Regional Administrative LF/MF Broadcasting Conference

REPORT OF THE FIRST SESSION (C.C.I.R. TEXTS)

(Geneva, 1974)

General Secretariat
of the
International Telecommunication
Union
Geneva

Foreword by the Director, C.C.I.R.

At the First Session of the LF/MF Broadcasting Conference, Geneva, 1974, the C.C.I.R., in Document No. 10 and its Annex, submitted for the information of delegates a comprehensive series of texts that were felt to be of direct application to the problems of the Conference.

When the Report by the First Session of the Conference was prepared, it was decided to annex a certain number of these texts to the Report as supporting technical information on which the planning work of the Second Session could be based.

This series of texts, which is contained in the present Annex, is shorter than the original series for the following reasons :

- certain of the texts, which were considered to be purely informative in nature or to be of secondary importance, have been omitted;

- other texts, the material of which has been embodied in the main body of the Report have been omitted to avoid duplication.

On the other hand, the opportunity is taken to draw the attention of the delegates to the Second Session of the Conference to the following texts of the C.C.I.R. which, while omitted from the original collection on account of their bulk, nevertheless contain material of direct and important application to the work of the Second Session. These texts are :

- Report 322 : World distribution and characteristics of atmospheric radio noise.

- Report 340 + Supplement No. 1 : C.C.I.R. atlas of ionospheric characteristics.

- Reports 413, 414 and 415 : Improved efficiency in the use of the radio-frequency spectrum.

All these texts are published separately from the normal Volumes of the C.C.I.R. and may be purchased from the I.T.U. Publications Division.

Finally, reference is made to Report 258-2 : "Measurement of man-made radio noise" which, while not included in the original series of texts, is nevertheless felt to contain matters of interest to the Second Session of the Conference. A copy of this text is therefore included in the present series.

Regional Administrative LF/MF Broadcasting Conference

REPORT OF THE FIRST SESSION (C.C.I.R. TEXTS)

(Geneva, 1974)

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

TABLE OF CONTENTS

Page

RECOMMENDATIONS

RECOMMENDATION 368-2

GROUND-WAVE PROPAGATION CURVES FOR FREQUENCIES BETWEEN 10 kHz AND 10 MHz

(Question 3-1/5)

(1951-1959-1963-1970-1974)

The C.C.I.R.,

CONSIDERING

(a) that ground-wave propagation curves for an extended range of frequencies are of continued importance for all types of radiocommunication, including navigational aids;

(b) that such curves are needed for a range of conductivities if they are to apply to the varying conditions met with in practice along land paths;

UNANIMOUSLY RECOMMENDS

that the curves in the Annex be used for the determination of ground-wave field strength at frequencies below 10 MHz under the conditions stated.

ANNEX

The attached curves apply to propagation at frequencies below 10 MHz.

The following points are to be especially noted with regard to them :

1. they refer to a smooth homogeneous earth;

2. no account is taken of tropospheric effects at these frequencies;

3. the transmitter and receiver are both assumed to be on the ground. Height-gain effects can be of considerable importance in connection with navigational aids for high-flying aircraft, but it has been decided not to include them at the present time;

4. the curves refer to the following conditions :

   - they are calculated for the vertical component of electric field from the rigorous analysis of van der Pol and Bremmer;

   - the transmitter is an ideal Hertzian vertical electric dipole to which a vertical antenna shorter than one quarter wavelength is nearly equivalent;

   - the dipole moment is chosen so that the dipole would radiate 1 kW if the Earth were a perfectly conducting infinite plane under which conditions the radiation field at a distance of 1 km would be $3 \times 10^5 \mu V/m$;

   - the curves are drawn for distances measured around the curved surface of the Earth;

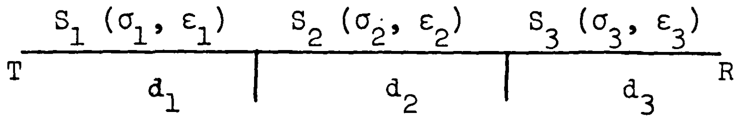
   - the inverse-distance curve A shown in the figures, to which the curves are asymptotic at short distances, passes through the field value of $3 \times 10^5 \mu V/m$ at a distance of 1 km;

5. the propagation loss defined in Recommendation 341 for ground-waves may be determined from the values of the field-strength in dB relative to $1 \mu V/m$ given in the attached curves by the use of equation (19) of Report 112;

6. the curves should, in general, be used to determine field strength, only when it is known that ionospheric reflections at the frequency under consideration will be negligible in amplitude - for example, propagation in daylight between 150 kHz and 2 MHz and for distances of less than about 2000 km. However, under conditions where the sky-wave is comparable with, or even greater than the ground-wave, the curves are still applicable when the effect of the ground-wave can be separated from that of the sky-wave, by the use of pulse transmissions, as in some forms of direction-finding systems and navigational aids;

7. the curves may be used for the determination of propagation over mixed paths (non-homogeneous smooth earth) as follows :

Such paths may be made up of sections S_1, S_2, S_3, etc. of lengths d_1, d_2, d_3, etc. having conductivity and dielectric constant σ_1, ε_1; σ_2, ε_2; σ_3, ε_3 etc. as shown below for three sections :



There are various semi-empirical methods of determining the propagation over such paths, of which that due to Millington [Millington, 1949] is the most accurate and has been made to satisfy the reciprocity condition. The method assumes that the curves are available for the different types of terrain in the sections S_1, S_2, S_3 etc. assumed to be individually homogeneous, all drawn for the same source T defined, for instance, by a given inverse-distance curve. The values may then finally be scaled up for any other source.

For a given frequency, the curve appropriate to the section S_1, is then chosen and the field $E_1(d_1)$ in dB(1μV/m) at the distance d_1 is then noted. The curve for the section S_2 is then used to find the fields $E_2(d_1)$ and $E_2(d_1 + d_2)$ and, similarly, with the curve for the section S_3, the fields $E_3(d_1 + d_2)$ and $E_3(d_1 + d_2 + d_3)$ are found, and so on.

A received field strength E_R is then defined by

$$E_R = E_1(d_1) - E_2(d_1) + E_2(d_1 + d_2) - E_3(d_1 + d_2) + E_3(d_1 + d_2 + d_3)$$

The procedure is then reversed, and calling R the transmitter and T the receiver, a field E_T is obtained, given by

$$E_T = E_3(d_3) - E_2(d_3) + E_2(d_3 + d_2) - E_1(d_3 + d_2) + E_1(d_3 + d_2 + d_1)$$

The required field is given by $\frac{1}{2} [E_R + E_T]$, the extension to more sections being obvious.

The method can in principle be extended to phase changes if the corresponding curves for phase as a function of distance over a homogeneous earth are available. Such information would be necessary for application to navigational systems.

8. this Recommendation should continue in use until such time as any revision can be made in accordance with the suggestions made in Report 428-1.

REFERENCES

FURUTSU, K. /¯1955_7, Propagation of electro-magnetic waves over a flat earth across a boundary separating different media and coastal refraction. J. Radio Res. Lab. (Tokyo), 2, 1.

GROSSKOPF, J. /¯1950_7, Zur Ausbreitung von Mittelwellen über inhomogenes Gelände. (On the propagation of medium waves over an inhomogeneous terrain). Fernmeldetechn. (FTZ), 3, 118.

MILLINGTON, G. /¯1949_7, Ground-wave propagation over an inhomogeneous smooth earth. Proc. IEE Part III, 96, 53.

MILLINGTON, G., and ISTED, G.A. /¯1950_7, Ground-wave propagation over an inhomogeneous smooth earth Par. 2. Experimental Evidence and Practical Implications. Proc. IEE, 97, 209.

SENIOR, T.B.A. /¯1957_7, Radio propagation over a discontinuity in the earth's electrical properties : I et II Coastal refraction. Proc. IEE, Part C, 104, 43, 139.

WAIT, J.R. /¯1961_7, On the theory of mixed-path ground-wave propagation on a spherical earth. NBS Journal of Research, 65D, 401.

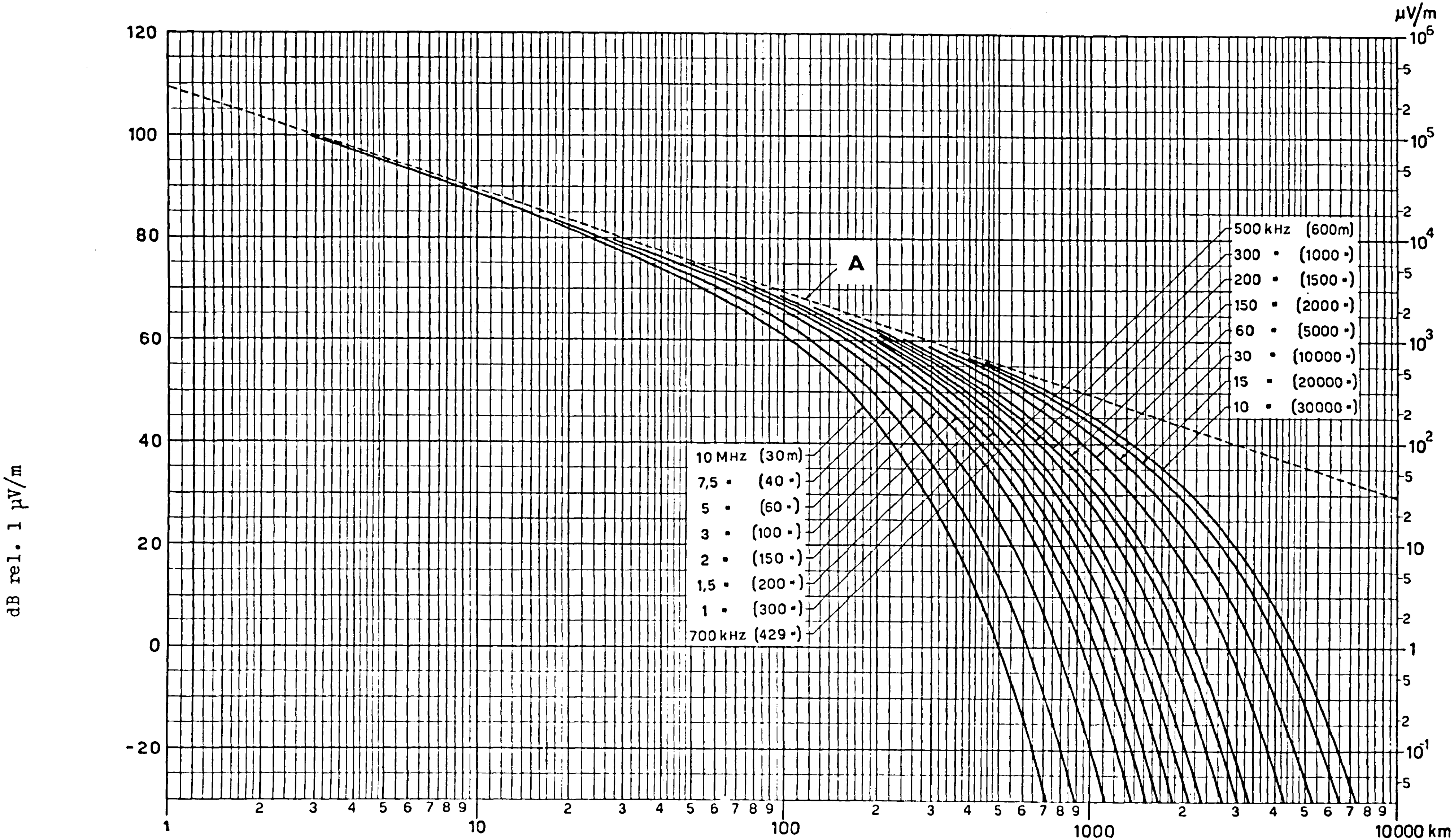


FIGURE 1

Ground-wave propagation curves; Sea, $\sigma = 4$ S/m, $\epsilon = 80$

A: Inverse distance curve

dB rel. 1 μV/m

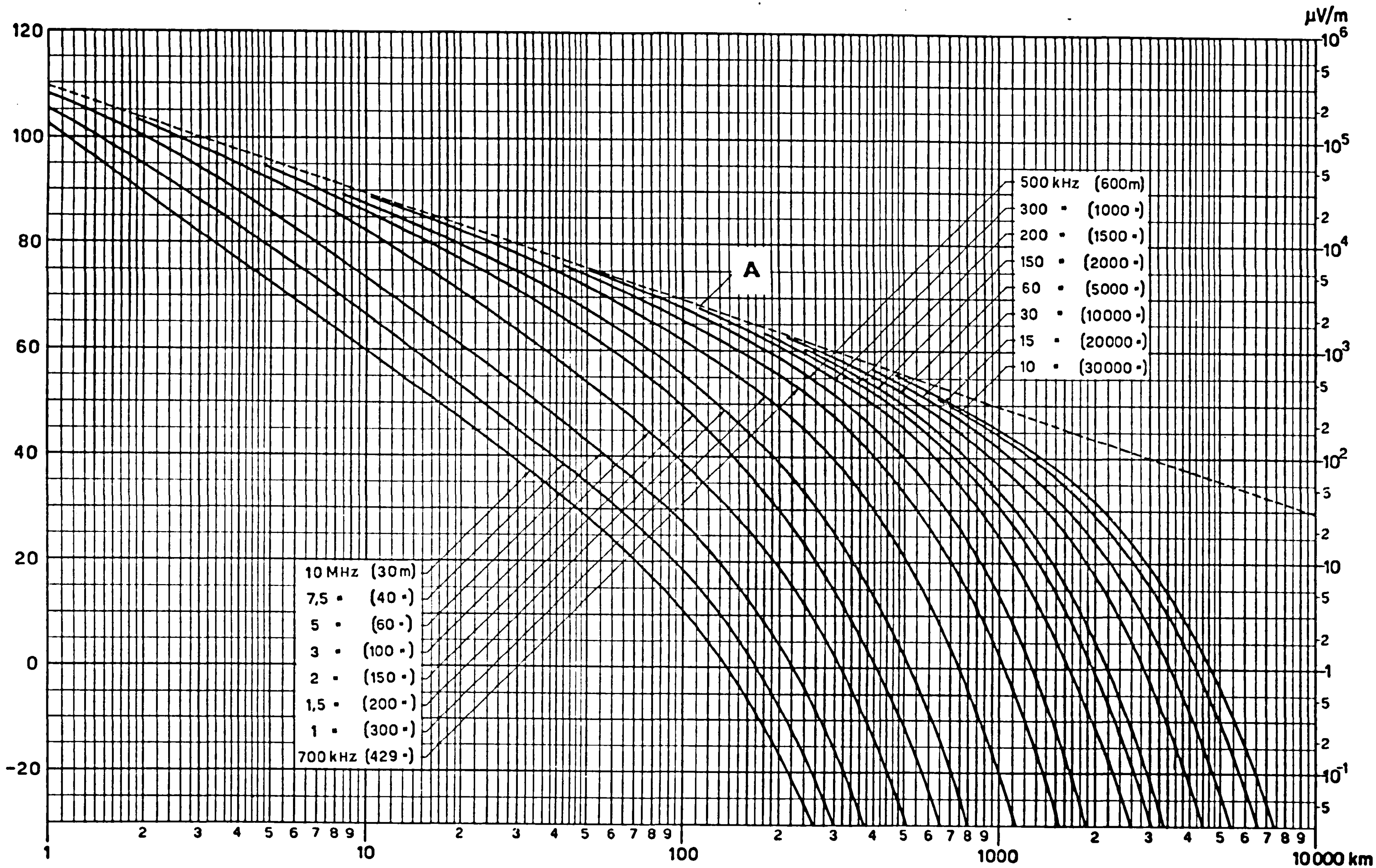


FIGURE 2

Ground-wave propagation curves ; Earth, $\sigma = 3 \times 10^{-3}$ S/m, $\varepsilon = 4$

A: Inverse distance curve

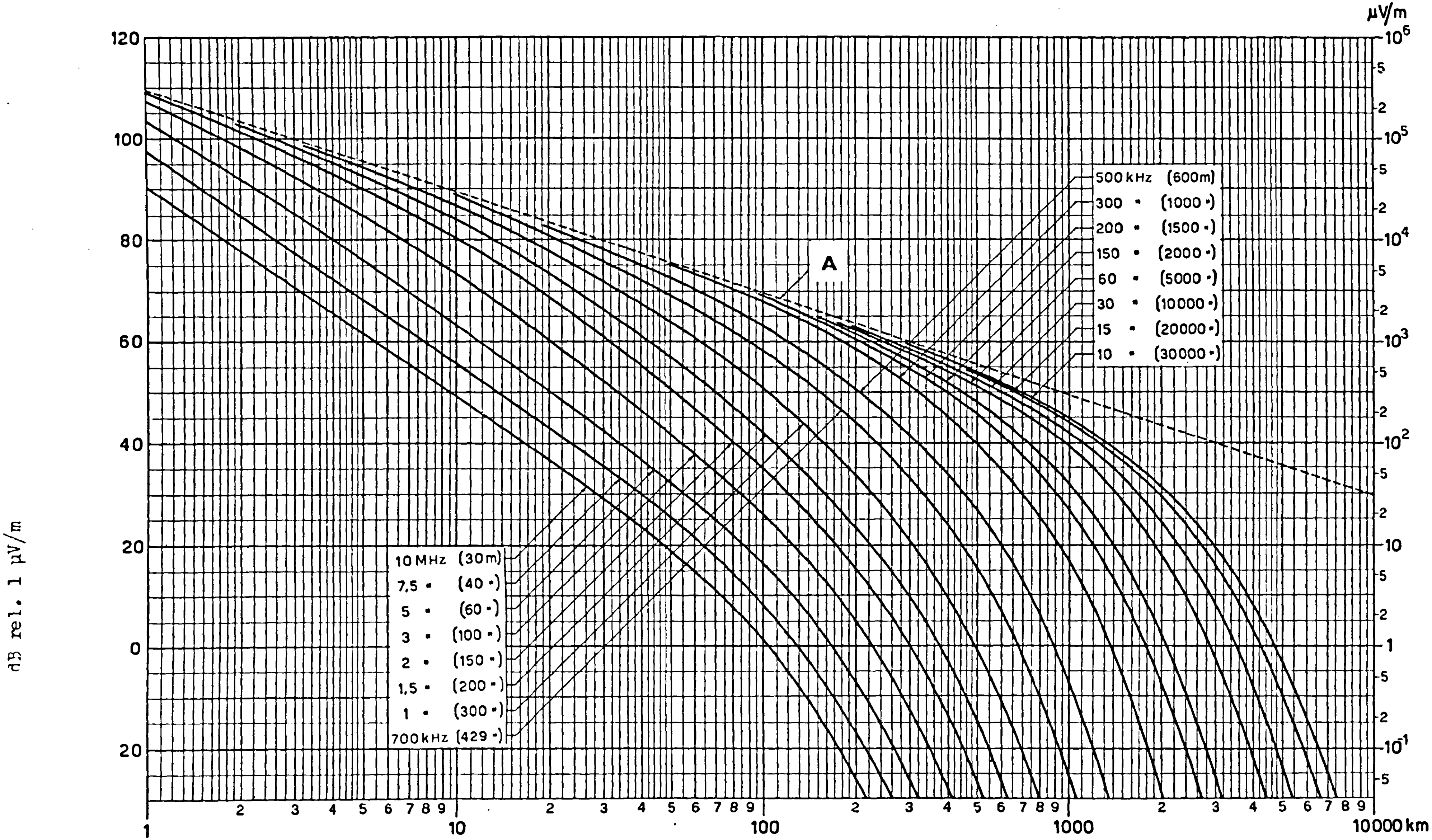


FIGURE 3

Ground-wave propagation curves; Earth, $\sigma = 10^{-2}$ S/m, $\varepsilon = 4$

A: Inverse distance curve

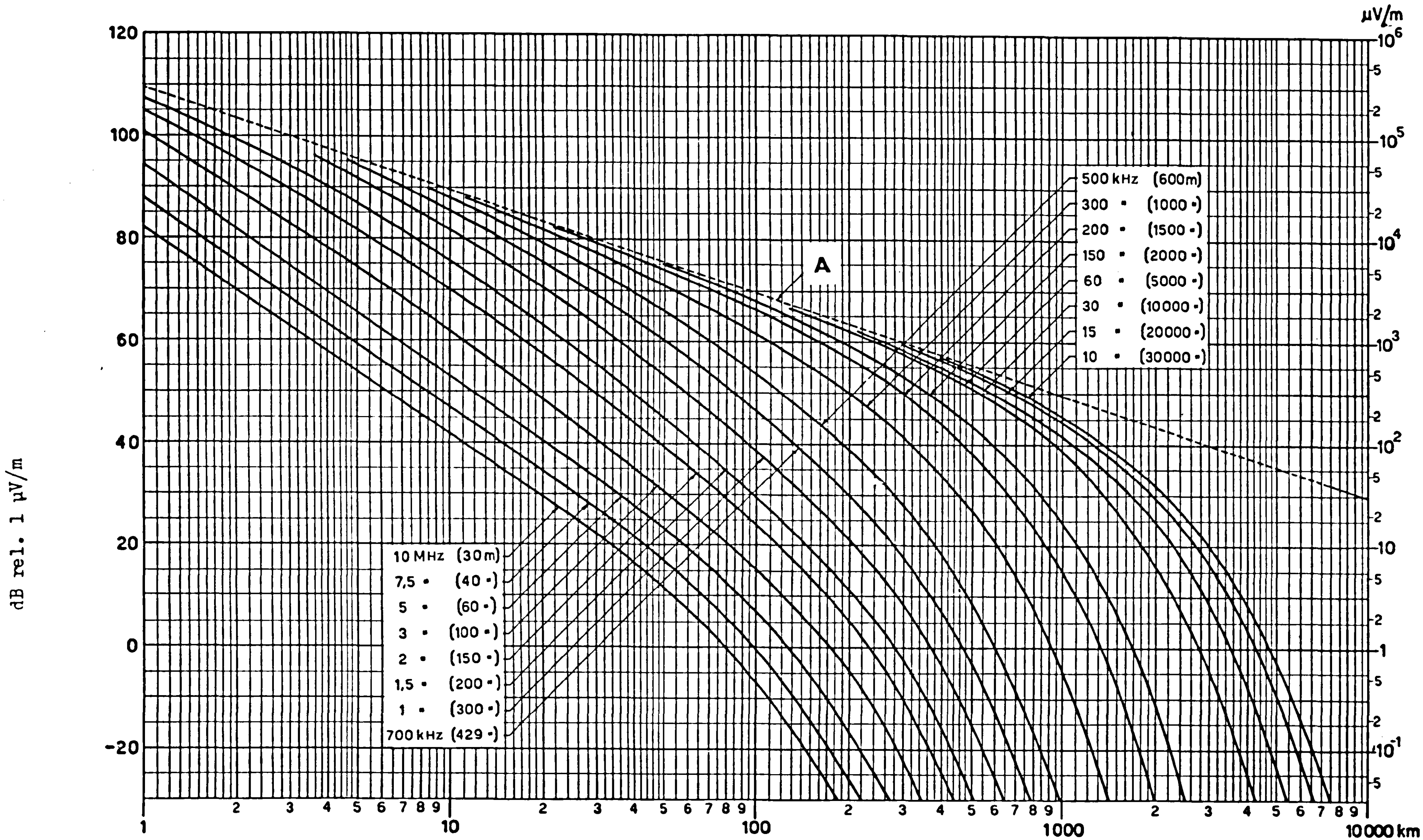


FIGURE 4

Ground-wave propagation curves; Earth, $\sigma = 3 \times 10^{-3}$ S/m, $\varepsilon = 4$

A: Inverse distance curve

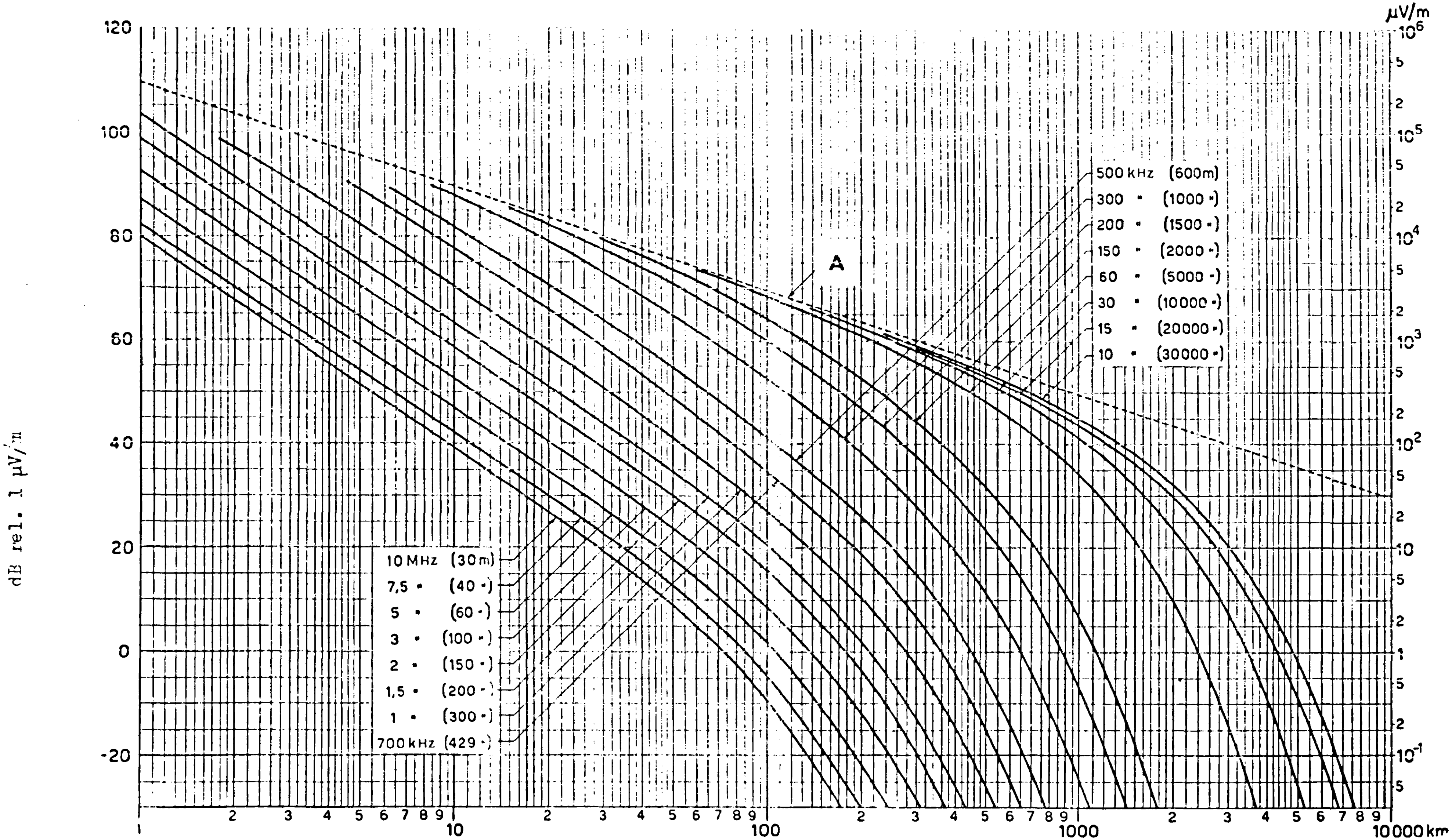


FIGURE 5

Ground-wave propagation curves; Earth, $\sigma = 10^{-3}$ S/m, $\varepsilon = 4$

A: Inverse distance curve

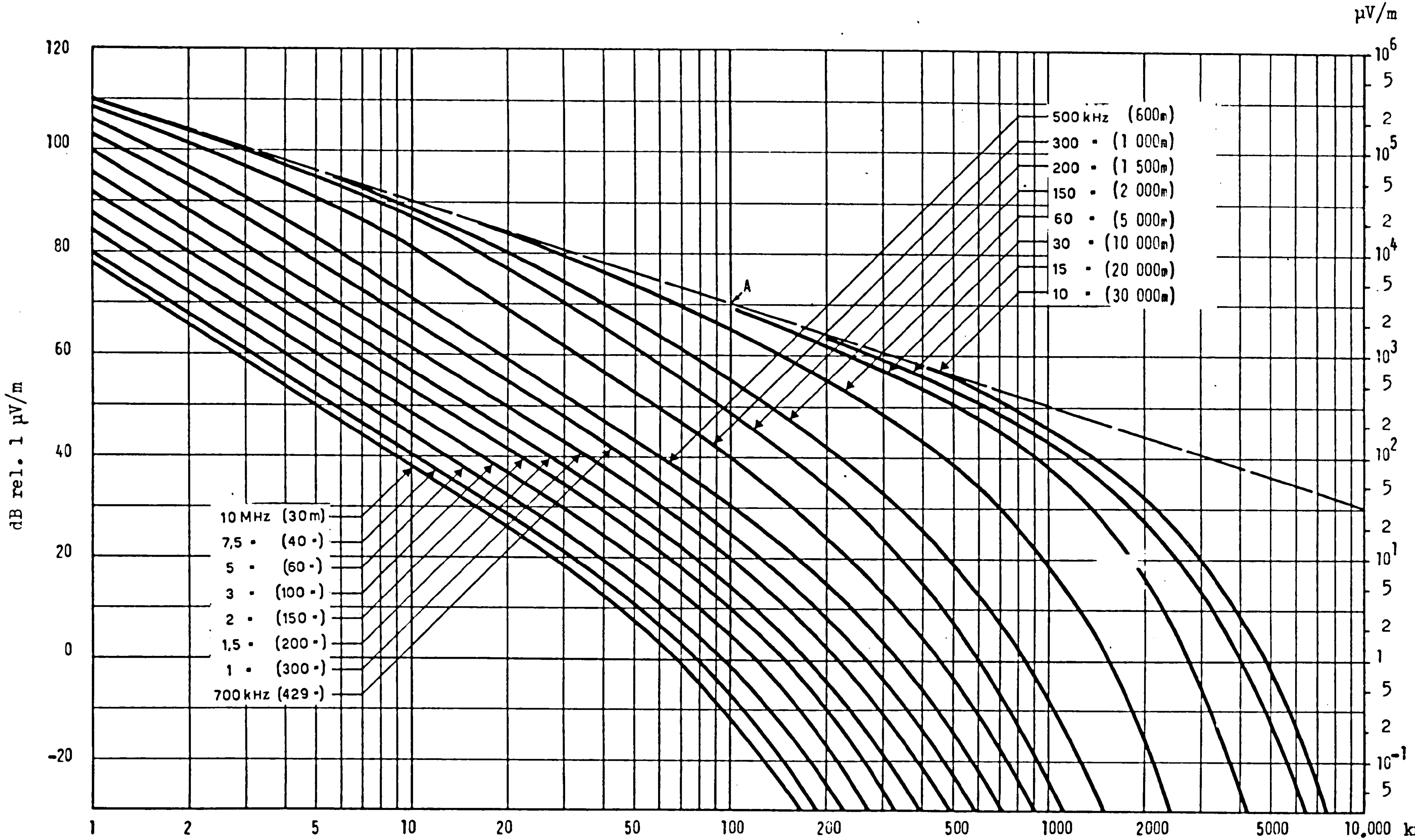


FIGURE 6

Ground-wave propagation curves: Earth

$\sigma = 3 \times 10^{-4}$ S/m, $\epsilon = 4$

A: Inverse listance curve

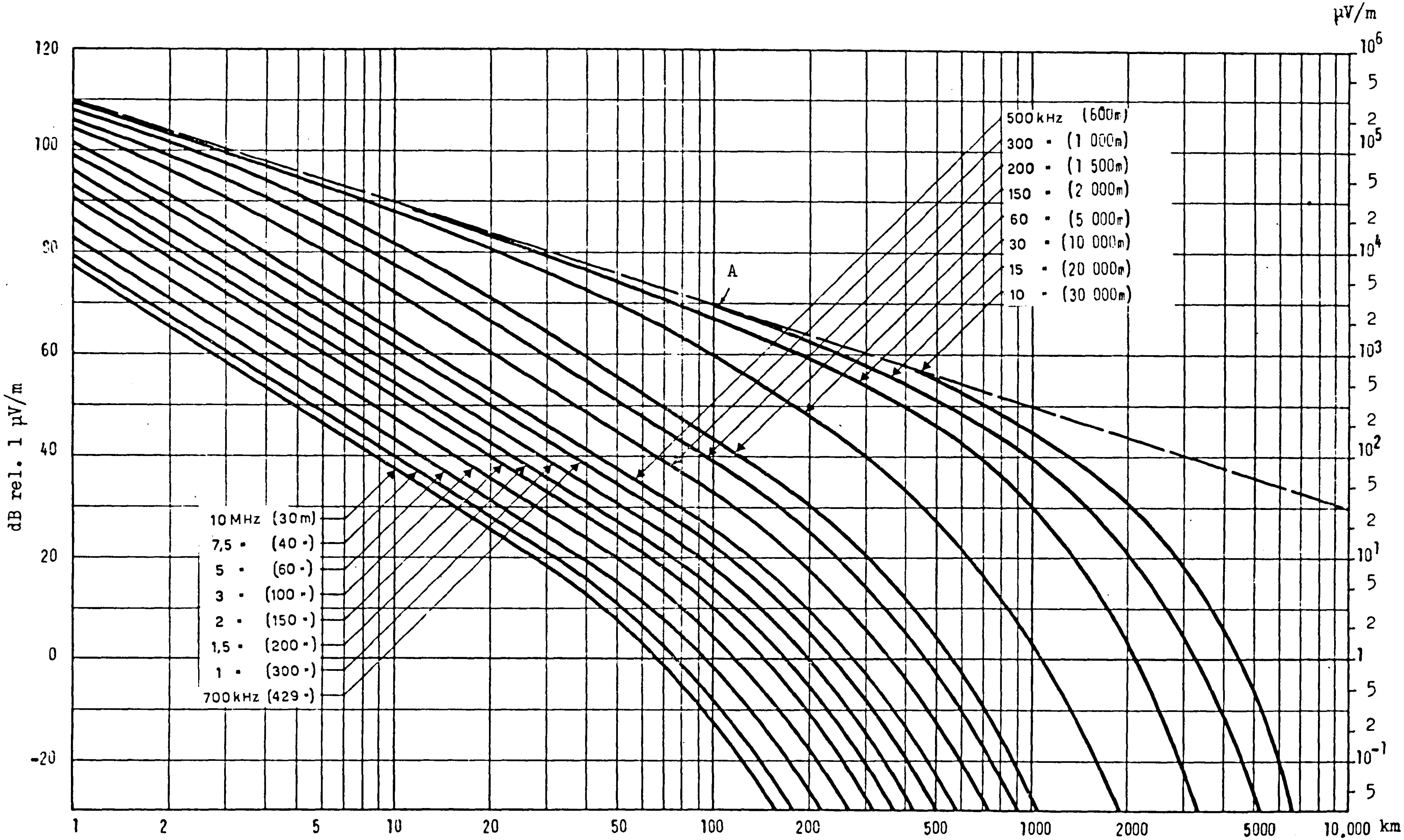


FIGURE 7

Ground-wave propagation curves: Earth

$\sigma = 10^{-4}$ S/m, $\varepsilon = 4$

A: Inverse distance curve

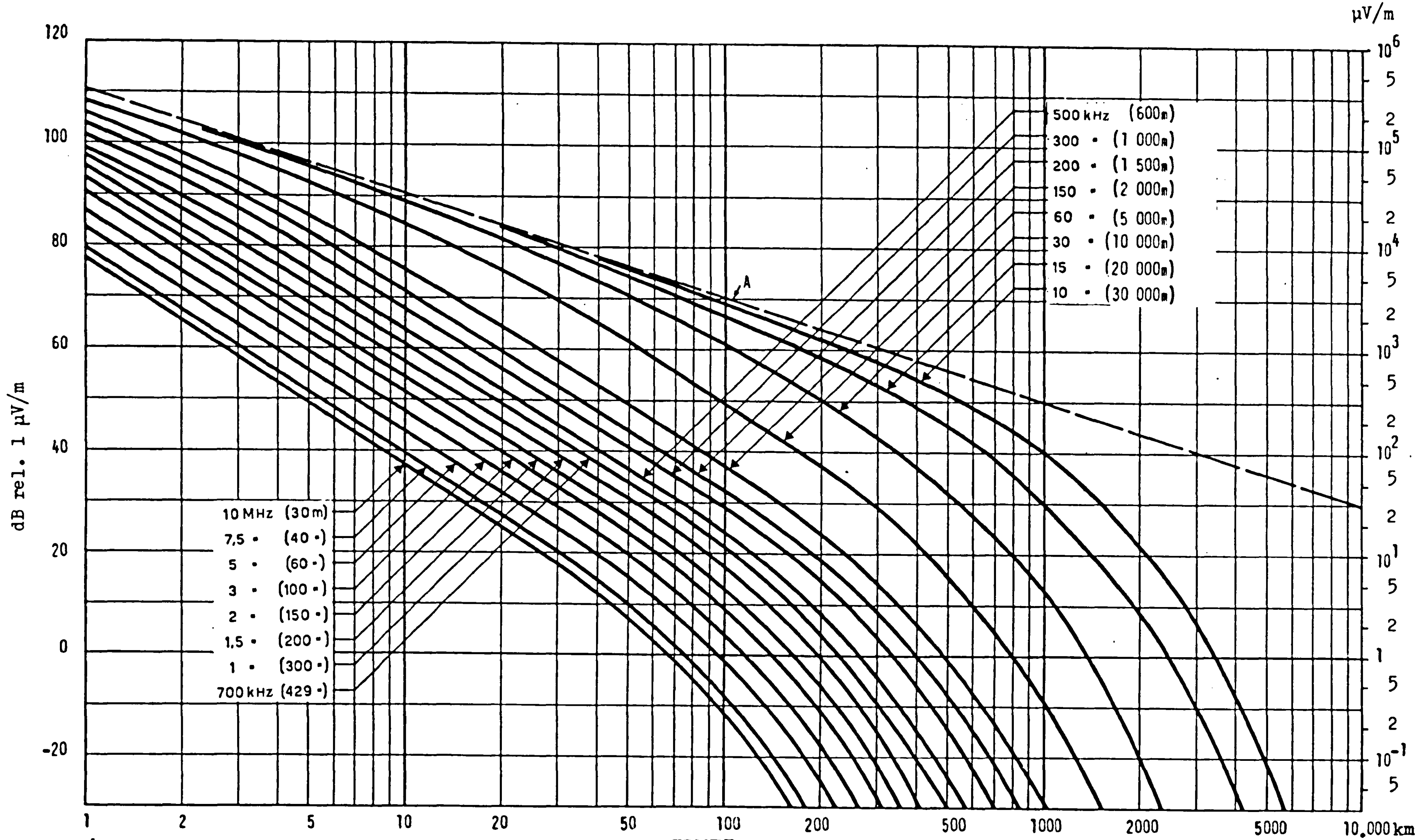


FIGURE 8

Ground-wave propagation curves; Earth

$\sigma = 3 \times 10^{-5}$ S/m, $\varepsilon = 4$

A: Inverse distance curve

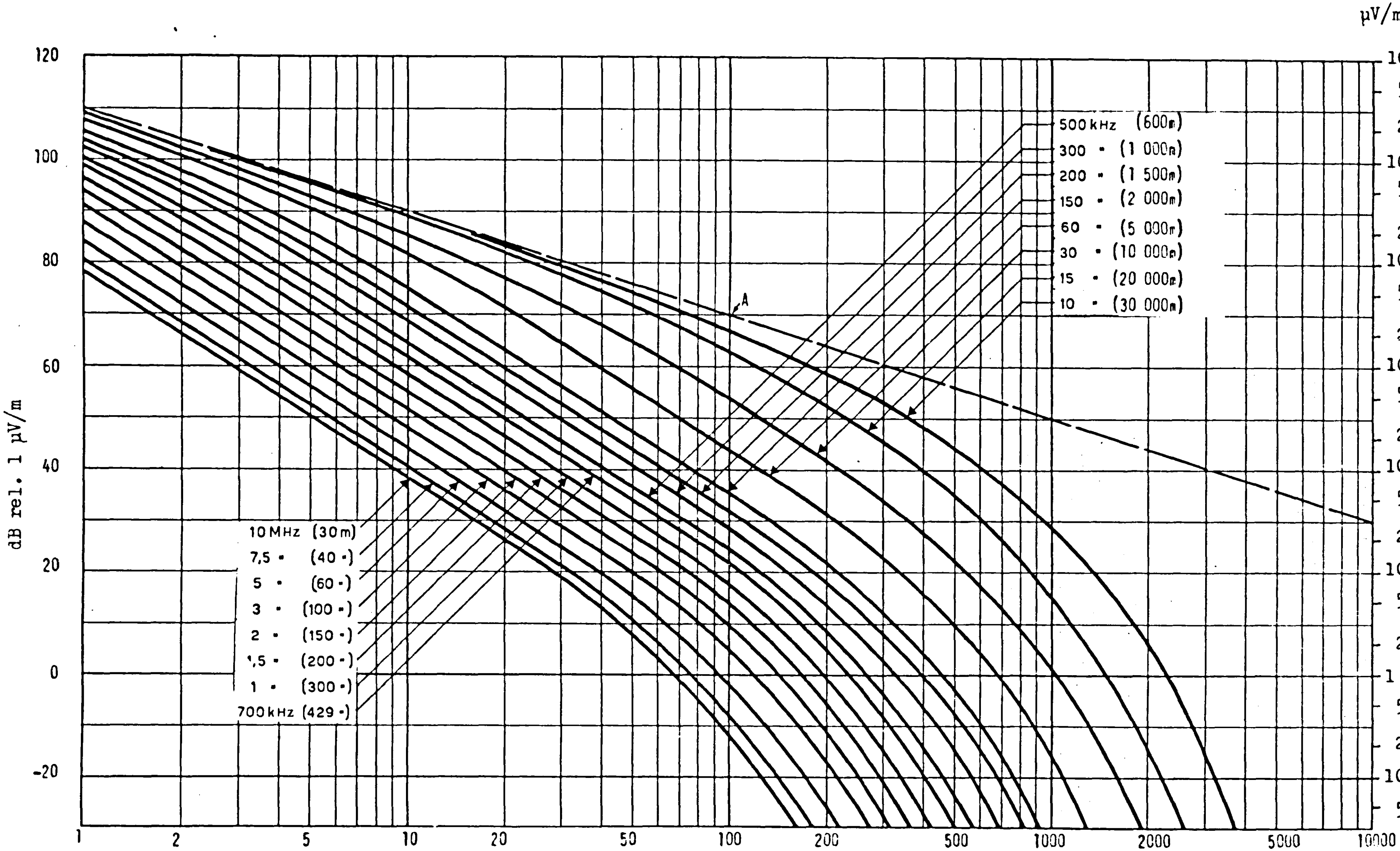


FIGURE 9

Ground-wave propagation curves; Earth

$\sigma = 10^{-5}$ S/m, $\epsilon = 4$

A = Inverse distance curve

RECOMMENDATION 372-1

USE OF DATA ON RADIO NOISE

(1951-1953-1956-1959-1963-1974)

The C.C.I.R.

UNANIMOUSLY RECOMMENDS

that the information contained in Reports 258-2 and 322-1 should be used in assessing the intensity and/or other characteristics of man-made and natural radio noise until new information to justify revision of these Reports is made available.

RECOMMENDATION 448-1

SOUND BROADCASTING IN BANDS 5 (LF) AND 6 (MF)

Radio-frequency protection ratio

(Study Programme 25A/10)

(1966-1974)

The C.C.I.R.,

UNANIMOUSLY RECOMMENDS

that the radio-frequency protection ratio (as defined in Recommendation 447), for co-channel transmissions (± 50 Hz), in bands 5 (LF) and 6 (MF), should be 40 dB when both the wanted and the unwanted signals are stable (ground-wave).

When the wanted signal is stable and the unwanted signal fluctuates (sky-wave), the radio-frequency protection ratio should be 40 dB at midnight for at least 50% of the nights of the year.

The radio-frequency protection ratio values specified above will permit a service of excellent reception quality. For planning purposes, however, lower values may be required. In this respect, proposals have been made by some countries and organizations (see Report 298-3).

ANNEX

This value of 40 dB takes account of the subjective effect of short-term fluctuations of the unwanted signal (see also Report 298-3, and Report 264-3, § 3.2), and corresponds to the ratio of the wanted field strength and the annual median value of the hourly medians of the interfering field strength at 2400 h local time at the midpoint of the path.

The protection so defined is provided :

- for 50% of the nights at 2400 h, local time,
- for more than 50% of the nights between sunset and midnight and between 0300 h and sunrise in the European Broadcasting Area;

- for more than 50% of the nights between sunset and 2100 h and between midnight and sunrise in Australia, and

- for 100% of the days during daylight hours.

Note 1.- The minimum usable field strength to which this protection ratio of 40 dB applies varies in the different regions and with frequency. Within the European zone, this minimum is of the order of 1 mV/m.

Note 2.- In the United States of America, when the wanted and unwanted signals are stable (ground-wave), the radio-frequency protection ratio for co-channel transmissions is 26 dB. When the unwanted signal is fluctuating (sky-wave), the same protection ratio is applied for 90% of the nights of the year, computed for the second hour after sunset. The minimum usable field strength is either 100 or 500 μV/m, depending upon the class of service.

RECOMMENDATION 498

SOUND BROADCASTING SYSTEMS IN BANDS 5 (LF) AND 6 (MF)

Interference due to ionospheric cross-modulation

(Study Programme 25E-1/10)

(1974)

The C.C.I.R.,

CONSIDERING

that ionospheric cross-modulation and hence harmful interference can result from excessive radiation towards the ionosphere;

RECOMMENDS*

that the maximum permissible radiation at any angle of elevation should be such that annoyance due to ionospheric cross-modulation does not exceed that agreed for co-channel interference (see Recommendation 448-1).

Note.- For the determination of the maximum radiation as a function of the angle of elevation see Report 460-1.

* The People's Republic of China and the United Kingdom reserve their opinions on this Recommendation.

RECOMMENDATION 499

SOUND BROADCASTING IN BANDS 5 (LF) AND 6 (MF)

Definitions of specific field strengths and service area

(1974)

The C.C.I.R.,

UNANIMOUSLY RECOMMENDS

that the following definitions should be used for sound broadcasting in bands 5 (LF) and 6 (MF) :

1. Minimum usable field strength (E_{min})*

The minimum value of the field strength necessary to permit satisfactory reception, under given specified conditions, in the presence of noise (natural and man-made), but in the absence of interference from other transmitters.

The value of the minimum usable field strength depends, amongst other things, upon :

- the frequency;
- the time of day and season of year; } see Report 322-1
- the geographical region; } see Report 322-1
- the protection ratio to be provided against noise;
- the receiver bandwidth.

In the broadcasting bands 5 (LF) and 6 (MF) man-made noise is usually more annoying than natural noise and, in areas of high population density, frequency planning will have to take account of these enhanced noise levels.

2. Nominal usable field strength (E_{nom})**

The minimum conventional value of the field strength necessary to permit satisfactory reception, under specified conditions in the presence of noise and interference from other transmitters.

* The minimum usable field strength corresponds to the term "minimum field strength to be protected" which appears in many C.C.I.R. texts. Where there is no possibility of ambiguity, the expression "minimum field strength" may be used.

** Where there is no possibility of ambiguity, the expression "nominal field strength" may be used.

Various studies show that, in the presence of interference due to other transmitters it is preferable, for optimum spectrum utilization, that the service area (see § 4, below) should be limited by interference rather than by noise. The nominal usable field strength is the value taken as a reference for planning.

3. Usable field strength (E_u)

The minimum value of the field strength necessary to permit satisfactory reception, under specified conditions, in the presence of noise and interference in an existing situation (or in that resulting from a Frequency Plan).

It may be expressed by the formula :

$$E_u = \sqrt{\sum_i (a_i E_{ni})^2 + E_{min}^2}$$

where

E_{ni} is the field strength of the i-th unwanted transmitter (in µV/m)*

E_{min} is the minimum usable field strength (in µV/m).

a_i is the radio-frequency protection ratio associated with the i-th unwanted transmitter, expressed as a numerical ratio of field-strengths.

In general, the usable field strength is different for each transmitter. For instance for two transmitters operating in the same channel but with different powers the usable field strength is higher for the transmitter having the lower power.

4. Service area (of a broadcasting transmitter)

The area within which the field strength of a transmitter is equal to or greater than the usable field strength.

The percentage of time during which this condition is satisfied should be stated.

The service area may be different under day-time and night-time conditions or vary with other factors.

---

* For a fluctuating unwanted signal, the percentage of time during which E_{ni} is exceeded should be stated.

R E P O R T S

REPORT 229-2*

ELECTRICAL CHARACTERISTICS OF THE SURFACE OF THE EARTH

(Question 1-2/5)

(1959-1963-1970-1974)

1. Introduction

This Report discusses the physical factors upon which the electrical characteristics of the surface of the Earth depend, reviews the methods which have been used to determine the ground constants and assesses the value of these methods in connection with the calculation of radio propagation; a list of references to published literature on this subject is given in C.C.I.R. documents of the XIth Plenary Assembly, Oslo, 1966, Vol. II, page 74.

2. The characteristics of the ground

The electrical characteristics of the ground or other medium may be expressed by three constants, the relative permeability, the dielectric constant and the conductivity. The relative permeability can normally be regarded as unity so that, in most propagation problems, we are concerned only with the dielectric constant ε and the conductivity σ. These two constants jointly influence wave propagation, in accordance with the following expression for the complex dielectric constant relative to a vacuum :

$$\varepsilon' = \varepsilon - j\ 18\,000\ \sigma/f = \varepsilon - j\ 60\ \sigma\lambda$$

where σ is in S/m, f is the frequency in MHz, λ is the free-space wave-length in metres, and the time factor exp $(j\omega t)$ is assumed. It may be noted that the displacement and the conduction current densities are in the ratio of ε to 60 $\sigma\lambda$, from which their relative importance can be judged. Figs. 1 and 2 show typical values of the ground constants as a function of frequency. It is seen that at frequencies above 100 MHz, account must be taken of the variation of dielectric constant with frequency and of the total conductivity (dipolar and ionic) [1]. Furthermore, it should be noted that a value of 80 has often been used for the dielectric constant of sea water over a wide range of frequencies. This value is incorrect except for low temperatures and frequencies below about 1 GHz. The actual value, even at low frequencies, depends on the temperature and composition of the sea water.

* Adopted unanimously

The conductivity values given for the specified types of surface in Figs. 1 and 2 are average values. The conductivity can vary considerably due to differences which exist in different parts of the world. In fertile areas higher values are applicable, while in mountainous and arctic regions the conductivity at frequencies below 100 MHz may be as low as 10^{-5} S/m. The water in lakes and rivers has a conductivity that increases with the concentration of impurities.

3. Factors determining the effective ground constants

The effective values of the constants of the ground are determined, not only by the nature of the soil, but also by its moisture content and temperature, by the frequency, by the general geological structure of the ground and by the effective depth of penetration and lateral spread of the waves. The absorption of energy by vegetation, buildings and other objects on the surface must also be taken into consideration.

3.1 Nature of the soil

Although it has been established by numerous measurements that the constants vary with the nature of the soil, it seems probable that this variation may be due not so much to the chemical composition of the soil as to its ability to absorb and retain moisture. It has been shown that loam, which normally has a conductivity of the order of 10^{-2} S/m can, when dried, have a conductivity as low as 10^{-4} S/m, which is of the same order as that of granite.

3.2 Moisture content

The moisture content of the ground is probably the major factor determining its electrical constants. Laboratory measurements have shown that, as the moisture content is increased from a low value, the constants increase, rapidly reaching their maximum values as the moisture content approaches the values normally found in such soils on site. At depths of one metre or more, the wetness of the soil at a particular site seems to be substantially constant all the year round and, although it may increase during rain, the drainage of the soil and surface evaporation soon reduces it to its normal value after the rain has stopped. The moisture contents of a particular soil may, however, vary considerably from one site to another, due to differences in the general geological formation which provide better drainage in one case than another.

3.3 Temperature

Laboratory measurements of soil constants have shown that, at low frequencies, the temperature coefficient of conductivity is of the order of 2 % per degree centigrade, while that of the dielectric constant is negligible. At freezing point there is generally a large decrease in both constants. Although these changes are appreciable, it must be borne in mind that the range of temperature variation during the year decreases rapidly with depth, so that temperature effects are likely to be important only at high frequencies where the penetration of the waves is small (see § 3.5), or when the ground is frozen to a considerable depth.

3.4 Frequency

Laboratory measurements on soil samples show that there is a variation of the constants with frequency which depends markedly on the moisture content. This variation is especially marked above 1 GHz, as shown in Figs. 1 and 2. The values for fresh water and sea water can be calculated for any frequency from the data given in [1].

3.5 General geological structure

The ground involved in over-land propagation is not usually homogeneous, so that the effective ground constants are determined by several different types of soil. It is, therefore, of great importance to have a complete knowledge of the general geological structure of the region concerned. The effective constants over an area or along a path are determined, not only by the nature of the surface soils but also by that of the underlying strata. These lower strata may form part of the medium through which the waves travel or they may have an indirect effect by determining the water level in the upper strata.

3.6 Penetration and spread of waves

The extent to which the lower strata influence the effective earth constants depends upon the depth of penetration of the radio energy, δ, which is defined as that depth at which the wave has been attenuated to 1/e (or 37 %) of its value at the surface. It depends upon the values of the earth constants and the frequency and is given in Fig. 3.

Fig. 3 shows that the penetration depth varies considerably with frequency. At low frequencies, except for sea water, strata down to a depth of 100 m or more must be taken into account. This is of particular importance when the upper strata are of lower conductivity and the energy can penetrate more readily to lower levels.

The radio energy received at a point does not travel solely by the direct path from the transmitter, but also by a large number of indirect paths distributed on either side of it. It is necessary, therefore, to consider the constants of the ground not only along the path itself, but also over the area covered by the lateral spread of the wave paths. No definite limits can be put on this area, but it has been suggested that it is effectively the first Fresnel half-wave zone, i.e., the ellipse having the transmitter and receiver positions as its foci and axes of $(D + \lambda/2)$ and $\sqrt{D\lambda}$ respectively, where D is the length of the direct path and λ is the wavelength.

3.7 Energy absorption by surface objects

Although surface objects have no direct influence on the constants of the ground itself, they can contribute appreciably to the attenuation of ground waves, and the effects of such energy losses may be taken into account by using appropriately modified values of the earth constants in propagation calculations.

Particularly high attenuation rates are associated with transmission loss in wooded terrain as shown in Fig. 4 [2, 3, 4, 6]. Such attenuation may increase even more when the trees are covered with wet snow, and under conditions of rain when the trees are in leaf.

4. Methods of measuring ground constants

The following methods have been used to determine one or both constants :

4.1 Laboratory measurement of soil samples

The dielectric constant and conductivity of samples of soil are determined by measurements of the resistance and reactance of capacitor units containing the soil as the dielectric. This method has been used for measurements on sea water and a wide variety of soils, including rock, at frequencies mainly in the range 1 kHz to 10 MHz.

4.2 Probe method of ground resistivity measurement

The conductivity of the ground is obtained by on-site measurements of the resistance between probes driven into the ground. The measurements are usually made with direct current using a system of four probes, a current being passed between one pair and the resultant potential difference being measured between the other pair. The depth to which the measurements are effective is determined by the spacing between the probes and the thickness of the surface layer or soil, or the height of the water table can be determined by a series of measurements made at different spacings.

The conductivity has also been deduced from the measured mutual impedance between two parallel lines laid on, or just above, the surface of the ground and earthed at their ends.

4.3 Wave-tilt method

This method is based on the fact that the surface losses give rise to a small radial component of the electric force vector. In general, the electric vector is elliptically polarized, and the major axis of the ellipse is tilted forward to account for the flow of power into the surface. The method involves a careful measurement of axial ratio and forward tilt of the ellipse with a rotatable dipole. When the surface is not horizontal, the measurement of the forward tilt should be made relative to the local normal to the surface, not relative to the vertical. It is reported that careful use of this method allows measurement of earth constants over a range of frequencies from 100 kHz to 40 MHz.

The wave-tilt method has been used successfully to measure horizontal inhomogeneities of the surface. Errors will result, however, if the measurements are made in the vicinity of areas where there are large horizontal gradients of conductivity, as with a transition from land to sea or from light soil to swampy soil.

4.4 Measurements of ground-wave attenuation

Measurements are made of the attenuation with distance of waves propagated along the ground and the ground conductivity is deduced by the comparison of the results with propagation curves, derived according to rigorous theories or semi-empirical methods regarded as acceptable in the case considered. The method is applicable at all frequencies.

4.5 Attenuation with depth below the surface

The ground constant may also be determined by measuring the relative rate of attenuation of the field strength as a receiver is lowered below the surface of the earth in a well or other suitable hole [5].

4.6 Measurements of phase-change (low frequencies)

The conductivity over homogeneous ground may also be deduced from measurements of the change of phase with distance of a ground-wave, the value of the constant being determined from the rate of change of the phase. This method, which has been used only at low frequencies, is found to be a more sensitive means of locating discontinuities in the ground than that provided by an attenuation measurement.

4.7 Atmospherics : dispersion of waves (low frequencies)

When an impulse, such as that generated by certain lightning strokes, is propagated over the earth, the wave shape is changed, i.e., the pulse is stretched, as the wave propagates over the surface. The degree of dispersion is a function of the conductivity. If the wave shape can be measured at two points in line with the source, one fairly close to the source, and the other remote, the observed change can be related to the calculated dispersion for various values of conductivity in an equivalent homogeneous earth. This method is only useful for the low-frequency range and for paths ranging from several hundred to several thousand kilometres in length.

4.8 By measurement of reflection coefficient (very high frequencies)

The reflection coefficient of the ground is measured in the field by methods involving normal incidence radiation. From the results, both the dielectric constant and the conductivity can be deduced, though with less accuracy in the case of the latter. This method is only suitable at very high frequencies.

5. Use of the methods in connection with propagation problems

From a study of the methods and of the factors affecting the ground constant, it is clear that most of the methods do not give all the information required for propagation calculations and that occasionally an extensive series of measurements is involved.

For example, laboratory measurements of soil samples may give accurate and detailed data on the constants of soil under its natural conditions, but it is necessary that this sampling should be extensive both along the path of propagation and in depth. It is also necessary to have an accurate knowledge of the geological structure of the path, to be able to use the data to assess the effective constants of the ground. This method is probably more suited to the investigation of the possible variations in the constants and the parameters on which they depend, than to the determination of the characteristics of a particular path.

The ground resistivity method takes more account of the general structure of the ground but only over a relatively small area. It is simple and convenient in practice and is probably the most suitable in cases where only the characteristics of the ground in the immediate vicinity of the transmitter or receiver are required. The effective constants to various depths are readily obtained, but for the assessment of path attenuation, measurements at a number of points along the path would have to be made, the intervals between the points being determined by the vertical stratification of the ground.

The wave-tilt method also takes account of the general structure of the ground around the point of measurement and gives the effective constants of the earth corresponding to the frequency used. The measurements will be in error near regions of large gradient of conductivity or in the vicinity of surface or buried objects of high conductivity. Measurements should not be made too close to the transmitting antenna, the minimum distance being about 10 wavelengths at low and medium frequencies, or one that is large compared with the antenna dimensions at high frequencies. The method becomes rather inaccurate at frequencies below 100 kHz because of the small angles of tilt which occur. In view of the dependence of the tilt on height above the surface, the usefulness of this method is restricted to frequencies below about 40 MHz. It may be used for determining path attenuation if a series of measurements is made along the path.

The ground-wave attenuation method is one of the most comprehensive, since it takes all factors into account. As with the method discussed in the preceding paragraph, the variations of earth constants along a path may be deduced if a series of measurements is made along the path. However, the results are probably not so accurate as those given by the ground resistivity or wave-tilt methods. Moreover, the results will apply only to the particular path used, or to one very similar. The method is not suitable for detailed measurements of earth constants over given small areas.

The phase-change method also takes all factors into account and, in addition, seems to be capable of giving more detailed information on inhomogeneous paths than can be obtained by the attenuation method. It has, however, the disadvantage of requiring an auxiliary VHF or UHF link to provide a reference for phase at the receiver.

Caution must be exercized in the last three methods to ensure that the measured field is not influenced by ionospheric waves, and that tall vegetation does not influence the results unduly, unless, of course, this is the effect it is desired to study (Fig. 4).

The reflection-coefficient method provides data which are applicable to only a small area of ground around the point of measurement, and, since it can be used only at very high frequencies, the depth of ground involved is also very small.

The dispersion method is well adapted for relatively long paths and low frequencies, and it therefore finds its principal application in connection with low-frequency navigation systems. The method has the advantage that no transmitter need be provided, but it also suffers the disadvantage that data can be accumulated only very slowly, because of the random and infrequent occurrence of suitable lightning strokes. It can be used at all distances, because the pulse method allows separation of the ground-wave from the ionospheric-wave. It requires more complicated equipment and involves more mathematical complexity than other methods. Further development of this method seems to be required to overcome some of the difficulties mentioned.

BIBLIOGRAPHY

1. SAXTON, J.A. and LANE, J.A. [1952], Electrical properties of sea water. Wireless Engineer (October).

2. RICE, P.L., [1971], Some effects of buildings and vegetation on VHF/UHF Propagation, Conf. Proc. of the 1971 IEEE Mountain-West Conference on Electromagnetic Compatibility, Tucson, Arizona, (November).

3. SAXTON, J.A. and LANE, J.A. [1955], VHF and UHF Reception. Wireless World, 61, p. 229.

4. BLOMQUIST, A. [1958], Local ground-wave field strength variations in the frequency range 30 - 1 000 MHz. Proc. Conf. on Electromagnetic Wave Propagation, Brussels, p. 127.

5. KACHPROVSKI, V., The propagation of radio waves and conductivity. Radio Journal of U.S.S.R. [1958] (in Russian). Translation in English, National Bureau of Standards translation T1-60 [June, 1959].

6. TAMIR, T. [1967], On radio-wave propagation in forest environments, IEEE Trans. on Antennae and Prop., Vol. 15, No. 6, pp. 806-817.

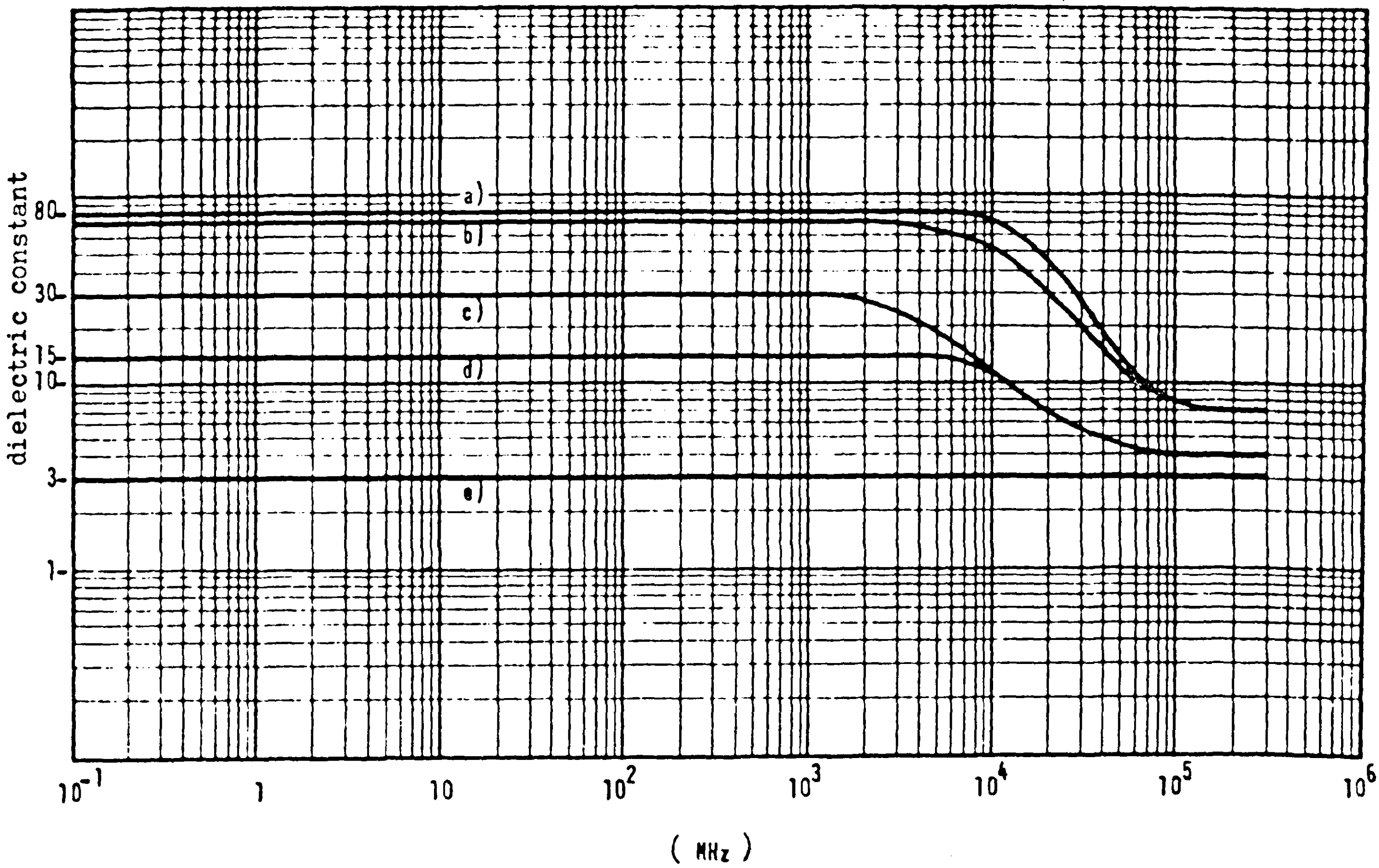


FIGURE 1

DIELECTRIC CONSTANT AS A FUNCTION OF FREQUENCY

a) Fresh water and pure water (20°C)
b) Sea water (20°C)
c) Wet ground
d) Average ground
e) Very dry ground and ice

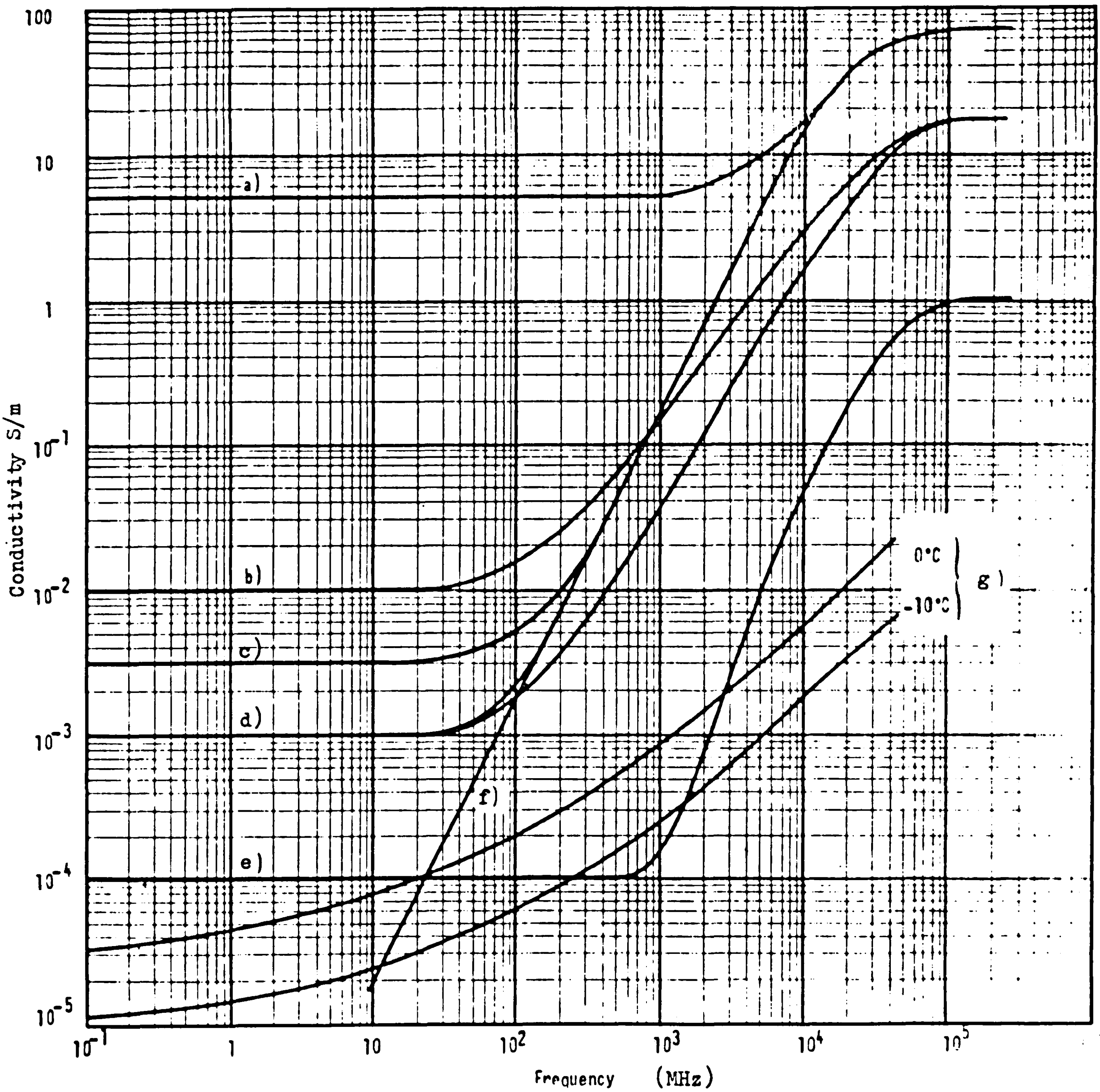


FIGURE 2

CONDUCTIVITY AS A FUNCTION OF FREQUENCY

a) Sea water (average salinity), 20°C
b) Wet ground
c) Fresh water, 20°C
d) Average ground
e) Very dry ground
f) Pure water, 20°C
g) Ice (Fresh water)

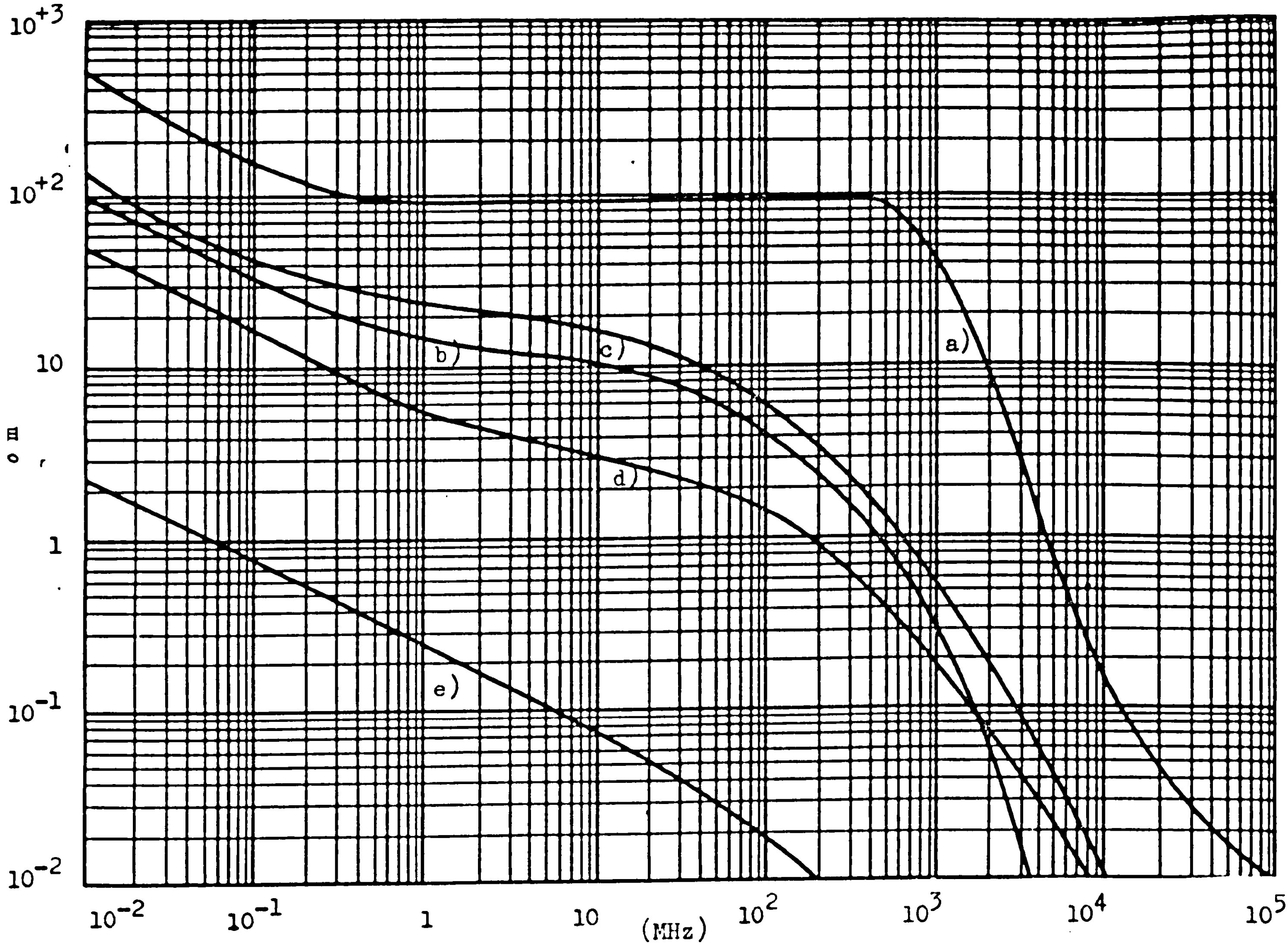


FIGURE 3

PENETRATION DEPTH AS A FUNCTION OF FREQUENCY

a) Very dry ground

b) Fresh water

c) Average ground

d) Wet ground

e) Sea water

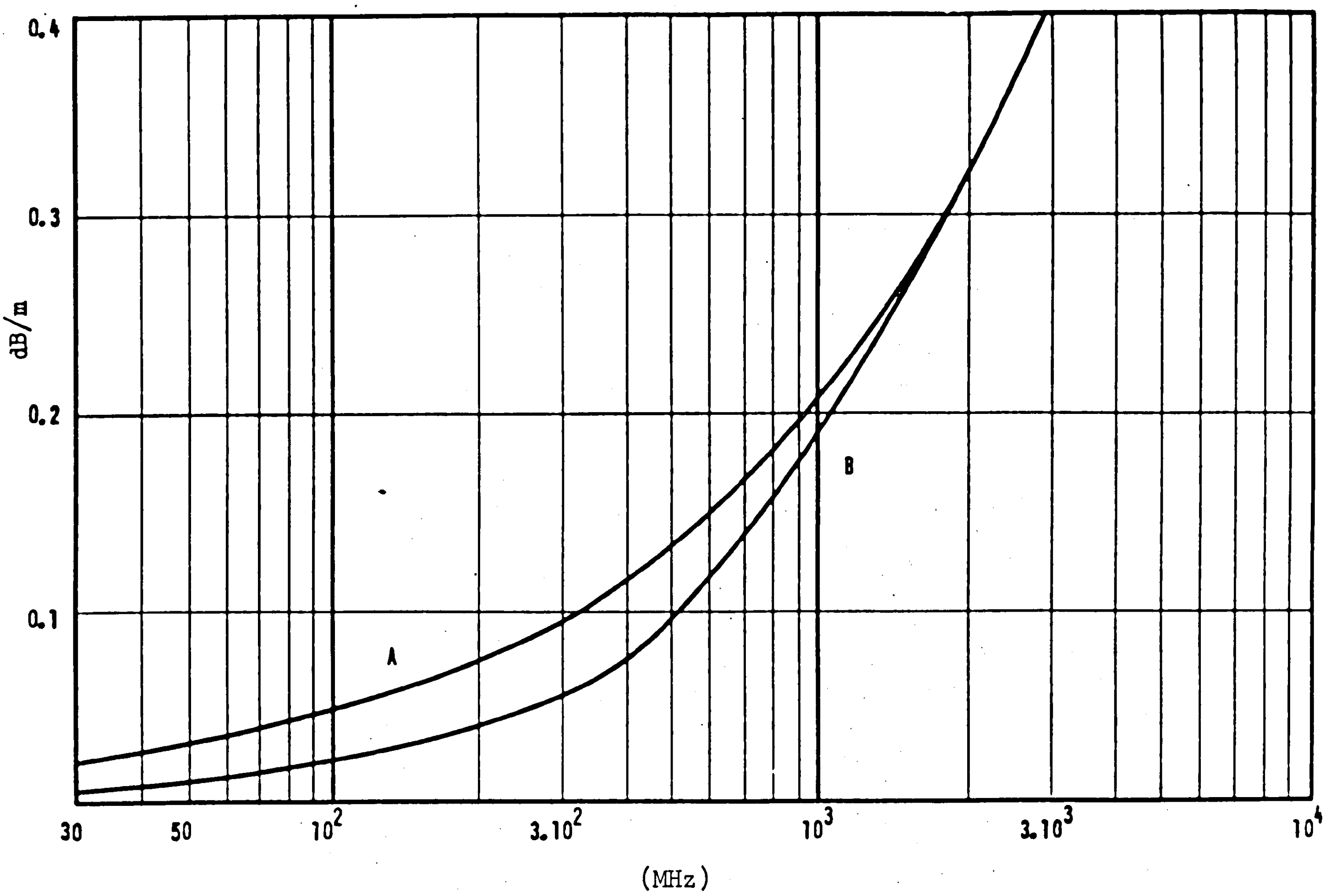


FIGURE 4

ADDITIONAL ATTENUATION OVER WOODED TERRAIN

A : Vertical polarization

B : Horizontal polarization

REPORT 258-2*

MAN-MADE RADIO NOISE

(Study Programme 7C/6)

(1963-1970-1974)

In the solution of telecommunication problems, it is highly desirable to be able to estimate the radio noise at any location as caused by different types of noise sources. At certain locations, unintended man-made noise may be dominant. Since such noise can arise from a number of sources, such as power lines, industrial machinery, ignition systems, etc., it varies markedly with location and time [Herman, 1971; Horner, 1971].

Current information is not available for estimating man-made noise intensities under all conditions but from limited observations [J.T.A.C., 1968; Disney, 1972] it is possible to derive typical values.

Median values of man-made noise power expressed in terms of Fa (dB above thermal noise at 288 K, see Report 322-1) attributed to man-made sources are shown in Fig. 1 for business, residential, rural and quiet rural areas. Measurements from 103 locations in the United States during 1966-1971 inclusive were used in the determination of the upper three curves. Business areas are defined as the core centres of large cities and urban areas as the residential sections of large cities as well as the suburban areas of large population centres. Rural areas are defined as small communities and farms, while the curve for quiet rural areas corresponds to the values of man-made noise at a quiet site as reported in Report 322-1. The dashed curve of galactic noise obtained from Report 322-1 is included for reference.

Note : The C.C.I.R. Secretariat is requested to convey the text of this Report to Study Group 1 for information.

* Adopted unanimously

REFERENCES

DISNEY, R.T. (1972) Estimates of man-made radio noise levels based on the Office of Telecommunications ITS data base, Proceedings IEEE International Conference on Communications, Order No. 72CH0622-1-COM, 20-13/20-19.

HERMAN, J.R. (1971) Survey of man-made radio noise, Progress in Radio Science, Vol. I, 315-348, U.R.S.I., Brussels.

HORNER, F. (1971), Techniques used for the measurement of atmospheric and man-made noise, Progress in Radio Science, Vol. II, 177-182, U.R.S.I. Brussels.

J.T.A.C. (1968) Unintended radiation, Suppl. 9 to Spectrum Engineering - The Key to Progress, IEEE, New York.

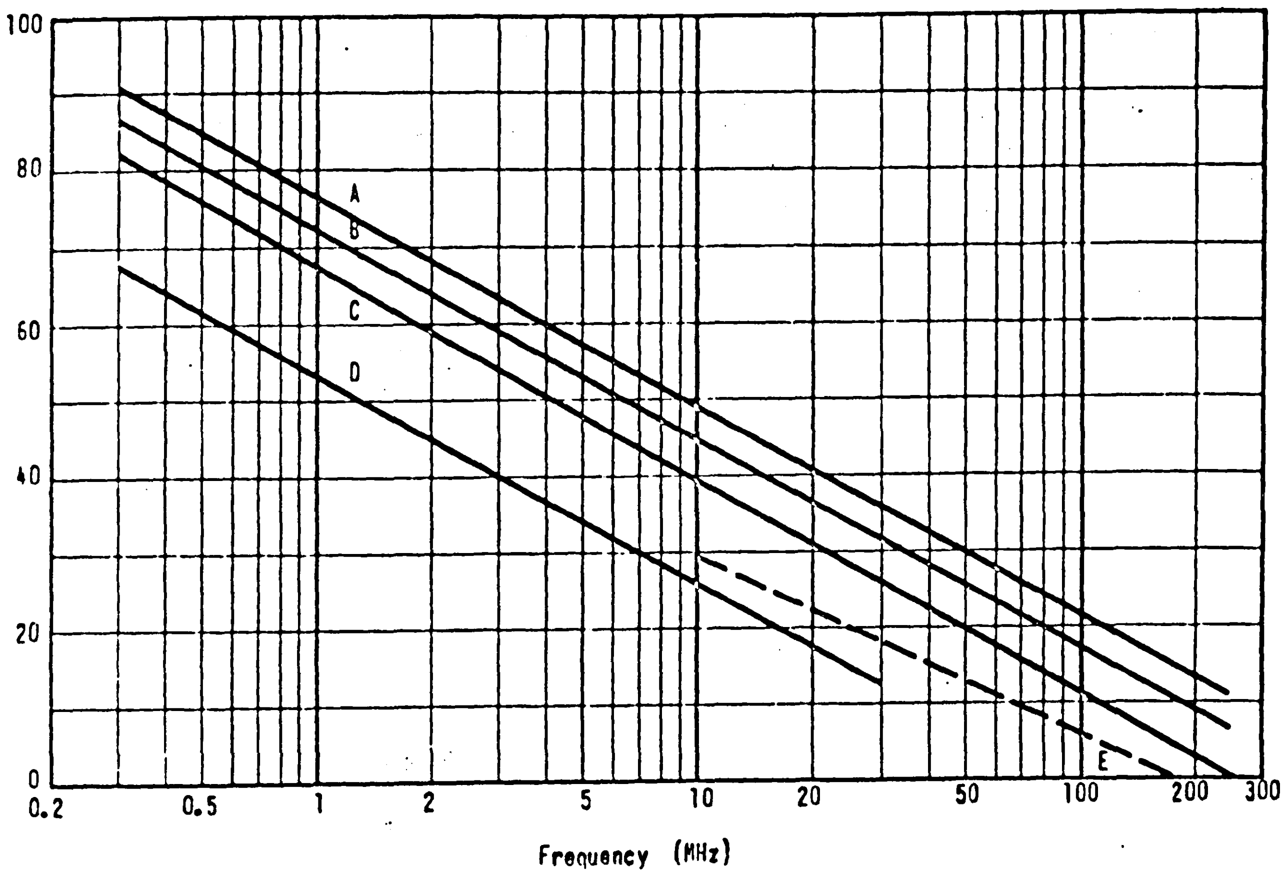


FIGURE 1

MEAN VALUES OF MAN MADE NOISE POWER FOR A SHORT VERTICAL LOSSLESS GROUNDED MONOPOLE ANTENNA

A: Business

B: Residential

C: Rural

D: Quiet rural

E: Galactic

REPORT 298-3*

PROTECTION RATIOS FOR AMPLITUDE-MODULATION SOUND BROADCASTING

(Study Programme 25A-1/10)

(1974)

1. Introduction

This Report is a summary of the information available on the subject of protection ratios for amplitude-modulation sound broadcasting services.

The protection ratios quoted refer, in all cases, to the ratios at the input to the receiver, no account having been taken of the effect of using directional receiving antennae.

Agreed values of protection ratios are essential for the solution of frequency assignment problems in amplitude-modulation sound broadcasting. Moreover, they may serve as basic reference data for the evaluation of the relative merits and the effectiveness to be expected with various amplitude-modulation transmission systems.

Protection ratios depend on a multitude of parameters among which transmission standards and receiver characteristics play an important role. Apart from technical factors there are others of physiological and psychological nature which have to be respected. It is, therefore, extraordinarily difficult to determine generally agreed values of protection ratios, even if both the transmission standards and the receiver characteristics are given.

A great amount of research work has been carried out since the beginning of broadcasting; this Report, however, is confined to results obtained since 1948.

2. Audio-frequency protection ratio

The audio-frequency protection ratio is the agreed minimum value of the audio signal-to-interference ratio considered necessary to achieve a subjectively defined reception quality (see Recommendation 447).

* Adopted unanimously

This ratio may have different values according to the type of service desired. It depends greatly on the type of the wanted and the unwanted programme. It is essential, therefore, to carry out a considerable amount of subjective listening tests, before a minimum value of the audio signal-to-interference ratio can be agreed upon.

It must clearly be stated that, due to physiological and psychological effects, it is completely impossible to fix reasonable values of the audio-frequency protection ratio by methods other than subjective tests.

3. Radio-frequency protection ratio

The radio-frequency protection ratio is the value of the radio-frequency wanted-to-interfering signal ratio that enables, under specified conditions, the audio-frequency protection ratio to be obtained at the output of a receiver.

These specified conditions include :

- the frequency spacing between the wanted and the interfering carrier;
- the characteristics of emission (type of modulation, modulation depth, dynamic compression, bandwidth of emission, harmonic distortion, etc.);
- the receiver characteristics (selectivity, susceptibility to non-linearities depending, for instance, on the receiver input voltage, etc.).

The radio-frequency protection ratio may, thus, be determined by means of subjective tests as in the case of the audio-frequency protection ratio. When proceeding in this way the number of parameters to be taken into account and, hence, the amount of work to be done will prove to be by far greater than in the preceding case. Comparable results can only be obtained, if the test conditions are rather similar. Recommendation 413-3, therefore, calls for a clear statement of the test conditions, together with the results obtained, in terms of the characteristics and parameters mentioned above.

However, the assessment of radio-frequency protection ratios can be considerably facilitated, once the audio-frequency protection ratio has been determined. Due to the fact that the majority of physiological and psychological effects only influence the audio-frequency protection ratio, it is possible to derive, under specified technical conditions and for a given value of the audio-frequency protection ratio, values of radio-frequency protection ratios, either by objective measuring methods or by graphical [Parreaux, 1972] or numerical [Petke, 1973; Gröschel, 1971] methods (see Report 399-2).

It must be emphasized that the last mentioned three methods for the establishment of radio-frequency protection ratios are based on the same basic ideas. They should lead, therefore, in principle, to the same results and, in fact, they do so, if the three methods are used with sufficiently high precision.

The lack of suitably reliable values for radio-frequency protection ratios in the past was mainly a consequence of the very complicated relationship between the radio-frequency protection ratio and the overall amplitude/frequency response of the receivers. The latter depends on the selectivity of the radio-frequency and the intermediate-frequency stages, the selectivity of the demodulator and the amplitude/frequency response of the audio-frequency stages. This difficulty has been partly overcome as a consequence of the establishment of the objective two-signal measuring method. This method, although quite reliable, has proved to be too complicated for general use, for example, by receiver manufacturers.

Numerical methods previously mentioned may however be used to relate data on receiver selectivity characteristics, as provided by the receiver manufacturers, to values of radio-frequency protection ratio. Although the calculations are complicated and need electronic aids, they enable, in contrast to the objective measuring method, the determination of the overall frequency response of the receiver for a given radio-frequency protection ratio curve.

4. General principle of non-subjective methods

All non-subjective methods assume the use of standardized conditions at both the transmitting and the receiving end of the transmission system, as described in Report 399-2.

In all interference problems, there are two different types of annoyance :

- the cross-talk from the interfering channel into the wanted channel, caused by the modulation, and

- the beat-note produced by both carriers.

The beat-note predominates in annoyance when the carrier-frequency separation is between about 0.25 kHz and 6 kHz, at least for the majority of receivers in use.

5. Data available on protection ratios

Generally agreed values of radio-frequency protection ratios are given in Recommendations 448-1 and 449-2. Report 457-1 deals with the effect of a limitation of the bandwidth of emission on radio-frequency protection ratios. The information given in these texts refers explicitly or, in the case of Recommendation 449-2, mainly to amplitude-modulation sound broadcasting in bands 5 (LF) and 6 (MF). Further information on protection ratios may be found in /_Belger and Rautenfeld, 1958; Liedtke, 1965_/. Data for broadcasting in band 7 (HF) are contained in Recommendations 261-1 and 411-1. The curves reproduced in Report 302 represent data at present available on the subject of Question 27/10 and Study Programme 27C/10 and refer principally to the protection ratios required to provide an acceptable broadcasting service in the Tropical Zone in the shared bands.

5.1 Radio-frequency protection ratios for ground-wave services

5.1.1 Stable wanted and interfering signals (ground-wave signal interfered with by another ground-wave signal)

In Recommendation 448-1, a value of 40 dB is given for use in bands 5 (LF) and 6 (MF) for co-channel transmissions.

With this value of radio-frequency protection ratio a high quality of reception is possible. For planning purposes, however, it may be necessary to adopt lower values. This problem has been studied by the E.B.U. /_Doc. 10/226 (E.B.U.), 1970-1974_/ and in Japan /_Doc. 10/286 (Japan), 1970-1974_/. The values that have been proposed are 30 dB and 26 dB, respectively.

Relative values of radio-frequency protection ratios as a function of the separation between the carrier frequencies of the wanted and the interfering signal are given in the form of curves in Recommendation 449-2. These curves are based partly on measurements made in accordance with the objective two-signal method of measurement and partly on computations (see Report 399-2). The influence of dynamic compression and audio-frequency bandwidth limitation can also be seen from these curves. It should be noted, however, that the full improvement in protection resulting from bandwidth limitation can only be obtained when the non-linearity of the transmitter is small.

5.1.2 Stable wanted and fluctuating interfering signal /_Belger *et al*, 1965_/

5.1.2.1 Short-term fading

Short-term fading of the interfering signal modifies the character of the disturbance felt by the listener : if, for a given audio-frequency signal-to-interference ratio, the interfering signal is made to fluctuate, the disturbance is subjectively felt to be more severe. Docs. X/5 (E.B.U.), X/31 (Federal Republic of Germany) and X/36 (France), 1963-1966 indicate that, to obtain the same degree of satisfaction of the listener, the protection must be increased by about 5 dB in the latter case.

In Recommendation 448-1, this value has been incorporated in the radio frequency protection ratio.

5.1.2.2 Long-term field strength variations

Report 264-3, § 4 gives a formula permitting the determination of the ratio between two fluctuating field strengths transmitted by the ionosphere.

In the case under consideration, this formula becomes, with some simplifications of form :

$$R(T) = F_{ou} - F_{on}(50) - \delta_H(100 - T) - \Delta_H(50) \qquad (1)$$

where

$R(T)$ is the ratio (dB) of the two field strengths exceeded during T% of the nights in a year;

F_{ou} is the field strength of the ground-wave of the wanted signal

$F_{on}(50)$ is the field strength of the ionospheric wave of the unwanted signal at midnight (local time) at the mid-point of the propagation path, which is exceeded during 50% of the nights in a year;

$\Delta_H(50)$ is the correction factor to be applied to field strength F_{on} to take into account the time at the mid-point of the path;

$\delta_H(T)$ is the correction factor to be applied to field strength F_{on} to take into account the percentage T of the nights in a year, at H hours (local time) at the mid-point of the path.

The values of $\Delta_H(50)$ and δ_H are given respectively in Figs. 6 and 7 of Report 264-3 as far as the European Broadcasting Area is concerned.

To ensure protection corresponding to a protection ratio of A(dB), the condition

$$A \leq R(T) \qquad (2)$$

must be satisfied.

5.2 Radio-frequency protection ratios for sky-wave services

A characteristic of the sky-wave service, especially when reception is being made with envelope detectors, is that propagation effects usually bring about a degradation of the received signal quality, for example, distortion in the case of selective fading. Because of this fact, it is considered that lower values of protection ratios should be applied to a sky-wave service as compared with a ground-wave service, the precise values depending upon whether the service is a primary one, as for broadcasting in band 7 (HF), or a secondary one, as for broadcasting in bands 5 (LF) and 6 (MF), where the primary service is provided by the ground-wave.

In Recommendation 448-1 no value is recommended for use when, in bands 5 (LF) and 6 (MF), the service is provided by the sky-wave. As a result of the studies carried out by the E.B.U. /̲ Doc. 10/226 (E.B.U.), 1970-1974 7̲ a value of 27 dB has been proposed. However, only a restricted amount of information is at present available on this aspect of broadcasting and administrations are strongly urged to carry out further studies.

5.3 Data used by the I.F.R.B.

In its technical examination of frequency notifications, according to the terms of Article 9 of the Radio Regulations, the I.F.R.B. uses the figures for protection ratios and receiver discrimination contained in its own Technical Standards, Series A, Fourth Edition, 1968.

6. Subjective assessment of the quality of reception

Doc. X/53 (U.S.S.R.), Bad Kreuznach, 1962, gives the results of statistical and subjective tests carried out in the U.S.S.R. on the effects of distortion and interference in a broadcast channel.

The tests were performed using a statistically founded subjective method, with special equipment which enabled a comparison to be made between an undistorted sound programme and a second programme, into which predetermined levels of distortion had been injected.

The object of these experiments was to determine the perceptibility of distortion and the following groups of listeners participated :

- qualified experts (sound-broadcasting producers),
- observers without special musical education and without training in the observation of distortion.

The results of these experiments were published in the form of graphs, showing the percentage of perceptibility as a function of the level of the distortion or interference injected.

All these tests were made on the basis of a large amount of statistical data. The correctness of the data obtained was checked by the methods of mathematical statistics. Results were given (see Doc. X/53 (U.S.S.R.) Bad Kreuznach, 1962), in terms of :

- linear distortion of different types (at various levels and for different frequency ranges),
- non-linear distortion (cubic, quadratic and "central cut-off" types),
- background noise (sinusoidal),
- white noise.

In the same document, a system of classification for the estimation of quality of reception is given.

Four classes of quality of reproduction are recommended which are established on the basis of the degree of perceptibility of distortion and interference (see Doc. X/53).

Some similar subjective listening tests were performed in Japan (1973) and the results are reported in Doc. 10/286 (Japan), 1970-1974. From this document the conclusion was drawn that a radio-frequency protection ratio value of 26 dB satisfies about 66.7% of the listeners.

REFERENCES

BELGER, E., RAUTENFELD, F. von [1958] Der erforderliche Gleichkanal- und Nachbarkanal-Storabstand beim amplitudenmodulierten Tonrundfunk (The protection ratios required for common channels and adjacent channels in amplitude-modulated sound broadcasting). Rundfunktechnische Mitteilungen, 2, 172-177.

BELGER, E., RAUTENFELD, F. von, VOGT, K. [April 1965] The wanted-to-interfering signal ratio required with an interfering signal fluctuating in time, in amplitude-modulation sound broadcasting. E.B.U. Review, Part A - Technical, 90, 69-72.

GRÖSCHEL, G. /‾1971_7 Out-of-band radiation and its influence on the adjacent channel with amplitude-modulated sound broadcasting. Nachrichtentechnische Fachberichte, 41, 41-49.

LIEDTKE, G.R. /‾April 1965_7 The effect of receiver characteristics and radiated bandwidth on the RF wanted-to-interfering signal ratio in amplitude-modulation sound broadcasting. E.B.U. Review, Part A - Technical, 90, 65-68.

PARREAUX, D. /‾August 1972_7 A graphical method of determining protection ratios in the case of LF and MF amplitude-modulated transmissions. E.B.U. Review - Technical, 134, 163-167.

PETKE, G. /‾October 1973_7 Determination by calculation of the RF protection ratio for AM transmission systems. E.B.U. Review - Technical, 141, 227-234.

REPORT 400-2*

SOUND BROADCASTING IN BANDS 5 (LF), 6 (MF) AND 7 (HF)

Factors limiting broadcasting coverage in band 6 (MF)**

(Study Programme 25F-1/10)

(1966-1970-1974)

1. Introduction

Broadcasting transmitter networks should be planned in such a way that coverage of the required area is provided using the minimum number of frequencies.

From the purely technical standpoint, the service area of each transmitter depends on a number of factors, for example transmitter power, minimum usable field strength, radio-frequency protection ratio, distance between transmitters sharing the same channel, channel spacing, ground conductivity and operating frequency.

The service areas vary considerably with the type of service required which may be ground wave by day, ground wave or sky-wave by night.

Studies have been carried out in France and in the Federal Republic of Germany in the framework of the activities of the European Broadcasting Union /̅ Eden and Minne, 1969 _/. In these studies one of the main aspects was to examine the influence on coverage of the radio-frequency protection ratio and the distance between transmitters sharing the same frequency.

Further studies, carried out within the European Broadcasting Union (E.B.U.) /̅ E.B.U., May, 1974; Eden and Minne, 1973 _/ and in Japan /̅ see Doc. 10/306 (Japan) 1970-1974 _/ have indicated the influence of channel spacing on area coverage.

* Adopted unanimously.

** The operational aspects of broadcasting coverage in band 6 are discussed more fully in Report 616.

2. Coverage factor as a function of distance

2.1 Definition and basic assumption

In the absence of noise, two transmitters operating on the same frequency with an equal power P kW, separated by a distance D km, have a service range R km, which depends on the radio-frequency protection ratio, A, (dB), but is independent of the transmitter power. In the presence of noise the service range is also dependent on the transmitter power.

The coverage factor, c, may be defined to be the ratio of the sum of all service areas, s_n, of the individual transmitters operating on the same frequency on a very extensive area S to the total area :

$$c = \Sigma\, s_n/S = (2\pi/\sqrt{3})\ (R^2/D^2).$$

The quantity R^2/D^2 is, thus, proportional to the coverage factor.

The coverage factor so defined is also known as area coverage per channel and is normally expressed as a percentage. If the area coverage obtainable using all the available channels in band 5 (MF) exceeds unity (100%) then this number represents, on average, the number of programmes that can be received at any location throughout the whole area under consideration.

To establish curves showing the dependency of $10^3 \times R^2/D^2$ or c, respectively, on the distance D with either A or P as parameters the following conditions were taken as a basis :

- transmitters of equal power;
- ground-wave propagation curves of Reccomendation 368-2;
- sky-wave field : annual median value of the hourly median values at midnight;
- sky-wave propagation curves derived from Fig. 2 of Report 264-3, extrapolated beyond 3500 km (see Fig. 1 of this Report).

The extrapolation was made in several ways :

- by extending the curves using formula (1a) of § 2 of Report 264-2 (propagation type No. 1);
- by halving the mean slope of the existing curves every 500 km from 3500 km onwards (propagation type No. 2);

- by taking an intermediate curve between the first two curves (propagation type No. 3);

- sky-wave propagation curve : Cairo (N/S) /‾C.C.I.R., 1938_7 (propagation type No. 4);

- sky-wave propagation curve : U.S.S.R. /‾Udaltsov and Schlyuger, 1972_7, for 1 MHz and geomagnetic latitude of 25.4° N (propagation type No. 5).

Correction factors taking account of the vertical radiation diagram of the transmitting antenna, magnetic dip, sunspot number, etc., were not applied to the field strength values obtained from the curves.

Note : Field strength measurements carried out in bands (LF) and 6 (MF) in the U.S.S.R. /‾Vilensky et al, 1969; Täumer and Müller, 1965_7 show that, particularly in band 6, substantially higher values of field strength were obtained at distances beyond 2000 km than would be expected from the curves of Report 264-3. A summary of these observations is contained in Report 431-1.

2.2 Results

2.2.1 Plane Earth

The curves in Figs. 2, 3 and 4 for a frequency of 1 MHz are given as examples. The figures are based on the assumption that there is only one interfering station and the service range was calculated under the worst condition, i.e. on the straight line connecting the wanted and unwanted transmitter. The figures show the dependency of the coverage factor on the distance between transmitters operating on the same frequency.

Fig. 2 is valid when a ground-wave service is limited by sky-wave interference from the unwanted transmitter and when, in the absence of noise, there is no power dependency. The parameter indicated on the curves is the radio-frequency protection ratio A. Also shown in decibels relative to 1 µV/m is the field F_1 of the wanted transmitter at the limit of the service area, for a transmission power of 1 kW with a short vertical antenna. For instance, a point of intersection on a curve shown by long dashes, for $F_1 = 40$ dB, and a curve $R^2/D^2 = f(D)$, for A = 25 dB, means that if the transmitters are separated by a distance D km (abscissa of the point of intersection) and for a protection ratio A = 25 dB, the field at the limit of the area, where the radio-frequency protection ratio is ⩾ 25 dB, is 0.1 mV/m.

Fig. 2 shows that :

- initially the coverage factor decreases as D increases and is smallest at approximately 1500 km. However, in practice, these relatively high coverage factor values at small distances between transmitters cannot be achieved because interference from more than one transmitter is to be expected;

- for distances beyond about 1500 km up to at least 4000 km, the coverage factor increases;

- beyond 4000 km, the variation of the coverage factor depends on propagation conditions. With propagation of type No. 3, the variation is only slight, at least for high radio-frequency protection ratios;

- the general shape of the curves, though varying with the propagation type for distances beyond 3500 km, is practically independent of the conductivity of the soil and the frequency;

- the optimum separation depends considerably on the propagation type but less so on the radio-frequency protection ratio.

Figs. 3 and 4 /¯Suzuki _et al_, 1974_/ show the influence of the power P (which is the parameter indicated on the curves) in the presence of noise for a radio-frequency protection ratio A = 40 dB and 26 dB respectively. The coverage factor c is presented on a logarithmic scale to enable a comparison to be made between the five examples shown :

- ground-wave service interfered by a ground-wave signal (day-time conditions), ground conductivity $\sigma = 3 \times 10^{-3}$. S/m; curves (A) see Figs. 3 and 4;

- ground-wave service interfered by a sky-wave signal (night-time conditions), ground conductivity $\sigma = 3 \times 10^{-3}$. S/m; propagation type No. 1 : curves (B_1) see Figs. 3 and 4; propagation type No. 4 : curves (B_2) of Fig. 3; propagation type No. 5 : curves (B_2) of Fig. 4;

- sky-wave service interfered by a sky-wave signal (night-time conditions); propagation type No. 1 : curves (C_1); propagation type No. 4 : curves (C_2) see Figs. 3 and 4.

Figs. 3 and 4 show that, in the presence of noise :

- the optimum separation between transmitters using the same channel varies considerably with transmitter power;
- the optimum separation is completely different under day-time and night-time conditions;
- the optimum separation is not very different under night-time conditions both for a ground-wave or a sky-wave service;
- the lowest coverage will be obtained when a ground-wave service is interfered by the sky-wave signal of an unwanted transmitter;
- at least with high-power transmitters (P ⩾ 30 kW), a sky-wave service would give a coverage similar to that of a ground-wave service at day-time;
- the sky-wave coverage is considerably reduced when propagation types Nos. 4 and 5 are applied;
- the ground-wave coverage during night-time is also reduced considerably for propagation types Nos. 4 and 5. In this case the maxima of coverage are less pronounced or disappear almost in comparison to those obtained with propagation type No. 1;
- at short distances the ground-wave coverage during night-time increases with decreasing co-channel distance almost independently of the propagation type applied for the calculation of the sky-wave interference. This effect results in higher coverage at lower co-channel distances whereas the service ranges decrease to a few kilometres only.

2.2.2 Spherical Earth

For interference from sky-wave signals either to a ground-wave or to a sky-wave service, suitable co-channel distances are of the order of the radius of the Earth, so that the spherical nature of the Earth must be taken into account. This has been done in [Eden and Minne, 1969] where only sky-wave service is considered and where potential interference from the nearest co-channel transmitters, all equally spaced, has been taken into account.

An attempt has been made, therefore, to cover a sphere with a network of equilateral spherical triangles. It can be shown that this can be done by approximating the sphere to a polyhedron. A tetrahedron, octahedron and icosahedron provide surfaces consisting of 4, 8 and 20 equilateral triangles, respectively. These triangles may be developed on to a plane and it is then possible to apply without difficulty a linear channel distribution to this development.

However, when reconstituting the polyhedron, some of the triangles will share sides or apices with other triangles, from which they were separated in the plane development. In those groups of triangles the channel distribution will then no longer necessarily be linear, and consequently restrictions on the use of the channels shown on these triangles will occur. The proportion of these (unusable) triangles with respect to the total number will be at most 40% in the case of the icosahedron, 25% in the case of the octahedron and 50% in the case of the tetrahedron. On the other hand, these triangles may be ignored to a large extent by making use of the fact that dry land occupies only one third of the Earth's surface. It is therefore, still possible to utilize the results that have already been obtained by considering networks on a plane surface.

Assuming that for the coverage of the land masses about 50% of the triangular surfaces will in fact be used, each channel can be used precisely 0.25 times the number of existing triangular planes. It is now possible to show as a final result the full relationship between the number of transmitters b, co-channel distance D, necessary transmitter power P and coverage factor c, that can be obtained in one single diagram. Fig. 5 shows this result. It should be noted that the absolute value fixed for any one of these parameters determines the values of all the others. When using this figure one should bear in mind that it can only give an estimation of these relationships.

In an additional study the influence of the radio-frequency protection ratio on the coverage factor was calculated using the same assumptions as stated previously. The results are shown in Fig. 6 and indicate that the coverage factor increases more rapidly with decreasing values of radio-frequency protection ratio when the distance between co-channel transmitters is relatively small. For a distance of 3000 km, for example, the coverage factor is 100 times higher when the radio-frequency protection ratio is 20 dB instead of 40 dB.

2.3 Conclusions

The main results of the studies mentioned above are reproduced in Fig. 5. Although the studies were purely theoretical and although little was known, at the time, of propagation beyond 3500 km (on which matter, however, further work has since been done, Report 575, the relationship between the parameters shown in Fig. 5 exists.

There is, especially, no escape from the fact that the number of transmitters that may operate on the same frequency is inversely proportional to the transmitter separation. It is also true that the coverage factor at least for the sky-wave increases with increasing transmitter separation for distances below about 5000 km. The accurate values of the coverage factor may, however, be considerably smaller, due to either additional interference (e.g. from adjacent channels) or higher field strengths from far distant transmitters or similar effects.

It should be noted that the coverage that can be achieved is least when a ground-wave service is interfered with by sky-wave signals.

There are, however, means by which improvements in coverage can be made, for example,the use of synchronized transmitter networks and, in certain cases, the use of directional transmitting antennae (see Report 616).

3. Coverage factor as a function of channel spacing

3.1 Basic assumptions

The influence of channel spacing on MF area coverage for both ground-wave and sky-wave services at night has been investigated for channel spacings between 5 and 10 kHz. The area considered was the combined European and African Broadcasting Areas (42×10^6 km^2) and a constant number of frequency assignments was assumed. The total area coverage with these assignments was calculated under various assumptions and presented in a number of curves showing coverage factor as a function of channel spacings between 5 and 10 kHz and for various numbers of total frequency assignments as a parameter.

3.2 Ground-wave service at night

Studies for ground-wave coverage have been carried out in Japan. The results are given in Fig. 7. They show that the maximum of coverage is obtained with a channel separation of about 8 kHz, almost independently of the number of assignments within the given area. The absolute value of coverage does not depend strongly on the number of assignments.

3.3 Sky-wave service

Similar studies were carried out in the Federal Republic of Germany for sky-wave coverage. The results are given in Fig. 8. In this case too the maximum coverage is obtained with a channel spacing of about 8 kHz. The value of the coverage, however, depends strongly on the number of assignments in the given area.

3.4 Conclusions

The results show that, compared with the present situation (essentially, 9 kHz or 10 kHz spacing), greater coverage would be obtained with a channel spacing of 8 kHz. This evidence is based on studies with a regular transmitter lattice and with trial assignments in the European and African Broadcasting Areas.

The result of a unique optimum value of 8 kHz in practically all cases may be explained with the help of Fig. 9.

If N frequency assignments in band 6 (MF) to transmitters (or synchronized groups) are required in a given area S and if co-channel interference only has to be taken into account, then the coverage improves with decreasing channel spacing, thus increasing the number of channels available. It is obvious that, in such a case, the average co-channel distance will also increase (curve A of Fig. 9) and that interference will be reduced by this measure. Low values of channel spacing would, in this case, be preferable.

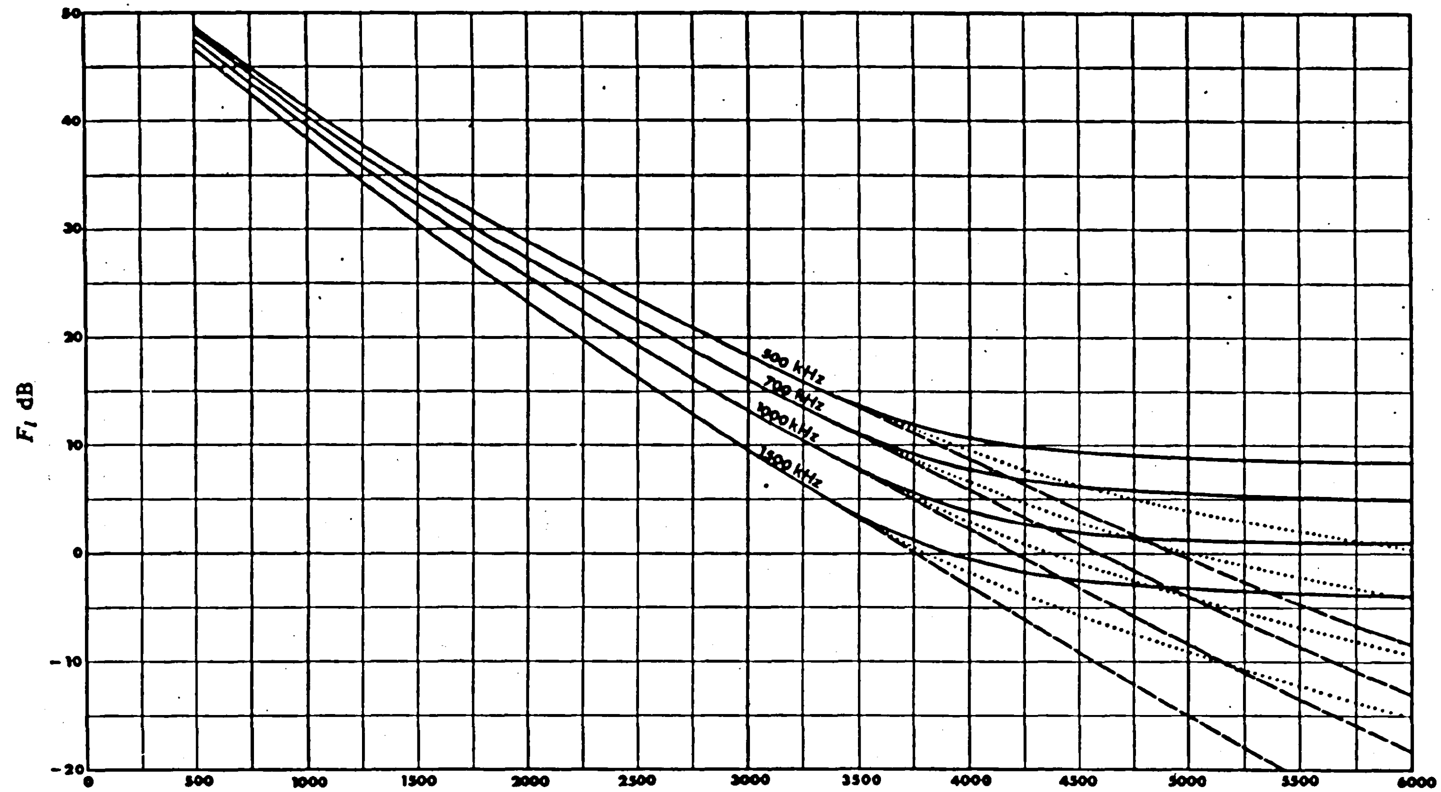
If, however, adjacent-channel instead of co-channel interference had to be taken into account, the rest of the parameters remaining unchanged, interference would increase and, hence, coverage would decrease with decreasing channel spacing (curve B of Fig. 9). High values of channel spacing would, therefore, be desirable in this case.

In practice, however, both types of interference have to be considered and it is obvious that the resulting coverage curve, as a function of frequency spacing, will be situated below the two curves discussed above. Furthermore, from the shape of the two limiting curves, it is very probable that the resulting coverage curve will have a maximum (curve c of Fig. 9).

It has been shown by a further study that the channel spacing corresponding to maximum coverage depends mainly on the relative radio-frequency protection ratio curve and corresponds to a relative value of about A_{rel} = -20 dB.

It has also been shown that in the present situation, in the European Broadcasting Area, for high-power transmitters ($\geqslant$ 100 kW), the effective interference levels are more than 10 dB greater for co-channel stations than for adjacent-channel stations. This indicates that the spacing could be reduced below 9 kHz, gaining more channels and permitting greater co-channel distances, without leading to undue adjacent-channel interference.

Studies carried out in the U.S.S.R. have shown the usefulness of preserving a channel spacing of 9 kHz.



Limit of the curves of Report 264-3

FIGURE 1

Ionospheric propagation curves (Report 264-3)

- - - - - Propagation type No. 1 ——— Propagation type No. 2 .... Propagation type No. 3

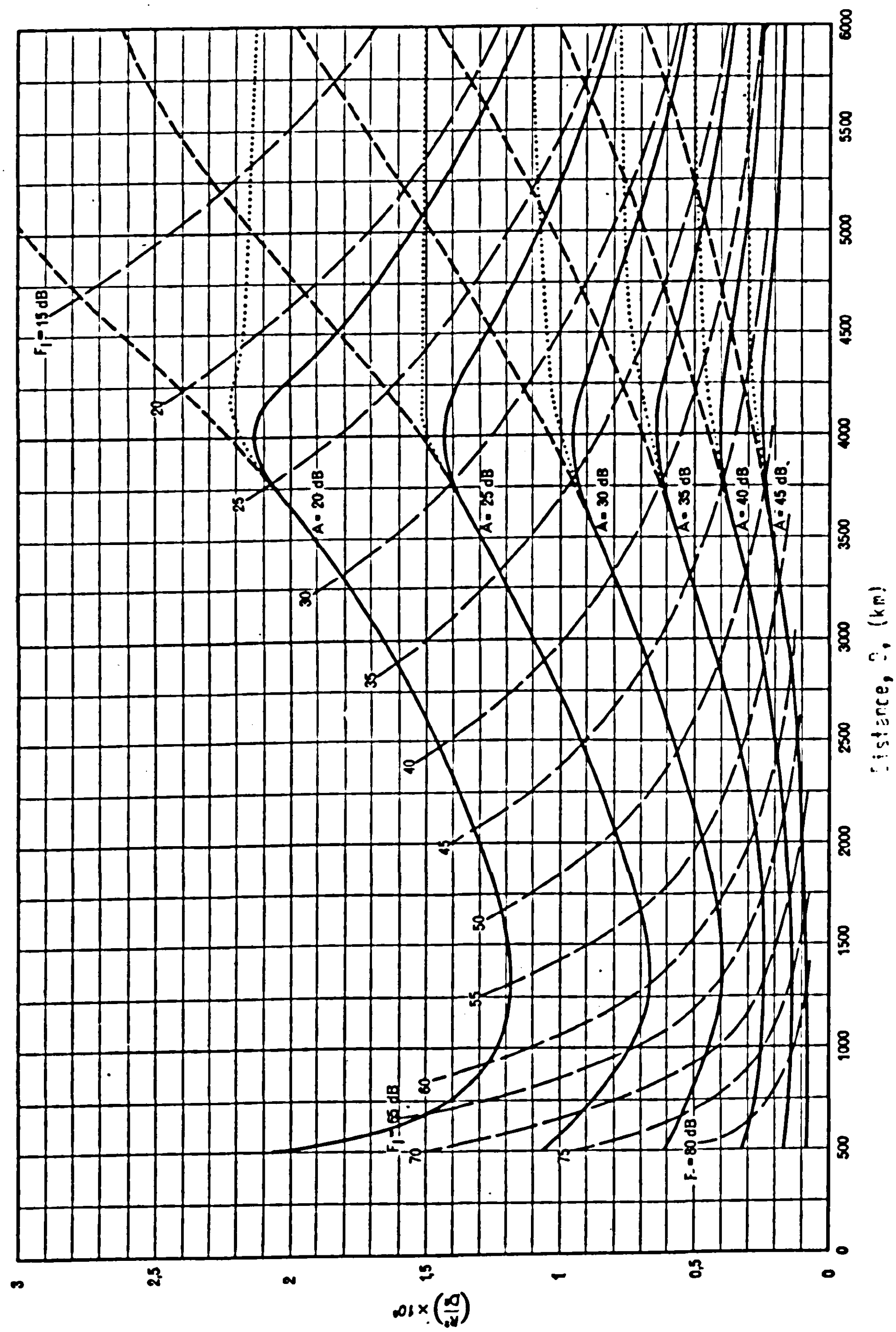


FIGURE 2

Coverage factor

$\sigma = 3 \times 10^{-3}$ S/m; $f = 1$ MHz

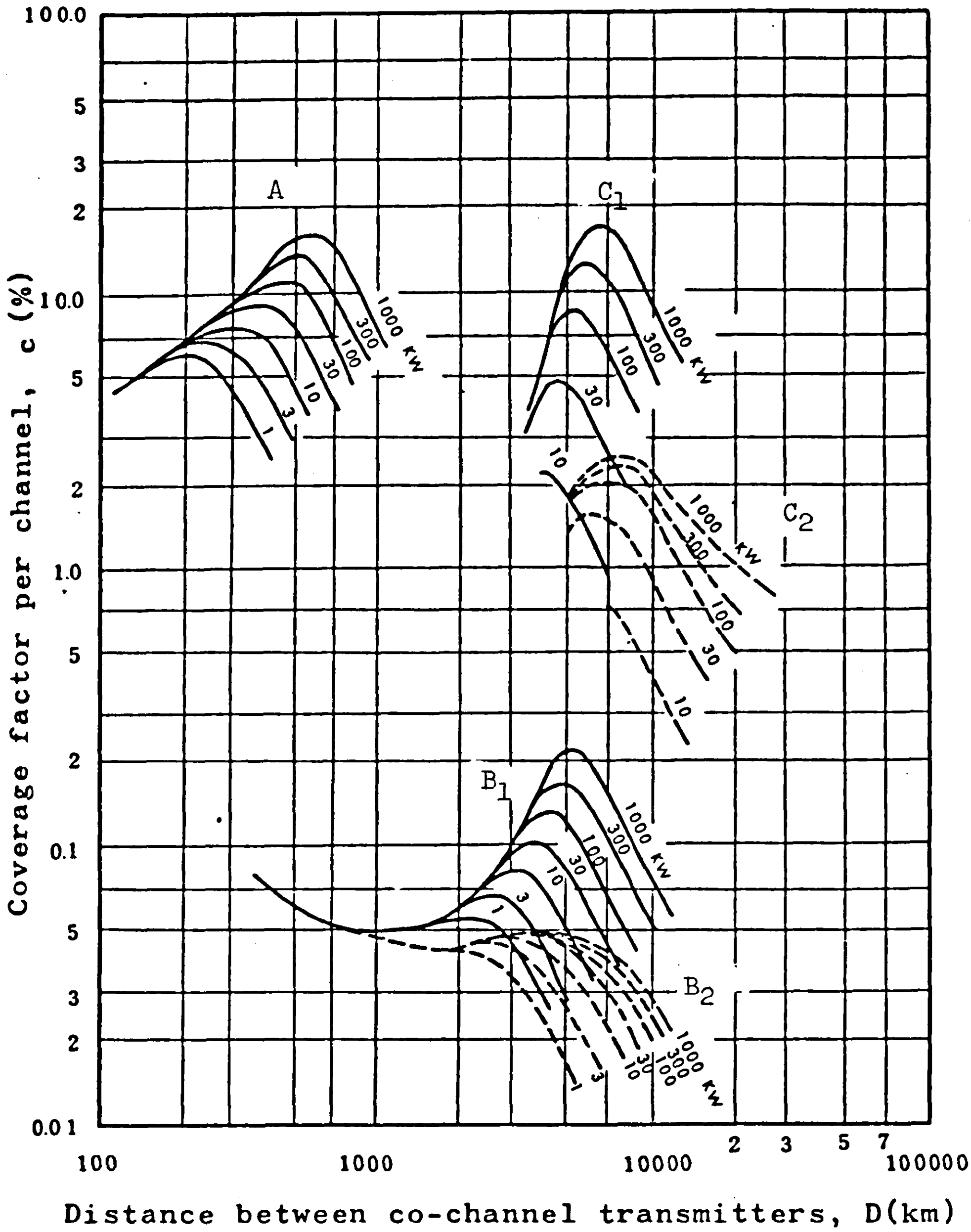


FIGURE 3

Coverage factor per channel, c as a function of distance between co-channel transmitters, D for various propagation curves

A : Ground wave service under day-time conditions
B : Ground wave service under night-time conditions
C : Sky-wave service under night-time conditions

(Radiation, P(kW) is constant at all angles of elevation)

Propagation curve

Ground wave: **Recommendation 368-1** ($\sigma = 3 \times 10^{-3}$ S/m)
Sky-wave : ——— **Report 264-2**(Rev.74)
-·----- **CAIRO(N/S)**

Frequency	f	1 000 kHz
Radio-frequency protection ratio	A	40 dB
Minimum field strength	F_{min}	61 dB

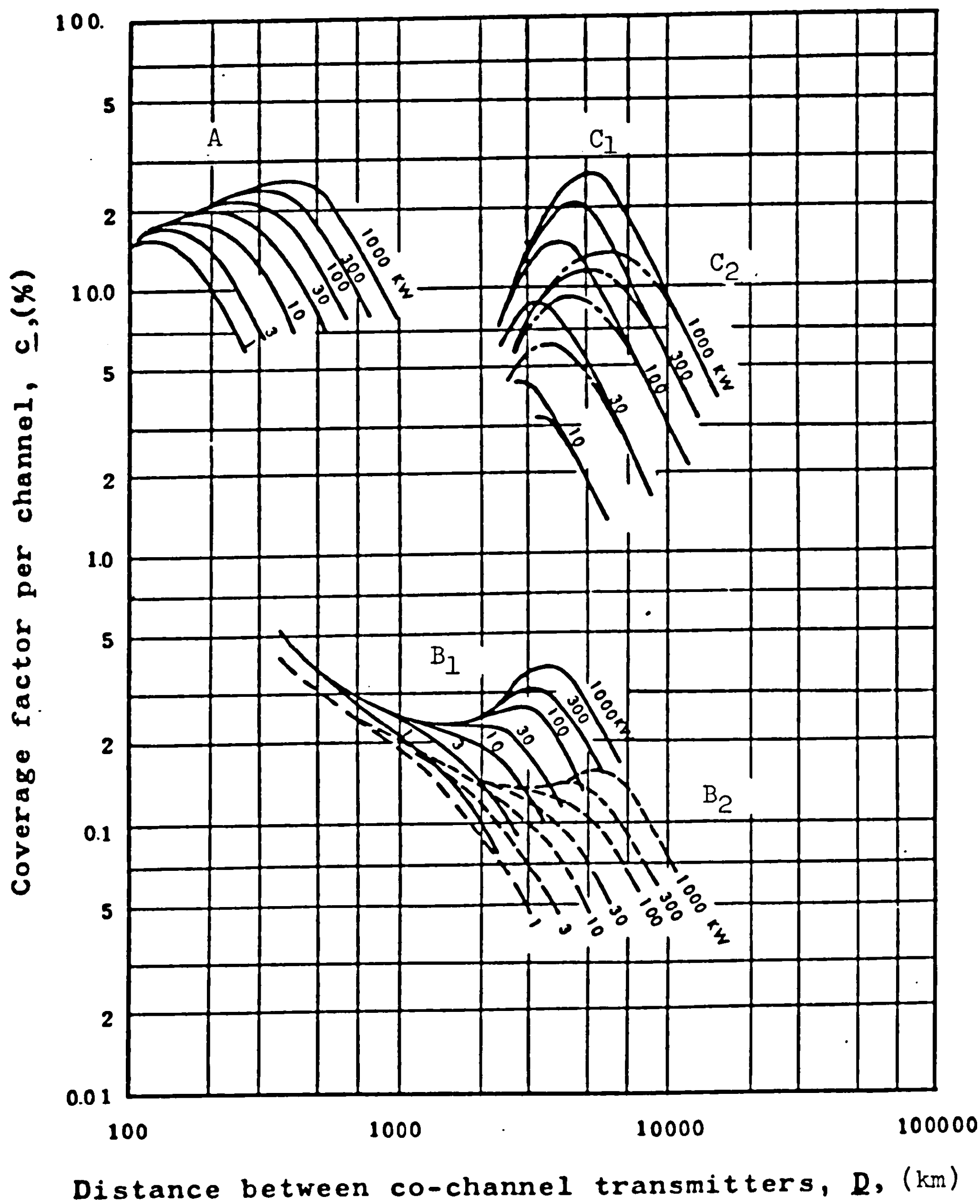


FIGURE 4

Coverage factor per channel, c as a function of distance between co-channel transmitters, D for various propagation curves

A : Ground wave service under day-time conditions
B : Ground wave service under night-time conditions
C : Sky-wave service under night-time conditions

(Radiation, P(kW), is constant at all angles of elevation)

Propagation curve

Ground wave: **Recommendation 368-2 ($\sigma = 3 \times 10^{-3}$ S/m)**
Sky-wave : ——— **Report 264-3**
- - - - **USSR**
—·— **CAIRO(N/S)**

Frequency	f	:	1 000 kHz
Radio-frequency protection ratio	A	:	26 dB
Minimum field strength	F_{min}	:	61 dB

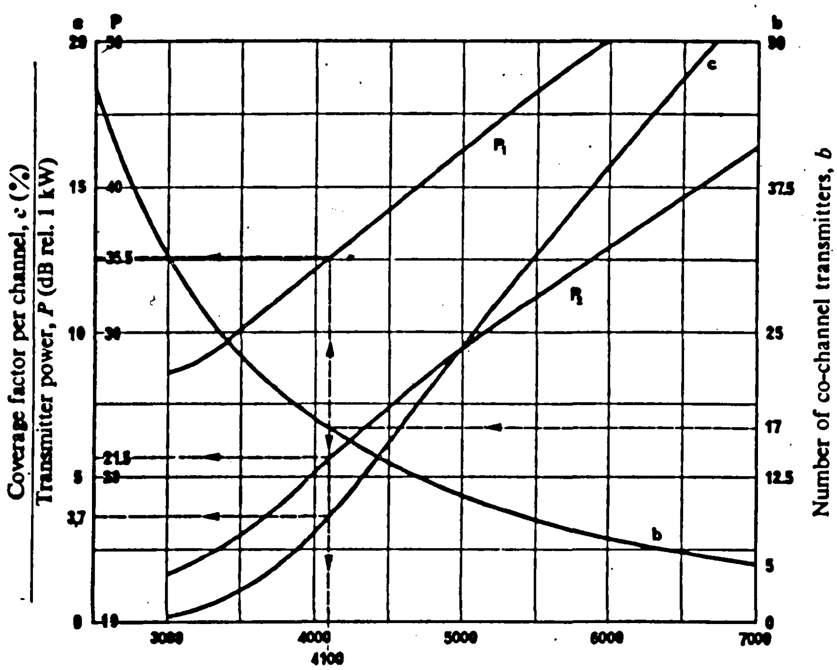


FIGURE 5

Number of transmitters, b, transmitter power P and coverage factor per transmitter, c, as functions of the separation between co-channel transmitters, D

Curves P_1: transmitter power (dB rel. 1 kW) for F_{min} = 74 dB rel. 1 μV/m
P_2: transmitter power (dB rel. 1 kW) for F_{min} = 60 dB rel. 1 μV/m
b : number of co-channel transmitters
c : percentage coverage factor per channel
Radio-frequency protection ratio : 40 dB
Frequency f : 1 MHz

Example:

If the number of transmitters sharing the same channel is taken as b = 17, then the co-channel transmitter separation is D = 4100 km, the coverage factor/channel is c = 3·7% and the e.m.r.p. necessary for all transmitters to make the coverage limiting factor interference rather than noise is:

P = 21·5 dB rel. 1 kW for F_{min} = 60 dB rel. 1 μV/m
or
P = 35·5 dB rel. 1 kW for F_{min} = 74 dB rel. 1 μV/m

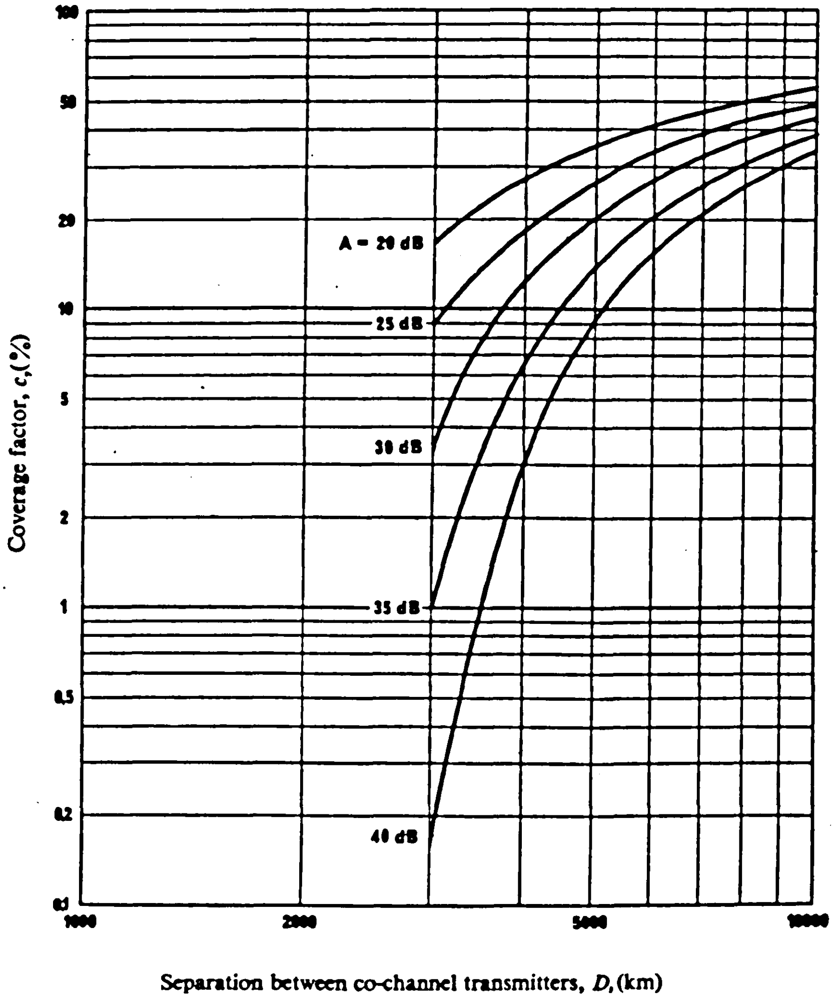
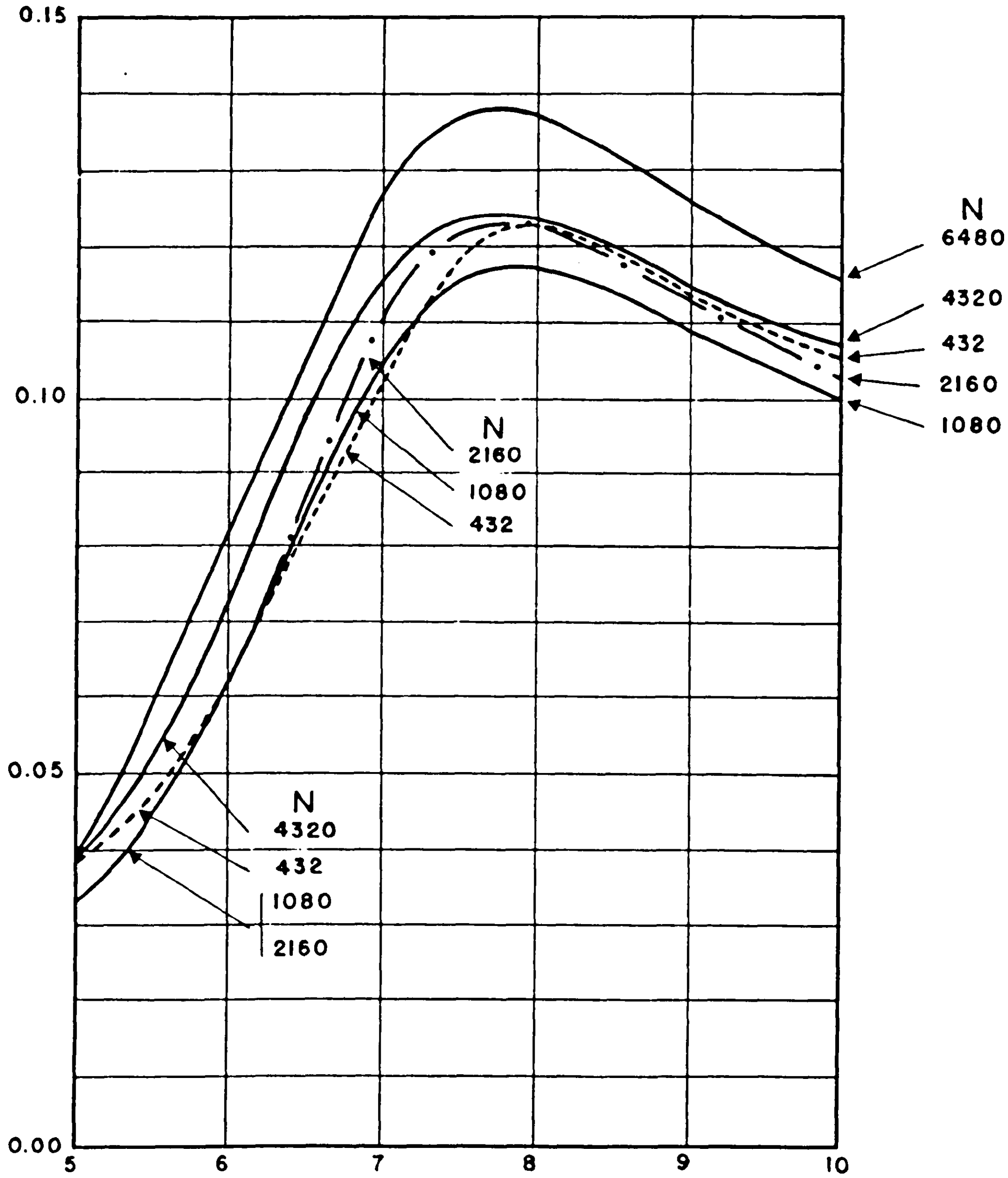


FIGURE 6

Coverage factor for a spherical Earth, c, as a function of separation between transmitters, D, with protection ratio, A as a parameter

Frequency: 1 MHz



Channel separation, Δ f(kHz)

FIGURE 7

Area coverage obtainable using a 1 080 kHz band with N stations in an area of 42×10^6 km^2 by a ground-wave service under night-time conditions

Propagation curve

Ground-wave : Recommendation 368-2 ($\sigma = 3 \times 10^{-3}$ S/m), at 1 MHz

Sky-wave CAIRO (N/S)

Protection ratio : A = 26 dB

Adjacent channel protection ratio curve : Recommendation 449-2, curve A

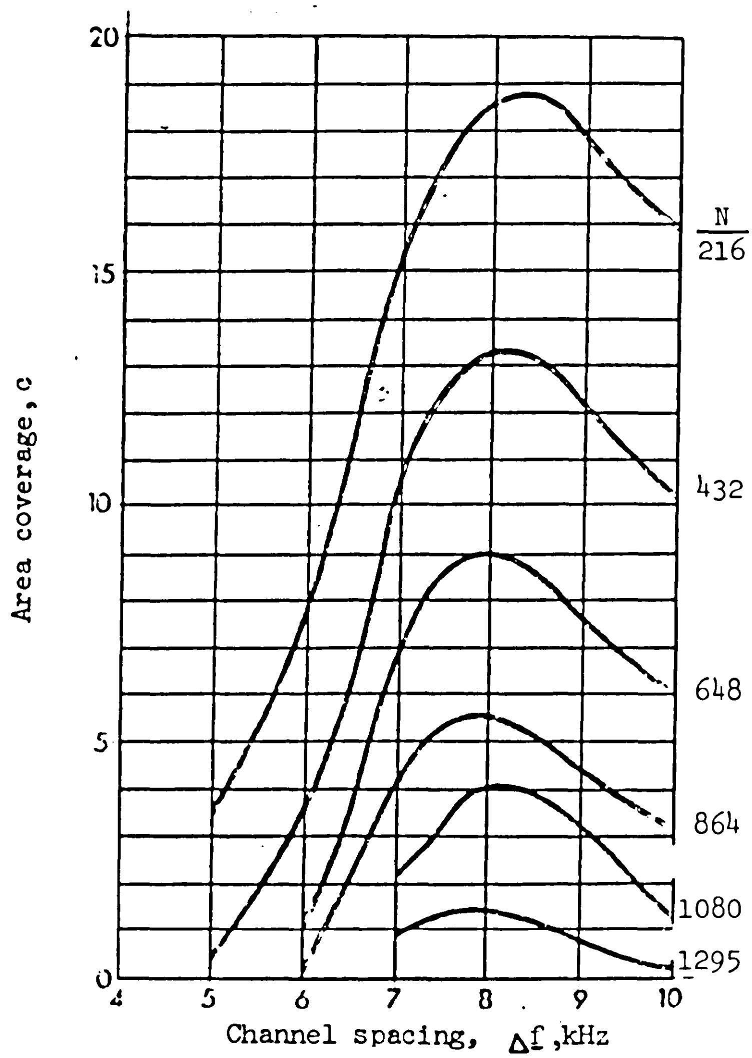


FIGURE 8

Area coverage obtainable by the sky-wave with all channels in band 6 (MF)

Parameter : number of frequency assignments N

Basic assumptions :

- total area : 42×10^6 km^2
- co-channel protection ratio for the median field : 27 dB
- relative protection ratios : curve of Recommendation 449-2
- each wanted transmitter interfered by three co-channel and three adjacent-channel transmitters
- sky-wave propagation curves :

  wanted signal : Report 264-3

  unwanted signal : Report 575 equation (3) /_Eden and Minne, 1973_/.

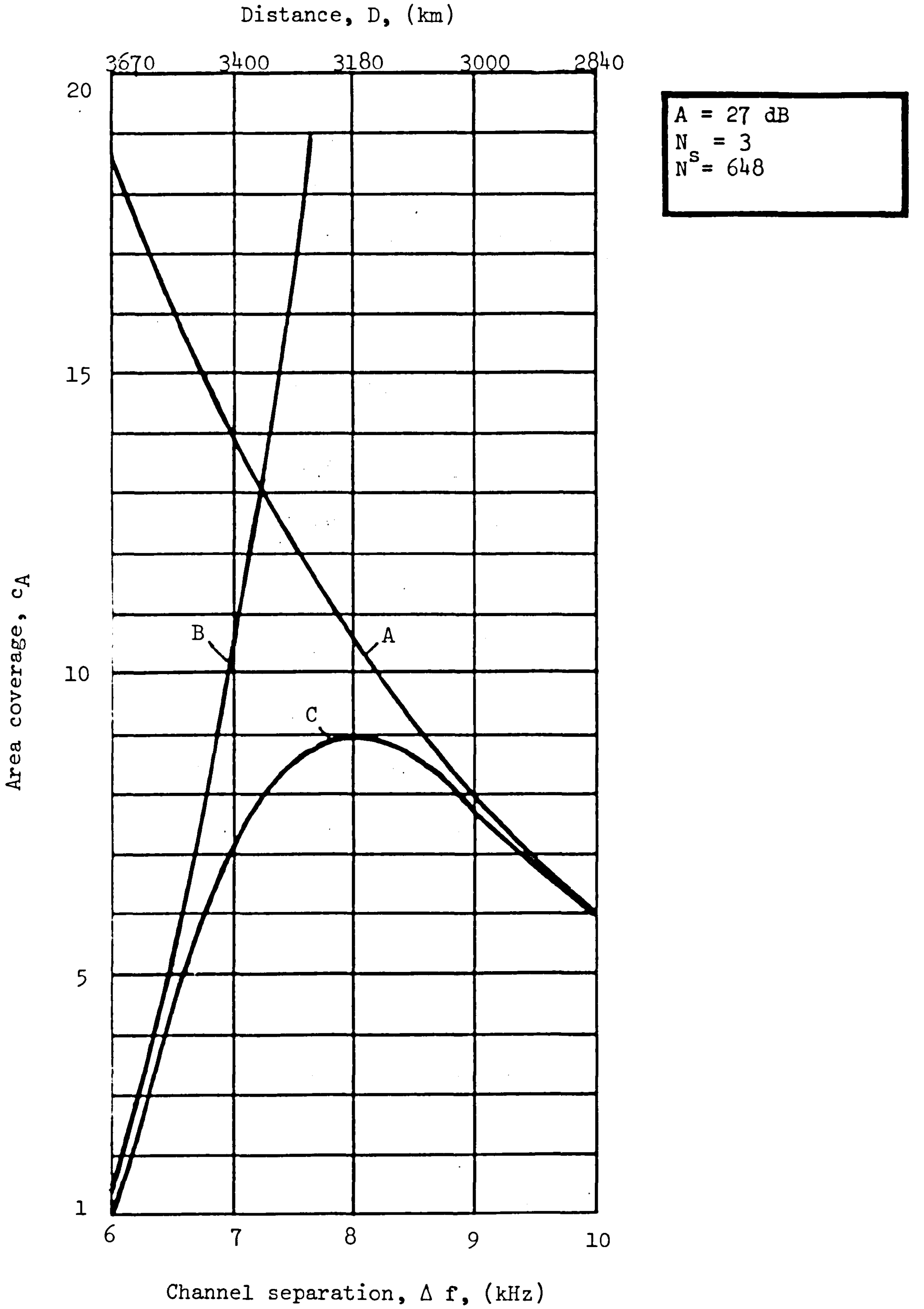


FIGURE 9

Limits for area coverage (radio-frequency protection ratio : 27 dB)

Curve A : area coverage in the presence of co-channel interference (three transmitters)

Curve B : area coverage in the presence of adjacent channel interference (three transmitters)

Curve C : area coverage obtainable in the presence of co-channel and adjacent-channel interference.

REFERENCES

C.C.I.R. /‾1938_7 Document de la Conférence Internationale des Radiocommunications du Caire, Tome 1, pp. 425-433.

C.C.I.R. /‾1970-1974_7 Doc. 10/306, Japan.

E.B.U. /‾May, 1974_7 Doc. Tech. 3206. Technical Parameters for LF/MF Broadcasting.

EDEN, H. and MINNE, D. /‾June, 1969_7 The determination of the limits of coverage in the MF broadcasting band, using regular, plane and spherical transmitter networks. E.B.U. Review, 115-A, 109-120.

EDEN, H. and MINNE, D. /‾December, 1973_7 Broadcasting coverage in the LF/MF bands. E.B.U. Review (Technical), 142, 262-272.

SUZUKI, Y. et al /‾January, 1974_7 Influence of propagation curves on the coverage factor, N.H.K. Laboratories, Note No. 175.

TÄUMER, F. and MÜLLER, K. /‾1965_7 Methods for predicting field strength at night in the 150-1 500 kHz range over distances of 300-3000 km. Technical Committee, O.I.R.T., Study Group IV, Prague.

UDALTSOV, A.N. and SCHLYUGER, I.S. /‾1972_7 Krivye rasprostranemiya ionosfernoi volny dlya radioveschchatelnogo diapazona (Sky-wave propagation curves for the broadcasting band). Geomagnetism i aeronomiya, 5.

VILENSKY, I.M., UDALTSOV, A.N. and SCHLYUGER, I.S. /‾1969_7 Ionospheric propagation in the 150-1 500 kHz range (in Russian). Geomagnetism i aeronomiya, 9.

BIBLIOGRAPHY

C.C.I.R. /‾1963-1966_7 Doc. X/134, E.B.U.

C.C.I.R. /‾1963-1966_7 Doc. X/148, France.

REPORT 401-2*

SOUND BROADCASTING IN BANDS 5 (LF) AND 6 (MF)

High-efficiency transmitting antennae

(Question 13/10)

(1966-1970-1974)

1. Antenna with reduced vertical radiation

Doc. X/21 (U.S.A.), 1963-1966, describes a high-efficiency anti-fading antenna consisting of a sectionalized tower of two 120° sections (used at the WOAI station at San Antonio, Texas). The fading zone area relative to the ground-wave service area is reduced from approximately 50% (for a 0.311 λ antenna) to about 30% for a ground conductivity of 10 x 10^{-3} S/m. The document exphasizes that in this type of antenna the current distribution must be kept as sinusoidal as possible by using a thin structure of uniform cross-section.

Observations. From experience in other countries it is evident that a high-efficiency anti-fading antenna should be of sectionalized construction and have a total electrical height of $2\lambda/3$ to λ, to produce the necessary rapid rise of sky-wave field strength near to the point where it equals that of the ground-wave. The effect of the resistive component of the antenna current on the vertical radiation pattern of a sectionalized tower can be reduced or compensated by multiple feeding. It should be noted that the location and extent of the fading zone varies due to changes in the properties of the reflecting ionospheric layers.

In practice, the fading zone is somewhat larger than that calculated. This might be due on the one hand to variations of the E-layer reflection and on the other hand to F-layer reflections. The design of antennae should take care of these effects.

2. Influence of ground conductivity on the vertical radiation pattern

Doc. 10/188 (United Kingdom), 1970-1974, gives the results of a theoretical study into the influence of ground conductivity on the vertical radiation patterns of typical vertical antennae. The study takes account of the diffraction of waves around the curvature of the Earth.

* Adopted unanimously.

Fig. 1 shows the field strength reduction which would occur if flat perfectly-conducting ground were replaced by an imperfectly-conducting curved Earth. Fig. 1 applies to vertical transmitting antennae up to 0.6 λ high. The curves of Fig. 1 extend to negative angles of radiation which apply when waves diffract around the curvature of the Earth and which are defined as the angular distance between the antenna and the tangent point for the wave.

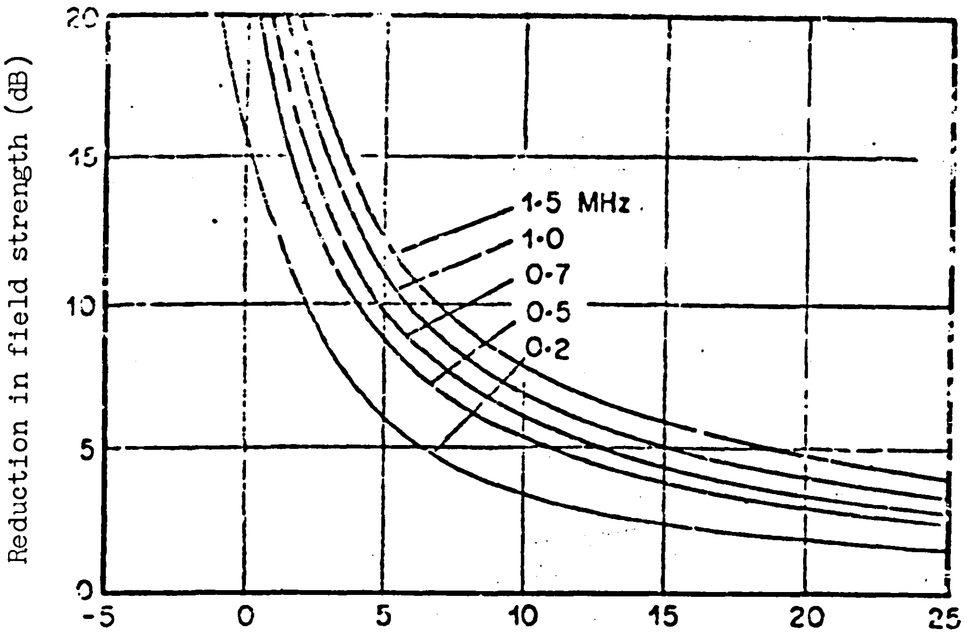
Ground loss may be defined as the reduction in field strength which occurs above a curved Earth when land replaces sea water. Ground loss may therefore be derived from Fig. 1 by subtracting field strength reductions for sea water from those for ground of the appropriate conductivity. The corresponding increase which occurs when land is replaced by sea water is known as "sea gain".

Doc. X/143 (United Kingdom), 1966-1969, gives the results of field strength measurements carried out to determine the effects of ground conductivity on low angle radiation over a relatively long transmission path of 1,400 km. Transmissions from Rome at 845 kHz were measured simultaneously at coastal and inland sites along a radial extending 100 km inland from a coastal site in Southern England. Because of the principle of reciprocity it is immaterial whether the antenna transmits or receives.

Fig. 1 shows the vertical radiation pattern calculated at a frequency of 1 MHz for a short vertical antenna over flat ground of poor conductivity (10^{-3} S/m), good conductivity (10^{-2} S/m) and sea water (4 S/m); fresh water appears to behave like ground of good conductivity. The vertical radiation pattern which would be obtained if the ground were a perfect conductor is also shown for comparison.

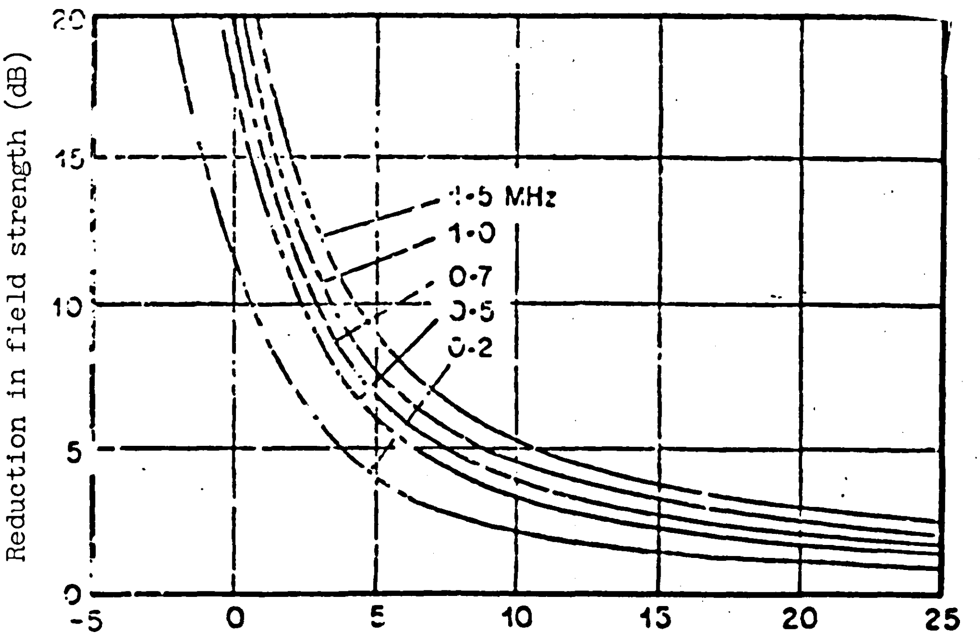
Fig. 2 shows the results of measurements in terms of field strength at the inland sites, B to K, relative to the coastal site, A. This Figure, therefore, shows how ground loss varies with distance from the sea at the frequency 845 kHz for an angle of arrival of about 4°. Also shown in Fig. 2 are theoretical curves for ground conductivities of 5×10^{-3} S/m and 10^{-2} S/m which are believed to be the limits for most of the area. Part of the theoretical curve for 2×10^{-2} S/m is also included since the first 10 km inland was known to be of about this value. Fig. 2 clearly demonstrates the large ground loss at sites well inland from the coast.

The effective ground loss as a function of the propagation path for single and multi-hop propagation has been calculated and is shown in Fig. 3. E-layer propagation has been assumed.



Angle of radiation above horizontal (degrees)

a) Ground conductivity, 10^{-3} S/m

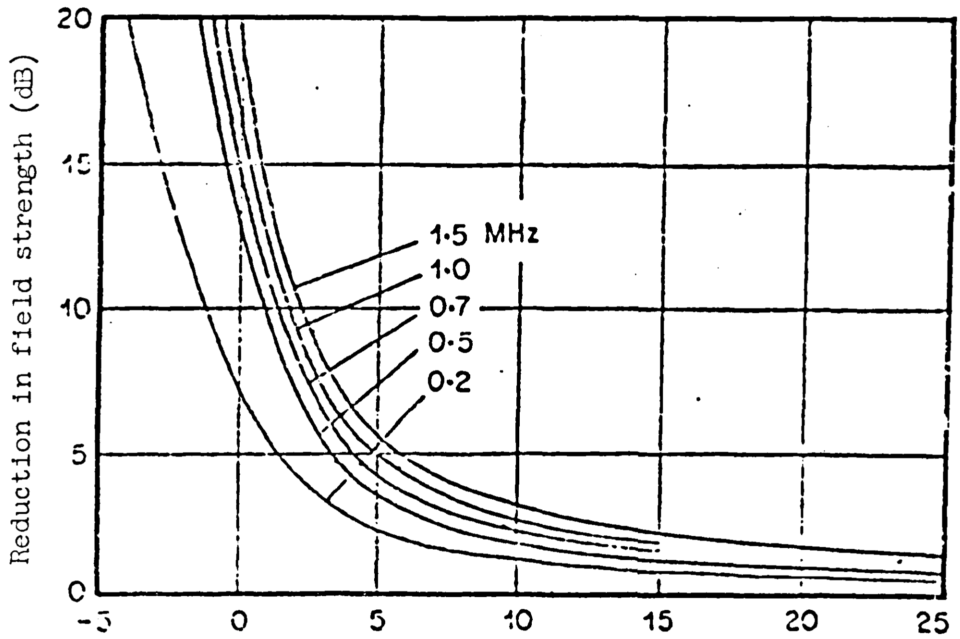


Angle of radiation above horizontal (degrees)

b) Ground conductivity, 3×10^{-3} S/m

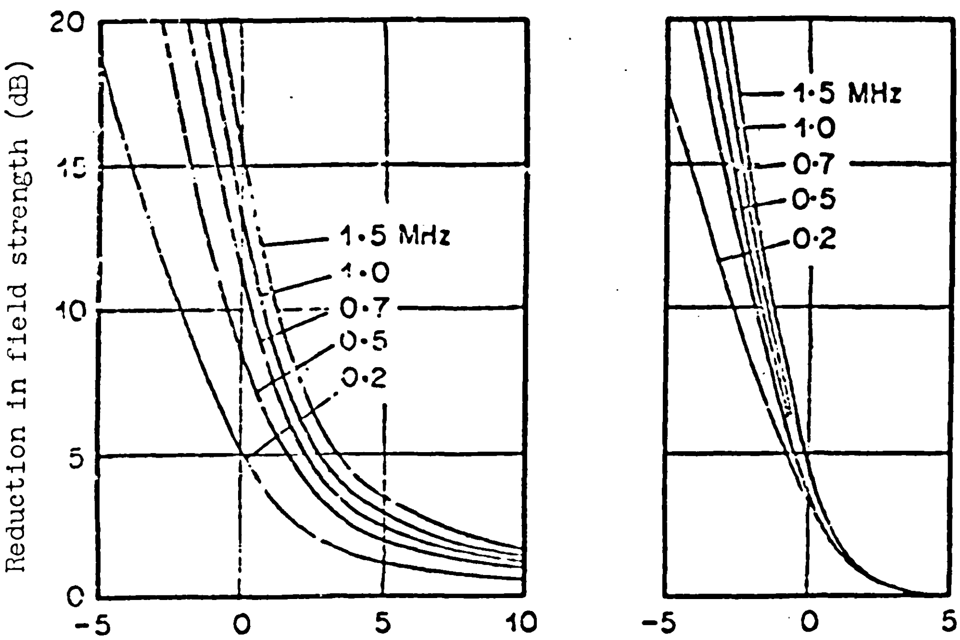
FIGURE 1

Reduction in field strength for vertical antennae up to 0.6 λ high, including the effect of curvature of the Earth



Angle of radiation above horizontal (degrees)

c) Ground conductivity, 10^{-2} S/m



Angle of radiation above horizontal (degrees)

d) Ground conductivity, 3×10^{-2} S/m

e) Ground conductivity, 4 S/m (sea water)

FIGURE 1 *(cont.)*

Reduction in field strength for vertical antennae up to 0.6 λ high, including the effect of curvature of the Earth

It is concluded that a transmitter operating in the MF band (band 6) will radiate sky-waves more efficiently at low angles of radiation if it is situated on a coastline facing the area to be served and that the ground loss does not reach its limiting value until the antenna is at least 50 km inland. To obtain maximum advantage open sea must extend from the coastline for a distance of at least 100 wavelengths in the direction of propagation.

Ground loss applies equally to transmitting and receiving antennae.

Doc. X/31 (Italy), 1966-1969, shows the influence of ground conductivity on sky-wave reception.

Field strength measurements were made over a 450 km transmission path (corresponding to the angle of elevation of about 24°) simultaneously at two points, one on the coast and the other situated inland about 2 km away in the same direction. In the first case, the wave was reflected by the sea and in the second by the ground. Two transmitters in Rome, one operating at 845 kHz and the other at 1 331 kHz, were used.

All the data recorded at both receiving points indicate that the median field strength at the coastal site on both frequencies, is 0.5 dB higher than the value measured inland. This result is in agreement with the calculated theoretical value.

Doc. 10/294 (U.S.S.R.), 1970-1974, gives comparative field strength measurement data in the frequency band 150 - 1 500 kHz. The data were obtained at two receiving points of different ground conductivity, one of which was located near the sea and the other inland at a distance of 60 km from the coast in the direction of the transmitter. Measurements were made on different frequencies over transmission paths of 1,200 to 1,500 km.

Median field strengths were measured at the two receiving points and compared with calculated values for a parallel polarized wave and for the corresponding ground surface by means of the modulus and phase of the Fresnel reflection coefficients.

The measured results indicate that the increase in field strength from a transmitter sited near to the sea when compared with an inland sited transmitter depends to a large extent on the length of the transmission path and that, on long paths, it may exceed 6 dB.

3. High-efficiency transmitting antennae

It should be emphasized that the capital and maintenance costs of a high-efficiency transmitting antenna should not be considered in isolation, but rather with regard to the cost and effectiveness of the broadcasting station as a whole. For example, for a broadcasting station with a transmitter output power of 100 kW or more, the cost of the antenna is often a relatively small part of the total expenditure.

3.1 Doc. X/57 (Federal Republic of Germany), 1966-1969, describes a transmitting antenna for use in band 5 (LF), which improves the service area by virtue of its high radiation efficiency. This antenna operates in the band 150 to 160 kHz, has a height of about $\lambda/10$ and a flat frequency response up to at least $\pm$ 6 kHz of the carrier frequency. Its radiation pattern is that of a vertical unipole antenna of the same physical height.

3.2 Doc. X/190 (Sweden), 1966-1969, gives information on experience gained with the broadcasting ring antenna for use in band 5 at Motala (191 kHz). The antenna is a stationary field ring antenna consisting of one central element (a vertical radiator of height 250 m) and five vertical radiators with a height of 200 m, equally spaced on a radius of 630 m (0.4 λ). The total field strengths at distances of up to 300 km from the antenna were recorded at night over a period of several years at several locations both before, and after, the change was made from a short vertical radiator to the ring antenna. The measurements show a substantial extension of the fading-free zone after the change of antenna. The theoretical vertical radiation diagram shows suppression of radiation at angles of 40° to 45° and this has been roughly confirmed by measurements from aircraft.

3.3 Doc. 10/28 (Federal Republic of Germany), 1970-1974, describes a switchable transmitting antenna for optimized day and night service in band 6 (MF). Two antennae of this type are in use at two broadcasting stations (Ismaning, 1 602 kHz and Langenberg, 1 586 kHz). The antenna consists of three insulated sections and this permits very flexible adjustment of the current distribution and allows changes in the vertical radiation pattern over a wide range. For example, it is possible to effect a reduction of the low angle radiation by up to 3.5 dB, a side lobe attenuation up to a maximum of 38 dB, and a gain in the horizontal plane of up to 6 dB. A suitable combination of these parameters results in an improvement in the co-channel radio-frequency wanted-to-interfering signal ratio of between 3 dB and 10 dB.

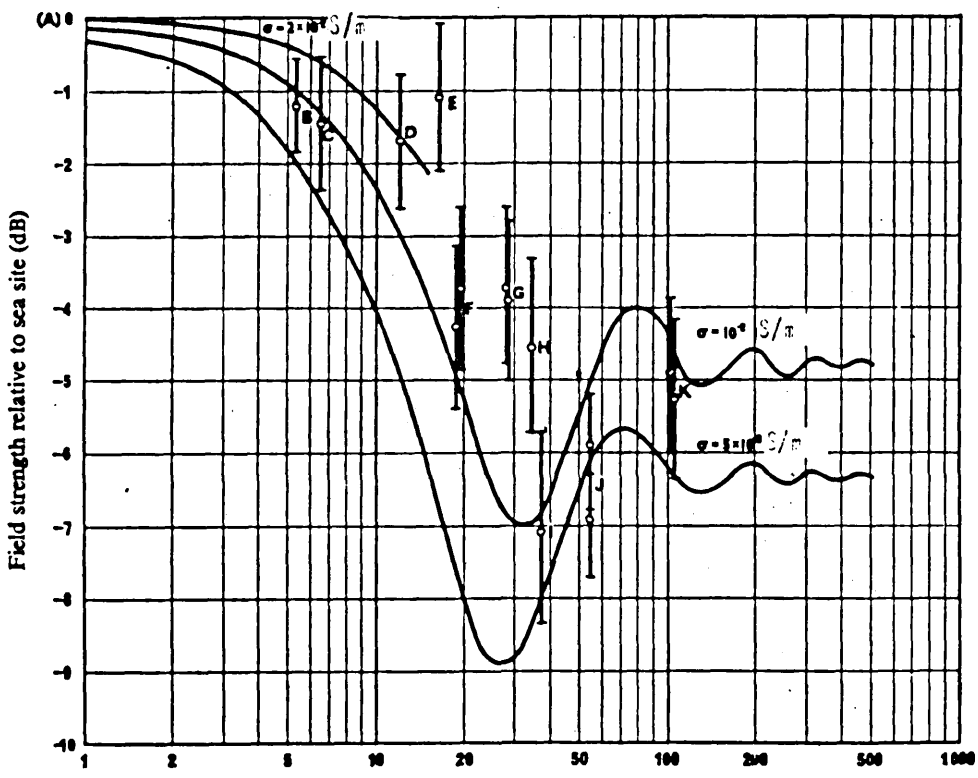


FIGURE 2

Theoretical and measured ground loss

——— : theoretical ground loss
O : measured ground loss

(Vertical lines indicate confidence limits)

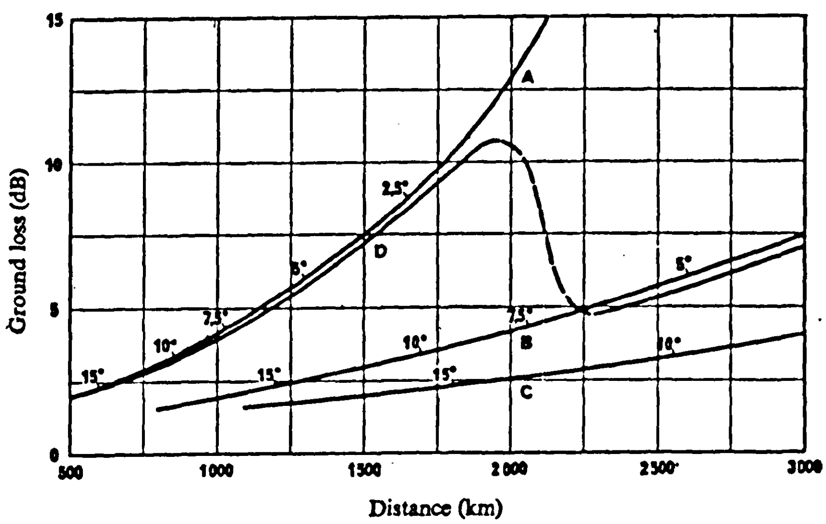
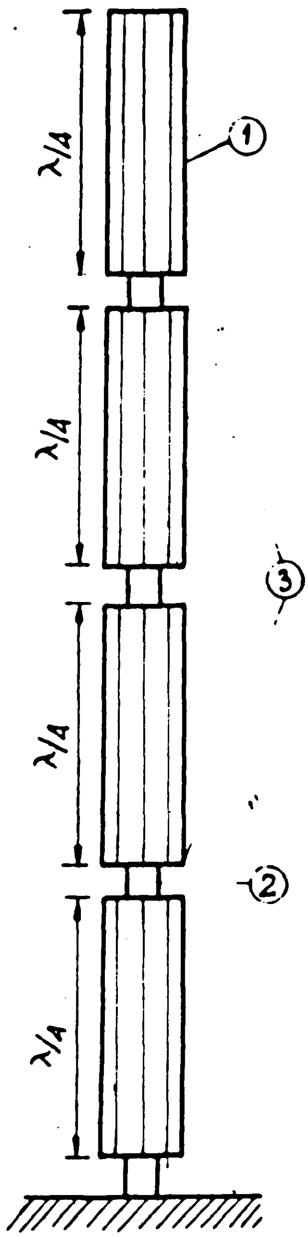


FIGURE 3

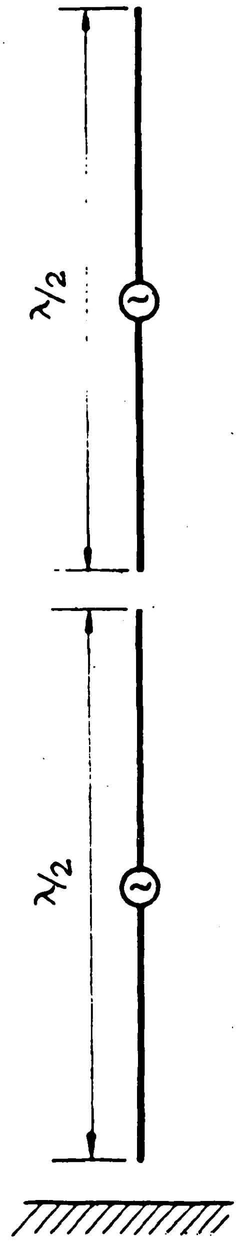
Ground loss for multi-hop propagation

The curves show the ground loss which occurs when sea water is replaced by ground of conductivity 5×10^{-3} S/m at one end of the path. E-layer reflection (layer height 90 km) is assumed and the numbers against the curves denote angles of radiation.

Curve A: single-hop mode
B: two-hop mode
C: three-hop mode
D: effective ground loss for all modes



(a)
Distribution of cages along the mast



(b)
Equivalent circuit

FIGURE 4

Double half-wave cage-type antenna

3.4 Doc. 10/62 (People's Republic of Poland), 1970-1974, describes a double half-wave cage-type antenna for use in band 6 (MF). This antenna consists of four cages of copper or aluminium wires. The cages are suspended on an earth, non-divided, mast, each cage ($\lambda/4$) being galvanically connected with the mast at its upper end and insulated from the mast at its lower end (see Fig. 4). In the document are given the results of a theoretical analysis of the antenna and the results of measurements on a metre-wave model.

By appropriate selection of the ratio and phase of the currents in the two dipoles, the vertical radiation pattern can be shaped within a wide range. This enables selection of the optimum operating conditions for both day-time and night-time conditions.

3.5 Doc. 10/73 (France), 1970-1974, reports on the existence of a high-gain band 6 (MF) broadcasting antenna at LILLE-Camphin on a frequency of 1 376 kHz. This antenna is of the full-wave type and is designed to increase the horizontal gain by reducing radiation in directions other than that of the horizon. It is centre-fed, but its quarter-wave skirt structure avoids cutting the tower with insulators. There is also no insulator at the base of the tower. Feeder matching is effected without the classical antenna unit, inductance or capacitance. The radiation diagram was regulated with the help of measurements made using a helicopter. A detailed description of the antenna is available [Lacharnay, 1969].

3.6 Doc. 10/292 (U.S.S.R.), 1970-1974, describes the design of an antenna the radiation pattern of which can be regulated in the vertical plane. The upper part of the antenna is a normal vertical radiator whilst the lower part is a vertical radiator with a reactance in the form of a short circuit loop connected to the base. To reduce its characteristic impedance inclined wires are suspended from the upper part of the antenna. A vertical wire screen is fixed to the lower part of the antenna reaching from the ground to a height of $H_1 = 0.4$ H.

Regulation of the radiation pattern in the vertical plane is provided by adjusting the current distribution by means of distributed constant lines. The antenna possesses anti-fading properties in a wide frequency band and has a gain of up to twice that of a base driven half-wave antenna.

The antenna can be used in band 6 (MF) with regulation of the current distribution and in band 5 (LF) under conditions corresponding to current antinode at the lower end of the screen.

REFERENCE

LACHARNAY, S. /‾1969_7, Nouvelle antenne hectométrique à grand gain à l'émetteur de radiodiffusion de LILLE-Camphin (Antenne à jupe). Revue Française de Radiodiffusion et de Television, 11

BIBLIOGRAPHY

AIZENBERG, G.Z., BIELOUSOV, S.P., LINDBERG, A.H. and JAMPOLSKIJ, W.S. /‾1961_7, Antifedingowaja antienna dia radiowieszczanija (An anti-fading antenna for radio broadcasting). Radiotechnika 16, 12, 21-30

ANDERSEN, J.B. /‾1963_7, Reception of sky-wave signals near a coastline. Journ. of Research, NBS, 67D, 3, 325-330

ANDERSEN, J.B. /‾1963_7, The radiation field from a vertical dipole on an inhomogeneous ground. Electromagnetic Waves and Antennas (ed. by E.C. Jordan), 1099-1112, Oxford, Pergamon Press

BEM, D.J. /‾1973_7, Antena klatkowa z ksztaltowana charakterystyka promieniowania w plaszczyznie pionowej (A cage antenna with controlled radiation pattern in the vertical plane). Prace Instytutu Łącznosci, XX, 1(69)

BIELOUSOW, S.P. /‾1967_7, Sredniewolnowyje antienny s regulirujemym raspredielenjem toka (Antenna for band 6 (MF) with adjustable current distribution.) Wiestnik swiazi, 8

CLEMMOW, P.C. /‾1953_7, Radio propagation over a flat earth across a boundary separating two different media. Phil. Trans. T. Soc., Series A, 246, 905, 1-55

COLLARD, M. /‾October 1973_7, The reduction of the results of field strength measurements to standardized conditions, for the purpose of studying LF and MF ionospheric propagation. E.B.U. Review - Technical, 141

JEFFERS, C.L. /‾November 1948_7, An antenna for controlling the non-fading range of a broadcasting station. Proc. IRE, Vol. 36, 1426-1431

JEFFERS, C.L. and KERSHNER, S.W., Design and performance measurements on a new anti-fade radio station WOAI

KERSHNER, S.W. and JEFFERS, C.L. /‾March 1960_7, Design and performance measurements on a new anti-fade antenna for radio station WOAI. IRE Transaction on Broadcasting, Vol. B.C.6, 1

KNIGHT, P. and THODAY, B.D.C. [1969], Influence of the ground near transmitting and receiving aerial on the strength of medium-frequency sky-waves. Proc. I.E.E., 116, 6, 911-919

MAGNUSSON, E. and STRANDEN, F. [June 1960], Planning the new Motala Long-Wave Broadcasting Station. E.B.U. Review, A, 107-113

MALLACH, P. [1971], Gestaltung des Vertikaldiagramms von Mittelwellen-Antennen (Design of vertical pattern of MF antennae). Nachrichtentechn. Fachber, 41, Hörrundfunk 2 - VDE - Verlag, Berlin

MILLAR, R.F. [1967], Propagation of electromagnetic waves near a coastline on a flat earth. Radio Sci., (U.S.), 2, 261-286

MONTEATH, G.D. [1951], Application of the compensation theorem to certain radiation and propagation problems. Proc. I.E.E., 98, IV, 1, 23-30

MONTEATH, G.D. [March 1958], The effect of the ground constants, and of an earth system, on the performance of a vertical medium-wave aerial. Proc. I.E.E., Vol. 105, Part C, 7, 292

PAGE, H. and MONTEATH, G.D. [May 1955], The vertical radiation patterns of medium-wave broadcasting aerials. Proc. I.E.E., Vol. 102, Part B, 3, 279

SPONZILLI, L. [1968], Confronto tra ricezioni notturne indirette di onde medie su terra e su mare (Comparison between night reception on land and at sea, of medium waves arriving via the ionosphere). Elettronica, 3, III trim.

WILLIAMS, H.P. [May 1947], The broadcast antenna : presented in the 1948 Radio Convention of the British Institute of Radio Engineers

REPORT 457-1*

SOUND BROADCASTING IN BANDS 5 (LF), 6 (MF) AND 7 (HF)

Necessary bandwidth of emission

(1970-1974)

1. Introduction

In an amplitude-modulation double-sideband sound broadcasting system the bandwidth of emission is approximately twice the audio-frequency bandwidth of the programme and, therefore, greatly influences the quality of reception. On the other hand, for a given frequency separation between adjacent channels, a limitation of the bandwidth of emission is desirable to avoid mutual interference.

The difference between the transmitted bandwidth for amplitude-modulation sound broadcasting and the receiver bandwidth has led to research /̄ C.C.I.R., 1966-1969a and b; Netzband and Süverkrübbe, 1968; Süverkrübbe, 1969; Petke, 1973_7 aimed at improving the whole transmission system. It appears that it would be useful to fix values for the audio-frequency bandwidth of the programme to be radiated as well as for the overall response of the receivers and to obtain these values by the use of band limiting filters. If both these bandwidths are nearly equal and are suitably related to the channel spacing the transmission system provides for the full utilization of the transmitted bandwidth as well as for the most favourable protection against adjacent channel interference /̄ Eden, 1967_7.

2. Assessment of the necessary bandwidth of emission

Obviously the bandwidth of emission as well as the pass-band of the receivers should be chosen in such a way that there is no unnecessary impairment of reception quality or any increase in adjacent channel interference /̄ Netzband and Süverkrübbe, 1968_7. In this respect a good solution would be to make the channel spacing, the bandwidth of emission and the receiver pass-band of equal value. Moreover, ideally there should be rectangular limitation of the bandwidth of emission and the received selectivity curve and no non-linear distortion in the transmitter. Under these conditions no adjacent channel interference would occur.

In practice, however, none of these requirements is met. In particular, the bandwidth of emission usually exceeds the channel spacing by a considerable amount and, in consequence, this has led to the manufacture of domestic receivers with reduced bandwidths which degrades the quality of sound reproduction. Moreover, adjacent channel rejection is not sufficiently improved. For planning purposes, however, it is necessary to achieve a suitable value of relative radio-frequency protection ratio, Report 400-2.

* Adopted unanimously.

3. General considerations

3.1 There exists a well-known interrelation between system bandwidth, carrier spacing and adjacent-channel radio-frequency protection ratio [Süverkrübbe, 1969; Petke, 1973].

3.2 The theoretically obtainable optimum value of protection against adjacent channel interference can be assessed by using an ideal receiver with rectangular pass-band characteristics. In this case the radio-frequency protection ratio is mainly determined by non-linear distortion in the transmitter.

3.3 A theoretical study of the energy spectrum including out-of-band radiation caused by transmitter non-linearities is contained in [Kettel, 1968]. Experimental investigations of the energy spectrum of a high-power transmitter operating in band 6 (MF) [C.C.I.R., 1966-1969] show that the term "occupied bandwidth" as defined in Article 1, No. 90 of the Radio Regulations does not give an adequate indication of the effects of bandwidth limitation on adjacent channel interference.

4. Measurement results

4.1 Measurements of the radio-frequency protection ratios for the case of various values of audio-frequency bandwidths, which are equal at both transmitter and receiver, and at different channel spacings have been carried out in the Federal Republic of Germany [Süverkrübbe, 1969] using the objective two-signal measuring method given in Report 399-2. For the measurements a high quality commercial receiver with an almost ideal pass-band characteristic was used. The interrelation between the parameters involved are shown in Fig. 1. For a given channel spacing there are many pairs of values of audio-frequency bandwidths and adjacent channel protection ratios. If, however, two of the parameters have been chosen, the third is definitely fixed.

4.2 Subjective listening tests were made in the United States of America and in the United Kingdom [C.C.I.R., 1966-1969a and b] whereas in the Federal Republic of Germany radio-frequency wanted-to-interfering signal ratio measurements [Netzband and Süverkrübbe, 1968] were made according to the objective two-signal method of measurement given in Report 399-2. In both cases, the radiated bandwidth was restricted by means of a low-pass filter at the audio-frequency input to the transmitter.

In the United States of America, two table models, one pocket transistor set and one automobile transistor set were used. In the United Kingdom, four transistor portables and one valve table model were taken. In the Federal Republic of Germany, the receivers used were E.B.U. reference receivers, MEK and MBF [I.T.U., 1964], five domestic receivers currently manufactured in the Federal Republic of Germany and two special receivers equipped with mechanical intermediate-frequency filters.

In the three countries, no noticeable degradation of the reception quality was observed with current types of receivers when the bandwidth of emission was limited by a low-pass filter, having a cut-off frequency of about half the adjacent channel carrier frequency separation, inserted at the input to the transmitter.

Mean values of improvement in adjacent channel rejection with current types of receiver resulting from the limitation of the bandwidth of emission, are given in Table I. Values obtained in the Federal Republic of Germany with a special receiver equipped with mechanical filters are shown in parentheses.

In the subjective listening tests carried out in the United States of America, the absolute values of adjacent ratio vary considerably with the type of programme, nevertheless, the mean values of improvement correspond fairly well to the values obtained by the objective method of measurement used in the Federal Republic of Germany.

TABLE I

Improvement in adjacent channel rejection

Ratio of audio-frequency bandwidth to channel spacing	Channel spacing Δf (kHz)	Cut-off frequency of low-pass filter (kHz)	Subjective tests (*S*) or objective measurements (*O*)	Mean value of improvement in adjacent channel rejection (dB)
0·45	10	4·5	*O* (FRG)	12 (29)
0·5	9	4·5	*O* (FRG)	5 (20)
0·5	9	4·5	*S* (UK)	3·6
0·525	10	5·25	*S* (USA)	3 (1)
0·5625	8	4·5	*O* (FRG)	2 (7)
0·5625	8	4·5	*S* (UK)	0·9
0·643	7	4·5	*S* (UK)	0·3
0·7	7·5	5·25	*S* (USA)	negligible

(1) This figure represents the difference between the extreme limits of the "just perceptible" radio-frequency wanted-to-interfering signal ratios obtained with and without filter /‾C.C.I.R., 1966-1969a_/.

4.3 The relationship between system bandwidth, carrier spacing and adjacent-channel radio-frequency protection ratio has been studied further by the E.B.U. These studies were based on the assumption that both the carrier spacing and the adjacent channel radio-frequency protection ratio have predetermined values. Furthermore, it was assumed that any amplitude modulation sound-broadcasting system to be specified for future use should be compatible with existing receivers.

In this study use has been made of the radio-frequency protection ratio values of Recommendation 449-2, thereby taking due account of the characteristics of current types of receiver. A channel spacing of 8 kHz has been assumed, since this is likely to provide highest efficiency in spectrum utilization (see Doc. 10/280 (E.B.U.), 1970-1974). The corresponding relative radio-frequency protection ratio value is then -20 dB.

The determination, on these grounds, of the audio-frequency bandwidth that can be transmitted by a suitably designed double-sideband, amplitude-modulation sound broadcasting system, can best be carried out by means of the numerical method for the determination of the radio-frequency protection ratio /̲ Petke, 1973 /̲.

Any amplitude-modulation sound broadcasting system has, in principle, the same effect on the reception quality as a low-pass filter. Amplitude-modulation systems designed in conformity with the channel spacing and protection ratio requirements mentioned above may, therefore, differ to some extent in bandwidth and rate of cut of the overall amplitude/frequency response. The investigations carried out were, therefore, extended to cover this aspect of the problem of the quality of reception.

It was assumed that the influence on the overall amplitude/frequency response of the entire system was equally distributed between the transmitting and receiving ends. This approach should, however, be considered as a first attempt only and additional studies will have to be carried out for different conditions.

As a result of the calculations made it was found that any one of the three overall amplitude/frequency response curves shown in Fig. 3 would provide satisfactory adjacent channel protection in an 8 kHz channelling system. The curves of Fig. 2 present pairs of values for the bandwidth b and rate of cut-off a_0 required at either end of the AM sound broadcasting system. The solid curve is only valid if use is being made of a notch filter in the receiver to eliminate the beat-note between adjacent channel carriers, whereas the broken line applies to the case where there is no notch filter. The particular points in Fig. 2 numbered ①, ② or ③ correspond to terminal equipment characteristics that would provide overall amplitude/frequency response curves A, B or C, respectively, in Fig. 3.

The results obtained are in close agreement with Fig. 1 which should be considered to provide limiting values, since it applies to the ideal case of rectangular pass-band characteristics. The system bandwidth thus decreases rapidly with decreasing rate of cut-off.

4.4 Results of listening tests

The influence on reproduction quality of an amplitude-modulation sound broadcasting system with 8 kHz channel spacing and a relative protection ratio value of -20 dB for adjacent channel interference has been simulated by using three specified low-pass filters. The pass-band characteristics of these filters are those of curves A, B and C in Fig. 3.

Subjective listening tests then showed quite clearly that a better subjective quality impression is obtained with frequency response curves A and B than with curve C. However, the difference in quality between curves A and B is very small, a fact which may be of considerable economic interest, since the rate of cut-off of the receiver is 20 dB/octave less with curve B than with curve A.

5. Radio-frequency and intermediate-frequency pass-band characteristics of current types of receiver

Receiver characteristics have been collated in various countries and are partly reproduced in Report 333, New Delhi, 1970. Radio-frequency and intermediate-frequency pass-band values between the 6 dB points are quoted ranging between 5 and 10 kHz. It should be noted that the reproduced audio-frequency bands are about half these values. The highest values mentioned are those of "first category" receivers in the U.S.S.R. [C.C.I.R., 1966-1969d] with variable selectivity.

It is known that there are many receivers with even smaller pass-bands than those mentioned in the above references. It has, however, been indicated that in some areas there exist receivers with larger pass-band.

6. Use of bandwidth limitation in operational practice

On an experimental basis, a growing number of transmitters are now operating in bands 5 (LF) and 6 (MF) with a limited bandwidth. One or more high-power transmitters are operated in this manner in the following countries : Federal Republic of Germany, Austria, Finland, France, Italy, Luxembourg, Monaco, the Netherlands, the United Kingdom and Sweden [E.B.U., 1971].

This development started in 1966 and public reaction to the effect on programme quality has been negligible. On the other hand, improved reception has been reported in several cases where adjacent channel interference had previously been severe.

7. A bandwidth-saving overtone transmission and reception system

A new method has been described /̲Gassmann, 1972 and 1973_7, applicable in bands 5 (LF), 6 (MF) and 7 (HF), which allows improved sound quality at the receiver while the audio-frequency modulating signal is restricted in bandwidth. The system is based on the fact that the human ear is unable to identify overtone frequencies above about 4 kHz in relation to the fundamental tone.

The improvement of the sound quality is effected by the addition of artificial overtones generated in the receiver. The amplitudes of the overtones are controlled by a pilot tone at the upper end of the audio-frequency pass-band. The pilot tone carries the information on the amplitude of the overtones and the necessary synchronizing signal in the form of a single-sideband modulation.

8. Out-of-band spectrum of double-sideband sound broadcasting emissions

Draft Recommendation 328-3, § 2.5.1, gives the limit curves for the level of the out-of-band radiation of amplitude modulated double-sideband broadcast emissions. The curves have no fixed relation to the level of the carrier since this relation depends on :

- the modulation factor of the transmitter (r.m.s. value);
- the necessary bandwidth of the emission;
- the bandwidth of the spectrum analyser.

However, the limit curves have a fixed relationship to the maximum level of the sideband components which depends only on the power distribution within the sidebands.

Detailed information on the corresponding values is contained in Report 325-2, § 9.

9. Necessary bandwidth of emissions in band 7 (HF)

9.1 Listening tests have been made on the quality of reception obtainable on short waves and the effects of a reduction of the necessary bandwidth. From these tests, it has been deduced that, although there will be some loss in quality if the audio-frequency band is limited to a highest modulating frequency of 6 400 Hz, this loss is not serious. Tests have also been made in which the audio-frequency band has been restricted to a highest modulating frequency of 5 000 Hz, when, however, the loss in quality becomes quite noticeable.

9.2 In band 7 (HF) 5 kHz channelling is common. It is therefore considered desirable that the bandwidth of the audio-frequency modulating signal band 7 (HF) should be 5 000 Hz and should, in no case, exceed 6 400 Hz.

10. Conclusions

10.1 Fig. 1 shows the relationship between the adjacent channel radio-frequency protection ratio, the channel spacing and the audio-frequency bandwidth and assumes that the audio-frequency bandwidth of the radiated programme is the same as that reproduced by the receiver. When two of the three parameters are selected, the third is definitely fixed. In general the channel spacing will be given and a particular value of radio-frequency protection ratio will be required. Then the full audio-frequency bandwidth as taken from Fig. 1 can be transmitted but full use of the bandwidth of the radiated signal can only be made if the receivers have selectivity characteristics corresponding to that of the audio-frequency filter at the transmitter.

10.2 Measurements made in the United Kingdom, the United States of America and the Federal Republic of Germany show that a reduction of adjacent channel interference can be obtained, if the bandwidth of emission is made approximately equal to the channel spacing. Neither in laboratory tests, nor in practice, has the restriction of the bandwidth of emission led to any noticeable deterioration in reception quality when using current types of domestic receiver. Thus, bandwidth limitation techniques could lead to a more efficient use of bands 5 (LF), 6 (MF) and 7 (HF) for broadcasting.

10.3 The predetermination of values of channel spacing and adjacent channel protection ratio in an amplitude-modulation sound broadcasting system is equivalent to a determination of the quality of audio-frequency reproduction. For example, in the case of 8 kHz channel spacing and -20 dB adjacent channel protection ratio, Fig. 2 shows that, with reasonable values for the rate of cut-off, an audio-frequency bandwidth of 4.2 kHz can hardly be exceeded. Moreover, it is evident from this figure that decreasing rates of cut-off imply decreasing values of audio-frequency bandwidth.

From subjective listening tests it is apparent that, within the predetermined limits shown in Fig. 2, the reception quality mainly depends on the audio-frequency bandwidth. However, when approaching the limits, a slight increase in audio-frequency bandwidth may imply a substantial increase in rate of cut-off, whereas the increase in reception quality may hardly be noticeable.

It may be assumed that similar studies for 9 kHz or 10 kHz channel spacing would lead to corresponding results showing the same tendencies. The apportionment of the overall amplitude/frequency response equally to the transmitter and receiver does not necessarily correspond to optimum conditions. On the contrary, computations indicate that the adjacent channel protection ratio is more sensitive to a modification of the amplitude/frequency response at the receiving end than at the transmitting end of the system. From an economic point of view, however, it may be undesirable to improve receiver selectivity. Further studies are, therefore, necessary before a final decision can be made.

REFERENCES

C.C.I.R. [1966-1969a], Doc. X/16, U.S.A.

C.C.I.R. [1966-1969b], Doc. X/142, United Kingdom

C.C.I.R. [1966-1969c], Doc. X/212, Federal Republic of Germany

C.C.I.R. [1966-1969d], Doc. X/196, U.S.S.R.

E.B.U. [August, 1971], Modulation processing techniques for AM sound broadcasting. Doc. Tech. No. 3088

EDEN, H. [December, 1967], Perspectives of replanning LF/MF broadcasting. E.B.U. Review 106-A, 242-251

GASSMANN, G.-G. [October, 1972], Hochwertige Musikübertragung mit nur 7 kHz Bandbreite, Bericht über die 9. Tonmeistertagung, Köln, 26. bis 29.10.1972, herausgegeben vom Verband deutscher Tonmeister. (High quality music transmission at only 7 kHz bandwidth) Report on the 9th meeting of sound engineers, Cologne, 26-29 October 1972, edited by "Verband deutscher Tonmeister" (Association of German sound engineers)

GASSMANN, G.-G. [November, 1973], Verbesserung der AM-Übertragungsqualität bei unveränderter Systembandbreite, Vortrag der NTG-Tagung "Hörrundfunk", Düsseldorf, November 1973. (Improvement of AM transmission quality at unaltered system bandwidth; paper read at the NTG-Conference "Sound broadcasting", Düsseldorf, November 1973)

I.T.U. [1964], African LF/MF Broadcasting Conference. Report by the Preparatory Meeting of Experts, Geneva, 1964, § 3.1, 11 and Appendix 2, 85-95

KETTEL, E. [February, 1968], Is the compatible single-sideband principle advantageous for AM broadcasting? E.B.U. Review 107-A, 8-15

NETZBAND, R. and SÜVERKRÜBBE, R. [June, 1968], The effects of bandwidth limitation in the transmission and reception of AM sound broadcasting, E.B.U. Review 109-A, 115-124

PETKE, G. [October, 1973], Determination by calculation of the RF protection ratio for AM transmission systems, E.B.U. Review - Technical, 141, 227-234

SÜVERKRÜBBE, R. [August, 1969], System bandwidth and channel spacing in AM sound broadcasting, E.B.U. Review 116-A, 161-164.

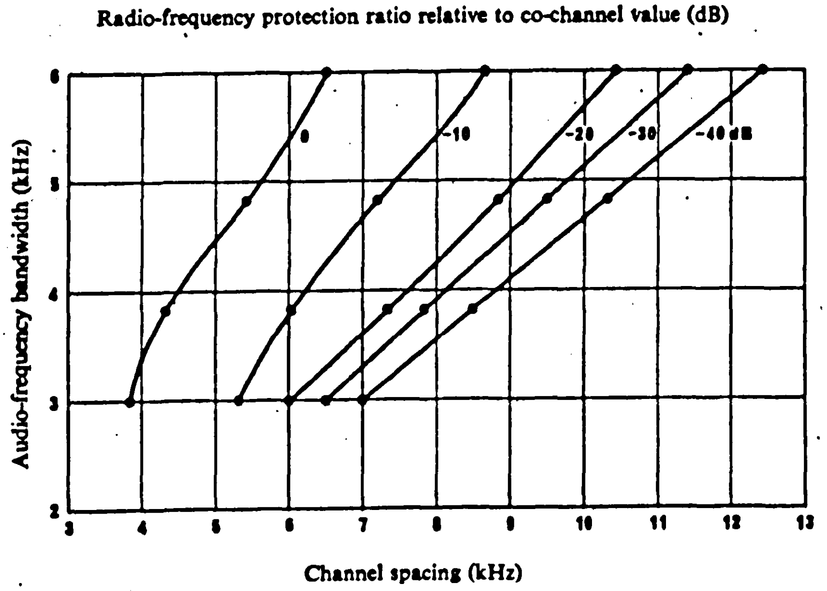


FIGURE 1

Use of the frequency spectrum

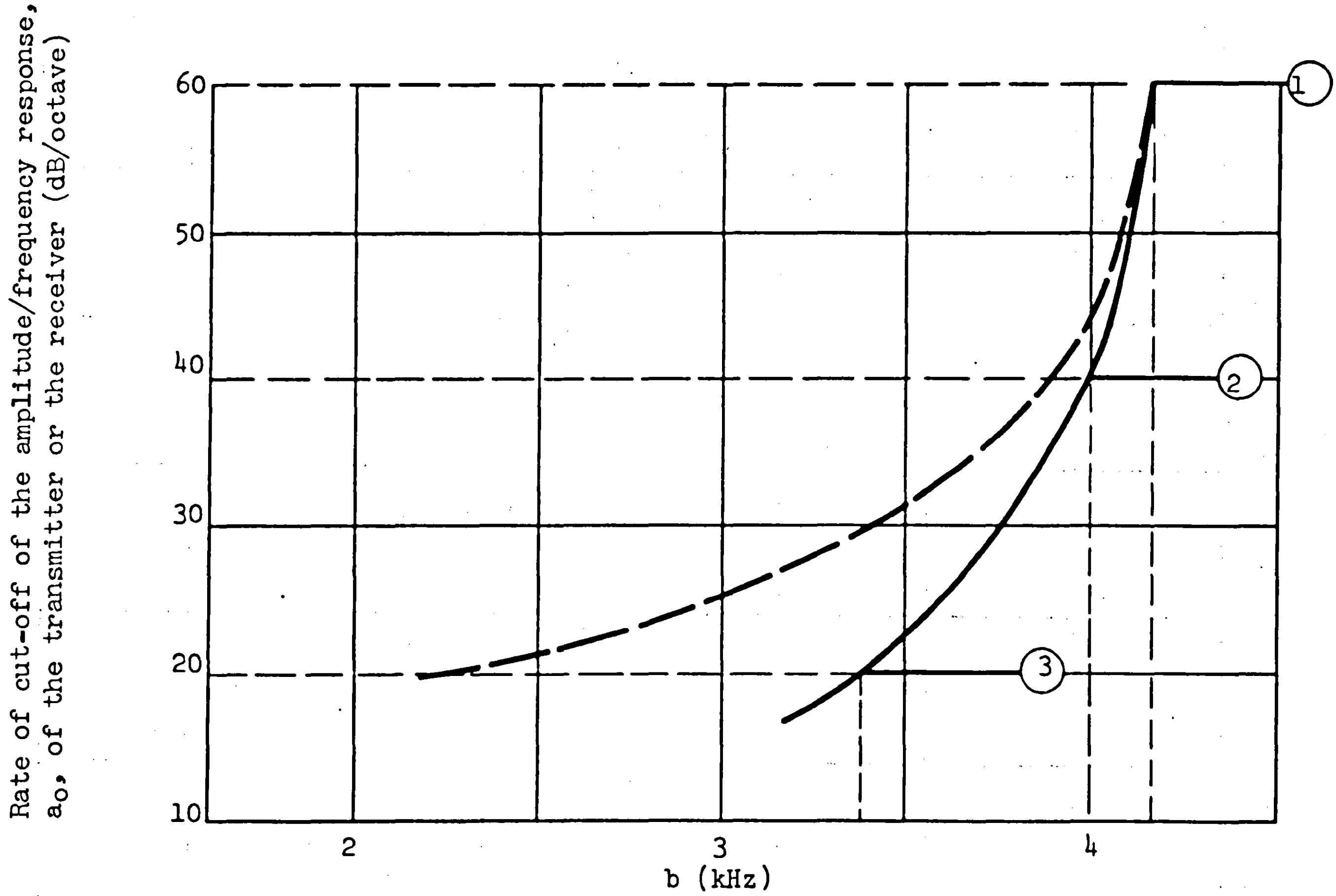


FIGURE 2

Characteristics of an amplitude-modulation sound broadcasting system for optimum quality of reproduction

Basic assumptions :

Channel spacing : 8 kHz
Relative adjacent channel protection ratio : -20 dB

———— : Characteristics including the effect of a notch filter for elimination of the carrier beat

— — — : Characteristics without notch filter

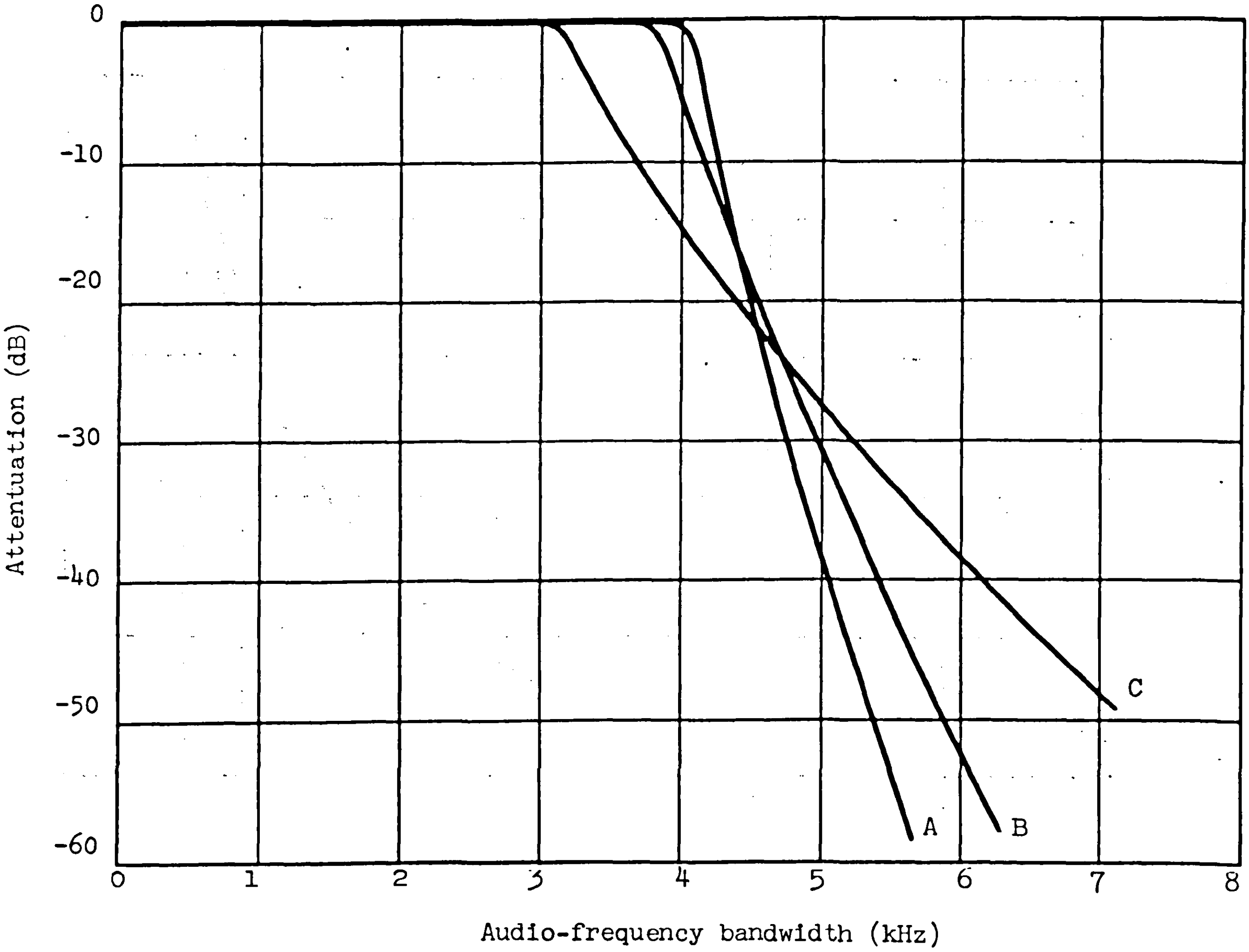


FIGURE 3

Overall amplitude/frequency response for an amplitude-modulation sound broadcasting system for optimum quality of reproduction

Curve A : overall rate of cut-off for system - 120 dB per octave

Curve B : overall rate of cut-off for system - 80 dB per octave

Curve C : overall rate of cut-off for system - 40 dB per octave

REPORT 458-1*

SOUND BROADCASTING IN BANDS 5 (LF), 6 (MF) AND 7 (HF)

(Question 25/10)

(1970 - 1974)

1. Introduction

Question 25/10 relates to the possibility of standardizing one or more sound broadcasting systems on a world-wide basis. It is clear that the study of this complex question is not sufficiently advanced to achieve this aim. The present Report, therefore, is only a summary of the information available, intended to encourage administrations, broadcasting organizations and industry to take an interest in these questions and to undertake the studies necessary to solve them.

At present, broadcasts in bands 5, 6 and 7, unlike sound and television broadcasting in band 8 (VHF), are operated throughout the world with an almost complete absence of internationally standardized transmission characteristics, with the exception of channel spacings and carrier frequencies for bands 5 and 6, but even these differ from region to region. The other transmission characteristics vary from country to country and in many cases even from transmitter to transmitter [E.B.U., 1971].

2. Systems available for standardization

The following list of possible systems cannot, at the present time, be considered as complete. Several of these systems are compared in [Haviland, 1969]. This study also shows that interference between transmitters must be considered when defining a system and the importance of well-defined channel spacings becomes apparent.

* Adopted unanimously

Modulation	Detection	Code
Amplitude-modulation, double-sideband	Envelope detection	AM-DSB-ENV
Amplitude-modulation, double-sideband	Synchronous detection	AM-DSB-SYNC
Compatible single-sideband amplitude-modulation	Envelope detection	CSSB
Single-sideband amplitude-modulation	Synchronous detection	SSB-SYNC
Frequency modulation (narrow band)		FM

Each of the above systems may incorporate modulation processing devices (see Note). If such a device is necessary in the receiver to obtain full advantage of a similar device in the transmitter, the code should be completed by a suitable abbreviation. Thus, an amplitude-modulation double-sideband system with envelope demodulation comprising a compressor in the transmitter and an expander in the receiver, is coded AM-DSB-ENV-COMPANDOR. An example is given in Annex I.

Note.- By "modulation processing" is understood any process consisting in altering certain characteristics of the modulation, such as the dynamic range, audio-frequency bandwidth, etc.

Descriptions of amplitude-modulation, double-sideband systems with synchronous detection appear in [Netzband, 1969] and [C.C.I.R., 1966-1969] and it should be noted that only these systems can serve as transition systems from amplitude-modulation double-sideband systems with envelope detection to single-sideband systems with synchronous detection. Receivers based on synchronous detection would produce undistorted audio-frequency signals for both the above systems ("receiver compatibility").

3. Characteristics to be specified

For the systems mentioned in § 2, the characteristics whose standardization will be required are given below. This list is not necessarily complete.

3.1 All systems

- channel spacing,
- carrier frequencies,
- intermediate frequency or frequencies,
- receiver oscillator frequency stability.

Note 1.- The relationship between these characteristics is shown in Annex II.

- audio-frequency bandwidth of the programme,
- necessary bandwidth of emission,
- overall bandwidth of the receiver.

Note 2.- For the relationship between these characteristics and the channel spacing, see Report 457-1. Deviations from standardized values may be tolerated, if they do not result in unacceptable interference.

- characteristics of modulation processing devices.

In addition, the following characteristics should be standardized.

3.2 Amplitude-modulation double-sideband systems

- maximum depth of modulation.

When laying down the characteristics of the transmission system and the reference receiver*, the following rules should be taken into account :

3.2.1 The transmission system and receiver characteristic should be suitably related, particularly in the amplitude/frequency response. Harmonic distortion should be reduced to acceptable values. In this respect, criteria for the determination of tolerances for the overall amplitude and phase characteristics and ways for the assessment of practical values are set out and discussed by Makiedonski [Makiedonski, 1974].

3.2.2 The audio-frequency bandwidth transmitted should be related to the carrier spacing.** (The precise bandwidth cannot be given; some administrations are of the opinion that it should be one half of the

* This is to obtain the best adaptation of a frequency-assignment plan to receivers of reasonable performance.

** See Report 457-1.

spacing between carriers, and some of them believe that this value may even achieve the value of unity; but this depends on the absolute channel spacing.

3.2.3 Uniform carrier spacings, with nominal carrier frequencies being an integral multiple of the carrier spacing, should be adopted at least within the broadcasting bands 5 and 6. (There are technical advantages also in the adoption of uniform carrier spacing on a world-wide basis, including band 7.)

3.2.4 The intermediate frequency, or frequencies, of the receiver should be an integral multiple of the carrier spacing.

3.3 <u>Single-sideband systems with synchronous detection</u>

- degree of reduction* of the carrier wave,
- degree of suppression of the unwanted sideband,
- maximum permissible values of intermodulation products,
- auxiliary signals to obtain receiver synchronization.

Note 3.- Some information on a range of suitable values for the degree of carrier reduction and on an acceptable level of intermodulation products is contained in Annex III (see also Doc. 10/14 (Federal Republic of Germany), 1970-1974).

Note 4.- In single-sideband suppressed carrier systems, the precision of the locally re-inserted carrier is important for the reception quality. Comprehensive subjective listening tests have shown / Thiessen, 1973 / that the effects of non-linear distortion and inaccuracy of the re-inserted carrier superimpose and can be described by :

$$\Delta Q = (k_2/10\%)^2 + (k_3/6\%)^2 + (\Delta f/12\ \text{Hz})^2$$

where ΔQ : impairment of quality on the basis of a 6-grade scale,

k_2, k_3 : distortion factors of the 2nd and 3rd harmonics,

Δf : frequency error, (Hz), of the re-inserted carrier.

A maximum value $\Delta Q_{max} = 0.25$ appeared to be just tolerable. Values of $k_2 = 2.9\%$, $k_3 = 1.7\%$ and $\Delta f = 3.5$ Hz would jointly be admissible if the disturbing effects are assumed to be evenly distributed.

* See Recommendation 326-2, § 1.5.

The considerations under § 3.2 would apply, and where possible the same characteristics should be adopted. In addition, account should be taken of the following rules :

3.3.1 The suppression of the same sideband (upper or lower) would have to be adopted within each broadcasting band. The present state of research indicates that in the technology of intermediate-frequency and audio-frequency filters suppression of the lower sideband is preferable. It is therefore suggested that for broadcasting in bands 5 and 6 the upper sideband should contain the full audio-frequency modulation.

3.3.2 The degree of carrier reduction should not exceed 12 dB.

3.3.3 Agreement would be required on whether one sideband should be totally suppressed or whether there should be a form of vestigial-sideband transmission according to a fixed amplitude/frequency response.

3.3.4 The audio-bandwidth transmitted should be related to the carrier spacing. (The precise bandwidth cannot be given, the fraction of the channel spacing might well approach unity).

3.4 Frequency modulation

- modulation index,
- maximum modulation frequency.

3.5 Compatible single-sideband systems

- maximum depth of modulation,
- degree of suppression of the unwanted sideband,
- maximum permissible values of intermodulation products.

4. Transition period

In order to achieve a smooth transition from double-sideband to single-sideband broadcasting, any single-sideband system as specified in § 3.3 should enable the satisfactory reception of a double-sideband signal as specified in § 3.2.

REFERENCES

C.C.I.R. /‾1966-1969_7, X/135, U.S.A.

E.B.U. /‾August, 1971_7, Modulation processing techniques in AM sound broadcasting. Doc. Tech. No. 3088.

HAVILAND, R.P. /‾June, 1969_7, A comparative study of communication systems using different modulation-demodulation techniques. E.B.U. Review 115-A, pp. 102-108.

MAKIEDONSKI, A. /‾1974_7, Analiza zniekształceń obwiedni sygnału zmodulowanego przy jednoczesnym występowaniu zniekształceń tłumieniowych i fazowych jego grupy falowej (Analysis of the envelope distortions of a signal modulated in the simultaneous presence of attenuation and phase distortion of its spectrum). Prace Instytutu Łączności, Tomo XXX, No. 3(75).

NETZBAND, R. /‾April, 1969_7, A novel arrangement for the reception of single-sideband and double-sideband transmissions in AM sound broadcasting. E.B.U. Review 114-A, pp. 60-63.

THIESSEN, P. /‾August, 1973_7, Assessment of the deterioration in quality of single-sideband transmissions as a result of frequency error and harmonic distortion. E.B.U. Review (Technical), p. 140.

Annexes : 3

ANNEX I

THE USE OF VARIOUS MODULATION PROCESSING DEVICES

In the O.I.R.T., studies have been made on the possibilities of increasing the modulation factor, i.e. the sideband power, by either trapezoidal modulation or dynamic-compression operation with transmitters operating in bands 6 (MF) and 7 (HF) [C.C.I.R., 1970-1974a]. The results were, that dynamic compression without clipping should be preferred, if the objective is to increase the sideband power with a minimum loss of quality (e.g. for music programmes). On the other hand, if a loss of quality is deemed unimportant (e.g., for speech programmes), trapezoidal modulation leads to a higher degree of sideband power.

Experiments carried out in the RFZ, Berlin, have confirmed the assumed increase of the sideband power as follows :

- Compression of the dynamic range by 12 dB :

  average gain with a rise-time of 0.5 ms and a decay-time of 35 ms : $\approx$ 6 dB.

- Compression of the dynamic range by 6 dB :

  average gain with a long decline period (1.5 s) for programmes with a wide dynamic range : $\approx$ 3 dB.

- Trapezoidal modulation :

  average gain with 5 dB increase in the level of the audio-frequency signal and clipping : $\approx$ 3 dB.

Studies have been carried out in Sweden concerning the improvement in radio-frequency wanted-to-interfering signal ratio obtained by using audio-frequency compression and expansion in connection with a double-sideband amplitude-modulation system and a frequency modulation system with a maximum deviation of $\pm$ 5 kHz [C.C.I.R., 1966-1969].

The audio-frequency range was from 40 to 5 000 Hz.

The compressor reduced the dynamic range of the audio-frequency signal, expressed in decibels, to half its value, the time-constants were 2 ms for the rise-time and 20 ms for the decay-time. The expander had characteristics reciprocal to those of the compressor.

The test results can be summarized as follows :

In the absence of interference, no change in quality was observed when using both compressor and expander in the system. The quality was also judged to be satisfactory by listening when only the compressor was used.

In the presence of co-channel interference, the radio-frequency protection ratios (dB) were found to be as follows :

	Type of modulation	
	Amplitude	Frequency
- without compressor and expander	40-50	40-45
- with compressor only	30-40	30-40
- with compressor and expander	20-25	25-30

It should be noted that these values were obtained when the unwanted transmitter was not equipped with a compressor.

In a more extensive study covering double-sideband amplitude-modulation only, the effect of compression and expansion on the radio-frequency protection ratio was investigated when the unwanted transmitter was also equipped with a compressor [C.C.I.R., 1970-1974b]. The study was made with different types of programme transmitted by both the wanted and the unwanted transmitters.

When a speech programme was interfered with by another speech programme, the reduction of the radio-frequency protection ratio was about 15 dB when using compression and expansion. No deterioration in reproduction quality has been reported. When only compression was applied there was a smaller reduction in protection ratio of about 10 dB; in this case, the quality of the reproduced sound was considered lower than acceptable and significantly worse than when no compression was applied.

When a music programme was disturbed by either music or speech, the result depended to a great extent on the character of the wanted programme. The advantage obtained with compression plus expansion or with compression only was always smaller than when the wanted programme was speech, and sometimes even negligible.

REFERENCES

C.C.I.R. /‾1966-1969_/, Doc. X/153, Sweden.

C.C.I.R. /‾1970-1974a_/, Doc. 10/66, O.I.R.T.

C.C.I.R. /‾1970-1974b_/, Doc. 10/43, Sweden.

ANNEX II

CHANNEL SPACING, PROTECTION RATIO AND INTERMEDIATE FREQUENCY

When choosing the carrier frequencies, channel spacing and also the intermediate frequencies to be used in receivers, it is important that they should be chosen to minimize interference from

- the local oscillators of the receivers in use or of nearby receivers, either by the fundamental or a harmonic frequency;
- harmonics of a transmitted frequency, or other possible intermodulation products /_ C.C.I.R., 1963-1966; SCART, 1966; C.C.I.R., 1970-1974_/.

If both the carrier frequencies and the intermediate frequency are an integral multiple of the carrier spacing, then all interfering products will also be integral multiples of the carrier spacing. Theoretically, therefore, maximum protection could then be obtained because the frequency difference between any interfering signal of this kind and the wanted carrier frequency would be zero or a multiple of the channel spacing.

If these requirements are to be met in a particular broadcasting band it would be essential for the channel spacing to be uniform throughout the band. It would be more advantageous, moreover, if this condition could be met in both bands 5 and 6 or better still throughout bands 5, 6 and 7. On the other hand, this condition should be satisfied on a world-wide scale or at least in those areas, where a single frequency assignment plan exists or will be established /_ Eden, 1967_/.

However, it must be noted that the disturbance caused by an interfering signal increases rapidly as its frequency difference from the wanted signal increases from zero.

Under present-day conditions the frequency differences might have any possible value and this may require an additional protection ratio of up to 17.5 dB. With the adoption of the proposed arrangement, the maximum frequency difference would depend on the accuracy with which the local oscillator frequency and the centre frequency of intermediate-frequency pass-band can be controlled. To achieve an improvement close to the maximum possible it would be necessary to achieve stabilities of the order of 100 Hz. As far as the intermediate-frequency stability is concerned this could be achieved by using ceramic or mechanical filters rather than using conventional intermediate-frequency coils. The control of the initial tuning operation and the frequency drift of the local oscillator may require special techniques in which automatic frequency control may be required. The adoption of the proposal would, therefore, give little improvement in the short term, with existing receivers, but would offer the chance of substantial improvement in the future without any disadvantages under present-day conditions.

REFERENCES

C.C.I.R. /¯1963-1966_7, Doc. X/161, France.

C.C.I.R. /¯1970-1974_7, Doc. 10/273, France.

EDEN, H. /¯December, 1967_7, Perspectives of replanning LF/MF broadcasting. E.B.U. Review 106-A, pp. 242-251.

SCART, /¯May, 1966_7, Contribution à l'étude de la fréquence intermédiaire pour les récepteurs de radiodiffusion destiné à recevoir les émissions en ondes kilométriques et hectométriques. Fascicule de documentation SCART, VII, edited by the SDSA, 16, rue de Presles, 75 Paris 15.

ANNEX III

CARRIER REDUCTION AND ACCEPTABLE INTERMODULATION LEVEL FOR SINGLE-SIDEBAND BROADCASTING TRANSMITTERS

In the event of the introduction of the single-sideband technique for amplitude-modulation broadcasting, it would seem desirable to use the definitions existing in Recommendation 326-2.

According to this Recommendation, the carrier component is defined in relation to the peak envelope power P_p of the emission.

The peak envelope power P_p of a radio transmitter is rated by the acceptable intermodulation level D_n.

For single-sideband broadcasting transmitters, the acceptable intermodulation level D_n which determines the non-linear distortion (quality) and the out-of-band radiation (adjacent channel interference) has not yet been established.

Since small non-linear distortion and adjacent channel interference are required, the acceptable intermodulation level D_n will be probably not less than 38 dB.

The sideband power P_s of a transmitter depends on the peak envelope power P_p and the chosen carrier suppression, "a".

For a single-sideband broadcasting transmitter, the most appropriate value of "a" will depend mainly on the carrier recovery requirements in the cheap single-sideband receiver. To be able to produce the reference carrier for the product demodulator at an acceptable cost, carrier reduction must be restricted to between about 6 and 12 dB, at the transmitter.

Fig. 1 shows the relation between the sideband power P_s and the carrier reduction, "a", for a given peak envelope power of the transmitter. The indication (1) denotes the values for modulation by a sinusoidal signal and the indication (2) denotes the values for noise or programme modulation. The values of the voltages U and the powers P are given as percentages related to their peak envelope values. With programme modulation and a carrier suppression of more than 30 dB, the sideband power P_s (2) will be about 10% of P_p. A transmitter operating with a carrier reduction of 6 dB can, when modulated with a programme signal, only radiate a sideband power P_s (2) of about 2.5% of its nominal peak envelope power.

For the calculation of P_s (2) it has been assumed that the ratio of the mean power to the peak envelope power is 0.1. (See Recommendation 326-2, Table I, class of emission A3J.)

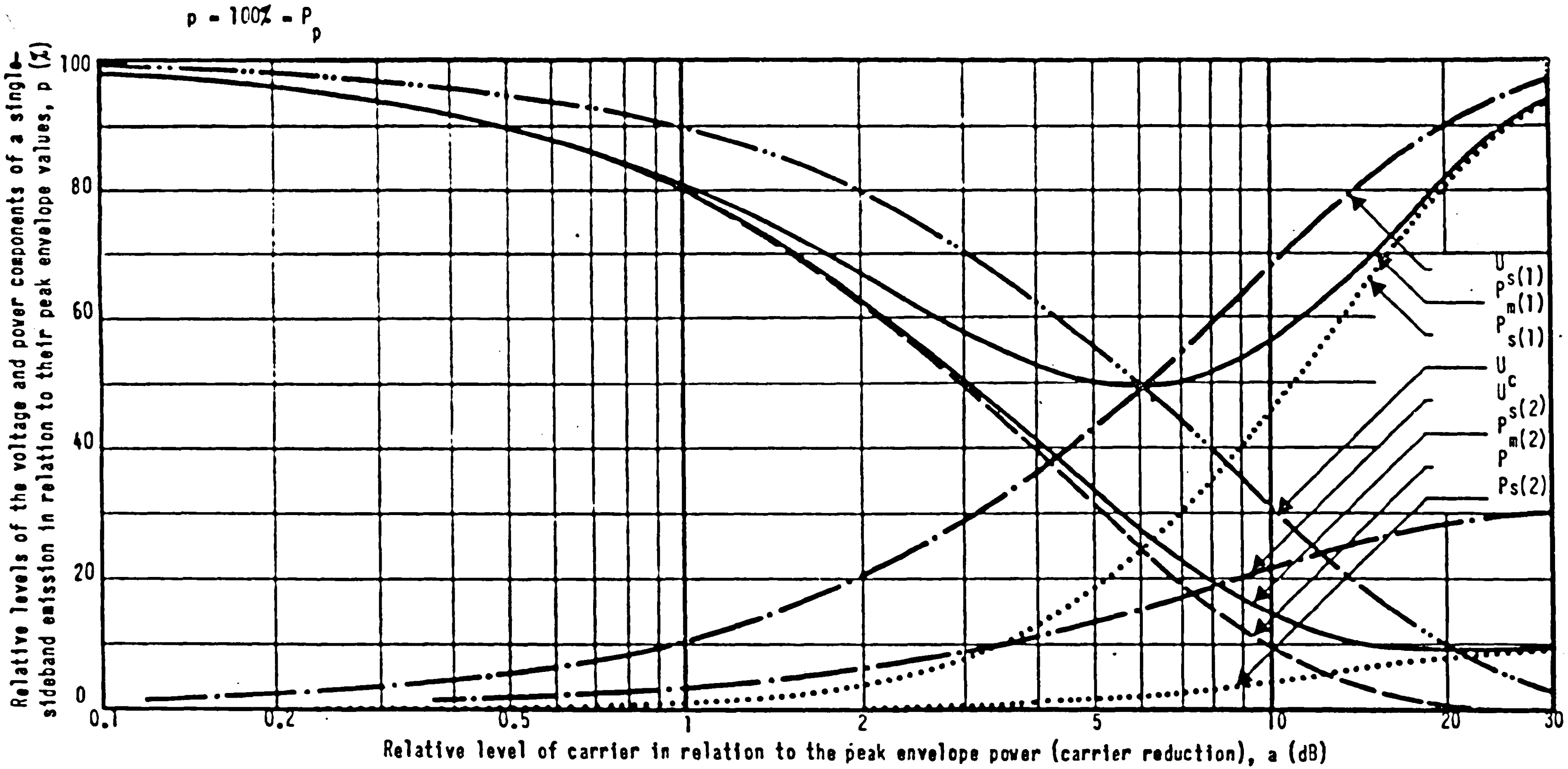


FIGURE 1

P_p	:	peak power of the transmitter (defined by means of the acceptable intermodulation level D_n).
U_c	:	carrier voltage (rms value).
$U_s(1)$	:	sideband voltage for modulation with a sinusoidal signal (rms value).
$U_s(2)$	:	sideband voltage for programme or noise modulation (rms value).
P_c	:	carrier power.
$P_s(1)$	:	sideband power for modulation by a sinusoidal signal.
$P_s(2)$	:	sideband power for programme or noise modulation.
$P_m(1)$	:	transmitter mean power for modulation by a sinusoidal signal.
$P_m(2)$	:	transmitter mean power for programme or noise modulation.

REPORT 459-1*

RADIO-FREQUENCY PROTECTION RATIO FOR SYNCHRONIZED BROADCASTING TRANSMITTERS

(Study Programme 25A-1/10)

(1970 - 1974)

It is a well-known fact that the radio-frequency protection ratios for transmitters working in the same channel can be improved considerably by synchronizing techniques, thereby increasing the effective service areas of these transmitters (see also Report 616). Actual values for these protection ratios depend on various factors, including the synchronization method. For frequency planning purposes it is desirable to have available internationally agreed radio-frequency protection ratios. For the African Broadcasting Area a value of 8 dB was laid down at the African LF/MF Broadcasting Conference [I.T.U., 1966].

The following sections supply information concerning other regions on protection ratios and associated matters.

1. Investigations carried out in the U.S.S.R. [C.C.I.R., 1966-1969]

These investigations have been carried out to determine values of signal-to-interference ratio applicable to reception of transmissions from synchronized transmitter groups comprising two or three transmitters. Both phase and frequency methods of synchronization were considered.

1.1 Explanation of the term "radio-frequency protection ratio"

The term "protection ratio" in this context means the ratio of the field strength of the strongest signal from one of the transmitters in the synchronized group to the resultant field strength of the remaining transmitters in the same group.

*Adopted unanimously.

1.2 Determination of the protection ratio

For the purpose of determining the protection ratio, use was made of a statistical method based on subjective impressions of reception quality from a transmitter in a synchronized group compared with reception quality of a single non-synchronized transmitter station. Twenty-six experts were employed - all of whom were technical and scientific broadcasting staff.

Protection ratio values for non-fading signals were determined under laboratory conditions and later verified under operational conditions.

For fading signals only operational tests using a synchronized network were carried out.

For all these tests the depth of maximum modulation was 90%.

1.3 Results of investigations

Fig. 1 shows the variations in protection ratio as a function of the phase shift between the carriers of two stations during day-time in the absence of fading. The parameter used in these curves is the percentage of experts who rates the total signal as being at least satisfactory. It will be seen from this figure that, to satisfy 90% of the listeners, the protection ratio for a network consisting of two synchronized stations for reception without fading was 4 dB.

Fig. 2 shows the variation in protection ratio as a function of the difference in frequency between two synchronized transmitters for the percentage of experts who found the reception quality to be satisfactory. This figure shows that, for non-fading signals with two synchronized transmitters and a protection ratio of 4 dB, it is necessary to have a synchronization accurate to 0.015 to 0.02 Hz, to satisfy 90% of listeners. With a frequency difference of 0.1 Hz the protection ratio has to be increased to 6 dB.

Fig. 3 contains similar curves for phase synchronization operation of three transmitters. To satisfy 90% of the listeners the protection ratio should not be less than 3.1 dB. (The standard value is 4 dB.)

It is concluded that when reception is affected by fading it will be necessary to increase the protection ratio to 7 to 8 dB in the case of two synchronized transmitters, and to 6 dB in the case of three transmitters.

2. Investigations carried out within the E.B.U. /¯E.B.U., 1957_/

Synchronizing techniques as developed up to 1964 (and in most cases still in use) in several countries, notably, Austria, France, Federal Republic of Germany, Italy, Netherlands, Norway, Sweden, United Kingdom, Australia and the United States of America, are described in /¯E.B.U., 1957_/ which contains an extensive bibliography, as well as a survey over the theoretical basis of these techniques.

3. Investigations carried out within the O.I.R.T. /¯C.C.I.R., 1970-1974; Augustin and Schulze, 1973_/

In the O.I.R.T., it was found that it is possible to simulate all the essential effects of synchronized or non-synchronized common channel systems (same programme) in practice by a model. Such a model, a block diagram of which is shown in Fig. 4, was developed by the Rundfunk- und Fernsehtechnisches Zentralamt of the Deutsche Post, Berlin. That model offers both economical and operational advantages, when carrying out studies on reception problems in the area, where the ground waves of synchronized transmitters interfere; i.e. without taking into account ionospheric fading effects.

When using the above-mentioned model system, it is possible to study synchronized or non-synchronized common channel systems in the laboratory. In particular, it has been found that the following measures are suitable /¯Augustin and Schulze, 1973_/. If the carrier frequencies differ only about 0.1 Hz and if the delay times of the sound signals between the studio and the transmitters of this system have been equalized, the following advantages then result :

- decrease of the interference zone to almost zero, and
- decrease of the selective fading effects, so that only amplitude fading effects still remain, which are entirely compensated by the automatic gain control of the receiver, without unacceptable distortions.

In conclusion, it can be said that these effects permit a protection ratio of 0 dB for day-time reception.

These theoretical results have been confirmed in field tests by using two transmitters of 20 kW operating in band 6 (MF) with a spacing of about 80 km.

REFERENCES

AUGUSTIN, E. and SCHULZE, R. /‾1973_7 Probleme des Gleichwellenrundfunks : Ein optimales Gleichwellensystem (Problems of synchronized broadcasting transmissions : An optimum system of synchronized transmitters) Techn. Mitt. des RFZ, 4, 95-97.

C.C.I.R. /‾1966-1969_7 Doc. X/213, U.S.S.R.

C.C.I.R. /‾1970-1974_7 Doc. 10/65, O.I.R.T.

E.B.U. /‾April 1957_7 Use of synchronized groups of transmitters in broadcasting. Doc. Tech. No. 3070 (Revised 1974).

I.T.U. /‾1966_7 Final Acts of the African LF/MF Broadcasting Conference, Geneva.

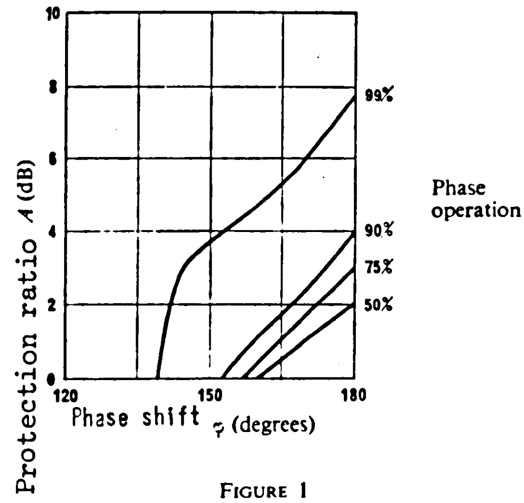


FIGURE 1

Quality of speech and music transmissions as a function of the phase difference between the carriers of two stations (non-fading conditions)

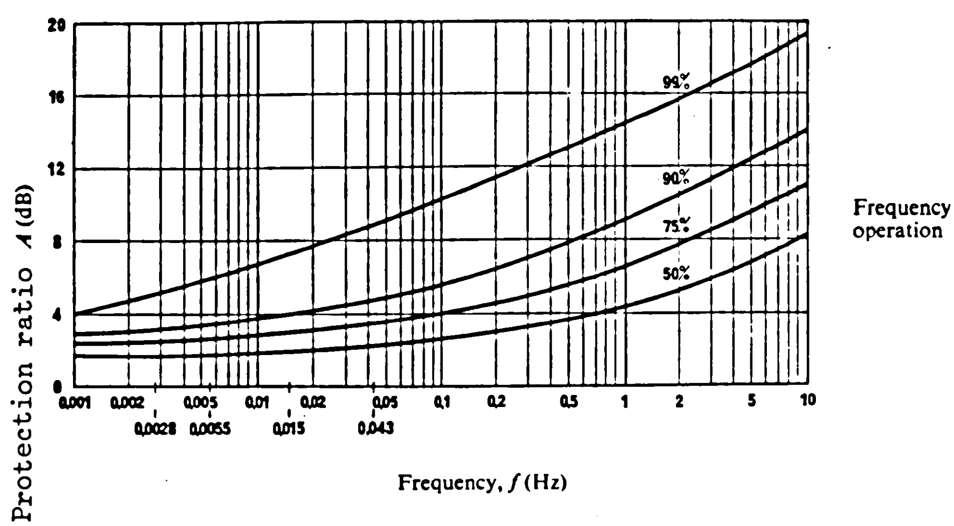


FIGURE 2

Quality of speech and music transmissions as a function of carrier synchronization accuracy of two stations (non-fading conditions)

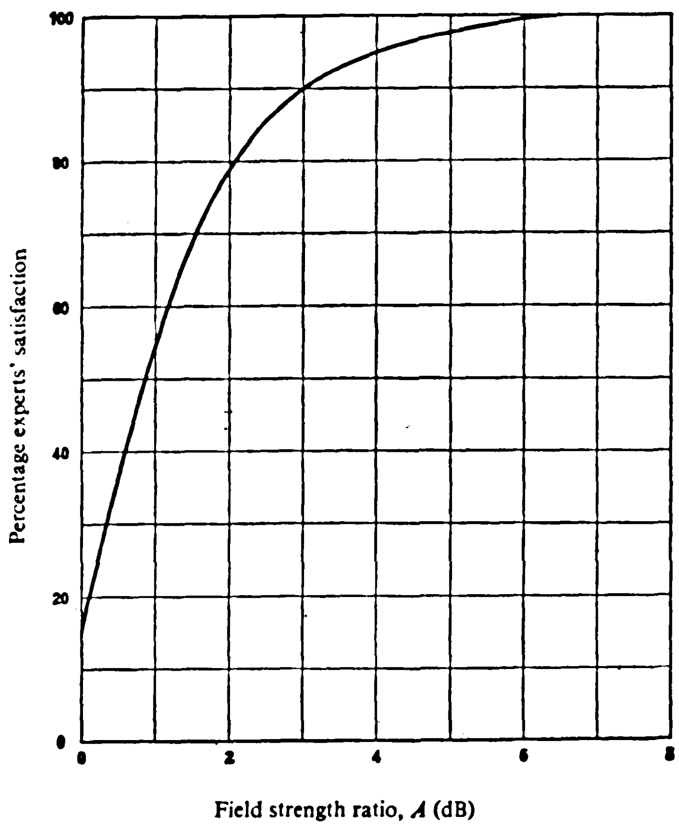


FIGURE 3

Quality of speech reception and of music transmissions as a function of the field-strength ratios of three transmitters synchronized in phase

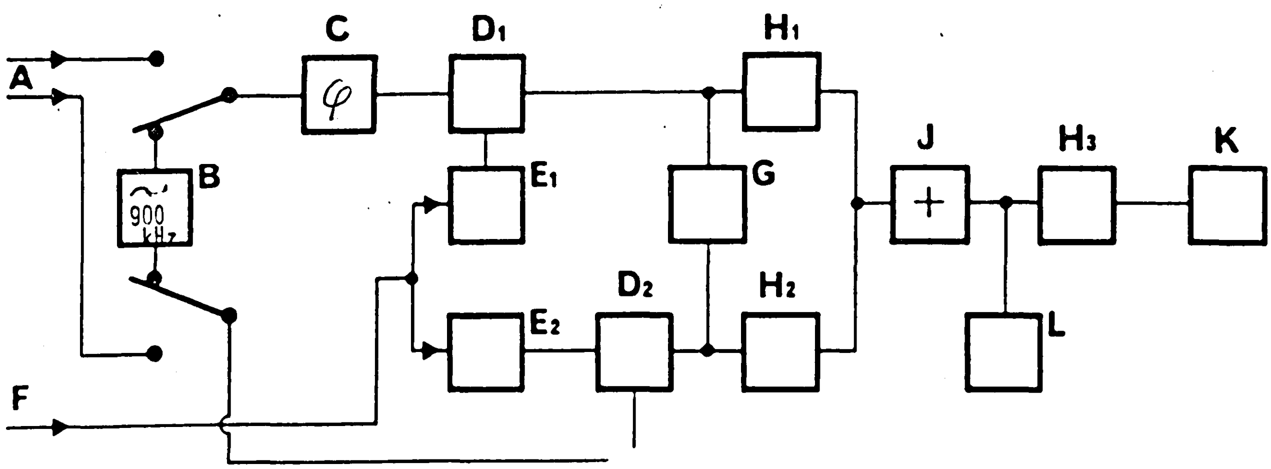


FIGURE 4

Schematic arrangement of common-channel model

A : External oscillator

B : Frequency standard (900 kHz)

C : Phase shifter

D_1, D_2 : Transmitters

E_1, E_2 : Audio-frequency delay line

F : Modulation

G : Oscilloscope

H_1, H_2, H_3 : Level adjustment

J : Adding network

K : Receiver

L : Level indicator

REPORT 460-1*

IONOSPHERIC CROSS-MODULATION

(Study Programme 25E-1/10)

(1970-1974)

The effects of ionospheric cross-modulation in bands 5 (LF) and 6 (MF) may become a problem of increasing severity as the power of transmitters continues to increase.

1. Detailed experiments on this subject have been carried out within the framework of E.B.U. in several countries, notably in the United Kingdom and in the Federal Republic of Germany [Haberkant and Vogt, 1966; Haberkant et al., 1971]. These experiments were carried out with conventional amplitude-modulation double-sideband transmissions. It is not yet possible to give the exact and final values of the interference observed, but the following results may be deduced from these experiments :

1.1 The percentage of cross-modulation increases practically linearly with the power of the interfering transmitter and also increases with the depth of modulation.

Note.- The percentage cross-modulation is the percentage by which the carrier of the wanted transmitter is modulated by the modulating frequencies of the interfering transmitter.

1.2 The cross-modulation depends primarily on the power radiated by the interfering transmitter in the direction of the reflection point of the wanted signal in the ionosphere.

Cross-modulation percentages less than 10 % are directly proportional to the power [Knight, 1973]; an increase of 3 dB in the interfering transmitter power, therefore, increases cross-modulation levels by 6 dB. The percentage of cross-modulation is also directly proportional to the depth of modulation of the interfering transmitter [Knight, 1973].

1.3 The percentage of cross-modulation decreases as the modulating frequency of the interfering transmitter increases. Laboratory experiments [Whythe and Reed, 1973] have shown that the subjective effect of cross-modulation can be related to co-channel interference. To produce a given

* Adopted unanimously

subjective grade of impairment, interference resulting from ionospheric cross-modulation requires 6 dB less input signal-to-interference ratio than does co-channel interference providing that the cross-modulation is referred to a modulation frequency of 300 Hz.

1.4 It should be noted that studies on the problem of ionospheric cross-modulation carried out by Study Group 6 are summarized in Report 574.

2. Fig. 1 shows the percentages of cross-modulation measured in many experiments / Knight, 1973 /. Each measurement has been standardized to the value which would have been observed if the interfering transmission had been radiated from a short vertical aerial with a carrier power of 100 kW and amplitude-modulated at 300 Hz to a depth of 80 %.

Fig. 1 includes a semi-empirical curve which shows the greatest percentage cross-modulation, averaged over a short period, likely to be observed; the condition for this is that the wanted signal should traverse the region of the ionosphere most strongly illuminated by the interfering transmitter. Fig. 1 shows that cross-modulation rises to a second maximum when the frequency of the interfering transmitter is close to the gyromagnetic frequency. Fig. 5 shows a map giving the value of the gyromagnetic frequency for different parts of the world / Laitinen and Hayden, 1950 /.

3. The effects of cross-modulation should be taken into account not only for sky-wave reception, but also for ground-wave reception at the edge of the service area when at night the sky-wave is no longer negligible. However, the effect of cross-modulation is reduced approximately in the ratio of the wanted signal levels, ground-wave to sky-wave, at the receiving point.

4. Preliminary conclusions

On the basis of measurements / Haberkant and Vogt, 1966; Haberkant et al, 1971 / examples may be given of the power flux levels, or the transmitter power as a function of the angle of elevation, which can cause disturbance to wanted transmissions.

For this purpose, an assumption is first made regarding the tolerable level of the depth of cross-modulation. According to the Annex to Recommendation 448-1, in connection with Report 264-3, § 3 (Statistical variation of the field strength or the propagation loss) and Report 298-3, § 2.2.2.1 (Short-term fadings), a radio-frequency protection ratio of approximately 30 dB is agreed for 10 % of the time in the case of a fluctuating unwanted signal. Ignoring the effect mentioned in § 1.3, the same disturbing effect is produced by 3 % cross-modulation for 10 % of the time. It has been shown / Haberkant et al, 1971 / that for frequencies at the upper end of the MF broadcasting band 6 (MF), this level of cross-modulation may be produced by a power flux within the E region of the ionosphere of about 2 μW/m^2 (-57 dB (W/m^2)), which corresponds to a maximum field strength of 27 mV/m (89 dB (μV/m)).

Assuming a height of 100 km of the reflecting layer (E region), it is possible to calculate the power radiated from various types of antennae which would produce this power flux within the E region. The <u>vertical transmitting antennae</u> that are commonly used show a vertical radiation pattern which depends in a well-defined fashion on the height (expressed in fractions of the wavelength, λ). In particular such vertical antennae do not radiate at an angle of elevation of 90°. Table I /̅ Haberkant et al, 1971_/ indicates, for a number of vertical transmitting antennae at different heights, the transmitter powers to be fed into these antennae to meet the above-mentioned requirements.

TABLE I

Length of vertical antenna	<0.25λ	0.25λ	0.5λ	0.55λ	0.64λ	0.64λ (1)
Transmitter carrier power (kW)	320	340	560	670	370	840

(1) First side lobe compensated

It is also possible to calculate the dependence of the radiated power on the angle of elevation, required to produce the same power flux, covering the whole range from 0° (horizontal radiation) to 90° (vertical radiation). The results are given in Table II.

TABLE II

Angle of elevation (degrees)	0	10	20	30	40	45	50	60	70	80	90
e.m.r.p.* (dB(1kW)) or c.m.f.*(dB(300V))	39.5	32	27.5	24.3	22.5	22	21.5	20.2	19.3	18.7	18.5
e.m.r.p. (kW)	9000	1600	570	230	190	160	140	105	85	75	70

The above tables give only approximate values because it is known, from theory, that ionospheric cross-modulation may be influenced by several parameters, such as the frequencies of the wanted and of the interfering transmitter (in particular seen in their relationship to the gyro-frequency) and the polarization of emission.

* e.m.r.p.: effective monopole radiated power; c.m.f.: cymomotive force. See also Report 618.

The powers given in Tables I and II are examples based on a small number of measurements at a frequency near the top end of band 6 (MF); they make no allowance for the change of cross-modulation with the carrier frequency of the disturbing signal. Also, they do not include the effect of reduced cross-modulation at the higher audio frequencies which permits interfering-transmitter powers to be increased by 3 dB.

It may be noted that services other than broadcasting have also suffered degradations due to ionospheric cross-modulation.

The results of many other measurements of ionospheric cross-modulation have been compared [Knight, 1973] and Fig. 1 shows that 100 kW radiated from a short antenna at frequencies in the lower part of the MF broadcast band 6 (MF) produces cross-modulation which may exceed 2 % for 50 % of the time. It may be shown [Haberkant, et al., 1971] that this corresponds to a cross-modulation level of 3 % exceeded for 10 % of the time. The power of 100 kW may therefore be directly compared with the power of 320 kW given in Table I. The greater power in Table I arises because the series of measurements on which it was based appear to give lower cross-modulation than the estimated worst case values shown by the curve in Fig. 1.

Fig. 1 also shows that cross-modulation levels caused by disturbing transmitters operating either at frequencies in band 5 (LF) or at frequencies close to the gyromagnetic frequency may be 10 dB greater than levels arising at frequencies in the lower part of band 6. A 5 dB reduction of disturbing-transmitter power reduces the cross-modulation level by 10 dB. Allowing for the modulation-frequency effect we conclude that, depending on the disturbing frequency in bands 5 (LF) and 6 (MF), transmitter powers in a range varying from the values in Tables I and II down to 7 dB lower may, at worst, give interference to a sky-wave service comparable with co-channel interference for 30 dB protection ratio.

Somewhat greater disturbing-transmitter powers may be radiated if ground-wave services, rather than sky-wave services, are to be protected from the effects of ionospheric cross-modulation, because the disturbing transmitter influences only the sky-wave component of the received signal. If the limit of the ground-wave service area is defined as the line where the ground-wave field strength exceeds the median sky-wave field strength by 14 dB, the median cross-modulation of the resultant signal will be 10 dB less than the median cross-modulation of the sky-wave. Disturbing-transmitter powers may therefore be 7 dB greater than the equivalent powers when the sky-wave is being protected.

5. Practical application of the conclusions

The E.B.U. has investigated the consequences on the planning of broadcasting networks in bands 5 (LF) and 6 (MF) to be drawn from the preliminary conclusions summarized in § 4 of this Report. The most urgent problem is that of maximum effective monopole-radiated power as a function of the angle of elevation and type of antenna when a certain amount of interference by ionospheric cross-modulation is not to be exceeded. The conclusions drawn so far from these studies are set out hereafter.

It is recommended that the annoyance due to cross-modulation should not exceed that resulting from co-channel interference with a protection ratio of 30 dB. However, cross-modulation, unlike co-channel interference, decreases with increasing modulation frequency, so that subjective experiments are necessary to relate the two effects. Such experiments have been carried out and have shown that the maximum depth of cross-modulation could be 6.3 % when the interfering transmitter is 80 % modulated by 300 Hz tone. It is recommended that this should be regarded as the maximum acceptable limit of cross-modulation.

Taking into account the dependence of cross-modulation on the carrier frequency of the unwanted emission and the height of the reflecting layer, Fig. 2 (curve A) shows the maximum effective monopole-radiated power (dB(1kW)) or cymomotive force (dB(300 V)) directed vertically upward which would produce, for 50 % of the time, the depth of cross-modulation specified above. The abscissa is the ratio of unwanted carrier frequency F_D to the gyrofrequency F_H (about 1.25 MHz in Europe). This curve is based on a large number of measurements in Europe and Australia as described in § 4 and Fig. 1, taking the observed values of cross-modulation as representing the worst values likely to occur over the most unfavourable geographical path.

In practical cases, account must be taken of the vertical radiation pattern of the antenna and of the increasing distance between the antenna and the reflecting point in directions other than vertical. Fig. 3 shows the permissible increase in e.m.r.p. in directions other than vertical allowed by the increasing distance only. An additional increase or decrease in power resulting from the vertical diagram of the antenna has to be taken into account. For practical application, the influences of increasing distance to the reflecting point and of the vertical radiation pattern of the antenna have been combined to one single correction factor ΔP which has to be added to that read from Fig. 2. This correction factor has been calculated for vertical antennae of different electrical length $\chi \approx \ell/\lambda$ and horizontal dipoles 0.5 λ long, at different heights $\chi \approx h/\lambda$ above ground assuming a height of 85 km for the region of the ionosphere in which cross-modulation should occur. The result of this calculation is given in Fig. 4.

In a ground-wave service which is to be protected against cross-modulation at night, it may be assumed that the sky-wave field strength of the wanted transmitter is 10 dB below the ground-wave field strength at the service limit. Since only the sky-wave component is subject to cross-modulation, an increase of 5 dB in radiation is permissible if only ground-wave services need be considered. This leads to curve B of Fig. 2.

As a practical example, consider a short vertical antenna in band 5 (LF) $(F_D/F_H) = 0.2$). Fig. 2 shows that to protect a ground-wave service, the maximum e.m.r.p. in a vertical direction would be 20 (dB(1 kW)), i.e., 100 kW. However, a short antenna produces a maximum value of field strength in the ionosphere at an angle elevation of 45°; Fig. 3 shows that an increase of 3 dB is permitted at that angle, giving an e.m.r.p. of 200 kW. However, it is more convenient to specify the e.m.r.p. in the horizontal direction; for a short antenna this is 3 dB greater than at 45°, i.e., 400 kW.

Accordingly, in this case, for a short vertical antenna ($\ell/\lambda \ll 0.1$), the value of $\Delta P = +6$ dB can be read from curve A in Fig. 4, which results in a total power fed to the antenna of P = +26 (dB(1kW)) ≈ i.e., 400 kW.

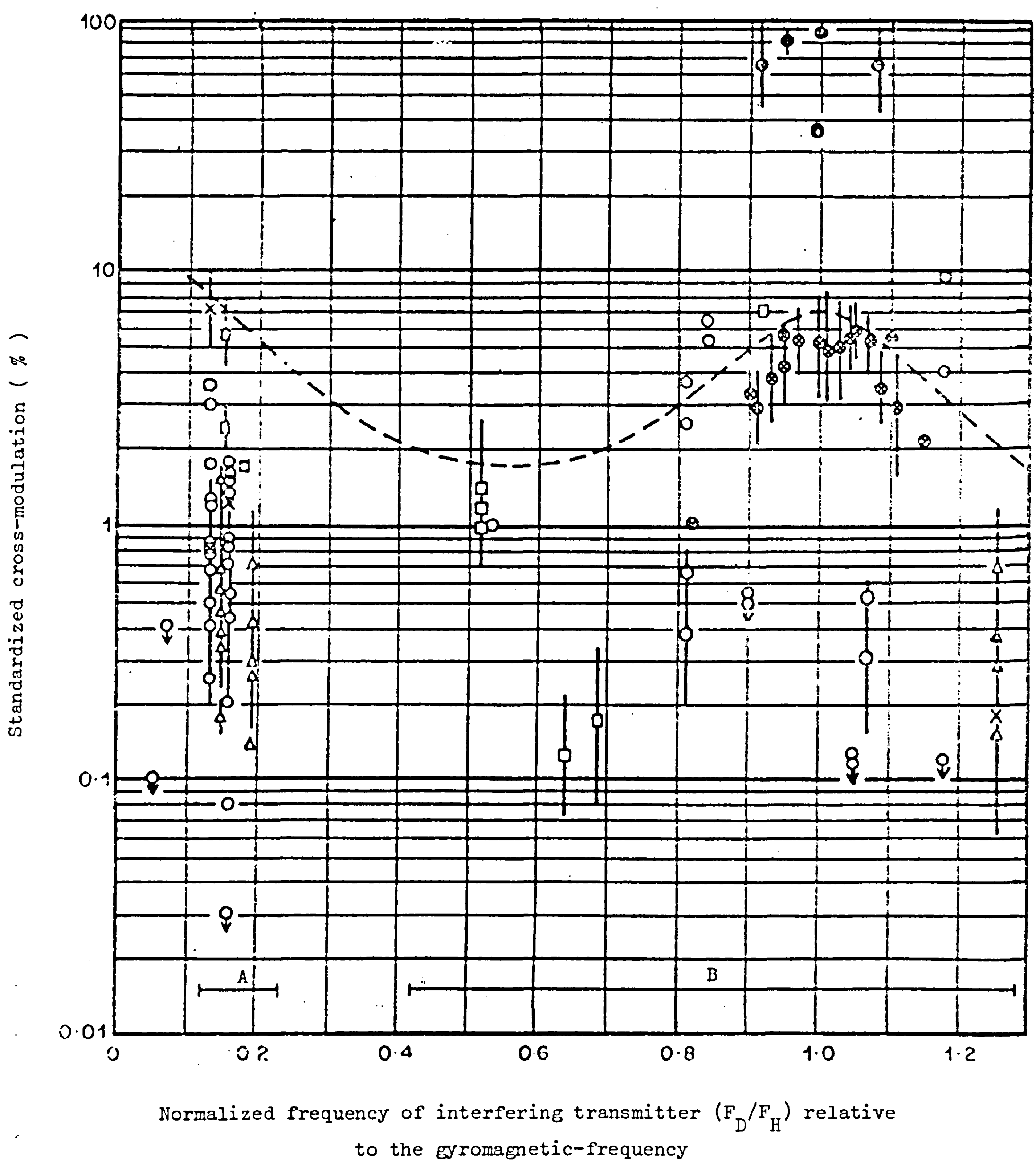

100
10
1
0·1
0·01
0
0·2
0·4
0·6
0·8
1·0
1·2
A
B
Standardized cross-modulation (%)
Normalized frequency of interfering transmitter (F_D/F_H) relative
to the gyromagnetic-frequency

FIGURE 1

Measurements of ionospheric cross-modulation
at medium latitudes

□	:	measurements before 1945	/̄ van der Pol and van der Mark, 1935; Bäumler and Pfitzer, 1935; Bailey, 1937; Grosskopf, 1938_7
O	:	measurements at Cambridge and Birmingham	/̄ Huxley, et al., 1947; Ratcliffe and Shaw, 1948; Huxley, et al., 1948; Huxley, 1950; Shaw, 1951; Bell, 1951_7
●	:	measurements in Italy	/̄ Cutolo and Ferrero, 1948 and 1949; Cutolo et al., 1950; Cutolo, 1952_7
⊗	:	measurements in Australia	/̄ Bailey et al, 1952; Hibberd, 1964_7
Δ	:	measurements in Western Europe after 1945	/̄ Haberkant and Vogt, 1966; Haberkant et al, 1971_7
X	:	other measurements	
---	:	semi-empirical upper limit	
A	:	band 5 (LF)	
B	:	band 6 (MF)	

Note.- The vertical lines represent a range of median values measured during the course of a night, or on different nights. The arrows pointing downwards indicate measured values which are less than the value indicated.

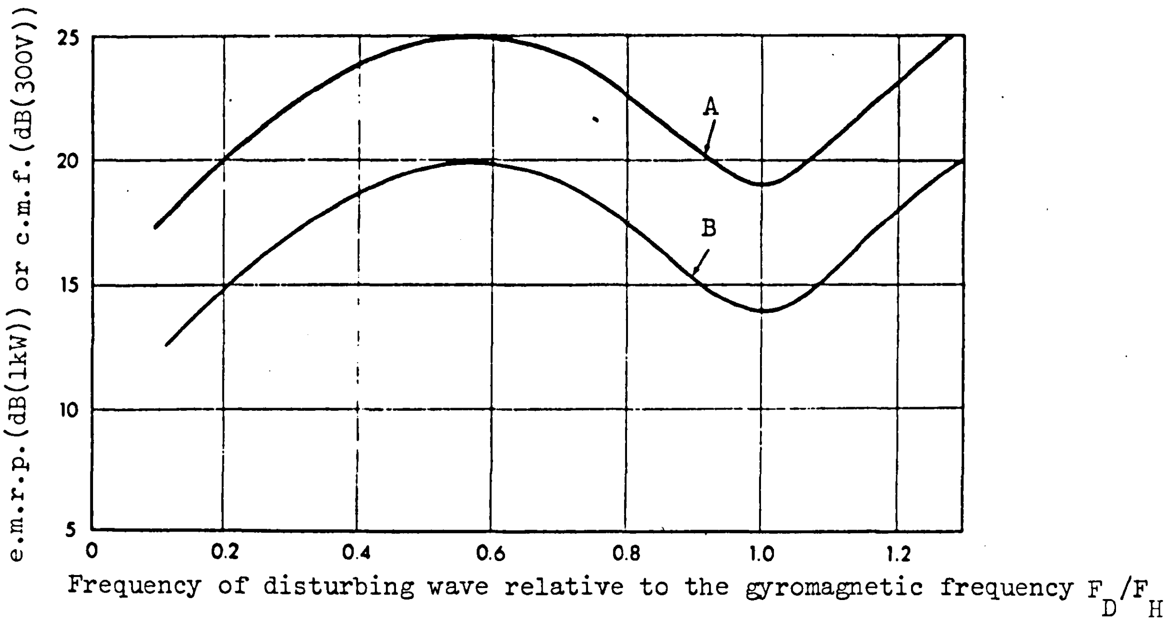


FIGURE 2

Vertically-incident radiation giving a quasi-maximum of 6.3 % cross-modulation at 300 Hz

A : for protection of sky-wave services

B : for protection of ground-wave services

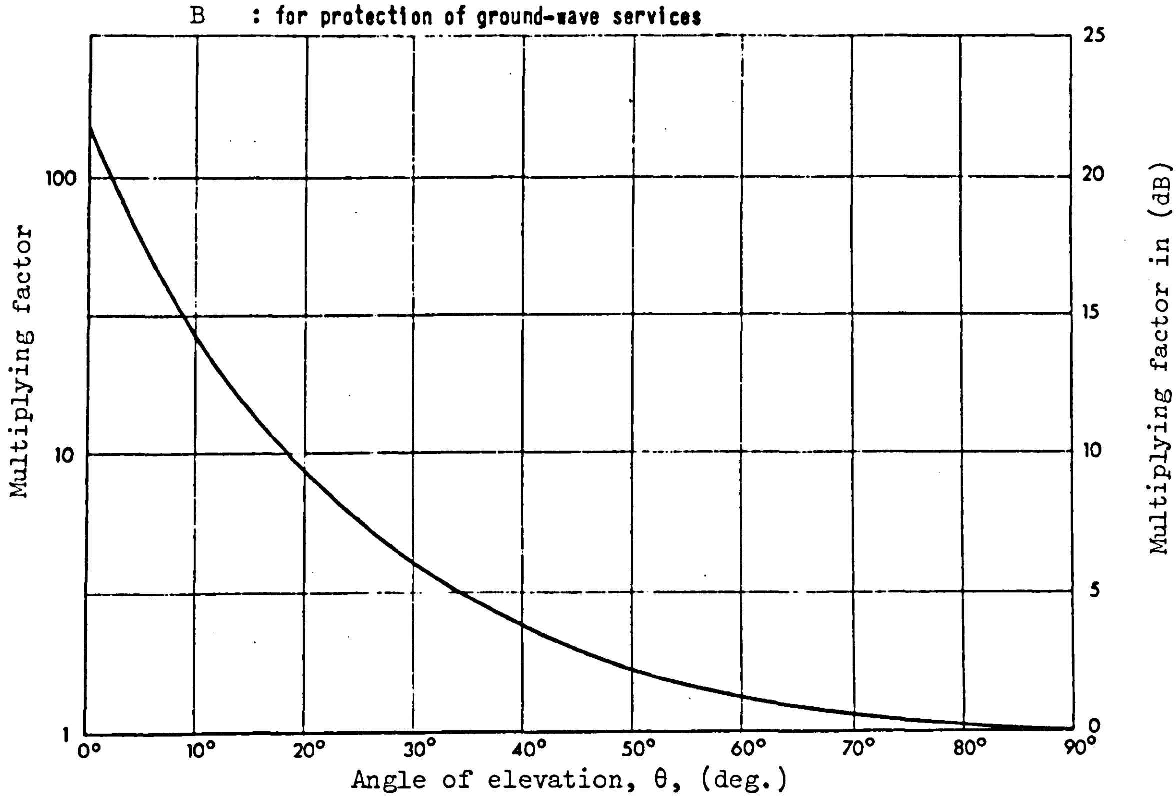


FIGURE 3

Variation of permissible radiation with angle of elevation

(Curvature of the Earth taken into account, assuming that cross-modulation takes place at a height of 85 km)

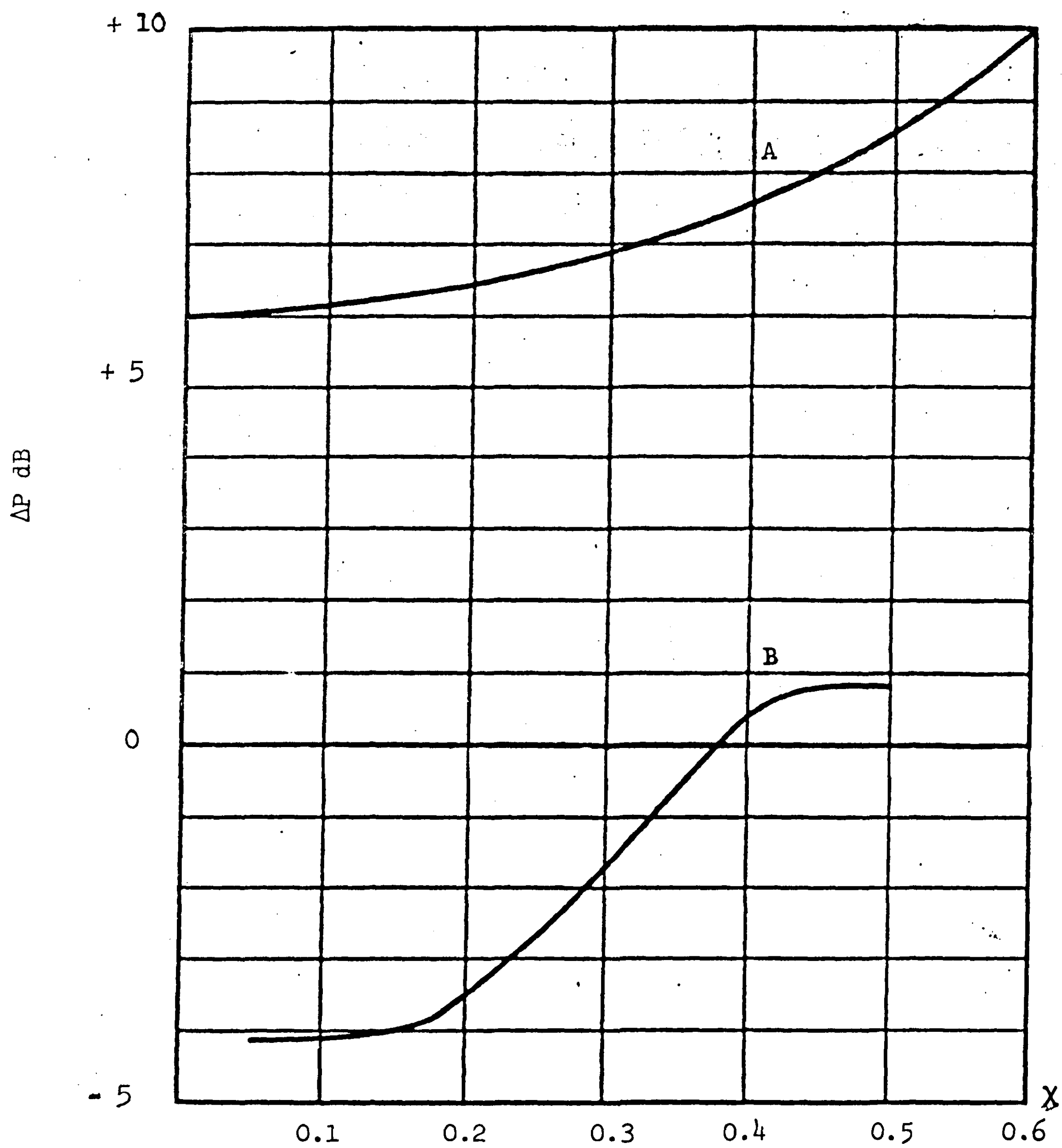


FIGURE 4

Correction factor ΔP, for different type of antennae

Curve A : vertical antenna
χ : relative length of antenna (ℓ/λ) (%)

Curve B : horizontal dipole (ℓ = 0.5λ)
χ : relative height above ground (h/λ) (%)

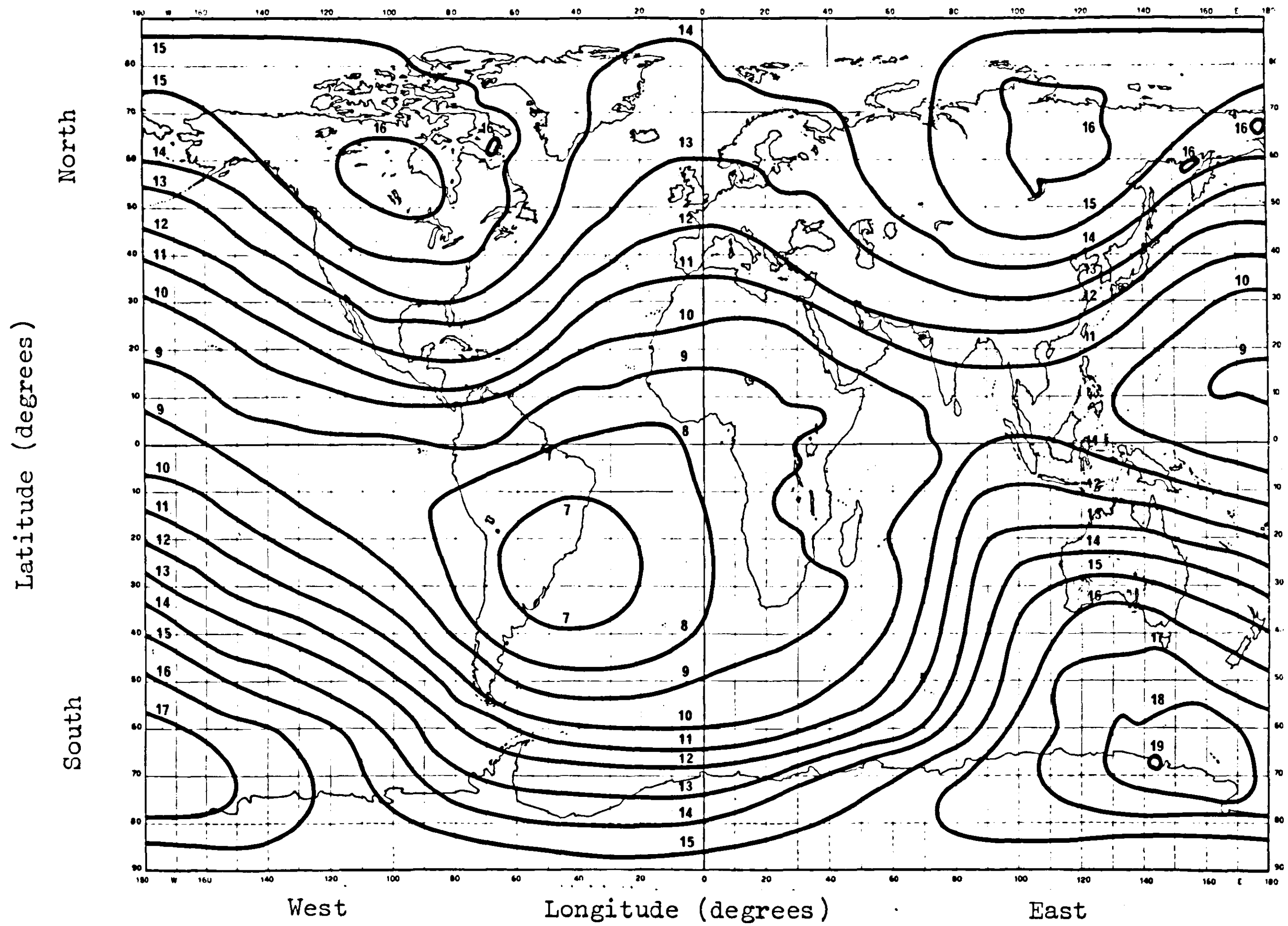


FIGURE 5

World-wide distribution of gyro-frequency (MHz)

REFERENCES

BAILEY, V.A. [15 May 1937] Resonance in the interaction of radio waves. Nature, 838-839.

BAILEY, V.A. et al [May 1952] Resonance in gyro-interaction of radio waves. Nature, 169, 911-913.

BÄUMLER, M. and PFITZER, W. [December 1935] Untersuchung der gegenseitigen Modulationsbeeinflussung elektrischer Wellen mit deutschen Rundfunksendern (Investigation of the influence of cross-modulation of electric waves with the German broadcasting transmitters). Hochfrequenztechnik und Elektroakustik, 46, 181-186.

BELL, D.A. [1951] Ionospheric interaction in disturbed conditions. Proc. Phys. Soc. (Section B), Vol. 64, 1053-1062.

CUTOLO, M. [May 1952] Determinazione sperimentale delle curve di risonanza nel moto degli elettroni lenti dell'alta atmosfera (Experimental determination of the resonance curves for the motion of slow electrons in the upper atmosphere). Nuovo Cimento, Vol. IX, 391-406.

CUTOLO, M. and FERRERO, R. [October 1948] Misura del grado di modulazione parassita nel fenomeno di girointerazione (Measurement of the degree of parasitic modulation on the phenomenon of gyro-interaction). Alta Frequenza, Vol. XVII, 212-216.

CUTOLO, M. and FERRERO, R. [January 1949] Photographic record and diagrams of Luxembourg effect with resonance (gyro-interaction). Nature, 163, 58-59.

CUTOLO, M., FERERRO, R. and MOTOZO, M. [1950] Determinazione sperimentale della curva di risonanza nel fenomeno di girointerazione (Experimental determination of the resonance curve in phenomenon of gyro-interaction). Alta Frequenza, Vol. XIX, 3-8.

GROSSKOPF, J. [January 1938] Die gegenseitige Modelungsbeeinflussung elektromagnetischer Wellen in der Ionosphäre (The influence of cross-modulation of electric waves in the ionosphere) . Hochfrequenztechnik und Elektroakustik, 51, 18-30.

HABERKANT, E. and VOGT, K. /‾August 1966_7 Measurement of ionospheric cross-modulation affecting two high-power LF broadcast transmitters E.B.U. Review, 98-A, 154-161.

HABERKANT, E. and VOGT, K. /‾1966_7 Messung der ionosphärischen Kreuzmodulation bei den Langwellen-Rundfunksendern Europa I und Luxemburg (Measurement of ionospheric cross-modulation on the long-wave broadcasting emissions Europe I and Luxembourg). Rundfunktechnische Mitteilungen, 4, 206-212.

HABERKANT, E., HEINZELMANN, G. and VOGT, K. /‾April 1971_7 The measurement of ionospheric cross-modulation, E.B.U. Review, 126-A, 50-55.

HABERKANT, E., HEINZELMANN, G. and VOGT, K. /‾1971_7 Die Messung der ionosphärischen Kreuzmodulation (The measurement of ionospheric cross-modulation). Rundfunktechnische Mitteilungen, 2, 49-55.

HIBBERD, F.H. /‾1964_7 An experimental study of gyro-interaction in the ionosphere, at oblique incidence. National Bureau of Standards, Technical Note 211, 4, 45-64.

HUXLEY, L.G.H. /‾February 1950_7 Ionospheric cross-modulation at oblique incidence. Proc. Royal Society, 200, Series A, 486-511.

HUXLEY, L.G.H. /‾1952_7 A synopsis of ionospheric cross-modulation. Nuovo Cimento, Supplement to Vol. IX, Series IX, 59-89.

HUXLEY, L.G.H., FOSTER, H.G. and NEWTON, C.C. /‾1 March 1947_7 Gyro-interaction of radio waves. Nature, 300-301.

HUXLEY, L.G.H., FOSTER, H.G. and NEWTON, C.C. /‾August 1948_7 Measurements of the interaction of radio waves in the ionosphere. Proc. Phys. Soc., 61, 134-146.

KNIGHT, P. /‾May 1973_7 LF and MF propagation : a study of ionospheric cross-modulation measurements. B.B.C. Engineering, 94, 12-21.

LAITINEN, O.P., HAYDEN, G.W. /‾1953_7 Analysis and prediction of sky-wave field intensities in the HF band, RPU 203, Technical Report No. 9, Signal Corps Radio Propagation Agency, Fort Monmouth, New Jersey, U.S.A.

RATCLIFFE, J.A. and SHAW, I.J. /‾July 1948_7 A study of the interaction of radio waves. Proc. Royal Society, 193, Series A, 311-343.

SHAW, I.J. /‾January 1951_7 Some further investigations of ionospheric cross-modulation. Proc. Phys. Soc. (Section B), 64, 1-20.

SHAW, I.J. /‾November 1951_7 Ionospheric cross-modulation, Wireless Engineer, 28, 335-342.

VAN DER POL, B. and VAN DER MARK, J. /‾1935_7 Interaction of radio waves. Tijdschrift Nederlandsch Radio Genootschap, 7, Part I, 12-17, Part II, 93-97.

WHYTHE, D.J. and REED, C.R.G. /‾1973/5_7 Ionospheric non-linearity : protection ratios required against cross-modulation interference (Luxembourg Effect). B.B.C. Research Department Report 1973/5.

BIBLIOGRAPHY

BAILEY, V.A. /‾1956_7 On the interaction of radio waves. Nuovo Cimento, Supplement to Vol. IX, Series X, 1430-1449.

B.B.C. /‾6 November 1968_7 Research Department, Report RA-17, Ionospheric non-linearity. Doc. Com. T.(A) 73/Com. T.(B) 97.

REPORT 616*

BROADCASTING COVERAGE IN BAND 6 (MF) - OPERATIONAL ASPECTS

(Study Programme 25F-1/10)

(1974)

1. Day-time coverage

The following results are based on the ground-wave propagation curves of Recommendation 368-2.

Due to the strong absorption of the sky-wave in band 6 during the day-time, only the ground-wave can be used for coverage. The service radius (see Annex I) depends on the frequency and on the electrical characteristics of the soil within the service area; this radius for higher transmitter powers is about 100 km. A transmitter network optimized for day-time coverage could be based on very low co-channel distances, i.e. on a considerably higher transmitter density than that existing at present. For example, a day-time network based on an average co-channel distance of roughly 500 km would provide, at any location, about ten radio programmes with good quality of reception.

Coverage during the day-time therefore does not represent a technical problem.

2. Night-time coverage

With the onset of darkness the absorption of the sky-wave is greatly reduced and high values of field-strength may build up during a period of one or two hours at distances of thousands of kilometres. This produces interference and limits the ground wave service range. In general, the sky-wave has been regarded mainly as a source of interference, and the systematic use of the sky-wave for coverage purposes has been envisaged for special cases only.

At night-time, the presence of the sky-wave gives rise to complicated technical problems and necessitates planning methods for very large areas based on internationally-agreed rules.

---

* Adopted unanimously

To obtain a clear picture of the possibilities of providing radio programmes in band 6 under various basic assumptions, a great number of frequency-assignment trials have been carried out within the E.B.U. and the coverage factors obtained have been calculated. These studies were made for the European and African broadcasting areas.

These trials were made on the basis of rather evenly distributed transmitters with equal power radiated from omnidirectional antennae, the sites of which, however, coincided with real or planned sites in Europe and Africa. The service areas were calculated using a statistical method and taking into account only the interference caused by the other transmitters. This method enables a valid comparison to be made between the results of two different trials, but the absolute values of the results should not be used without due care.

For the purpose of the calculations, certain values of radio-frequency protection ratio* have been adopted. These different values of radio-frequency protection ratio correspond, of course, to different grades of service. It is evident that the service areas so calculated are larger for smaller values of this ratio than for the higher values. The increase in service area with decreasing value of protection ratio (i.e. with decreasing grade of service) does not imply that better listening conditions will be obtained: the listening conditions do not depend on the protection ratio, but only on the power and on the configuration of the interfering transmitters.

It should be noted that, when comparing the results of two different trials, the differences may be more or less pronounced depending on the radio-frequency protection ratio, i.e. the grade of service adopted. Therefore the calculation results should not be discussed without making mention of the corresponding grade of service.

Finally, it should be recalled that, in the calculations, statistical propagation data have been used. In particular, ionospheric field-strength prediction curves have been taken, which represent median values (i.e. values for 50% of the time) for an average frequency of 1 000 kHz.

It can be assumed, therefore, that the results obtained are reasonably suitable for representing the average situation for the whole of the spectrum covered by band 6.

Some of the results are summed up hereafter.

* Radio-frequency protection ratio as defined in Recommendation 447.

2.1 Ground-wave coverage at night

The total amount of ground-wave coverage depends in the first place on the co-channel distance, i.e. on the transmitter density. For a given transmitter power, the ground-wave coverage increases with increasing co-channel distance (see Report 400-2). Thus, for 300 kW transmitters, and assuming protection ratios of 40 dB, 33 dB and 27 dB, the following percentages of the combined surface areas of Europe and Africa can be covered by employment of the 121 channels now available in band 6 :

TABLE I

Co-channel distance (km)	Ground-wave coverage					
	Radio-frequency protection ratio					
	40 dB		33 dB		27 dB	
	Number of programmes	Area coverage (%)	Number of programmes	Area coverage (%)	Number of programmes	Area coverage (%)
2 700	1	6	1	11	1	21
3 500	1	8	1	15	1	25
4 100	1	9	1	17	1	28

Because of the uncertainty of field-strength prediction data for distances beyond 3 500 km, it cannot yet be stated to what extent co-channel distances greater than the values quoted will lead to a further increase in ground-wave coverage. These coverage factors can possibly be improved by the use of synchronized networks and of directive antennae. Moreover, the population coverage can be made superior to the surface coverage by appropriate transmitter siting. Little numerical information is available on these possible improvements.

The question of what transmitter power provides the greatest possible ground-wave coverage for a given transmitter density has been the subject of detailed studies (see Report 400-2), from which a sufficiently accurate answer may be derived. Furthermore, it should be recalled that night-time ground-wave coverage is also limited by interference between the ground-wave and the sky-wave from the same transmitter, but this effect has been ignored in the calculation of the approximate service ranges as given in Annex II.

2.2 Sky-wave coverage

Under the same assumptions as those made in § 2.1 (300 kW transmitters, 40 dB, 33 dB or 27 dB protection ratio) the sky-wave would provide coverage of the combined surface areas of Europe and Africa, with use of the entire band 6 as follows :

TABLE II

Co-channel distance (km)	Sky-wave coverage					
	Radio-frequency protection ratio					
	40 dB		33 dB		27 dB	
	Number of programmes	Area coverage (%)	Number of programmes	Area coverage (%)	Number of programmes	Area coverage (%)
2 700	negligible		1	30	6.1	100
3 500	1	15	[illegible].4	100	23.3	100
4 100	2.5	100	14.9	100	31.6	100

It can be seen that at night the sky-wave service depends far more than the ground-wave service on the transmitter density adopted : for high transmitter densities (i.e. co-channel distances even smaller than 2 700 km) nocturnal coverage decreases rapidly, whereas a co-channel distance of 4 100 km would permit the reception of several programmes at any location within the area considered. The majority of these programmes would, of course, be originated far from the reception point. Moreover, the fact should not be overlooked that it is impossible, contrarily to the ground-wave, to achieve consistently good quality by means of the sky-wave. Account should also be taken of the fact that, in practice, the area covered at night will not be continuous, for there will be an annulus embracing ranges in the region between 100 km and 200 km in which severe selective fading will be caused by interference between the ground-wave and the sky-wave. This effect has been neglected in the studies made so far. Examples for approximate service ranges are given in Annex II. The fact remains that the utilization of the sky-wave would allow better use to be made of the spectrum in respect of area coverage because the ratio between the service area and the area of interference is more favourable. Finally, it should be recalled that, in conditions yielding satisfactory night-time ground-wave coverage, there will normally also result a reasonable amount of sky-wave coverage.

2.3 Combination of ground-wave and sky-wave services

It can be concluded from §§ 2.1 and 2.2 that good results for both types of service may be obtained if the high-power co-channel transmitters are sufficiently widely spaced.

3. Combination of day-time and night-time services

As shown in §§ 1 and 2, transmitter networks devised for good coverage during the day-time differ fundamentally from those set up for good coverage at night-time : the co-channel distances would, for example, be about 500 km for day-time and about 4 000 km for night-time. As the corresponding total number of transmitters of these networks would have a ratio equal to the square of the ratio of the co-channel distances, the coexistence of both networks would mean that, in this example, only one out of every 64 transmitters could be operated after sunset. In this example, two extreme cases of optimum coverage conditions are compared, neither of which corresponds to present practice. If in any network all transmitters remain in operation day and night this will lead to reduced coverage either at day-time or at night-time, or, in the case of a network based on a compromise between the two types of network, to reduced coverage during day and night.

On the other hand, the transition from efficient day-time operation to efficient night-time operation would lead to some problems of an operational and administrative nature. In fact, as shown, the majority of the day-time transmitters would have to be closed down at sunset, to avoid unacceptable interference during the hours of darkness. The time of close-down itself may then depend on the season and the latitude, especially at high and medium latitudes. Moreover, because of the comparatively slow build-up of the sky-wave after sunset, there will always be a period when either the ground-wave network suffers interference (if all transmitters are still in operation) or the sky-wave signals are still too weak. Although the difficulties mentioned above appear to make the general use of such a mode of operation impracticable, its potential advantages are such that a further study is desirable particularly in respect of certain special cases.

4. Population coverage

While the area coverage assumes an important aspect of coverage, there is another aspect, namely, that of population coverage. Studies on the problems of population coverage have been initiated in some countries / Suzuki et al, 1974 /, but further study is required on this point.

5. Improvements of coverage

5.1 Synchronized networks

A synchronized network is a group of transmitters intended primarily for a ground-wave service radiating the same programme at a common frequency.

In most European countries, the use of synchronized networks to replace single transmitters of equivalent power leads to better adaptation of coverage to population distribution, and thereby increases total population coverage. Annex III shows some examples of the results obtained in various countries. The use of synchronized groups is most effective in those countries where there are widely-spread areas of high population density.

It should be emphasized :

- that acceptable reception quality of the sky-wave signal is more likely in those areas where the sky-wave of one transmitter of the synchronized group predominates;

- that the interference from a synchronized group is equivalent to that from a single transmitter sited at the centre of gravity of the group, with a power equivalent to the total power of the group, provided that the average distance between the group of transmitters is not more than about one-tenth of the distance to the nearest co-channel transmitter;

- that synchronized networks are of less value in small countries;

- that the use of directional transmitting antennae improves the coverage from synchronized networks;

- that the use of product demodulators decreases the non-linear distortion due to interference between the transmitters of a synchronized network; this would increase the coverage obtained.

On the other hand, transmitters of a synchronized network may radiate different programmes during daylight hours, if the transmitters are sufficiently widely spaced.

It is obvious that investment and operational costs are higher for a synchronized network than for a single transmitter; nevertheless, the use of synchronized networks should be envisaged in each case where the advantages quoted are to be expected.

5.2 Antenna directivity

5.2.1 Vertical diagram of vertically-polarized transmitting antennae

An antenna may be designed to have a particular vertical radiation pattern so that the power is concentrated in the particular vertical segment or segments that will achieve the type of coverage required.

By concentrating the power in the horizontal plane it is possible to improve the ground-wave day-time coverage or to use a lower transmitter power for the same coverage. Where the onset of fading, and not co-channel interference, is the factor limiting ground-wave coverage, an anti-fade antenna will improve ground-wave coverage. This improvement is only likely to be obtained with frequencies at the lower end of band 6, in situations where ground conductivity is better than average. Finally, although such antennae may lead to a reduction in ionospheric cross-modulation, they provide a poorer sky-wave service, for the same interference, at shorter ranges (distances greater than 2,000 km).

By concentrating the power away from the horizontal plane, the sky-wave coverage is improved, but ground-wave coverage becomes less good and the risk of ionospheric cross-modulation is greater.

5.2.2 Horizontal diagram of vertically-polarized transmitting antennae

By concentrating the radiated power in given horizontal directions particular coverage requirements can be met. Although the general use of directional antennae in a frequency plan does not lead to an overall improvement of coverage, the use of directional antennae will be advantageous when considering the coverage within individual countries, mainly because it may lead to a better adaptation to specific wanted service areas and also to a reduction of interference in specific cases. In a particular case the employment of an antenna which is directional in the horizontal plane will allow a frequency channel to be used in a given zone where this frequency could not be used with an omnidirectional antenna. The use of such a directional antenna can reduce the interference in the service area of another co-channel transmitter and as a result permit the reduction of the co-channel distance. This is the principal advantage of an antenna with a directional horizontal pattern.

5.2.3 Economic considerations

In general any antenna, the vertical or horizontal radiation characteristics of which are designed to fulfil specific requirements, will cost more than non-directional antennae. Special requirements for the vertical radiation pattern normally lead to higher structures, and the cost of a vertical structure increases rapidly with height.

Special requirements for the horizontal radiation pattern lead to multi-element antenna arrangements and therefore to the use of more extensive sites.

The cost of any antenna design will be lower at the higher-frequency end of band 6. Local weather conditions will be an important factor influencing the cost.

5.3 Relative merits of antennae with horizontal and vertical radiating elements

A conventional vertical transmitting antenna will provide a useful ground-wave service for a limited range and a sky-wave service at night at greater ranges. At an intermediate range there is a zone where fading is more severe because the ground- and sky-wave field strengths are nearly equal.

The use of a horizontal radiating element or an array of such elements, which is practicable in band 6 (MF), has certain advantages when the main purpose is to provide a night-time, sky-wave service, but it is not suitable for providing a day-time service by ground-wave.

The main advantage is that it can be designed to provide a nearly constant sky-wave field-strength from the transmitter out to the edge of the service area. The design may provide for a service range up to the feasible maximum (about 1,000 km) or may be designed for a more limited service range (e.g., about 500 km). Nevertheless, very close to the transmitter (within a few kilometres) there may be degradation of quality because of interference between the small unavoidable ground-wave and the sky-wave. If this area is required to have a good service, a small "fill-in" transmitter using a different frequency and vertical polarization may be necessary.

Calculations which take account of the differing directivities and polarization-coupling losses for the case of a single horizontal dipole in place of a short vertical antenna have been presented [Suzuki et al, 1974]. The importance is stressed of allowing for the effects of imperfect ground conductivity, which not only reduces the low-angle radiation from vertical antennae but also increases the low-angle radiation from horizontal antennae in certain directions. In the latter context, the reduction of co-channel interference from low-angle propagation modes expected from the use of a horizontal transmitting antenna, if used in place of a vertical antenna, may be over-estimated by as much as 20 dB if perfectly conducting ground is assumed when in practice the ground conductivity is poor.

The results of the theoretical studies [B.B.C., 1972] show that, for a given transmitter power, where reflections are confined to the E Region, the use of a horizontal dipole in place of a short vertical antenna can reduce the level of co-channel interference by 10 to 15 dB for typical ground characteristics. More recent studies and practical measurements at temperate latitudes have, however, shown that for frequencies and times at which high-angle F Region reflections occur, the advantage is much reduced, because of the strong excitation of multi-hop propagation modes.

A disadvantage of the use of a horizontal antenna is that it is necessary to change over to a vertical antenna for day-time service, but in general, a comparable area of service may not be obtained without the use of many transmitters. Here also there is a problem of change-over as discussed already under § 3. Another disadvantage is that the cost of transmitting antenna may be large, particularly for the lower frequencies in band 6.

In general, it will be necessary to limit the radiated power to suitable values as a function of the angle in the vertical plane, to avoid causing serious ionospheric cross-modulation. (See Report 460-1.) This requirement may be more difficult to fulfil with horizontal antenna systems than for a vertical antenna.

It has recently been suggested that a horizontal antenna should consist of one or more pairs of crossed dipoles appropriately fed to transmit elliptically-polarized waves in the wanted directions and so as to excite the ordinary wave more strongly than the extraordinary wave. The main advantage over a system radiating linearly polarized waves is that since ionospheric cross-modulation is caused mainly by the extraordinary wave, less cross-modulation should in theory result for a given transmitter power. A further advantage would be a reduction of polarization coupling loss.

In conclusion, it can be stated that vertical radiation from horizontally-polarized antennae can be valuable in certain special cases. Its general introduction into a frequency-assignment plan, however, cannot be recommended on the basis of the information available now, as a means of obtaining a higher density of assignments.

Measurements have been carried out in Poland to compare the effectiveness of vertical and horizontal polarization for ground-wave coverage using frequencies in the upper part of the band 6 (MF). Measurements were made at distances of up to 20 km from the transmitter, the transmission paths being over built-up areas as distinct from open country, and the results indicate that the attenuation of horizontally polarized waves appears to be considerably less than would be expected from the theory of ground-wave propagation over a smooth Earth /_Siczek and Stasierski_/.

5.4 Low-power stations

The purpose of low-power transmitters is to cover limited areas, such as towns, where the field-strength of the main transmitters is insufficient, or possibly for the transmission of local programmes.

For an efficient service these stations must be included in the plan. It seems that in practice they can only operate with a protected field-strength well above that of other stations (in particular at night).

Apart from low-power transmitters which are part of a synchronized network (see § 5.1), these transmitters may use :

- either channels allocated to transmitters of different powers;
- or one or several special channels (formerly called International Common Frequencies (ICFs)).

In the first case, the sites of the stations and their other characteristics must be clearly determined in the plan, and any later addition would be dangerous. In the second case, it would be sufficient to state the geographical areas where these transmitters may be sited (taking account of adjacent-channel interference) and, in addition, to indicate the number of transmitters per area and the maximum power which may be used.

Studies already made show that the present number of ICFs (two) is quite insufficient, and that a total of five to ten would be preferable.

From a technical point of view, these transmitters would be more efficient if their frequencies were in the lower part of band 6, but in practice some of them would no doubt have to use channels throughout the spectrum. Moreover, the maximum power admissible and the number of low-power transmitters depend on the frequency /_Lari and Moro, 1971_/.

REFERENCES

B.B.C. /‾1972_/ Research Report No. 1972/21 : MF propagation : the reduction of interference by the use of horizontal-dipole transmitting aerials.

LARI, G. and MORO, G. /‾October 1971_/, Low-power MF broadcasting transmitters in the European Broadcasting Area. E.B.U. Review, Part A, Technical, 129, 205-213

SICZEK, S., STASIERSKI, L., Porownanie skutecznosci nadawania z polaryzacja, pionowa i pozioma (Comparison between effectiveness of vertical and horizontal transmitting antennae). Prace Instytutu Łaçznosci, (in course of publication)

SUZUKI, Yoshio et al /‾January 1974_/, Influence of propagation curves on the coverage factor. NHK Laboratories Note, Serial No. 178

BIBLIOGRAPHY

E.B.U. /‾May 1974_/, Technical parameters for LF/MF broadcasting. Doc. Tech. No. 3206

C.C.I.R. /‾1971-1974_/, Doc. 10/187, United Kingdom

C.C.I.R. /‾1971-1974_/, Doc. 10/252, E.B.U.

C.C.I.R. /‾1971-1974_/, Doc. 10/271, Poland (People's Republic of)

Annexes : 3

ANNEX I

APPROXIMATE DAY-TIME SERVICE RANGES

Day-time service ranges have been calculated in the absence of interference from unwanted transmitters by using the propagation curves given in Recommendation 368-2. For the limitation of the service ranges tentative values of the minimum field strength have been assumed :

2.2 mV/m (67 dB (μV/m)) for the lower third of band 6 (MF) (525 kHz to 900 kHz approximately)

0.8 mV/m (58 dB (μV/m)) for the upper third of band 6 (MF) (1 250 kHz, approximately, to 1 605 kHz)

Three values of ground conductivity are assumed :

- good conductivity (σ = 10×10^{-3} S/m)
- average " (σ = 3×10^{-3} S/m)
- poor " (σ = 1×10^{-3} S/m)

When considering the figures so obtained, it should be borne in mind that the average situation of transmitting sites in many countries by no means corresponds to a ground conductivity of $\sigma = 3 \times 10^{-3}$ S/m; moreover, the fact that many such sites are situated on hilly or mountainous terrain would normally lead to service ranges below the figures quoted in the following sections.

The radiated power in the horizontal plane is assumed to be 500 kW.

TABLE III

Frequency (kHz)	Service range (km)		
	σ = 1	σ = 3	σ = 10
Lower third of band 6			
525		180	310
900	80	130	
Upper third of band 6			
1 250		105	180
1 605	60	90	

ANNEX II

APPROXIMATE NIGHT-TIME SERVICE RANGES

The following assumptions are made for the calculation of the night-time service ranges :

- two transmitters on the same frequency at a distance of 3,500 km and radiating the same power, this power being such that the mutually caused interference is the only factor determining the service range*; the interference between the ground-wave of the wanted transmitter and its own sky-wave has been ignored;
- ground-wave propagation according to Recommendation 368-2;
- ground conductivity : $\sigma = 3x10^{-3}$ S/m;
- sky-wave propagation according to Report 264-3;
- protection ratio : 27 dB, 33 dB, and 40 dB.

TABLE IV

Protection ratio (dB)	Service range (km)	
	525 kHz	1 605 kHz
Ground-wave service		
27	170	90
33	135	70
40	95	55
Sky-wave service		
27	635	850
33	420	660
40	< 300 (1)	450

(1) The C.C.I.R. curves are not valid for distances less than 300 km.

* The trend shown in Table IV also appears for other cases of interference (more than two transmitters, different distances, etc.).

ANNEX III

COVERAGE OBTAINED FROM SYNCHRONIZED TRANSMITTERS

Table V shows the result of studies where the day-time and night-time coverage of existing groups of synchronized transmitters were compared with the coverage that would have been obtained by a hypothetical single transmitter suitably placed and having a total power equivalent to the total power of the synchronized group.

TABLE V

Ratio of the coverage obtained by a synchronized group of transmitters and a single transmitter

Origin	Frequency (kHz)	Number of trans-mitters	Total power (kW)	Coverage ratio			
				Day		Night	
				Surface	Population	Surface	Population
O.R.F.	1 025	4	300	1.45	1.68		1.83
B B.C.	1 214	16	270		1.26		3.2 (1) 3.0 (2)
RAI	1 367	14	85	2.12	3.84	1.39(3) 1.18(4) 0 .81(5)	6.24(3) 7.39(4) 17.74(5)

(1) Including interference from transmitters not belonging to the synchronized group.

(2) Interference between the transmitters of the synchronized group only.

(3) Co-channel protection ratio 20 dB against transmitters not belonging to the synchronized group.

(4) Co-channel protection ratio 25 dB against transmitters not belonging to the synchronized group.

(5) Co-channel protection ratio 40 dB against transmitters not belonging to the synchronized group.

REPORT 617*

CHARACTERISTICS OF SOUND BROADCASTING RECEIVERS AND RECEIVING ANTENNAE

Principal characteristics for frequency planning purposes

(Study Programme 36A/10)

(1974)

1. Introduction

Many characteristics of sound broadcasting receivers and antennae may be defined together with methods of measurement and limiting values but only those concerned with frequency planning are of interest to the C.C.I.R. Certain aspects of these characteristics are treated in numerous Recommendations and Reports (see Recommendations 237-1, 239-1, 331-3, 332-3, 333, 334-2, 412-1, 413-3, 415, 416, 447, 448-1, 449-2; Reports 184-2, 185-2, 186-2, 188-1, 189, 190-1, 192-1, 193-1, 298-3, 300-3, 302, 328, 330, 399-2, 405-2, 458-1, 459-1, 464-1). Many of the contents of these Recommendations and Reports have been rendered obsolete by changes in receiver design techniques. Furthermore, the data on some receiver characteristics is presented in the form of maximum, mean and minimum values for a wide range of designs.

This Report lists the characteristics of sound broadcasting receivers and antennae necessary for frequency planning work with appropriate references where definitions, methods of measurement and limits come within the scope of other international organizations such as the IEC and CISPR.

2. Categories of receivers

A planning conference should take into consideration the category of receiver which will be used for the system of broadcasting service envisaged.

Data collected in accordance with this Report should relate only to the mean values of the characteristics for receivers that are typical of good, current engineering practice in the country concerned. This is to avoid undue influence being exerted on future planning standards by receiver designs at the extreme upper and lower ends of the performance range.

*Adopted unanimously

A reference receiver could be defined taking into account the mean values.

3. Technical characteristics

3.1 Antennae

Frequency-modulation reception

The values of antenna characteristics contained in Recommendation 419 and Report 122-2 relate to antennae in situ. Only data relating to directivity, forward gain and cross-polarization protection of antennae tested under idealized conditions need be recorded.

Definitions and methods of measurement are contained in IEC Publication 138.

Amplitude-modulation reception

No characteristics are suggested for antenna systems.

Note.- IEC Publication 315-1A describes methods of coupling signals into magnetic antennae for measurements on both amplitude-modulation and frequency-modulation receivers.

3.2 Selectivity

3.2.1 Passband and attenuation slope

Definition and method of measurement

For the amplitude-modulation broadcasting bands see IEC Publication 315-3, clauses 15, 17, 18 and 19; the value of the parameter "a" being fixed at 6 dB. This refers to single-signal measurement, the results of which can easily be transferred, graphically or numerically, to radio-frequency protection ratio values (see clause 3.4) by the two-signal methods described in Report 399-2.

A two-signal measuring method is also mentioned in clause 16 of IEC Publication 315-3.

For frequency-modulation broadcasting in band 8 (VHF): see IEC Publication 315-4* clauses ...

* IEC Publication 315-4 is in preparation

3.2.2 Intermediate-frequency rejection ratio

This characteristic is of interest to amplitude-modulation broadcasting.

Definition : IEC Publication 315-3, clause 24

Method of measurement

The single signal method described in clause 25 of the same publication.

Presentation of results

From the graphs obtained according to clause 27 of the same publication only the worst figure in each broadcasting band is recorded.

3.2.3 Image rejection ratio

Definition : IEC Publications 315-3 for amplitude modulation and 315-4* for frequency modulation.

Method of measurement

For the amplitude-modulation bands the single-signal method described in IEC Publication 315-3 is used.

For frequency-modulation broadcasting in band 8 (VHF) it is necessary to use a two-signal method as described in IEC Publication 315-4*.

Presentation of results

From the graphs obtained according to IEC Publications 315-3 and 315-4*, only the worst figure in each broadcasting band is retained.

3.2.4 Intermediate-frequency values

The main factors determining the interference in receivers are : The value of image and intermediate-frequency rejection ratio and the production of harmonics of the intermediate frequency and/or the oscillator frequency.

It is necessary to choose the value of the intermediate frequency carefully to minimize the risk of interference without unduly increasing the cost of the receiver.

* IEC Publication 315-4 is in preparation

Amplitude-modulation receiver

No single value of intermediate frequency is, at present, satisfactory for the whole European area.

Nevertheless, studies have shown that when a frequency plan is being established for a large area, two values of intermediate frequency may be recommended to minimize interference and to permit all available channels to be used.

Finally, any future plan must take into account compatibility with existing receivers.

Annex II of Doc. 10/273 (France), 1970-1974, gives additional information on the determination of intermediate frequency (see Docs. 10/186 (United Kingdom), and 10/272, 10/273, 10/274, 10/275, 10/276, 10/277 (France), 1970-1974).

The following table gives some of the intermediate frequencies used at present and should be completed.

Country	Oscillator position	Intermediate frequency (kHz)			Observation
		1	2	3	
France	High	455	480		
United Kingdom	High	460			
German Democratic Republic	High	455	468		
Japan	High	455			

Attention is drawn to Report 458-1 which proposes that the intermediate frequency should be chosen as an integral multiple of the frequency separation between carriers.

Frequency-modulation receiver

For this type of receiver a value of 10.7 Mhz is usual.

3.3 Sensitivity

3.3.1 Definition

For planning purposes, the word "sensitivity" covers the maximum usable sensitivity, which is understood as noise limited sensitivity, as defined for amplitude modulation in IEC Publication 315-3, clause 72, and for frequency modulation in IEC Publication 315-4*. This refers to a chosen value of audio-frequency signal-to-noise ratio which is defined in IEC Publication 315-3.

Sensitivity should be presented as a single mean figure for each broadcasting band, from which the minimum usable field strength may be calculated.

Other limitations may be significant, for example, impulsive noise, galactic noise, atmospheric noise, man-made noise, etc., depending on the location and on the receiving antenna used.

3.3.2 Conditions of measurement

According to IEC Publications 315-3 for amplitude modulation and 315-4* for frequency modulation.

No specific signal-to-noise ratio is standardized at this moment, but a choice may be made for the type of receiver being considered.

The following parameters are suggested :

- audio-frequency signal-to-noise ratio : 26 dB for amplitude-modulation

  30 dB for frequency-modulation

- output power : 50 mW.

3.4 Radio-frequency protection ratios

General

Radio-frequency protection ratio**, as a parameter for frequency planning, is defined as the radio-frequency wanted-to-interfering signal ratio at the receiver input, producing a specified grade of sound impairment. It will depend, amongst other things, on the nature of the wanted signal (modulation characteristics, frequency deviation, etc.), on the type of interfering signal (AM, FM, CW, etc.) and their frequency separation. The information should be presented in the form of graphs showing

* IEC Publication 315-4 is in preparation

** See Recommendation 447 which applies to amplitude modulation and Recommendation 412-1 which applies to frequency modulation.

the protection ratio, for interference assessed as Grade 4 impairment*, i.e. perceptible, but not annoying, as a function of frequency separation between the wanted and unwanted signals for each type of unwanted signal. If the protection ratio varies with the wanted signal level (due to non-linearity in the input stages of the receiver), this should be indicated. For frequency planning purposes the protection ratio figures obtained, for Grade 4 impairment* would need to be modified to take account of the grade of impairment that can be tolerated, bearing in mind the percentage of the time the impairment can be suffered. For this purpose, additional observations for more than one grade of impairment would be valuable.

"Usable field strength" and "service area" are defined in Recommendation 499.

Frequency-modulation receivers

The radio-frequency protection ratio graphs should cover frequency separations from zero to 400 kHz above and below the wanted signal frequency.

It should be noted that protection ratio is only directly related to impairment grade under linear conditions. For example, whereas a 6 dB increase in the level of an unwanted co-channel signal may result in an impairment assessment that is numerically one grade smaller, a similar increase in the level of an adjacent channel interfering signal may lower the impairment grading by more than one grade. To convert a protection ratio based on Grade 4 impairment* to that for a lower grade it is necessary to define this relationship. This can be done by making observations at levels of impairment other than that of Grade 4.

Amplitude-modulation receivers

Radio-frequency protection ratio for amplitude-modulation receivers employing an external antenna is defined in terms of the wanted-to-interfering signal ratio at the receiver input terminals. However, for receivers employing built-in magnetic antennae, the protection ratio is more conveniently expressed in terms of the ratio of wanted-to-interfering field strength required to produce a specified grade of sound impairment. The protection ratio will depend, amongst other things, on the depth of modulation, the programme material of both signals, the extent of any audio-frequency bandwidth restriction, the degree of compression applied at the transmitter and the frequency spacing between wanted and unwanted signals. The protection ratio figures for Grade 4* impairment should be presented in graphical form, relating them to frequency spacing from zero up to 3 or 4 channel widths.

In some instances objective methods are available that provide good correlation with subjective observations (see Report 298-3 and Report 399-2.

* See Report 623

3.5 Oscillator frequency

The position of the oscillator frequency relative to that of the wanted signal should be indicated as follows : "low" or "high". The tuning tolerance should also be indicated, in other words the limits between which the receiver can be mis-tuned but can still provide an acceptable sound quality.

3.6 Interference generated by the receiver

The radiation of the oscillator at its fundamental frequency and its harmonics on the one hand and of the intermediate-frequency and its harmonics on the other hand should be reduced to comply with CISPR Recommendation 24 (see IEC/CISPR Publication No. 7, Geneva).

REPORT 618

DEFINITIONS OF RADIATION IN BAND 5 (LF) AND 6 (MF)

(1974)

The LF/MF frequency-assignment plans for the European Broadcasting Area (Copenhagen, 1948) and the African Broadcasting Area (Geneva, 1966) are based on the carrier power supplied by the transmitter to the antenna. It is not possible, therefore, to determine the interference potential without a knowledge of the radiation characteristics including the efficiency of the antenna and feeder system.

Two definitions may be used to specify this radiation :

- the cymomotive force (c.m.f.);
- the effective monopole radiated power (e.m.r.p.).

1. Cymomotive force

1.1 Definition

Cymomotive force (in a given direction)

The product formed by multiplying the electric field-strength at a given point in space, due to a transmitting station, by the distance of the point from the antenna. This distance must be sufficient for the reactive components of the field to be negligible; moreover the finite conductivity of the ground is supposed to have no effect on propagation.

The cymomotive force (c.m.f.) is a vector; when necessary it may be expressed in terms of components along axes perpendicular to the direction of propagation.

The c.m.f. is expressed in volts; it corresponds numerically to the field-strength in mV/m at a distance of 1 km.

---

* Adopted unanimously

1.2 Determination of the c.m.f.

1.2.1 Vertical antennae : For vertical antenna systems which are actually in operation, the c.m.f. in a horizontal direction is obtainable by measurements of field strength on a radial line over the range 2 λ to 15 λ from the aerial system. Here λ is taken to be either the wavelength or the maximum dimensions of the antenna, whichever is the greater, in order to avoid the effect of reactive fields. If E is the field strength at distance d, the product Ed is plotted graphically against d. The best-fitting line is extrapolated to d = 0, and the product $(E_o d_o)$ gives the c.m.f.

For the single mast, it is desirable to take the average of values for a few radials. For a multiple mast system, separate measurements are required on a number of radials to establish the c.m.f. as a function of bearing.

For directions above the horizontal, a correction should be derived theoretically from the behaviour over a perfectly conducting plane. Alternatively, field strength measurements may be made from a helicopter.

For antenna systems which have not yet been constructed, or whenever for some other reason measurements cannot be made reliably, the c.m.f. may be estimated from a calculation of the system performance over a perfectly conducting surface, and from the estimated efficiency of the antenna system.

1.2.2 Horizontal dipole array : In this case, the most practical method is a computation for the array over a perfectly-conducting ground, assuming the total transmitter power (less the loss introduced by the feeder) represents the radiated power. In this case the c.m.f. should be the combination of two orthogonal components, perpendicular to the direction of propagation, made on a root mean square basis.

1.3 Transmitter carrier power as a function of c.m.f.

For a single vertical mast radiator, neglecting losses :

$$P = (F_c / 300)^2 \cdot (1 / g_e)$$

where P : transmitter carrier power in kW

F_c : c.m.f. in the horizontal direction in volts

g_e : gain of antenna relative to a short vertical antenna

More generally, the total power radiated into space (in other words, the power to be supplied to the antenna if losses are neglected) is related to the c.m.f. by

$$W = 1/120\pi \iint_{sphere} F_c^2 (\varphi,\theta) \cos\theta . d\theta d\varphi$$

where F_c (φ,θ) is the c.m.f. as a function of the azimuth φ and the angle of elevation θ (W is in watts and F_c is in volts).

2. Effective monopole radiated power

2.1 Definition

The power supplied to an antenna, multiplied by its gain in a given direction, referred to that of a short vertical antenna in the horizontal direction.

No. 102 of the Radio Regulations defines the gain referred to a short vertical antenna as :

"The gain (Gv) of an antenna in a given direction when the reference antenna is a perfect vertical antenna, much shorter than one quarter of the wave-length, placed on the surface of a perfectly conducting plane earth".

The reference antenna, when fed with 1 kW, produces a field-strength of 300 mV/m at 1 km distance and is aligned precisely with the ground-wave propagation curves of Recommendation 368-2 and the sky-wave curves of Report 264-3.

2.2 Determination of e.m.r.p.

For vertical antennae only, e.m.r.p. may be measured or estimated in the manner described in § 1.2 for determining c.m.f.

3. Relationship between c.m.f. and e.m.r.p.

The value of c.m.f., in volts, is related to e.m.r.p. by the formula :

e.m.r.p. = $(c.m.f/300)^2$ kW

The following table gives some practical examples of c.m.f. and e.m.r.p. in the absence of losses.

Transmitter power (kW)	Antenna	Gain relative to a short vertical antenna (dB)	c.m.f. (V)	c.m.f. (dB (300 V))	e.m.r.p. (kW)
0.01	short vertical	0 dB	30	-20	0.01
0.1		0 dB	95	-10	0.1
1.0		0 dB	300	0	1.0
10		0 dB	950	+10	10
100	r/2 vertical	2 dB	3 800	+22	160
300		2 dB	6 600	+27	475
		2 dB	12 000	+32	

4. Use of propagation curves

The ground-wave propagation curves of Recommendation 368-2 and the sky-wave propagation curves given in Report 264-3 are drawn nominally for a field strength of 300 mV/m at 1 km and thus apply to a c.m.f. of 300 V. However, the sky-wave curves were established from measurements to which a correction was applied in each case for the vertical radiation pattern (over good ground) of the transmitting antenna, but no correction was applied for the effect of finite ground conductivity on the sky-wave field strength. These curves therefore include the effect of average ground conductivity, which (as compared with a perfectly conducting ground) can cause significant reduction of sky-wave at low angles. This effect is discussed in Report 401-1. It can be shown that for all types of vertical antenna systems of interest for applications in bands 5 (LF) and 6 (MF) the ground effect is substantially independent of the type of antenna, and correction for the antenna gain and vertical radiation pattern may be made with good accuracy by correcting the calculated pattern for a perfectly-conducting flat earth.

The practice is already established for propagation curves to apply to a radiated power of 1 kW from a short vertical antenna and this corresponds to a c.m.f. in the horizontal direction of 0 dB relative to 300 V.

Printed in Switzerland