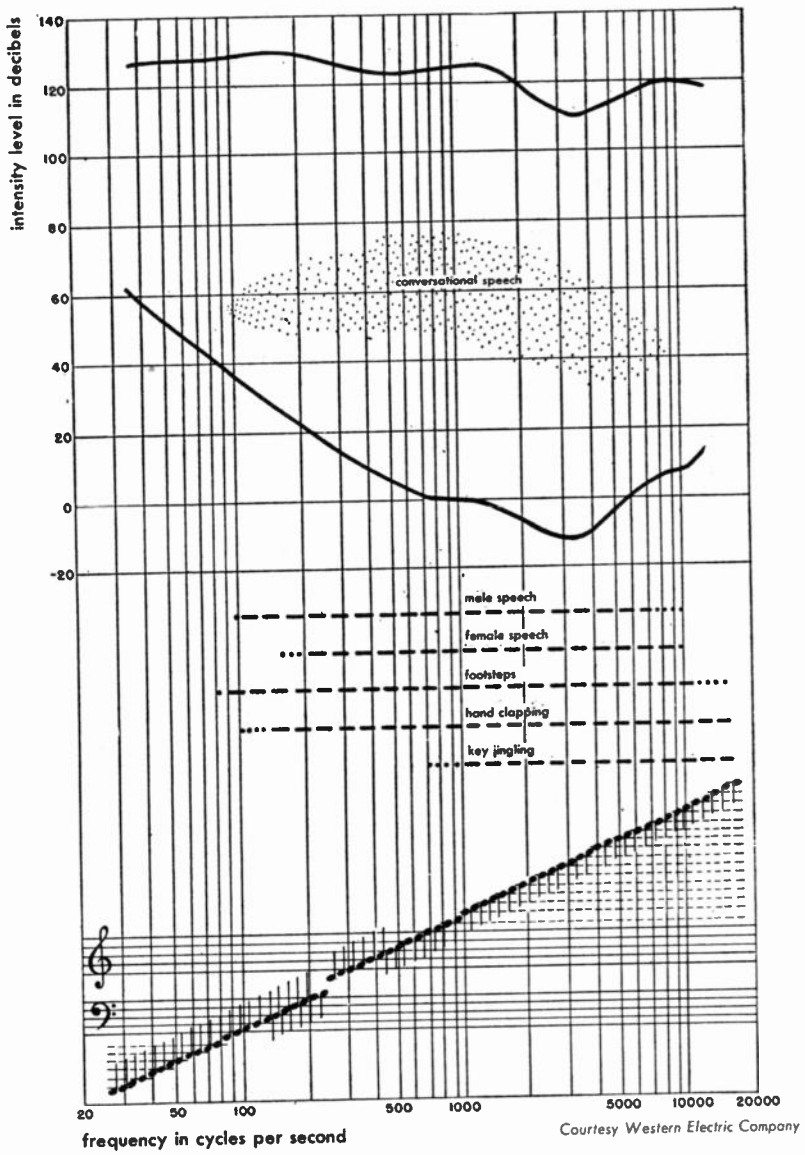


Fig. 10—Frequency ranges of male and female speech and other sounds. Intensity levels of conversational speech. Zero level equals 10^{-16} watt per square centimeter.

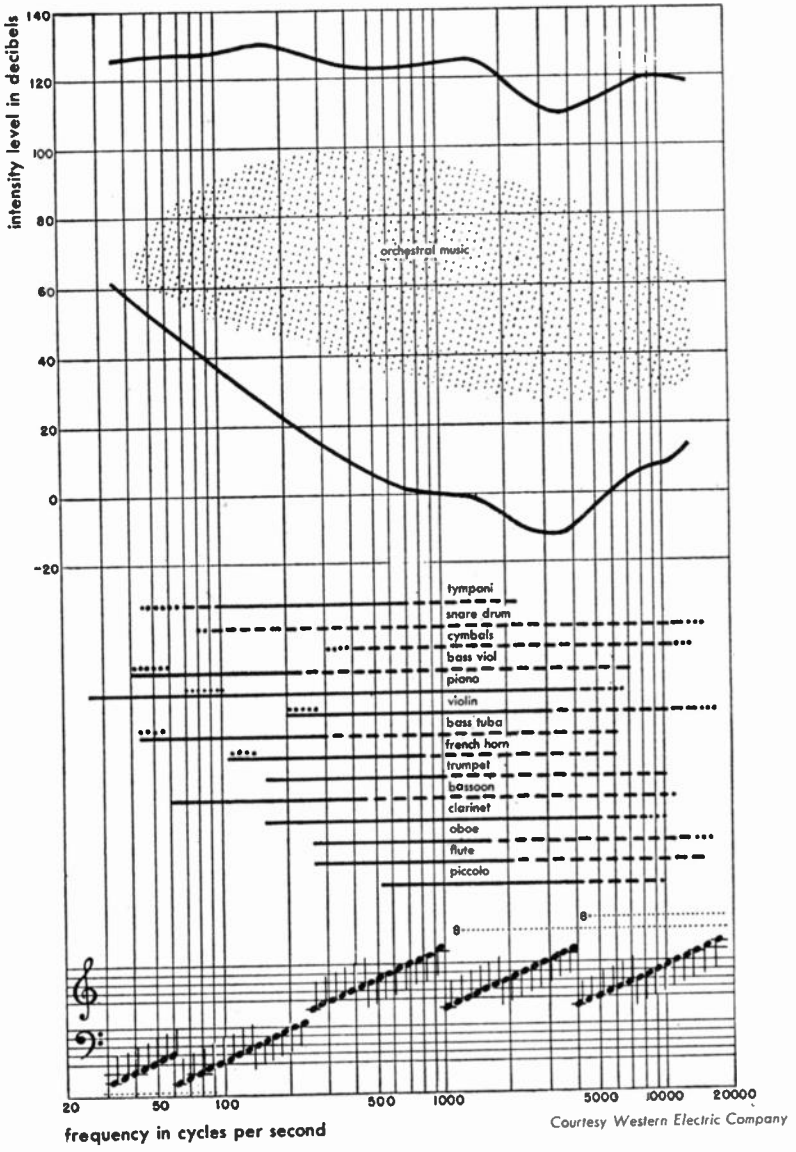
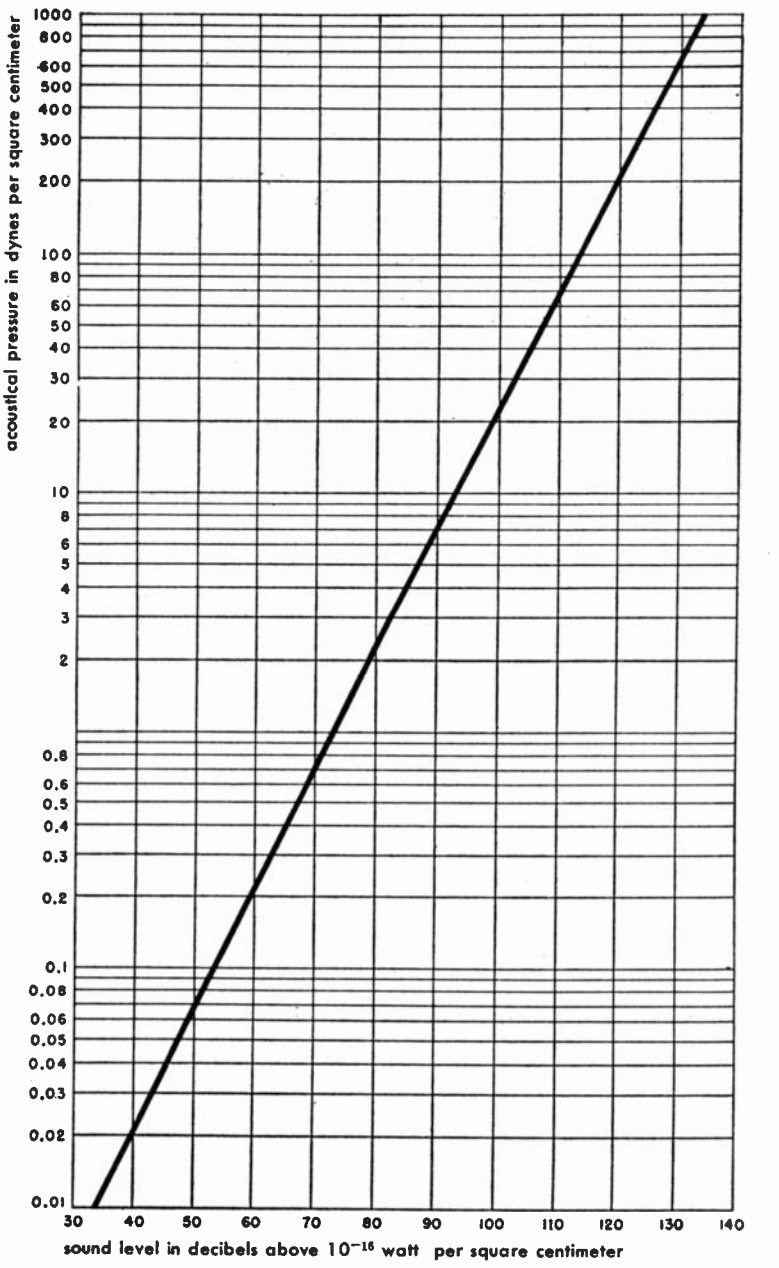


Fig. 9—Frequency ranges of musical instruments. Intensity levels of music. Zero level equals 10^{-16} watt per square centimeter.



Courtesy Western Electric Company

Fig. 11 One dyne per square centimeter is equivalent to an acoustical level of plus 74 decibels.

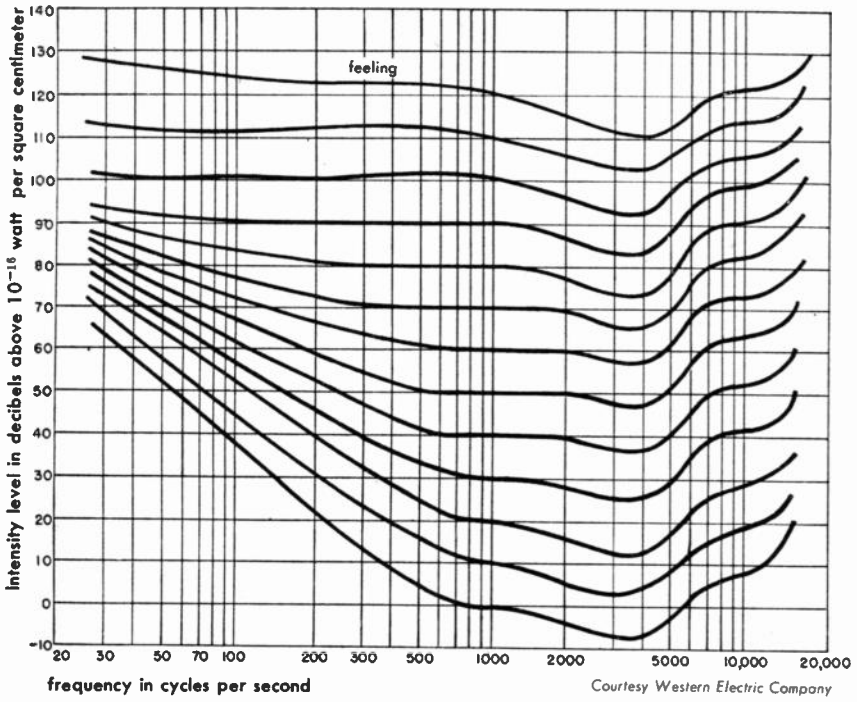
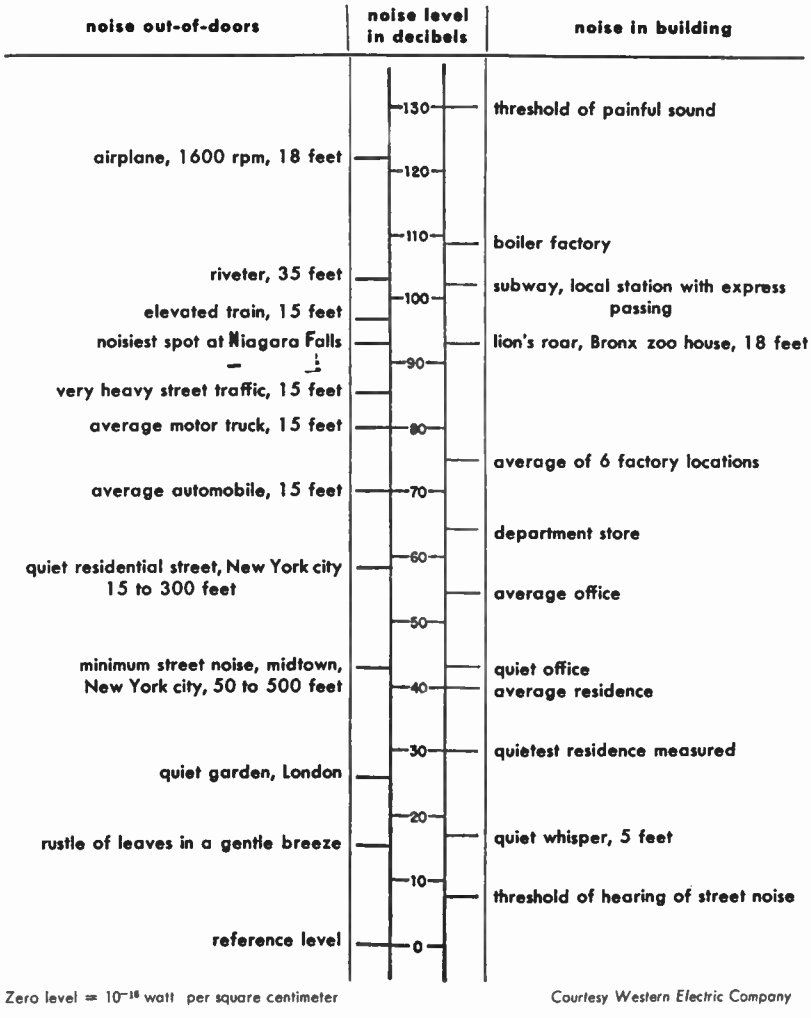


Fig. 12—Equal loudness contours.

FIG. 13—Noise levels



POLYCYLINDRICAL DIFFUSERS IN ROOM ACOUSTIC DESIGN*

By John E. Volkmann

Acoustic Development Section, Sound Engineering Dept., R.C.A. Victor

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.

Before presenting data on the convexed wood panels or diffusers described in this paper, let us briefly discuss some general observations on the action of sound in rooms and halls known for their acoustic excellence, a fuller discussion of which may be found in the literature.[1] In many of these rooms, as, for example, the Philadelphia Academy of Music, which has several tiers of boxes, and wood paneling throughout the auditorium, the projecting surfaces which are comparable in dimensions to the wave-length of sound tend to disperse the reflections and give a more diffuse distribution of sound. The important point regarding sound diffusion is that it does not lessen the total energy in the room, but rather it increases the number of reflections per unit time and hence lessens the intensity level of the individual reflections. This factor is of practical importance in the placement of microphones in that it lessens the effect of interferences between the direct sound and the first reflections. The small increments of energy and random phases of the diffused sound also produce a smoother decay curve in the enclosure. Since a smooth decay curve[2] presupposes the absence of echoes, rooms with sound diffusers apparently can tolerate a slightly greater reverberation time and thereby effect a better compromise between the optimum conditions for speech and music. This increased reverberation time coupled with the effects of panel resonance

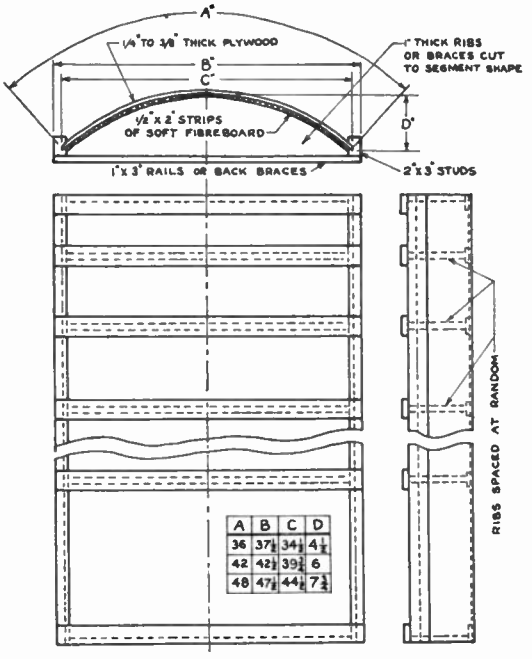


FIG. 1. *Convex plywood panel.*

may account for rooms treated with polycylindrical diffusers sounding somewhat larger than ordinary rooms.

A second factor of importance in the acoustics of the Philadelphia Academy of Music 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.[3] This reradiated energy does not follow the regular law of equal angle of incidence and reflection, but due to panel vibration acts more like a loudspeaker diaphragm and, therefore, for many frequencies either disperses the incident energy over a wide angle or changes its direction. Similar diffusion also occurs due to reradiation from cavity resonators formed by the boxes and other pockets in the tier balconies. A third important factor in the Academy acoustics is that the radiation from the wood paneling further occurs due to direct "telephonic" transmission from the original sound sources on the stage through the wood flooring and panel mounting structure. Since the panels in the Academy are more or less of different sizes and shapes the panel resonance frequencies are

*Presented at the Twenty-Sixth Meeting of the Acoustical Society of America in New York, October 24-25, 1941.

[1] F. R. Watson, *Acoustics of Buildings* (John Wiley and Sons, New York, 1930), second edition; H. Bagenal and A. Wood, *Planning for Good Acoustics* (Methuen and Co., 1930); V. O. Knudsen *Architectural Acoustics* (John Wiley and Sons, New York, 1932); P. E. Sabine, *Acoustics and Architecture* (McGraw-Hill, 1932).

[2] See C. C. Potwin and J. P. Maxfield, 'A modern concept of acoustical design,' J. Acous. Soc. Am. 11, 48 (1939), for interesting comments on modulation effects in the decay curve due to shifting interference patterns. Also R. L. Hanson, 'Liveness of rooms,' J. Acous. Soc. Am. 3, 318 (1932).

[3] Hope Bagenal and Alex. Wood, *Planning for Good Acoustics* (Methuen and Co., 1931), p. 10.

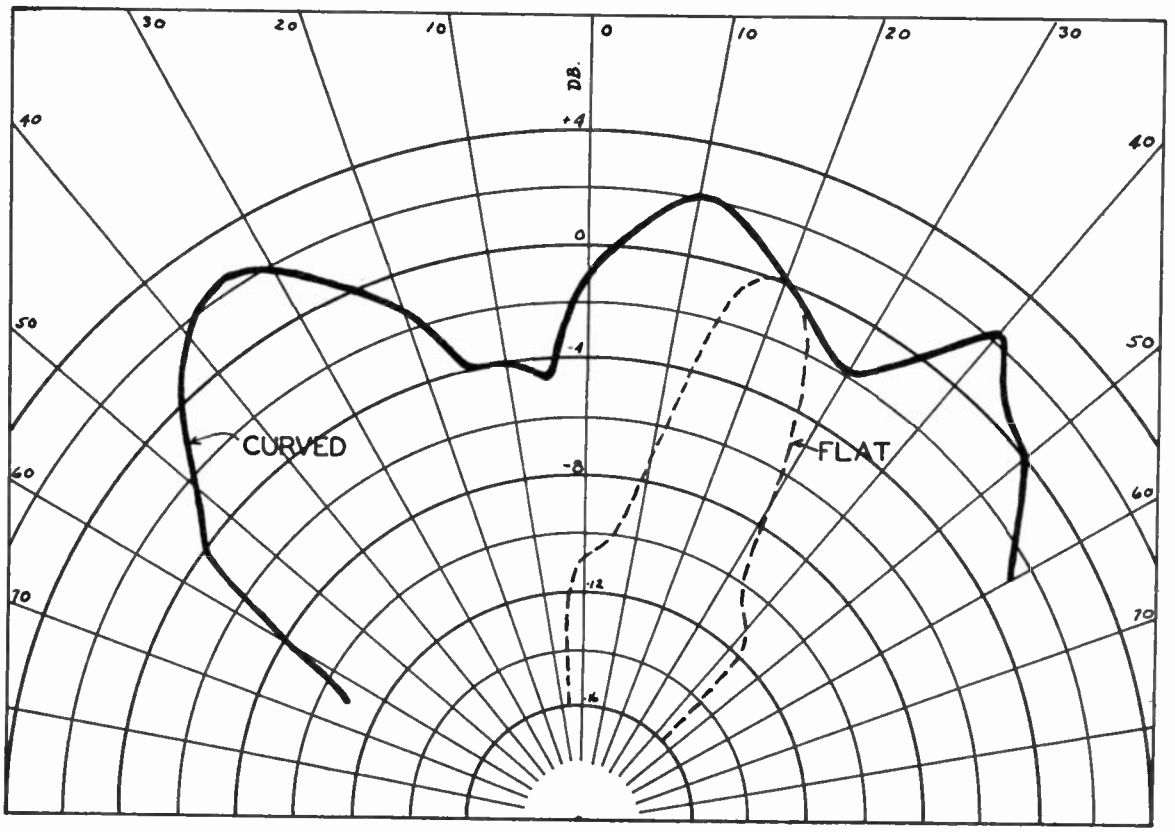


FIG. 2. *Polar distribution characteristics of reflected wave for convex and flat panels.*

not selective. Two interesting factors to note here are that the 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 audience with sound which gives a certain feeling of body or depth to the sound. The "feeling" effect of sound is further enhanced in the Academy by the transmission of sound through the wood floor to the seats and from other structures in the room.

Consideration of this diffuse aftersound in rooms known for their good acoustics has led to the following developments: (1) The use of convex curved surfaces, usually cylindrical wood paneling, in the acoustic design of rooms which forms the topic of the present paper. (2) The use of a multiplicity of "room" loudspeakers on sound reproducing systems for creating the feeling of depth or body through the spatial effect of enveloping the audience with sound. Such "room" loudspeakers have been used separately and in combination with "direct" loudspeakers for adding realism to reproduced reverberation.

CONVEX WOOD PANELS

Figure 1 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 are spaced at random have strips of 1/2" Celotex or other soft fiber board 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 by either direct transmission from the original sources 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 wave-length. Dispersion characteristics for a curved and flat panel plotted on polar coordinates are shown in Fig. 2. This shows clearly the diffusing action of convex curved surfaces and was obtained by rotating the panel about its long axis while keeping

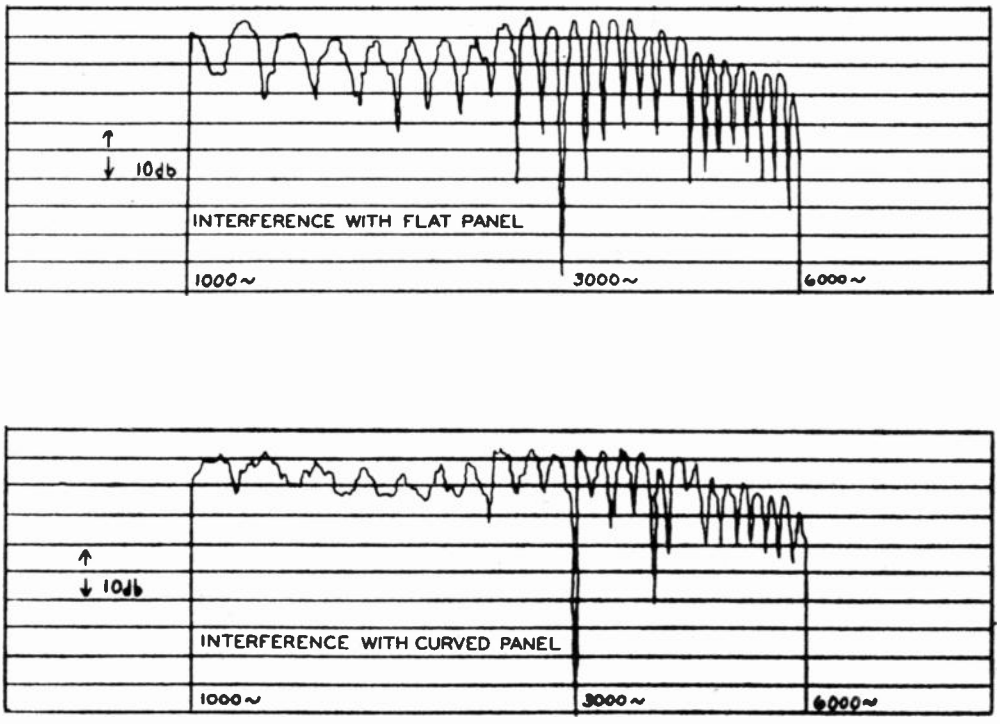


FIG. 3. *Interference between direct and reflected waves for convex and flat panels.*

the source and directional pick-up 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 Fig. 3. Note that the aiding effect at some frequencies and the cancelation at others is less for the convex panel. The relative intensity levels of the direct and reflected waves used in obtaining the interference curves are shown in Fig. 4. 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 wave-length radiated, the distribution will tend to the 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 Fig. 5. In addition to the dispersion and radiation action, the vibration of the wood paneling aids the absorption efficiency over more rigid materials. Preliminary data indicates a coefficient of approximately 0.18 over a considerable band of frequencies, which checks data given by Bagenal & Wood on flat 3-plywood panels.

STUDIO WITH POLYCYLINDRICAL WOOD PANELS

Fig. 6 is a photograph of one of the studios in the new 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 the 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

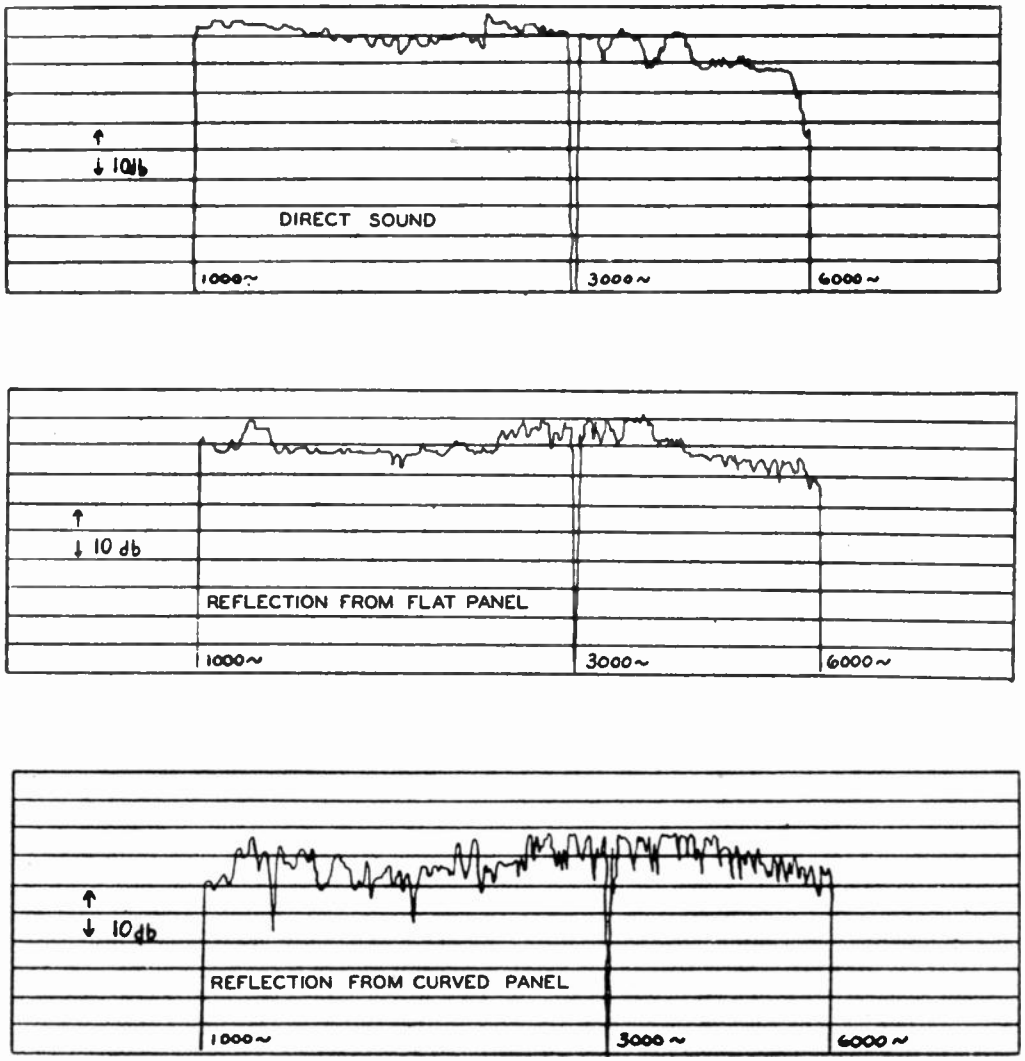


FIG. 4. *Direct and reflected response of panels used in interference measurements.*

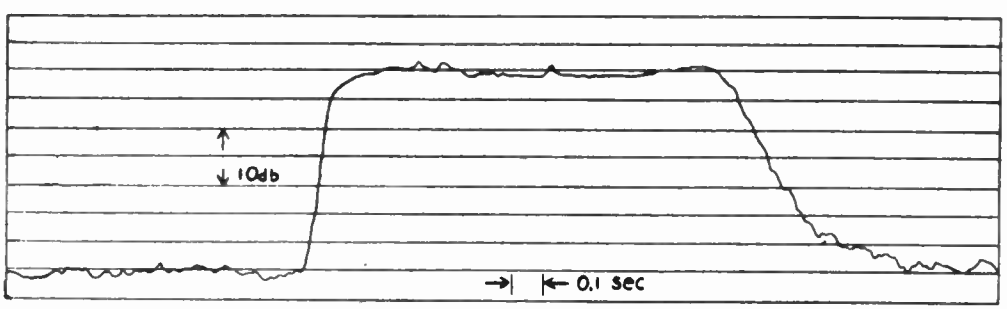


FIG. 5. *Growth and decay curve of vibrating convex panel.*

sound. The high degree of diffusion obtained in this type of room is evidenced in the smoothness of the decay curves. The reverberation curve for this studio is shown in Fig. 7, which conforms reasonably well with published optimal times.[4]

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

[4] *Robert M. Morris and Georgé M. Nixon, 'NBC studio design,' J. Acous. Soc. Am. 11, 48 (1939)*

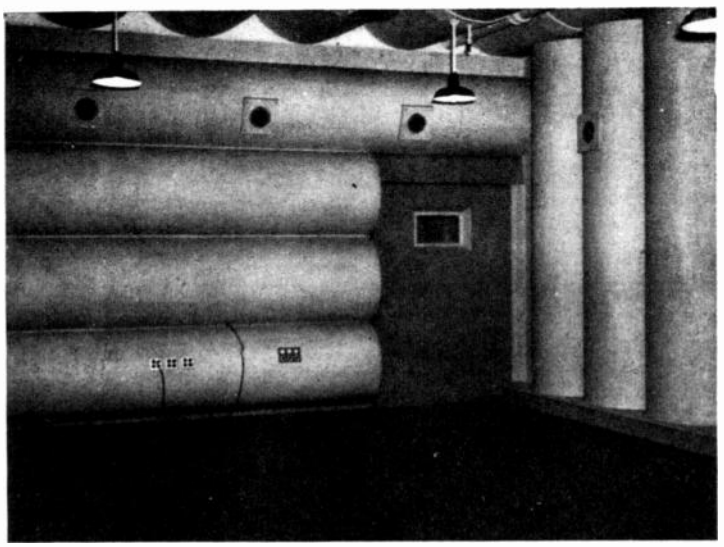


FIG. 6. *Listening studio at RCA showing polycylindrical surfaces with axes mutually perpendicular.*

steps in order to avoid the "piling up" of room resonances. This is especially important 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.

A chart giving preferred dimensions *versus* room size for various types of rooms is shown in Fig. 8. If a room is very small and nearly cubical in shape the direct ratio of the cube root of two would be preferred (see curves C : D : E). For average studio sizes the ratio should be near the cube root of four (see curves B : D : F). This approximates the frequent practice in the broadcast field of using a ratio of 2 : 3 : 5. If a low ceiling is necessitated then the ratio given by curves B : C : G would be preferred. In all cases the dimensions shown are derived from the ratio of the $\sqrt[3]{2}$. 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 TYPICAL APPLICATIONS OF CONVEX SURFACES

The first application of the general principles outlined in this paper was in the RCA Recording Studio in South America which is shown in Fig. 9. This studio is approximately 38,000 cu. ft. and has a calculated reverberation time of 0.9 sec. It has a wooden floor, 70 percent convex reflectors of 1"

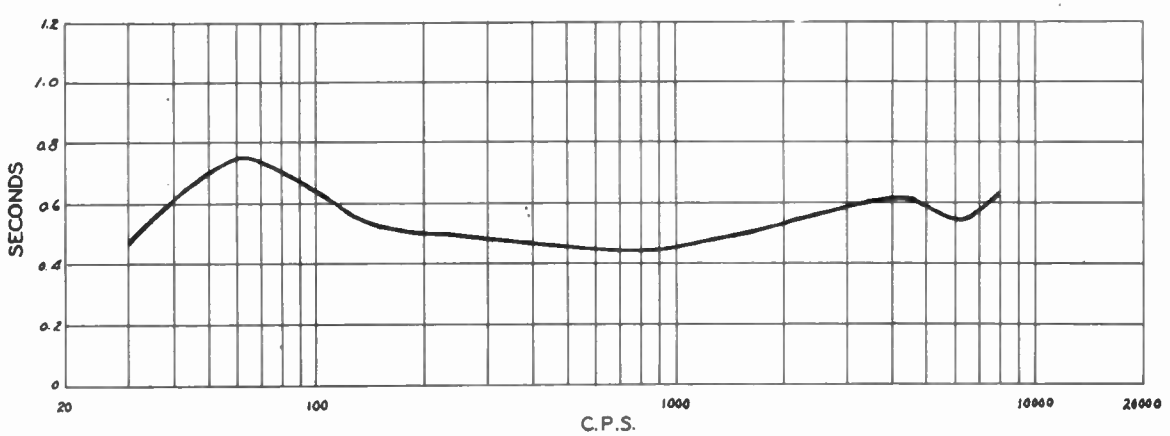


FIG. 7. *Reverberation time of listening studio.*

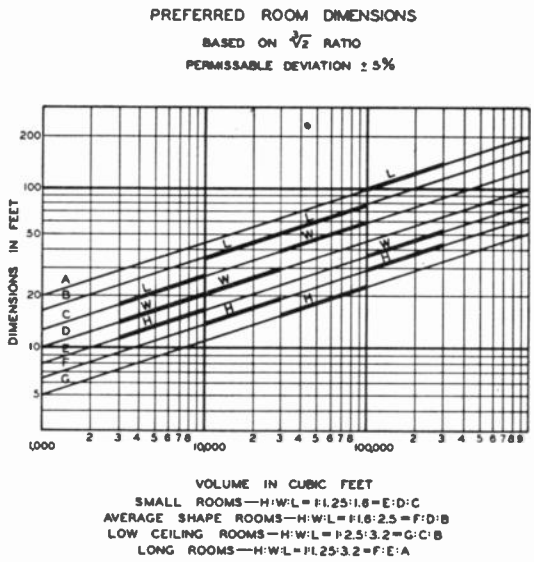


FIG. 8.

plaster and 30 percent 1" rockwool. A similar treatment, except that the polycylindrical diffusers were wood and less rockwool was used, is shown in Fig. 10 on the RCA Disk recording studio, New York, New York. This general type of design has also been applied to the WFAA Studios as mentioned in Dr. Boner's paper in collaboration with K.C. Morrical.

An application of polycylindrical design to an orchestra shell which was used last winter for a recording by Leopold Stokowski on the Walt Disney Live Action Stage and which is here reproduced through their courtesy, is shown in Fig. 11. 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.

Functional styling in acoustics is receiving more and more recognition through a growing cooperation between architect and engineer. The styling sketches in Figs. 12 to 14 by Mr. Robert Holley on projects either under way or contemplated, show the adaptability of cylindrical surfaces to functional styling. Fig. 12 is one of several studios now under construction in the east, while Fig. 13 shows the proposed design for the RCA film recording studio in New York. Fig. 14 shows the styling for a theater with side wall panels streamlined. Innumerable combinations of convexly curved surfaces will suggest themselves to the designer.

In conclusion it is gratifying to know that wherever this general type of polycylindrical wood diffusers has been used along with the necessary absorbents for optimum reverberation the results have been more than satisfactory. The author wishes to acknowledge the assistance received from his associates in the collection of data particularly from Dr. K.C. Morrical who carried through the design and tests on the RCA Disk Recording Studio, 24th Street, New York, New York. The author is also indebted to Dr. C.P. Boner for information and discussion in connection with his tests and application of convex panels to broadcast studios.

FIG. 9. *RCA disk recording studio in South America.*

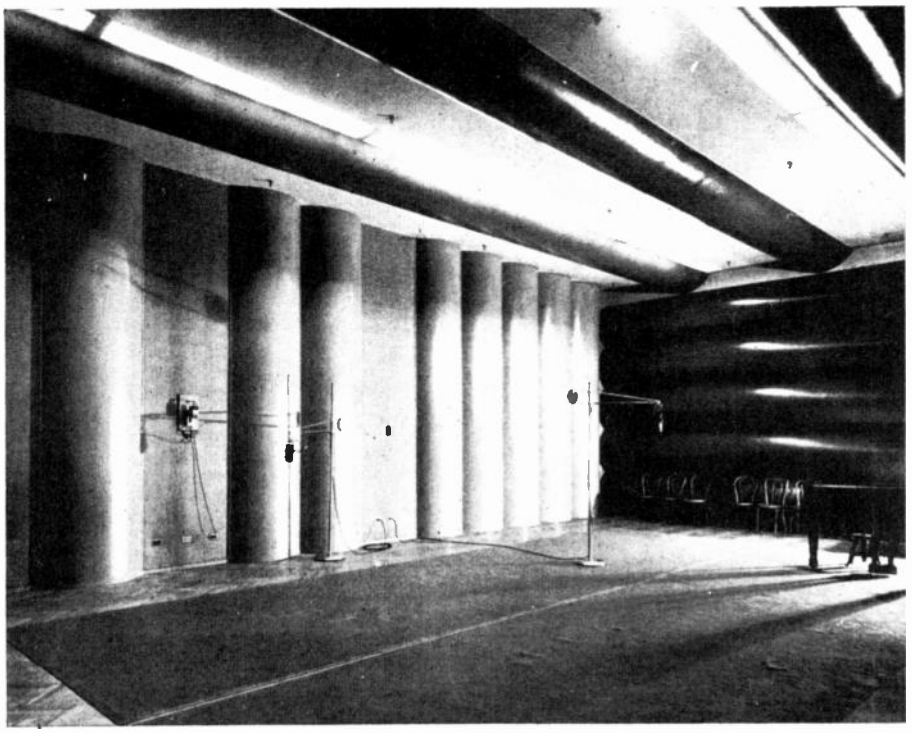


FIG. 10. *RCA disk recording studio in New York.*

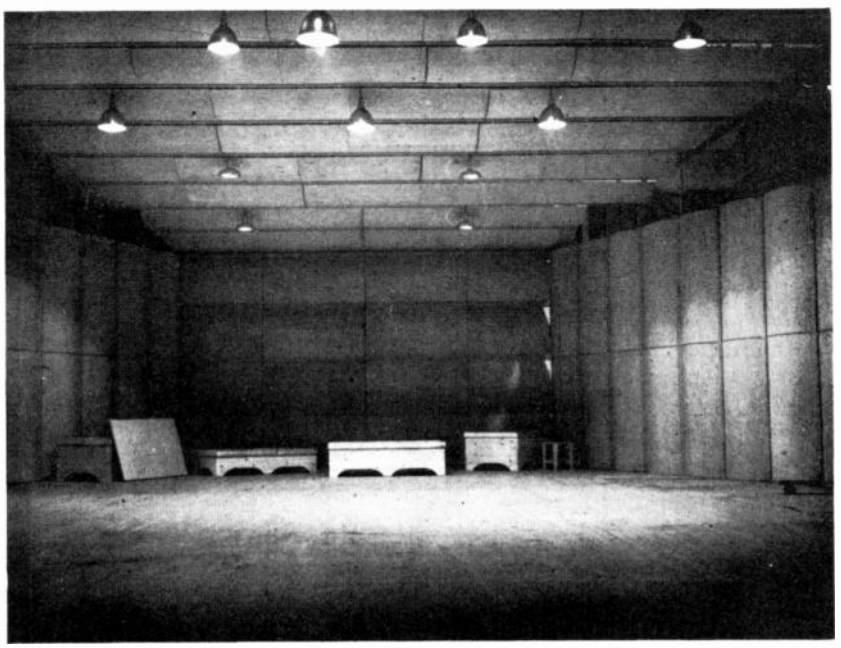


FIG. 11. *Orchestra shell with polycylindrical plywood panels.*
(Courtesy Walt Disney Studios)

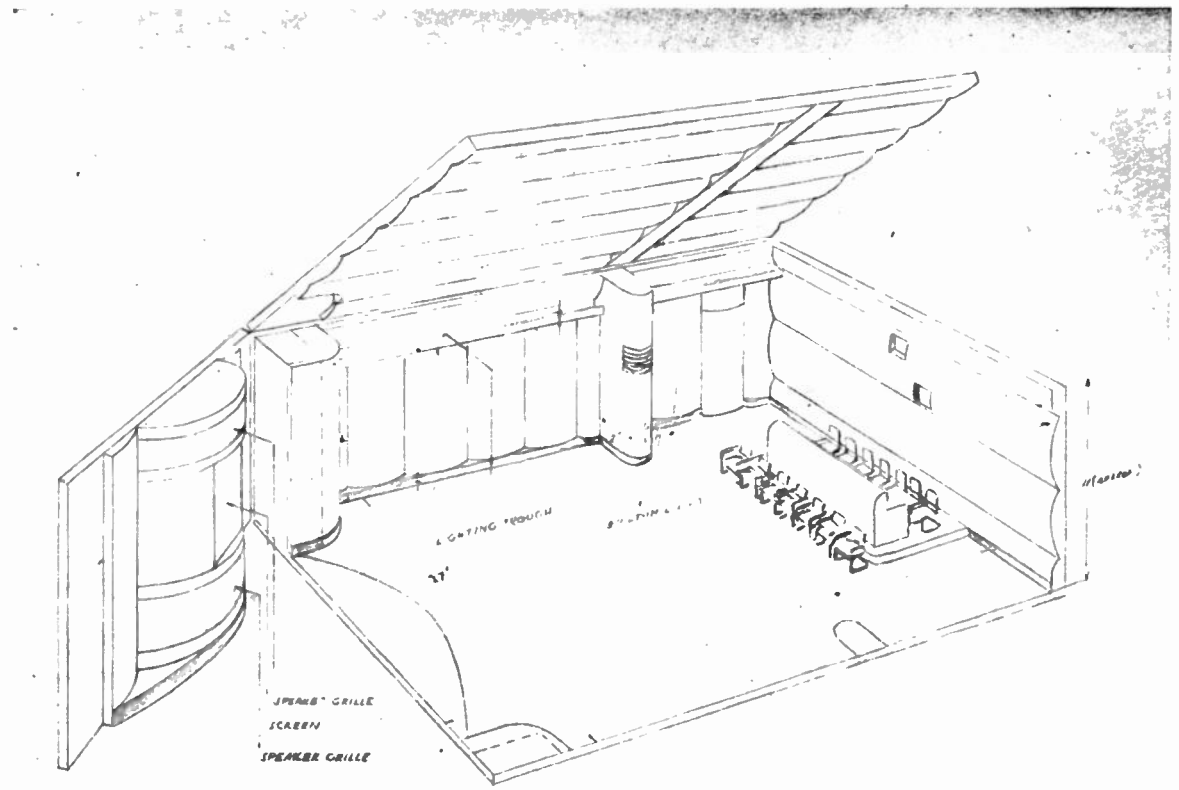


FIG. 12. *Proposed design of a small film recording studio and review room.*

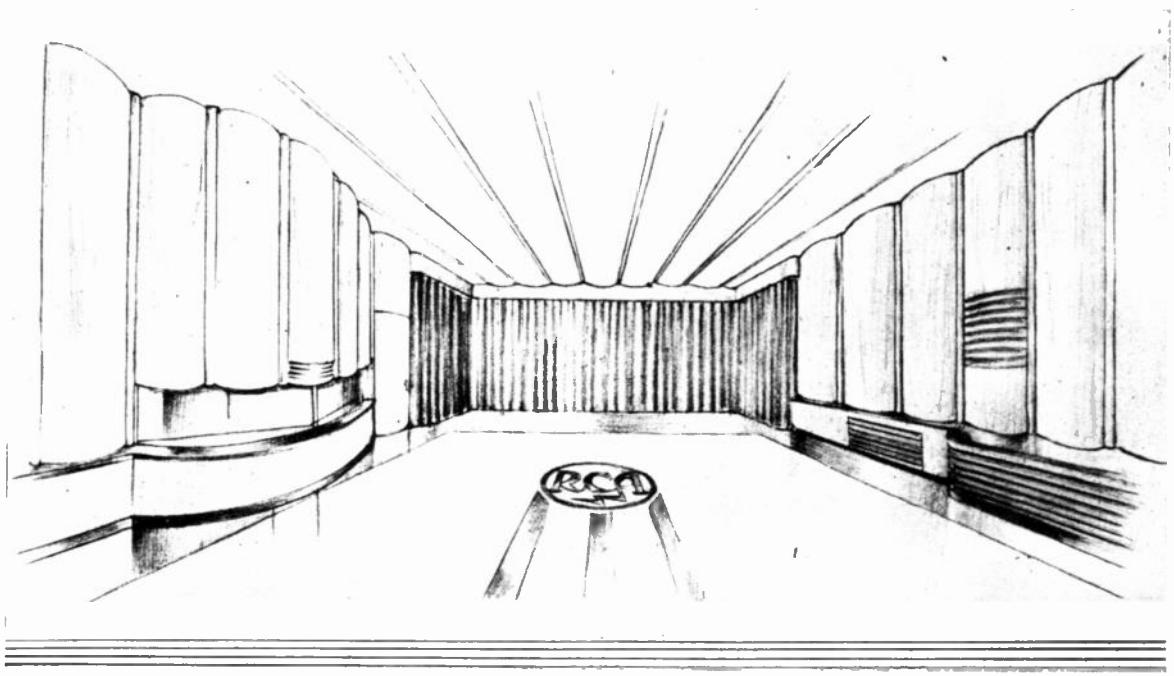


FIG. 13. *Proposed design for RCA film scoring studio.*

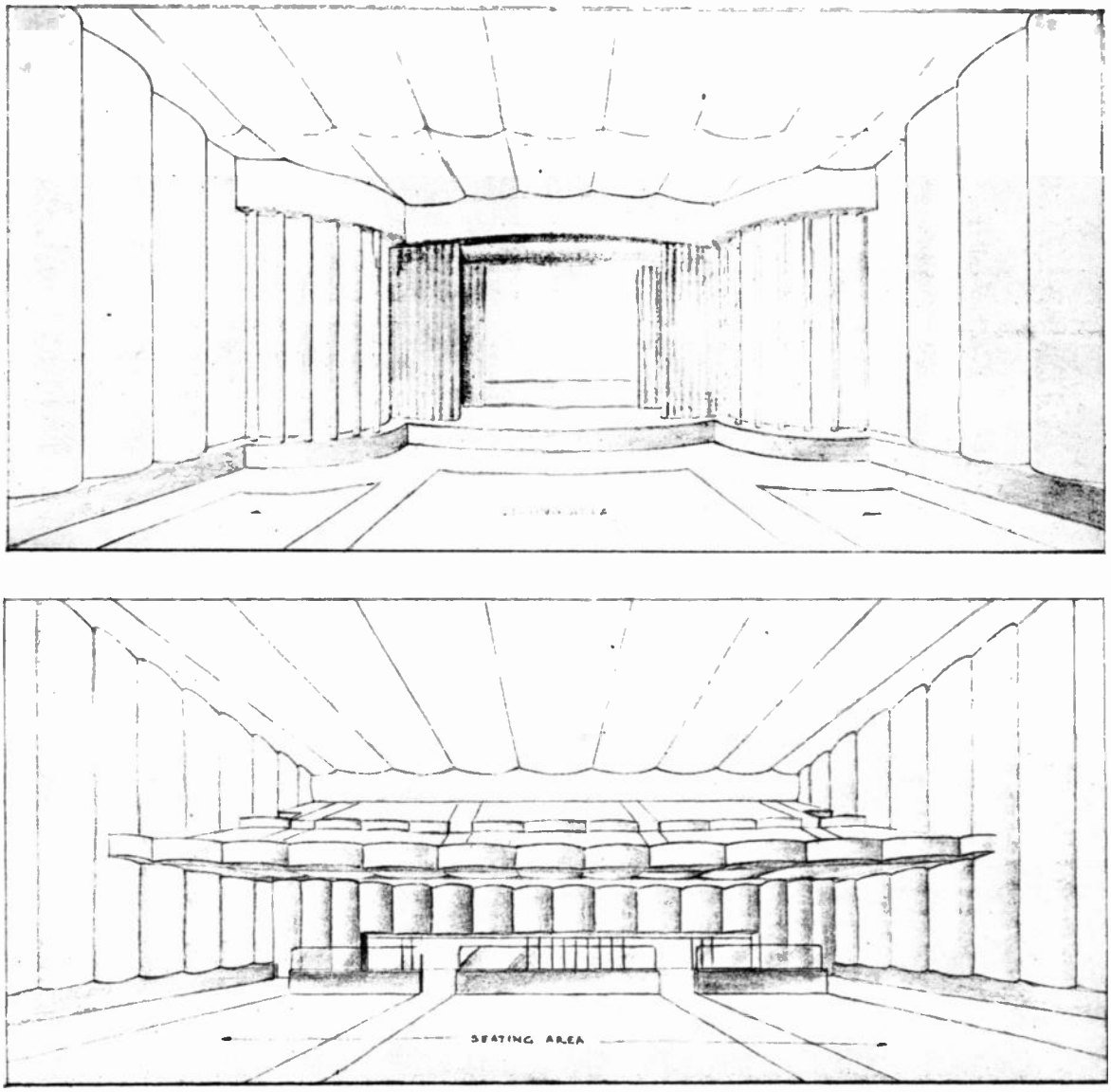


FIG. 14. *Proposed design of a sound movie theater.* Upper, *stage of Cinema Evcanto showing suggested acoustic treatment.* Lower, *view from stage.*

LOCATING THE TELEVISION STUDIOS

(Reprinted through the courtesy of the RCA Victor Division, Radio Corporation of America)

IMPORTANCE OF LOCATION

The location for the television studios 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 to some degree the cost of the station, 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) Freedom from interference.
(e) Facilities: power, water, etc.
(f) Nearness to outside program sources.
(g) Location with relation to transmitter site.

In applying each of these considerations in turn to a location which is under consideration, the following further discussion may be helpful.

ADEQUATE SPACE FOR OPERATIONS

Ordinarily, the studio location will also be the administrative center of the station and space will be needed for offices as well as for operations. The following requirements are provided as a check list:

Studios and rehearsal space.
Control rooms.
Film projection rooms and rewind rooms.
Actors' dressing rooms and wash rooms.
Clients' rooms and public viewing rooms.
Space for storage of scenery and lights.
Effects room.
Effects and scenery shop.
Equipment storage room and shop.
Executive, sales and other offices.
Heating and ventilation.
Rooms for script writers.
Garage space for mobile unit.
Receiving room for remote radio circuits.
Foyer for audience or reception room.
Viewing rooms for tryouts.
Toilet facilities.

The size and arrangements of studio quarters is considered in greater detail in another section. However, it will be obvious that large studios with plenty of ceiling height will be desirable for television purposes.

COST OF LAND, BUILDINGS OR RENT

It is, of course, essential to know the initial capital expenditures as well as the likely operating costs of the plant, exclusive of broadcasting equipment. 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

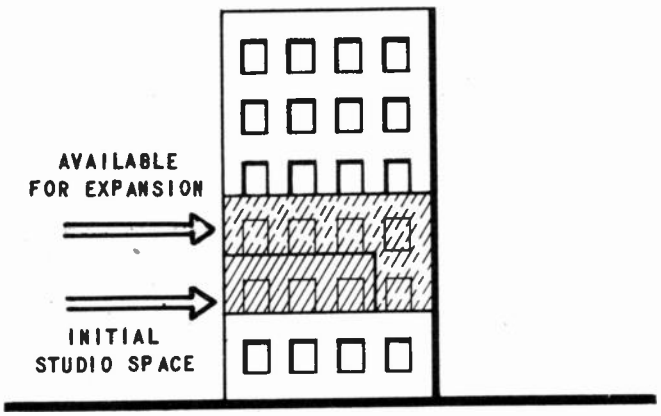
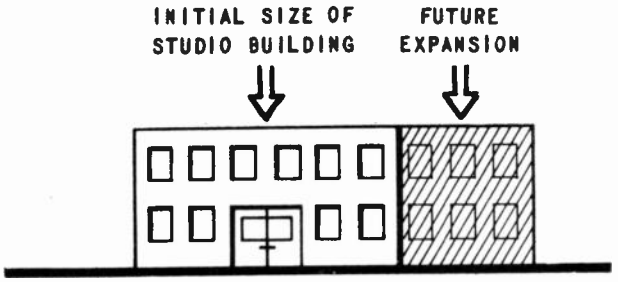


FIG. 1



PROVIDE FOR FUTURE EXPANSION OF STUDIOS

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.

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.

CONVENIENCE IN REACHING LOCATIONS

Television is likely to employ actors who may appear in theatres 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. 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.

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. Noise can be eliminated from studios in city structures by use of a "floating" construction which isolates the studio floor, walls and ceiling from the building members plus sound deadening material properly used in the wall construction. In quiet locations, simpler sound proofing may be satisfactory. Use of scund absorbent material between walls and ceiling spaces may be sufficient.

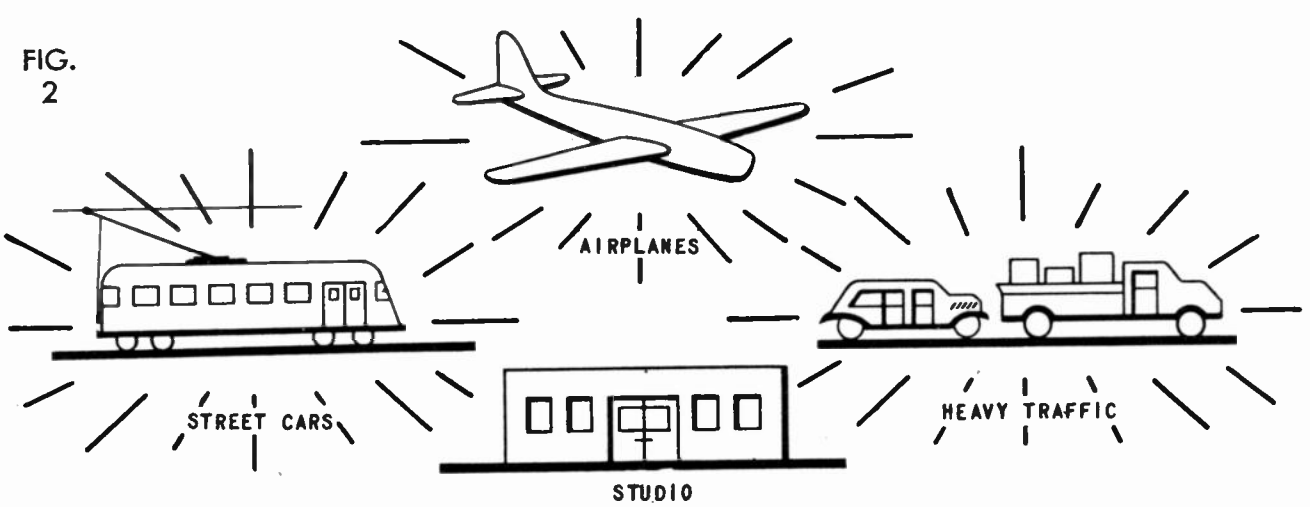
In the case of studio buildings on a separate plot, the best cure for noise is a quiet location. Some common sources of noise are heavy street traffic, railroad whistles and airplanes. Studio buildings located near airports or along airways will be subject to roar from passing planes. Since air travel is on the increase, it is well to select a location which is unlikely to be near a future air route.

If a quiet spot is found, simple sound absorbing material can be used within the walls of the structure and beneath the roof. Such material is desirable for heat insulation and will serve a double function.

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.

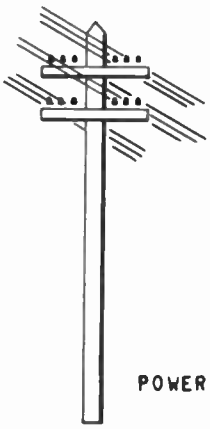
Electrical disturbances are not usually a serious consideration in sound broadcasting but present problems peculiar to television. Changing electric fields caused by breaking or switching high power electric circuits may affect video systems. Sources of such disturbances are elevator contactors, heavy electrical machinery, electric locomotives or traction systems, smoke or dust precipitators, X-ray machines and radio transmitters including a "short wave" and standard broadcast stations. Inasmuch as standard 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 inter-

FIG. 2

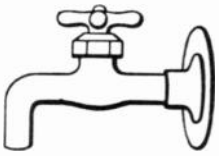


AVOID SOURCES OF INTERFERENCE

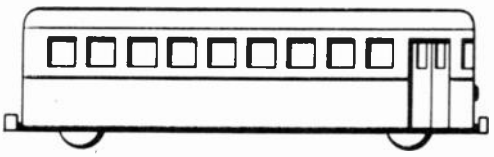
FIG. 3



POWER



WATER



TRANSIT

HEAT

CHECK AVAILABILITY OF FACILITIES

ference 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.

FACILITIES

The studio equipment will require a well-regulated source of power, preferably coming from the same system supplying power to residential areas. 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. Switching 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 film projectors may require three phase supplies. It may be advantageous to operate banks of lights across different phases to reduce "hum."

NEARNESS TO PROGRAM SOURCES

A good many television programs may originate at points outside of the studio and be picked up by field equipment. Signals from the field apparatus may be transmitted by radio, 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 minimum length. If a radio relay transmitter operating on very high frequencies is to be employed for this link, the receiving antenna must be as high as possible; for example, on top of a tall building. A short coaxial cable can then be used to carry signals to the studio.

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.

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 audio and video circuits must be provided between them and these will add to the cost in proportion to the problems which they entail.

In general, there are four situations which

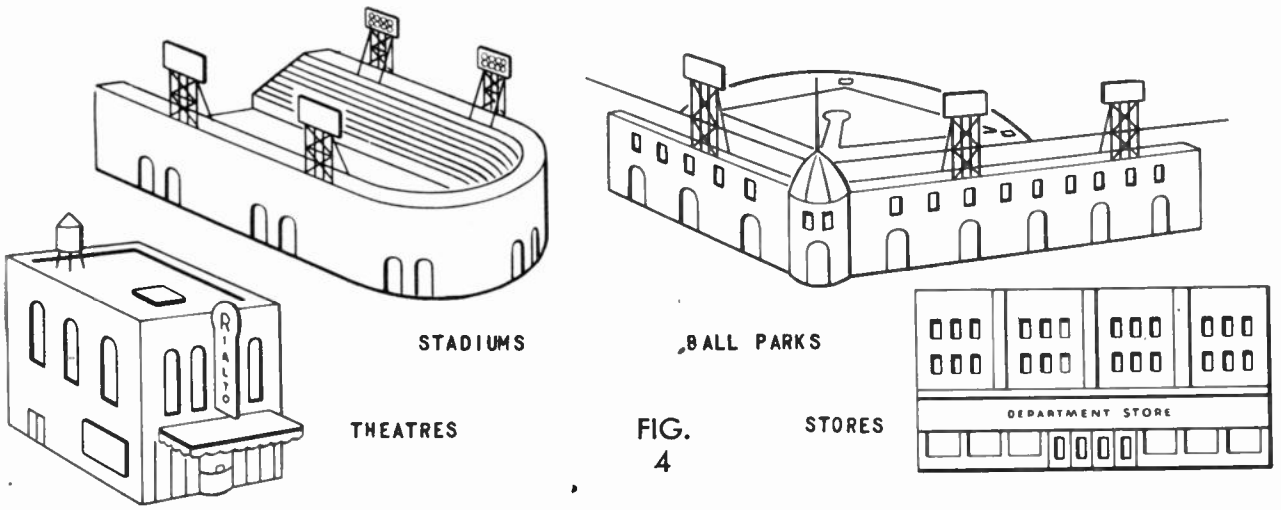


FIG. 4

LOCATE NEAR PROGRAM SOURCES

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.

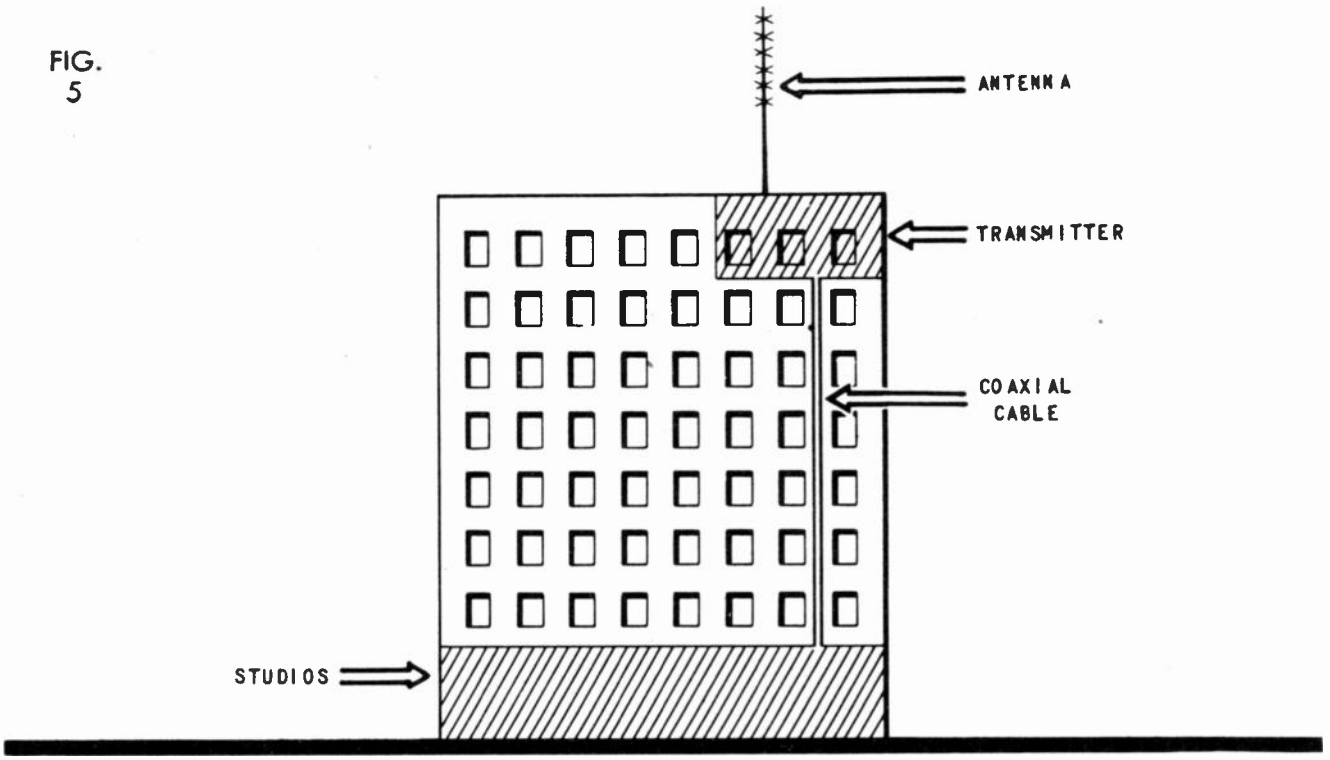
The video link in (a) will undoubtedly be coaxial cable. In (b) and (c) it may be either coaxial cable, equalized telephone line, or radio relay--with the latter two most likely. In (d) it will almost certainly be radio relay. These four types of locations are illustrated in the figures above. On another page is a table in which a general comparison of the cost of various types of links is given.

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.

SUMMARY

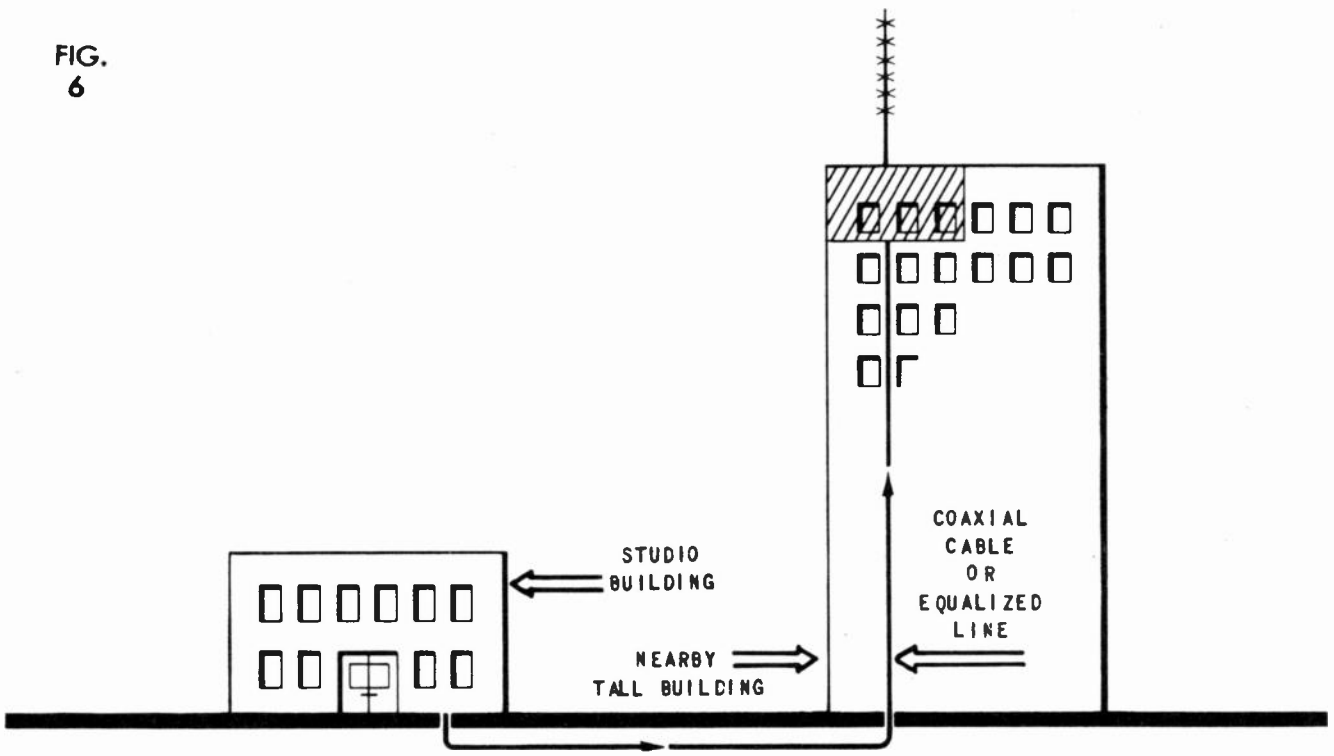
A list of factors to consider in choosing a television studio location has been presented and discussed. Each site which is under consideration should be carefully checked against this list. A comparative table (with estimated costs for each possible location) may be helpful in doing this—particularly if there are several sites of nearly equal attractions. Finally, to these general considerations, each prospective station operator must add his own consideration of such local factors as the competitive situation, prestige involved, and relation to other businesses in which he may be engaged.

FIG. 5



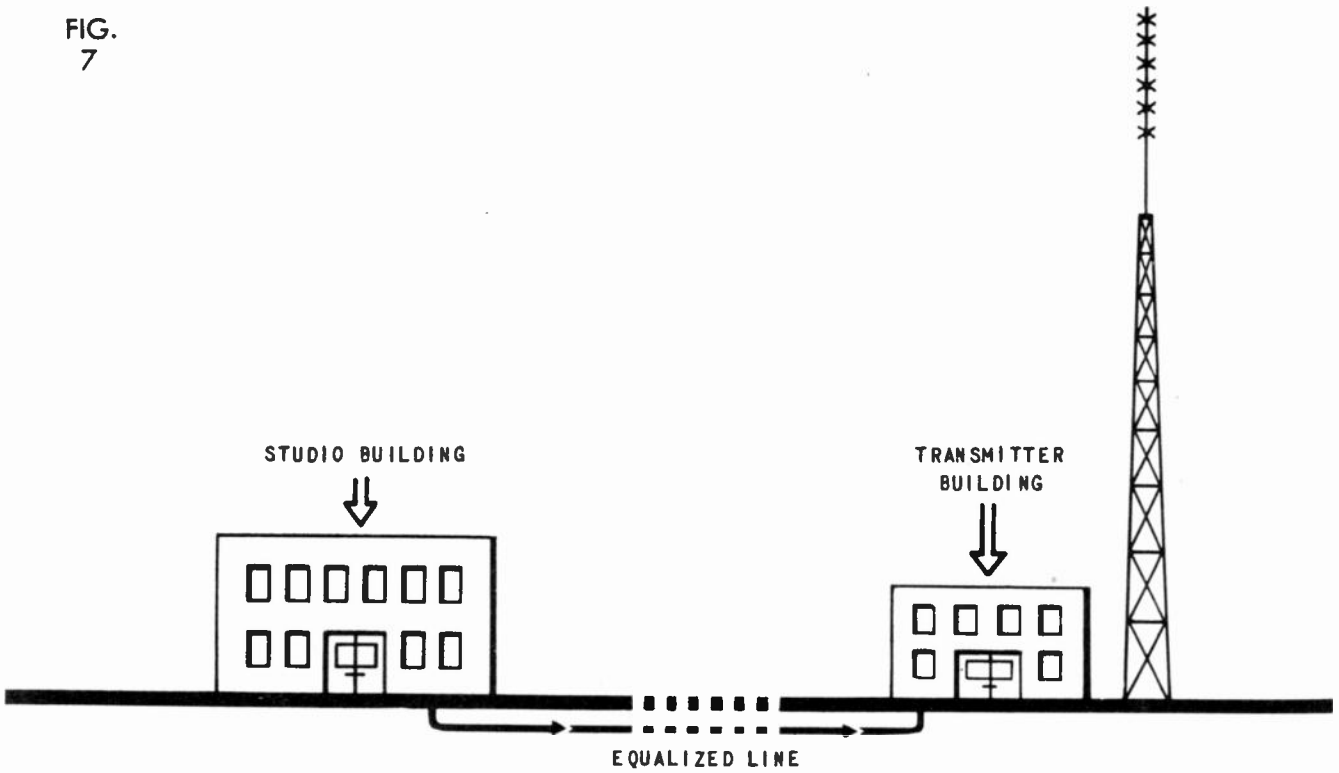
STUDIO AND TRANSMITTER IN SAME BUILDING

FIG. 6



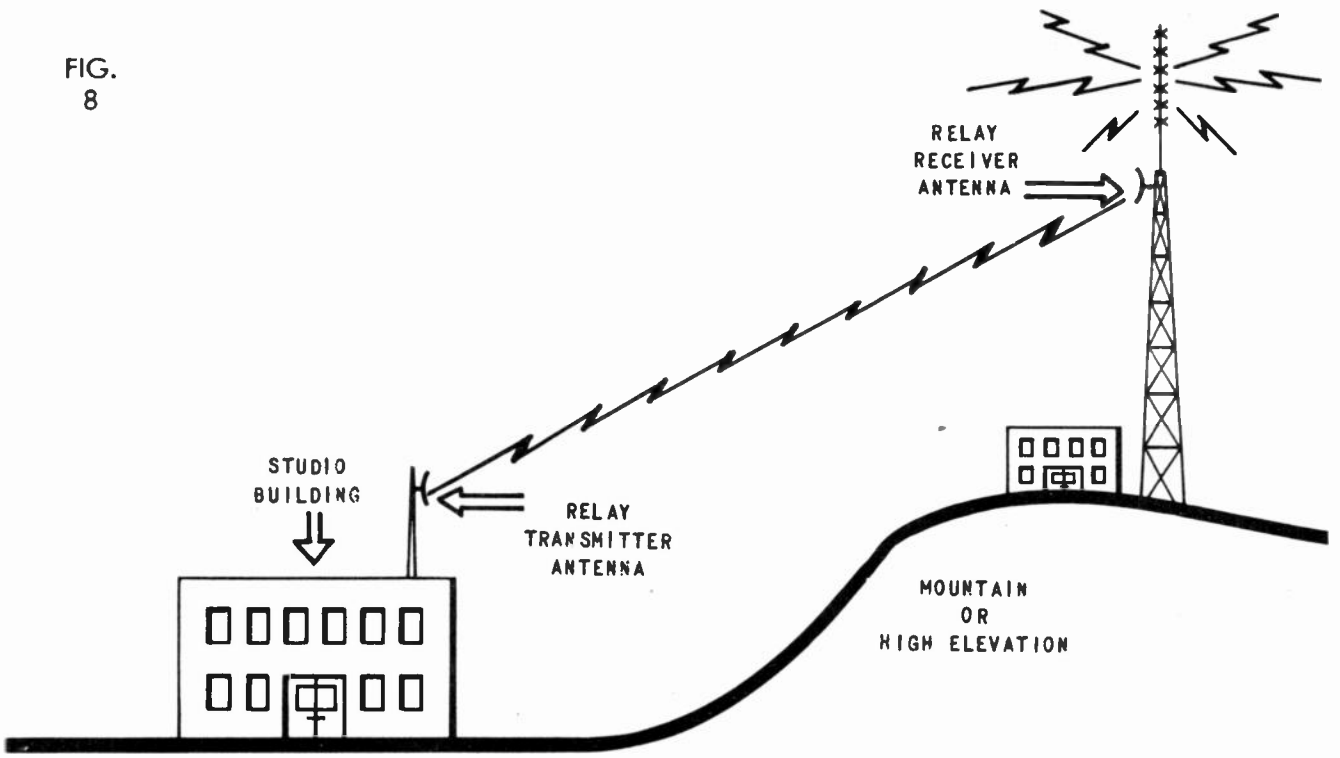
TRANSMITTER ON A NEARBY TALL BUILDING

FIG.
7



TRANSMITTER BUILDING SOME DISTANCE AWAY

FIG.
8



TRANSMITTER ON A MOUNTAIN TOP OR OTHER REMOTE LOCATION

INTERCONNECTING FACILITIES FOR BROADCASTING

(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.)

TABLE OF CONTENTS

Part	*Subject*
1	General
2	Common Terminology
*3	Services Available to Broadcasters
4	Program Loop Transmission
5	The Standard Volume Indicator
*6	Network Operation

**To be issued at later date.*

PART 1 - GENERAL

With few exceptions the interconnecting circuits used in radio 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 radio programs from the point of origination to one or more radio 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 volume 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.

3. Transmitter

Unless otherwise qualified this refers to the broadcasting transmitter complete with power, audio and radio equipment and radiating system. In a few cases where this point is connected by a loop directly with a test room, the telephone company checks volume 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 with this point when program is transmitted from it directly to a telephone toll office.

6. Public Address System - Location

A point at which a public address system is located. The telephone company checks volume with this point if program is transmitted directly to it from a telephone company test room.

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 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., those 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 4 - PROGRAM LOOP TRANSMISSION

The common meeting ground of the telephone companies and the broadcasters is the telephone loops 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.

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.

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 second method is to apply repeating coils of 4:1 impedance ratio at the two ends of the loop circuit. Up to the lengths of the various gauges of conductors shown in Table 1, the excess of losses at low frequencies over those at higher frequencies introduced by this arrangement results in making transmission uniform within about 1 db at all frequencies between 35 and 8000 cycles. Beyond these lengths the special equalizer has to be added or used by itself without the assistance of 4:1 impedance ratio coils.

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.

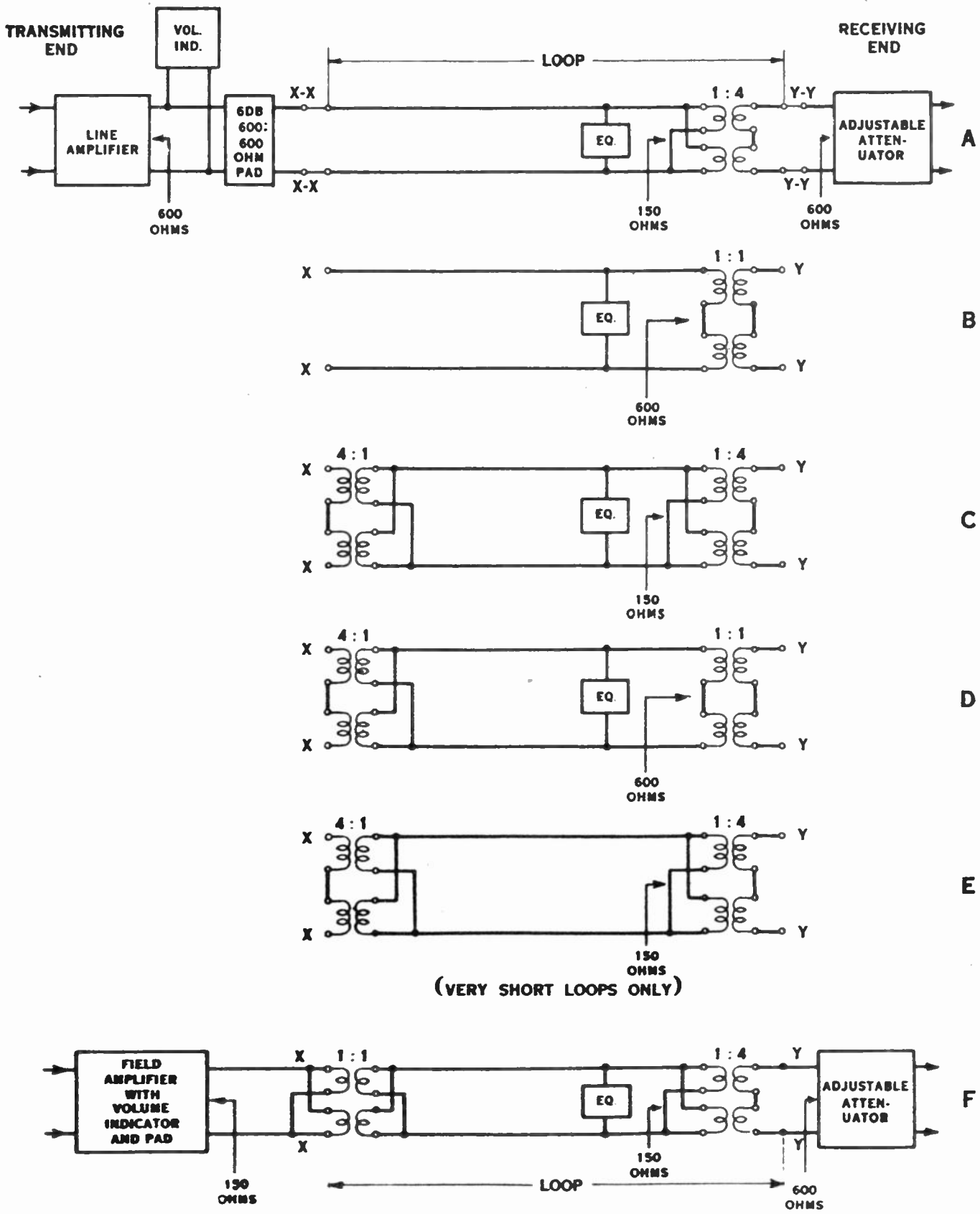
If the deviations caused in the volume indicator readings are to be compensated, or if the volume indicator can be adequately isolated, the equalizing effect of the 4:1 impedance ratio transmitting coil may be combined with that of the equalizer if desired.

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. Dis-



EQUIPMENT ARRANGEMENTS
ON NON-LOADED EQUALIZED LOOPS

FIG. 1

cussion 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 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.

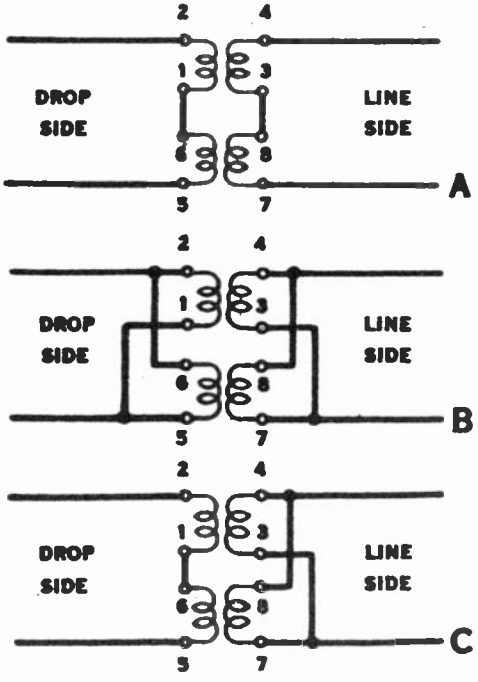
LOOP EQUALIZATION

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

TABLE 2

Terminal Connections and Impedance Data For Western Electric Company No. 111-C and No. 119-C Coils



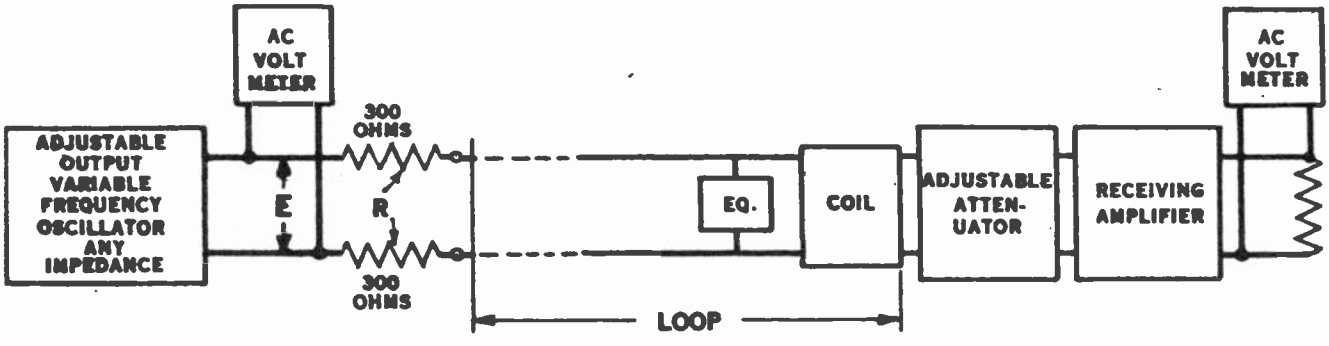
	111-C		*119-C*	
	Impedance Ratio	Nominal Impedances In Ohms	Impedance Ratio	Nominal Impedances In Ohms
	Drop Line	Drop Line	Drop Line	Drop Line
A	1: 1	600: 600	1.15: 1	600*: 600*
B	1: 1	150: 150	1.15: 1	150*: 150*
C	4: 1	600: 150	4.6: 1	600*: 150*

*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.

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, 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



Note: Coils to be used at either or both ends should be included as parts of the loop during equalization.

FIG. 2

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.

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

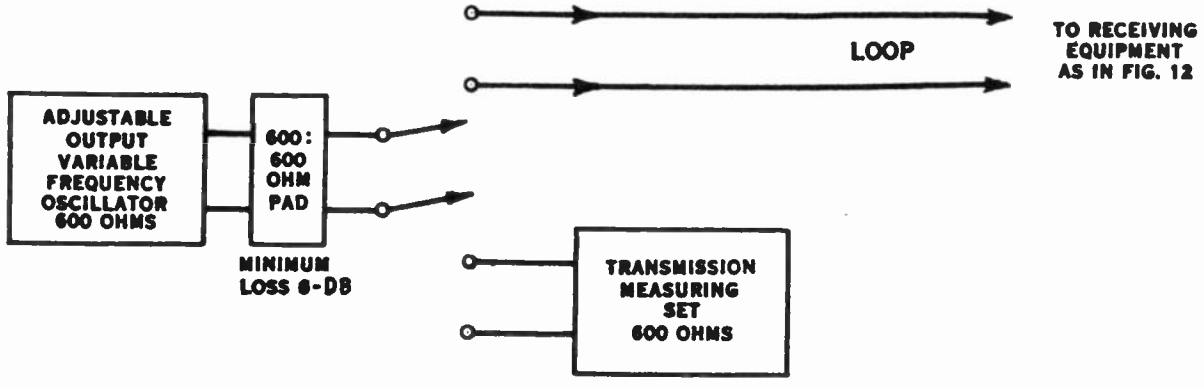


Fig. 3

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.

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.

If a 150-ohm amplifier is used, as in Fig. 4 for 150-ohm equalization, no coil is required for impedance reasons, but (R) should then be 150 ohms total (75 ohms in each side). If any pads are used these should be 150 ohm pads.

The arrangement in Fig. 2 is readily adaptable to any impedance condition simply by using the corresponding amount of series resistance.

Testing Frequencies

The following frequencies are recommended for general use in equalizing nonloaded cable loop circuits.

If oscillators available do not provide all of the frequencies noted, other neighboring ones may be substituted. If important deviations in measurements at frequencies not included in these lists are suspected, suitable frequencies to bring these out should be added. If it is desired to check transmission at points beyond the nominal ranges indicated, the additional frequencies included in parentheses are recommended. In cases where an 8000-cycle equalizer is used to equalize a 5000-cycle circuit initial tests and check tests should be made using the frequencies given for 8000-cycle equalization in order to avoid undesirable deviations above 5000 cycles.

Equalization Testing Levels

The level of single frequency testing power used in equalizing program transmission loops in exchange type telephone plant should not exceed 1 milliwatt at the transmitting terminals of the loop. While higher levels can be tolerated at low frequencies, the interfering effect is much greater for comparable levels at higher frequencies. Accumulated experience of the telephone company has shown that in order to minimize danger of interference to neighboring circuits, one milliwatt is the maximum amount of power that should be used generally for sustained testing tones where a uniform level is used throughout the audio range.

In providing proof of performances data for FM broadcasting stations it is required that the frequency characteristic be measured at levels corresponding to 25, 50, 75 and 100% modulation. Where studio transmitter facilities

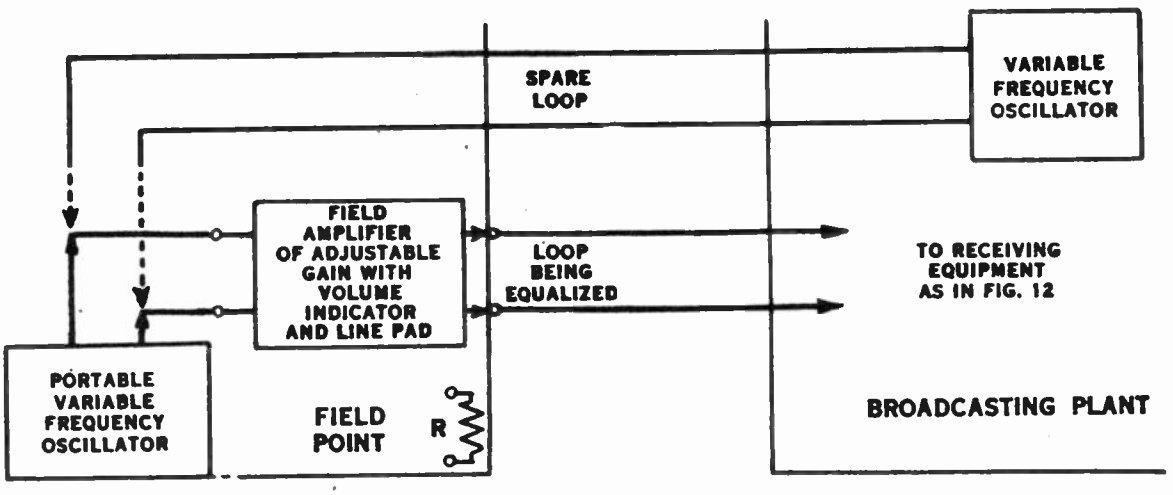


Fig. 4

For 5000-Cycle Equalization		*For 8000-Cycle Equalization*		*For 15000-Cycle Equalization*	
For Initial Tests	**For Check Tests**	**For Initial Tests**	**For Check Tests**	**For Initial Tests**	**For Check Tests**
(80)		35		30	30
100	100	50	50	50	
300		70		70	
500		100		100	
1000	1000	300		300	
2000		500		400	
3000		1000	1000	500	
4000		2000		1000	1000
4500		3000		2000	
5000	5000	4000		3000	
(5300)		5000		4000	
		6000		5000	
		7000		6000	
		8000	8000	7000	
		(8500)		8000	8000
				9000	
				10000	
				11000	
				12000	
				13000	
				14000	
				15000	15000

are provided by the Telephone Company it will not be desirable, during normal telephone traffic periods, to use sufficient testing power to produce these levels. Any proposal to use testing levels higher than 1 milliwatt and involving telephone plant should be reviewed with the Telephone Company and suitable testing periods agreed upon.

Volume Checks With Low Frequency Tones

After a loop has been equalized, or at other times, transmission checks at operating volume may be desired to facilitate obtaining or checking settings for attenuators or amplifiers at the receiving terminal to bring the volume indicator at that point into alignment with that at the transmitting point. These checks should be made using a testing tone of 400 or 500 cycles for the reasons brought out in Part 5 in discussion of "CORRECTION OF VOLUME INDICATOR READINGS."

In adjusting the testing tone to obtain plus 8 vu on the loop, a standard volume indicator should be connected as shown in one of the recommended methods. (See Part 5).

If the adjustment at the receiving point is found to be greater than plus or minus 1 db from the calculated setting of the receiving attenuator or amplifier, the loop and associated equipment should be checked for the existence of trouble.

A properly corrected reading of a volume indicator at a transmitting point may differ from that at an associated receiving point because of the use of different values of isolating pads, etc., at the two points, or because, by design a different volume is normally transmitted to the loop than is transmitted from the output of the loop receiving equipment. In making tone checks, therefore, it will be necessary to take into account properly the differences in readings which should exist for these reasons.

NOISE LEVELS

Noise measurements are made by the Telephone Companies by means of a special instrument known as the 2B Noise Measuring Set. This consists essentially of a high-quality quiet amplifier and an indicating meter which has dynamic characteristics very similar to those of the standard volume indicator. Measurements made with this equipment are in terms of decibels above a reference level of 10^{-12} watts in 600 ohms (90 db below 1 mw).

Where noise measuring sets of this type are not available, a good approximation of the noise level may be obtained by measuring, at a particular point on the circuit without the program, with a standard volume indicator adding sufficient amplification ahead of the volume indicator to give a convenient indication on

the meter. It is important that the supplemental amplification contributes little to the over-all noise being measured.

In the "Standards of Good Engineering Practices Concerning FM Broadcast Stations" the requirement for the over-all noise from studio to output of the transmitter is stated as follows: "The transmitting system output noise level frequency modulation in the band 50 to 15,000 cycles shall be at least 60 decibels below the audio-frequency level representing a frequency swing ± 75 kc.

In order to interpret the noise measured on studio-transmitter circuits to FM stations (as referred to the +8 vu point) in the terms used in the F.C.C. Standards of Good Engineering it is necessary to apply a correction to adjust measurements for the relationship between the program level at the +8 vu point and the audio-frequency level causing a 75 kc swing. Unless level limiting amplifiers are used it has been customary for broadcasters to allow a margin of about 10 db between the signal which would cause 100 per cent modulation and the nominal program level. This means that if a 1000-cycle "line-up" tone were transmitted over the circuit and caused the volume indicator to read +8 vu (at the nominal +8 vu point) the transmitter would be modulated at a level about 10 db below the maximum permissible value which, with frequency modulated transmitters, is about ±25 kc swing (10 db below the ±75 kc maximum). There is some indication that the FM broadcasters may want to allow an even larger differential between the nominal program level and the signal causing 100 per cent modulation but with the increasing use of level limiting amplifiers the 10 db value seems reasonable. Under the above conditions if the lineup tone were raised in level to cause a 75 kc swing, a level of +18 dbm (decibels above one milliwatt 1000-cycle tone in 600 ohms) would exist at the nominal +8 vu point. Since the noise levels in the Standards of Good Engineering Practice and proof of performance refer to an audio-frequency level causing a 75 kc swing, when considering over-all performance requirements the noise measured at the +8 vu point should be referred to +18 dbm. With a permitted total noise at the transmitter output 60 db below reference and with three major and likely equally contributing sources of noise, namely, the studio equipment, the transmitting equipment and the connecting circuit, the telephone circuit should not contribute noise which would measure higher than a value 65 db below this level of +18 dbm. In other words, to meet the F.C.C. standards the permitted noise, as measured at the +8 vu point, would be about 43 db above reference noise, reference being 10^{-12} watts in 600 ohms flat weighting.

NON-LINEAR DISTORTION

By design of equipment and control of the operating levels of any intermediate amplifiers that may be used on a studio-transmitter circuit for an FM station, the contribution of the line to the total harmonic distortion will ordinarily be less than 1 per cent when measured by the usual types of harmonic distortion measuring equipment available in the commercial market.

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

* 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.

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.

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.

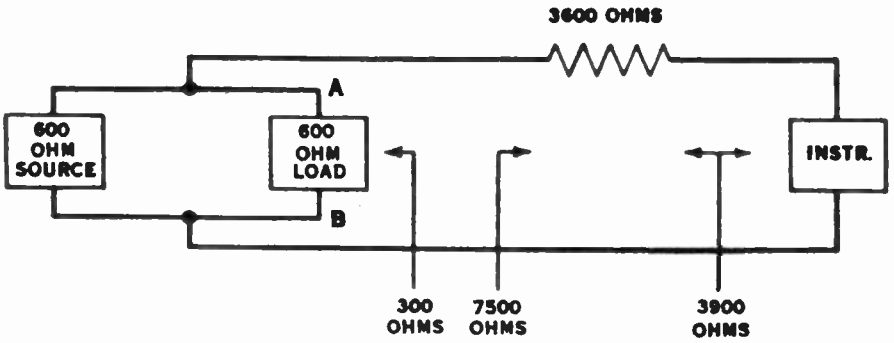


FIG. 1

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

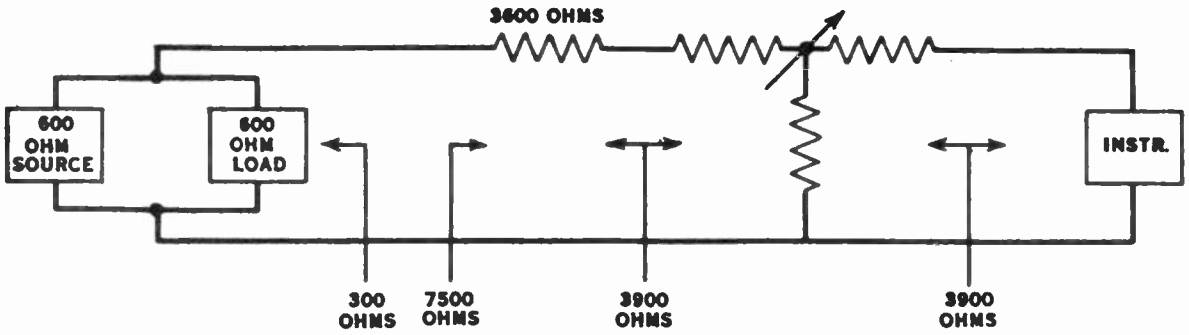


FIG. 2

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,

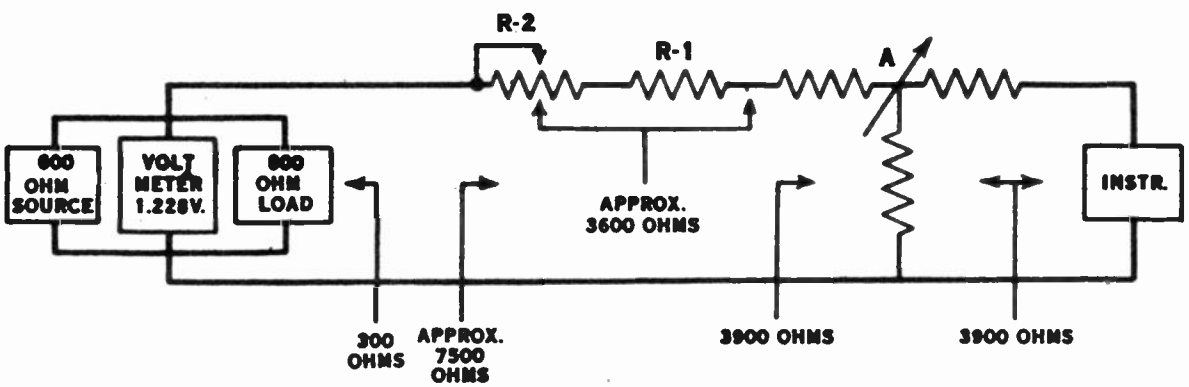


FIG. 3

it should be brought to 0 by means of the mechanical 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 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.

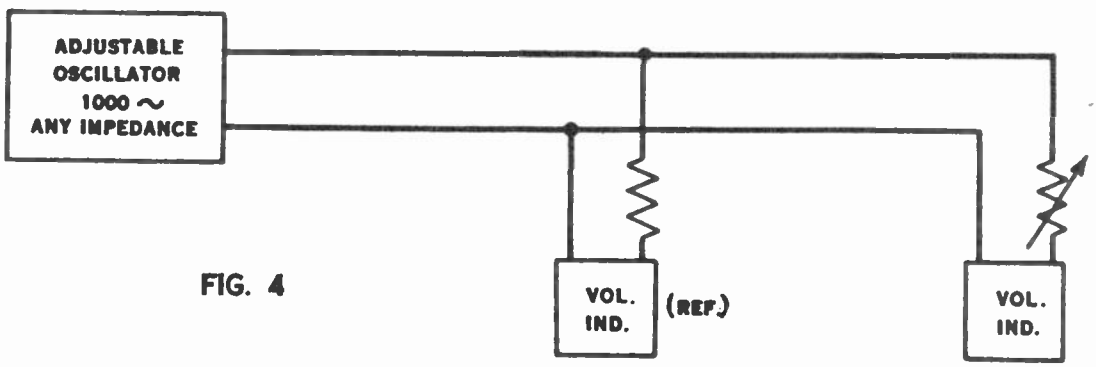


FIG. 4

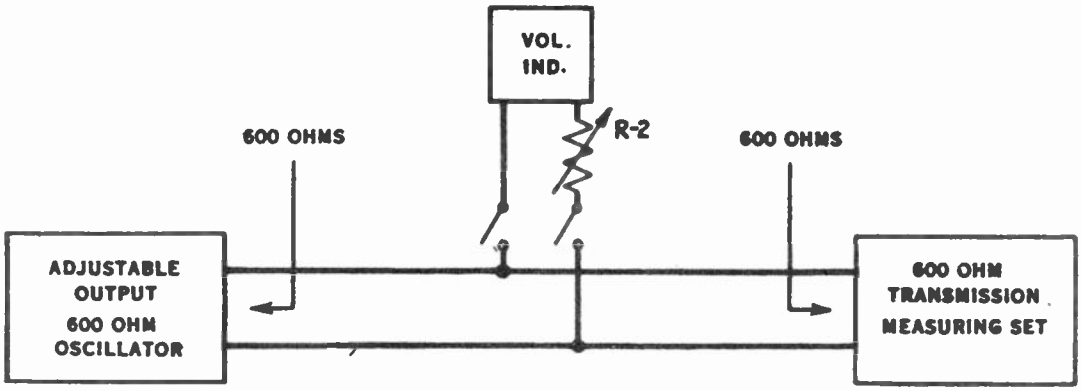


FIG. 5

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)

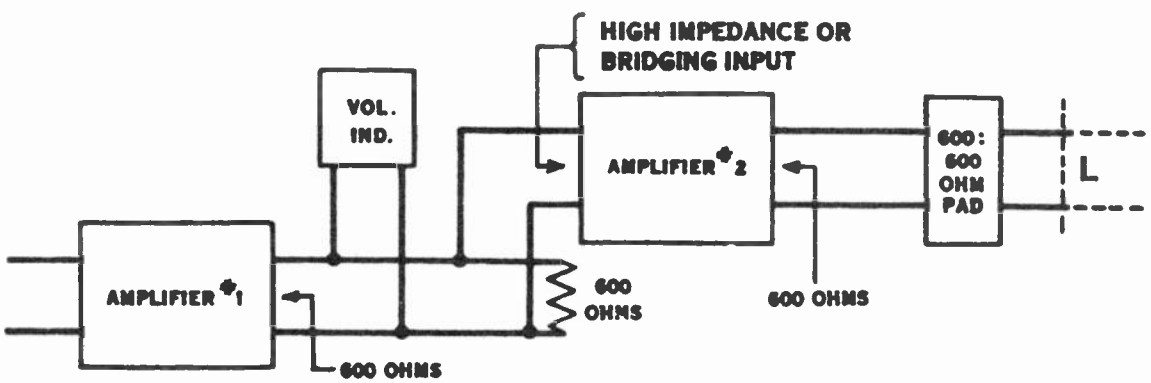


FIG. 6

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)

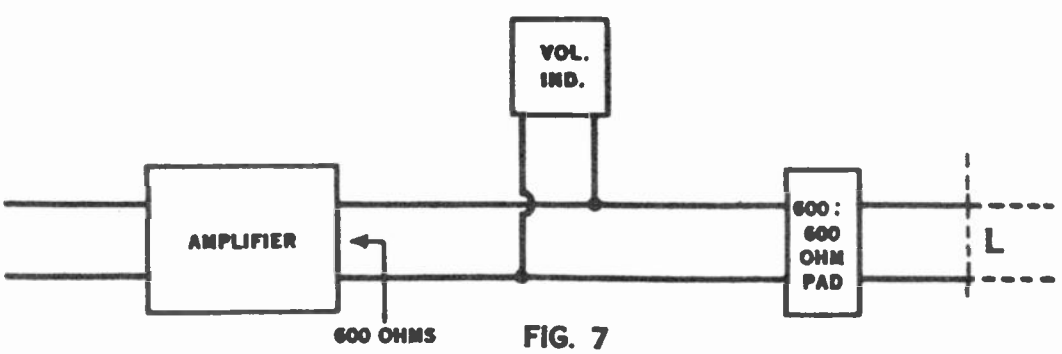


FIG. 7

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.

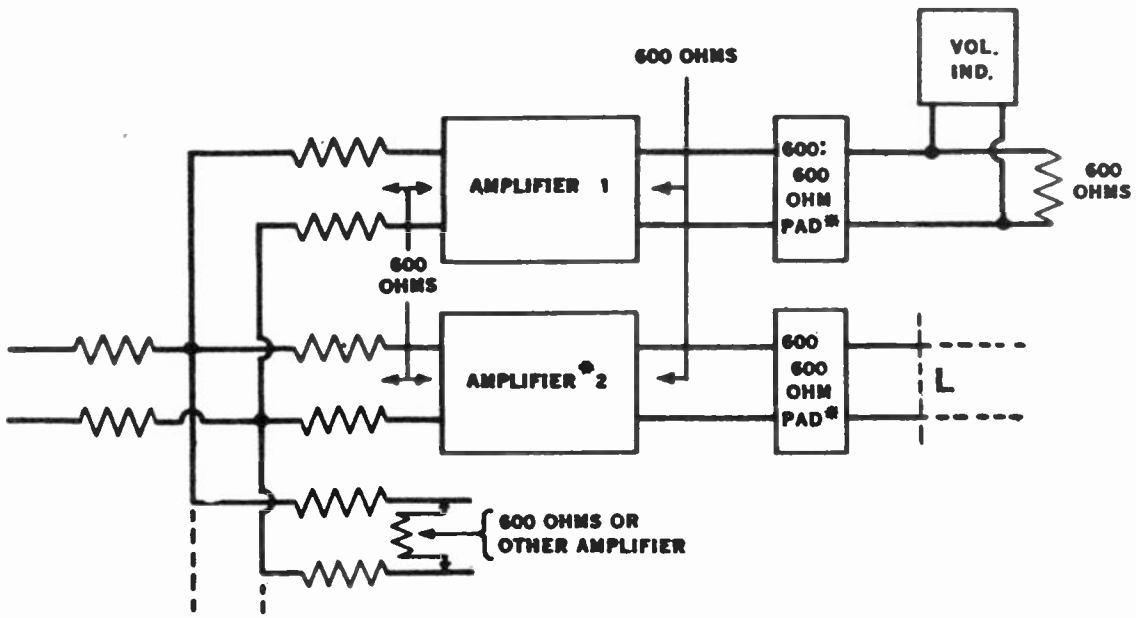


FIG. 8

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

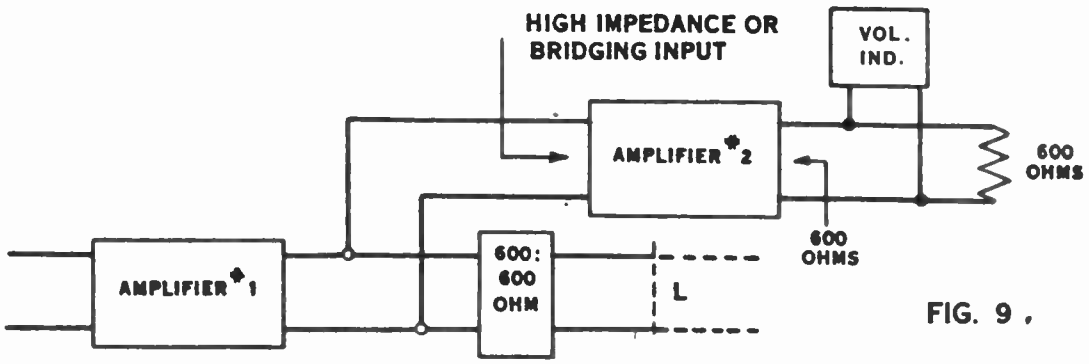


FIG. 9 .

* 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 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

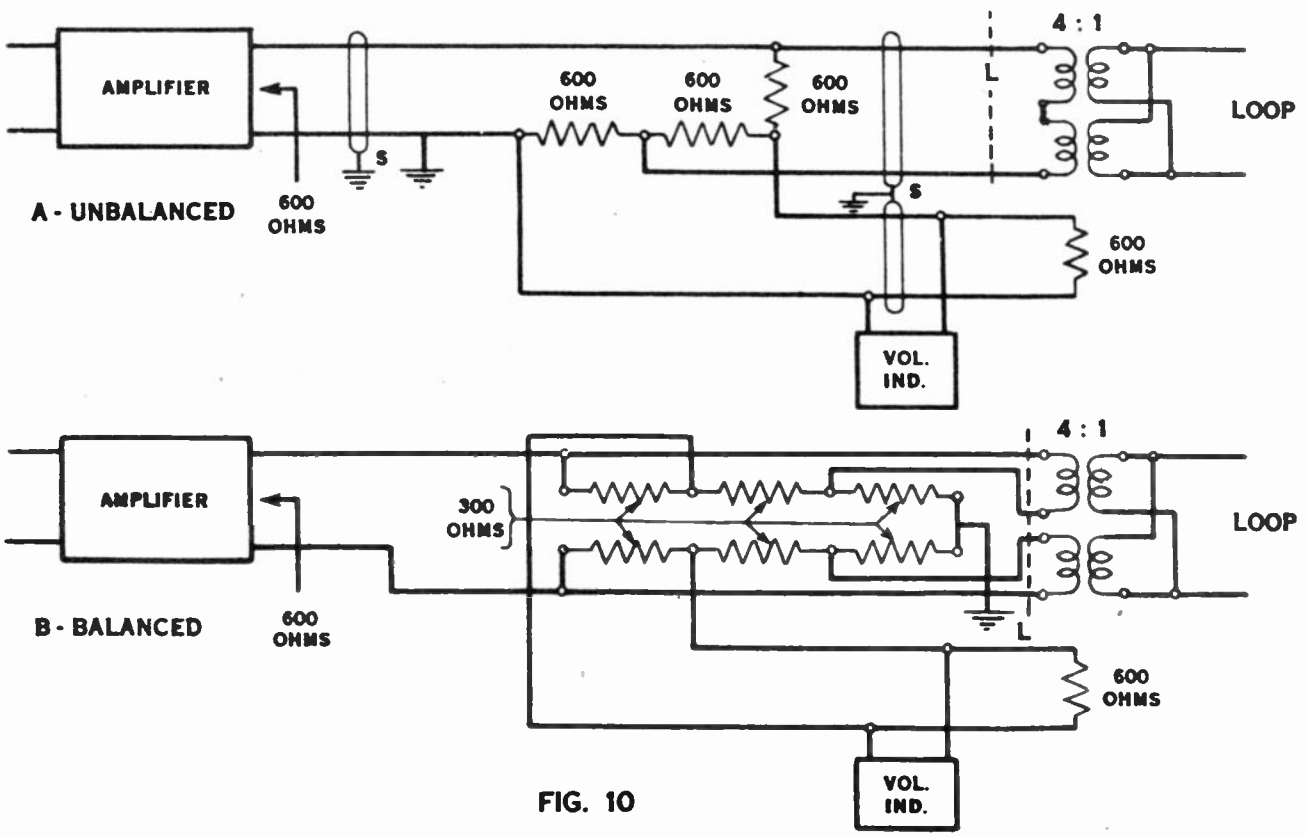


FIG. 10

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

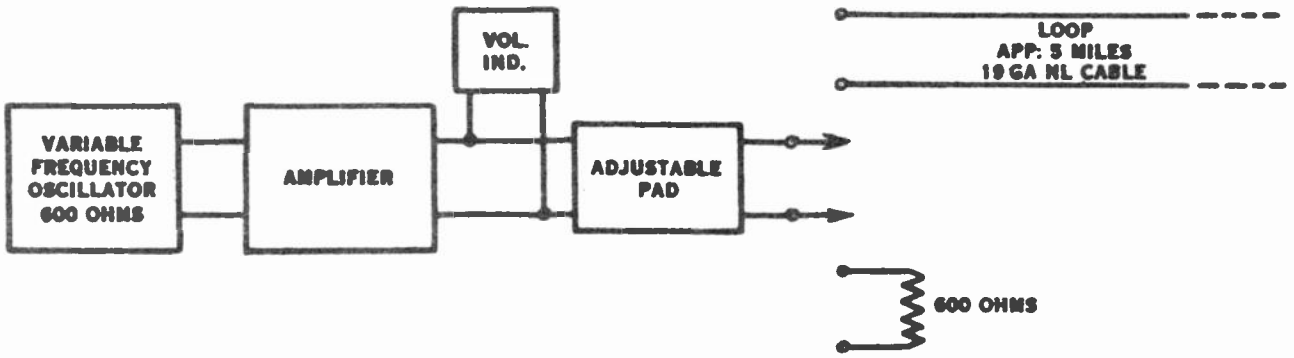
Peak checking between the telephone company and the broadcasters will normally be done by reference to the 0-100 scale on the volume indicator.

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.

TESTING ARRANGEMENT



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.

APPENDIX

EFFECT OF TRANSMITTING PAD LOSS ON VOLUME INDICATOR READINGS

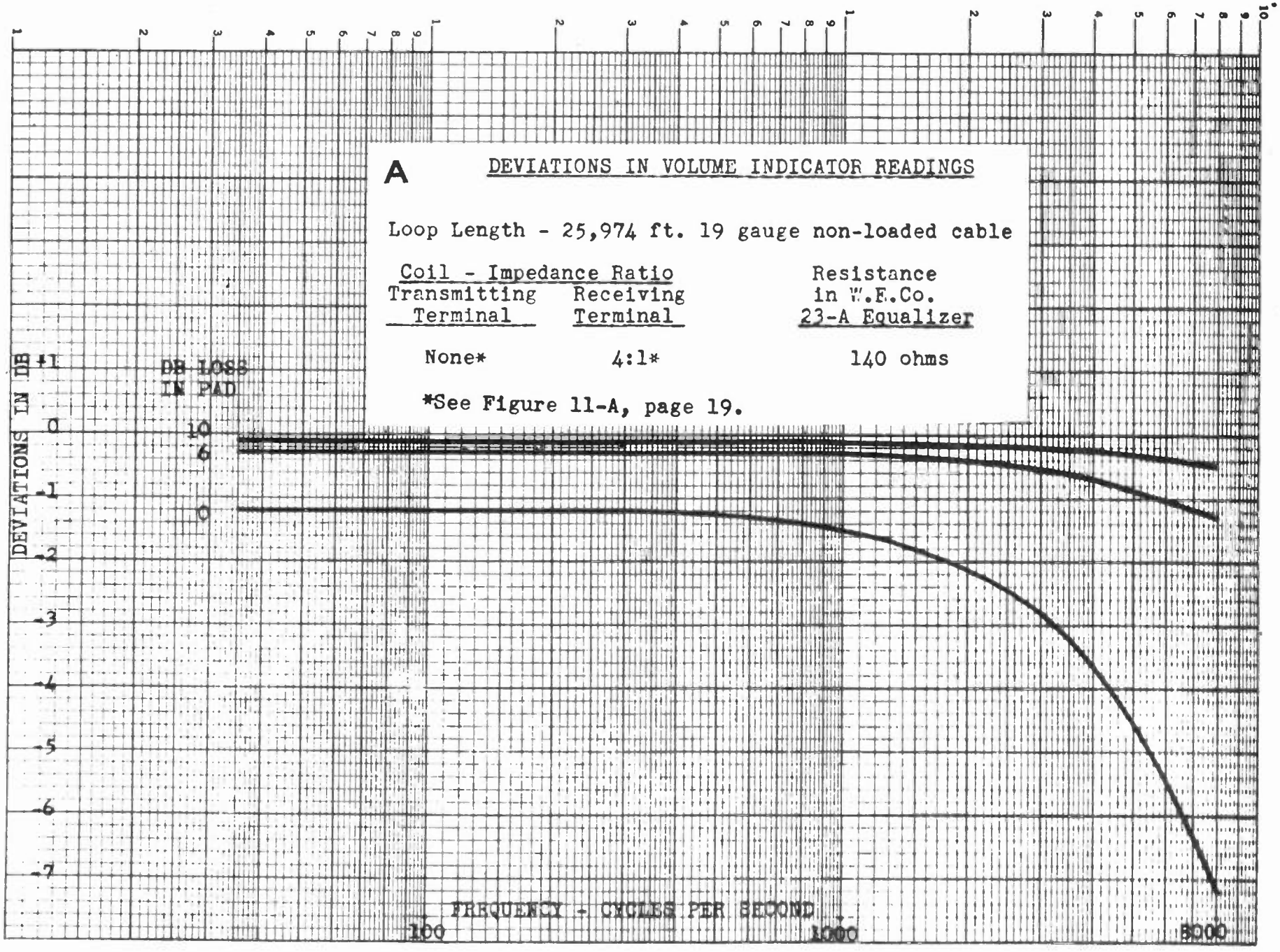
A test was made for the purpose of demonstrating the relative effectiveness of different amounts of loss in a transmitting pad, in reducing the deviations of volume indicator readings when connected across a loop, from the

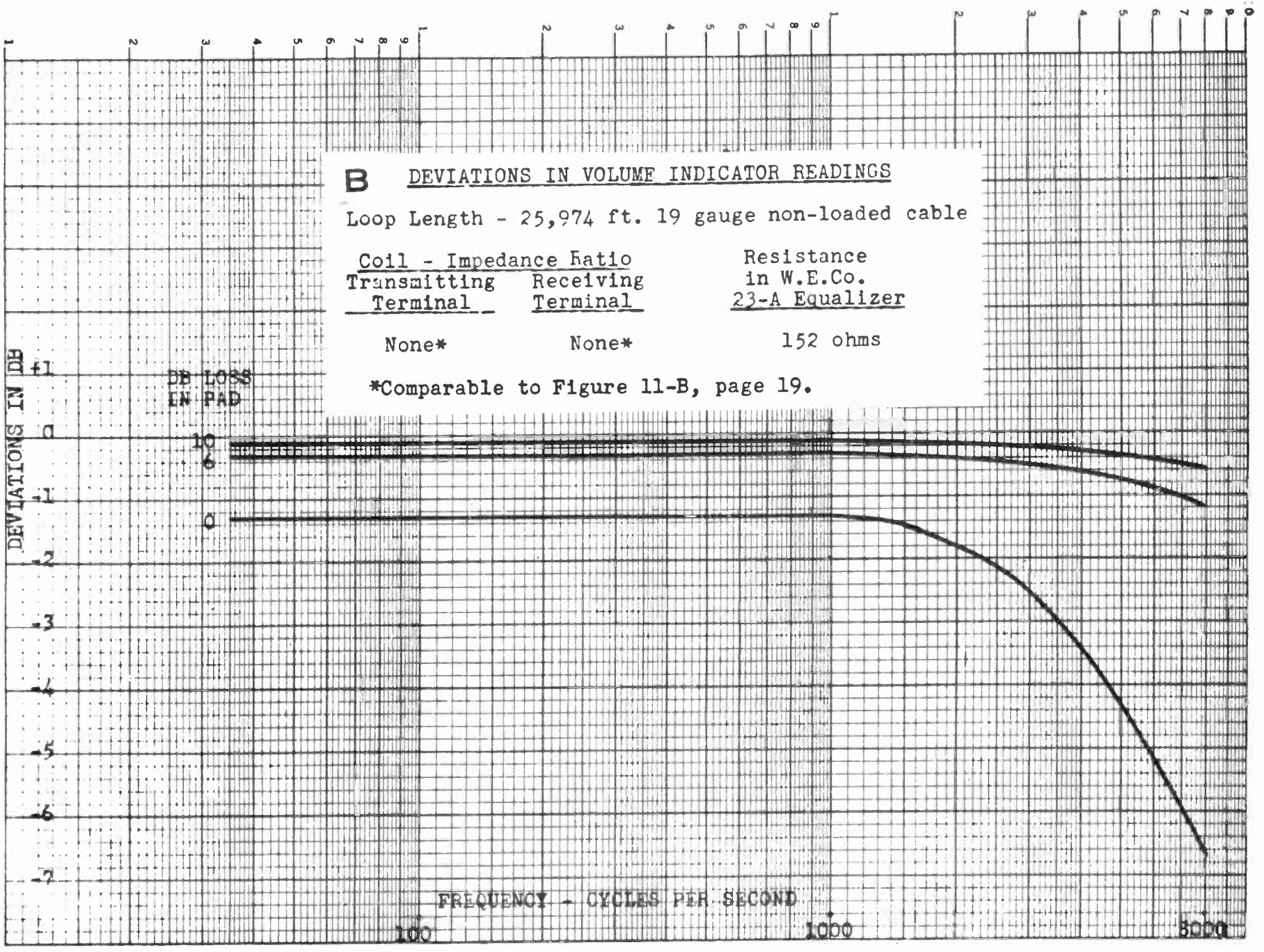
5. Steps 1, 2, 3, and 4 were repeated for each of four conditions of the loop equipment shown as A, B, C, and D, in Figure 1 (Part 4)., except that receiving coil was omitted entirely in B and D.

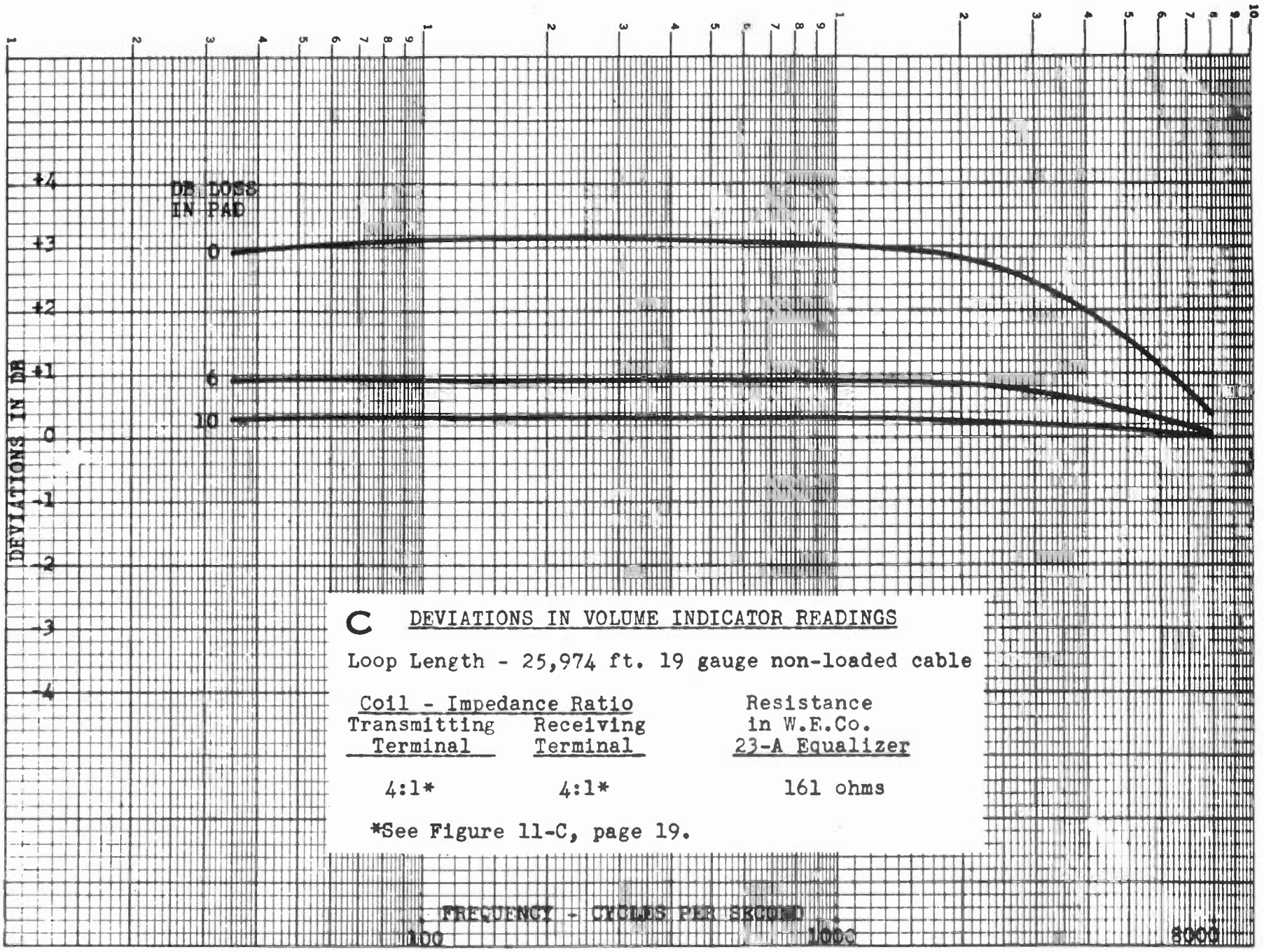
RESULTS

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.


A
DEVIATIONS IN VOLUME INDICATOR READINGS
Loop Length - 25,974 ft. 19 gauge 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 11-A, page 19.
DEVIATIONS IN DB
+1
0
-1
-2
-3
-4
-5
-6
-7
DB LOSS IN PAD
10
6
0
FREQUENCY - CYCLES PER SECOND
100
1000
5000


B DEVIATIONS IN VOLUME INDICATOR READINGS
Loop Length - 25,974 ft. 19 gauge 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 11-B, page 19.
DEVIATIONS IN DB
+1
0
-1
-2
-3
-4
-5
-6
-7
DB LOSS IN PAD
10
6
0
FREQUENCY - CYCLES PER SECOND
100
1000
8000

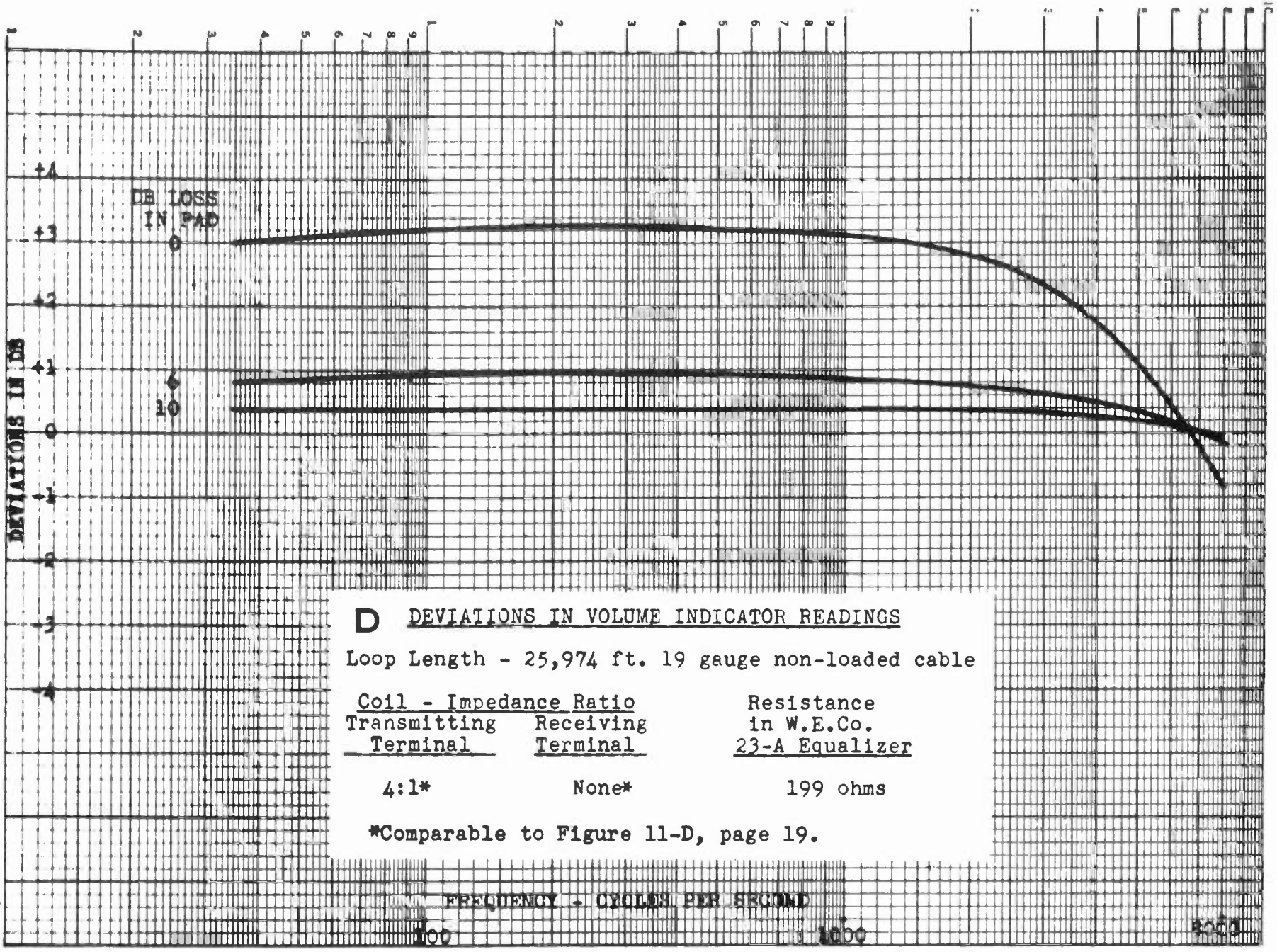


C DEVIATIONS IN VOLUME INDICATOR READINGS

Loop Length - 25,974 ft. 19 gauge 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 11-C, page 19.



D DEVIATIONS IN VOLUME INDICATOR READINGS

Loop Length - 25,974 ft. 19 gauge non-loaded cable

Coil - Impedance Ratio		Resistance
Transmitting Terminal	Receiving Terminal	in W.E.Co. 23-A Equalizer
4:1*	None*	199 ohms

*Comparable to Figure 11-D, page 19.

THE MEASUREMENT OF AUDIO DISTORTION

By H. H. Scott, Technology Instrument Corporation

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 as generally used 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 annoying in real high-quality reproduction.

The conventional practice has been to measure non-linear distortion in terms of the harmonic components added to a single frequency test-tone 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 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 $\pm$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 circuit, 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 $\pm$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 rss 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 push-button operated R-C feedback type, 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 oscillators of this type the standard push-button 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. This is the only commercial oscillator with a low enough distortion 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 continuously tunable R-C type as commercially produced generally has a somewhat higher distortion through the medium-frequency range than the better grades of beat-frequency oscillators. 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 generally available two-tone distortion tests will become quite generally used, particularly in cases where high amounts of distortion are encountered, since it is generally 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. The problem is further complicated in the case of television transmitters, where the allowable

WRH

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 on 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. Need-

less 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.

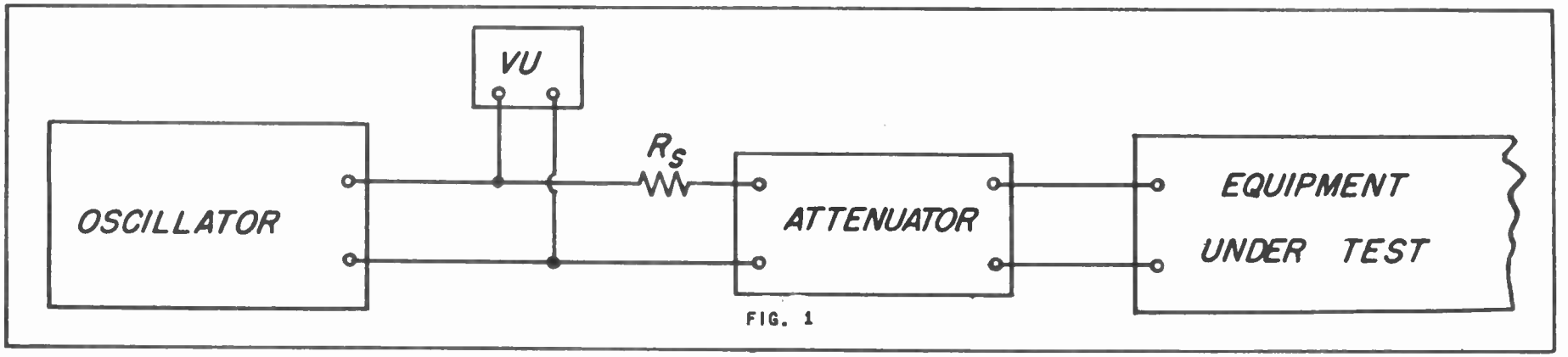


FIG. 1

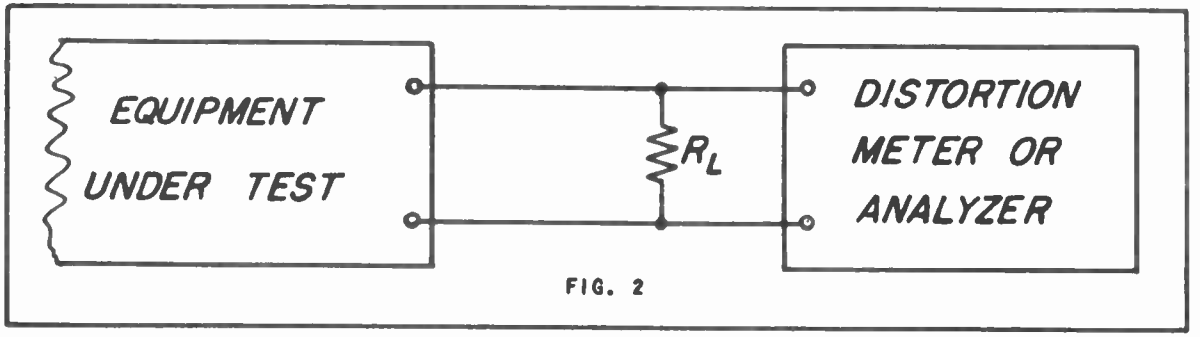


FIG. 2

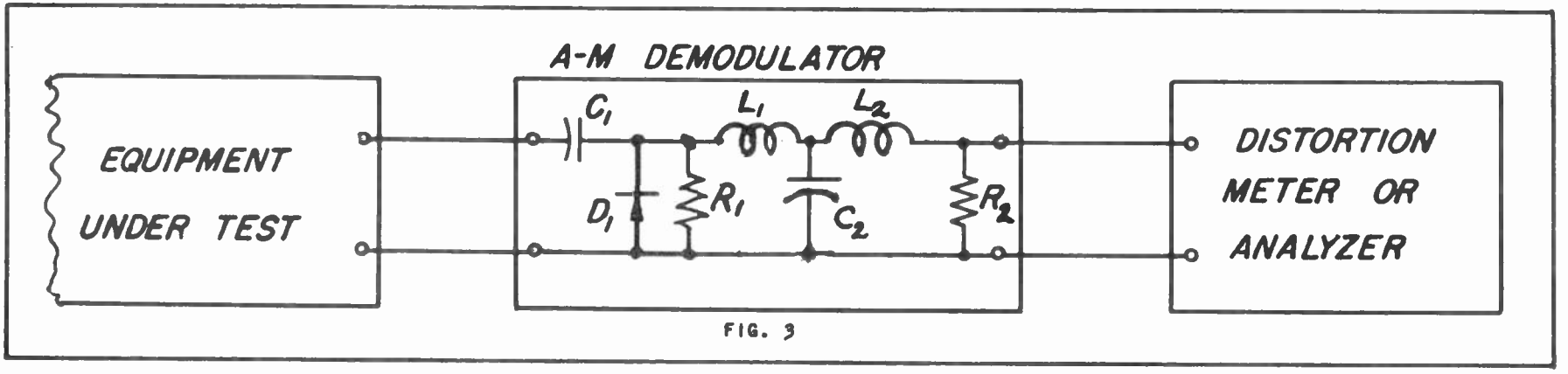


FIG. 3

GLOSSARY OF DISK-RECORDING TERMS

By Howard A. Chinn,
General Engineering Dept., Columbia Broadcasting System
(Reprinted from the Proceedings of the Institute of Radio Engineers, November, 1945)

INTRODUCTION

During 1941 the Engineering Committee of the National Association of Broadcasters formed a Recording and Reproducing Standards Committee for the purpose of formulating standards for electrical transcription and recordings made for radio broadcasting. Sixteen technical standards and good engineering practices were adopted[1] and are now followed by the industry.

A number of other items were under study by subcommittees and one additional item was completed before the war interrupted all activity in this field. The item in question is a glossary of disk-recording terms prepared by Subcommittee III and approved by the Executive Committee. This material has never been published, however, and in view of the potential post-war interest in recording, it seems opportune that the glossary be made available generally, particularly since it is not believed that material of this type exists elsewhere in the literature.

The members of the subcommittee which prepared the glossary consisted of H. A. Chinn, Columbia Broadcasting System, Inc., Chairman; E. J. Content, WOR; C. Lauda, World Broadcasting System; and G. E. Stewart, National Broadcasting Company.

GLOSSARY OF TERMS PERTAINING TO CONSTANT-ROTATIONAL-SPEED DISK RECORDING

Abrasive: The grinding material sometimes incorporated in record stock for the purpose of shaping the needle point to fit the groove properly.

Acetate disks: Various acetate compounds used for solid and laminated (which see) disks. The term is often erroneously used to describe cellulose-nitrate discs (which see).

Advance ball: A rounded support (often sapphire) attached to the recording head which rides on the discs to maintain a uniform mean depth of cut by correcting for small variations in the plane of the disc surface.

Angle of groove: The angle from wall to wall of an unmodulated groove in a radial plane perpendicular to the surface of the disk.

Backed stampers: A thin, metal matrix (which see) which is attached to a backing material, generally a metal sheet 1/8 inch to 1/4 inch thick.

Binder: A resinous material which causes the various materials of a record compound to adhere to one another.

Biscuit: A small slab of the stock material, from which records are pressed, as it is prepared for use in the presses.

Blank groove: A groove upon which no modulation is inscribed.

Burnishing surface (of cutting stylus): The portion of the cutting stylus directly behind the cutting edge which smooths the groove.

Burnishing tool: The stylus sometimes used to smooth the groove of a recording.

Cake wax: A thick disk of wax (which see) upon which an original recording is inscribed.

Capacitor pickup: A phonograph pickup which depends for its operation upon the variation of its capacitance.

Carbon-contact pickup: A phonograph pickup which depends for its operation upon the variation in the resistance of carbon contacts.

Cellulose-nitrate disks: See lacquer disks.

Center hole: The hole in the center of the record, which fits the center pin of the turntable.

Center pin: The shaft protruding from the center of the turntable used for centering the record.

Chip: The material removed from the disk by the recording stylus in cutting the groove.

Christmas-tree pattern: A term sometimes used in referring to the optical pattern (which see).

Condenser pickup: See capacitor pickup.

Constant amplitude: Recordings wherein all frequencies of the same intensity are inscribed at the same amplitude.

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[1] L. C. Smeby, "Recording and reproducing standards," Proc. I.R.E., vol. 30, pp.355-356; August, 1942.

Constant velocity: Recordings wherein frequencies of a given intensity are inscribed with the same maximum velocity of the cutting stylus.

Core: The central layer or basic support of certain types of laminated disks. (See laminated and lacquer disks.)

Crossover frequency: See transition frequency.

Crossover spiral: Same as spread groove (which see).

Crystal pickup: A pickup which depends for its operation on the piezoelectric effect of certain (generally Rochelle salt) crystals.

Cutter: An electromechanical transducer which transforms electric energy into mechanical motion which is inscribed into the original record by the cutting stylus. Also known as recording head.

Cut double (triple, etc.): Make two (three, etc.) original recordings simultaneously.

Cutting stylus: The cutting tool which cuts the groove into the original record.

Damping: See mechanical damping.

Drive pin: A pin similar to the center pin, but located to one side thereof, which is sometimes used to prevent the record from slipping on the turntable.

Drive-pin hole: A hole in the record which fits over the turntable drive pin.

Dubbing (in a cutting stylus): Same as burnishing surface (which see).

Dubbing (in recording): A recording made by re-recording from one or more records.

Dulling: Forming the burnishing surface of the cutting stylus.

Duping: To make duplicates by re-recording.

Dynamic pickup: A phonograph pickup in which the electrical output results from the motion of a conductor in a magnetic field.

Eccentric circle: A blank, locked groove (which see) whose center is other than that of the record (generally used in connection with mechanical control of phonographs).

Eccentricity: The eccentricity of the recording spiral with respect to the record center hole.

Fast spiral: A blank, spiral groove having a pitch that is much greater than that of the recorded grooves.

Feedback cutter: A cutter provided with a feedback circuit (separate from the driving circuit) in which a voltage, for inverse feedback to the driving amplifier, is induced by the movement of the cutting stylus.

Filler: The bulk material of a record compound as distinguished from the binder (which see).

Flowed-wax platter: Disk base (usually metal) upon which wax is flowed.

Flutter: Frequency modulation caused by spurious variations in groove velocity.

Frequency record: A record upon which have been recorded various frequencies throughout the desired frequency spectrum.

Groove: The track cut in the record by the stylus.

Groove contour: The shape of the groove in a radial plane perpendicular to the surface of the record.

Groove speed: See groove velocity.

Groove velocity: The linear velocity of the groove with respect to the stylus.

Grouping: Nonuniform spacing between grooves.

Guard circle: An inner concentric groove inscribed on a record to prevent reproducer from being damaged by being thrown to the center of the record.

Hill-and-dale recording: See vertical recording.

Hot plate: A heated table used for (a) softening the biscuits of record material prior to placing them in the press or (b) making flowed waxes.

Instantaneous recording: A recording which may be used without further processing.

Label: The identification markings on paper or similar material, at the center of the record.

Lacquer disks: Disks, usually of metal, glass, or paper, which are coated with a lacquer compound (often containing cellulose nitrate) and used either for "instantaneous" recordings or lacquer masters.

Lacquer master: A term improperly applied to a "lacquer original" (which see).

Lacquer original: An original recording on a lacquer disk which is intended to be used for the

making of a metal master.

Laminated record: A disk composed of several layers of material. Normally used with one thin facer on each side of a core.

Land: The record surface between two grooves.

Lateral compliance: The ability of a reproducing stylus to move laterally with respect to the record groove while in the reproducing position in a record.

Lateral recording: A recording in which the groove modulation is in the plane of the record and along a radius.

Lead screw: The threaded rod which leads the cutter or reproducer across the surface of the disc.

Lead-in spiral: A blank, spiral groove at the beginning of a record, generally having a pitch that is much greater than that of the recorded grooves.

Locked groove: A concentric, blank groove at the end of modulated grooves whose function is to prevent further travel of the reproducer.

Magnetic pickup: A reproducer employing an armature placed in a magnetic field and coupled mechanically to the reproducing stylus. An electric potential is generated in a coil placed in this field when the stylus is actuated by the modulated groove of a record.

Master: The negative produced from the original recording (which see).

Master stamper: A master used as a stamper to make pressings.

Matrix: The negative from which duplicate records are molded. (See also stamper.)

Mechanical damping: The mechanical resistance which is generally associated with the moving parts of a cutter or a reproducer.

Metal master: The metal negative produced directly from the original recording.

Metal negative: Same as metal master (which see).

Metal mold: Same as matrix (which see).

Mother: A positive produced directly from the metal master or negative.

Needle (reproducing needle): A replaceable reproducing stylus (which see).

Needle drag: Same as stylus drag (which see).

Needle pressure: Same as stylus pressure (which see).

Optical pattern: The pattern which is observed when the surface of a record is illuminated by a beam of parallel light.

Orange peel: Mottled surface of a defective disc having an appearance similar to the skin of an orange.

Original recording: See lacquer original and wax original.

Overcutting: Excessive level in recording to an extent that one groove cuts through into an adjacent one.

Pickup: A mechanicoelectrical transducer which is actuated by the undulations of the record groove and transforms this mechanical energy into electrical energy.

Pinch effect: A pinching, or in some cases a lifting of the reproducing stylus, twice each cycle in the reproduction of lateral recordings, caused by the recording stylus cutting a narrower groove when moving across the record while swinging from a negative to a positive peak.

Playback: An expression used to denote the immediate reproduction of a recording.

Pold: The curve that the center of a sphere traces when the surface of the sphere is rolling along a sine wave.

Postemphasis: The complement in reproduction of pre-emphasis (which see).

Pre-emphasis: A method of recording whereby the relative recorded level of some frequencies is increased with respect to other frequencies.

Pressing: A record produced in a record-molding machine from a matrix or stamper.

Processing: Making the master, mother, and matrix (which see).

Recording head: Same as cutter (which see).

Re-recording: A recording made from the reproduction of a recording. (See also dubbing.)

Reference recording: Recording of a program or other material made for the purpose of checking same.

Reproducing stylus: The "needle" or jewel which follows the undulations in the record groove and transmits the mechanical motion thus derived to the pickup mechanism.

Rumble: Low-frequency vibration mechanically

transmitted to the recording or reproducing turntable and superimposed on the reproduction.

Safety: A second recording, made simultaneously with the original, to be used for duplication should the original be damaged.

Shaving: Process of removing material from a wax disc of recording material to obtain a plane surface.

Shell or shell stamper: A thin metal matrix (generally 0.015 to 0.020 inch thick).

Spew: The excess record material which is ejected from the record press in the manufacture of pressed records.

Spread groove: A groove, with greater than normal pitch, cut between recordings of short-time duration, thus separating the recorded material into bands while still enabling the reproducing stylus to travel from one band to the next.

Sputtering: A process sometimes used in the production of the metal master, wnerein the wax or lacquer original is coated with an electrical conducting layer by means of an electrical discharge in a vacuum. Sometimes called cathode sputtering.

Stamper: A negative (generally made of metal) produced from the mother (which see) and from which the finished pressings are molded. (See also matrix.)

Stylus drag: The expression used to denote the effect of the friction between the record surface and the reproducing stylus.

Stylus force: Effective weight of reproducer or force in vertical direction on stylus when it is in operating position.

Stylus pressure: Term sometimes erroneously used to denote effective weight of reproducer or stylus force (which see).

Stylus weight: Actually stylus force (which see).

Surface noise: The noise reproduced in playing a record due to rough particles in the record material and/or irregularities in the walls of the groove left by the cutting stylus.

Throw-out spiral: A blank spiral groove at the end of a recording, generally at a pitch that is much greater than that of the recorded grooves.

Throw-out tail: End of throw-out spiral (which see).

Tracing distortion: A harmonic distortion introduced in the reproduction of records because of the fact that the curve traced by the center of the tip 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" (which see).

Tracking error: The angle (in a lateral recording) between the vertical plane containing the vibration axis of the mechanical system of the reproducer and a vertical plane containing the tangent to the record groove.

Transition frequency: The frequency at which the change-over from constant-amplitude recording to constant-velocity recording takes place.

Translation loss: The loss in high-frequency reproduction which occurs as the groove velocity decreases.

Turnover frequency: Same as transition frequency (which see).

Vertical compliance: The ability of a reproducing stylus to move in a vertical direction while in the reproducing position on a record.

Vertical recording (hill-and-dale recording): A recording wherein the groove modulation is in a plane tangent to the groove and normal to the surface of the record.

Vertical stylus force: See stylus force.

Wax: A blend of waxes with metallic soaps (also see cake wax).

Wax master: A term improperly applied to a "wax original" (which see).

Wax original: An original recording on a wax surface for the purpose of making a metal master.

William (or willy): A negative produced from a mother to produce still another mother.

Wow: A low-frequency flutter (which see).

TECHNICAL STANDARDS AND GOOD ENGINEERING PRACTICES
OF THE
NATIONAL ASSOCIATION OF BROADCASTERS
FOR
ELECTRICAL TRANSCRIPTIONS AND RECORDINGS FOR RADIO BROADCASTING

NOTE

The Recording and Reproducing Standards Committee was organized at Detroit on June 26, 1941. Seventy-seven members of the Committee, representing organizations interested in recording and reproduction for radio broadcasting, participated in the work. Sixteen standards, adopted before the war interrupted this activity, are attached hereto.

The Committee is expected to complete the remaining items, already approved for standardization.

Officially adopted March 19-20, 1942
by the NAB Board of Directors.

1. OUTER DIAMETERS

It shall be standard that the outer record diameter fall within the limits specified in the following table:

Nominal	Finished Records (Pressings or Instantaneous)	Lacquer Originals for Process
16"	15-15/16" ± 3/32"	17-1/4" ± 1/16"
12"	11-7/8" ± 1/32"	13-1/4" ± 1/16"
10"	9-7/8" ± 1/32"	11-1/4" Minimum

2. CENTER HOLE DIAMETER

It shall be standard that the record center hole diameter be 0.286" ± 0.001".

3. TURNTABLE CENTER PIN DIAMETER

It shall be standard that the diameter of the center pin of a transcription turntable be 0.2835" ± 0.0005".

4. OUTERMOST GROOVE DIAMETER

It shall be standard that the diameter of the outermost groove be within the limits specified in the following table:

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"

5. INNERMOST GROOVE DIAMETER

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 R.P.M. records and not less than 3 3/4" in the case of 78 R.P.M. records.

6. UNIFORMITY OF GROOVE SPACING

It shall be standard that the recorded grooves on a record shall be so spaced that at no point (except the concentric stopping groove) does the pitch deviate from the mean groove pitch by more than 5 per cent.

7. STOPPING GROOVE

It shall be standard that at the termination of the recording groove spiral a locked concentric stopping groove shall be provided.

8. NUMBER OF BLANK GROOVES

It shall be standard that the number of blank grooves, before modulation occurs, shall be not less than two complete revolutions nor more than four, exclusive of any starting spiral.

9. RECORDING TURNTABLE SPEED (R.P.M.)

It shall be standard that the mean speed of the recording turntable be either 33 1/3 or 78.26 R.P.M. ± 0.5%.

10. WOW FACTOR

It shall be standard that the maximum instantaneous deviation from the mean speed of the recording turntable, when making the recording, shall not exceed ± 0.1% of the mean speed.

11. RECORD WARP

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".

12. MINIMUM LABEL INFORMATION

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 or 33 1/3
c. Direction of feed (start) - outside-in or inside-out
d. Recording frequency characteristic

13. FREQUENCY CHARACTERISTIC FOR VERTICAL RECORDING

It shall be standard that the recorded frequency characteristic on vertically recorded records be as shown in figure 1.

14. FREQUENCY CHARACTERISTIC FOR LATERAL RECORDING

It shall be standard that the recorded frequency characteristic on laterally recorded records be as shown in figure 2.

15. STARTING SPIRAL GROOVES PER INCH

It shall be good engineering practice in recordings having a starting spiral to use a rate of eight grooves per inch for the spiral. (Tolerance ± 2 grooves per inch)

16. RECORDING GROOVES PER INCH

It shall be good engineering practice to use numbers of grooves per inch in recording as follows: 96 - 104 - 112 - 120 - 128 - 136 - etc., in increments of eight. (Tolerance ± 2 grooves per inch)

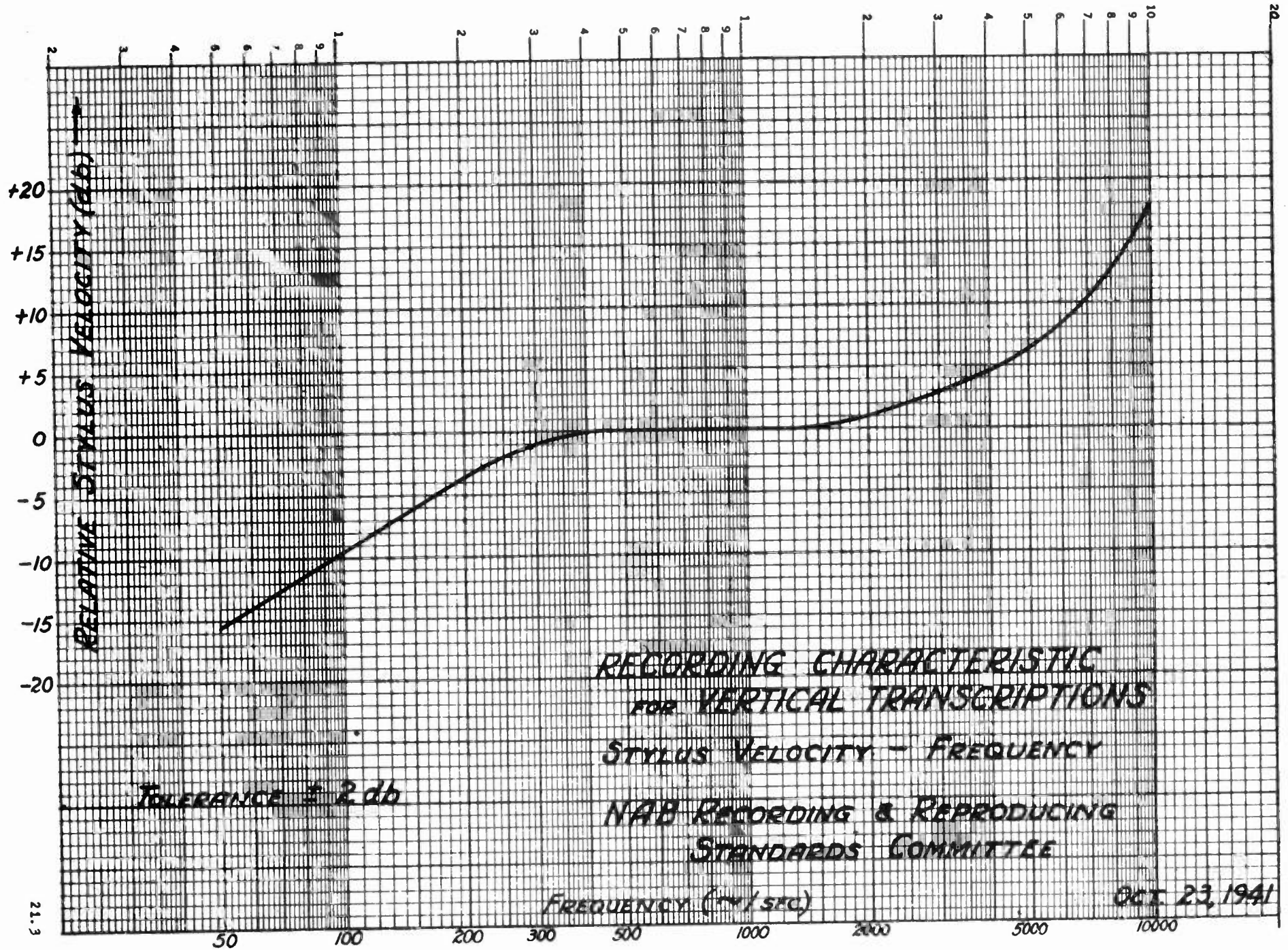
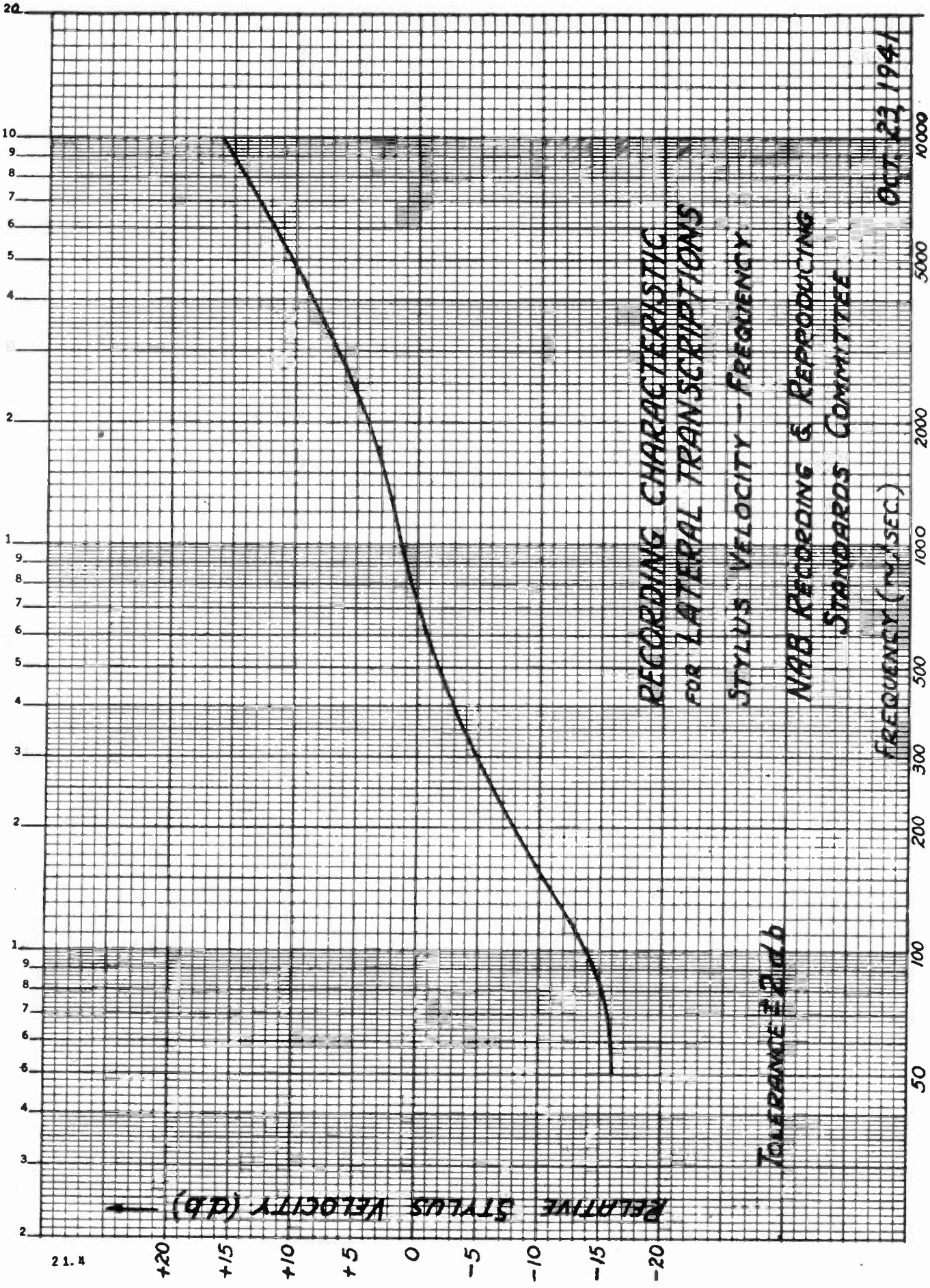

RELATIVE STYLUS VELOCITY (db)
+20
+15
+10
+5
0
-5
-10
-15
-20
50
100
200
300
500
1000
2000
5000
10000
FREQUENCY (~/SEC.)
RECORDING CHARACTERISTIC
FOR VERTICAL TRANSCRIPTIONS
STYLUS VELOCITY - FREQUENCY
NAB RECORDING & REPRODUCING
STANDARDS COMMITTEE
OCT. 23, 1941
TOLERANCE ± 2 db

Figure 1

Figure 2


RECORDING CHARACTERISTIC
FOR LATERAL TRANSCRIPTIONS
STYLUS VELOCITY - FREQUENCY
NAB RECORDING & REPRODUCING
STANDARDS COMMITTEE
OCT. 23, 1941
FREQUENCY (~/SEC.)
RELATIVE STYLUS VELOCITY (db)
TOLERANCE ± 2 db
21.4

PRACTICAL DESIGN OF VIDEO AMPLIFIERS

By Elliott A. Henry

(Reprinted through the courtesy of the RCA Victor Division, Radio Corporation of America.)

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_0, 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

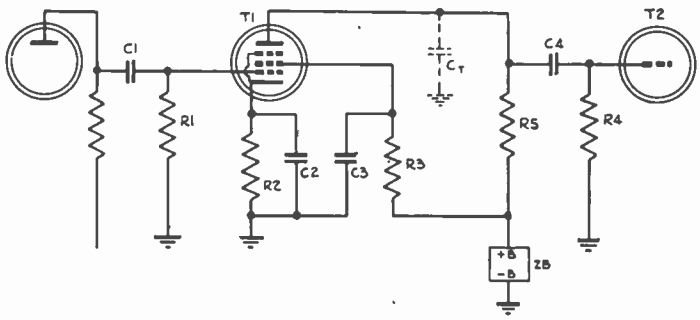


FIG. 1. *Conventional R-C coupled amplifier stage.*

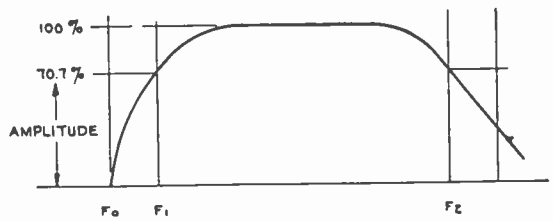


FIG. 2. *Gain-Frequency plot of Figure 1.*

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° at F_1 and decrease 45° at F_2 from the mid-frequency value and therefore a change in the phase angle of 90° 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_4-C_4; 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.

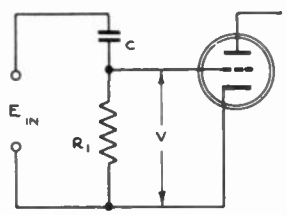


FIG. 3. *Grid coupling network.*

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:

$$Z_k = \frac{R\ X_c}{\sqrt{R^2 + X_c^2}} \qquad (Eq.\ 4)$$

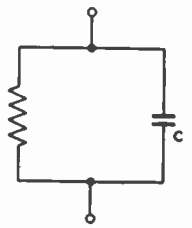


FIG. 4. *Equivalent cathode or plate load network.*

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.

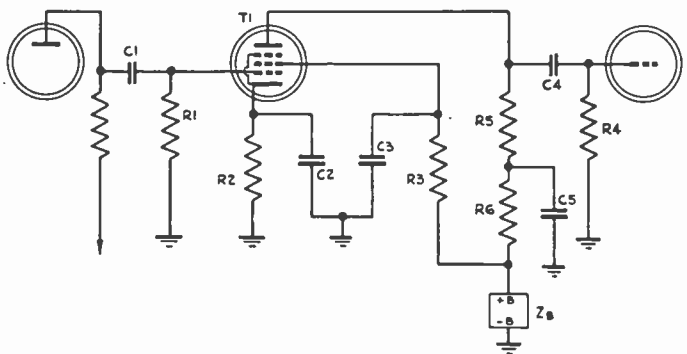


FIG. 5. *Amplifier stage with low frequency correction network (R_6-C_5).*

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 us. 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:

$$A = G_m Z_p \qquad (Eq.\ 6)$$

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:

$$E = IZ \qquad (Eq.\ 7)$$

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:

$$R_2 C_2 = R_6 C_5 \qquad (Eq.\ 8)$$

$$\text{and } \frac{C_2}{C_5} = \frac{R_6}{R_2} = A$$

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:

$$C_{in} = C_{gk} + \left[C_{gp} (1 + A) \right] \qquad \textit{(Eq. 10)}$$

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:

$$A = \frac{u\ Z_L}{Z_L + R_P} \qquad \textit{(Eq. 11)}$$

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.

$$C_{eff} \cong C_{gk} \frac{1}{1 + G_m Z_k} = \frac{C_{gk}}{1 + G_m Z_k} \qquad \textit{(Eq. 12)}$$

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:

$$C_T = \frac{1}{2\pi\ F\ R} \qquad \textit{(Eq. 13)}$$

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 1 .

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 and 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_k, 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

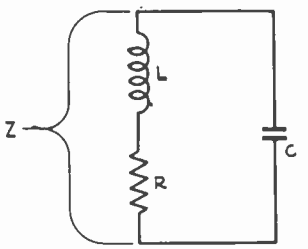


FIG. 6. *Basic shunt peaked network.*

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.

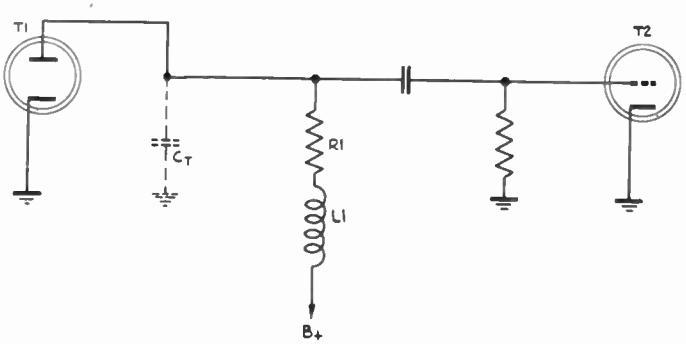


FIG. 7 *Shunt peaked stage.*

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:

$$R_1 = X_{C_T} \text{ at } F_c \qquad (Eq.\ 15)$$

And L_1 is such that its reactance at F_c is one-half of X_{CT} at F_c, or:

$$X_{L_1} = \frac{X_{C_T}}{2} \text{ at } F_c \qquad (Eq.\ 16)$$

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:

$$X_{C_T} = \frac{1}{6.28 \times 5 \times 10^6 \times 25 \times 10^{-12}} = \frac{10^6}{785} = 1273 \text{ ohms}$$

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 6, 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:

$$R_1 = .85\ X_{C_T} \text{ at } F_c \qquad (Eq.\ 18)$$

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.

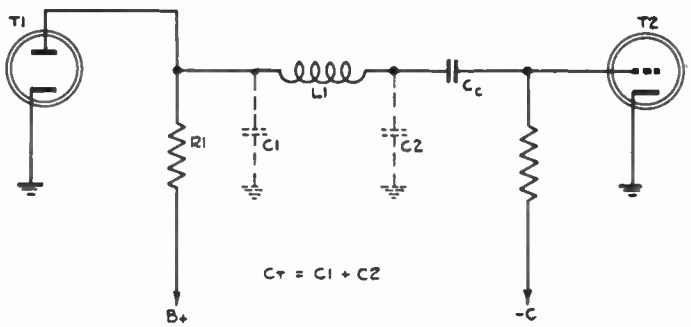


FIG. 8. *Series peaked stage.*

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.)

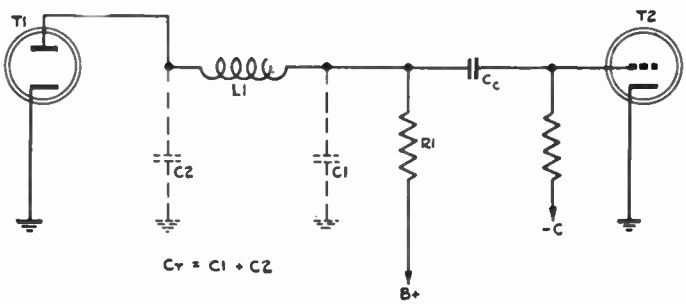


FIG. 9. *Series peaked stage.*

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:

$$C_T = C_{out} \text{ of } T_1 + C_{in} \text{ of } T_2 + C_{stray} = C_1 + C_2 \qquad (Eq.\ 20)$$

$$C_2 = 2C_1 \qquad (Eq.\ 21)$$

$$R_1 = 1.5 \times X_{C_T} \text{ at } F_c \qquad (Eq.\ 22)$$

$$L_1 = \frac{1}{2(\pi F_c)^2 C_1} = .67\ C_T\ R_1^2 \qquad (Eq.\ 23)$$

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).

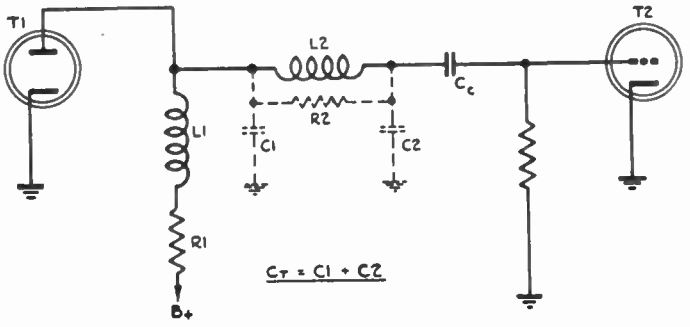


FIG. 10. *Combination peaked stage.*

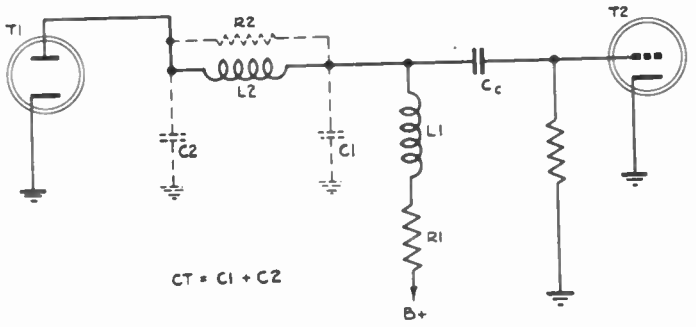


FIG. 11. *Combination peaked stage.*

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 critera for combination peaking is:

$$C_T = C_1 + C_2$$

$$C_2 = 2C_1$$

$$L_1 = .12 \times C_T \times R_1^2 \qquad (Eq.\ 24)$$

$$L_2 = .52 \times C_T \times R_1^2 \qquad (Eq.\ 25)$$

$$R_1 = 1.8\ X_{C_T} \text{ at } F_c \qquad (Eq.\ 26)$$

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 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.

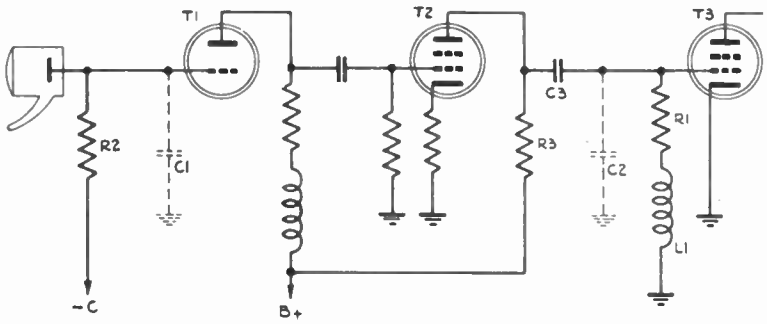


FIG. 12. *"Hi-Peaker" stage.*

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

$R_3 > 10 \times X_{L_1}$ at F_c *(Eq. 27)*

$X_{C_3} < .1\ R_3$ at lowest frequency *(Eq. 28)*

$R_1 = \frac{L_1}{R_2 C_1}$ where R = ohms, L = uhenries, C = ufds. *(Eq. 29)*

$L_1 = \frac{25.33 \times 10^3}{(2 F_c)^2 \times C_2}$ *(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:

$R_3 > 10 \times 6.28 \times 5 \times 10^6 \times 8.43 \times 10^{-6} = 2650$ ohms or greater

From Equation 28:

$X_{C_3} = < .1 \times 2650 = 265$ ohms or less
$C_3 = 20$ 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.

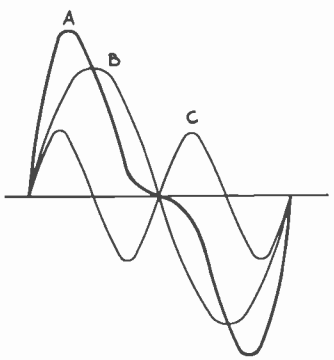


FIG. 13. *Complex wave with components in phase.*

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.

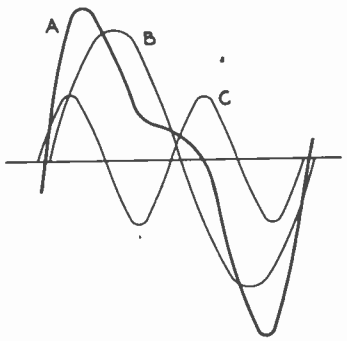


FIG. 14. *Complex wave after both component waves are delayed 30°.*

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.

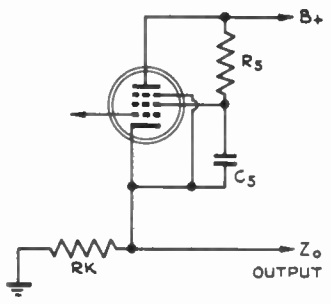


FIG. 15. *Pentode cathode follower.*

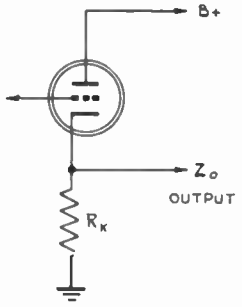


FIG. 16. *Triode cathode follower.*

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:

$$\left(\frac{1}{G_m} = \frac{1}{.009} = 111\right) \quad Z_o = \frac{111 \times 160}{271} = 65.7 \text{ ohms}$$

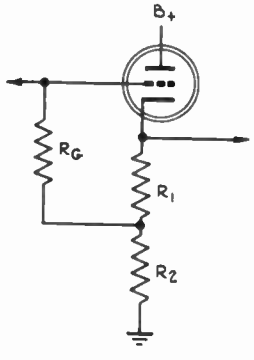


FIG. 17. *Cathode follower with Z_o matched to load.*

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:

$$\text{unloaded—} \quad A = \frac{.009 \times 205}{1 + .009 \times 205} = \frac{1.845}{2.845} = .648$$

$$\text{loaded—}\quad A = \frac{.009\dfrac{72 \times 205}{72 + 205}}{1 + .009\dfrac{72 \times 205}{72 + 205}} = \frac{.009 \times 54.7}{1 + .009 \times 54.7} = \frac{.492}{1.492} = .33$$

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.

$$R = \frac{1000 \times 6700}{6700 - 1000} = 1175 \text{ ohms}$$

In critical applications, generally, the peaking coils are made with a moveable hipermeability iron core for adjusting the inductance to take care of un-predictable minor variations in circuit and stray capacities. The gain-frequency characteristic of the amplifier may be checked with a good grade signal generator supplying the constant voltage input and a wide range vacuum tube voltmeter for monitoring the output. The response of the amplifier may be observed visually using a video sweep generator and a wide range oscilloscope.

A standard oscilloscope may be used in place of the wide range oscilloscope by inserting a linear detector between the amplifier and oscilloscope input and using a sinusoidal voltage equal to the sweep frequency for the time base.

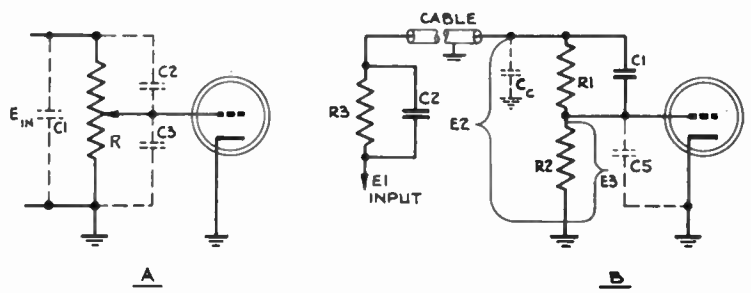


FIG. 18. *Attenuating systems.*
A. *Uncompensated.* B. *Compensated.*

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.

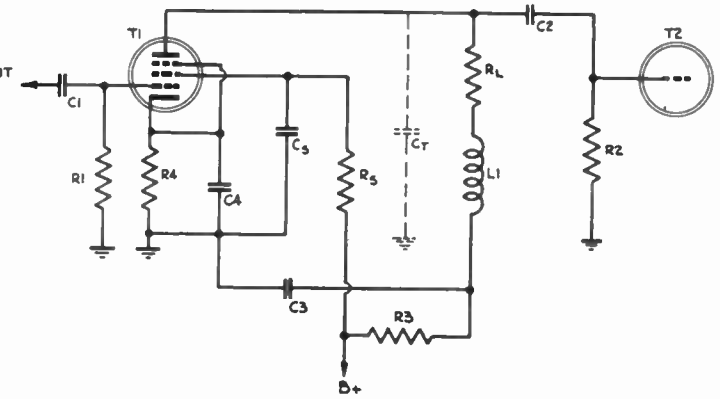
SUMMARY

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.



$\text{Gain} = G_m R_L$

$C_T = C_{pk} + C_{gk}$ of T_1 and T_2 respectively + wiring capacity

F_C = highest frequency of correction

F_1 = lowest frequency of correction

$$\left.\begin{aligned} R_L &= Xc_T \text{ at } F_C \\ L_1 &= \frac{R_L}{4\pi F_C} \end{aligned}\right\} \text{General}$$

$$\left.\begin{aligned} R_L &= .85\ Xc_T \text{ at } F_C \\ L_1 &= \frac{.3}{(2\pi F_C)^2 C_T} \end{aligned}\right\} \text{Conservative}$$

$$Xc_S < \frac{2}{G_m} \text{ at } F_1$$

$$R_S > \frac{3/F}{C_S} \text{ at } F_1$$

To compensate for R_1—C_1 or C_2—R_2

$$C_3 = \frac{C_2 R_2}{R_L}$$

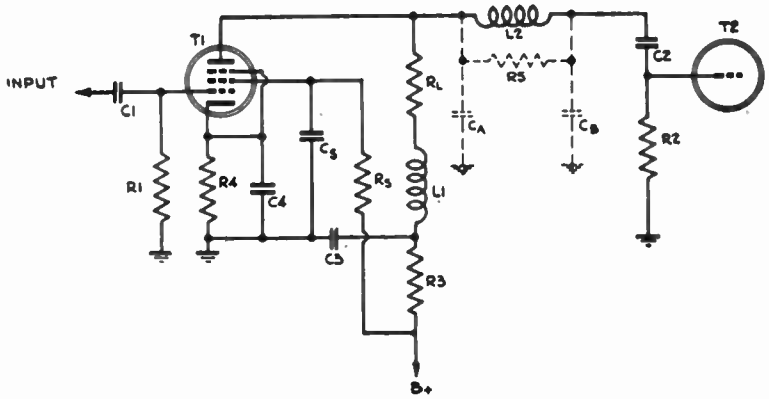
$R_3 > 20\ Xc_3$ at F_1

To compensate for R_4—C_4

$R_4 C_4 = R_3 C_3$ 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.



$\text{Gain} = G_m R_L$

$C_T = C_A + C_B$

$C_B = 2\ C_A$

F_C = highest frequency of correction

F_1 = lowest frequency of correction

$R_L = 1.5\ Xc_T$ at F_C

$L_1 = .67\ C_T R_L^2$

$$Xc_S < \frac{2}{G_m} \text{ at } F_1$$

$$R_S > \frac{3/F}{C_S} \text{ at } F_1$$

To compensate for R_1—C_1 or R_2—C_2

$$C_3 = \frac{C_2 R_2}{R_L}$$

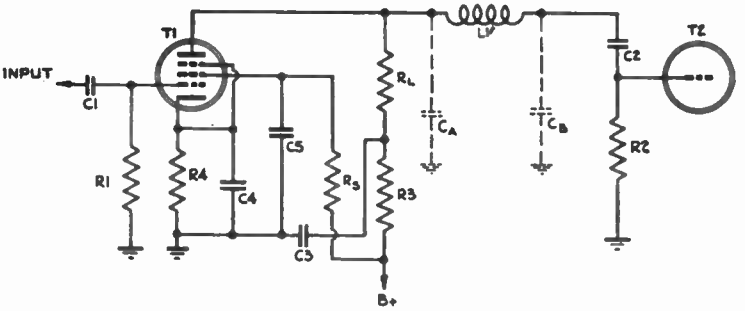
$R_3 > 20\ Xc_3$ at F_1

To compensate for R_4—C_4

$R_4 C_4 = R_3 C_3$ 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

$$R_L = 1.8\ X_{C_T} \text{ at } F_C$$

$$L_1 = .12\ C_T R_L^2$$

$$L_2 = .52\ C_T R_L^2$$

$$X_{C_3} = \frac{2}{G_m} \text{ at } F_1$$

$$R_S > \frac{3/F}{C_S} \text{ at } F_1$$

$$R_5 \cong 5\ R_L \text{ by experiment}$$

To compensate for R_1—C_1 or R_2—C_2

$$C_3 = \frac{C_2 R_2}{R_L}$$

$$R_3 > 20\ X_{C_3} \text{ at } F_1$$

To compensate for R_4—C_4

$$R_4 C_4 = R_3 C_3 \text{ and } \frac{R_3}{R_4} = \frac{C_4}{C_3} = G_m R_L$$

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.

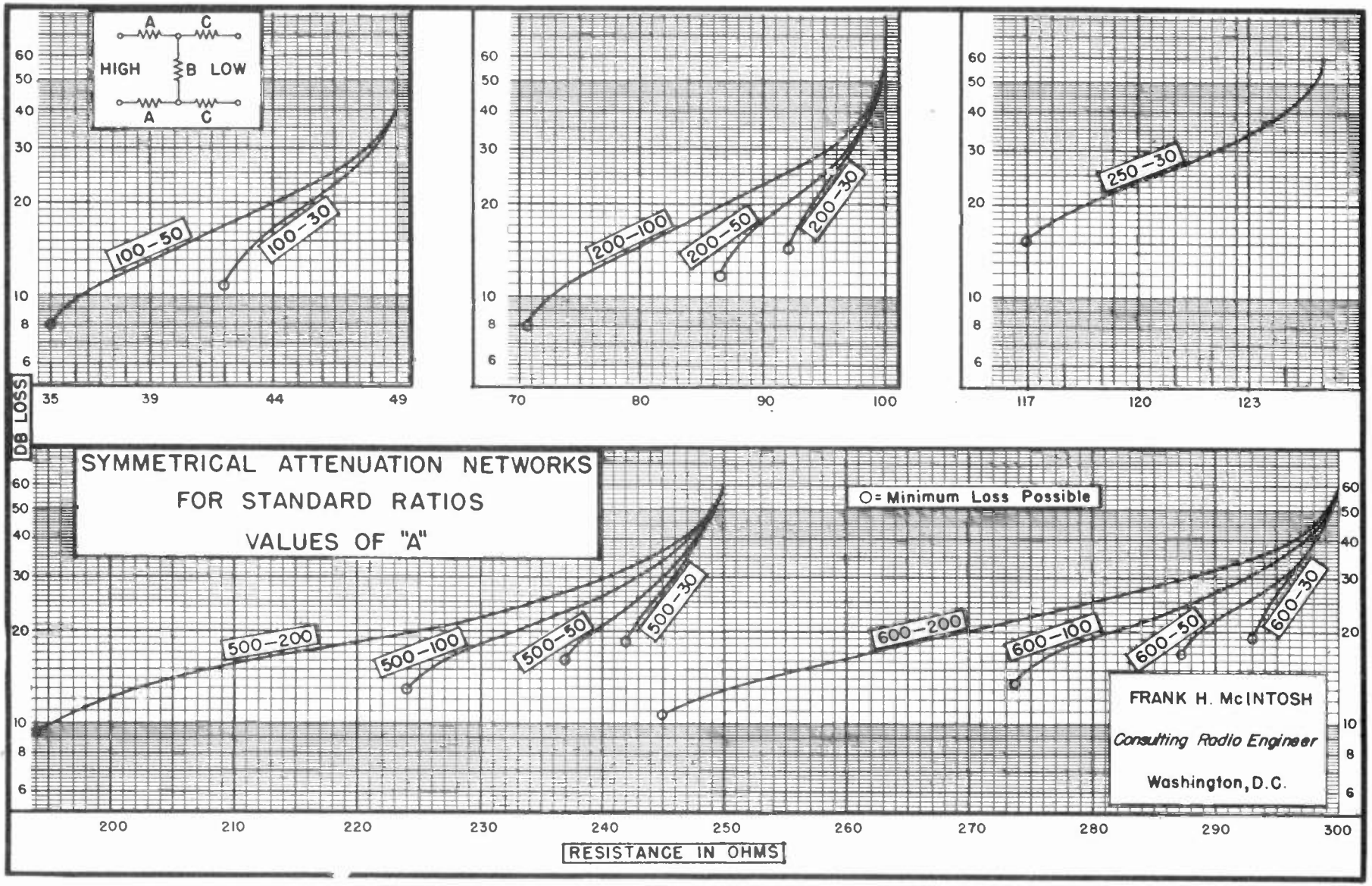

A
C
HIGH
B
LOW
A
C
100-50
100-30
200-100
200-50
200-30
250-30
500-200
500-100
500-50
500-30
600-200
600-100
600-50
600-30
DB LOSS
60
50
40
30
20
10
8
6
35
39
44
49
70
80
90
100
117
120
123
200
210
220
230
240
250
260
270
280
290
300
SYMMETRICAL ATTENUATION NETWORKS
FOR STANDARD RATIOS
VALUES OF "A"
○= Minimum Loss Possible
FRANK H. McINTOSH
Consulting Radio Engineer
Washington, D.C.
RESISTANCE IN OHMS

Fig 1.

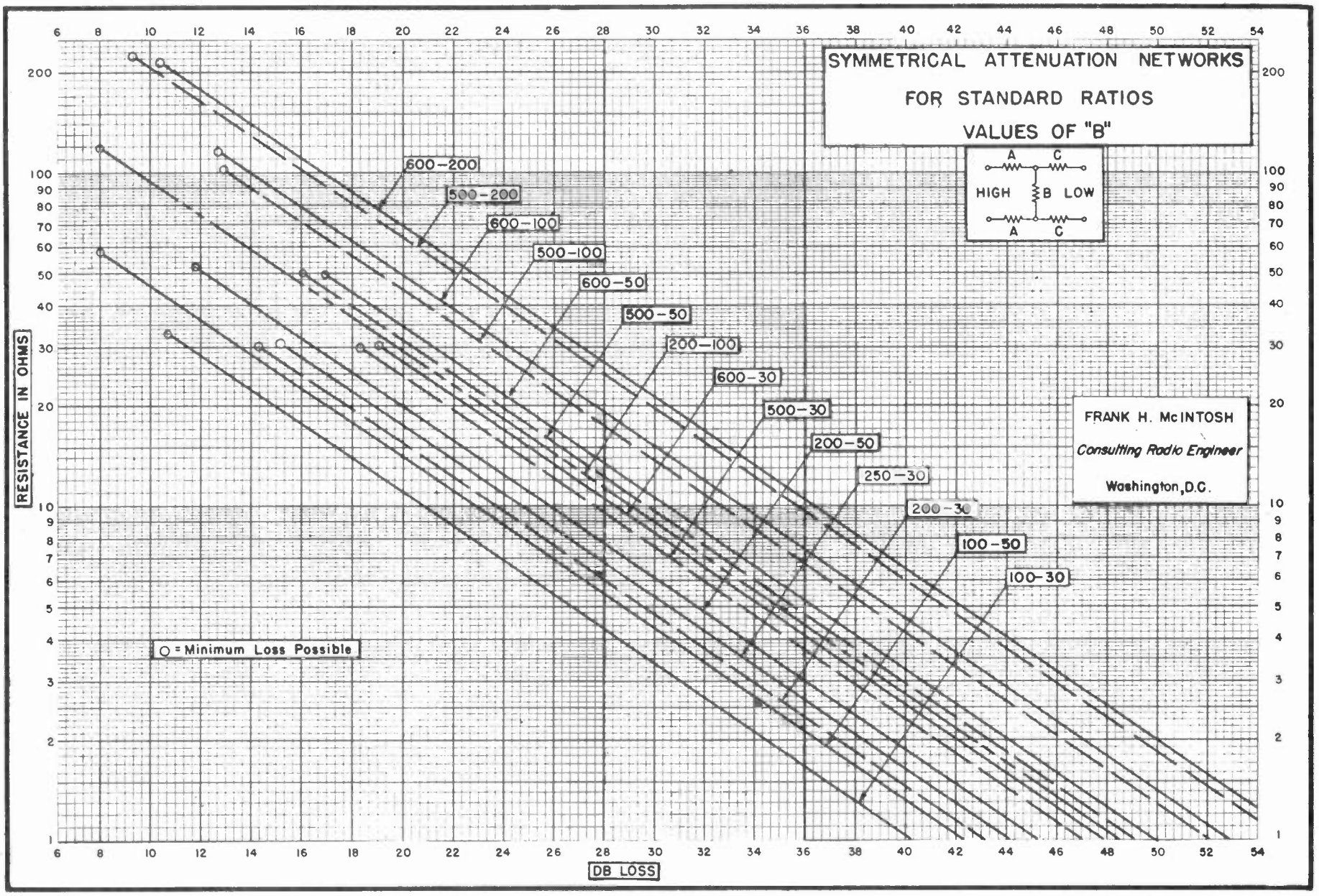

SYMMETRICAL ATTENUATION NETWORKS
FOR STANDARD RATIOS
VALUES OF "B"
A C
HIGH B LOW
A C
600-200
500-200
600-100
500-100
600-50
500-50
200-100
600-30
500-30
200-50
250-30
200-30
100-50
100-30
FRANK H. McINTOSH
Consulting Radio Engineer
Washington, D.C.
○ = Minimum Loss Possible
RESISTANCE IN OHMS
DB LOSS
6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54
200 100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1

FIG 2

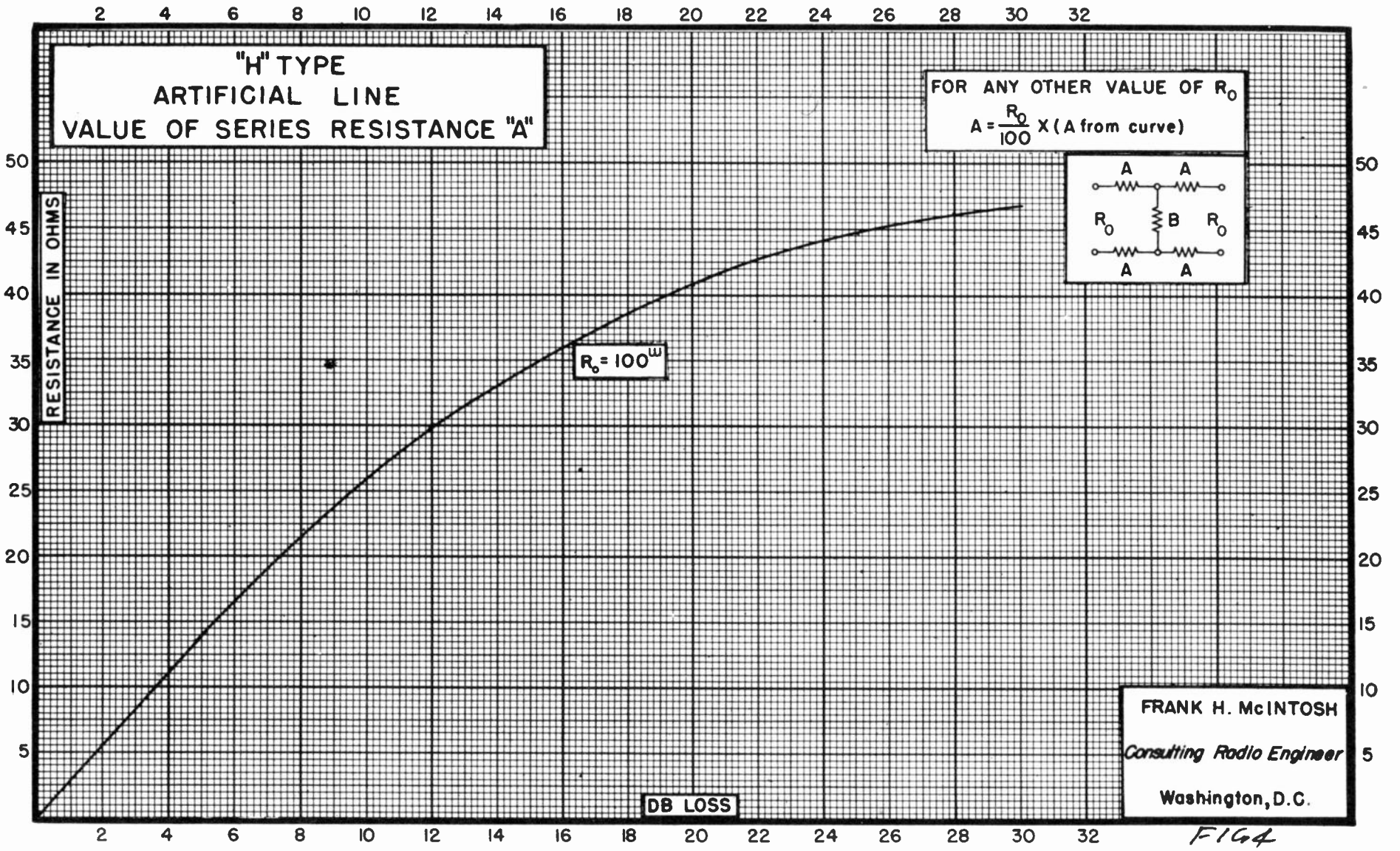

"H" TYPE
ARTIFICIAL LINE
VALUE OF SERIES RESISTANCE "A"
FOR ANY OTHER VALUE OF R_0
$A = \frac{R_0}{100} \times (A \text{ from curve})$
A A
R_0 B R_0
A A
RESISTANCE IN OHMS
$R_0 = 100^{\omega}$
DB LOSS
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
5 10 15 20 25 30 35 40 45 50
FRANK H. McINTOSH
Consulting Radio Engineer
Washington, D.C.

FIG 4

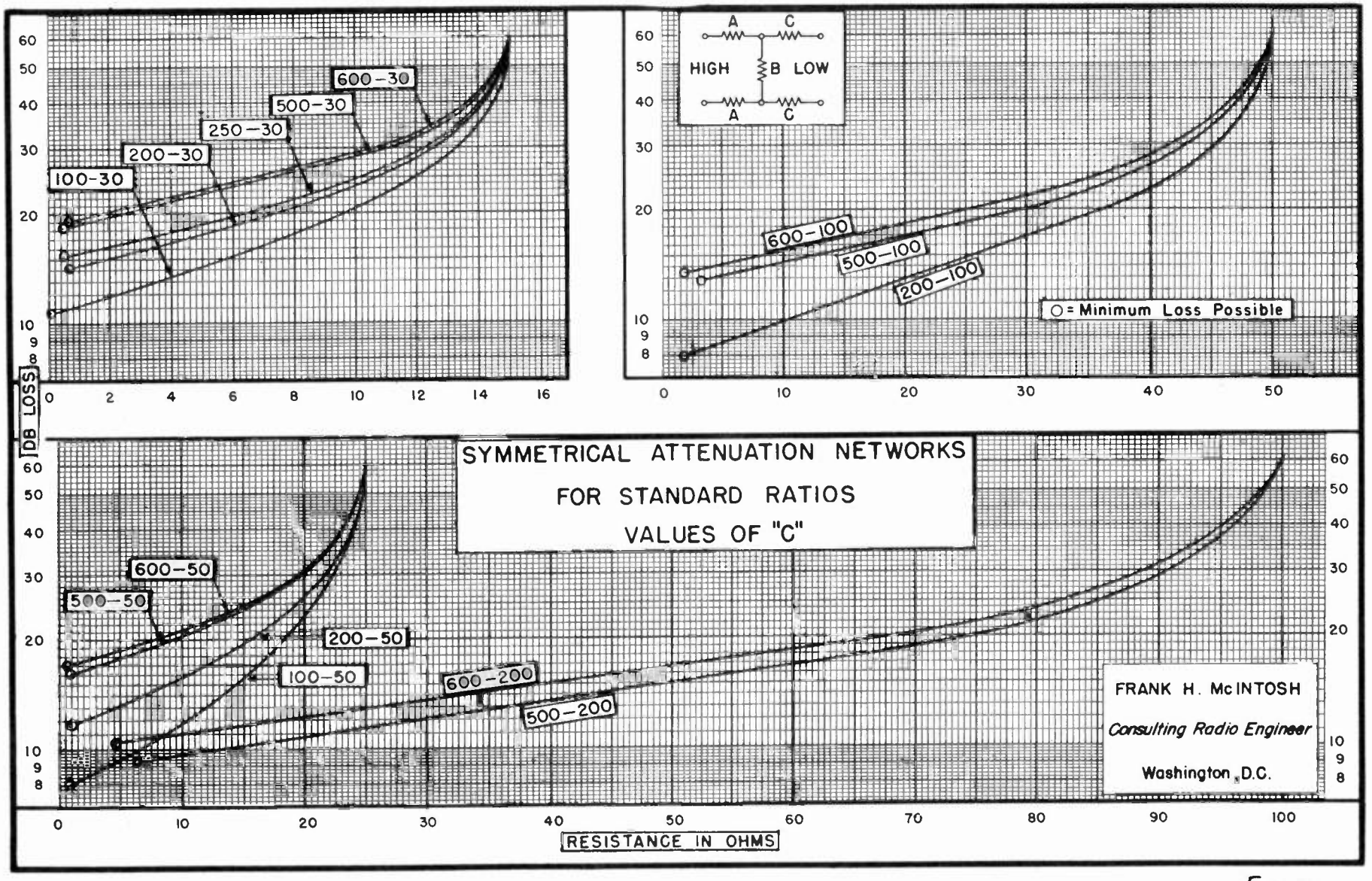

SYMMETRICAL ATTENUATION NETWORKS
FOR STANDARD RATIOS
VALUES OF "C"
DB LOSS
RESISTANCE IN OHMS
600-30
500-30
250-30
200-30
100-30
600-100
500-100
200-100
600-50
500-50
200-50
100-50
600-200
500-200
HIGH
LOW
A
B
C
○ = Minimum Loss Possible
FRANK H. McINTOSH
Consulting Radio Engineer
Washington, D.C.

Fig 3

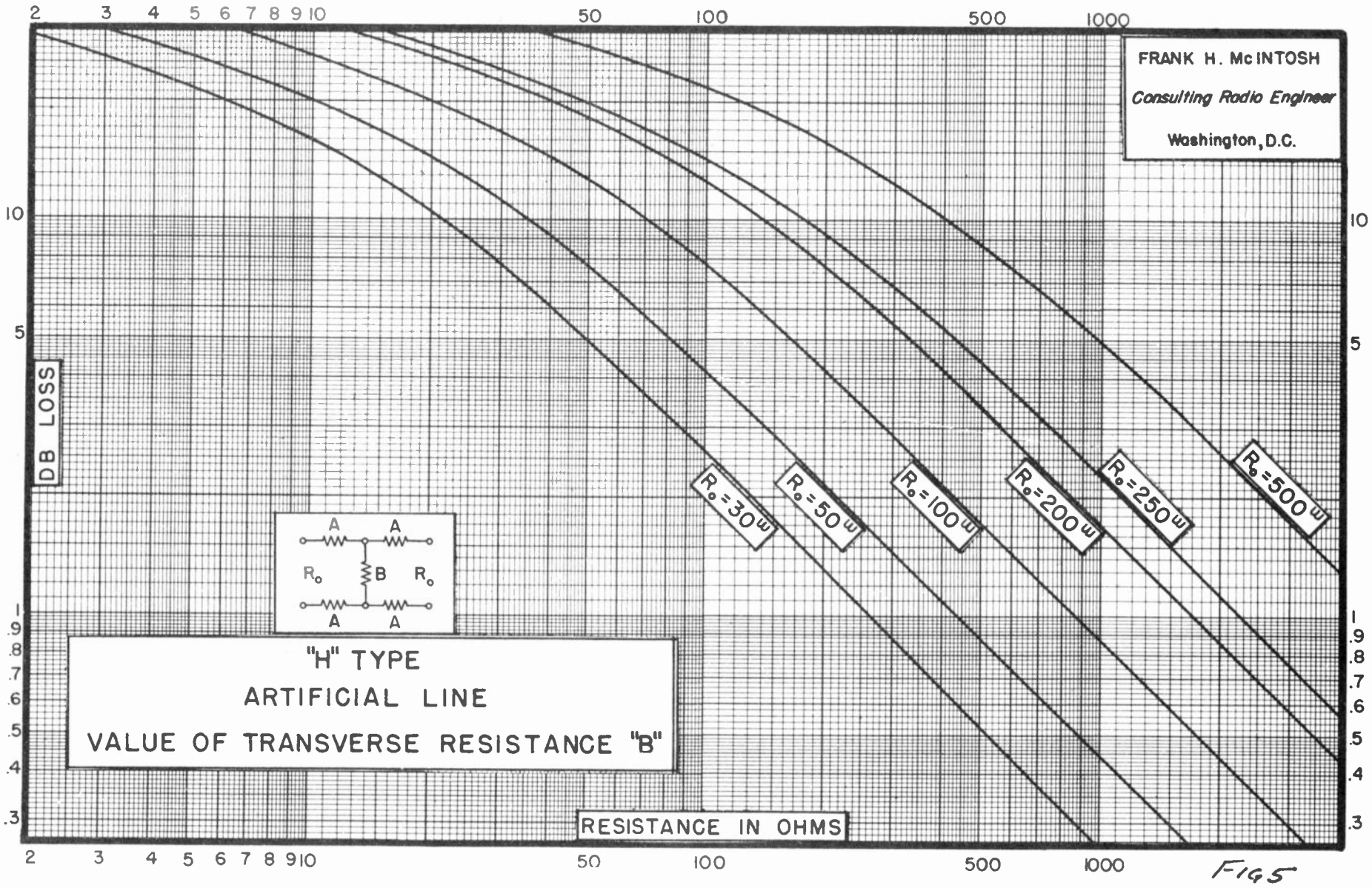
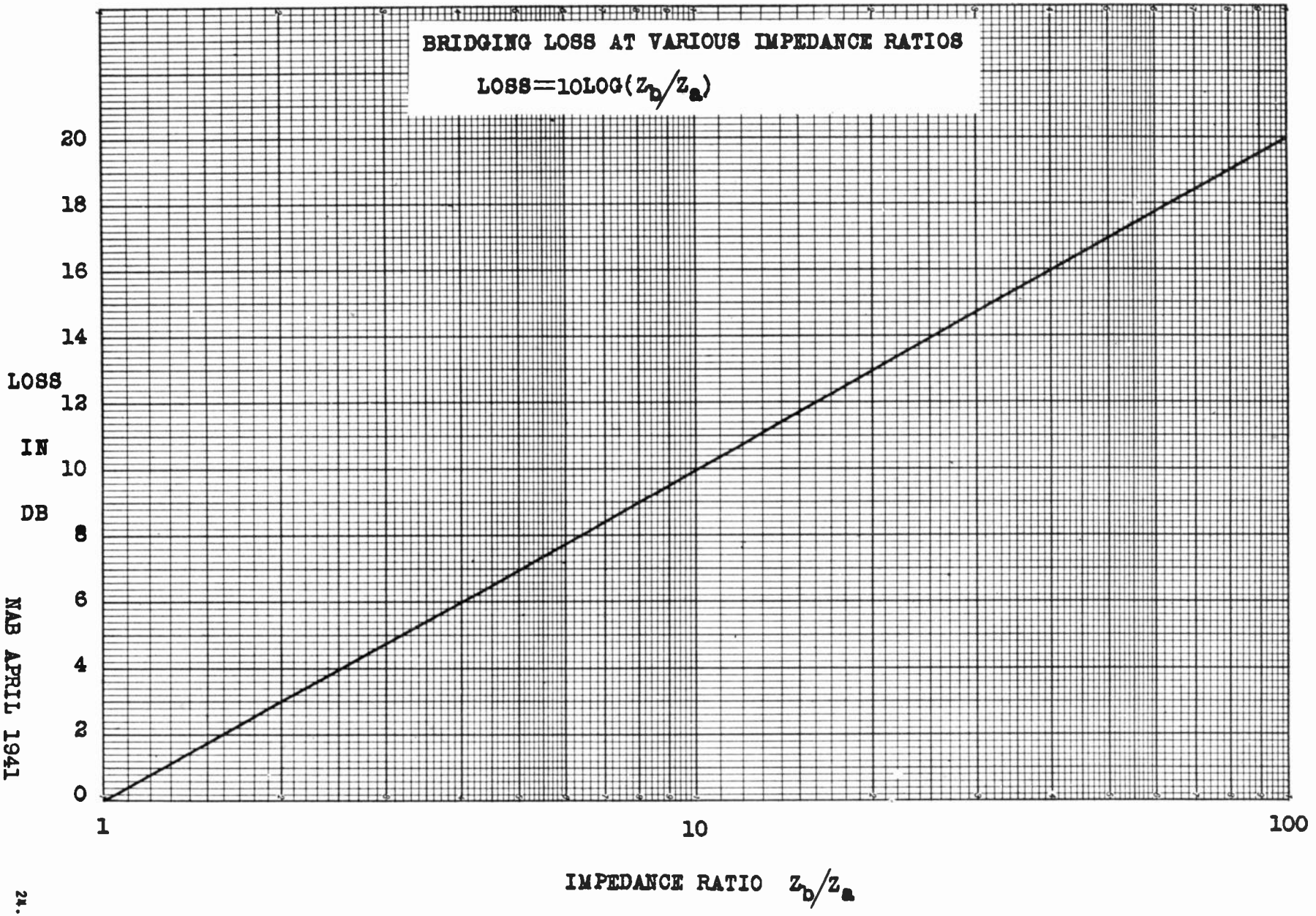

FRANK H. McINTOSH
Consulting Radio Engineer
Washington, D.C.
DB LOSS
RESISTANCE IN OHMS
2 3 4 5 6 7 8 9 10 50 100 500 1000
10 5 1 .9 .8 .7 .6 .5 .4 .3
R_o=30ω
R_o=50ω
R_o=100ω
R_o=200ω
R_o=250ω
R_o=500ω
A A
R_o B R_o
A A
"H" TYPE
ARTIFICIAL LINE
VALUE OF TRANSVERSE RESISTANCE "B"

FIG 5



BRIDGING LOSS

NAB APRIL 1941

24.1

DECIBELS

Power Ratio	Voltage or Current Ratio	—db+	Voltage or Current Ratio	Power Ratio	Power Ratio	Voltage or Current Ratio	—db+	Voltage or Current Ratio	Power Ratio	Power Ratio	Voltage or Current Ratio	—db+	Voltage or Current Ratio	Power Ratio
10^{-1}		10		10	.251	.501	6.0	2.00	3.98	.0501	.224	13.0	4.47	19.95
10^{-2}	10^{-1}	20	10	10^{2}	.246	.496	6.1	2.02	4.07	.0490	.221	13.1	4.52	20.42
10^{-3}		30		10^{3}	.240	.490	6.2	2.04	4.17	.0479	.219	13.2	4.57	20.89
10^{-4}	10^{-2}	40	10^{2}	10^{4}	.234	.484	6.3	2.07	4.27	.0468	.216	13.3	4.62	21.38
10^{-5}		50		10^{5}	.229	.479	6.4	2.09	4.37	.0457	.214	13.4	4.68	21.88
10^{-6}	10^{-3}	60	10^{3}	10^{6}	.224	.473	6.5	2.11	4.47	.0447	.211	13.5	4.73	22.39
10^{-7}		70		10^{7}	.219	.468	6.6	2.14	4.57	.0437	.209	13.6	4.79	22.91
10^{-8}	10^{-4}	80	10^{4}	10^{8}	.214	.462	6.7	2.16	4.68	.0427	.207	13.7	4.84	23.44
10^{-9}		90		10^{9}	.209	.457	6.8	2.19	4.79	.0417	.204	13.8	4.90	23.99
10^{-10}	10^{-5}	100	10^{5}	10^{10}	.204	.452	6.9	2.21	4.90	.0407	.202	13.9	4.96	24.55
1.000	1.000	0	1.00	1.00	.200	.447	7.0	2.24	5.01	.0398	.200	14.0	5.01	25.12
.977	.989	.1	1.01	1.02	.195	.442	7.1	2.27	5.13	.0389	.197	14.1	5.07	25.70
.955	.977	.2	1.02	1.05	.191	.437	7.2	2.29	5.25	.0380	.195	14.2	5.13	26.30
.933	.966	.3	1.04	1.07	.186	.432	7.3	2.32	5.37	.0372	.193	14.3	5.19	26.92
.912	.955	.4	1.05	1.10	.182	.427	7.4	2.34	5.50	.0363	.191	14.4	5.25	27.54
.891	.944	.5	1.06	1.12	.178	.422	7.5	2.37	5.62	.0355	.188	14.5	5.31	28.18
.871	.933	.6	1.07	1.15	.174	.417	7.6	2.40	5.75	.0347	.186	14.6	5.37	28.84
.851	.923	.7	1.08	1.18	.170	.412	7.7	2.43	5.80	.0339	.184	14.7	5.43	29.51
.832	.912	.8	1.10	1.20	.166	.407	7.8	2.46	6.03	.0331	.182	14.8	5.50	30.20
.813	.902	.9	1.11	1.23	.162	.403	7.9	2.48	6.17	.0324	.180	14.9	5.56	30.90
.794	.891	1.0	1.12	1.26	.159	.398	8.0	2.51	6.31	.0316	.178	15.0	5.62	31.62
.776	.881	1.1	1.14	1.29	.155	.394	8.1	2.54	6.46	.0309	.176	15.1	5.69	32.36
.759	.871	1.2	1.15	1.32	.151	.389	8.2	2.57	6.61	.0302	.174	15.2	5.75	33.11
.741	.861	1.3	1.16	1.35	.148	.385	8.3	2.60	6.76	.0295	.172	15.3	5.82	33.88
.724	.851	1.4	1.18	1.38	.145	.390	8.4	2.63	6.92	.0288	.170	15.4	5.89	34.67
.708	.841	1.5	1.19	1.41	.141	.376	8.5	2.66	7.08	.0282	.168	15.5	5.96	35.48
.692	.832	1.6	1.20	1.45	.138	.372	8.6	2.69	7.24	.0275	.166	15.6	6.03	36.31
.676	.822	1.7	1.22	1.48	.135	.367	8.7	2.72	7.41	.0269	.164	15.7	6.10	37.15
.661	.813	1.8	1.23	1.51	.132	.363	8.8	2.75	7.59	.0263	.162	15.8	6.17	38.02
.646	.804	1.9	1.25	1.55	.129	.359	8.9	2.79	7.76	.0257	.160	15.9	6.24	38.90
.631	.794	2.0	1.26	1.59	.126	.355	9.0	2.82	7.94	.0251	.159	16.0	6.31	39.81
.617	.785	2.1	1.27	1.62	.123	.351	9.1	2.85	8.13	.0246	.157	16.1	6.38	40.74
.603	.776	2.2	1.29	1.66	.120	.347	9.2	2.88	8.32	.0240	.155	16.2	6.46	41.69
.589	.767	2.3	1.30	1.70	.118	.343	9.3	2.92	8.51	.0234	.153	16.3	6.53	42.66
.575	.759	2.4	1.32	1.74	.115	.339	9.4	2.95	8.71	.0229	.151	16.4	6.61	43.65
.562	.750	2.5	1.33	1.78	.112	.335	9.5	2.99	8.91	.0224	.150	16.5	6.68	44.67
.550	.741	2.6	1.35	1.82	.110	.331	9.6	3.02	9.12	.0219	.148	16.6	6.76	45.71
.537	.733	2.7	1.37	1.86	.107	.327	9.7	3.06	9.33	.0214	.146	16.7	6.84	46.77
.525	.724	2.8	1.38	1.91	.105	.324	9.8	3.09	9.55	.0209	.145	16.8	6.92	47.86
.513	.716	2.9	1.40	1.95	.102	.320	9.9	3.13	9.77	.0204	.143	16.9	7.00	48.98
.501	.708	3.0	1.41	2.00	.1000	.316	10.0	3.16	10.00	.0200	.141	17.0	7.08	50.12
.490	.700	3.1	1.43	2.04	.0977	.313	10.1	3.20	10.23	.0195	.140	17.1	7.16	51.29
.479	.692	3.2	1.45	2.09	.0955	.309	10.2	3.24	10.47	.0191	.138	17.2	7.24	52.48
.468	.684	3.3	1.46	2.14	.0933	.306	10.3	3.27	10.72	.0186	.137	17.3	7.33	53.70
.457	.676	3.4	1.48	2.19	.0912	.302	10.4	3.31	10.96	.0182	.135	17.4	7.41	54.95
.447	.668	3.5	1.50	2.24	.0891	.299	10.5	3.35	11.22	.0178	.133	17.5	7.50	56.23
.437	.661	3.6	1.51	2.29	.0871	.295	10.6	3.39	11.48	.0174	.132	17.6	7.59	57.54
.427	.653	3.7	1.53	2.34	.0851	.292	10.7	3.43	11.75	.0170	.130	17.7	7.67	58.88
.417	.646	3.8	1.55	2.40	.0832	.288	10.8	3.47	12.02	.0166	.129	17.8	7.76	60.26
.407	.638	3.9	1.57	2.46	.0813	.285	10.9	3.51	12.30	.0162	.127	17.9	7.85	61.66
.398	.631	4.0	1.59	2.51	.0794	.282	11.0	3.55	12.59	.0159	.126	18.0	7.94	63.10
.389	.624	4.1	1.60	2.57	.0776	.279	11.1	3.59	12.88	.0155	.125	18.1	8.04	64.57
.380	.617	4.2	1.62	2.63	.0759	.275	11.2	3.63	13.18	.0151	.123	18.2	8.13	66.07
.372	.610	4.3	1.64	2.69	.0741	.272	11.3	3.67	13.49	.0148	.122	18.3	8.22	67.61
.363	.603	4.4	1.66	2.75	.0724	.269	11.4	3.72	13.80	.0145	.120	18.4	8.32	69.18
.355	.596	4.5	1.68	2.81	.0708	.266	11.5	3.76	14.13	.0141	.119	18.5	8.41	70.79
.347	.589	4.6	1.70	2.88	.0691	.263	11.6	3.80	14.45	.0138	.118	18.6	8.51	72.44
.339	.582	4.7	1.72	2.95	.0676	.260	11.7	3.85	14.79	.0135	.116	18.7	8.61	74.13
.331	.575	4.8	1.74	3.02	.0661	.257	11.8	3.89	15.14	.0132	.115	18.8	8.71	75.86
.324	.569	4.9	1.76	3.09	.0646	.254	11.9	3.94	15.49	.0129	.114	18.9	8.81	77.62
.316	.562	5.0	1.78	3.16	.0631	.251	12.0	3.98	15.85	.0126	.112	19.0	8.91	79.43
.309	.556	5.1	1.80	3.24	.0617	.248	12.1	4.03	16.22	.0123	.111	19.1	9.02	81.28
.302	.550	5.2	1.82	3.31	.0603	.246	12.2	4.07	16.60	.0120	.110	19.2	9.12	83.18
.295	.543	5.3	1.84	3.39	.0589	.243	12.3	4.12	16.98	.0118	.108	19.3	9.23	85.11
.288	.537	5.4	1.86	3.47	.0575	.240	12.4	4.17	17.38	.0115	.107	19.4	9.33	87.10
.282	.530	5.5	1.88	3.55	.0562	.237	12.5	4.22	17.78	.0112	.106	19.5	9.44	89.13
.275	.525	5.6	1.91	3.63	.0550	.234	12.6	4.27	18.20	.0110	.105	19.6	9.55	91.20
.269	.519	5.7	1.93	3.72	.0537	.232	12.7	4.32	18.62	.0107	.104	19.7	9.66	93.33
.263	.513	5.8	1.95	3.80	.0525	.229	12.8	4.37	19.05	.0105	.102	19.8	9.77	95.50
.257	.507	5.9	1.97	3.89	.0513	.227	12.9	4.42	19.50	.0102	.101	19.9	9.89	97.72
										.0100	.100	20.0	10.00	100.00

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Every broadcast station should maintain a carefully selected technical library available for use by its Engineering Department personnel. The following works have been carefully selected and are recommended for consideration:

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2. *Electronic Engineering Master Index, By Frank A. Petraglia.* Is a definitive guide to the radio-electronic engineering literature published during the past two decades. No major reference of this type has ever been available to provide radio engineers with a means for gaining ready access to desired technical information. As a result, bibliographical research has until now been a time-consuming task, since too many separate sources had to be consulted. To overcome this difficulty, this "master" compilation brings together all sources, in one convenient volume. The compilation contains approximately 15,000 entries, the majority of which are the titles of all engineering articles that have appeared in the leading professional periodicals. 318 pages, 1945. Electronics Research Publishing Company, $17.50.

3. *Electrical Communication, By Arthur L. Albert.* General treatment of the whole field of electrical communications, both wire (telegraphy and telephony) and wireless (radio). 534 pages, 397 illustrations, 2nd Edition, 1940. Wiley, $5.00.

4. *Electrical Engineers Handbook: Communications and Electronics, By Pender and McIlwain.* Engineering reference book covering all phases of communication and electronics. 1022 pages, 981 illustrations, 1936. Wiley, $5.00.

5. *Reference Data For Radio Engineers, By Federal Telecommunication Laboratories and International Telephone and Telegraph Corporation.* The second edition of this widely accepted pocket-size handbook, revised and enlarged, now includes important radio technical data developed during the war. 400 charts and diagrams makes available quickly the answers to problems that normally arise in practical radio work. 336 pages, 400 charts. Second edition, 1946. Federal Telephone and Radio Corporation, $2.00.

6. *Frequency Modulation, By John F. Rider.* Practical exposition of the subject from the serviceman's standpoint, but including worthwhile theoretical background. 136 pages, illustrated, 1940. Rider, $1.00.

7. *Fundamentals of Radio, By F.E. Terman.* An elementary version of the author's "Radio Engineering" with simplified treatment intended for readers of limited mathematical ability. 458 pages, 278 illustrations, 1938. McGraw-Hill, $3.75.

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