INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

C.C.I.R.

DOCUMENTS OF THE

Xth PLENARY ASSEMBLY

GENEVA, 1963

VOLUME II

PROPAGATION

Published by the

INTERNATIONAL TELECOMMUNICATION UNION

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Recommendations of Sub-section G.1 — Propagation over the surface of the earth and through the non-ionized regions of the atmosphere

Reports of Sub-section G.1 — Propagation over the surface of the earth and through the non-ionized regions of the atmosphere

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* This list includes only those Study Programmes which do not derive from Questions. A Study Programme derived from a Question carries the same serial number as this Questions followed by a letter (e.g., S.P. 102A (XII)). It is inserted in the book immediately after the Question from which it is derived.

ARRANGEMENT OF VOLUMES I TO VII OF THE DOCUMENTS OF THE Xth PLENARY ASSEMBLY OF THE C.C.I.R.

(Geneva, 1963)

VOLUME I	Emission. Reception. Vocabulary (Sections A, B, K and Study Groups I, II and XIV)
VOLUME II	Propagation (Section G and Study Groups V and VI)
VOLUME III	Fixed and mobile services. Standard frequencies and time signals. International monitoring (Sections C, D, H and J and Study Groups III, XIII, VII and VIII)
VOLUME IV	Radio-relay systems. Space systems and radioastronomy (Sections F and L and Study Groups IX and IV)
VOLUME V	Broadcasting, sound and television (Section E and Study Groups X, XI, XII and the C.M.T.T.)
VOLUME VI	Opinions and Resolutions of a general nature Reports to the Plenary Assembly List of participants List of documents in numerical order
VOLUME VII	Minutes of the Plenary Meetings.

Note 1. — To facilitate references, the pagination in the English and French texts is the same.

Note 2. — At the beginning of Volume VI will be found information concerning the Xth Plenary Assembly of the C.C.I.R. and the participation at this meeting, on the presentation of texts (Definitions, origins, numbering, complete lists, etc.) together with general information on the organization of the C.C.I.R.

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RECOMMENDATIONS OF SUB-SECTION G.2 (IONOSPHERIC PROPAGATION)

REPORTS OF SUB-SECTION G.2 (IONOSPHERIC PROPAGATION)

QUESTIONS AND STUDY PROGRAMMES ASSIGNED TO STUDY GROUP VI (IONOSPHERIC PROPAGATION); OPINIONS AND RESOLUTIONS OF INTEREST TO THIS STUDY GROUP

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RECOMMENDATIONS OF SUB-SECTION G.1 — PROPAGATION OVER THE SURFACE OF THE EARTH AND THROUGH THE NON-IONIZED REGIONS OF THE ATMOSPHERE

RECOMMENDATION 168 *

PRESENTATION OF ANTENNA RADIATION DATA

(Question 49)

The C.C.I.R., (London, 1953—Warsaw, 1956)

CONSIDERING

(a) that the aims pursued by the I.T.U. require a knowledge of the radiation in free space in all directions from the antennae used in international radiocommunication;

(b) that antenna radiation is well represented by diagrams showing the field strength or the power radiated in every direction of space;

(c) that, alternatively, the antenna radiation can be represented by the vectorial specific cymomotive force *F* in every direction in space (See Note);

UNANIMOUSLY RECOMMENDS

1. that, in diagrams of antenna radiation, contours representing the radiation in free space in all directions be labelled in terms of relative radiated power or field strength;

2. that an alternate method of presentation may also be employed consisting of diagrams of contours representing the radiation in all directions of space in terms of the vectorial specific cymomotive force *F*;

3. that the Director, C.C.I.R. should take account of the above considerations, when antenna diagrams are being drawn.

Note. — The specific cymomotive force, *F*, is a vector expressed in volts, defined as the product *E.d*, where *E* is the vectorial free-space field radiated by the antenna in a particular direction at a distance *d* from the centre of radiation of the antenna when the total radiated power is 1 kW.

Where the antenna dimensions are not negligible in relation to the wave-length, or to the distance at which the measurements are made, the limit of the product *E.d* as *d* approaches infinity, is regarded as the c.m.f. To measure the c.m.f. in these instances, the field measured at a finite distance must be modified by an appropriate correction factor **.

The radiated power *W* and the cymomotive force *F* are related by the equation $F^2 = 377\ W$, where *F* is expressed in volts and *W* is expressed in watts per unit solid angle in the direction considered.

When the polarization of the electric field is elliptical, the c.m.f. may be shown as the magnitude and direction of the two main axes of the ellipse of polarization.

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* This Recommendation replaces Recommendation 108.

** See e.g. " Carlo Micheletta . Sulla determinazione della forza cimomotrice di emittitori con antenne a paraboloide " — Piccole Note-Recensioni e Notizie — I.S.P.T. 1, 1956, p. 13.

RECOMMENDATION 310 *

DEFINITIONS OF TERMS RELATING TO PROPAGATION IN THE TROPOSPHERE

The C.C.I.R., (Geneva, 1951 — Los Angeles, 1959)

CONSIDERING

that it is well known that the propagation of waves of frequencies greater than 30 Mc/s is greatly influenced by meteorological conditions in the troposphere;

UNANIMOUSLY RECOMMENDS

that the list of definitions annexed hereto be adopted for incorporation in the vocabulary;

VOCABULARY OF TERMS USED IN RADIO PROPAGATION THROUGH THE TROPOSPHERE

	Term	Definition
1.	*Troposphere*	The lower part of the earth's atmosphere extending upwards from the earth's surface, in which temperature decreases with height except in local layers of temperature inversion.
2.	*Tropopause*	The upper boundary of the troposphere, above which the temperature increases slightly with respect to height, or remains constant.
3.	*Temperature inversion*	In the troposphere: an increase in temperature with height.
4.	*Modified refractive index*	For a given height above sea level: the sum of the refractive index of the air at this height and the ratio of this height to the radius of the earth.
5.	*Refractive modulus*	One million times the amount by which the modified refractive index exceeds unity.
6.	*M-unit*	A unit in terms of which refractive modulus is expressed in accordance with the preceding definition.
7.	*M-curve*	A curve showing the relationship between refractive modulus and height above the earth's surface.
8.	*Standard refractive modulus gradient*	That uniform variation of refractive modulus with height above the earth's surface which is regarded as a standard for comparison. The gradient considered as normal has a value of 0·12 M-units per metre (3·6 M-units per hundred feet).
9.	*Standard radio atmosphere*	For tropospheric propagation: an atmosphere having the standard refractive modulus gradient.
10.	*Basic reference atmosphere*	An atmosphere defined by the relationship: $n(h) = 1 + \left\{289 \times 10^{-6} \exp(-0{\cdot}136h)\right\}$ where h is the height above sea-level in km. *Note.* — The refractive index in the first kilometre of the basic reference atmosphere is very nearly equal to that in an atmosphere corresponding to an earth of effective radius of 4/3 the real radius.

* This Recommendation replaces Recommendation 54.

	Term	Definition
11.	*Standard refraction*	The refraction which would occur in a standard radio atmosphere (see Fig. 1).
12.	*Super-refraction*	Refraction greater than standard refraction (see Fig. 1).
13.	*Sub-refraction*	Refraction less than standard refraction (see Fig. 1).
14.	*Standard propagation*	The propagation of radio waves over a smooth spherical earth of uniform electrical characteristics under conditions of standard refraction in the atmosphere.
15.	*Tangential wave path*	In radio-wave propagation over the earth: a path of propagation of direct wave, which is tangential to the surface of the earth. The tangential wave path is curved by atmospheric refraction.
16.	*Radio horizon*	The locus of points at which direct rays from the transmitter become tangential to the earth's surface.
17.	*Effective radius of the earth*	The radius of a hypothetical earth for which the distance to the radio horizon, assuming rectilinear propagation, is the same as that for the actual earth with an assumed uniform vertical gradient of refractive index. (For the standard atmosphere, the effective radius is 4/3 that of the real earth.)
18.	*Tropospheric-radio duct*	A stratum of the troposphere within which an abnormally large proportion of any radiation of sufficiently high frequency is confined and over part or all of which there exists a negative gradient of refractive modulus. The upper bounding surface is determined by a local minimum value of the refractive modulus. The lower bounding surface is either the surface of the earth or a surface parallel to the local stratification of refractive properties at which the refractive modulus has the same values as that at the local minimum value of the refractive modulus (see Fig. 2, 3 and 4).
19.	*Surface duct* *Ground-based duct*	A tropospheric-radio duct having the earth as its lower boundary and in which the modified refractive index is everywhere greater than the value at the upper boundary (see Fig. 2 and 3).
20.	*Elevated duct*	A tropospheric-radio duct of which the lower boundary is an elevated surface at which the modified refractive index has the same value as at the upper boundary (see Fig. 4).
21.	*Duct thickness* *Duct width*	The difference in height between the upper and lower boundaries of a tropospheric-radio duct.
22.	*Duct height*	The height above the surface of the earth of the lower boundary of an elevated duct (see Fig. 4).
23.	*Tropospheric mode*	Any one of the possible modes of propagation in the troposphere.
24.	*Trapped mode*	A mode of propagation in which the energy is substantially confined within a tropospheric-radio duct.
25.	*Mixing ratio*	The ratio of the mass (in grammes) of water vapour in a given volume of the atmosphere to the mass (in kilogrammes) of the dry air in the same volume.

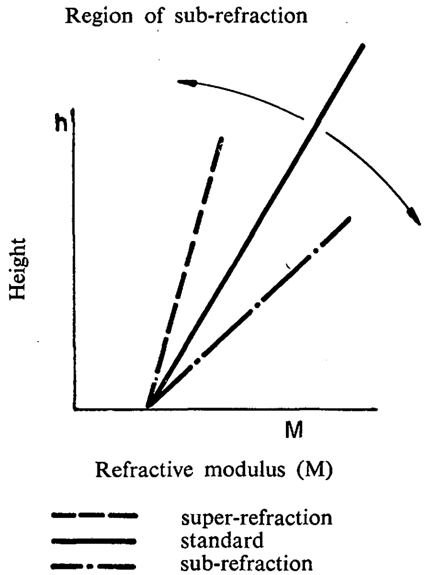

FIGURE 1

M-curves

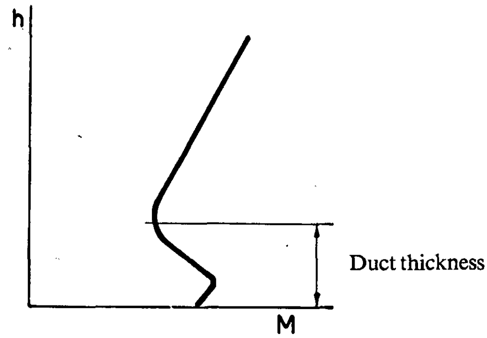

FIGURE 2

Surface duct

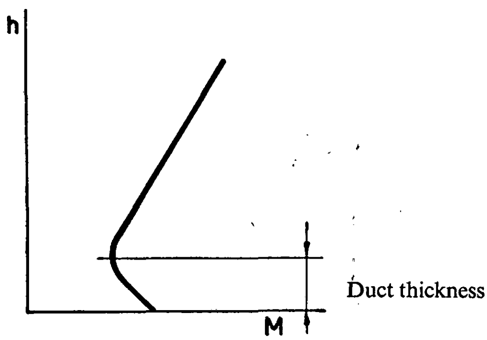

FIGURE 3

Surface duct

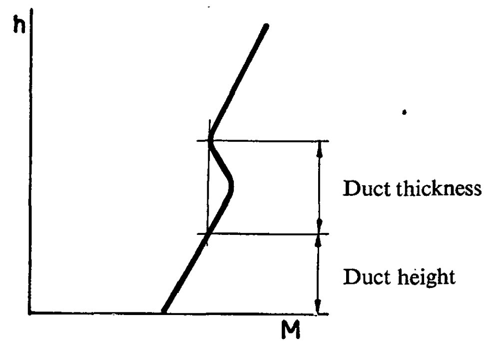

FIGURE 4

Elevated duct

RECOMMENDATION 311 *

PRESENTATION OF DATA IN STUDIES OF TROPOSPHERIC-WAVE PROPAGATION

The C.C.I.R., (London, 1953 — Warsaw, 1956 — Los Angeles, 1959)

CONSIDERING

(a) that there is an urgent need for guidance to be given to engineers in the planning of broadcasting, television and fixed link services in the frequency band 30-4000 Mc/s;

(b) that it is important to determine how the field strengh in this frequency band depends on meteorological conditions and upon the nature of the terrain at locations both within and beyond the horizon;

(c) that to facilitate the comparison of results, it is desirable that Administrations and operating agencies should present field-strengh data in a uniform manner;

(d) that it is not yet possible to establish a final method of presenting results and a system of statistical analysis best suited to the requirements expressed in § *(a)* and *(b)*;

UNANIMOUSLY RECOMMENDS

1. that the field strengths exceeded for 0 1%, 1%, 10%, 50%, 90%, 99% and 99·9% of the overall time should, whenever possible, be determined for all locations at which measurements are made;

2. that for broadcasting and television, the median values of field strength exceeded at 10%, 50% and 90% of the locations should be determined;

3. that it is desirable to amplify these overall statistics by a more detailed and precise analysis; for this purpose, the methods proposed in Annex I of the present Recommendation, or in Doc. 172 (France) of Warsaw, 1956, or in Doc. V/28 (France) of Geneva, 1958 might be taken as a basis;

4. that the statistical results of field-strength measurements should be displayed on probability paper. The field strength sould be plotted along the ordinate and expressed in db rel. 1μV/m, the values of field strength increasing, moving up the ordinate. The percentage of total valid recording time, or percentage of locations should be plotted along the abscissa, with a scale following the Gaussian probability law, percentages increasing from left to right. An example of a log-normal distribution plotted on probability paper is given in Annex II;

5. that all measured values of field strength should be normalized to correspond to those that would be obtained with a vertical half-wave dipole, or with a similar horizontal dipole placed broadside to the direction of the receiving point, the dipole in each case being at least several wavelengths above the ground and radiating 1 kW;

6. that, for broadcasting and television, and whenever possible, all measurements should be referred to a receiving antenna 10 m above the ground and this antenna should not be highly directional in the vertical plane.

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* This Recommendation replaces Recommendation 170.

ANNEX I

It should be noted that the recommendations given above refer particularly to the propagation of waves over long distances (especially in connection with interference problems in sound and television broadcasting) and also to propagation characteristics within the service areas of sound and television broadcasting stations. While the first interest lies in ascertaining those values of field strength exceeded for various percentages of the overall time at varying distances, for a more detailed analysis it might, however, be useful to analyze measurements within unit periods of 1 hour. This latter procedure would permit studies to be made of diurnal variations, while similarly seasonal variations could conveniently be studied by grouping the values obtained at specified hours of the day for a whole month and examining the change of field-strengh distributions from month to month. Presentation of the results in this form would, moreover, permit later correlation of radio measurements with meteorological data.

For the study of propagation over fixed line-of-sight links in the VHF (metric), UHF (decimetric) or SHF (centimetric) bands, a more precise correlation between received field strength and prevailing atmospheric conditions might be required. For this and other reasons it is considered that results should be capable of being presented separately for each hour of the day of each month during which tests are being conducted. At the same time, overall distribution curves for periods of one month will be required to permit a study of seasonal variations; overall distribution curves for even longer periods will also, no doubt, be required by the planning engineer. It is generally convenient to refer results to the free space value for the distance and other conditions concerned.

Although it will usually be necessary to preserve, for reference, the original charts upon which the field-strength variations are recorded, it is essential that some much simpler and more conveniently accessible means of displaying the essential data be employed. One method is to plot the maximum, median and minimum field strengths for each hour on linear graph paper, the spread of results within the hour being shown by a vertical line. In addition, by determining the hourly median value or the value over some other percentage of the time, it is possible to obtain, for any given hour of the day, the statistical distribution of these values for a month (or any other desired period of time).

ANNEX II

The Gaussian probability scale is defined by

$$P(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \exp\{-\xi^2/2\}\, d\xi$$

For abscissae $x = 0$, $x \to \infty$ and $x \to -\infty$, the corresponding values of the probability $P(x)$ are 50%, 0% and 100%.

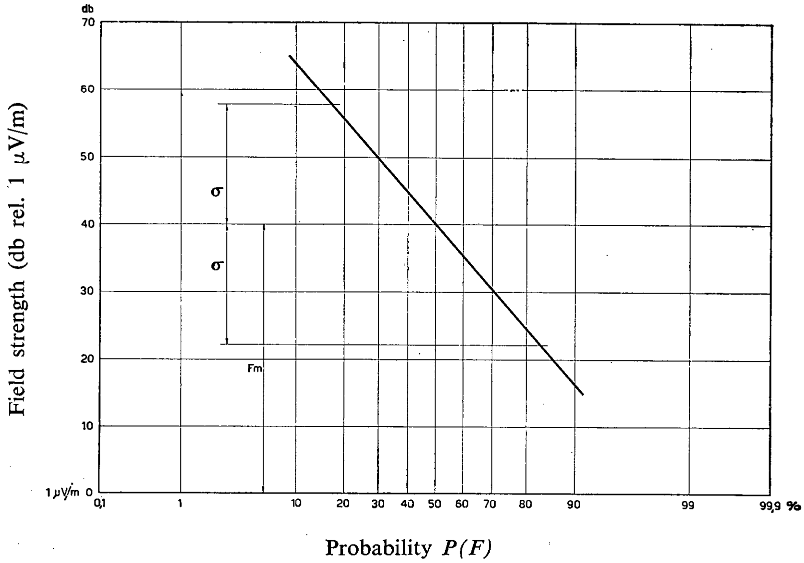
An amplitude Gaussian distribution for a field strengh F measured in db (log-normal distribution) is given by:

$$P(F) = \frac{1}{\sigma\sqrt{2\pi}} \int_F^{\infty} \exp\left\{-(f-F_m)^2/2\sigma^2\right\} df$$

$P(F)$ is the probability (percentage of time or locations) that the field-strength E expressed in db above 1 μV/m ($F = 20 \log E$) will exceed the level F. F_m is the median value of F, i.e. that which is exceeded for 50% of the time or locations. σ is the standard deviation, so that $P(F_m - \sigma) \approx 84\%$ and $P(F_m + \sigma) \approx 16\%$.

It is often of interest to know the field strength exceeded for 1% or 10% of the time; when the distribution is log-normal, the distribution curve is a straight line, and the corresponding deviations are given by 2·32 σ and 1·28 σ.

The accompanying graph illustrates the presentation of log-normal distribution.



Graph showing log-normal distribution of field-strength measurements.

RECOMMENDATION 368 *

GROUND-WAVE PROPAGATION CURVES FOR FREQUENCIES BELOW 10 Mc/s

(Question 246 (V))

(Geneva, 1951 — Los Angeles, 1959 — Geneva, 1963)

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 Mc/s under the conditions stated.

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* This Recommendation replaces Recommendation 307.

ANNEX

The attached curves apply to propagation at frequencies below 10 Mc/s.

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. that the curves are based on the rigorous analysis of the problem given by van der Pol and Bremmer;

4. the curves are referred to what has been called an unattenuated field-strength of $3 \times 10^5/D$ (μV/m) where D is the distance from the transmitter in km*. This field would actually correspond to the case of a vertical antenna, shorter than one quarter wavelength, radiating 1 kW when placed on the surface of a perfectly conducting plane earth. The propagation loss, defined in Recommendation 341 for ground-waves, may be determined from the values of the field-strength E (db rel. 1 μV/m), given in the attached curves, by the use of equation (19) of Report 112;

5. 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;

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 kc/s and 2 Mc/s 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.

* *Note by the C.C.I.R. Secretariat:* The distance D is measured along the straight line joining the two points and not along the arc of the great circle between them.

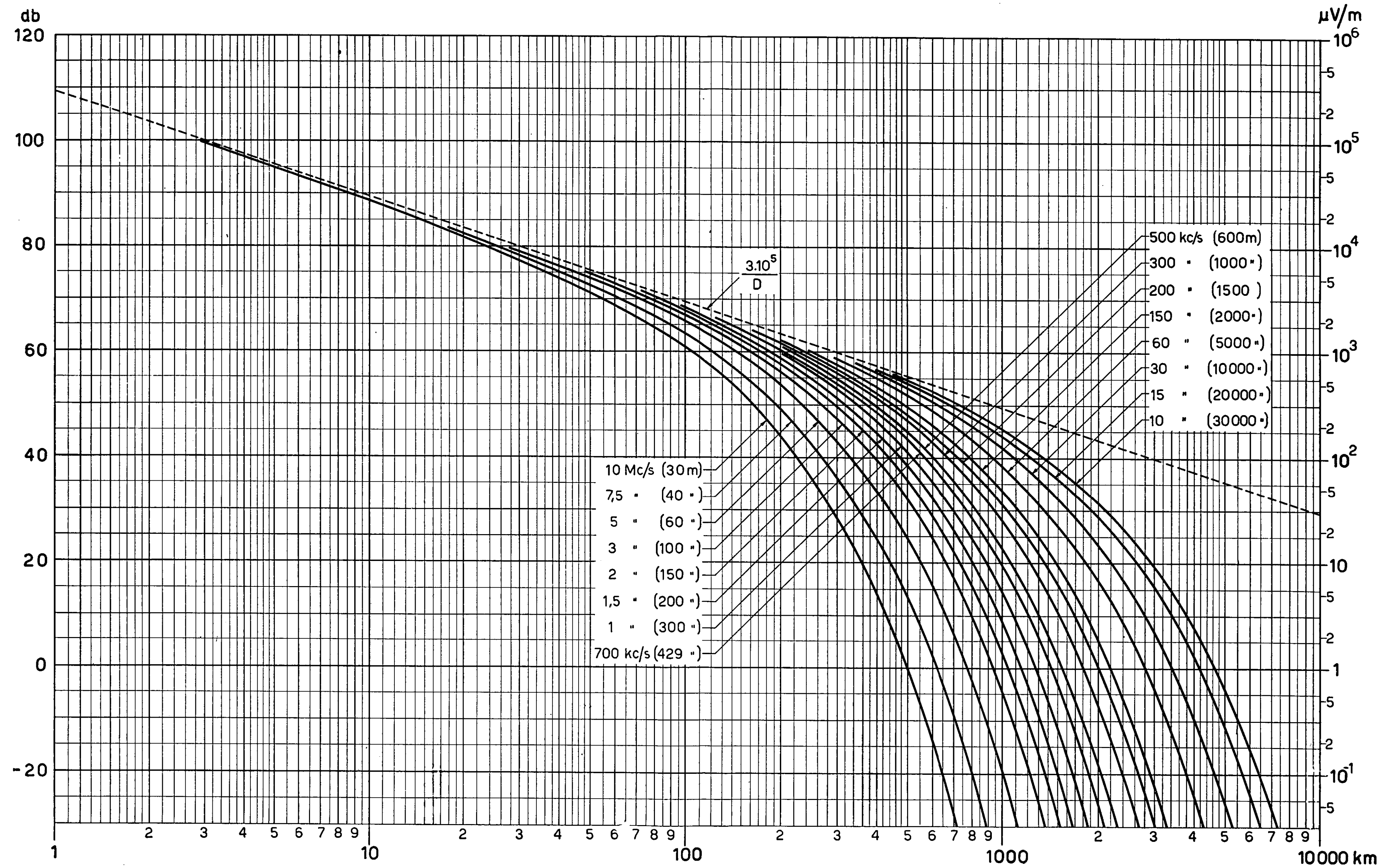

FIGURE 1

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

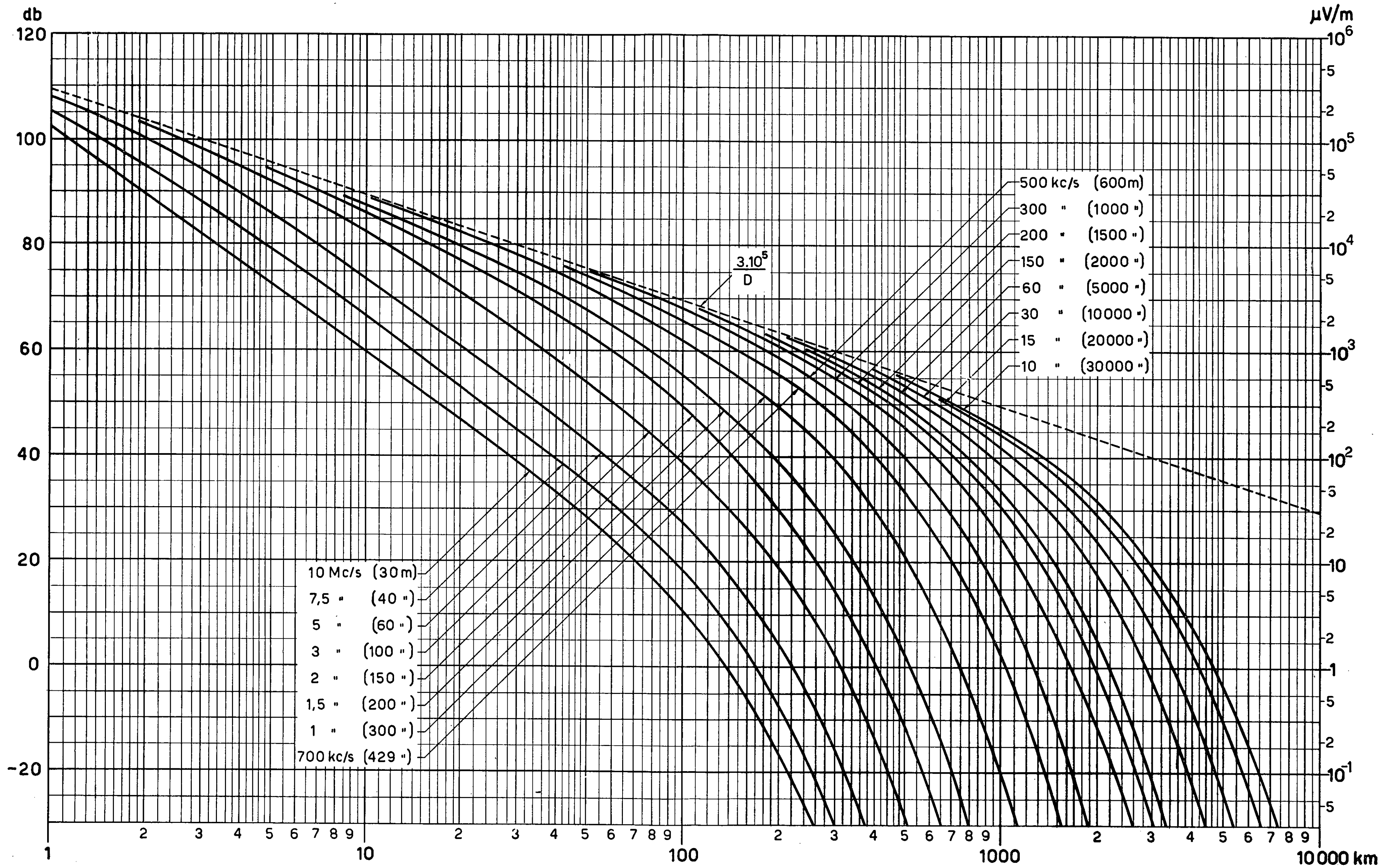

FIGURE 2

Ground-wave propagation curves: Earth, $\sigma = 3 \times 10^{-2}$ mho/m, $\varepsilon = 4$

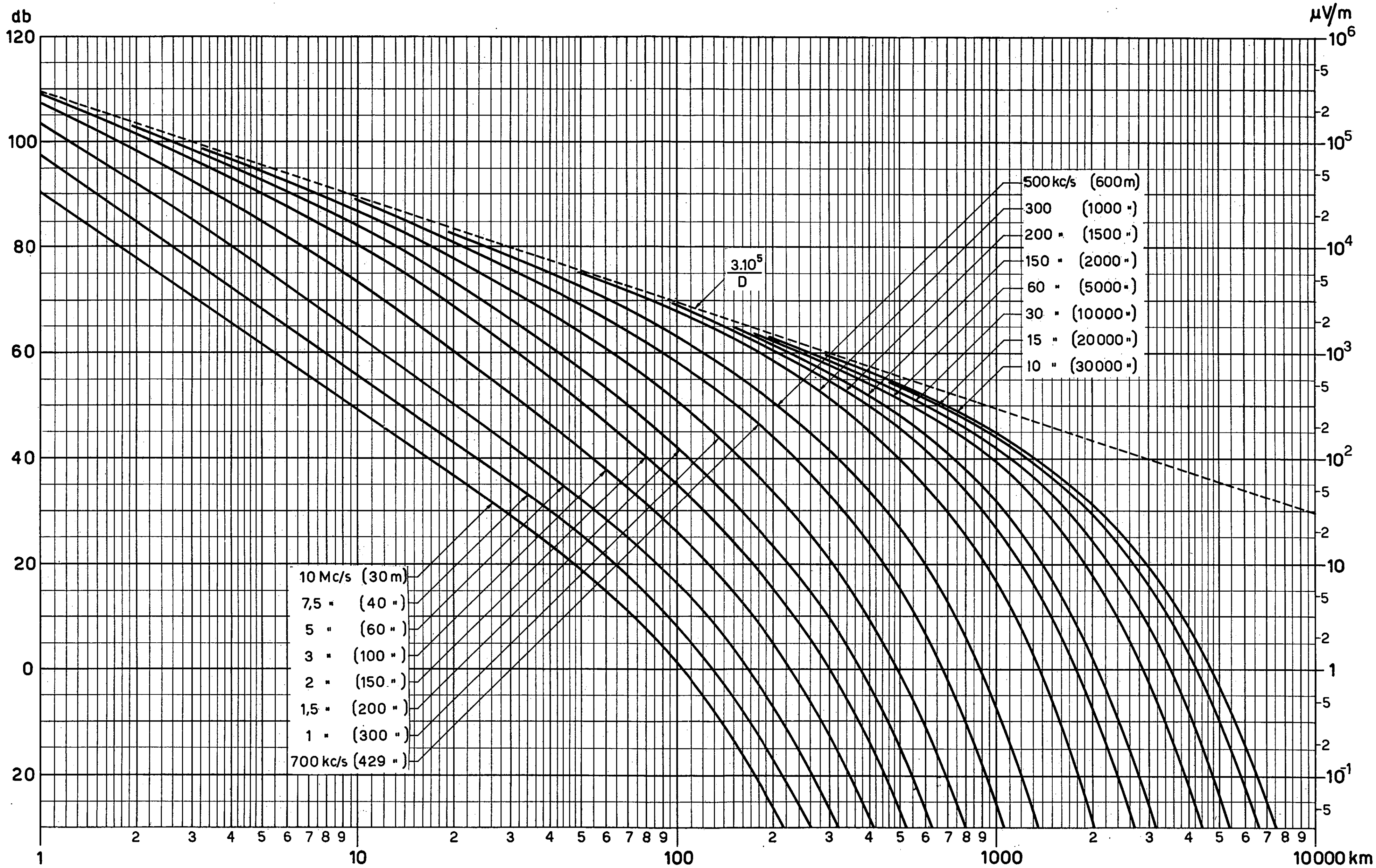

FIGURE 3

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

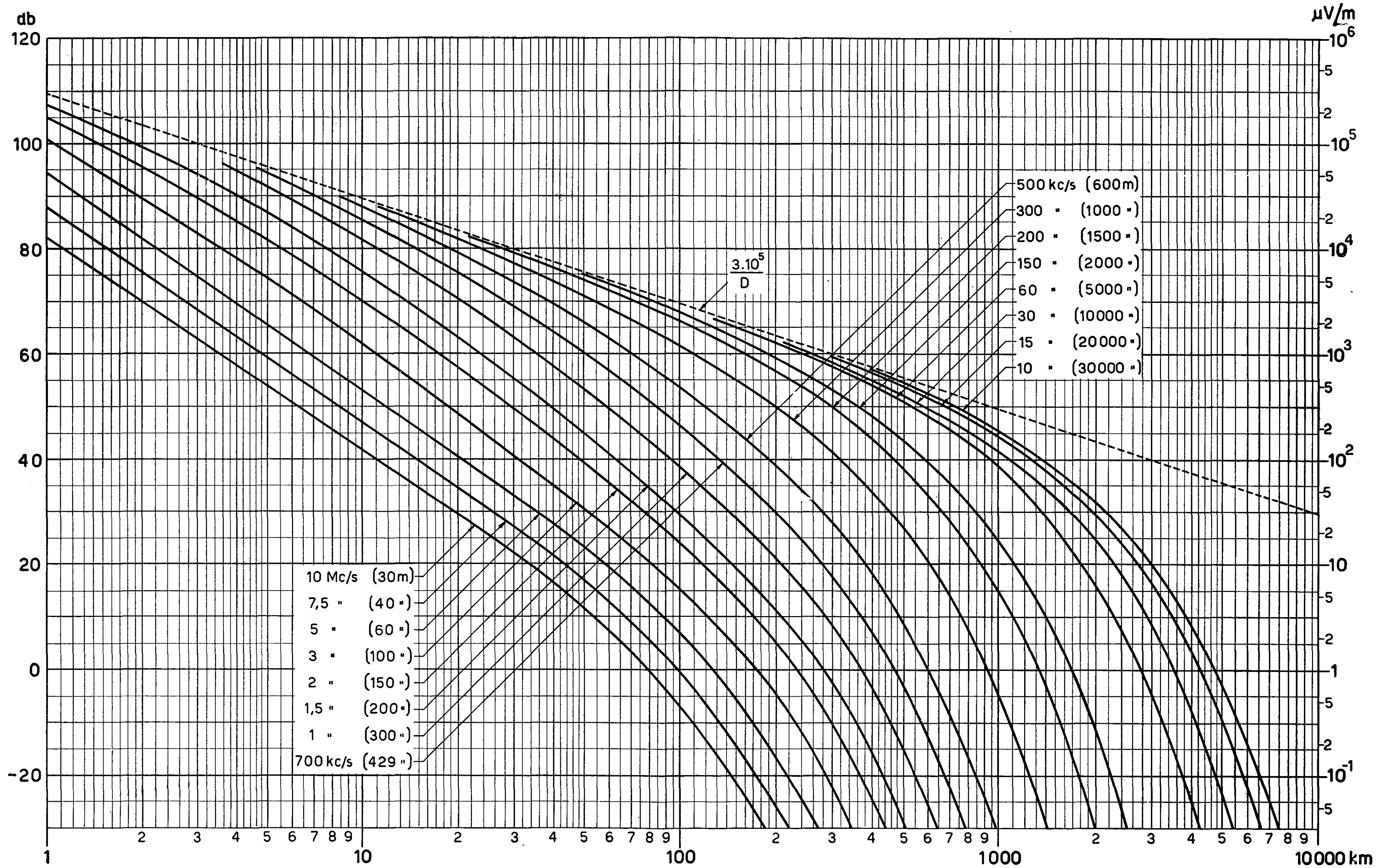

FIGURE 4

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

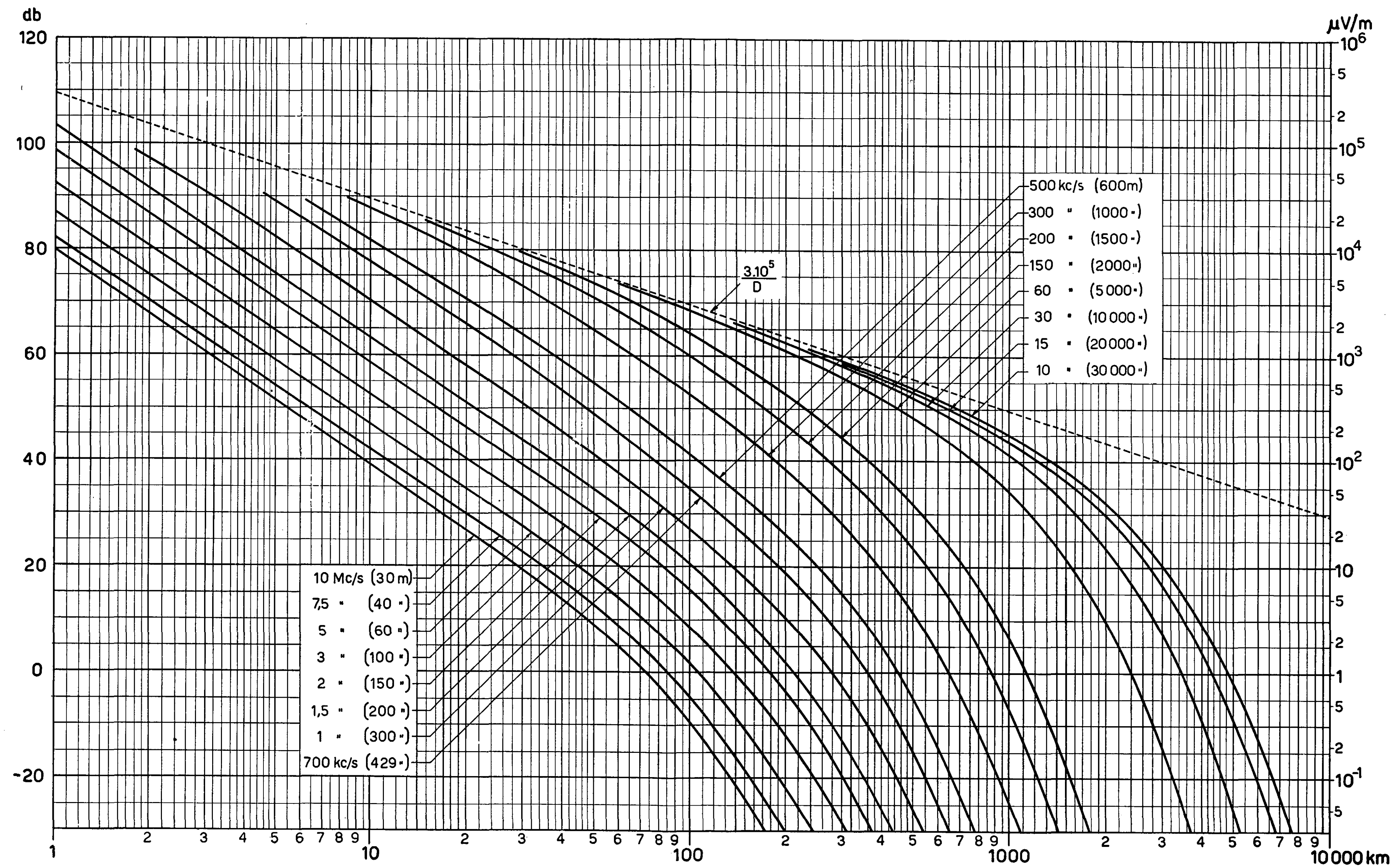

FIGURE 5

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

RECOMMENDATION 369 *

DEFINITION OF A BASIC REFERENCE ATMOSPHERE

(Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

that the dependence of the refractive index n of the atmosphere at radio frequencies upon the height h is well expressed by the law

$$n(h) = 1 + a.\exp(-bh)$$

where a and b are constants that can be determined statistically for different climates (see Report 231);

UNANIMOUSLY RECOMMENDS

that the basic reference atmosphere be defined by the relationship

$$n(h) = 1 + 289 \times 10^{-6} \cdot \exp(-0{\cdot}136h)$$

where h is the height above sea level (km).

Note : The gradient of the refractive index in the first kilometre of the basic reference atmosphere is nearly equal to that in an atmosphere, the effect of which can be represented by an effective radius of the earth 4/3 the real radius.

RECOMMENDATION 370 **

VHF AND UHF PROPAGATION CURVES FOR THE FREQUENCY RANGE FROM 40 Mc/s TO 1000 Mc/s ***

Broadcasting and mobile services

(Geneva, 1951 — London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that there is a need to give guidance to engineers in the planning of broadcast and mobile radio services in the VHF and UHF bands;

(b) that, for stations working in the same or adjacent frequency channels, the determination of the minimum geographical distance of separation required to avoid intolerable interference due to long-distance tropospheric transmission, is a matter of great importance;

* This Recommendation replaces Recommendation 309.

** This Recommendation replaces Recommendation 312.

*** It must be emphasized that the curves of this Recommendation are intended for use in the planning of broadcasting and mobile services for the solution of interference problems over a wide area; they should not be used for point-to-point communication links, for which systems the actual terrain profile may be determined and more accurate methods of field-strength prediction may be used.

(c) that the annexed curves are based on the statistical analysis of a considerable amount of experimental data (see Report 239);

UNANIMOUSLY RECOMMENDS

that the revised curves given in Annexes I and II be adopted for provisional use.*

ANNEX I

VHF BANDS (40-250 Mc/s)

1. The curves of Annex I were prepared from data obtained mainly in the United States of America and Western Europe; many more measurements were made for distances up to about 500 km than for greater distances, and the curves have their greatest reliability up to about 500 km.

2. The values of field strength are expressed in db rel. 1 μV/m for 1 kW effective radiated power from a half-wave dipole, and apply to both vertically and horizontally polarized waves.

3. Figs. 1, 2 and 3 show the field strengths exceeded at 50% of the receiving locations and for 50%, 10% and 1% of the time, respectively. The curves for values exceeded for 50% and 10% of the time apply to land paths as well as sea paths in the North Sea area. The full-line curves for 1% of time apply to land paths, and the dotted lines apply to sea paths in the North Sea area. Experience has shown that in the Mediterranean and the Gulf of Mexico, particularly in the summer, field strengths may exceed the figures given by the curves for the North Sea area by as much as 20 db, for distances exceeding some 200 km.
   Values of field strength for distances greater than about 700 km, obtained by extrapolation of these curves (dashed lines), should be used with caution.

4. The curves of Fig. 1, 2 and 3 apply to a receiving antenna height of 10 m above ground at the receiving location, and to various transmitting antenna heights, the transmitting antenna height being somewhat arbitrarily defined as the height of the antenna above the average level of the ground between distances of 3 km and 15 km from the transmitter, over the sector in which it is required to know the magnitude of the fields.
   For distances well within the normal horizon, the field strengths at other transmitting and receiving antenna heights may be estimated by assuming a linear increase in height-gain for antennae, the heights of which are well below the maximum of the first ground-reflection lobe. At distances well beyond the horizon, the effect of changing the transmitting antenna height may be determined approximately as follows: to obtain the field strength at a distance of X (km) from the transmitter, for a transmitting antenna height of h_1 (m), the curves for 300 m and 10 m should be read for a distance of $(X + 70 - 4 \cdot 1\sqrt{h_1})$ km. For intermediate distances near the horizon, the adjusted portions of the curves for beyond-the-horizon distances may be merged with the adjusted curves for distances well within the horizon.

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* It must be emphasized that the curves are based on data obtained mainly in temperate climates and should be used with caution in other climates.

5. The field strengths given in Figs. 1, 2 and 3 apply to 50% of receiving locations in the rolling terrain found in many parts of Europe and North America. For such terrain, the field strengths for other percentages of receiving locations may be obtained by using the distribution curve given in Fig. 4.

Neither the curves of Figs. 1, 2 or 3, nor the distribution curve of Fig. 4, can be assumed to apply accurately in very hilly or mountainous regions. In band III, and for such terrain, one should use one half the value of the attenuation correction factor (db), given in Annex II, § 3 (UHF bands).

6. It is known that the median field-strength varies in different climatic regions, and data for a wide range of such conditions in North America and Western Europe show that it is possible to correlate the observed values of median field-strength with the refractive index gradient in the first kilometre of the atmosphere above ground level. If n_s and n_1 are the refractive indices at the surface and at a height of 1 km respectively, and if ΔN is defined as $(n_1 - n_s) \times 10^6$, then in a standard atmosphere, $\Delta N \approx -40$, and the 50% curves of Fig. 1 refer to this case. If the mean value of ΔN in a given region differs appreciably from -40, the appropriate median field-strengths for all distances beyond the horizon are obtained by applying a correction factor of $-0{\cdot}5\,(\Delta N + 40)$ db to the curves. If ΔN is not known, but information concerning the mean value of N_s is available, where $N_s = (n_s - 1) \times 10^6$, an alternative correction factor of $0{\cdot}2\,(N_s - 310)$ db may be used, at least for temperate climates. Whilst these corrections have so far only been established for the geographical areas referred to above, they may serve as a guide to the corrections which may be necessary in other geographical areas. The extent to which it is reliable to apply similar corrections to the curves for field strengths exceeded 1% and 10% of the time is not known. It is expected, however, that a large correction will be required for the 1% and 10% values, in regions where super-refraction is prevalent for an appreciable part of the time.

ANNEX II

UHF BANDS (450–1000 Mc/s)

1. The values of field strength are expressed in db relative to 1 μV/m for 1 kW effective radiated power from a half-wave dipole, and apply to both vertically and horizontally polarized waves.

2. The influence of irregularities in the terrain is of greater importance in bands IV and V (UHF) than in bands I, II and III (VHF). The parameter Δh is used to define the degree of irregularity; it is the difference in the heights exceeded for 10% and 90% of the propagation path in the range 10 km to 50 km from the transmitter (see Fig. 5).

3. Figs. 6, 7 and 8 show the field strengths exceeded at 50% of the locations and for 50%, 10% and 1% of the time respectively. They refer to the kind of rolling irregular terrain, found in many parts of Europe and North America, for which a value of Δh of 50 m is considered representative. For greater or lesser values of Δh, a correction should be applied to the curves. At distances up to 100 km, the attenuation correction factors of Table I should be applied to the curves.

Thus, in rough terrain for Δh of 150 m, the portions of the curves in Figs. 6, 7 and 8 for distances less than 100 km should be reduced by 10 db. At distances greater than 200 km, half the value of the attenuation correction factor (db) in the above table should be assumed. In the intermediate region between 100 and 200 km, the two portions of the adjusted curves should be merged smoothly.

TABLE I

Δh (m)	Attenuation correction factor (db)
$\leqslant$ 50	—10
50	0
100-200	10
200-400	20

Values of field-strength at distances greater than about 700 km obtained by (dashed lines) extrapolation of these curves should be used with caution.

4. The curves of Figs. 6, 7 and 8 apply to a receiving antenna height of 10 m above ground at the receiving location, and to transmitting antennae at various heights; the height of the transmitting antenna being somewhat arbitrarily defined as the height of the antenna above the average level of the ground between distances of 3 km and 15 km from the transmitter over the sector in which it is required to know the magnitude of the fields. For distances well beyond the horizon, the effect of changing the transmitting antenna height may be determined approximately as follows: to obtain the field strength at a distance of X (km) from the transmitter for a transmitting antenna height, h_1 (m), the curves for 300 m and 10 m should be read for a distance of $(X + 70 - 4{\cdot}1\sqrt{h_1})$ km.

5. The field strengths given in Figs. 6, 7 and 8 are expected to be exceeded at 50% of the receiving locations in rolling terrain, such as is frequently encountered in Europe and North America. For this kind of terrain, the field strengths for other percentages of receiving locations may be obtained by using the distribution curves given in Fig. 9.

6. The only data available relating to oversea propagation are for the North Sea and Mediterranean areas. In Fig. 10, the median curve up to about 80 km distance is the theoretical curve for propagation over a smooth earth in a standard atmosphere; the curves for field strengths exceeded for 1%, 5%, 10% and 50% of the time for greater distances, are based on measurements in the North Sea area over a period of nearly 18 months. Limited measurements of the median value of field strength in the Mediterranean are in good agreement. There is evidence, however, that the field strengths exceeded for small percentages of time in the Mediterranean are greater than those experienced in the North Sea area.

7. The curves of Fig. 10 refer to transmitting and receiving antenna heights of 300 m and 10 m, respectively. The field strengths exceeded for small percentages of the time are not expected to be sensitive to appreciable changes in the transmitting antenna height for distances well beyond the horizon. The field strengths exceeded for 50% of the time may be adjusted for all distances and for other transmitting antenna heights by the method given in §4.

8. These curves are based on long-term (several years) values, and may be taken as representative of average climatic conditions throughout temperate regions. It must be noted, however, that for short periods of time (perhaps a few hours, or even a few days), fieldstrengths may occur which greatly exceed those given in Figs. 6, 7, 8 and 10.

9. Insufficient data exist for determining field strengths over mixed land and sea paths to the same degree of accuracy as for over land and over sea paths ,but a method for such calculations is described in Report 239.

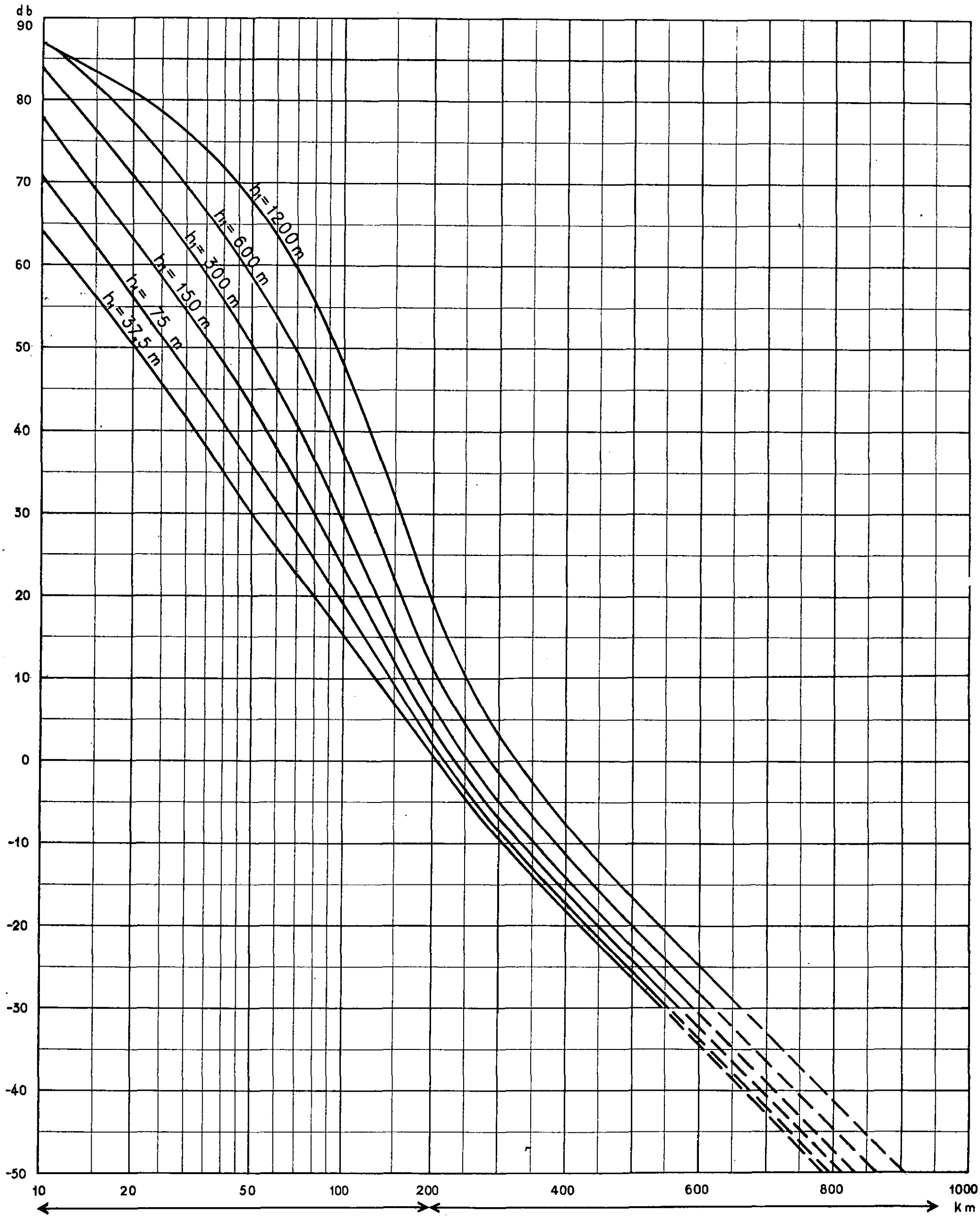


FIGURE 1

Field-strength (db rel. 1 μV/m) for 1 kW e.r.p.

Frequency: 40–250 Mc/s (Bands I, II and III); Land and sea; 50% of the time; 50% of the locations; h_2 = 10 m.

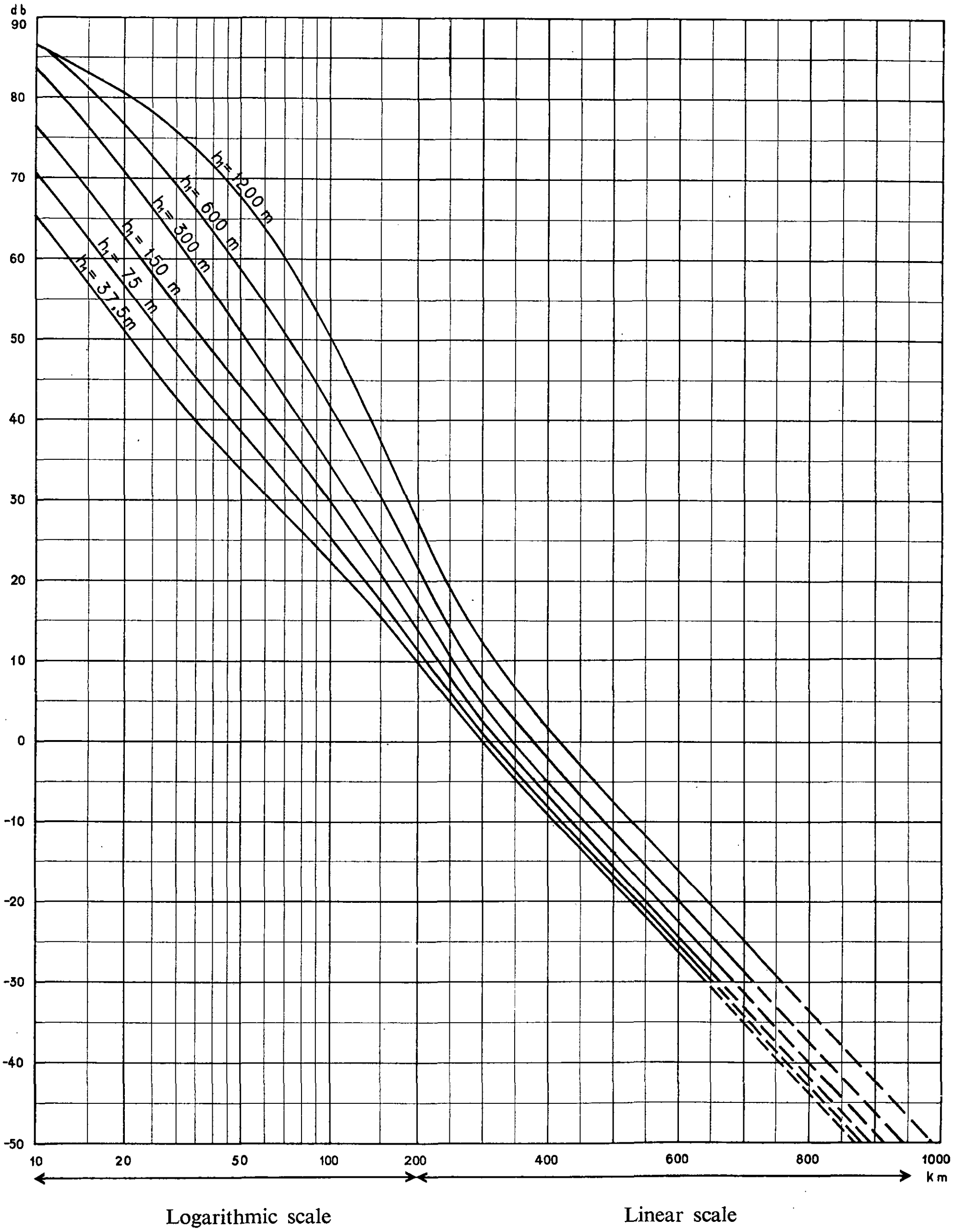


FIGURE 2

Field-strength (db rel. 1 μV/m) for 1 kW e.r.p.

Frequency: 40–250 Mc/s (Bands I, II and III); Land and sea; 10% of the time; 50% of the locations; h_2 = 10 m.

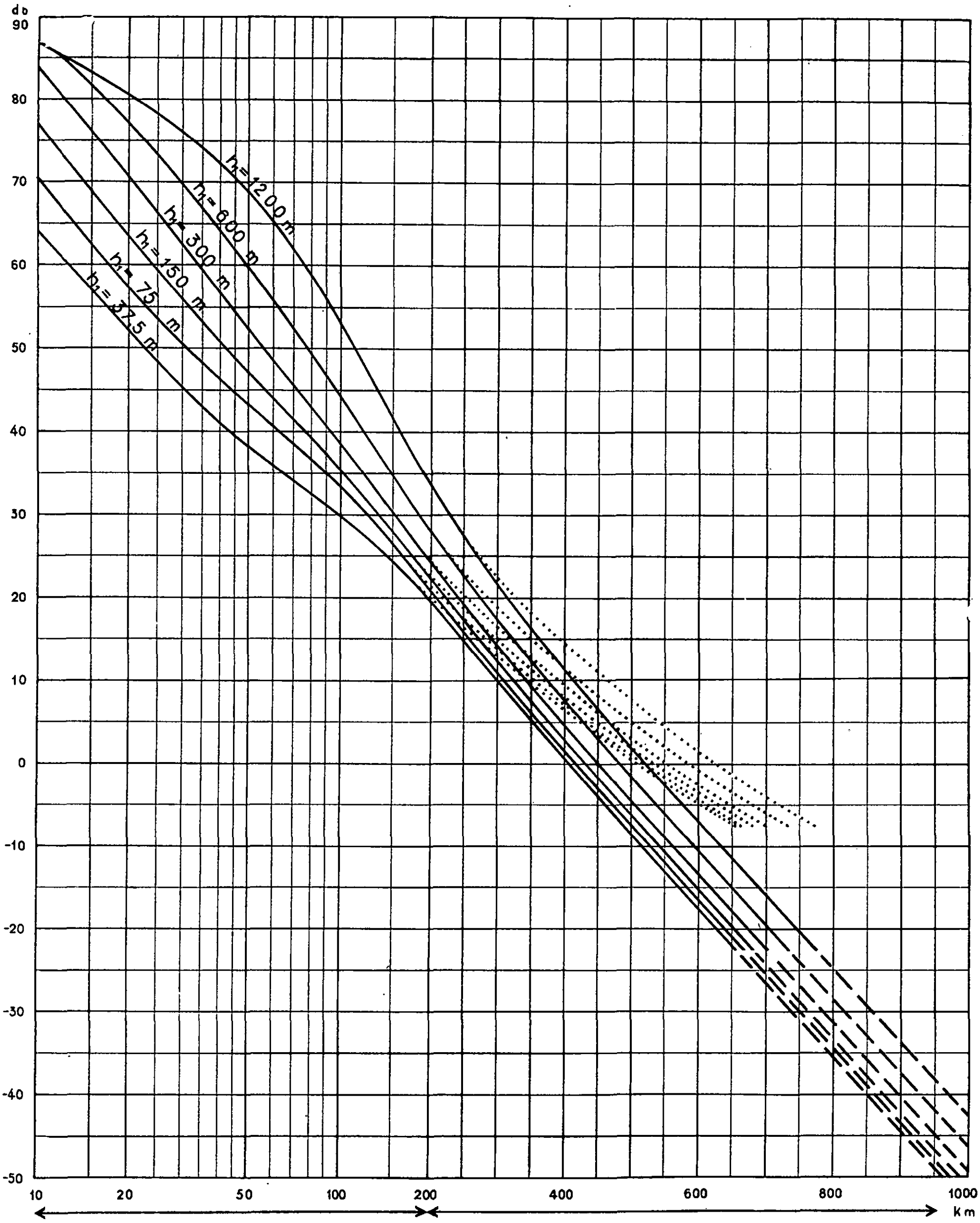
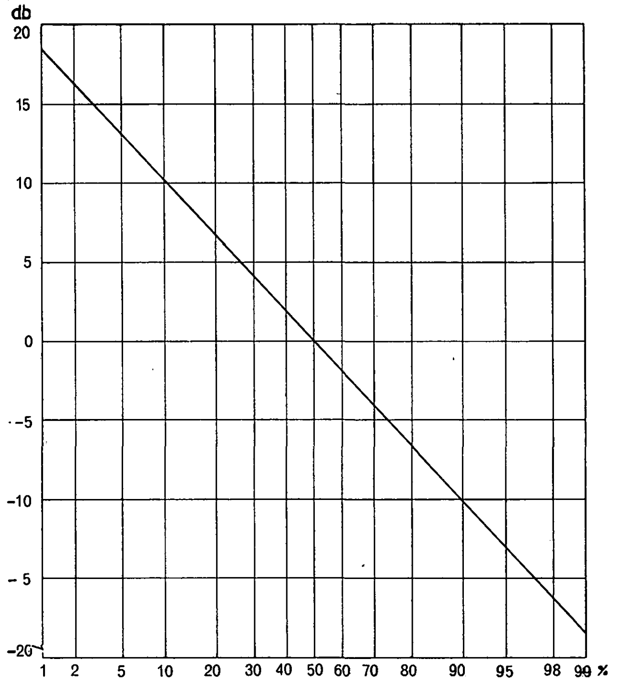


FIGURE 3

Field-strength (db rel. 1 μV/m) for 1 kW e.r.p.

Frequency: 40–250 Mc/s (Bands I, II and III); Land and sea; 1% of the time; 50% of the locations; h_2 = 10 m.

———— – – – – – land ————-------- North sea.



Percentage of receiving locations

FIGURE 4

Ratio (db), of the field strength for a given percentage of receiving locations to the field strength for 50% of receiving locations.

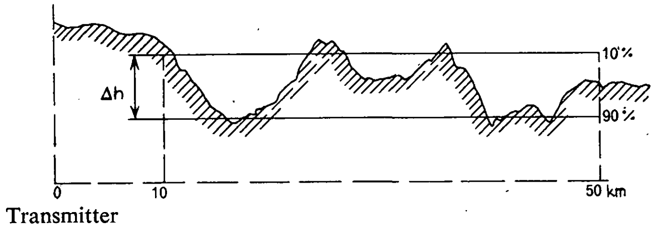


FIGURE 5

Definition of the parameter Δh

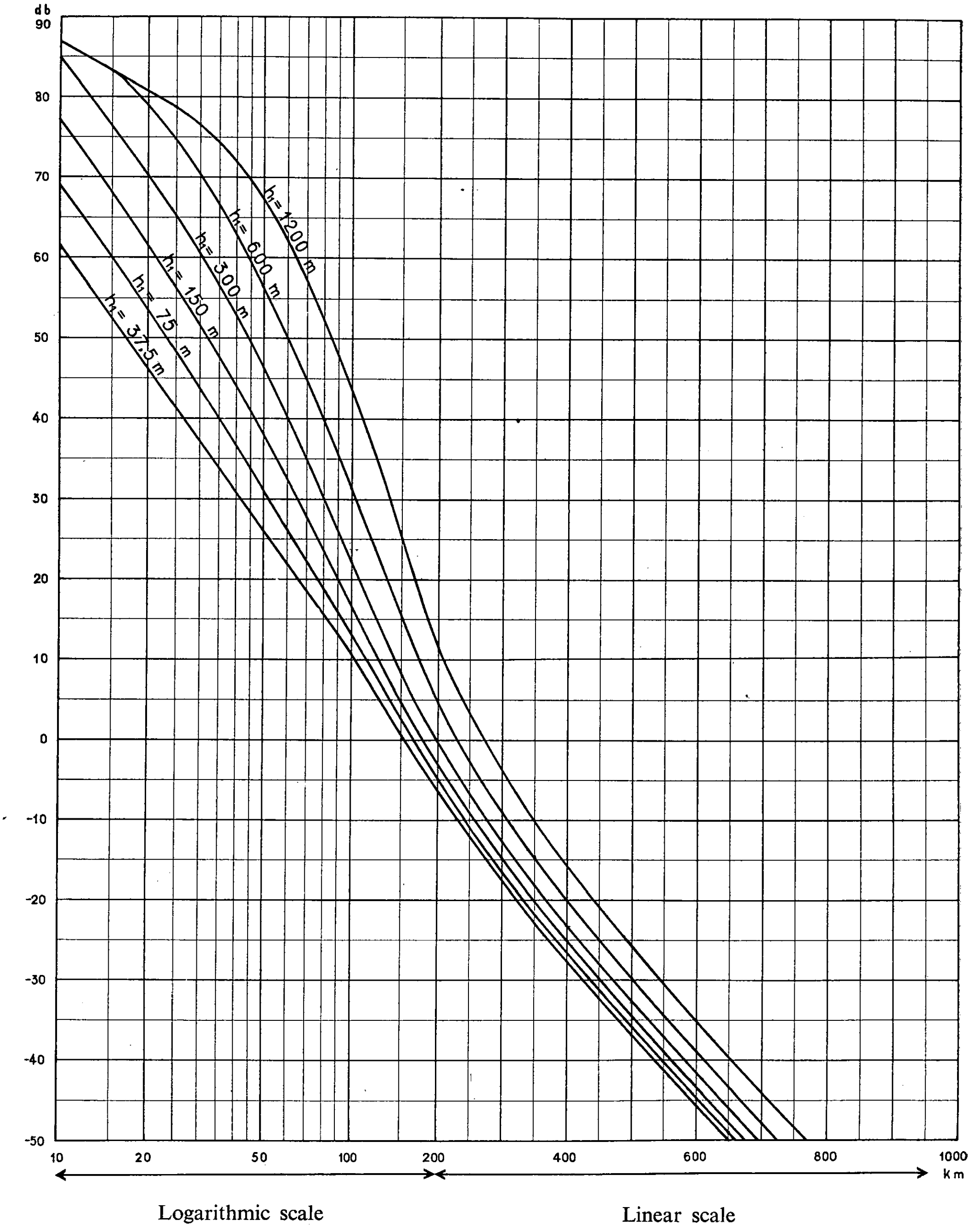


FIGURE 6

Field-strength (db rel. 1 μV/m) for 1 kW e.r.p.

Frequency: 450–1000 Mc/s (Bands IV and V); Land; 50% of the time; 50% of the locations; h_2 = 10 m; Δh = 50 m.

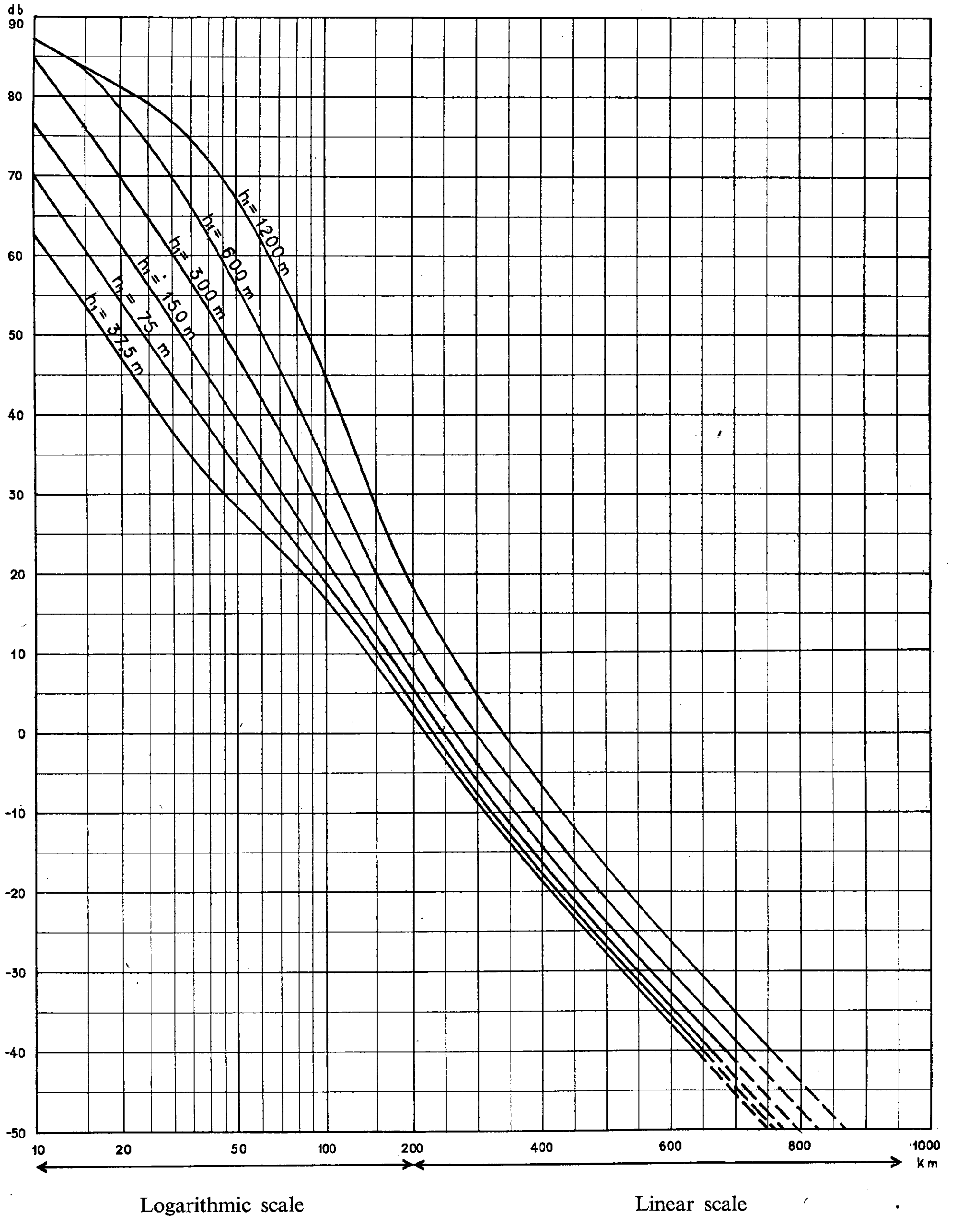


FIGURE 7

Field-strength (db rel. 1 μV/m) for 1 kW e.r.p.

Frequency: 450–1000 Mc/s (Bands IV and V); Land; 10% of the time; 50% of the locations; h_2 = 10 m; Δh = 50 m.

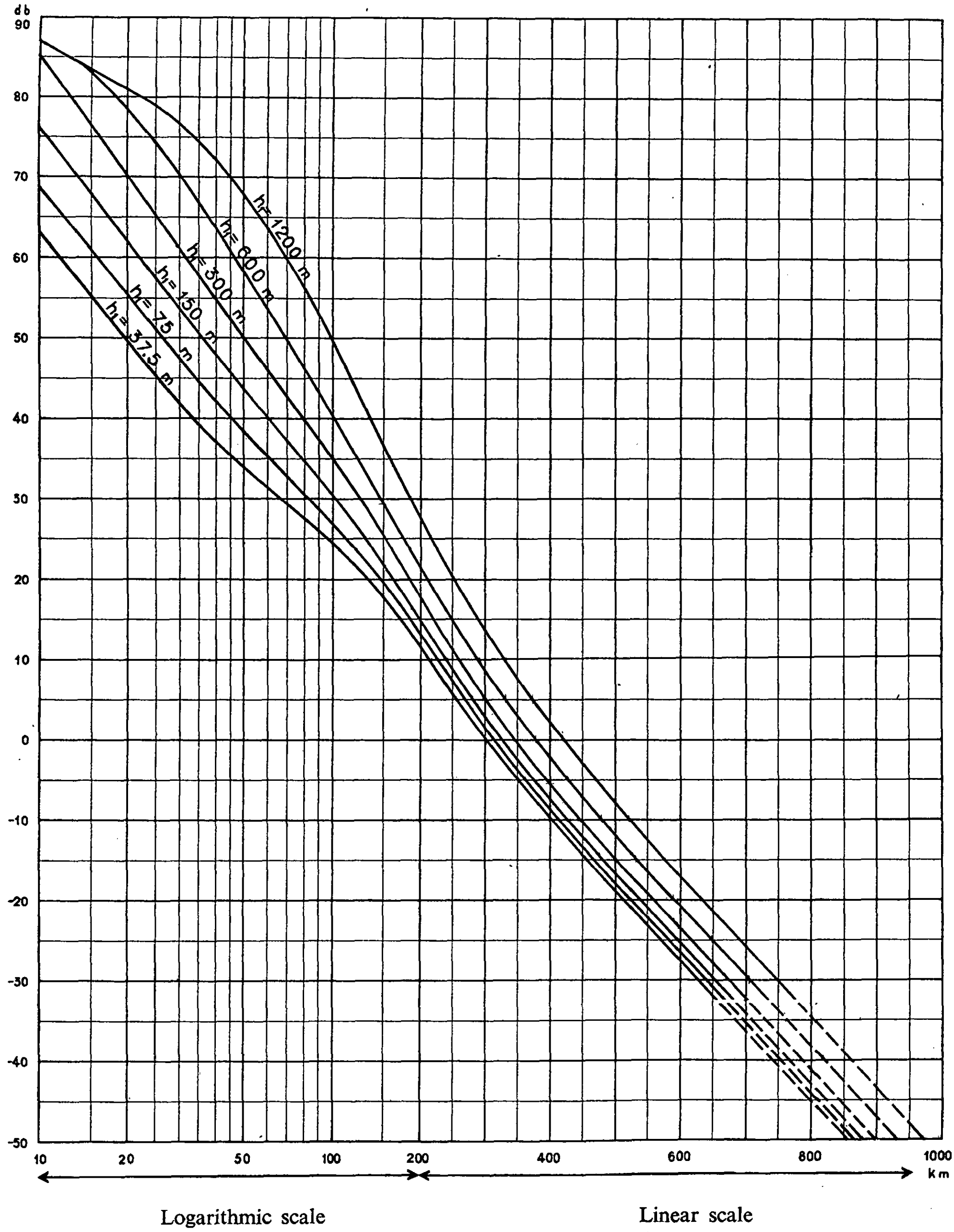
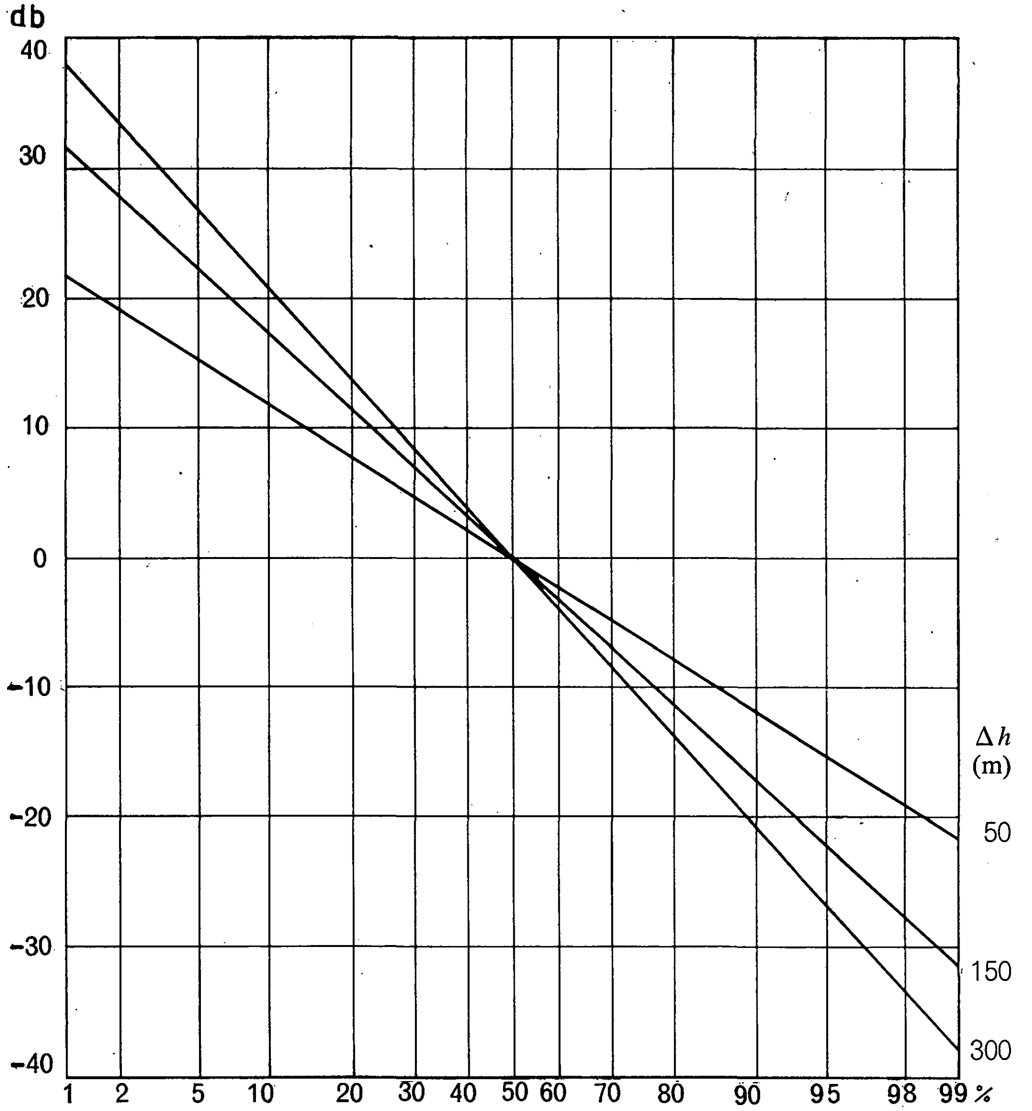


FIGURE 8

Field-strength (db rel. 1 µV/m) for 1 kW e.r.p.

Frequency: 450–1000 Mc/s (Bands IV and V); Land; 1% of the time; 50% of the locations; h_2 = 10 m. Δh = 50 m.



Percentage of receiving locations

FIGURE 9

Ratio, (db), of the field strength for a given percentage of receiving locations to the field strength for 50% of receiving locations.

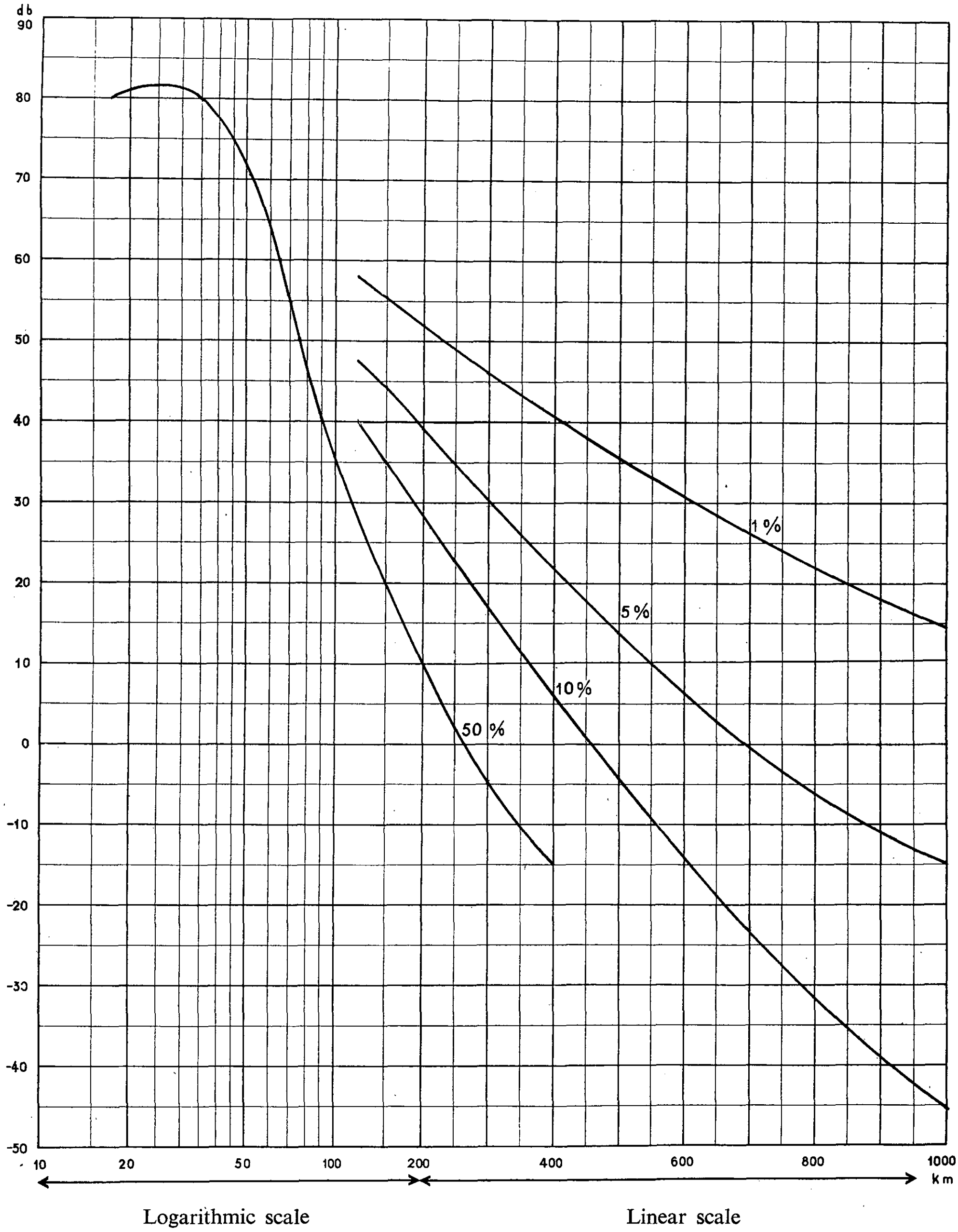


FIGURE 10

Field-strength (db rel. 1 μV/m) for 1 kW e.r.p.

Frequency: 450–1000 Mc/s (Bands IV and V); Sea; 1%, 5%, 10% and 50% of the time; 50% of the locations; h_1 = 300 m; h_2 = 10 m.

REPORTS OF SUB-SECTION G.1 — PROPAGATION OVER THE SURFACE OF THE EARTH AND THROUGH THE NON-IONIZED REGIONS OF THE ATMOSPHERE

REPORT 43 *

REVIEW OF PUBLICATIONS ON PROPAGATION

(Recommendation 14)

(Geneva, 1951 — Warsaw, 1956)

Recommendation 14 served to focus attention on the extraordinary amount of effort which is being expended in learning the facts of radio propagation and in applying them to radio operations and to international control and adjustment of the various radio services. This great field of effort is illustrated by the reviews prepared by eleven members in response to Recommendation 14, which appear as Annexes ** to Doc. 115 of Washington, 1950. These reviews, mostly report on the period 1938 to 1948 inclusive. The field of radio propagation was summarized under C.C.I.R. auspices in 1937, covering progress up to that time. The results were given in " Report of Committee on Radio Wave Propagation ", which was distributed by the Bureau of the International Telecommunication Union before the 1938 Cairo Conference, and was published in *Proc. IRE*, **26**, 1193-1234 (October, 1938).
ation 14, which appear as Annexes** to Doc. 115 of Washington, 1948. These reviews, in most cases, report on the period 1938 to 1948 inclusive. The field of radio propagation was summarized under C.C.I.R. auspices in 1937, covering progress up to that time. The results were given in " Report of Committee on Radio Wave Propagation ", which was distributed by the Bureau of the International Telecommunication Union before the 1938 Cairo Conference, and was published in *Proc. IRE*, **26**, 1193-1234 (October, 1938).

Since 1937, work on radio propagation has been exceedingly active and extensive. The phenomena of the ionosphere have been intensively studied and the results increasingly applied to the practical determination of optimum frequencies for long-distance transmission over any transmission path at any time. Propagation via the troposphere has been vigorously explored and much has been learned, particularly regarding propagation at VHF and higher frequencies. Microwave propagation has been pioneered. Ground-wave propagation has been reduced to quantitative calculation.

It is thus clear that a vast amount of work on radio propagation has been going on and is continuing. This field is now recognized as fundamental to radio operations and engineering. The work in progress is undertaken for a variety of motives and objectives. Some of it is on basic physical phenomena, some directed closely to specific engineering applications, and all of it is of interest.

The extent and value of the work on radio propagation is further illustrated by its extensive use in recent international conferences. Many compilations of methods of using ionospheric-propagation data and an extraordinary number of charts have been prepared for, and by, recent international conferences. These have been indispensable in conference work and will be needed even more in the future. As they were prepared hurriedly to meet specific needs, a valuable service could be rendered by reviewing them and, if necessary, supplementing them.

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* This Report replaces Report 3.

** The reviews of radio propagation work, submitted by various countries, appear as the following Annexes to Doc. 115 of Washington, 1950;

A	Belgium	G	Sweden
B	U.S.A.	H	Switzerland
C	France	I	Union of South Africa
D	Italy	K	Netherlands
E	New Zealand	L	Canada
F	United Kingdom		

It is believed that no other worth-while specific guidance " regarding desirable future work " could be given in any overall manner by the C.C.I.R. or any other body. On the other hand, the questions established and the studies made by the C.C.I.R. do provide incentives and objectives which are taken into account by the Administrations, companies, research institutes and individuals engaged in radio-propagation work. The effect of the C.C.I.R. work as a whole upon the various programmes of radio-propagation work will therefore provide the real answers to Recommendation 14. The means by which the C.C.I.R. enables the various people in this field to work together is a valuable means of furthering and co-ordinating the work.

The C.C.I.R. Secretariat may be requested to distribute to Study Group Chairmen contributions which, in the view of an Administration, may be of interest to other Administrations on the subject of radio propagation and which may be sent to the C.C.I.R. Secretariat for that purpose.

The choice of new questions and other acts of future Plenary Assemblies will in fact be the " regular recommendations ", envisaged in Section B 7 of Recommendation No. 1 of the International Radio Conference, Atlantic City, 1947.

REPORT 46 *

TEMPORAL VARIATIONS OF GROUND-WAVE FIELD STRENGTH

(Study Programme 52)

(Warsaw, 1956)

Contributions to this study, which were submitted to the VIIIth Plenary Assembly, Warsaw 1956, are summarized below:

Doc. 24 (Federal Republic of Germany), deals with a series of measurements made to observe the temporal variations of the field strength of various medium-frequency broadcast transmitters and to observe also the actual variations of the effective electrical constants of the soil. It was concluded that the observed field variations were not caused by variations in effective soil constants since, seasonally, a period of high field values (in winter) occurred simultaneously with low observed values of the soil constants, and vice versa. Some preliminary correlation between the variations of the soil constants and the level of subterranean water was, however, obtained.

Doc. 140 (United Kingdom), confirms previous observations which showed high values of field strength in winter months and correspondingly low values during summer months. It is concluded that, although changes of conductivity of the soil and obsorption due to vegetation could both account for the effects observed, the latter is the more probable explanation.

Doc. 182 (France), refers also to measurements reported in Doc. 196 (France) which were made over a sea path. The field was found to remain constant within a range of 6 db and showed no seasonal trend.

Doc 220 (F. P. R. of Yugoslavia), presents a discussion on the effect of temperature variations on the soil conductivity and the field strength.

Doc. 274 (Netherlands), makes two brief references to the temporal variation effect. It was observed in the VHF (metric) band that field strengths in winter were 1 to 2 db higher than in summer over medium distances and that the presence of leaves in summer time increased the absorption.

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* This Report, which replaces Report 20 and completes the work of Study Programme 52, was adopted unanimously.

Note. — The above Report should be brought to the attention of the U.R.S.I. by the Director, C.C.I.R., with a view to encouraging that organization to expedite its work bearing on these studies, requesting the U.R.S.I. to inform the C.C.I.R. of the results of its study.

REPORT 227 *

MEASUREMENT OF FIELD STRENGTH, POWER FLUX DENSITY (FIELD INTENSITY), RADIATED POWER, AVAILABLE POWER FROM THE RECEIVING ANTENNA AND TRANSMISSION LOSS

(Los Angeles, 1959)

1. Introduction

This Report is submitted with the intention of collecting, in one paper, the available pertinent information on Question 8, which was originally formulated at the Vth Plenary Assembly, Stockholm, 1948. Since that time it has become apparent that for many purposes the measurements of parameters other than field strength have come into use, particularly for the description of the performance of complete systems. These parameters are power flux density (field intensity), available power from the receiving antenna and transmission loss **. The relations between these parameters are given in the Annex.

2. Purpose of measurements

Measurements of the above parameters are generally made for one of several purposes:

2.1 to determine the adequacy of the radio signal for a given service;

2.2 to determine the interfering effects of an emission;

2.3 to observe propagation phenomena, either for use in communication studies or to gain information of value to other physical studies;

2.4 to check the strength of unwanted radiations of any waveshape arising from equipment which produces electromagnetic energy not intended to carry information and also to assess the efficiency of devices for the suppression of such radiation.

3. Antennae used for the measurements

The measurement of field strength may be made with any kind of receiving antenna, but below approximately 30 Mc/s either loop or rod antennae are generally used on field-strength sets [7, 8, 9]. The loop antennae are balanced and/or shielded to reduce electric field pick-up. At present, general practice is to use an unbalanced loop with an electric shield split at the top. Most loops are multiturn, although some instruments employ single turn loops. Rod antennae cannot be effectively shielded from magnetic fields and in this frequency

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* This Report, which replaces Report 138, was adopted unanimously.

** Further discussion of the concept of transmission loss is given in Recommendation 341 and Report 112.

range are normally operated in an unbalanced manner with the rest of the instrument and power supply acting as ground.

Above about 30 Mc/s half-wave dipoles [7, 8, 9] are generally employed, although they are sometimes used in portable field strength equipment as low as 18 Mc/s and for recordings of field strength at fixed locations at much lower frequencies. At these frequencies, when grazing incidence at the ground is involved, propagation is normally independent of polarization. However, certain noise and interference measurement procedures are in use [1, 2, 3, 4, 13, 15], in which very close spacings are employed and arbitrary standard sare normally required. Even then complications arise, due to the rapid rate of decay of the fields in the near-in region. Measurements so made may not be representative of the actual fields at greater distances and this type of procedure should be avoided if at all possible, except where it simulates the actual physical situation encountered in practice.

The measurement of the available power in the same receiving antenna, as is used in the radio system under test, will often provide a more directly useful result than would be provided by the use of a simple standard antenna, particularly in view of the fact that the received field will often be so complex that it will be most difficult to calculate the performance of the actual system in terms of field-strength measurements made with simple dipole antennae.

For the measurement of weak electromagnetic fields, directional antenna arrays may be required.

4. Effects of environment on the measurements

Field-strength or available power measurements should, in general, be made with the receiving antenna at the same location in which it will be used in practice. For a broadcast system, the performance is substantially affected by the presence of trees, buildings, overhead wires, etc. and it is important that such environmental factors should not be avoided in the measurements. A broadcast system is best evaluated by measurements made at a series of receiving locations systematically chosen by the method described in Report 228.

However, in the special case of field-strength measurements made for the purpose of determining the radiated power or directivity of a transmitting antenna, it is desirable to use carefully selected sites with a minimum of disturbing environmental factors, so that the values of the transmission loss or inverse distance field may be determined with greater accuracy.

In selecting a site for making measurements, the following factors should be kept in mind:

4.1 The radio-frequency fields at VHF and UHF may be distorted by wooden poles or other dielectrics as well as by conductors. If either the radiator or receiver is housed in a building for protection from the weather, this structure should be made preferably from materials of low dielectric constant which will not absorb water. Certain plastic materials have been found suitable in this respect. Where possible, measurements should be made with and without the structure to determine its effect. If there are buildings at the field-strength set location, the ends of the receiving antennae should be as far as possible from the walls.

4.2 At all frequencies, the effects of overhead wires, cables or other conductors must be considered, and the receiving antenna should, if possible, be located at a distance from the disturbing object of at least several times the height of the object in areas of good ground conductivity and even further away in areas of poor conductivity. If a loop receiving antenna is used, the presence of such disturbing influences may often be detected from observations of the direction of arrival of the signal or from the poor definition of the nulls in the directional receiving pattern. If it is required to investigate nulls in a radiation pattern, special precautions may be necessary since a long power or communications line may conduct energy into the area of the null region where measurements are being made.

4.3 At frequencies above a few Mc/s, disturbing effects from underground cables do not usually have to be considered, but at frequencies much below 2 Mc/s such cables can cause appreciable errors in field-strength measurements made near them, even when the cables are buried a few metres. Very long underground cables (or cables connecting to overhead lines) are especially to be avoided. Fortunately, the disturbing fields are generally the induction fields and the effect of the cables can be determined by measuring at a number of locations at different distances away from the cables to determine the rate of attenuation of field strength. In regions of very poor ground conductivity these cables can be very troublesome and the effects may be complicated by directional patterns.

4.4 Vertically polarized fields in the VHF and UHF bands may be greatly affected by the ground conditions. If the source antenna and the field-strength measuring antenna are horizontally polarized and close to the ground and either one is raised, the fields will tend to rise almost linearly with height until a maximum is approached and then the field will vary cyclically as the antenna is further raised. However, with vertically polarized antennae, the fields will remain substantially the same until a certain height is reached, and then there will be cyclic variations. The height range of relatively constant field will vary almost inversely with frequency and almost directly with dielectric constant, except where conductivity is high, as with sea water. For example, a vertically polarized field at 40 Mc/s is fairly constant with height up to about 5 m over ordinary land; however, measurements over fresh water show that the field is constant to a considerably greater height. Failure to appreciate this phenomenon may lead to some serious errors in evaluation.

4.5 The disturbing effects may be different for different kinds of equipment; for example, movement of the operator in the vicinity of a field-strength set with a loop antenna has little influence, but if a rod antenna is used the effect may be considerable.

4.6 It is shown in the Annex that it is sometimes preferable to measure either the fieldstrength or the propagation loss, rather than the transmission loss, since these parameters are more nearly independent of the effects of the receiving antenna height or other environmental factors.

5. Effects of polarization

At low frequencies, vertically polarized waves are of almost exclusive interest except for sky-wave reception where horizontal polarization may be used. So far as ground-wave propagation is concerned, the polarization continues as radiated, except for minor wave-front tilt. However, for ionospheric reflections, the received signal is a mixture of vertical and horizontal polarization [10], except for certain frequencies and distances. Thus, a loop receiving antenna will not exhibit normal directional characteristics with reflected ionospheric signals.

Above about 30 Mc/s, both polarizations are useful for transmission purposes, since the antennae are located an appreciable fraction of a wavelength or more above ground and absorption of the horizontal component by the ground is not a serious problem. There is little change in the polarization whether the signal is propagated over long distances via the troposphere or over short distances along the ground. However, conductors and other bodies near the transmitter or receiver may absorb one polarization and re-radiate or scatter an appreciable component of the other. Many sources may radiate both types of polarization. In addition, harmonic and other spurious radiation may be polarized differently from the fundamental as well as have maxima and minima at different locations from those of the fundamental.

6. Units of measurement

Field strengths are usually measured in volts per metre or convenient submultiples thereof. This unit is strictly applicable only to the electric component of the field, but it is also generally used for expressing measurements of the magnetic component, especially for radiation fields in free space where the energies associated with both components are equal. Alternatively, at frequencies exceeding 1000 Mc/s, the power flux density (field intensity) may be measured in watts (or submultiples) per square metre.

If the emissions being measured have a bandwidth greater than that of the field-strength set, consideration must be given to the effect of this factor on the measurements. For impulsive noise with widely spaced impulses and a uniform energy distribution throughout the part of the spectrum under consideration, the peak voltage will be a direct linear function of bandwidth and this leads to the unit of microvolts per metre per kilocycle (or microvolts per metre in a kilocycle band) [1, 3]. The concept of transmission loss is very useful for certain systems and propagation studies [16]. The transmission loss is defined as the ratio (in decibels) of the transmitting antenna power input to the available power output from the receiving antenna. The unit employed is the decibel.

7. Accuracy and repeatability of the measurements

From the discussion in the Annex, it is observed that the measurement of all the quantities under consideration here involves the determination both of the open circuit voltage in the receiving antenna as well as either the effective length, or the radiation resistance. The accuracy of determination of the latter two factors will depend upon the nature of the antenna and especially its environment, but, under ideal conditions such errors should be negligible compared to the error in measuring the open circuit voltage. The feasible absolute accuracy of measurement of the open circuit voltage is probably somewhat better than is shown in Table I;

TABLE I

Frequency band	Accuracy of measurement ($\pm$ db)	Minimum field strengh at which this accuracy is obtained (μV/m)
10 – 30 kc/s	2	10 (1)
30 – 300 kc/s	2	5 (1)
300 – 3000 kc/s	2	2 (1)
3 – 30 Mc/s	2	2 (1)
30 – 300 Mc/s	2	2
300 – 3000 Mc/s	3	5 (2)
3 – 30 Gc/s	5	10 (2)

(1) The minimum values will be somewhat higher for field-strength sets with loop antennae.
(2) 1 μV/m corresponds to $2{\cdot}7 \times 10^{-15}$ watts/sq.m.

Under the special conditions encountered at monitoring stations, some improvement of the accuracy figure should be obtainable at considerably lower minimum field strengths. Recommandation 378 covers these requirements. When measuring noise and interference of an impulsive nature lower accuracies may, in general, be tolerated [1, 3, 13].

The relative accuracy or repeatability of the measurements will usually be substantially greater than their absolute accuracy, provided the radiation source being measured remains constant. However, certain types of radiation sources, such as the leakage from a signal generator, harmonics and other spurious outputs from transmitters, oscillator radiation from receivers, radiation in the null of a directional antenna, etc., may vary substantially with time, and this may result in apparent inaccuracies of measurement which, in reality, are simply due to a lack of stability of the quantity being measured.

8. Circuitry of the field-strength measuring set [1, 2, 7]

The signal delivered to the field-strength set may vary from a fraction of a microvolt to several volts and the design must be such as to avoid errors due to overloading and cross modulation in the early stages. At least one tuned circuit before the first tube and an radio-frequency attenuator are generally employed and are followed by a mixer and an amplifier having suitable gain and bandwidth. A calibrated intermediate-frequency attenuator may precede the intermediate-frequency amplifier chain, but sometimes change of bias to the intermediate-frequency tubes is used to provide the required attenuation. The intermediate-frequency amplifier drives the detector and metering circuits. Occasionally pre-set switching of measuring circuits by coaxial relays may speed up measurements.

Many sets are designed to provide an approximately logarithmic input/output characteristic, which is very useful when measuring or recording fading signals, etc. The required characteristic is obtained either by shaping the pole pieces of the output meter or, more frequently, by the use of a suitably designed automatic gain control of the intermediate-frequency amplifier.

9. Self-calibration techniques

A few sets depend solely on their constructional stability, without provisions for self-calibration. Some check may be obtained in these sets by noting the tube noise indication. This approach is not too satisfactory, at present, unless signal generators are available for frequent checking. In general, self-calibration is provided by one of the following methods:

9.1 continuously variable frequency calibration oscillator with thermo-couple amplitude check. This probably has the best long term stability;

9.2 continuously variable frequency calibration oscillator with crystal diode, tube diode, or grid current indicator. The latter is generally unsatisfactory because of errors which often occur in its use;

9.3 fixed frequency calibration oscillator for setting the sensitivity of the field-strength set at one or more places in each band. This method has the difficulty that changes in receiver alignment can cause serious errors at other frequencies unless some further check is employed, such as the use of an impulse generator for extrapolation to other frequencies;

9.4 noise diode (especially for noise measuring sets). This is a compact and convenient type of calibrator for noise measurements, or rough measurements, but is not wholly satisfactory as used at present for other kinds of measurement, both because of its own accuracy problems and the effect of receiver bandwidth. The observed instability may be more related to the portable nature of the equipment in which this method is used rather than to any fundamental inherent errors of a noise diode;

9.5 impulse generator (especially for noise meters). This type of source is preferable for impulse noise measurements, but it has the limitation that, if changes in receiver bandwidth occur, the calibration may be unsatisfactory for measurements other than impulse noise;

9.6 built-in signal generator and signal generator attenuator. This is probably the best method but generally results in increased cost and weight, especially since very good shielding and filtering are required.

The self-calibration facilities are generally satisfactory over limited periods of time and the instruments should be periodically checked against external standards which should, whenever possible, provide the same type of waveform as the signal to be measured. It is well to make frequent checks until the stability of the particular instrument is determined. These should be made at various levels to check attenuators as well as signal sources and should include checks of the linearity of the interpolation meter. During these checks, it is generally well to verify the alignment with a sweep oscillator at several levels. Misalignment may cause operating difficulties, affect attenuator ratios, affect response on broadband signals, and cause regenerative effects resulting in bandwidth changes with signal level. Occasionally, the regenerative effects may be due to the feeding back of an intermediate-frequency harmonic to earlier stages and may result in a rather sharp change in sensitivity as the frequency is varied. Similar abnormal effects may occur in sets in which there is unwanted coupling between the calibrating oscillator and the rest of the set.

10. External methods of calibration

Of the external methods of calibration, two have found wide application. At frequencies below 20 Mc/s, it is possible to calibrate a field-strength set with a loop antenna by the establishment of an accurately calculable voltage induced by a second coaxial loop of known dimensions carrying a known current [5, 8, 9, 14]. In the other method, which is particularly useful at the higher frequencies and which is applicable with either loop or rod antennae, calibration is effected by means of a known radiation field using horizontally polarized waves, [6, 8, 9, 14]. For both methods, an overall calibration of the field-strength set, including the receiving antenna, is obtained under conditions similar to those likely to be encountered during subsequent use of the set.

11. Power supplies

All power supplies, including those for the tube heaters should be adequately stabilized, and the primary power source should provide sufficient voltage at all times to ensure proper operation of the stabilizing apparatus.

12. Special precautions [7]

Before measurement is made:

12.1 Radio-frequency and intermediate-frequency attenuators should be checked against each other, if possible, and against the scale of the indicating meter.

12.2 When measuring strong signals, or a weak signal in the presence of strong signals, e.g. harmonic or other spurious emissions, precautions should be taken to avoid overloading the early stages of the set. In the latter case, the use of filters at the set input is recommended.

13. Parameters suitable for measurement purposes

For continuous wave signals, the type of measurement made (average, peak, etc.), is relatively unimportant. However, with complex waveforms, the indicated value of the field-strength or available power will be influenced by the characteristics of the measuring instrument, i.e., its detector characteristics, bandwidth, dynamic range, integration time, etc. Thus, the equipment must be designed to measure a parameter that is suitable for the evaluation of the type of waveform that is present. With a coherent signal of known waveform, one parameter is usually sufficient; but with an incoherent function such as atmospheric noise, two or more parameters are often necessary for an adequate description.

13.1 *Measurement of average value*

The average value of a signal is given by the receiver when the circuit following a linear envelope detector is designed to average the detector output voltage over a time interval long enough for rapid variations to be imperceptible. The average value is generally preferred for many modulated emissions, including amplitude- and frequency-modulated telephony (A3 and F3). It is also used for on-off keyed telegraphy (A1 or A2), where the key-down position can be maintained during measurement. It may also be used to measure the peak value on signals having a high duty factor for pulses at the peak value, such as television visual emissions with positive synchronizing signals. The peak value will of course be derived from the average value by the addition of a predetermined correction factor. It is also used as one of the parameters in evaluating atmospheric noise and other interference phenomena.

13.2 *Measurement of peak value*

The peak value of a signal is given by the receiver when the detector circuit is designed to give an output corresponding to the maximum instantaneous voltage of the signal. This may be measured by one of the following types of circuits:

— cathode-ray oscillograph at the output of the RF or IF amplifier;

— slide-back detector with audible or visual indicator to show when the threshold has been exceeded;

— peak detector with slave rectifier having a memory and a manual or automatic zero resetting device.

Peak measurements are particularly suitable for low duty-cycle signals, including impulsive interference, but are often subject to greater fluctuations than the quasi-peak or average values. If the bandwidth of the signal to be measured is greater than that of the field-strength set, then the peak value of the emission as measured by the detector is affected. While measurements made at one bandwidth can be corrected to another bandwidth for certain simple types of emission, this is not the typical situation and bandwidth standardization for the sets is necessary if comparisons are to be made. Under such conditions, the bandwidth of the field-strength set should be stated. Similar bandwidth considerations may apply as in quasi-peak measurements, and reference should be made to Table I in § 13.3 for standard bandwidths.

13.3 *Quasi-peak measurement*

The quasi-peak value is that measured when the detector output is weighted by adjustment of its charge and discharge time constants T_c and T_d and the mechanical time constant of the indicating meter T_m. Because of its convenience, the quasi-peak value is generally used for types of emission which are keyed or pulsed, or for which the average value varies with modulation level. It is generally appropriate for impulsive interference measurements and, if the charge and discharge time constants are suitably chosen, quasi-peak measurements can provide a direct indication of the audible effect produced by interfering signals of any shape on modulated transmissions such as telephony.

As regards bandwidth, similar considerations to those of peak measurements apply, and care must be used in selecting both the bandwidth and the charge and discharge time constants to suit the type of emission being measured and to prevent overloading the set. Only a few sets of standard constants have been recognized by qualified organizations, and these are listed in Table II.

TABLE II

Frequency Range (Mc/s)	Bandwidth at 6 db down (kc/s)	Charge time constant T_c (sec.)	Discharge time constant T_d (sec.)	Mechanical time constant T_m (sec.)
0·015–0·15	Variable (0·08–0·8) (2)	0·001 (2)	0·600 (2)	
0·15–30	9 (1) Variable (1–12) (2)	0·001	0·160 0·600 (2)	0·160 (1)
25–300	120 (1) 150 (2)	0·001	0·550 (1) 0·600 (2)	0·1 (1)

(1) C.I.S.P.R. [1].
(2) A.S.A. [2].

Note.— The constants without asterisks are used by both organizations.

13.4 *R.m.s. voltage*

The r.m.s voltage [17] is measured by means of a thermocouple or electronic squaring circuit in conjunction with a suitable averaging circuit. It provides a direct measurement of the average power received in the bandwidth of the measuring instrument. For emissions with a uniform frequency spectrum, the r.m.s. voltage is proportional to the square root of the bandwith (the average power is proportional to the bandwith). The r.m.s. value is suitable for the measurement of many types of broadband phenomena, but is particularly useful in the measurement of atmospheric noise [18]. Since the squared values have a wider range of fluctuation than the original phenomenon, a wider dynamic range and longer time constant are required. With atmospherics, a time constant of 500 s has been found satisfactory.

13.5 *Average logarithm*

The average logarithm is obtained by inserting a logarithmic amplifier between the detector and the averaging circuit. This type of measurement, in conjunction with measurements of the average and r.m.s. values, provides information on the character or interference potential of noise. For atmospheric noise, these three parameters provide a means of determining the complete amplitude-probability distribution [11, 17].

13.6 *Statistical measurement*

It is frequently of interest to determine the statistical variations of field strength with time, by considering the variation of the instantaneous values, or the variations of the average value of any of the above parameters. The latter can be measured by means of time totalizers with several pre-set thresholds, so that the total time above each threshold is indicated on motor-driven counters. These counters are read at the end of any desired period of time.

When the variations of the instantaneous values are of interest, electronic counting circuits are used that will respond to the instantaneous IF or detector output. By means of suitable gating and threshold circuits, the amplitude-probability distribution of these values can be obtained. The complete amplitude-probability distribution has been found useful in evaluating the interference, particularly that of atmospheric noise, to the reception of various types of signals [12].

14. Parameters to be measured for different types of emission

Table III is a summary of suggested parameters for the measurement of various emissions, as classified in Article 2, of the Radio Regulations, Geneva, 1959.

TABLE III

Type of emission	Parameter measured (see § 12)
A0, A2, A3, A4, A9 F0, F1, F2, F3, F4, F5, F9 (1) A1 (key down) A5 (negative sync.) (2)	Average
A1, A3A, A3B, A9A	Quasi-peak
A5 (positive sync.) P0 and other pulsed emissions	Quasi-peak or peak

(1) Care must be exercised that the bandwidth of the field-strength meter is adequate to pass the FM emissions.
(2) It is usual to define the field strength of a negative sync. television signal as the peak-white value. This value can be derived from the average value, if the waveform being radiated is known at the time the measurement is made.

When the radiated power is wholly or largely independent of the degree of modulation, it should suffice, for most field-strength measurements, to specify the unmodulated carrier power. However, when the radiated power is largely dependent on the degree of modulation, it appears desirable, for high precision field-strength measurements, for the two terminals to cooperate, either by recording the transmitter output power with an instrument having characteristics similar to those of the field-strength recorder, or by the transmission of special signals.

15. Radiated power

The radiated power from a transmitting antenna may be determined either as:

15.1 the input power to the transmitting antenna diminished by the loss in its antenna circuit, or;

15.2 the measured available power in a lossless receiving antenna increased by the transmission loss, the reception being carried out at some carefully chosen location where the transmission loss can be calculated.

At the lower frequencies, the radiated power is often determined by measuring an unattenuated inverse distance field, i.e. the radiation field expected at a unit distance on a perfectly conducting plane surface. Then the radiated power may be determined by calculations which allow for the radiation characteristics of the particular antenna under consideration.

ANNEX

THE RELATIONS BETWEEN FIELD-STRENGTH, POWER FLUX DENSITY (FIELD INTENSITY) AND THE AVAILABLE POWER IN THE RECEIVING ANTENNA

Let e denote the field strength (V/m). The power flux density (field intensity), f (W/m²) is given by:

$$f = \frac{e^2}{z} \tag{1}$$

where z is the characteristic impedance of the medium in which the measurement is made. In air or free space $z \approx 120\,\pi\,\Omega$.

The absorbing area of a receiving antenna with gain, g_r, relative to an isotropic antenna may be expressed:

$$a_e = \frac{\lambda^2\, g_r\, r_f}{4\,\pi\, r} \tag{2}$$

where λ is the wavelength in the medium, r is the radiation resistance of the antenna while r_f is the radiation resistance the antenna would have if it were in free space. Combining equations (1) and (2), we find the following formula for the available power, p_a', from a lossless receiving antenna:

$$p_a' = \frac{e^2\,\lambda^2\, g_r\, r_f}{4\,\pi\, z\, r} = \frac{v^2}{4r} \tag{3}$$

The v in equation (3) denotes the open circuit voltage induced in the receiving antenna. Solving equation (3) for v, we find the following general relation between the field strength and the open circuit voltage for an antenna with gain, g_r, and free space radiation resistance, r_f:

$$v = e\,\sqrt{\lambda^2\, g_r\, r_f \,/\, \pi\, z} = el \tag{4}$$

We see by equation (4), that the measurement of the field strength involves essentially two steps:

— the measurement of the open circuit voltage, and

— the determination, either by calculation or measurement, of the effective lenth, l, of the receiving antenna [5, 6, 15 and 19].

Similarly, we see by equation (3), that the measurement of the available power also involves two steps:

— the measurement of the open circuit voltage, and

— the determination, either by calculation or measurement, of the radiation resistance of the receiving antenna. Note, however, that the radiation resistance, and, thus, the available power, depends upon the height of the receiving antenna above the ground, whereas its effective length is, at least to a good first approximation, independent of this height or of other environmental influences. This is one of the advantages of measuring the field strength rather than the available power in some applications. Note that the propagation loss L_p may be so defined that it is also independant of such effects of the local environment on the antenna impedance.*

* See Report 112 for a more complete discussion of propagation loss.

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REPORT 228 *

MEASUREMENT OF FIELD STRENGTH FOR VHF (METRIC) AND UHF (DECIMETRIC) BROADCAST SERVICES, INCLUDING TELEVISION

(Question 138)

(Los Angeles, 1959 — Geneva, 1963)

1. Description of coverage

For the purpose of frequency assignment, the description of coverage for VHF (metric) and UHF (decimetric) broadcast services (television, broadcasting, frequency-modulation broadcasting, etc.), should be in terms of the extent to which service is provided to potential viewers or listeners. The service may be classified in accordance with the quality of the signal at an individual location. For the purpose of assigning stations, it is probably necessary to consider only one quality of service; however, it may be useful for other purposes to define more than one quality.

Several methods have been proposed for describing the service coverage of broadcast stations in the VHF (metric) and UHF (decimetric) bands.

An acceptable method for describing broadcast service should meet the following general criteria [1]:

1.1 it should show the location and extent of all areas provi ded with a given quality of service;

1.2 it should take into account significant variations with time;

1.3 the method of specifying service should be sufficiently fine-grained to be capable of showing the amount (area or population) and location of service in distinct areas and directions from the transmitter;

1.4 it should be capable of showing the effect of interference from one or more stations in terms of the amount and location of service lost;

1.5 it should be capable of showing two or more qualities of service;

1.6 it should be possible to predict the service area by means of a reasonable number of measurements and/or calculations of field strength;

1.7 it should lend itself to simple two-dimensional presentation.

After extensive studies on the various methods for describing VHF (metric) and UHF (decimetric) broadcast services, the location probability has been recommended [1, 2] as the best statistic for describing services. A brief description of the meaning of this statistic is given for the benefit of those not familiar with the term. Under steady-state laboratory conditons, it has been possible to evaluate statistically the useful signal-to-interfering signal ratios which are required to produce pictures or sound of a quality acceptable to different observers in the presence of various types of interference. The ratio accepted by some percentage of the observers, say 50%, is chosen as the acceptance ratio for each type of interference. At any specific location, the useful signal and/or the interference may vary with time, so that the term " time-availability " is used to indicate the percentage of time for which the acceptance ratio is exceeded. A particular quality of service corresponds to a specified

* This Report, which replaces Report 142, was adopted unanimously.

acceptance ratio exceeded for a given percentage of time at an agreed standard receiving installation. The location probability is then defined as the probability of receiving this quality of service or better. Alternatively, the location probability may be defined as the percentage of locations in a small area, for which this quality of service or better is expected. To minimize computations, the single value of 90% time availability may be adopted as the satisfactory level. This figure might be changed as found desirable, or several levels and standard receiving installations might be adopted to show different qualities of service.

Location probability describes in a satisfactory manner the location and amount of the service available from the point of view of the station assignment and allocation planner, the operating authority and the viewer or listener. It is believed that this statistic is the most meaningful and practical for the description of television and frequency modulation broadcast service and easily meets all the above criteria. Location probability is preferable to the signal-to-interference ratio or the useful signal level as a service index, because it provides a comparable measure of the quality of service which is independent of frequency, distance, etc. Although the signal-to-interference ratio might be more easily comprehended, it has the disadvantage of requiring different numbers at different frequencies and distances to describe the same quality of service. The useful signal level is anun satisfactory index, in that it varies with frequency and cannot take into account interference other than receiver noise. However, when the interference is receiver noise, then contours of constant location probability will also be contours of constant field strength. Procedures for the computation of location probability are relatively simple and rapid [2, 3].

Two illustrations of the presentation of service by the use of location probability are given in Figs. 1 and 2. The solid curves represent contours of constant service along which the location probability of a given quality of service is constant for a standard installation. Where service is limited by noise, rather than co-channel interference, the location probability found at a given distance along any radial in Fig. 1, corresponds to some fixed median-time, median-location value of field-strength. For example, a location probability of 0·5 in Fig. 1 corresponds to a median field-strength of 57 db rel. to 1/uV/m. Fig. 1 shows a great amount of detail, possibly more than could be shown normally with a practical amount of data. However, such detail might be desired for specific sections of a station service area, depending upon the particular problem at hand. Fig. 2 shows what a service map might look like in a more typical case, where the great amount of data for a more detailed map like Fig. 1 is not available.

It is well known, that under practical operating conditions, many people will use an installation just good enough to provide a satisfactory service, but will go to extremes to get the service. Thus, in a strong-signal area many people will use indoor antennae, whereas in weak-signal areas many will employ extremely good installations. Consequently, the number of people receiving a satisfactory signal may well be different than that computed from location probabilities based on a standard receiving installation. However, to provide an objective description of available service, it is desirable to refer always to a fixed quality of service, received on a standard installation. The adoption of a standard receiving installation also makes possible the computation of the combined effects of multiple sources of interference.

Besides meeting all the required criteria, this portrayal of service has several other advantages. The effective service area, or the population served by an individual station, may be computed by summing the products of the location probability multiplied by the area or the population respectively to which this probability applies [2, 3].

This method of portrayal is also convenient for estimating the interference effects of existing, new or proposed stations in neighbouring areas. Thus, the overall location probability for service in the presence of a number of interfering services, is approximately the product of the individual location probabilities for service of the useful station in the presence of each source of interference acting alone [2]. This approximation is fairly good when the resultant overall location probability is 50% or better and improves as the resultant service increases. More accurate methods for computing the effects of multiple interference are also available [2, 4].

2. Method of measurement

Field-strength measurements of VHF (metric) and UHF (decimetric) wave broadcasting stations are made to meet the following objectives:

2.1 to provide a basis for assessing the extent of service of any given quality;

2.2 to check the directional pattern and power radiated from a transmitting antenna;

2.3 to provide data with a view to increasing general knowledge concerning propagation conditions in the bands concerned.

In making measurements, the following conditions should be fulfilled:

2.4 measurements should be readily reproducible so that they can be checked subsequently, if required;

2.5 the procedure should provide the required information in an efficient manner;

2.6 the method should not be hazardous nor too expensive.

Various methods of measurement currently in use fulfill the foregoing criteria with varying degrees of success.

It is certainly easier to make the measurements, if the wave collector is about 3 or 4 m above the ground, but a height of 10 m more nearly corresponds to the height of the receiving antenna of a typical installation. After obtaining results for a height of 3 m in relatively flat and open terrain, they can be suitably corrected for height, but height correction is difficult for very irregular terrain or built-up areas, more particularly at UHF. Therefore, 10 m would seem to be the best height for the measurement antenna and ideally a great many independent sample observations should be obtained at this standard height.

In making measurements of the coverage of television transmitters, the normal practice in all bands is to measure the field strength of the sound channel and to apply the appropriate factor to obtain the peak field strength of the picture signal which is expected to correlate closely with the quality of reception as a general rule.

It is desirable that the recorded results of a survey should relate to the field strength available for 50% of the time. Within 20 to 30 km from the transmitting site, the fading range will generally be very small and no great error will have been introduced by making measurements at any time, irrespective of the prevailing refractivity of the lower atmosphere. At the greater ranges at which survey measurements are made, as for a high-power transmitter, fading effects may lead to a serious error. At these greater ranges, it is desirable, while a survey is in progress, to make continuous field strength recordings at a fixed reference point, which may, however, need to be changed as the survey proceeds. From examination of these records, it can be decided whether any particular survey measurements should be rejected or whether they could be adjusted for normal conditions.

In the course of a coverage survey, most of the measurements are made in towns and large villages, sometimes supplemented by measurements along radials from the transmitter site.

2.7 *Measurements at frequencies below 100 Mc/s.*

Normally, below 100 Mc/s, a continuous record of field strength is made by a travelling vehicle, usually with a suitable chart recorder geared to the road wheels of the vehicle. Ideally, the method of measuring at the full standard receiving antenna height of 10 m is desirable, but there remains the practical consideration of surveying a large area within a reasonable time. A large number of comparative measurements, made at 10 m and at those heights practicable for mobile recording, confirms that a linear correction is of sufficient accuracy at frequencies below 100 Mc/s. For mobile measurements of this kind, it is clearly convenient to use an omnidirectional antenna.

As a rule, it is not convenient to make measurements at a height of 10 m over long lengths of road, near overhead wires, trees, etc., but short runs (30 to 150 m) or individual spot measurements can be made at this height. As will be described in more detail below, it is possible to use a systematic procedure of statistical sampling for determining the locations at which these short runs or spot measurements should be made. The degree of accuracy in estimating the area or population provided with a given quality of service may also be determined. The short distance runs are made along a short section of road, centred on the measurement point selected and the median value of the field measured on this run is referred to this location. As compared with spot measurements made at the given locarion, the advantage of the short distance runs is that the median value which it gives is more readily reproducible. Spot measurements are more easily made and may also be used to obtain a distribution of the field strength with respect to time over the period involved.

In the presentation of the results, the exact position of the measuring points is plotted on a map and the median or spot value of the field at those points is shown. The following particulars are noted for each point in a separate report; local topography, height and type of vegetation, housing, obstacles, weather conditions, times of day and any other local features likely to affect the received field (if necessary, photographs from measuring sites can be provided). An indication should also be given of the median, maximum and minimum values of field strength for each short mobile run or measurement group and the of direction from which the maximum signal arrives if other than the direction of the transmitter.

2.8 *Measurements at frequencies above 100 Mc/s.*

At frequencies above 100 Mc/s, particularly in bands IV and V, field-strength measurements must be made at the required height of 10 m, since linear height-gain between 3 m and 10 m should not be assumed at UHF.

An estimate is made here of the number of independent single sample measurements required to achieve the desired degree of accuracy. This accuracy is generally required to be greater when measuring field strength within the critical range 46 to 66 db and 60 to 80 db rel. 1 μV/m for VHF and UHF respectively. Towns where the median field strength is outside these ranges can be considered to be either inadequately served or to have good coverage, so that in these cases small errors in measurement of field strength are less important. Fig. 3 shows the number of independent sample measurements required to give 95% probability that the probable error ε in a median value will be less than 2 db or 4 db. In practice, the acceptable sampling error ε should not be greater than 2 db in the critical zone, but may be increased to 4 db where accuracy is less important. The relationship between the necessary number of samples and the " variation factor ", V, defined as the ratio (in decibels) of the field strengths exceeded at 50% and 90% respectively of the locations within the town or other compact area under consideration, is given in Fig. 3, which is derived from the assumption that the distribution of field strength is log-normal.

The value of the variation factor, V, usually lies within the range 5–10 db at VHF or 5–15 db at UHF although in a few cases it may reach 20 db. Fig. 4 shows the distribution of V for a number of towns in the United Kingdom at both VHF and UHF. Generally, the median value of V taken for Fig. 4 is used for the determination of the required number of independent samples, but if during a survey, it becomes apparent that V differs appreciably from the median of those values shown in Fig. 4, the number of samples taken is increased. In general, the number of samples should be between 10 and 100, if the above limits are to be maintained.

Another method of deciding the number of sample measurements required, which may have advantages over the method described above, particularly at UHF, is to measure initially the overall range of scatter R of the field strength at a few topographically high and low points. It can be assumed that the range R is equal to 6σ, where σ is the standard deviation. For a log-normal distribution, $V = 0 \cdot 214R$.

To assess the extent of service, the measurement procedure may be considered a sampling process in which the cumulative distribution of the sample represents an estimate of the variations within a given area of the actual fields. The choice of sampling locations should be free of bias and should as nearly as possible represent typical operating installations. An important factor affecting the choice of sampling locations is the tendency for successive measurements made adjacent to each other to be correlated among themselves, that is they are serially correlated. Independent measurements made with sufficient separation to eliminate serial correlation provide an efficient estimate of the variations of the fields. Studies indicate that significant serial correlation between successive measurements will be present at separations normal to the path of propagation up to one or two kilometres [3, 5, 6]. Serial correlation will be present in radial measurements at even greater separations.

2.9 *Selection of sites for measurements.*

As far as practicable, the urban measuring locations are usually selected at random by reference to a town map, the density of measurements nevertheless being varied according to the population distribution. At each measuring location, a single sample value of field strength may be obtained or, alternatively, a cluster of some four or five measurements may be made at points separated by only a few metres, and the estimated mean of these four or five values recorded as the " sample location " measurement. It is often found that there is substantial correlation between field-strength measurements separated by only a few metres, particularly if a multi-element antenna is employed, but much greater variations between those widely separated, e.g., over different areas of a town. The " single sample " method is often preferred, because of the additional time that may be taken in making " cluster " measurements (due to the frequent raising or lowering of the receiving antenna), or because of the hazard in moving the measuring vehicle while the antenna is fully erected. However, the mean of a cluster is more readily reproduced than a single sample observation, and it can be shown that a given accuracy in assessing the overall variation factor in the area under consideration can be achieved by some 10% to 15% less cluster " measurements " than " single sample " measurements.

All the sample measurements are made using a receiving antenna mounted at the standard height of 10 m. At UHF and at VHF in hilly terrain, typical directional antennae should be used to discriminate against echo signals from surrounding hills and buildings.

For each urban area under consideration, a graph is constructed of the location distribution of field strength from which may be found the percentage of locations at which any given field strength is exceeded.

To arrive at an estimate of the cumulative distribution of field strength in an incremental area within the service area of the transmitter, a sample set of measurements should be obtained in such a way that the propagation characteristics are similar throughout the area of measurement. For example, systematic effects such as large variations of field with distance, should be avoided. One way in which this can be accomplished is to confine each set of sample measurements to an annular area, or segment thereof, centred on the transmitter.

The measurement locations should be laid out on circles or circular arcs centred on the transmitter. The choice of radii for the circles will depend largely upon the location probabilities expected. Therefore, it is extremely helpful to make estimates in advance of the dependence upon distance of the location probabilities for the particular case in question. Fig. 5 shows a hypothetical example of this dependence, based on a relationship between field strength distance for a television station operating in the 54 Mc/s to 88 Mc/s frequency band and assuming a log-normal distribution with a standard deviation of 6 db to represent the dispersion of field-strength values in the incremental areas. Studies of irregular-terrain propagation at these frequencies [2, 3, 5, 6, 7], indicate that the logarithm of the field strength has an approximately normal distribution. In this example, the location probabilities indicate the percentage of the areas at the distances indicated, that would be expected to have a field strength in excess of 57 db rel. 1μV/m. Fig. 6 illustrates a possible distribution of locations for the measurements. It should be noted that, in this example, the greatest concentration of points is proposed at the distance for which the location probability is 0·5, to provide in the most efficient manner information about the total area served. The separations between adjacent measurements should be adequate to eliminate, or at least to minimize, the effects of serial correlation.

2.10 *Presentation of results.*

When the proposed measurement locations, determined in a manner similar to Fig. 6, are transposed to an actual map, it will be found that many of them lie in inaccessible areas. In such cases, the measurement will probably be made nearby at a location which is accessible. The important point to consider in choosing alternate locations is to avoid introducing bias, such as might be the case, for example, if these alternate locations were unduly concentrated along highways.

It would be a relatively simple matter to include other observations along with the basic field-strength measurements. At a selected number of the locations variations with time could be recorded over a reasonably long period of time. Also the effect of antenna height, antenna directivity, picture or sound quality etc., could be observed. Additional measurements could be made in areas of special interest.

In addition to the method of coverage presentation given in this Report, it is usual to present a field-strength map showing the position of the median contours. The amount of detail that needs to be shown, depends upon the degree of irregularity of the terrain and is greater at UHF than at VHF. The supplementary information required with such a map is a table, showing the median field-strength and variation factor for 50% to 90% of the locations for each of the more important centres of population.

It may also be useful to present a map similar to Fig. 1, but showing only two or three major demarcations of service zone; for example, the area within which, in any locality, more than 70% or 95% of viewers can obtain a satisfactory service.

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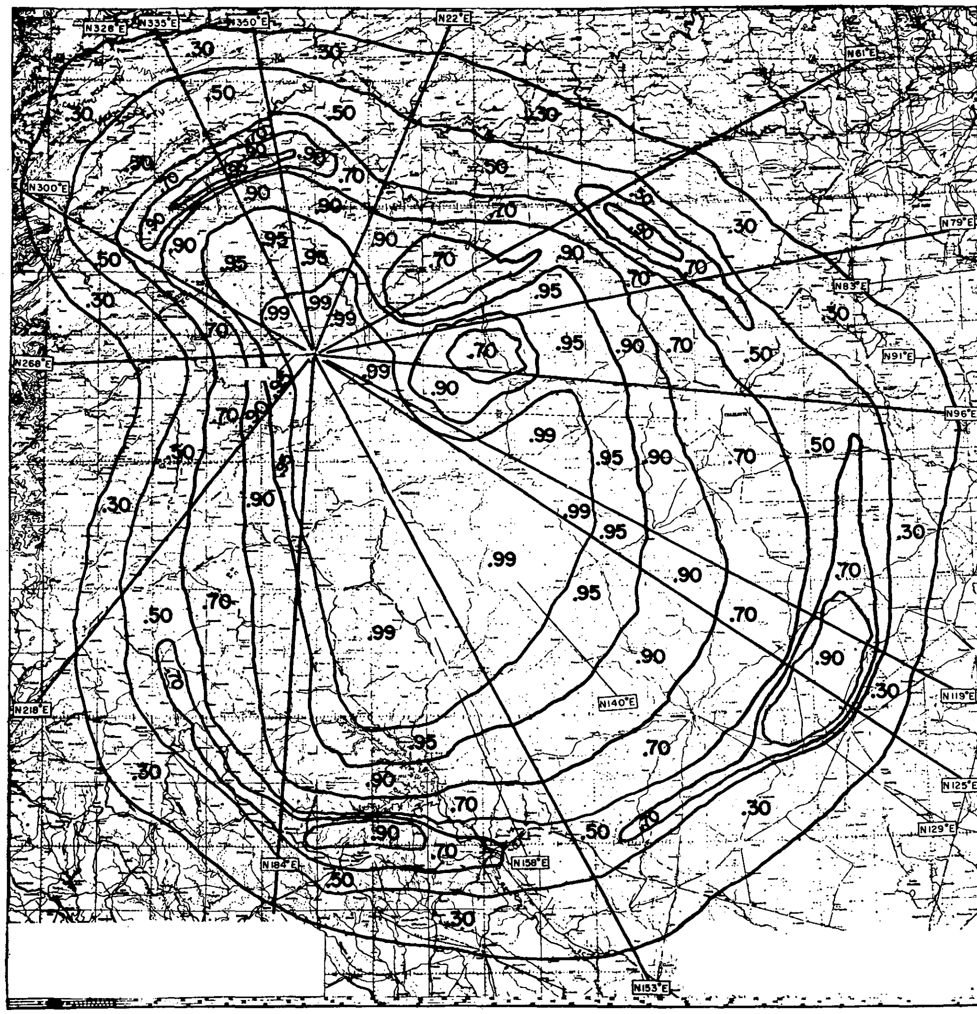

FIGURE 1

The concept of service probability

The numbers indicate the probability of locations receiving an acceptable service for at least 90% of the time

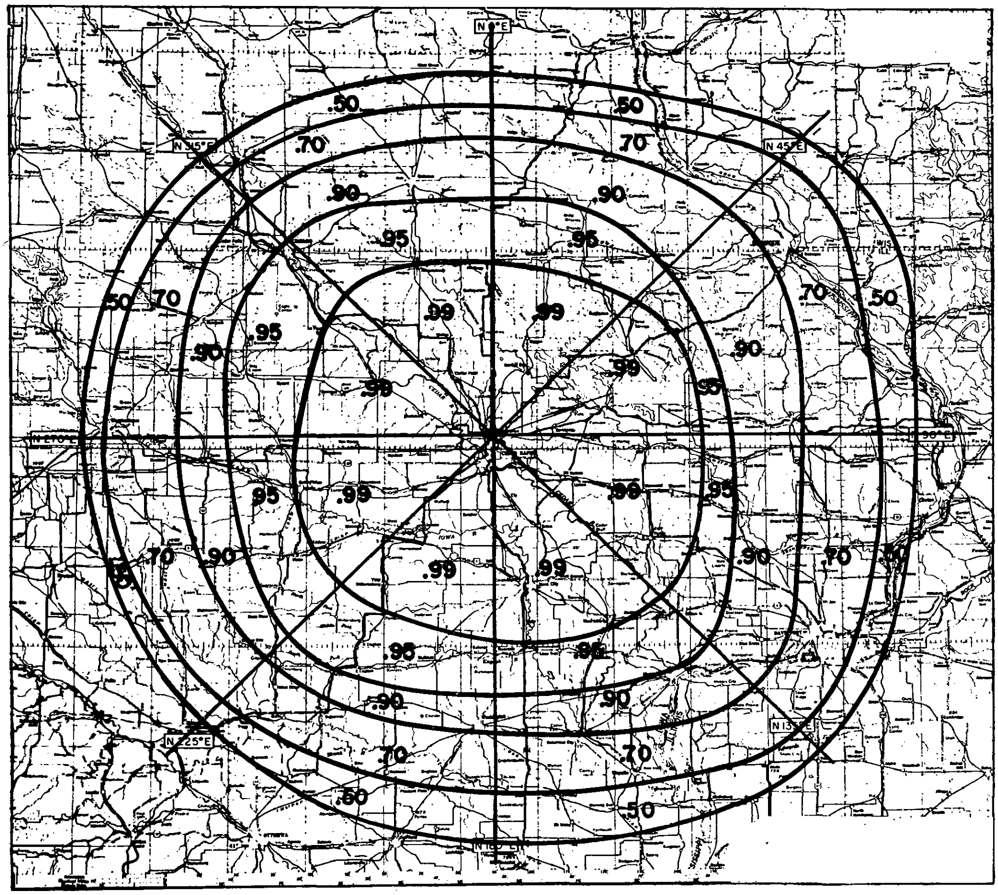

FIGURE 2

The concept of service probability

The numbers indicate the probability of locations receiving an acceptable service for at least 90% of the time

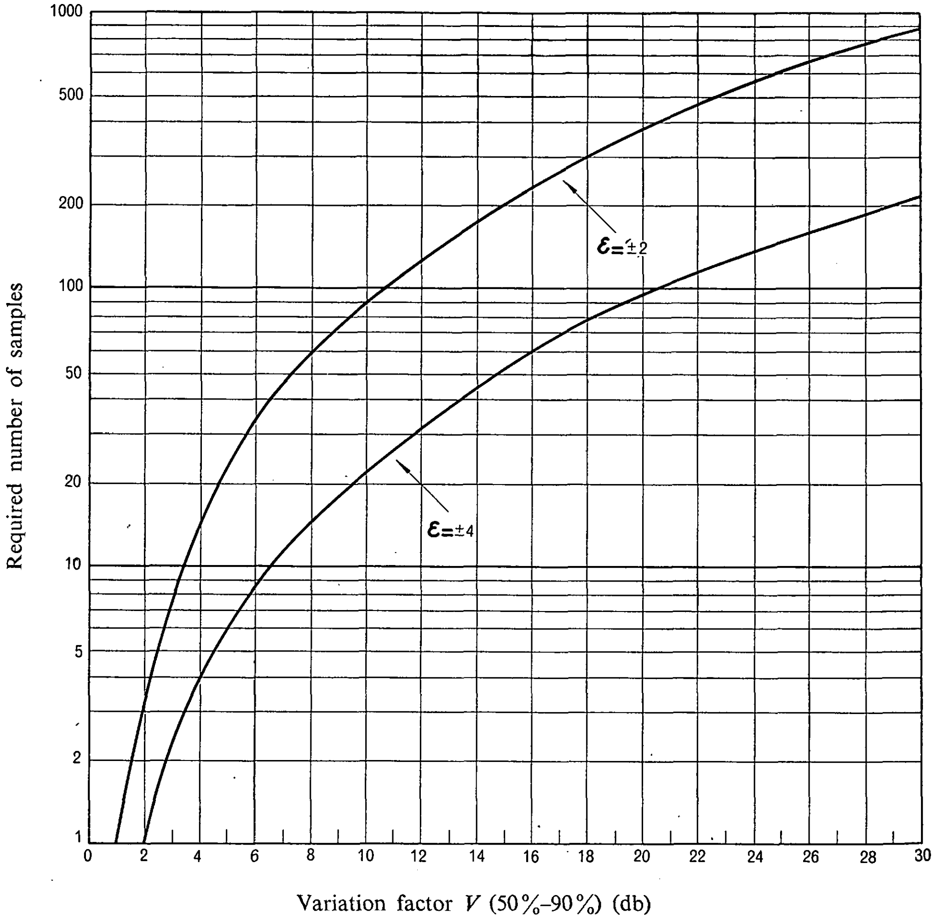

FIGURE 3

Number of sample measurements required to give 95% probability that the error ε the in median value will be less than 2 db or 4 db

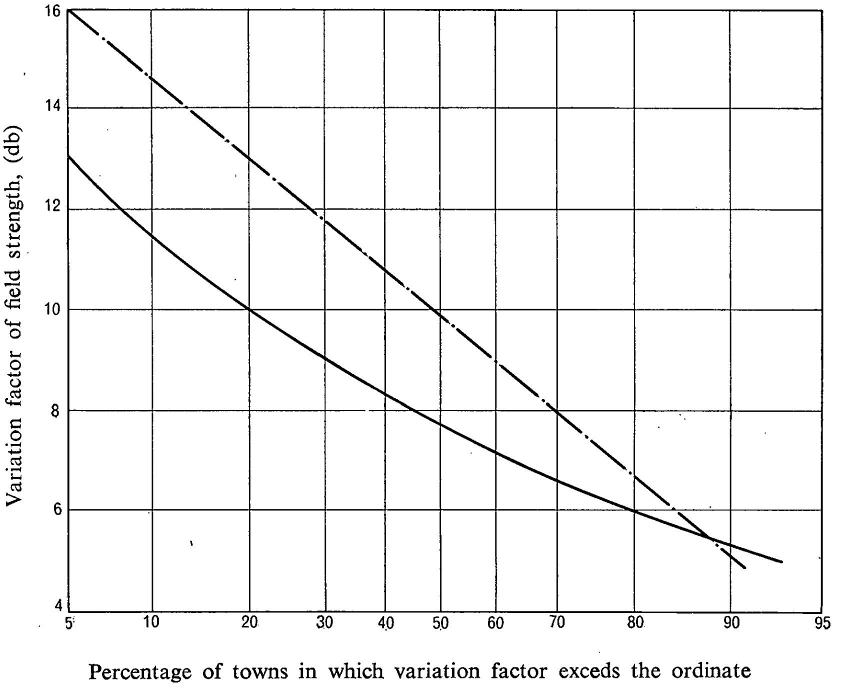

FIGURE 4

Distribution of values of variation factor for towns in the United Kingdom

All measurements made with the receiving antenna 10 m (30 ft) above ground level

—·—·—·—·— Band V measurements in 121 towns

———————— Band III measurements in 40 towns

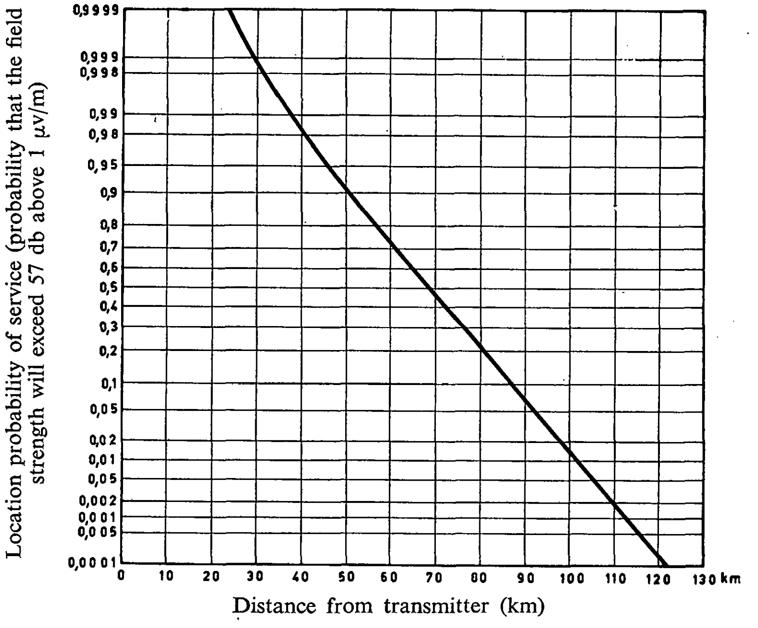

FIGURE 5

Variation of the location probability of service with distance from the transmitter. Based on typical propagation characteristics of a television station operating at 100 kW e.r.p. in the 54—88 Mc/s band

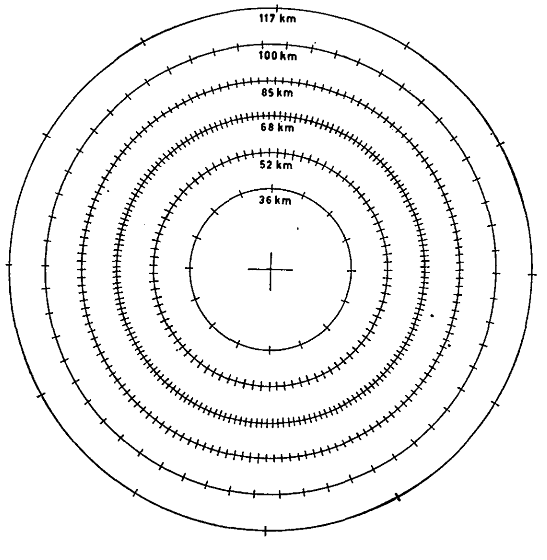

FIGURE 6

Possible scheme of measurements for a 100 kW station over average terrain
(The transmitter is located at the centre of the diagram).

REPORT 229 *

DETERMINATION OF THE ELECTRICAL CHARACTERISTICS OF THE SURFACE OF THE EARTH

(Study Programme 246 B (V))

(Los Angeles, 1959 — Geneva, 1963)

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 at the end of the Report.

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 dieletric constant relative to a vacuum:

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

where σ is in mho/m, f is the frequency in Mc/s, 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 proportional respectively to ε and $60\sigma\lambda$. The relative importance of the two constants, ε and σ, can be judged from the relative magnitudes of these two current densities. Table I shows the frequency at which the two current densities are equal for several types of surface. When the frequency is less than about 1/3 of the value shown in this Table, the effect of the displacement current, or of ε, is practically negligible. Conversely, when the frequency is greater than about 3 times the value shown, the effect of the conduction current, or of σ, is similarly negligible.

TABLE I

Frequency at which displacement and conduction current densities are equal

ε	σ (mho/m)	f (Mc/s)
80	4	900
10	10^{-2}	18
5	10^{-3}	3·6

* This Report, which replaces Report 139, was adopted unanimously.

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} mho/m can, when dried, have a conductivity as low as 10^{-4} mho/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 content 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 the constants of samples of various types of soil have shown that the temperature coefficient of conductivity is of the order of 2% per degree centigrade, while that of the dielectric constant is negligible and that at freezing point there is a large rapid change 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. It is noted, however, that the variation of conductivity is appreciable only at abnormally low values of moisture content and that the apparent change in dielectric constant may be due mainly to polarization effects. It is uncertain, therefore, whether, in practice, frequency has any substantial influence on the constants of homogeneous soil (see, however, § 3.6).

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 ground constants depends upon the depth of penetration of the radio energy. This in turn depends on the value of the constants and the frequency. If the depth of penetration, δ, is defined as that depth in which the wave has been attenuated to $1/e$ (or 37%) of its value at the surface, then over the frequency range 10 kc/s to 10 Mc/s, δ has the values shown in Table II. It will be seen that at frequencies of 10 Mc/s and above, only the surface of the ground need be considered, but at lower frequencies, strata down to a depth of one hundred metres or more must be taken into account. It is particularly important to take account of the lower strata when the upper strata are of lower conductivity since more energy penetrates to the lower levels than happens with an upper layer of higher conductivity.

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 values of the ground constants used in propagation calculations may take account of the effects of such energy losses.

In particular, it has been found that the attenuation of the ground-wave over wooded terrain, at a frequency of 75 Mc/s, may be very much greater for a vertically-polarized wave than for a horizontally-polarized wave (Doc. V/24 (Federal Republic of Germany) of Geneva, 1962).

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 kc/s to 10 Mc/s.

4.2 *Probe method of ground resistivity measurement*

The conductivity of the ground is obtained by measurements on site 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 (Doc. V/20 (Poland) of Geneva, 1962). It is reported that careful use of this method allows measurement of earth constants over a range of frequencies from 100 kc/s to 40 Mc/s (Doc. V/1 (Federal Republic of Germany) of Geneva, 1962).

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 *Ground wave attenuation measurement*

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 constants may also be determined by measuring the relative rate of attenuation of the field strength with a receiver as it is lowered below the surface of the earth in a well or other suitable hole. [37].

4.6 *Phase change measurements*

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 *By measurement of reflection coefficient*

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.

4.8 *Dispersion of sferic waves*

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.

5. Use of the methods in connection with propagation problems

From a study of the methods and of the factors affecting the ground constants, 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 kc/s 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 Mc/s (Doc. V/1 (Federal Republic of Germany) of Geneva, 1962). It may be used for determining path attenuation if a series of measurements is made along the path (Doc. V/21 (P.R. of Poland) of Geneva, 1962). (See also Report 236.)

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 exercised 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.

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, such as Loran-C. 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.

TABLE II

Depth of penetration of waves into ground

Frequency	Depth δ(m)		
	σ = 4 mho/m ε = 80	σ = 10^{-2} mho/m ε = 10	σ = 10^{-3} mho/m ε = 5
10 kc/s	2·5	50	150
100 kc/s	0·80	15	50
3 Mc/s	0·14	5	17
10 Mc/s	0·08	2	9

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REPORT 230 *

GROUND-WAVE PROPAGATION OVER INHOMOGENEOUS EARTH

(Study Programme 246 B (V))

(Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

Steady progress has been made under Study Programme 135**.

The progress made since the VIIIth Plenary Assembly has been equally marked and suggests further modifications to the Study Programme. This progress has been especially in the direction of generalizing the conditions under which it is possible to handle the rigorous mathematical analysis and to reduce it to a form of practical use to the engineer.

Because of the great complexity of the problem, various idealizations have been introduced in the theoretical analysis, for instance that the transmission path consists of well-defined homogeneous sections or that any stratification of the ground is parallel to the surface of the earth which is assumed to be smooth. Study is now being directed to the extension of the analysis to general cases more usually found in practical conditions. Some progress is being made in the treatment of the case where two sections of a path are separated by a region of transition, and of the case where a change in the constants of the earth is associated with a change in the elevation of the surface.

Even in the analysis of idealized cases, certain mathematical approximations have to be made, but these are in general admissible except possibly in considering the field in the vicinity of a marked inhomogeneity. In this connection, an interesting investigation by Wait [A.12] of the field in the vicinity of the boundary between two sections of a path may be mentioned, where a more accurate analytical procedure has been adopted.

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* This Report, which replaces Report 141, was adopted unanimously.

** Study Programme 135 has been replaced by Study Programme 246B(V).

In so doing, he has assumed that the surface impedances of the two sections are constant right up to the boundary; but although he has pointed out that this assumption is not justified at distances small enough to be comparable with the skin depth in the soil, this is not a severe restriction since the skin depth is usually much less than a free-space wavelength.

Godzinski [F.13] has extended this analysis to the case where two homogeneous sections are separated by a transition region in which the surface impedance changes linearly and has determined the complex attenuation function at all points near the boundaries. His results show that the details of the transition region are not important provided that the width of this region is small compared with the wavelength. However, his analysis is formally incomplete, in that it implies at discontinuity of the derivative of the surface impedance at the beginning and at the end of the transition region.

The assumption of a constant or linearly varying surface impedance over a finite horizontal area of the earth's surface is really equivalent to the introduction of virtual line sources parallel to the boundaries, since, if the tangential magnetic field is continuous across a boundary, the tangential electric field (which is perpendicular to the boundary) must be discontinuous. This is equivalent to locating a magnetic line source along the boundary.

Fortunately, these virtual sources at the boundaries of separation are not of practical significance except for an observer very near to a well-defined boundary such as a coastline. This conclusion is also substantiated by recent model experiments carried out at the University of Colorado.

The problem of providing the engineer with graphical presentations, enabling him to solve certain cases of propagation over well-defined sections, or which allow him to make approximate computations of coastal refraction, has been considered in the following papers:

— by Feinberg, E. L., [C.1], where graphs are given referring to coastal refraction for wavelengths of 300 and 600 metres;
— by Wait, J. R. [A.10] and Wait, J. R. and Householder, J. [A.11], where attenuation and phase data are presented in graphical form for two-section plane and spherical paths with various values of the conductivities;
— by Furutsu, K. [A.6, 7; E.1], where graphical representations are given of the attenuation function for two-section plane paths, for certain three-section plane paths, and for many-section spherical paths consisting of a number of very long homogeneous sections;
— by Godzinski, Z. [A.13], where curves are given which enable simple calculations to be made of attenuation and phase for two- and three-section plane paths and for many-section spherical paths especially when the sections are alternately short and long;
— by Wait, J. R. [A.18], where the amplitude and phase factors for two-section paths over both flat and spherical eath and for low and medium frequencies (Bands 4, 5 and 6) are shown by tables or graphs.

In these papers the boundaries between the sections have been assumed sharp, whereas in practice, they may be more or less gradual. However, the results of an investigation of the influence of a transition zone between sections have shown that in some special cases, at least at larger distances from the boundary, it is admissible to assume that the boundary is sharp instead of gradual [C.1, A.16, F.13].

With regard to the analysis of the refraction caused by path inhomogeneities, it appears that it may be extended in the future to discuss the possibility of changes in wave polarization in the vicinity of inhomogeneities and its influence on errors in radio direction finding [A.9]. On the other hand, the work carried out in the United Kingdom [A.17] suggests that, in most practical cases, large random errors are predominant and that it is impracticable to use experimental measurements to check the theoretical estimates of ground-wave deviation at a coast-line. It is similarly difficult to check the theory of wave propagation parallel to a boundary by field-strength measurements along a coast-line.

The discussion of the effect of horizontal stratification of the ground [B.1, B.4, B.5, B.6, B.7 and A.18], has shown that it is possible to introduce effective earth constants which determine both the attenuation of the wave and the shape of its ellipse of polarization. When the inhomogeneity of the ground is of a more complicated nature, the connection between the effective earth constants and the shape of the polarization ellipse is much more complicated and that is a factor that is of importance in the measurements of the electrical parameters of the ground.

The changes of the electrical constants of the ground have an influence on the amplitude, phase, polarization ellipse and the height-gain factor relative to the ground-wave. None of these characteristics depends, however, in a simple manner on the local values of the earth constants. This problem is important in connection with the possibility of geological prospecting by radio methods and it is due for fuller investigation in the future.

It may be noted that, in an increasing number of theoretical investigations using approximate boundary conditions, use is being made of the concept of surface impedance. It is thought that this trend may be useful to practical engineers who are familiar with this concept in other fields. There exists, in fact, a close analogy between inhomogeneous transmission lines and horizontally stratified ground which may prove helpful when calculating effective earth constants [B.4, B.5, B.6, B.7, B.10, A.18 and A.19].

Because of the labouriousness of the theoretical methods, the most widely accepted of the semi-empirical methods [F.3, F.4, F.5 and F.6], namely Millington's method and the equivalent numerical distance method (equivalent conductivity method) [F.1, F.2], have been compared with theory [F.8]. Millington's method has been found to give good agreement with theory and it is believed that it may be used for most practical purposes [F.14]. The agreement is closer for amplitude than for phase, but even with phase changes, it gives results that are within the limits of practical measurements, bearing in mind the difficulties mentioned above.

The methods of equivalent numerical distance or equivalent conductivity have the advantages of simplicity where many computations have to be made, but they can sometimes give rise to large errors. It is therefore necesary when using this method to take great care to remain within the domain of its limited application, making, if need be, controlled checks by other methods at a number of points within the range in which it is wished to apply it.

In the past it has been assumed that the ground, though inhomogeneous, is smooth, either plane or spherical. It is now being recognized that the fact that the ground may also be irregular may affect the study of the inhomogeneities. The analysis of such a general problem is, however, extremely difficult [C.1 to C.7]. Great value may, therefore, be attributed to the investigations of Furutsu [C.2, C.3 and C.8] who, in addition to showing the close analogy between the analysis for propagation over inhomogeneous earth and over a surface with small undulations, has succeeded in combining both aspects of ground-wave propagation in the same analysis. He has given formulae and curves for some special cases which may be of great practical value and has opened the way to a more general study including at the same time both surface irregularities and inhomogeneities of the ground.

For propagation over relatively long over-land paths at low frequencies, as in certain pulse navigation systems, it becomes very difficult to determine the attenuation and phase functions analytically and horizontally, especially in view of the lack of detailed knowledge regarding this distribution. It has been proposed [D.7], that the equivalent conductivity of the inhomogeneous earth over the path can be determined by measuring the dispersion of suitable sferic pulses at two distances from the source and comparing this dispersion with that calculated for a homogeneous spherical earth for several values of conductivity. The argument is made that the predictability of the electrical path length over land can be improved to such an extent that it is virtually as good as that for a sea path if the equivalent conductivity for the land path can be determined to an accuracy of one or two significant figures. The characteristics of both homogeneous and inhomogeneous earth for pulse transmission have received considerable theoretical attention (section D of Bibliography), but more comparison with experimental results is required.

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REPORT 231 *

REFERENCE ATMOSPHERES

(Study Programme 192 (V))

(Los Angeles, 1959 — Geneva 1963)

Reference atmospheres for the calculation of propagation characteristics.

To calculate certain propagation characteristics, it is necessary to specify the profile of the refractive index n of the atmosphere as a function of the height h above the surface of the earth as well as the characteristics of the terrain. In the past, most field strength, phase and bending calculations have been made using an assumed constant gradient of refractive index with height and it has been established that the same field strengths are expected for this linear-profile atmosphere as would be obtained for an earth with no atmosphere, but with an effective radius ka, where a is the real radius and k is determined by:

$$k = 1 \Big/ \left(1 + \frac{a}{n} \cdot \frac{\mathrm{d}n}{\mathrm{d}h}\right) \tag{1}$$

Recently, it has become desirable to extend the calculations of propagation characteristics to regions where the assumption of a constant gradient does not represent a satisfactory description of the atmosphere. This assumption may lead to large errors in the calculation of field strengths at high altitudes or in the calculation of phase at low frequencies.

It has been observed, that the variations of the mean values of the refractive index of the atmosphere may often be well approximated by the following exponential formula [1, 2].

$$n(h) = 1 + N_s \exp \{-bh\} \times 10^{-6} \tag{2}$$

where $N = (n-1) \times 10^6$ and the suffix s refers to the values at the surface of the earth; h is the height above the surface expressed in kilometres, and b is determined by the relation:

$$\exp \{-b\} = 1 + \Delta N / N_s \tag{3}$$

where ΔN is the difference in the N-values at a height of 1 km above the surface, and at the surface. Note that ΔN is a negative quantity.

Some studies [2, 3, 4, 5] have shown that ΔN is in general correlated with the surface value N_s. From this correlation, relations varying according to the climate have been deduced as follows:

$$\Delta N = -7 \cdot 32 \exp (0 \cdot 005577\, N_s) \text{ in the U.S.A. [2]} \tag{4}$$

$$\Delta N = -9 \cdot 30 \exp (0 \cdot 004565\, N_s) \text{ in the F.R. of Germany [5]} \tag{5}$$

$$\Delta N = -3 \cdot 95 \exp (0 \cdot 0072\, N_s) \text{ in the United Kingdom [4]} \tag{6}$$

The above formulae may be used for estimating ΔN in the usual case where only surface meteorological data are available. With $N_s = 289$ and $a = 6370$ km, one obtains from formulae (2), (3) and (4), $k = 4/3$ and $b = 0 \cdot 136$; this is the basic reference atmosphere. If extensive radio-sonde data are available, so that a good determination can be made of the average difference

* This Report, which together with Report 233 replaces Reports 146 and 147, was adopted unanimously.

ΔN between the values at the surface and at a height of one kilometre above the surface, these actual average measured values of ΔN and of N_s may be used in (2) and (3), for determining the characteristics of the atmosphere.

In summary, the above formulae provide a method for estimating mean refractive-index profiles for any geographical location in the world. When average values of ΔN and N_s are both known, these values may be substituted directly in (2) and (3) whereas, when only N_s is known, equation (4) may be used to determine ΔN. In this latter case, these procedures presume the validity of the above-mentioned correlation of ΔN and N_s.

For calculations of transmission loss, phase and bending, it is customary to assume a horizontally homogeneous atmosphere; this assumption is usually realistic when dealing with average propagation conditions.

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REPORT 232 *

CONSTANTS IN THE EQUATION FOR THE RADIO REFRACTIVE INDEX

(Study Programme 192 (V))

(Geneva, 1963)

In the Annex to Study Programme 192 (V), the C.C.I.R. gives the formula for the parameter $N = (n-1) \times 10^6$ as follows:

$N = (77 \cdot 6/T)\ (p + 4810e/T)$,

n = refractive index of the air,

T = absolute temperature (°K),

e = water-vapour pressure (mb),

p = atmospheric pressure (mb).

This formula has been used extensively by the C.C.I.R., particularly in connection with Report 233.

* This Report was adopted unanimously.

During the General Assemblies of the I.G.G.U. (Helsinki, 1960) and the U.R.S.I. (London, 1960), a slightly different formula using other units was recommended. A study [1] indicates that the C.C.I.R. formula, with units as above, should continue to be used by the C.C.I.R. It appears that it might be slightly more accurate than the U.R.S.I./I.G.G.U. formula, and in any case is entirely adequate to meet the C.C.I.R. requirements for determining the radio refractive-index of the atmosphere, considering the inaccuracies of measurements of atmospheric temperature, pressure and water-vapour pressure.

It appears desirable that a single formula using identical and homogeneous units be adopted by all organizations.

Note. — This Report should be drawn to the attention of the I.G.G.U. and the U.R.S.I. by the Director, C.C.I.R. for their comments.

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REPORT 233 *

INFLUENCE OF THE ATMOSPHERE ON WAVE PROPAGATION

(Study Programme 192 (V))

(Los Angeles, 1959 — Geneva, 1963)

1. Correlation between propagation beyond the line-of-sight and radio-meteorological parameters.

Much work has been done on the quantitative study of the influence of radio-meteorological phenomena on propagation, but it would be a mistake to assume that the problem has now been finally solved.

For many years, numerous measurements in temperate countries have taken into account the variation of the refractive index with height. To simplify the problem, the atmosphere has been represented by the difference $\Delta N \times 10^{-6}$ between the refractive index at a height of one kilometre and the index on the ground. In a number of instances, theory and practice agree in showing the existence of a correlation between the variations in the field observed and the quantity ΔN. This correlation has been clearly demonstrated in temperate countries only, when the comparison is made on the basis of monthly, or at least weekly, medians [1, 2, 3, 4].

By using annual mean figures, a standard radio-atmosphere was introduced, corresponding to an equivalent radius of the earth equal to 4/3 the real radius. Later, a basic reference atmosphere was formulated in which N varies exponentially with altitude.

Recommendation 370, Annex I, § 10 gives a formula whereby variations in the median field strength or the transmission loss may be approximately assessed as a function of ΔN, or as a function of N_s.

The concept of " equivalent gradient " was also introduced. This is a hypothetical constant gradient which, when replacing the actual gradients over a given path, produces the same total refraction [5].

Improvements have also been made in the correlations between the gradient (ΔN or equivalent gradient), and the characteristics of the observed field (intensity, fluctuations), by

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* This Report which, together with Report 231, replaces Reports 146 and 147, was adopted unanimously.

consideration of parameters which depend on the stability of the atmosphere, assessed either by the Richardson number [6], or by the work required to raise a unit mass of air by 1 km in the region of the base of the " common volume " [7]. These two quantities, incidentally, lead to comparable results. To represent the variations in the atmosphere, a parameter has been studied which comprises the sum of the gradient of the index (or better, of the equivalent gradient) and of a term proportional to stability [8, 9]. Although the results thus obtained are encouraging, there is not sufficient information to generalize them [10].

A function of the potential refractive-index has also been studied [11]. It should be noted that the gradient of this potential index is related theoretically to the measurement of the stability of the atmosphere.

Correlation has also been observed between the vertical gradient of the refractive index and the value of this index at the surface of the earth [2, 12, 13, 14], when a direct correlation between observed field-strength and the values of refractive index at the surface has been established [15 and 16]. The refractive index at the surface is easier to determine from the existing statistical meteorological data than from the gradient of the index; the latter requires radio-sonde measurements, which are usually performed at specified hours each day in the meteorological observatories of the world. A detailed study of the correlation between field strength and the value of the refractive index at the surface has been carried out in the United States for distances far beyond the horizon. The correlation coefficients between the median values of the two quantities for periods of about 10 days have been found to be at least 0·75. Good correlation has also been obtained in Japan [17], but the results in other regions of the world, particularly in Europe and Africa, are not as conclusive. It is, therefore, considered necessary that further studies should be undertaken in regions of the world with diverse climates. Recommendation 370, Annex I, § 6, provides a formula for the approximate evaluation of the variations in the median values of field strength, as a function of the surface values of refractive index, for paths several hundred kilometres in length, and for frequencies between 40 and 500 Mc/s, which take into account the preceding discussion.

The variations of the index of refraction are important not, only in consideration of variation in the field strength or transmission loss, but also in consideration of the total bending of radio waves passing through the troposphere [18]. Studies carried out in the United States indicate a good correlation between the variations in the bending and the variations in the vertical gradient or the values of refractive index at the surface. The vertical gradient leads to a somewhat better prediction for angles of elevation less than 3°, while the value at the surface is much better than the gradient at angles of elevation greater than 3°. Further studies are, however, necessary.

It does not seem possible to prepare world-wide charts of the equivalent gradient or of the stability parameters referred to above. In conclusion, world-wide charts have been prepared, both for the vertical gradient and for the index at the surface for different times of day, at each season of the year. These charts are intended for radio engineers. It is a matter of urgency that systematic studies should be pursued, in conformity with Study Programme 192 (V), on a world-wide scale, of the correlation between all the parameters indicated above, and the variations in radio propagation.

2. Charts of refractive index at the surface

Hereafter, the quantity N defined by $N = (n-1) \times 10^6$ will be studied, where n is the refractive index of the air. N will be considered here in terms of monthly mean values.

It is well known that N decreases systematically with altitude. To avoid confusion between the variations of N due to the altitude h of an observatory and those due to climatology, it is interesting to study the possibility of calculating the corresponding value of N reduced to sea level. The relation between N and h has been investigated empirically. For certain regions of the globe this relation is exponential and the parameters can be predetermined (Report 231). Each value of N measured at the surface of the ground can then be corrected by a factor greater than unity, to obtain the value of N at sea level, N_0.

From the above it can be seen, that for N_0 to be perfectly representative, in a given location, it is essential and sufficient that the exponential law $N(h)$ should be applicable.

To ascertain the value N at any known point of altitude h_i, it will suffice to determine the corresponding value N_0 on the charts by interpolation and to calculate $N(h_i)$ from the formulae suggested in Report 231. Here again the value $N(h_i)$ will be all the more representative, if the above condition is fulfilled.

The monthly mean value of $N(h)$ has also been studied. There are theoretical and experimental reasons for believing that $N(h)$ is systematically exponential in high-latitude regions. The inhomogeneity of data for inter-tropical regions, indicates that it is doubtful whether these reasons will exist in such regions [14, 19].

3. Preparation of N_o-charts

N was first calculated, at the surface of the earth (N_s), as a function of the meteorological parameters, deduced from the measurements published monthly by WMO. Three hundred and six stations in various parts of the world were used in this way. In general, five years of observations were used in the period between 1949 and 1958 for each station, with the exception of the stations in the U.S.S.R., for which only the IGY data were available [20].

For oceanic areas, the pressure was deduced from seasonal average charts, the temperature was estimated from surface isotherms of water and humidity, estimated on the basis of seasonal variation charts of the wet-bulb thermometer.

N_s being known, N_o was calculated from the formula:

$$N_o = N_s \exp\{0 \cdot 1057\, h\}$$

in which h is the altitude (km)*. (This formula is a simplification of those in Report 231).

With the information available, it is not possible to prepare N_o charts for the four seasons at the times stated in Study Programme 192 (V).

Fig. 1 to 3 show the charts, on which the following lines of equal value have been plotted:

— mean values of N_o for February;

— mean values of N_o for August;

— yearly minimum monthly mean of N_o.

Note. — In view of the scale of the charts, the number of measurement points and the methods of calculation, the accuracy of the diagram is of the order of several N-units.

The Administration of the U.S.A. has done more accurate and detailed work for its territory [20].

4. Charts of ΔN

Here, the altitude of the observation station seems to be relatively unimportant, provided the relief is not too irregular. Hence ΔN has been calculated from the formula:

$$\Delta N = N_1 - N_s$$

in which N_1 is the value of N at 1 km above the ground and N_s the value of N at ground level. Unfortunately, there are too few measuring stations to enable world-wide charts to be prepared and the work has, therefore, been confined to areas for which the quantity of information was deemed sufficient.

* Details concerning the preparation and accuracy of these charts will be found in [21].

5. Preparation of the charts

For the preparation of the three charts for the northern hemisphere, a projection on a plane tangential to the earth at the North Pole was chosen. A similar procedure relative to the South Pole was followed for the Australian charts.

Although the nominal hours of observations, required by the C.C.I.R. in Study Programme 192 (V), were 0200 and 1400 UT, the error in using the observations supplied by some Administrations for the hours 0300, 0400, 1500 and 1600 UT was negligible. The time zones are marked on the charts from 0000 UT onward.

Certain meteorological observations, made over short periods of time, have been made available. Although these results did not cover the entire period of 1951-55 required by the C.C.I.R., they were used as a guide in regions of sparse data. Regions where the contours were determined from such data are indicated by dashed lines.

6. Accuracy of the results

While an important purpose of the charts is to indicate wide variations of radioclimatology, they do provide values of ΔN with an accuracy of the order of 5 N-units.

7. Data used

The data used for the preparation of the charts are listed in the following Tables I-V and the derived contours of ΔN are given in Figs. 4-35.

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TABLE I *

Values of — ΔN *for the European- African sector*

No.** of station	0200 UT February	0200 UT May	0200 UT August	0200 UT November	1400 UT February	1400 UT May	1400 UT August	1400 UT November
	French Community							
1	44				35	32	38	41
2	69				60	84	54	60
3	25	28	35	25	19	27	25	24
Note: Data from the stations at Cayenne (Guiana), and Tananarive (Madagascar) are at the disposal of the C.C.I.R. These results have not been made use of in this Report.								
	Denmark							
4	38·8	43·0	49·8	38·8	36·7	38·1	41·0	38·8
5	33·4	34·4	39·9	35·8	33·7	36·2	38·6	35·8
Note: The figures for ΔN supplied by Station No. 5, relate to a difference of altitude of 935 metres. The results have been adapted to a value of 1000 m for the preparation of the charts.								
	Algeria							
6	43	54	56	47	43	51	66	49
Note: Results prior to 1960 provided by France.								
	France							
7	41	47	50	49	38	37	43	49
8	36	42	40	37	37	44	44	41
9	35	41	43	39	31	38	39	37
10	34	39	41	31	33	35	38	38
11	48	45	48	41	43	45	46	42
	Morocco							
12	49							
Note: Results prior to 1953 provided by France.								
	Netherlands							
13	35	43	46	39	34	38	43	40
	United Kingdom							
14	40·1	41·3	44·9	41·4	38·9	39·6	43·2	41·0
15	40·5	44·9	49·2	42·3	41·2	45·3	48·3	42·9
16	40·1	41·6	45·8	41·8	39·7	40·3	43·5	42·0
17	39·3	40·6	44·0	41·5	38·9	39·2	42·8	40·5
18	40·8	43·7	48·6	43·0	39·1	40·5	44·6	42·5
19	39·2	42·9	45·0	41·0	39·5	42·0	45·0	41·0
20	38·6	41·5	42·8	40·2	38·0	40·6	41·8	40·2
21	39·1	41·8	44·1	40·5	39·7	40·9	44·2	40·1
22	39·6	42·4	46·4	41·9	39·3	42·4	46·0	42·0
23	39·1	41·0	44·5	39·6	40·4	41·4	43·6	40·0
24	39·9	42·2	45·7	41·1	39·3	42·4	45·0	41·3
	Czechoslovak S.R.							
25	34·1	35·9	39·0	33·9	32·7	34·9	35·4	34·5
	Tunisia							
26	40	53	77	48	46	43		51
Note: Results prior to 1953 provided by France.								
	Federal Republic of Germany							
81	38	43	48	41	38	37	40	42
82	37	42	44	37	35	34	37	39
83	37	42	46	40	36	35	39	40

* These data refer to measurements made at 0200 and 1400 UT from 1 Feb. 1953 to 31 Mar. 1957 and 0000 and 1200 UT beginning on 1 April 1957.

** For location of stations see Table V.

TABLE II

Values of — ΔN for the American sector

No. of station *	0200 UT February	0200 UT May	0200 UT August	0200 UT November	1400 UT February	1400 UT May	1400 UT August	1400 UT November
				United States of America				
27	45·5	57·4	66·8	50·8	43·2	56·0	63·6	48·0
28	45·2	50·4	66·1	49·2	45·2	47·8	62·2	47·7
29	46·7	61·6	67·0	50·2	45·3	56·2	58·8	48·3
30	52·3	69·8	74·3	52·2	47·6	57·3	60·8	46·8
31	36·7	42·7	50·3	40·1	35·6	40·5	48·1	39·4
32	50·9	59·3	61·0	52·4	44·8	47·9	53·4	49·5
33	50·5	59·0	61·5	52·1	46·7	52·4	57·1	49·3
34	43·2	58·0	63·8	48·0	40·7	49·2	58·0	44·6
35	36·4	46·6	55·8	39·8	35·0	42·2	51·6	38·0
36	36·4	42·1	49·2	38·2				
37	41·4	47·9	53·0	42·4	41·2	47·0	50·4	42·3
38	49·0	49·0	65·6	52·5	46·6	48·5	61·6	47·2
39	38·6	48·1	56·0	42·2	38·4	50·0	56·2	41·6
40	38·2	41·4	51·8	39·7	38·2	41·6	51·2	39·2
41	39·3	49·0	53·6	40·8	39·5	47·6	53·2	41·8
42	37·1	38·6	47·2	38·2	36·6	36·6	45·4	37·7
43	38·0	42·2	51·9	40·5	38·1	41·8	50·8	39·4
44	36·2	40·1	49·9	37·1	35·7	38·6	45·0	37·6
45	36·1	40·6	48·5	37·8	35·9	37·6	47·8	37·3
46	38·3	47·0	43·9	39·6	41·3	52·6	58·7	42·1
47	37·7	49·2	55·5	41·1	35·7	43·5	53·0	39·5
48	38·0	46·0	53·7	43·0	38·7	45·0	51·7	40·8
49	40·5	32·3	42·3	44·8	43·7	34·4	47·7	43·2
50	37·7	36·7	48·9	36·6	39·1	36·5	49·4	37·0
51	36·1	40·8	46·4	37·4	36·2	38·5	45·9	37·2
52	38·5	48·2	52·7	39·7	39·0	49·0	53·8	41·6
53	40·3	35·2	29·3	42·4	38·9	40·8	38·3	40·8
54	38·1	37·6	46·9	37·6	38·8	37·8	49·5	37·5
55	36·4	34·7	31·0	38·4	36·5	39·2	40·8	38·3
56	36·8	33·6	38·5	36·0	38·0	34·9	43·3	36·9
57	32·2	25·8	26·0	32·6	36·7	28·9	32·1	35·4
58	36·1	40·7	36·6	36·8	40·0	47·8	48·0	39·2
59	36·0	44·0	47·2	38·1	37·4	45·0	51·7	39·7
60	36·5	40·2	50·9	38·1	36·9	38·7	52·8	38·6
61	36·0	36·8	41·4	37·6	36·1	36·8	38·2	38·0
62	34·3	37·4	41·8	35·5	34·7	38·3	47·2	36·0
63	31·8	31·2	32·7	32·5	32·0	33·5	37·4	32·7
64	30·1	26·2	34·2	30·7	33·8	29·2	40·6	31·6
65	33·2	28·6	32·6	32·5	32·9	30·5	36·3	33·6
66	28·4	26·8	36·6	28·2	31·2	29·8	39·1	30·4
67	30·9	32·3	31·6	32·3	32·0	34·5	37·2	32·9
68	31·5	30·4	30·8	32·1	32·6	31·9	32·7	33·0
69	37·0	41·6	55·4	38·6	37·0	43·1	54·2	39·2

Note: The values of ΔN actually relate to the hours of 0300 and 1500 UT. The United States Administration can make information from certain additional stations available to the C.C.I.R.

* For location of stations see Table V.

TABLE III

Values of — ΔN *for the Pacific sector*

No. of station *	0200 UT February	0200 UT May	0200 UT August	0200 UT November	1400 UT February	1400 UT May	1400 UT August	1400 UT November
				Japan				
70	39	47	49	42	39	47	53	44
71	37	46	55	40	37	46	53	42
72	36	47	59	40	35	45	58	40
73	34	43	50	39	38	44	49	40
74	36	45	53	41	38	46	50	42
75	32	40	49	36	35	39	51	38
76	34	43	53	39	35	43	51	39
77	32	38	45	35	34	38	44	36
78	32		48	39	33	39	45	34
79			59				63	
80	49	55	57		49	56	57	

Note 1: For all the above stations, ΔN has been calculated between the station altitude and an altitude above sea-level of 1000 m. The value used in plotting the chart have been adapted for a difference in altitude of 1000 m.
Note 2: All the values above relate to the hours of 0300 and 1500 UT.

TABLE IV

Values of — ΔN *for tne South Pacific sector*

No. of station *	0200 UT February	0200 UT May	0200 UT August	0200 UT November	1400 UT February	1400 UT May	1400 UT August	1400 UT November
				Australia				
84	28	35	35	32		48	44	49
85	8	11	12	9	27	21		17
86	33	32	32	27		52	51	
87	17	17	16	16	32	27	38	27
88	25	20	17	18	62	18	31	35
89	48	48	51	46				
90	48	28	30	44	74	70	68	63
91	37	37	37	36				
92	33	32	31	30				
93	13	18	17	13				
94		44	35	47				
95	40	42	41	41				
96			40	50				
97	36	36	34	32	53	46		47
98	44	44	36	45				
99	33	34	36	32				
100	46	35	36	39	61	50	47	64
100 *bis*	48	37	33	40				
101	52	36	36	50	63	55	54	56
102	19	24	22	20				
103					52	49	43	63
				French Commonwealth				
104	47	44	44	43				

Note 1: The above values were calculated on the assumption that the mean index could coincide with the index worked out from the mean values for pressure temperature and humidity. The minimum values are subject to an error of 2 to 3 units of N at most.
Note 2: Station No. 92 has been omitted from the chart because of the lay-out chosen.
Note 3: For all the stations above ΔN was calculated between the station altitude and an altitude above sea-level of 1000 m. The values used for plotting the charts were transformed so as to apply to a difference in altitude of 1000 m.
Note 4: All the values above apply to 0400 and 1600 hours UT.
Note 5: No use was made of the values of ΔN for stations Nos. 87 and 93 in plotting the charts.

* For location of stations see Table V.

TABLE V
Location of stations

No. of station	Name	Position: Latitude	Position: Longitude	Altitude (m)	Notes
1	Bangui	04° 22′ N	18° 34′ E	386	
2	Dakar	14° 40′ N	17° 26′ W	40	
3	Fort-Frinquet	25° 14′ N	11° 37′ W	360	
4	Kastrup	55° 38′ N	12° 39′ E	0	
5	Thorshavn	62° 01′ N	06° 46′ W	65	
6	Alger	36° 43′ N	03° 15′ E	25	
7	Bordeaux	44° 50′ N	00° 42′ W	49	
8	Brest	48° 26′ N	04° 25′ W	103	
9	Nîmes	43° 51′ N	04° 24′ E	60	
10	Trappes	48° 46′ N	02° 00′ E	168	
11	Weather ship	45° 00′ N	16° 00′ W	0	
12	Casablanca	33° 34′ N	07° 40′ W	58	
13	de Bilt	52° 06′ N	05° 11′ E	5	
14	Aldergrove	54° 39′ N	06° 13′ W	79	
15	Camborne	50° 05′ N	05° 32′ W	87·8	
16	Downham Market	52° 37′ N	00° 22′ E	36·9	16 replaced by 16 *bis* on 19 Nov. 51
16 *bis*	Hemsby	52° 41′ N	01° 41′ E	12·8	
17	Fazakerly	53° 28′ N	02° 55′ W	17·1	
18	Larkill	51° 12′ N	01° 48′ W	133	18 replaced by 18 *bis* on 29 Apr. 53
18 *bis*	Crawley	51° 05′ N	00° 12′ W	144	
19	Lerwick	60° 08′ N	01° 11′ W	81·7	
20	Leuchars	56° 23′ N	02° 53′ W	5·8	
21	Stornoway	58° 13′ N	06° 20′ W	13·7	
22	Valentia	51° 56′ N	10° 15′ W	13·7	
23	Weather ship	59° 00′ N	19° 00′ W	11	
24	Weather ship	52° 30′ N	20° 00′ W	11	
25	Praha	50° 07′ N	14° 32′ E	374	
26	Tunis	36° 50′ N	10° 14′ E	4	
27	Hatteras, N.C.	35° 15′ N	75° 40′ W	3	
28	Oakland, Calif.	37° 40′ N	122° 12′ W	5	
29	Lake Charles, La.	30° 13′ N	93° 09′ W	6	
30	Brownsville, Tex.	25° 55′ N	97° 28′ W	6	
31	Portland, Maine	43° 39′ N	70° 19′ W	6	
32	Miami, Florida	25° 49′ N	80° 17′ W	7	
33	Tampa, Florida	27° 58′ N	82° 32′ W	11	
34	Charleston, S.C.	32° 54′ N	80° 02′ W	14	
35	Dist. Columbia	38° 54′ N	77° 03′ W	22	
36	Albany, N.Y.	42° 45′ N	73° 48′ W	27	
37	Tatoosh Is., Wash.	48° 23′ N	124° 44′ W	36	
38	Santa Maria, Calif.	34° 54′ N	120° 28′ W	79	
39	Little Rock, Ark.	34° 44′ N	92° 14′ W	81	
40	Joliet, Ill.	41° 30′ N	88° 10′ W	179	
41	Nashville, Tenn.	36° 07′ N	86° 41′ W	183	
42	Carabou, Maine	46° 53′ N	67° 58′ W	191	
43	Toledo, Ohio	41° 34′ N	83° 28′ W	191	
44	Buffalo, N.Y.	42° 56′ N	78° 43′ W	215	
45	Sault St. Marie, Mich.	46° 28′ N	84° 22′ W	221	
46	San Antonio, Texas	29° 32′ N	98° 28′ W	242	
47	Greensboro, N.C.	36° 05′ N	79° 57′ W	275	
48	Atlanta, Georgia	33° 39′ N	84° 25′ W	303	
49	Phoenix, Ariz.	33 26′ N	112° 02′ W	339	
50	International Falls, Min.	48° 36′ N	93° 24′ W	343	
51	Pittsburgh, Pa.	40° 21′ N	79° 56′ W	388	
52	Oklahoma City, Ok.	35° 24′ N	97° 36′ W	397	
53	Medford, Oregon	42° 23′ N	122° 52′ W	405	

TABLE V

No. of station	Name	Position		Altitude (m)	Notes
		Latitude	Longitude		
54	Bismark, N. Dak.	46° 46′ N	100° 45′ W	506	
55	Spokane, Wash.	47° 37′ N	117° 31′ W	600	
56	Glasgow, Mont.	48° 11′ N	106° 38′ W	643	
57	Las Vegas, Nevada	36° 04′ N	115° 10′ W	664	
58	Big Springs, Texas	32° 14′ N	101° 30′ W	773	
59	Dodge City, Kansas	37° 46′ N	99° 58′ W	790	
60	North Platte, Neb.	41° 08′ N	100° 42′ W	849	
61	Boise, Idaho	43° 34′ N	116° 13′ W	871	
62	Rapid City, S. Dak.	44° 09′ N	103° 06′ W	981	
63	Great Falls, Mont.	47° 30′ N	111° 21′ W	1124	
64	El Paso, Texas	31° 47′ N	106° 30′ W	1194	
65	Grand Junction, Col.	39° 06′ N	108° 32′ W	1474	
66	Albuquerque, N. Mex.	35° 03′ N	106° 37′ W	1620	
67	Lander, Wyo.	42° 48′ N	108° 43′ W	1694	
68	Ely, Nevada	39° 17′ N	114° 51′ W	1909	
69	Omaha, Neb.				
70	Kagoshima	31° 34′ N	130° 33′ E	5·4	
71	Yonago	35° 26′ N	133° 21′ E	7·9	
72	Shionomisaki	33° 27′ N	135° 46′ E	74·9	
73	Tateno	36° 03′ N	140° 08′ E	27·2	
74	Wajima	37° 23′ N	136° 54′ E	6·9	
75	Sendai	38° 16′ N	140° 54′ E	39·8	
76	Akita	39° 41′ N	140° 06′ E	9·9	
77	Sapporo	43° 01′ N	141° 20′ E	18·1	
78	Wakkanai	45° 25′ N	141° 41′ E	3·2	
79	Weather ship	29° 00′ N	135° 00′ E	0	
80	Marcus Island	24° 18′ N	153° 58′ E	16·7	
81	Emden	53° 20′ N	07° 15′ E	2	
82	Hannover	52° 22′ N	09° 45′ E	52	
83	München	48° 08′ N	11° 34′ E	524	
84	Adelaide	34° 57′ S	138° 31′ E	4	1600 UT information for 1945
85	Alice Springs	23° 48′ S	133° 53′ E	555	do. for 1945-46
86	Amberley	27° 38′ S	152° 43′ E	26	
87	Charleville	26° 25′ S	146° 17′ E	305	
88	Cloncurry	20° 40′ S	140° 30′ E	193	do. for 1944-45
89	Cocos Island	12° 11′ S	96° 50′ E	3	
90	Darwin	12° 28′ S	130° 55′ E	27	
91	Heard Island	53° 06′ S	72° 31′ E	5	0400 UT do. for 1954-55
92	Hobart	42° 53′ S	147° 20′ E	53	
93	Kalgoorlie	30° 46′ S	121° 27′ E	370	
94	Lord Howe Island	31° 31′ S	159° 03′ E	47	do. for 1955
95	Macquarie Island	54° 30′ S	158° 57′ E	6	do. for 1953-54
96	Mawson	67° 36′ S	62° 53′ E	16	do. for 1953
97	Laverton	37° 52′ S	144° 46′ E	14	1600 UT do. 1944-45
98	Norfolk Island	29° 03′ S	167° 56′ E	110	
99	Guildford	31° 56′ S	115° 57′ E	11	
100	Rathmines	33° 03′ S	151° 36′ E	3	For 1953. Replace by 100 *bis* in 1954
100 *bis*	Williamtown	32° 48′ S	151° 51′ E	7	0400 UT for 1954-55
101	Garbutt	19° 15′ S	146° 46′ E	4	1600 UT for 1944-45
102	Woomera	31° 20′ S	135° 55′ E	169	
103	Pearce	31° 40′ S	116° 01′ E	56	1600 UT do. for 1945-46
104	New Amsterdam	37° 50′ S	77° 34′ E	28	

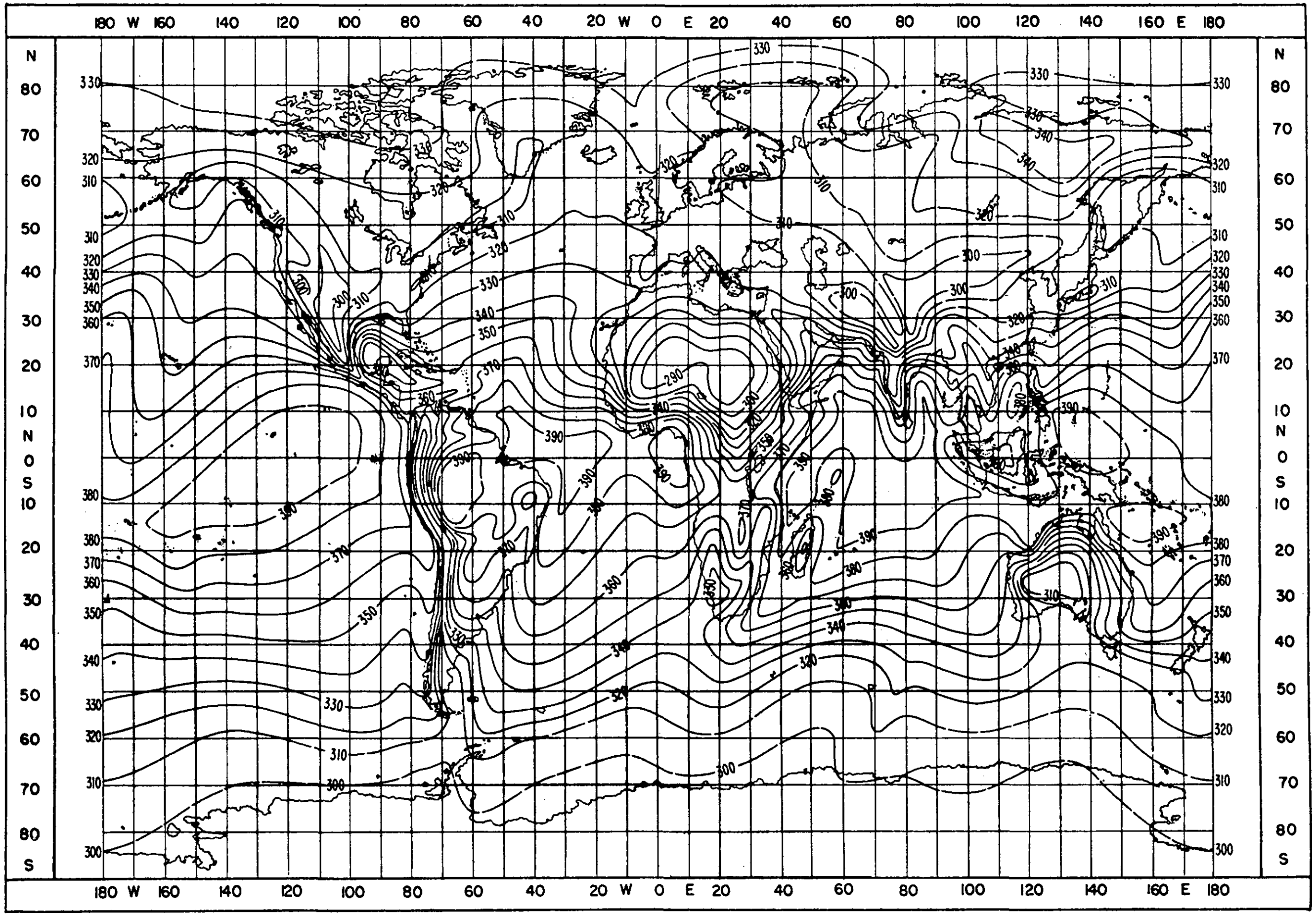

FIGURE 1

World-wide mean value of N_0 for February

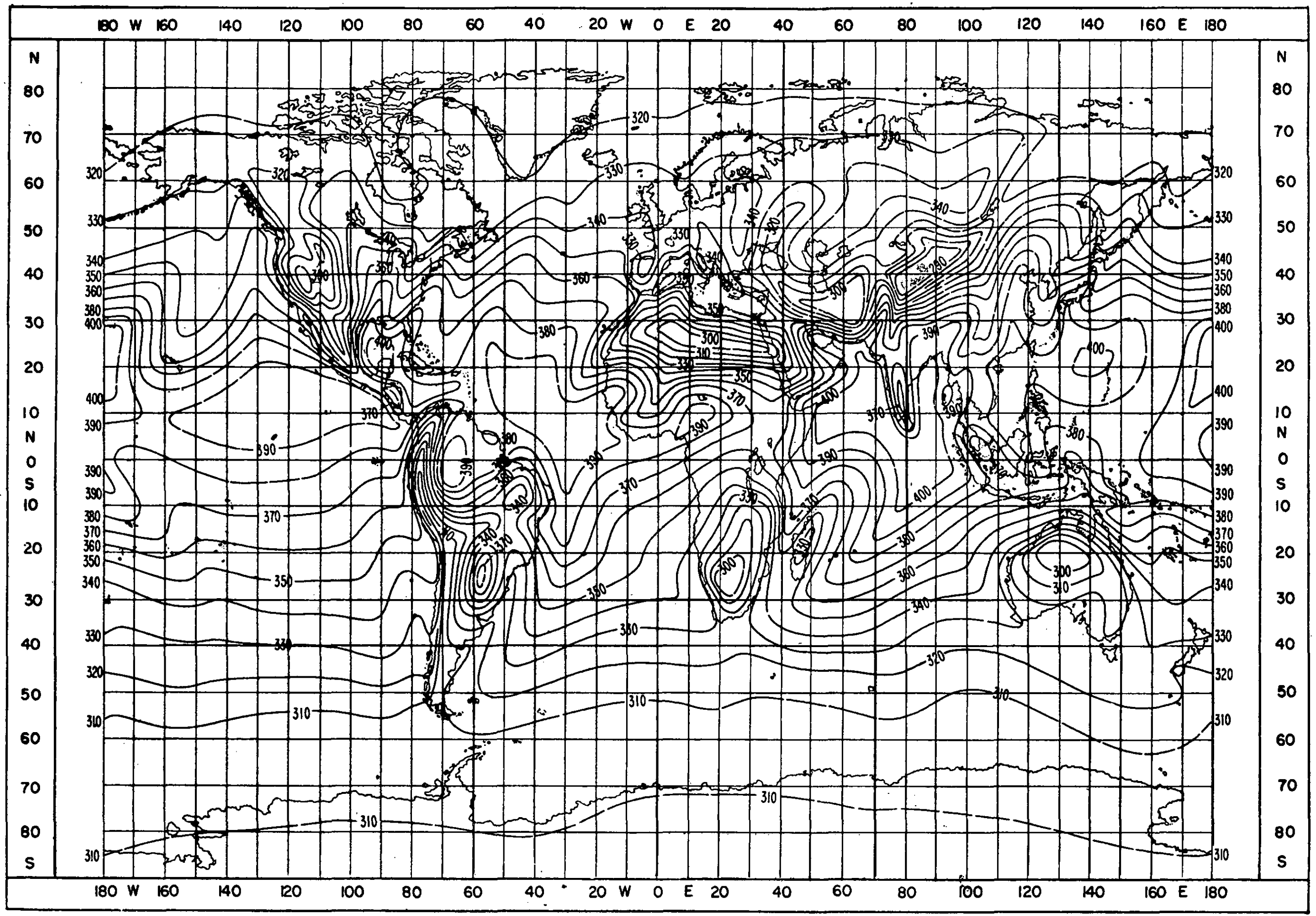

FIGURE 2

World-wide mean value of N_0 for August

[redacted]

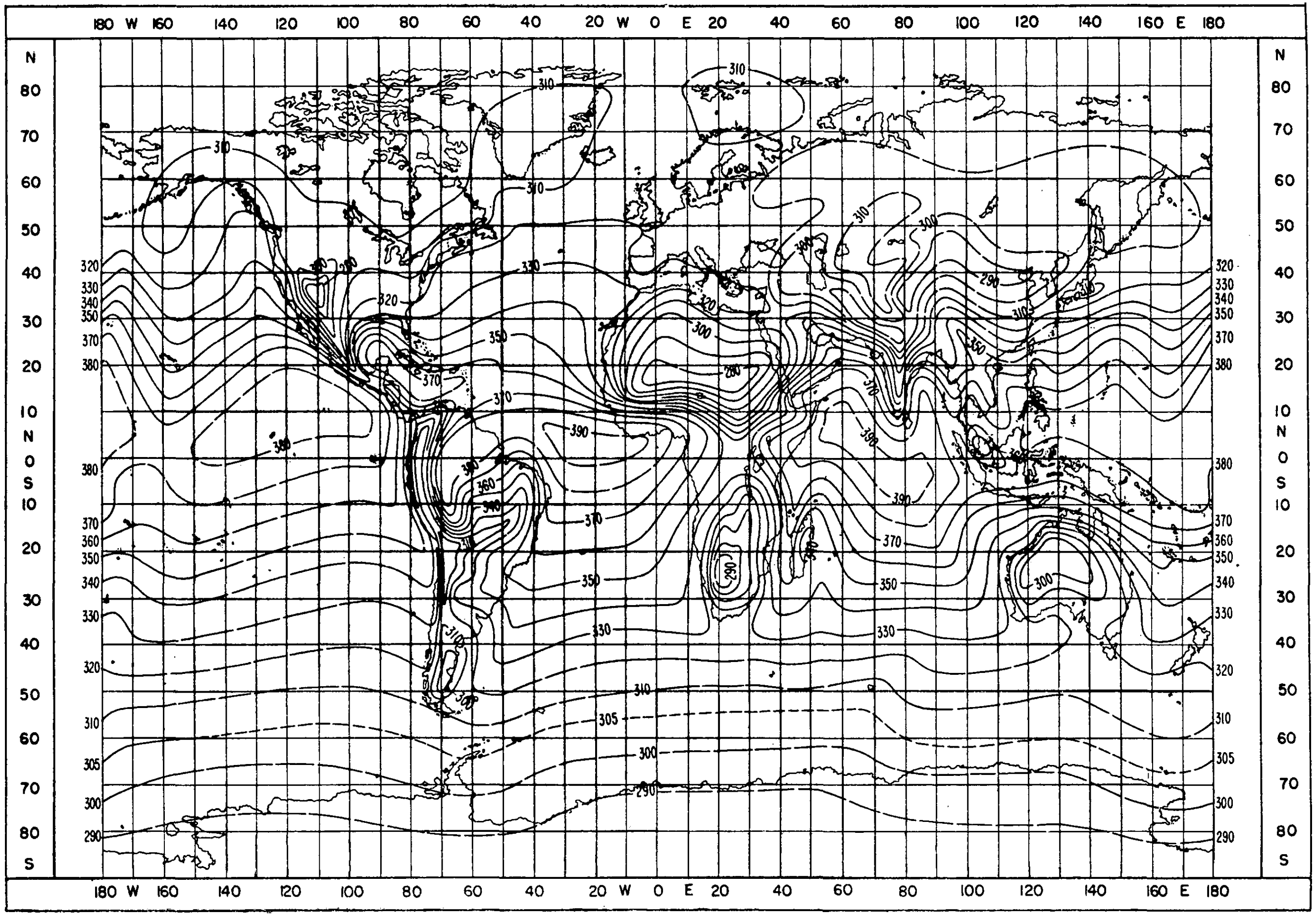

FIGURE 3

Yearly minimum monthly mean value of N_0.

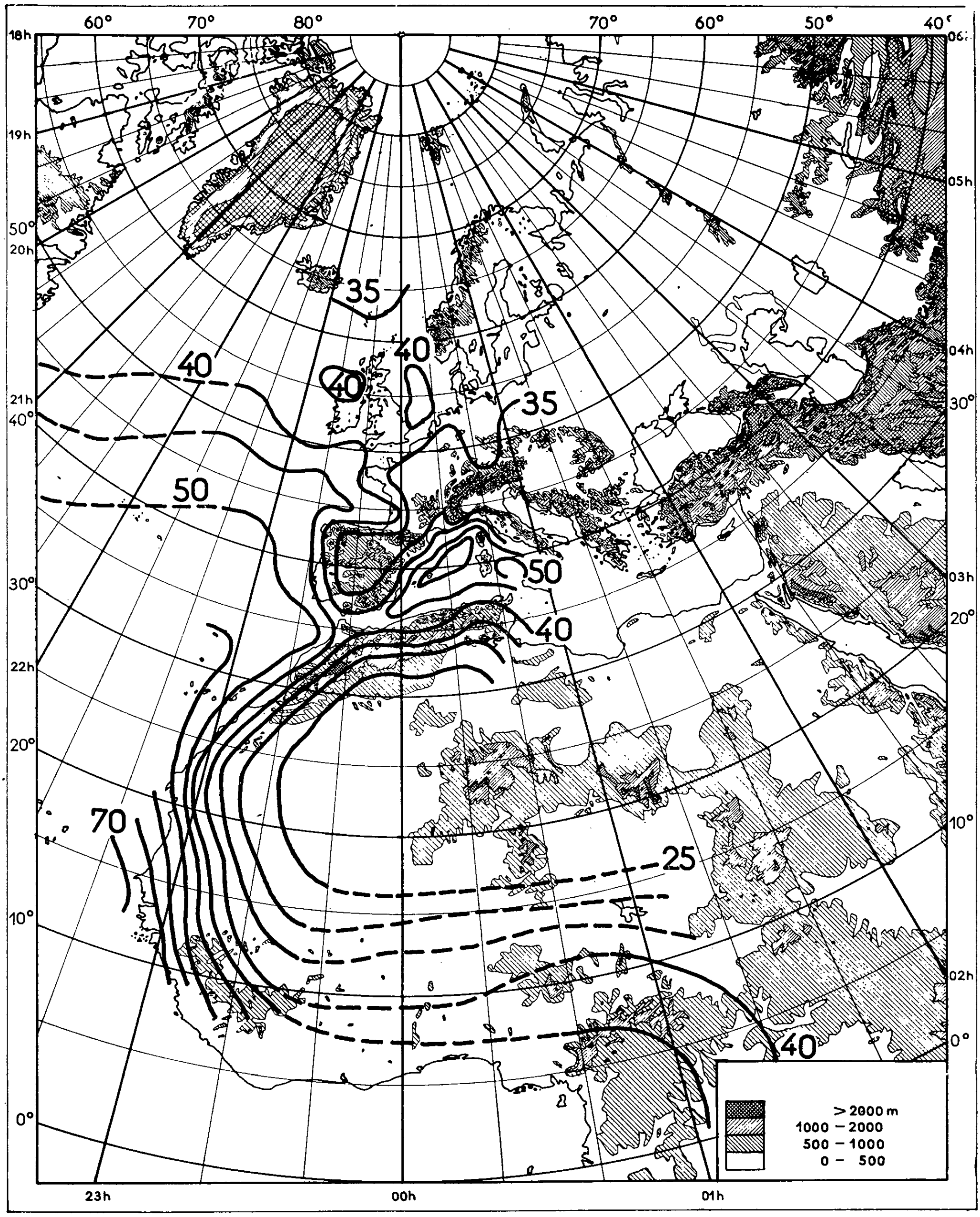

FIGURE 4

Iso —ΔN chart for the European-African sector for the month of February, 0200 hrs UT.

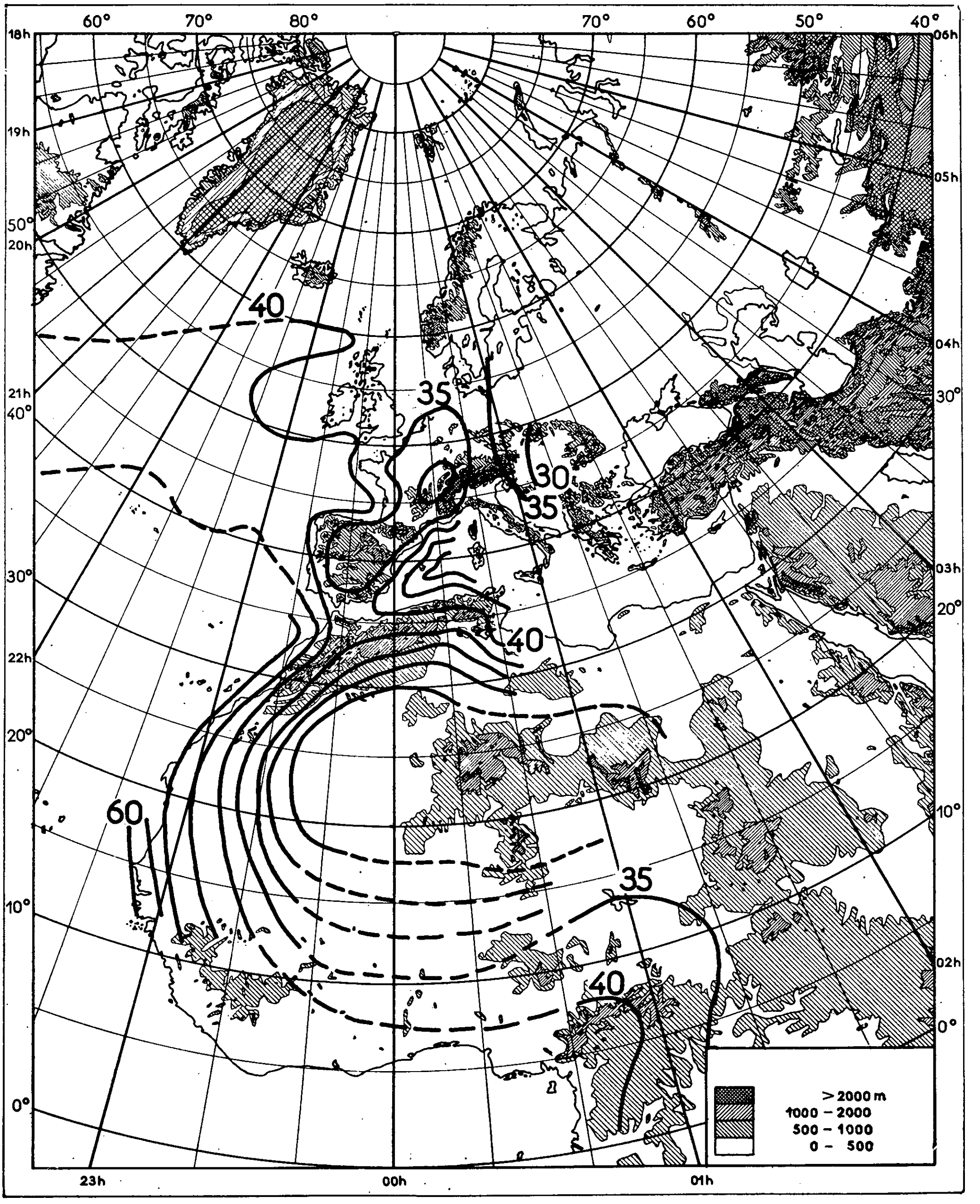

FIGURE 5

Iso —ΔN chart for the European-African sector for the month of February, 1400 hrs UT.

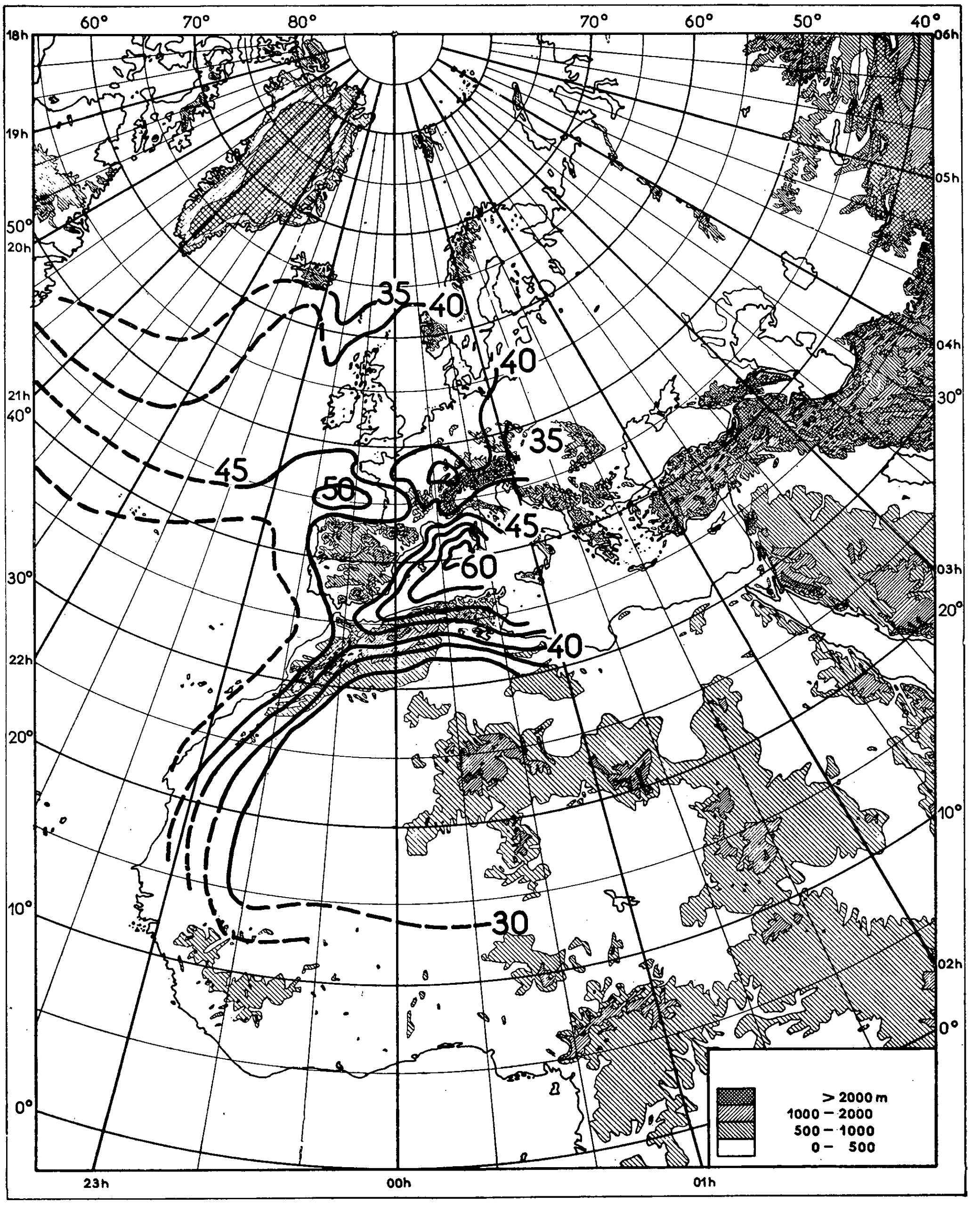

FIGURE 6

Iso —ΔN chart for the European-African sector for the month of May, 0200 hrs UT.

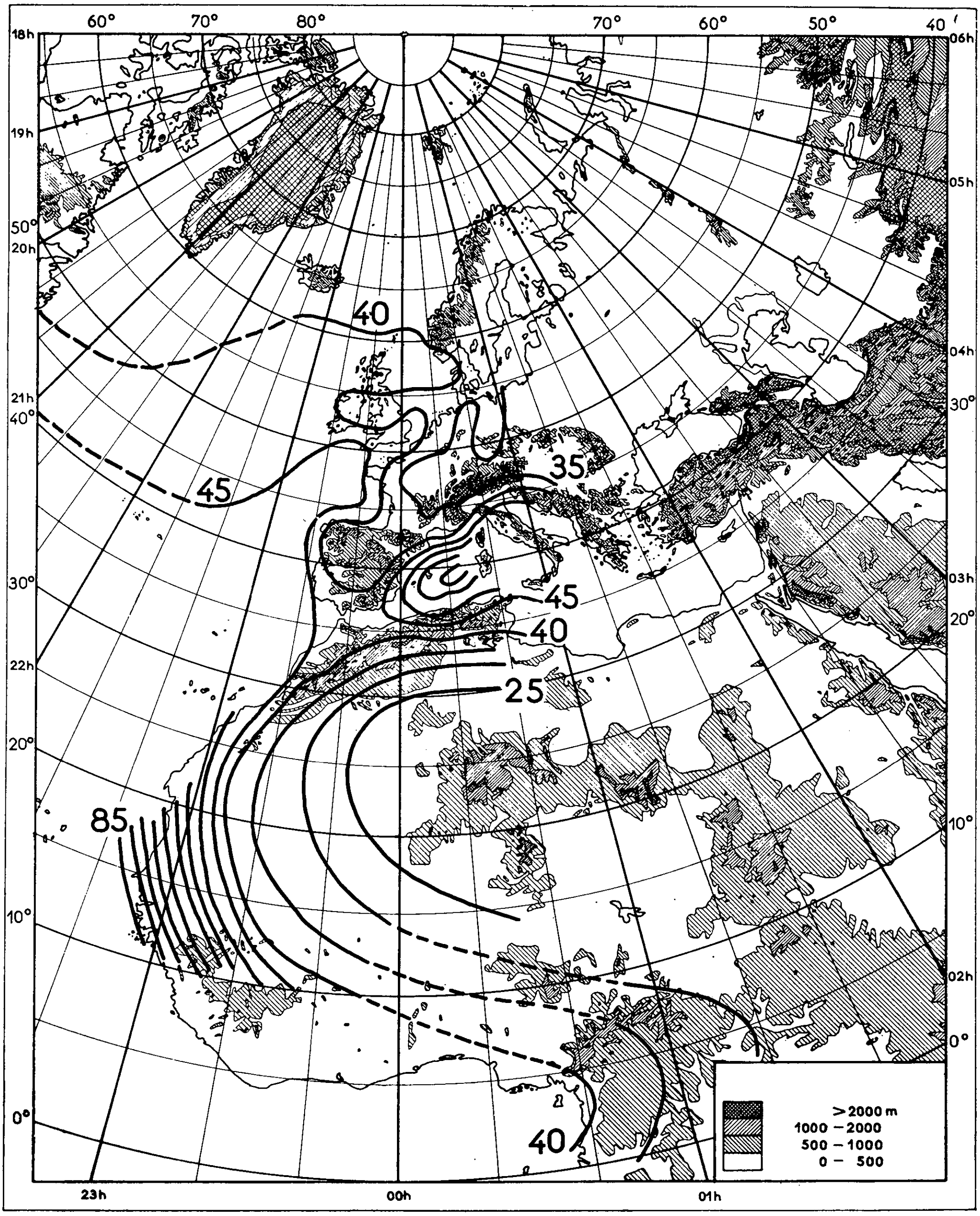

FIGURE 7

Iso —ΔN chart for the European-African sector for the month of May, 1400 hrs UT.

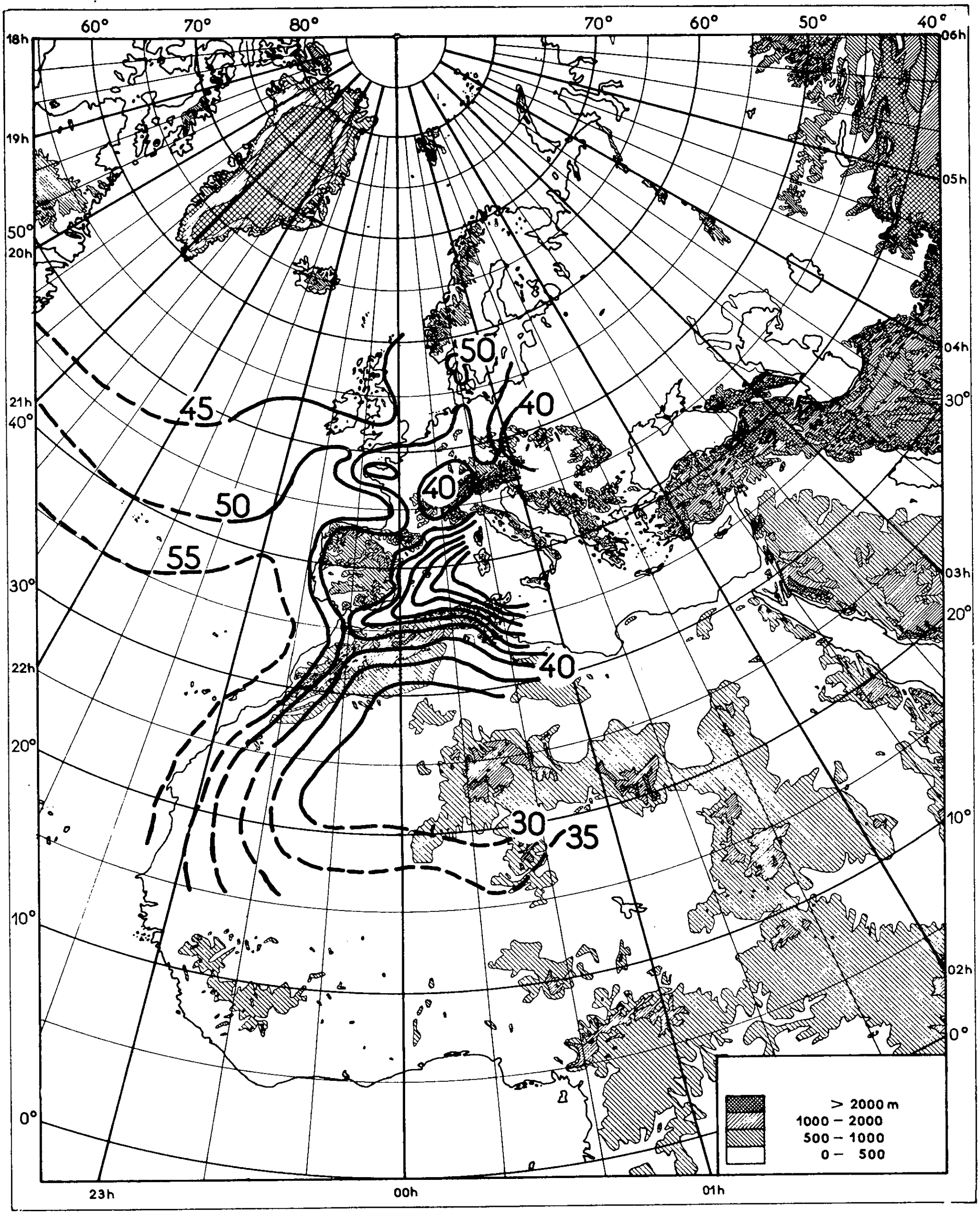

FIGURE 8

Iso —ΔN chart for the European-African sector for the month of August, 0200 hrs UT.

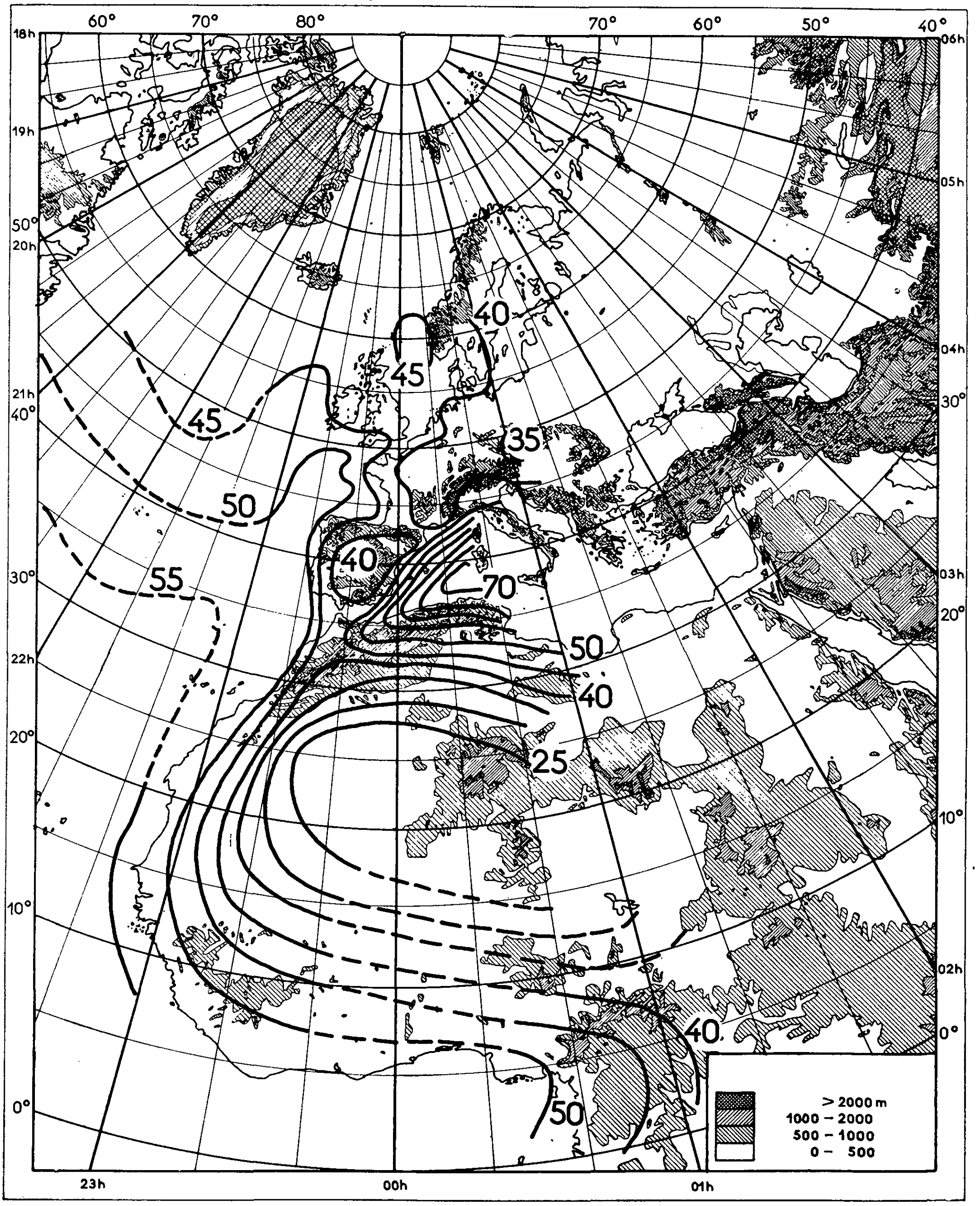

FIGURE 9

Iso —ΔN chart for the European-African sector for the month of August, 1400 hrs UT.

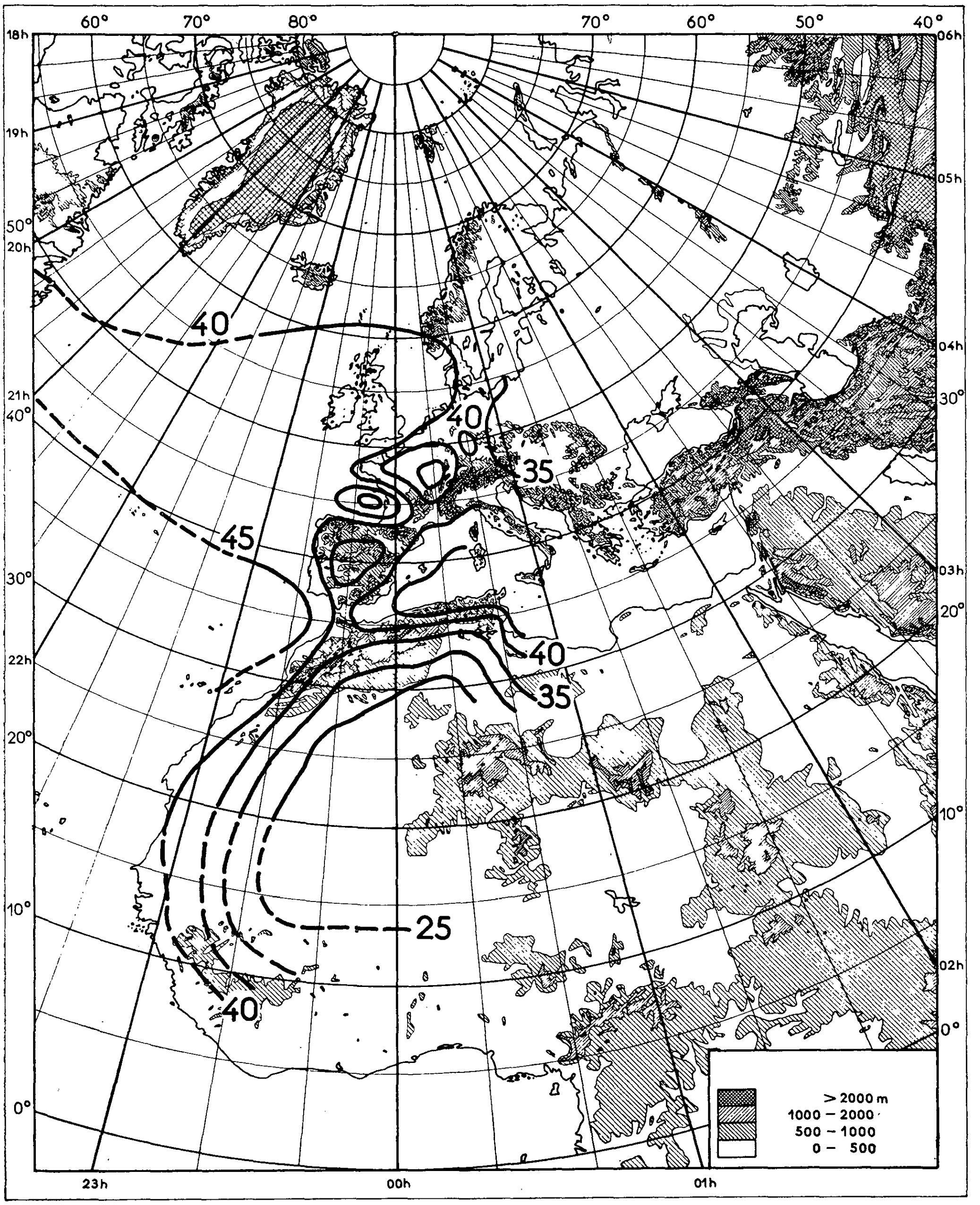

FIGURE 10

Iso —ΔN chart for the European-African sector for the month of November, 0200 hrs UT.

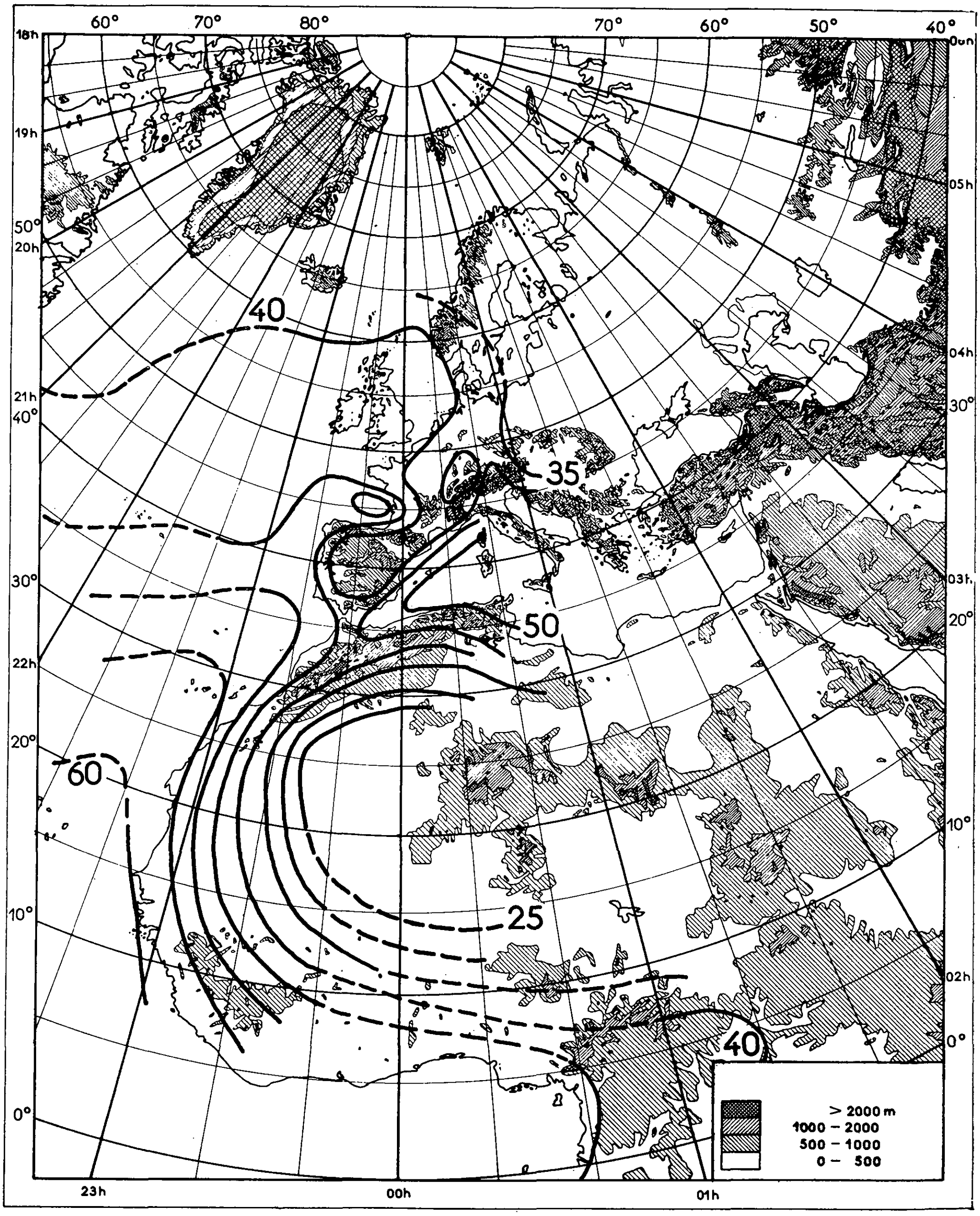

FIGURE 11

Iso —ΔN chart for the European-African sector for the month of November, 1400 hrs UT.

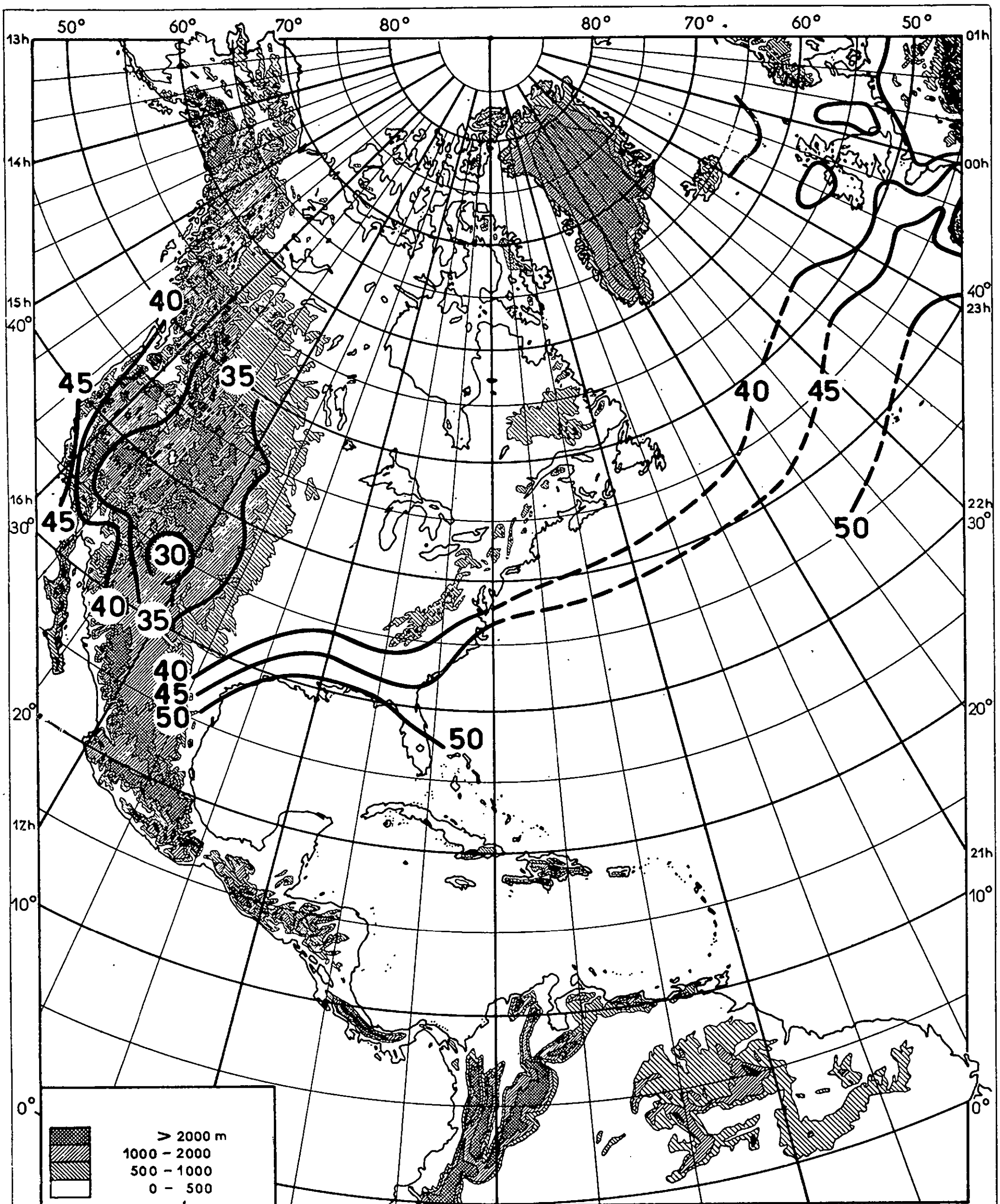

FIGURE 12

Iso —ΔN chart for the American sector for the month of February, 0300 hrs UT.

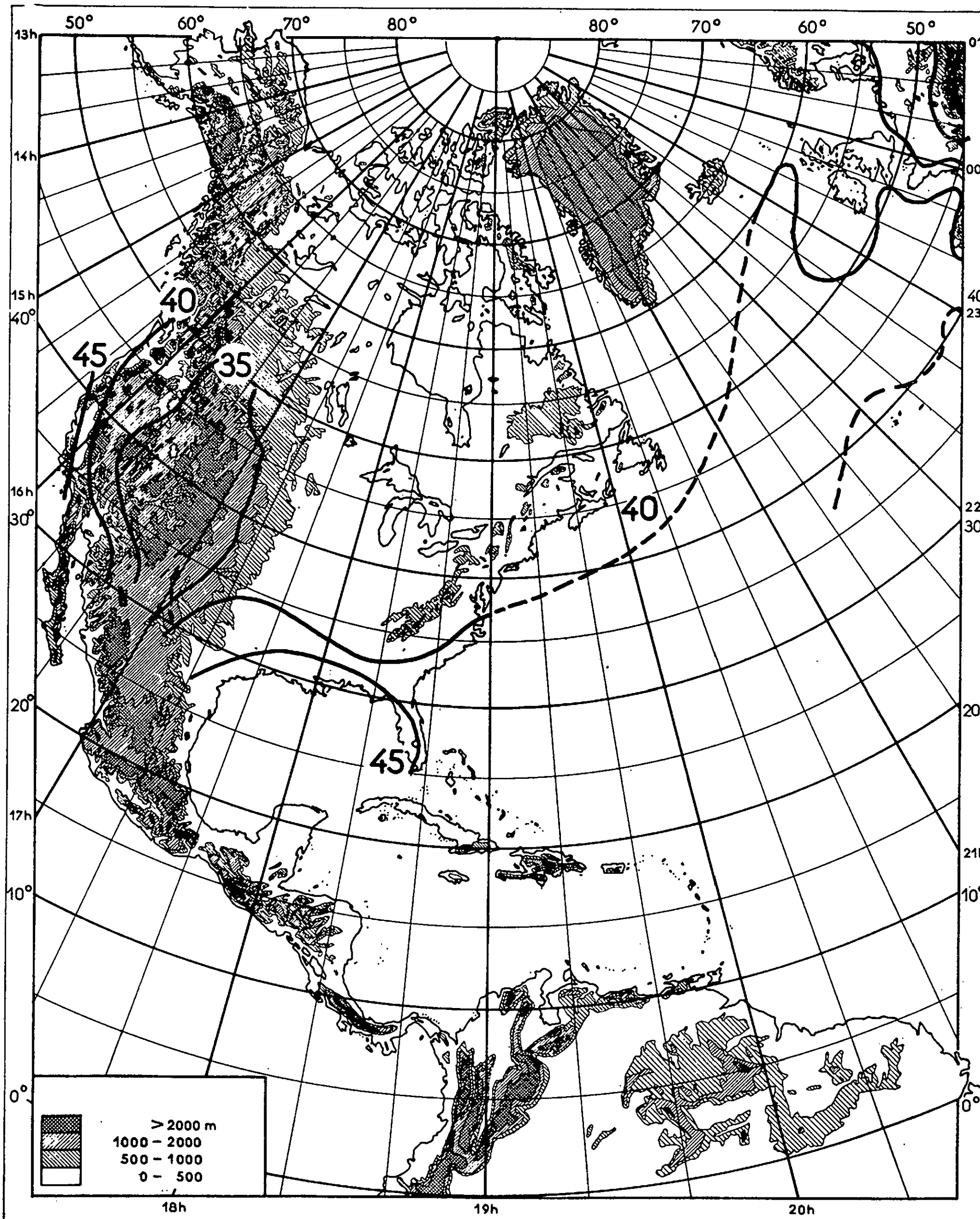

FIGURE 13

Iso —ΔN chart for the American sector for the month of February, 1500 hrs UT.

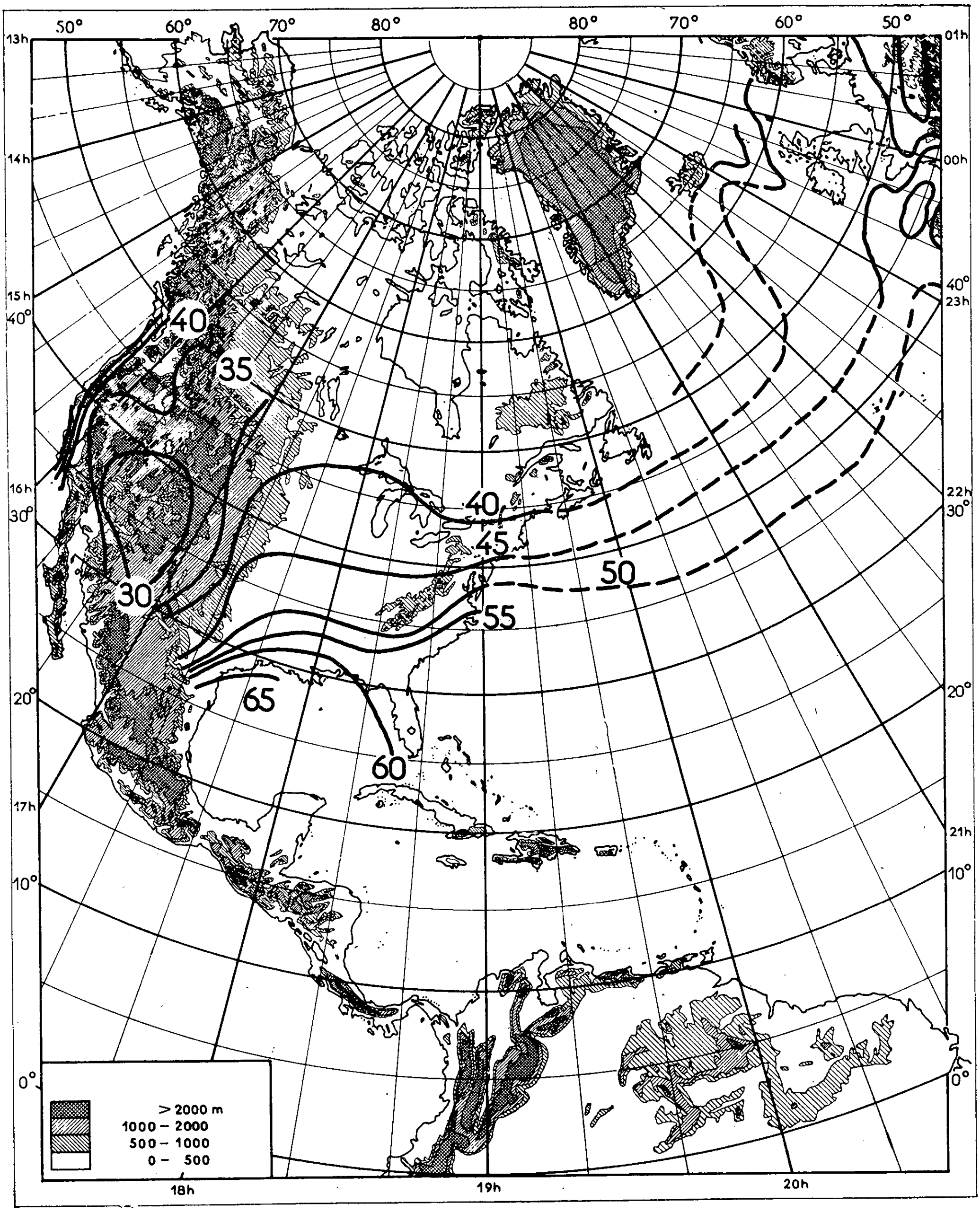

FIGURE 14

Iso —ΔN chart for the American sector for the month of May, 0300 hrs UT.

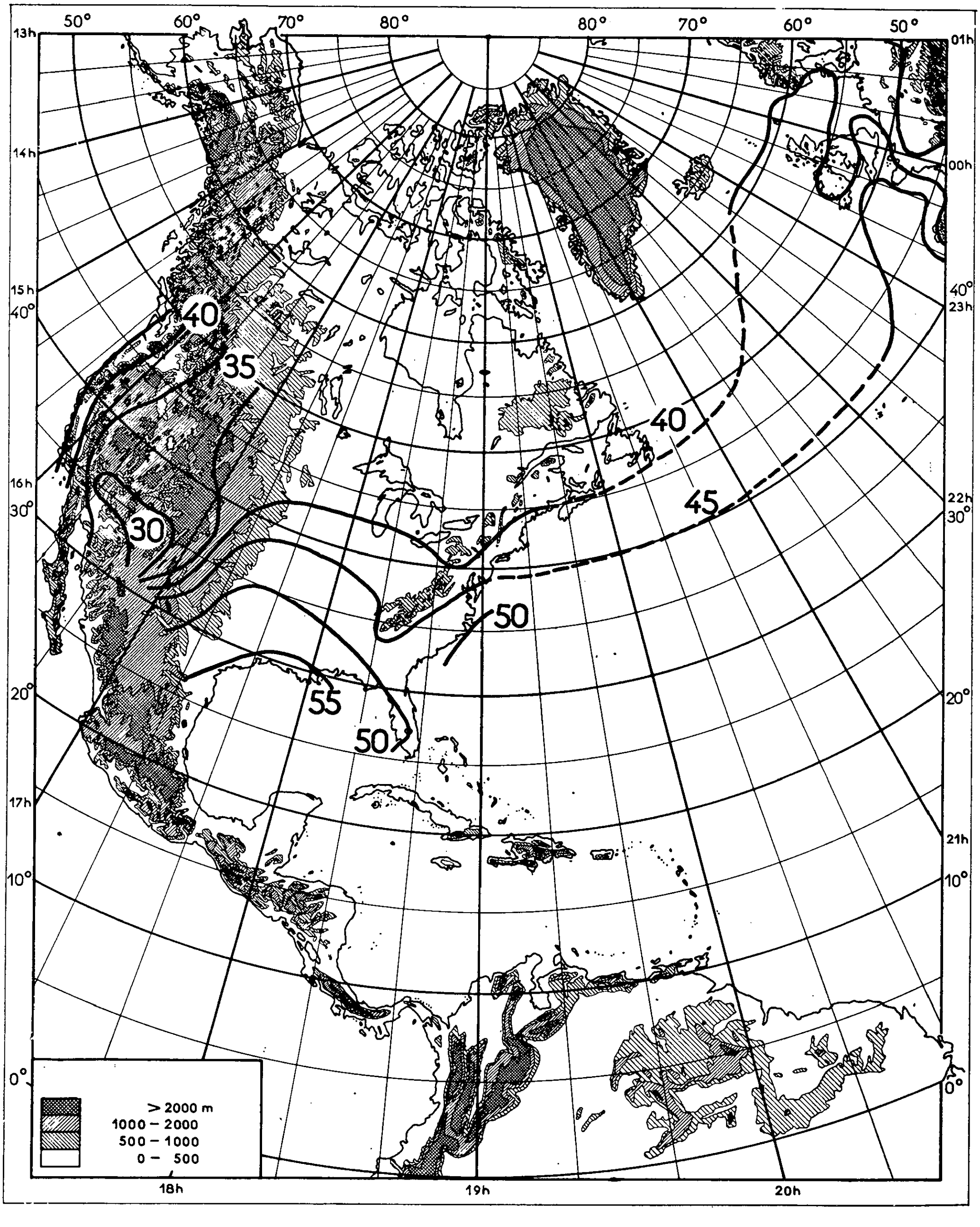

FIGURE 15

Iso —ΔN chart for the American sector for the month of May, 1500 hrs UT.

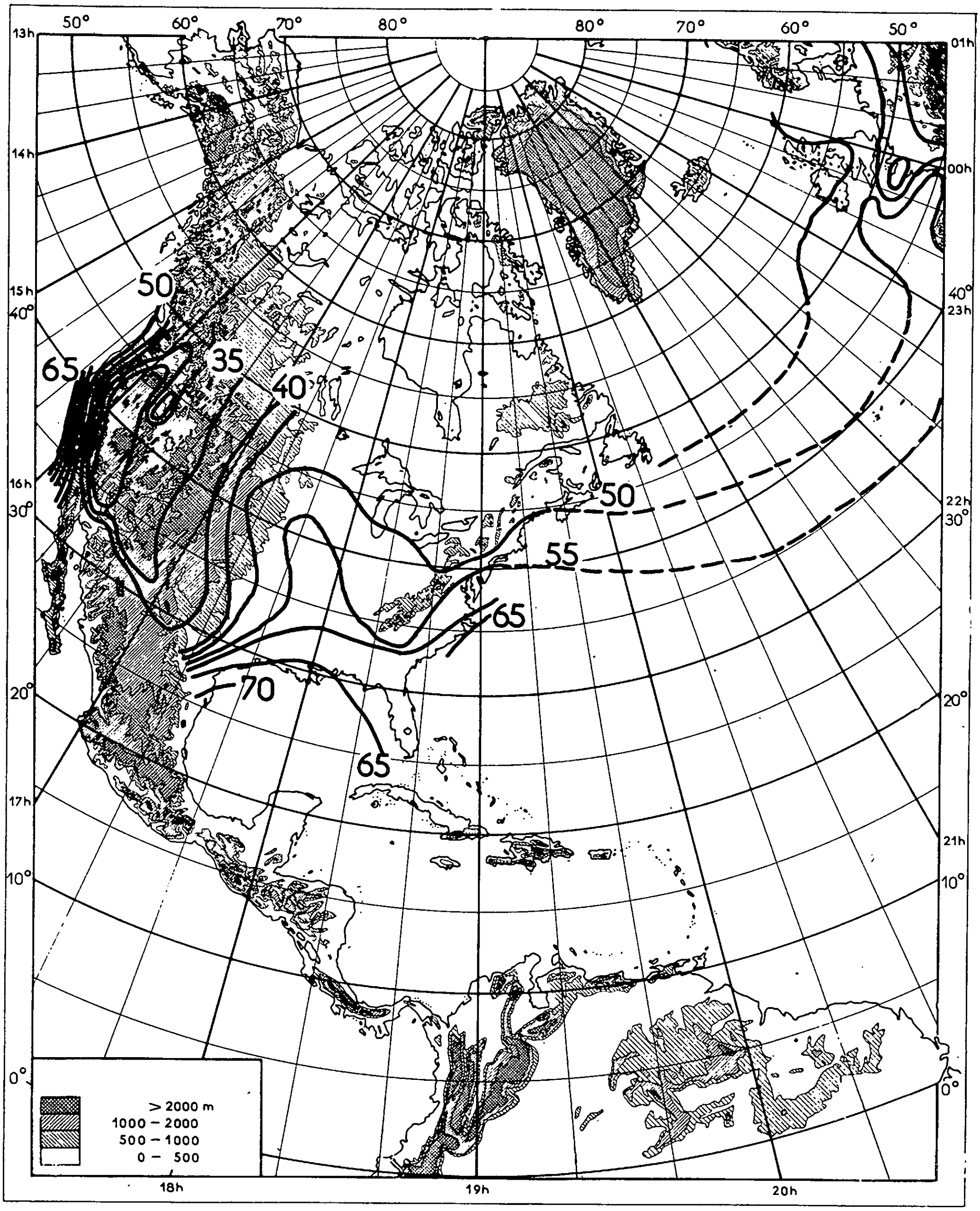

FIGURE 16

Iso —ΔN chart for the American sector for the month of August, 0300 hrs UT.

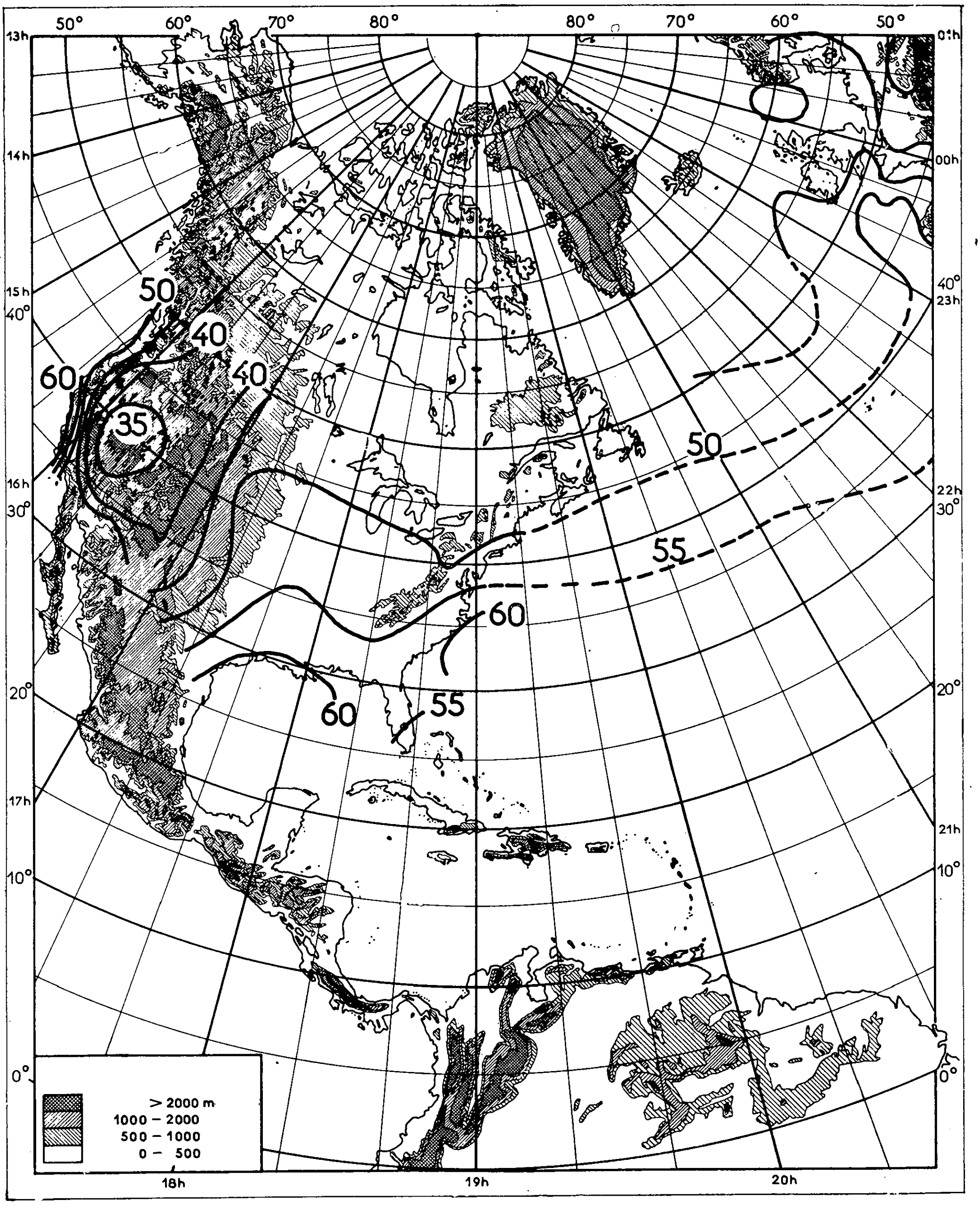

FIGURE 17

Iso —ΔN chart for the American sector for the month of August, 1500 hrs UT.

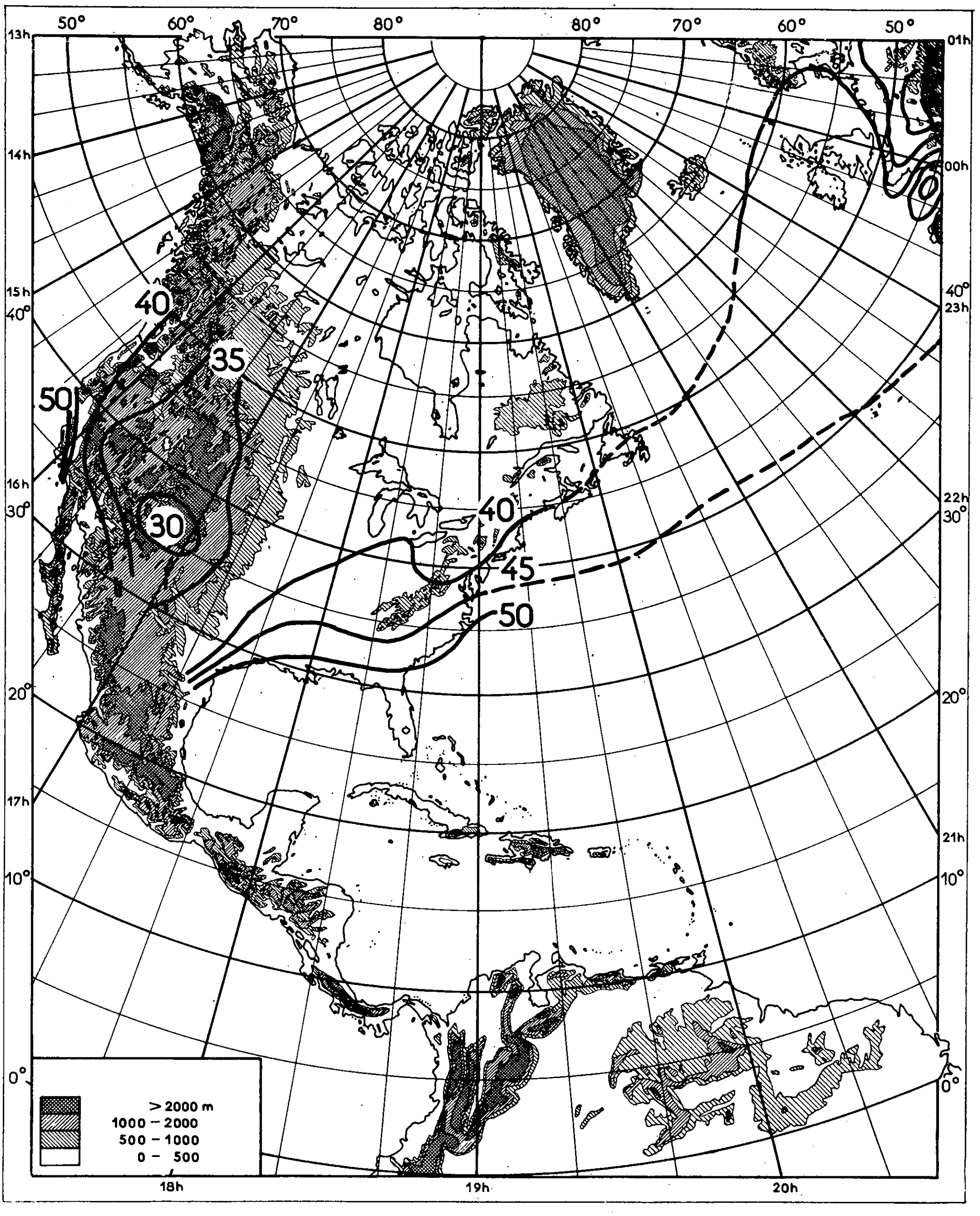

FIGURE 18

Iso —ΔN chart for the American sector for the month of November, 0300 hrs UT.

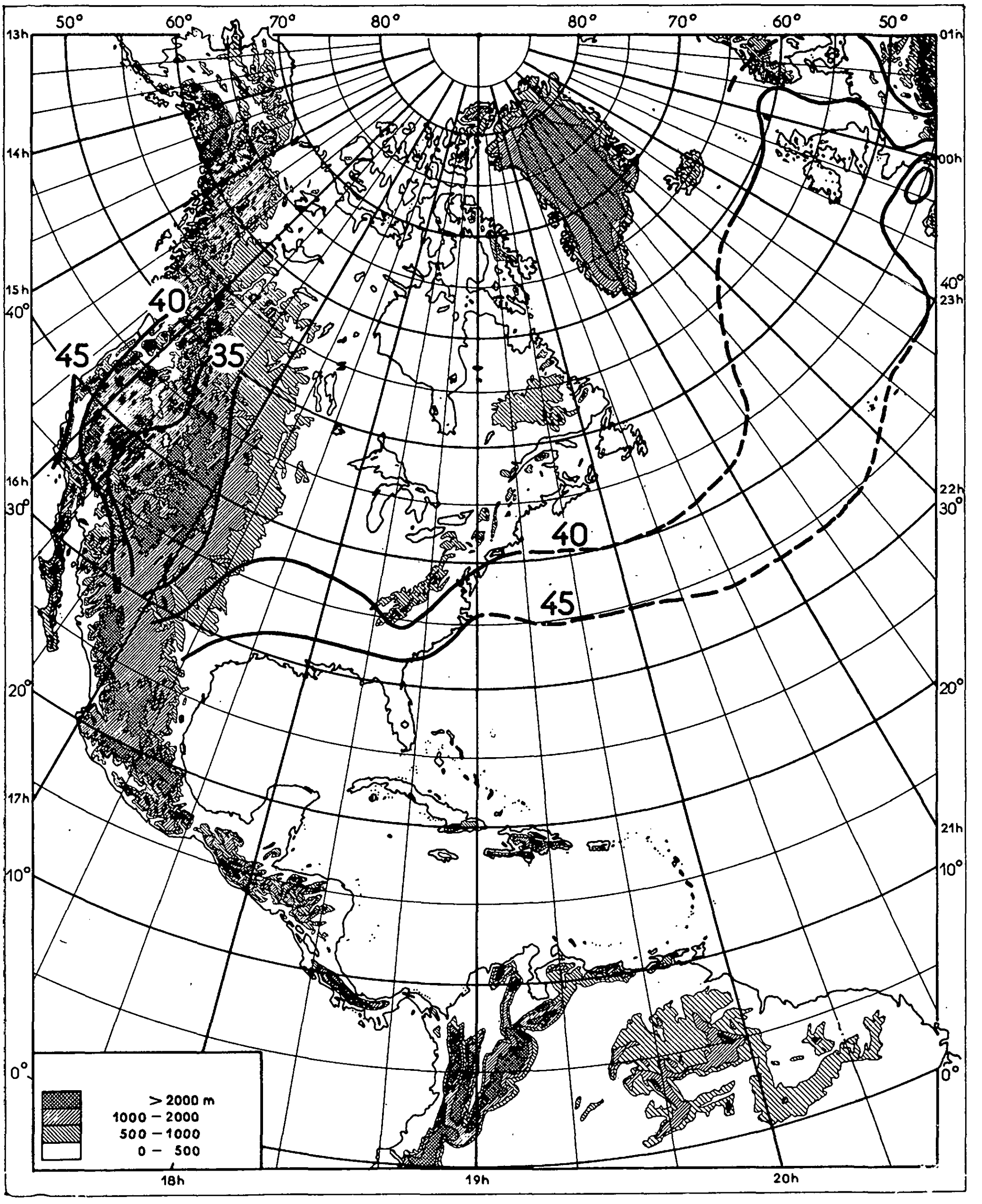

FIGURE 19

Iso —ΔN chart for the American sector for the month of November, 1500 hrs UT.

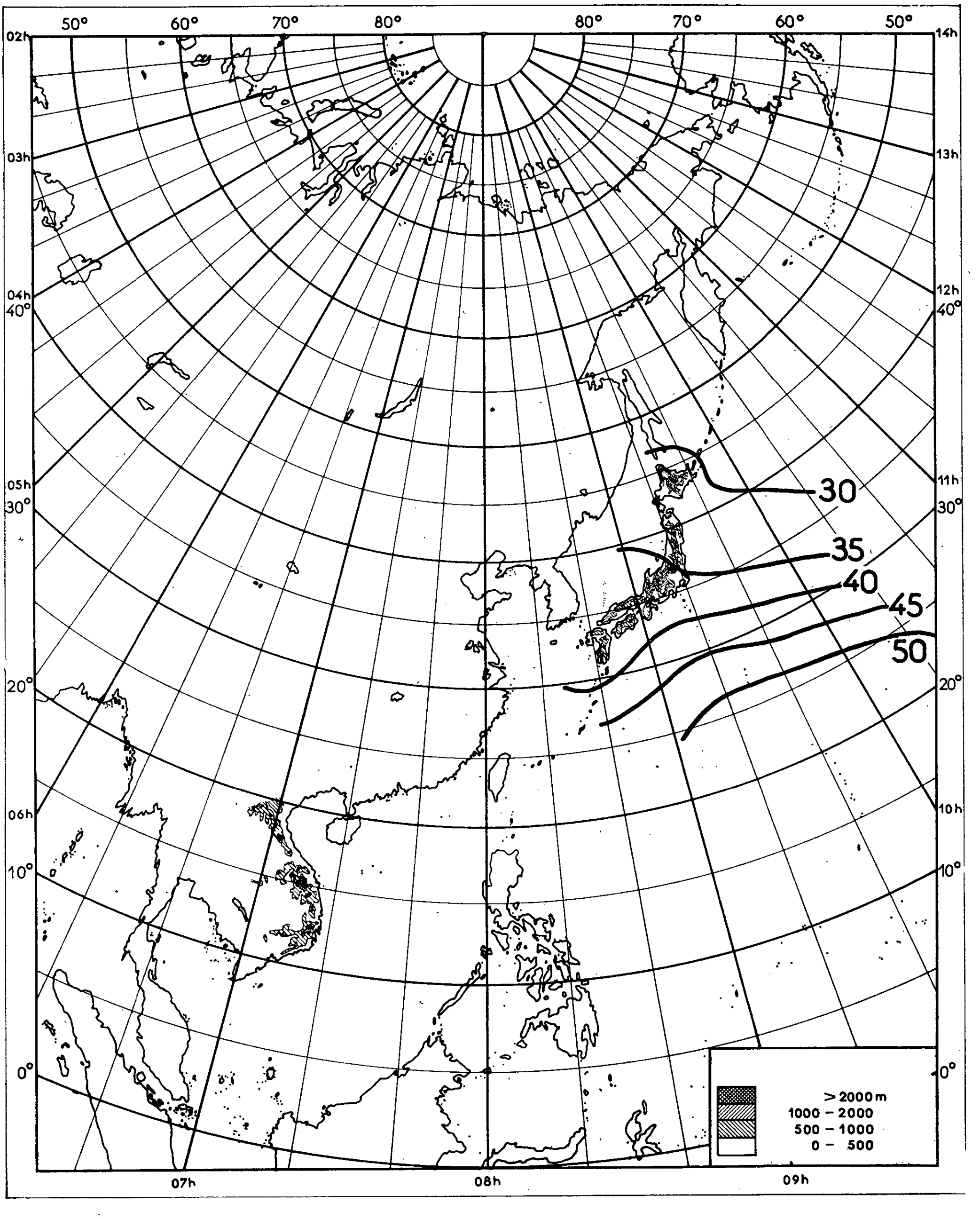

FIGURE 20

Iso —ΔN chart for the Pacific sector for the month of February, 0300 hrs UT.

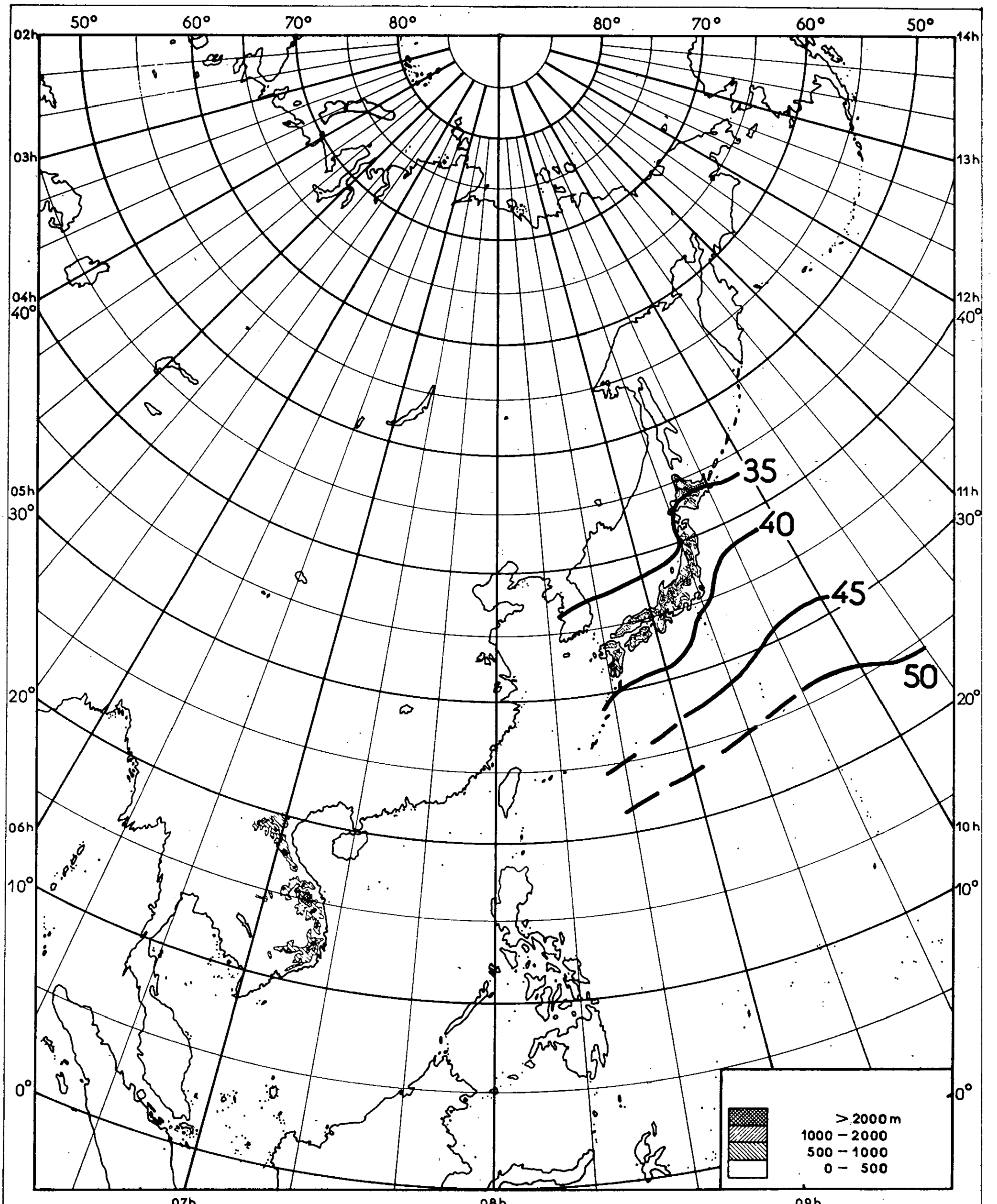

FIGURE 21

Iso —ΔN chart for the Pacific sector for the month of February, 1500 hrs UT.

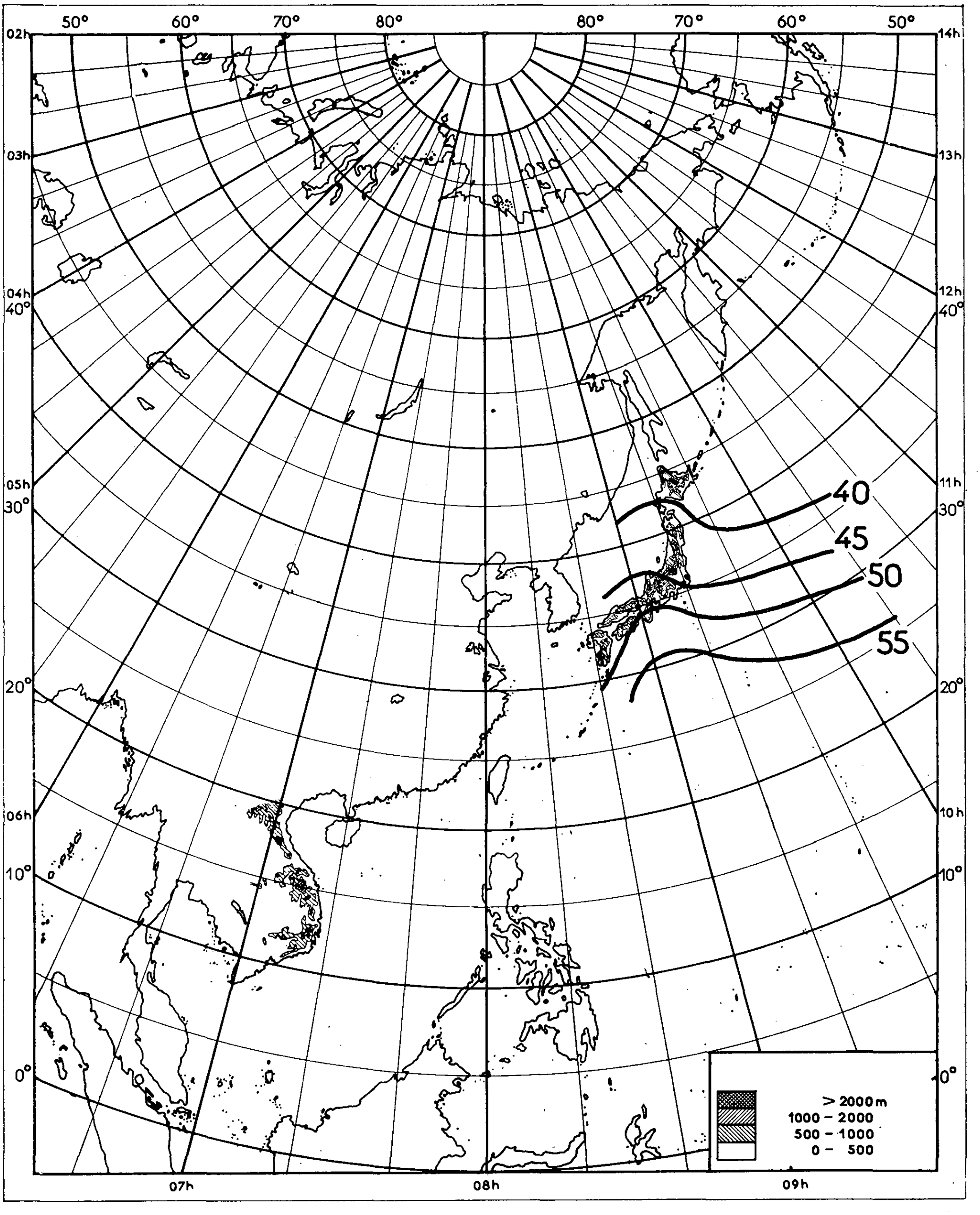

FIGURE 22

Iso —ΔN chart for the Pacific sector for the month of May, 0300 hrs UT.

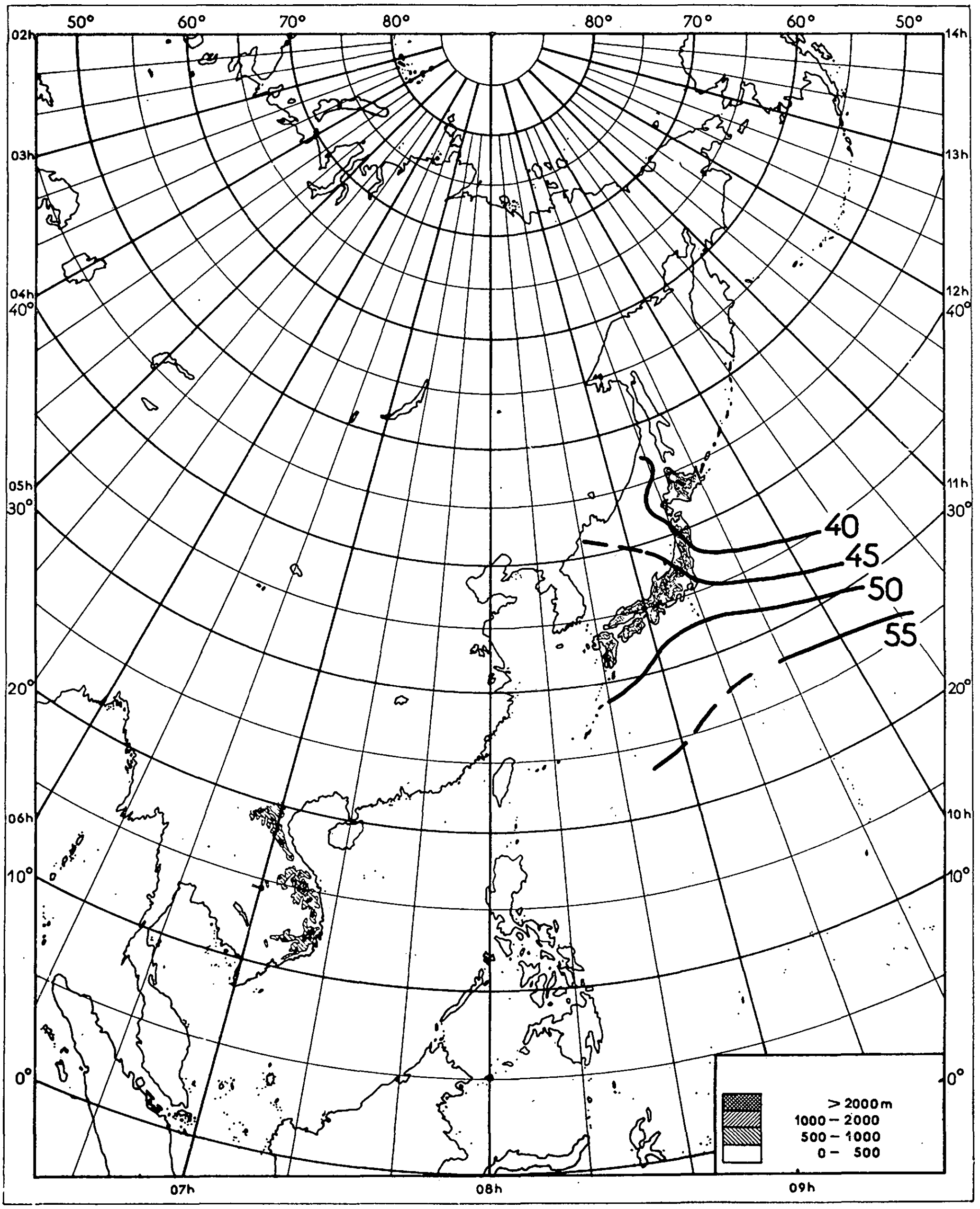

FIGURE 23

Iso —ΔN chart for the Pacific sector for the month of May, 1500 hrs UT.

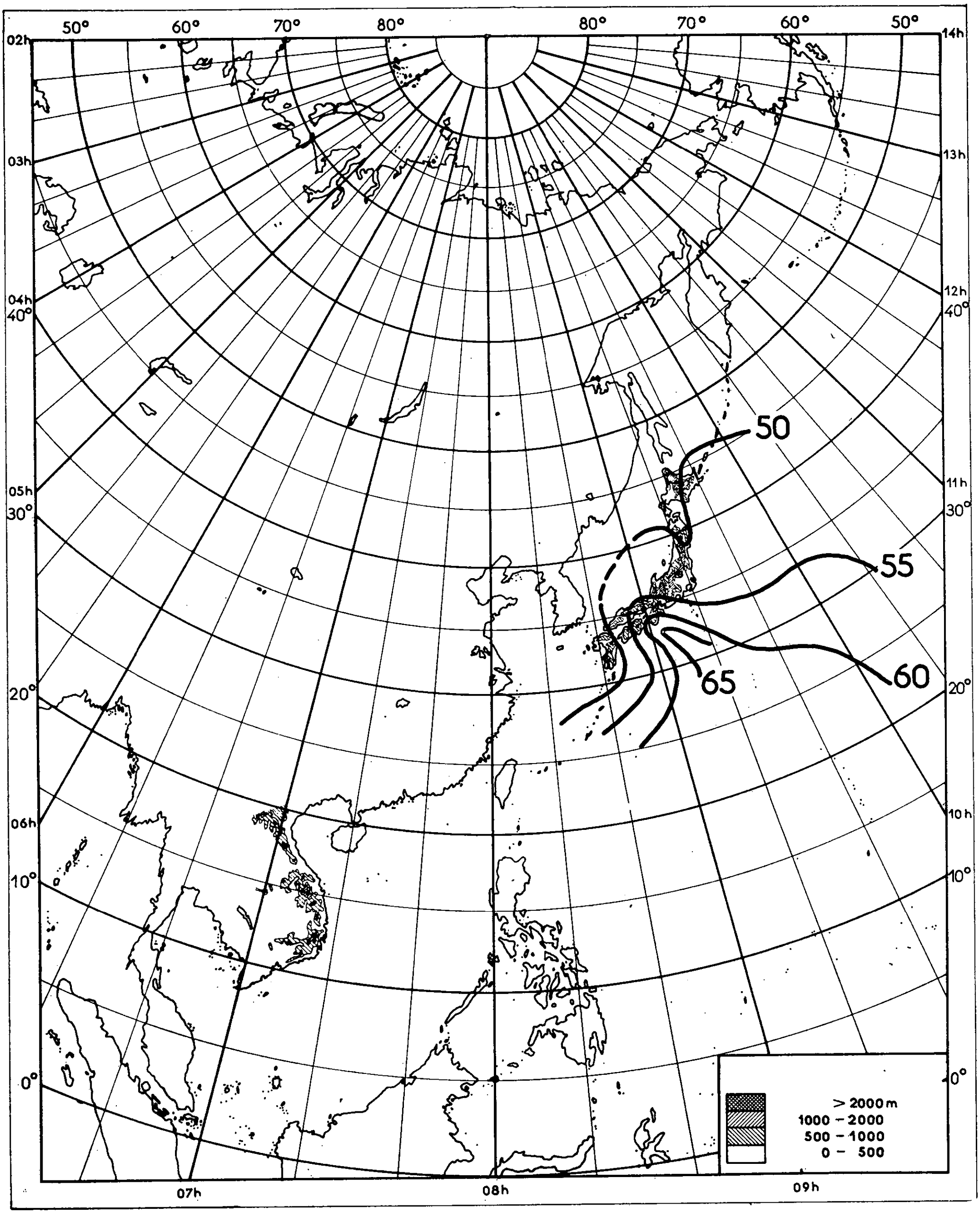

FIGURE 24

Iso —ΔN chart for the Pacific sector for the month of August, 0300 hrs UT.

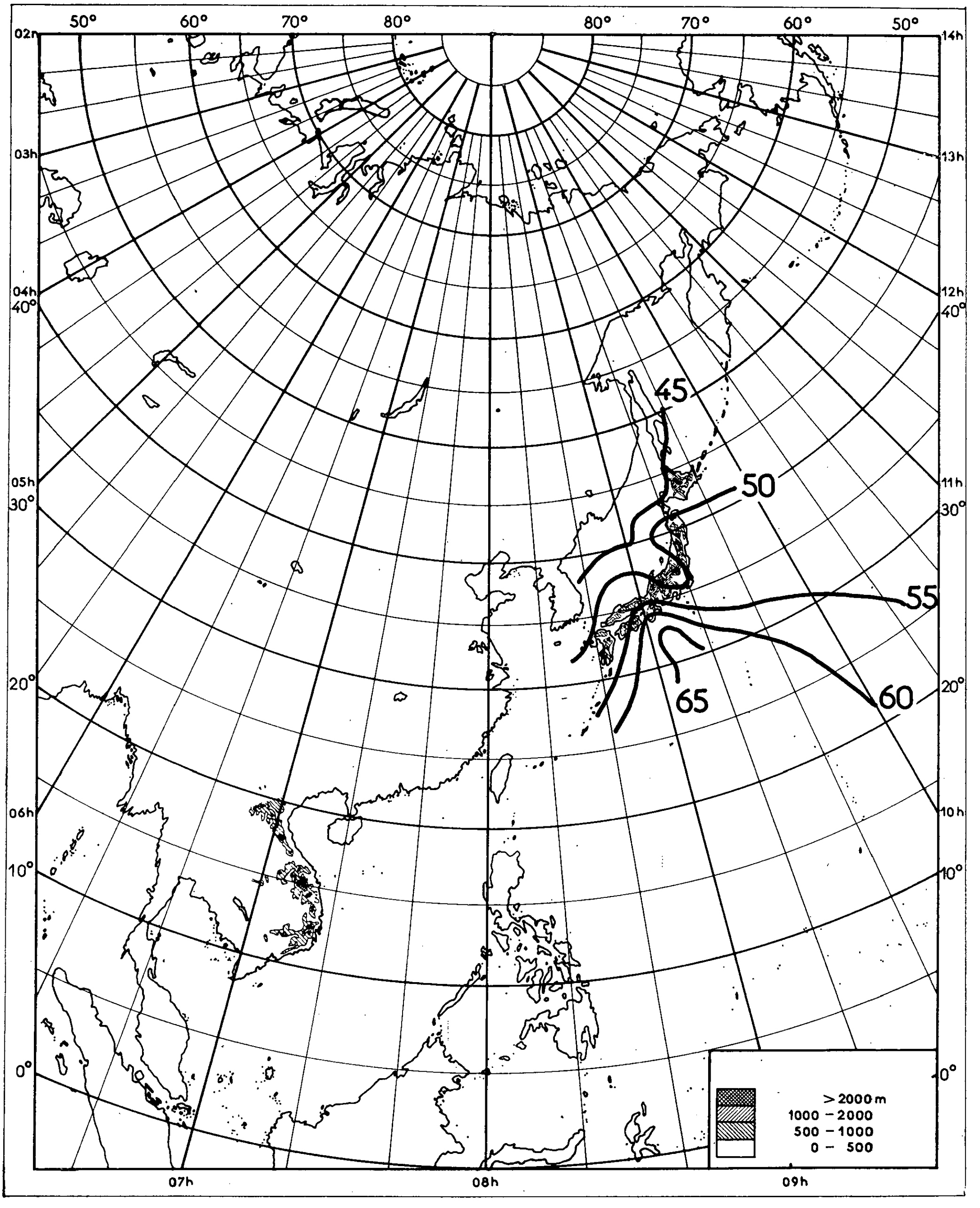

FIGURE 25

Iso —ΔN chart for the Pacific sector for the month of August, 1500 hrs UT.

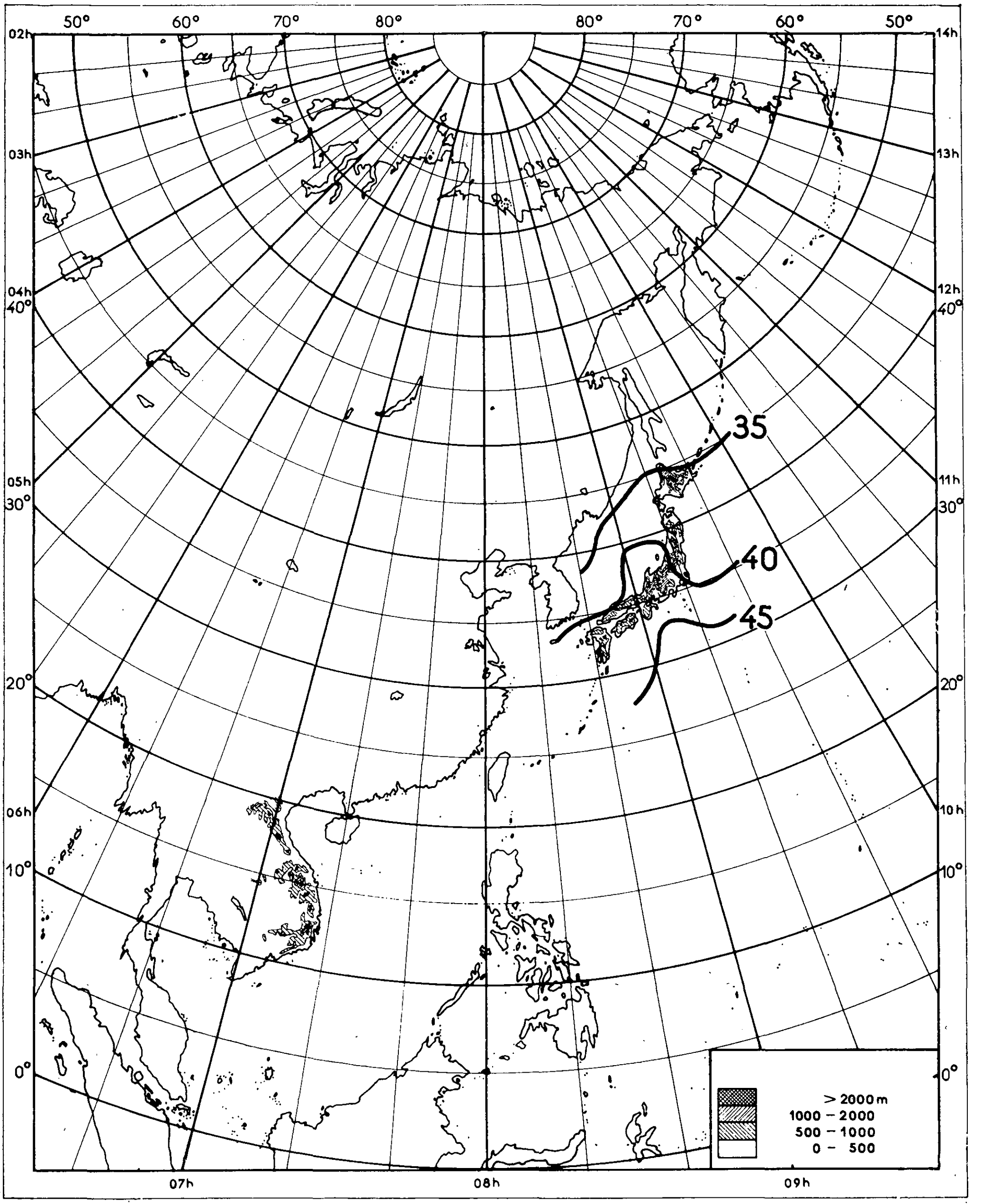

FIGURE 26

Iso —ΔN chart for the Pacific sector for the month of November, 0300 hrs UT.

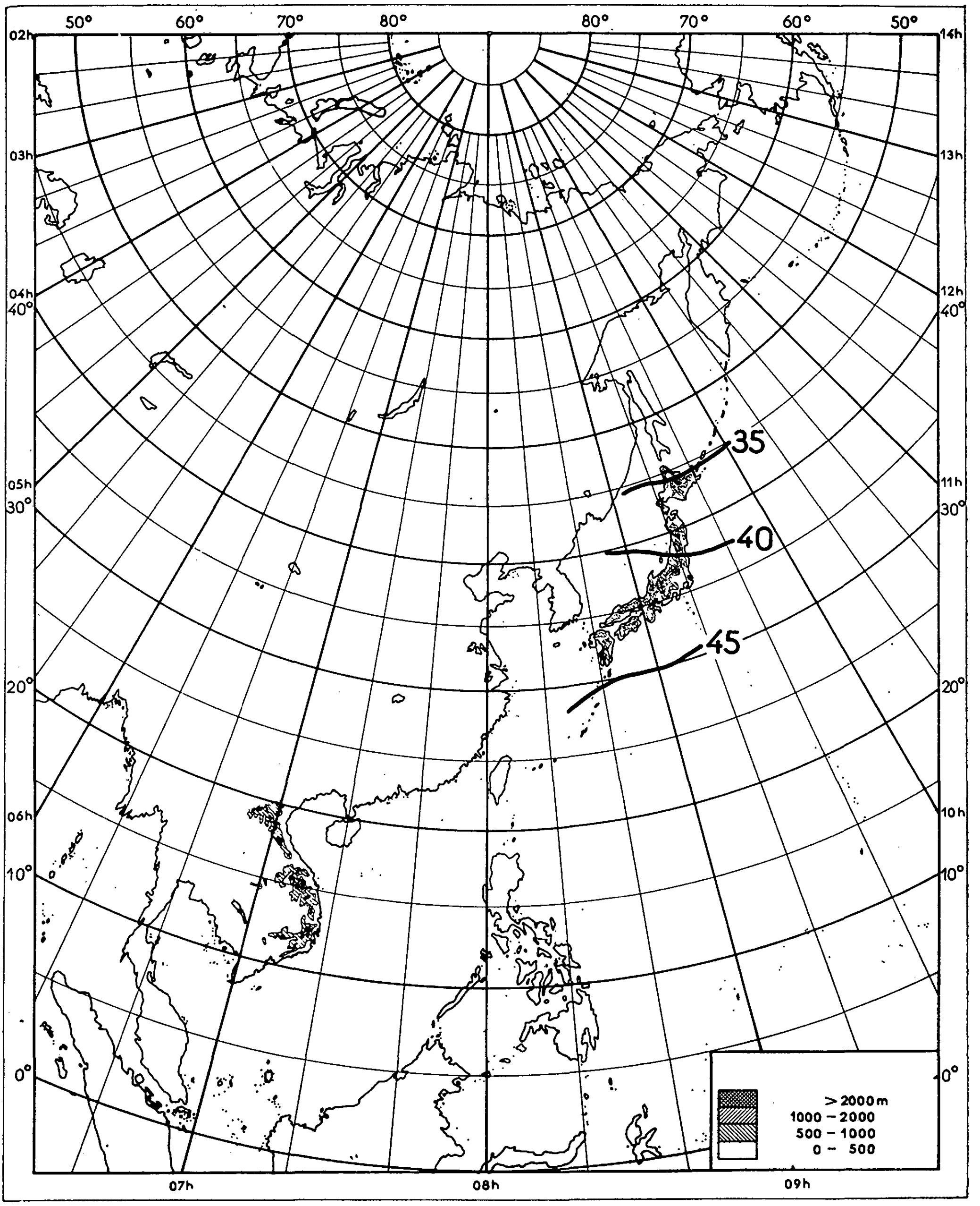

FIGURE 27

Iso —ΔN chart for the Pacific sector for the month of November, 1500 hrs UT.

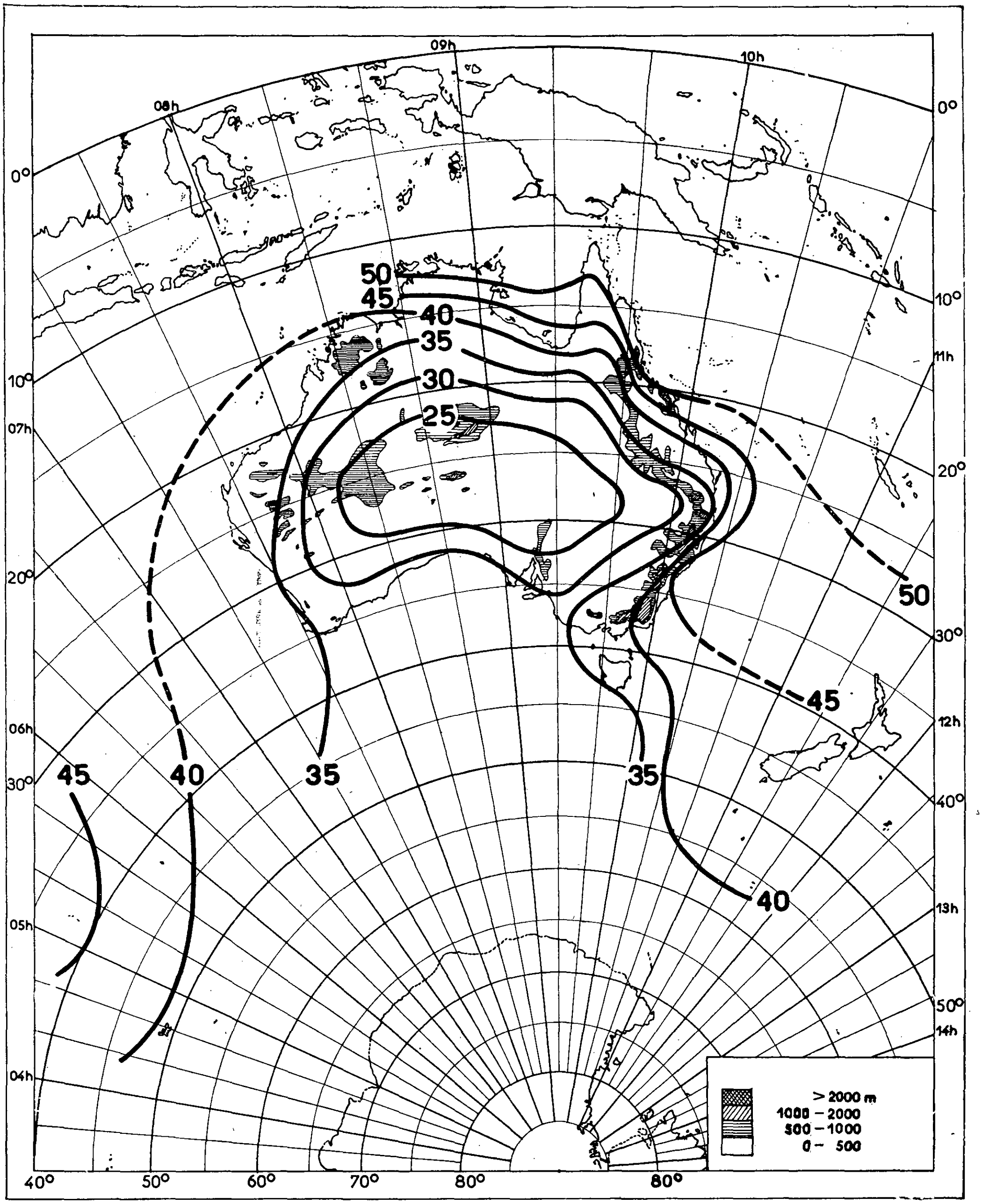

FIGURE 28

Iso —ΔN chart for the South Pacific sector for the month of February, 0400 hrs UT.

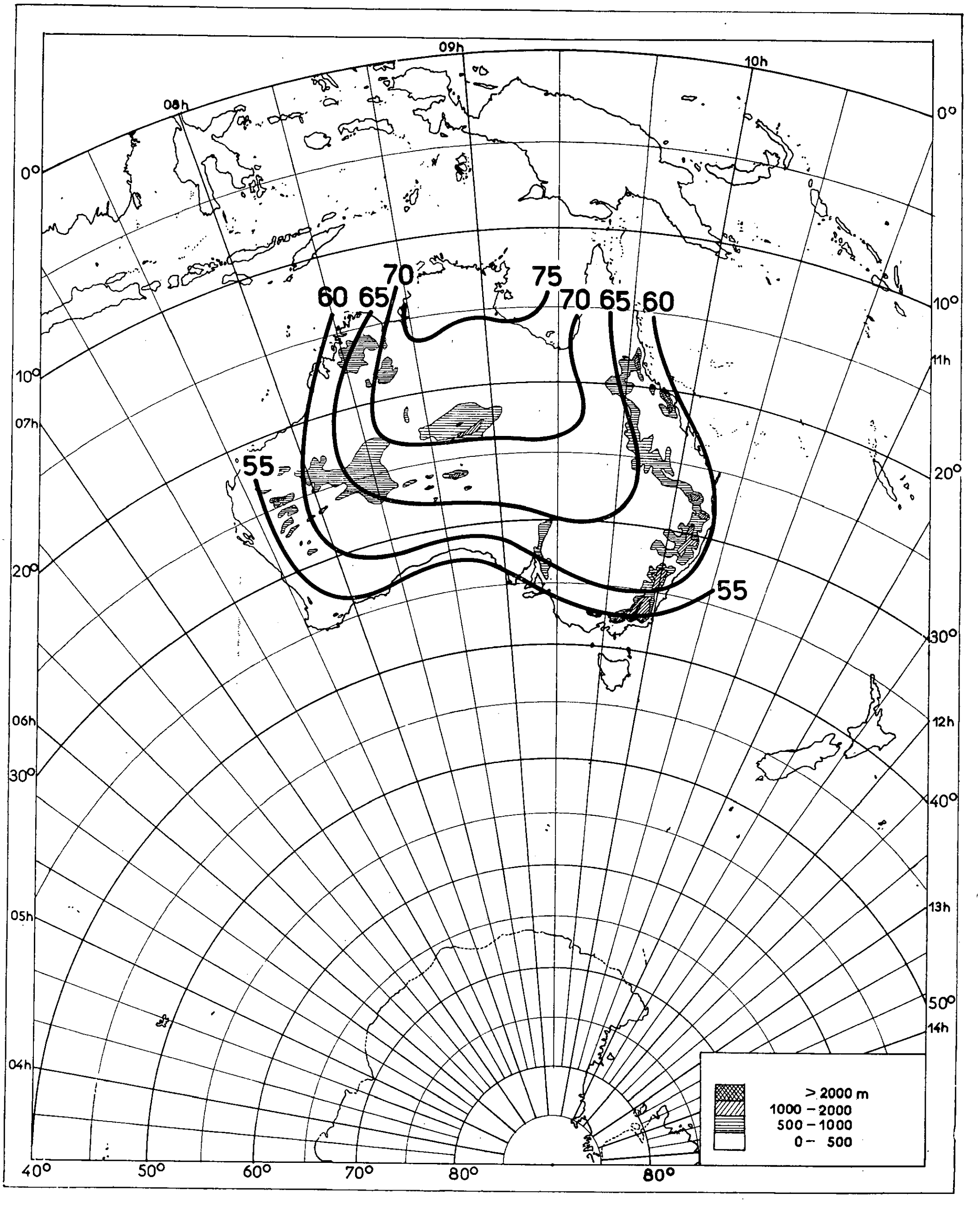

FIGURE 29

Iso —ΔN chart for the South Pacific sector for the month of February, 1600 hrs UT.

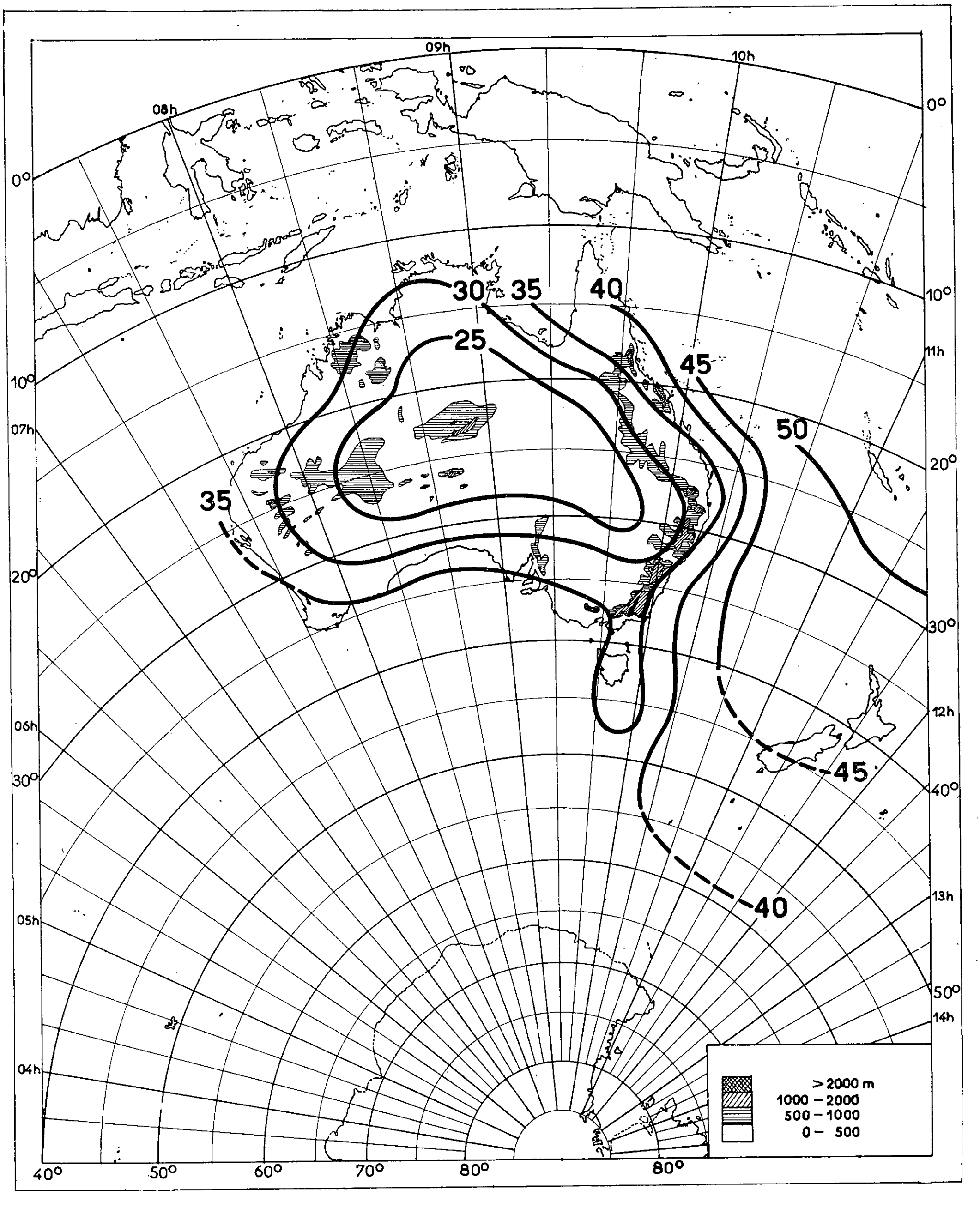

FIGURE 30

Iso —ΔN chart for the South Pacific sector for the month of May, 0400 hrs UT.

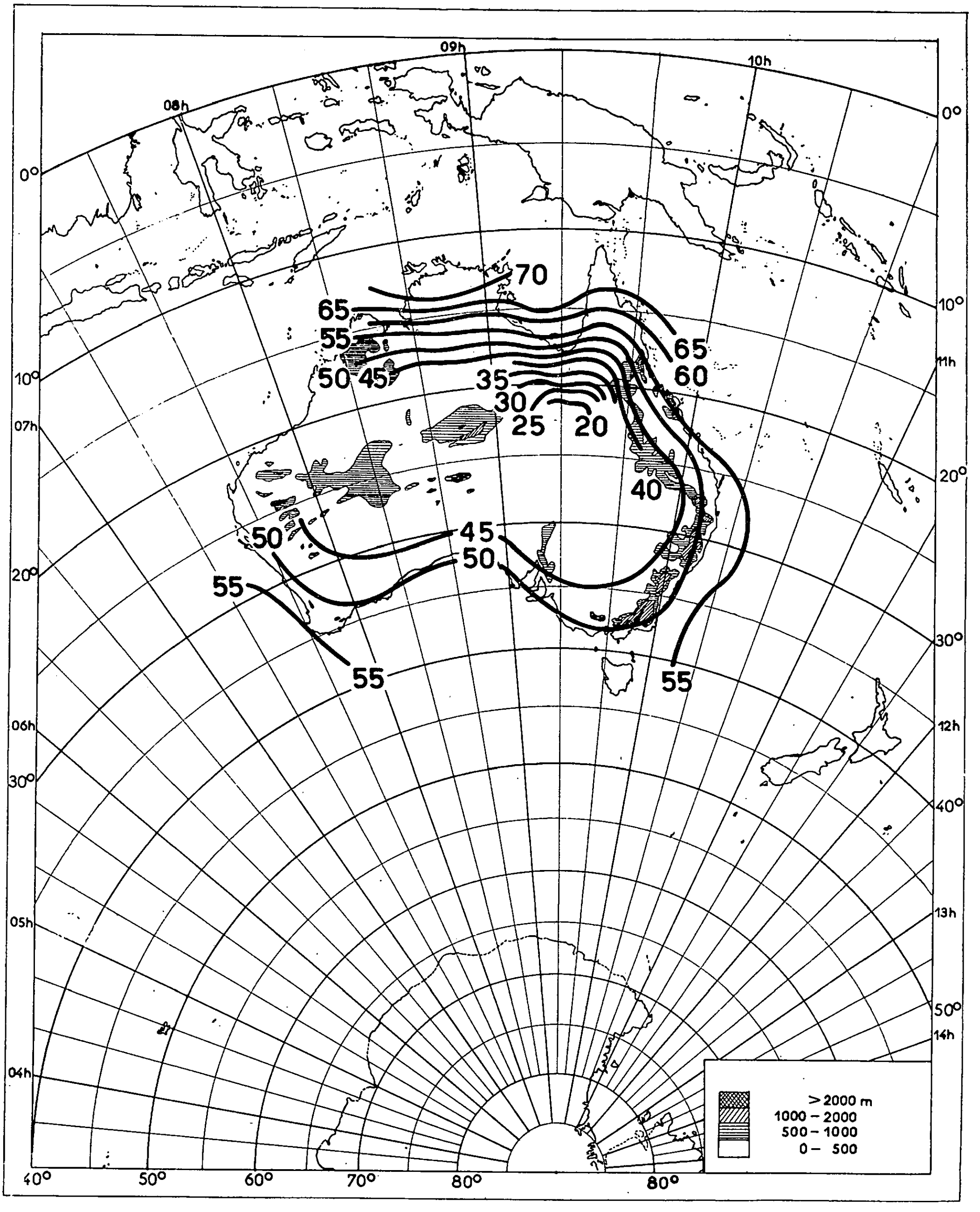

FIGURE 31

Iso —ΔN chart of the South Pacific sector for the month of May, 1600 hrs UT.

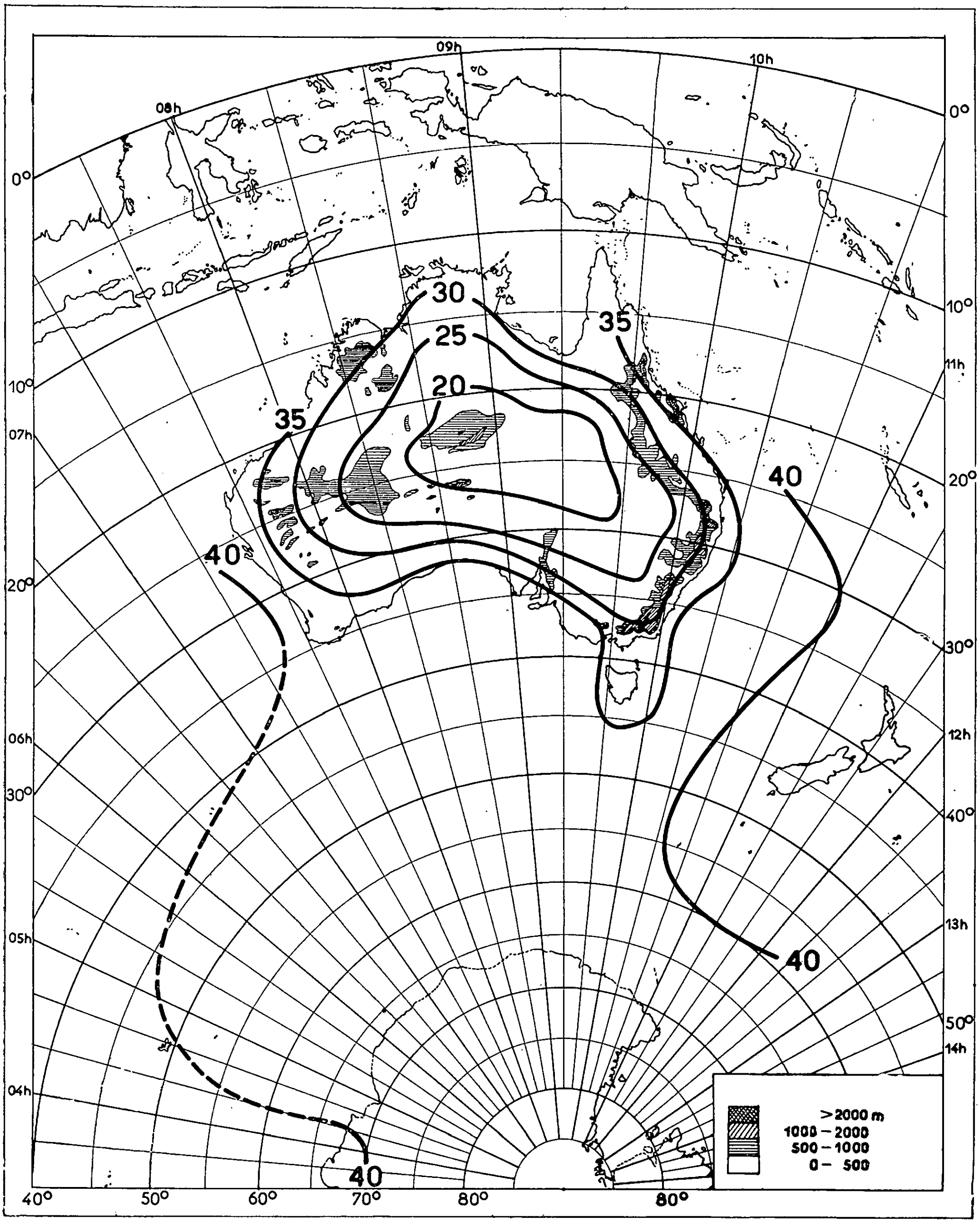

FIGURE 32

Iso —ΔN chart for the South Pacific sector for the month of August, 0400 hrs UT.

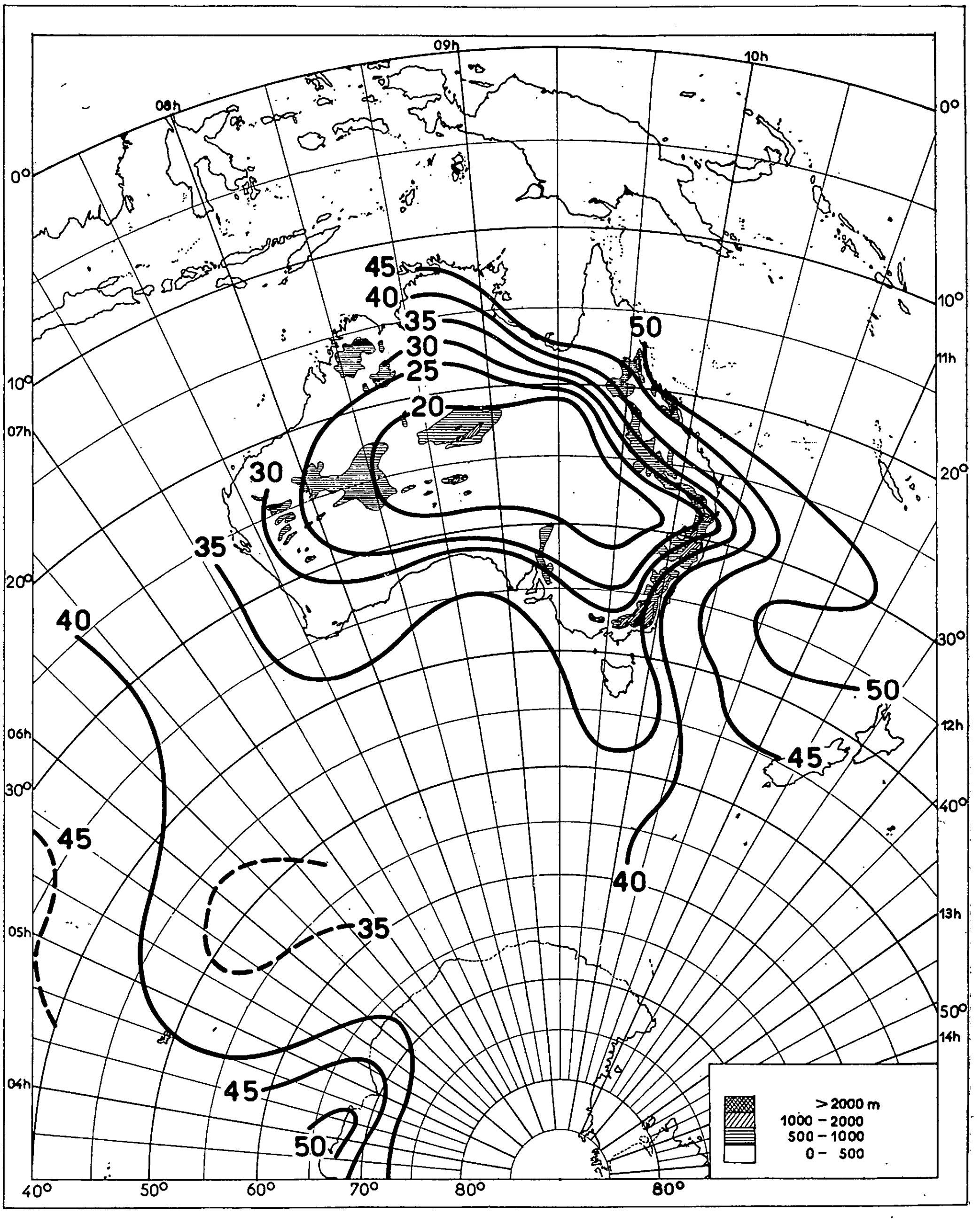

FIGURE 33

Iso —ΔN chart for the South Pacific sector for the month of August, 1600 hrs UT.

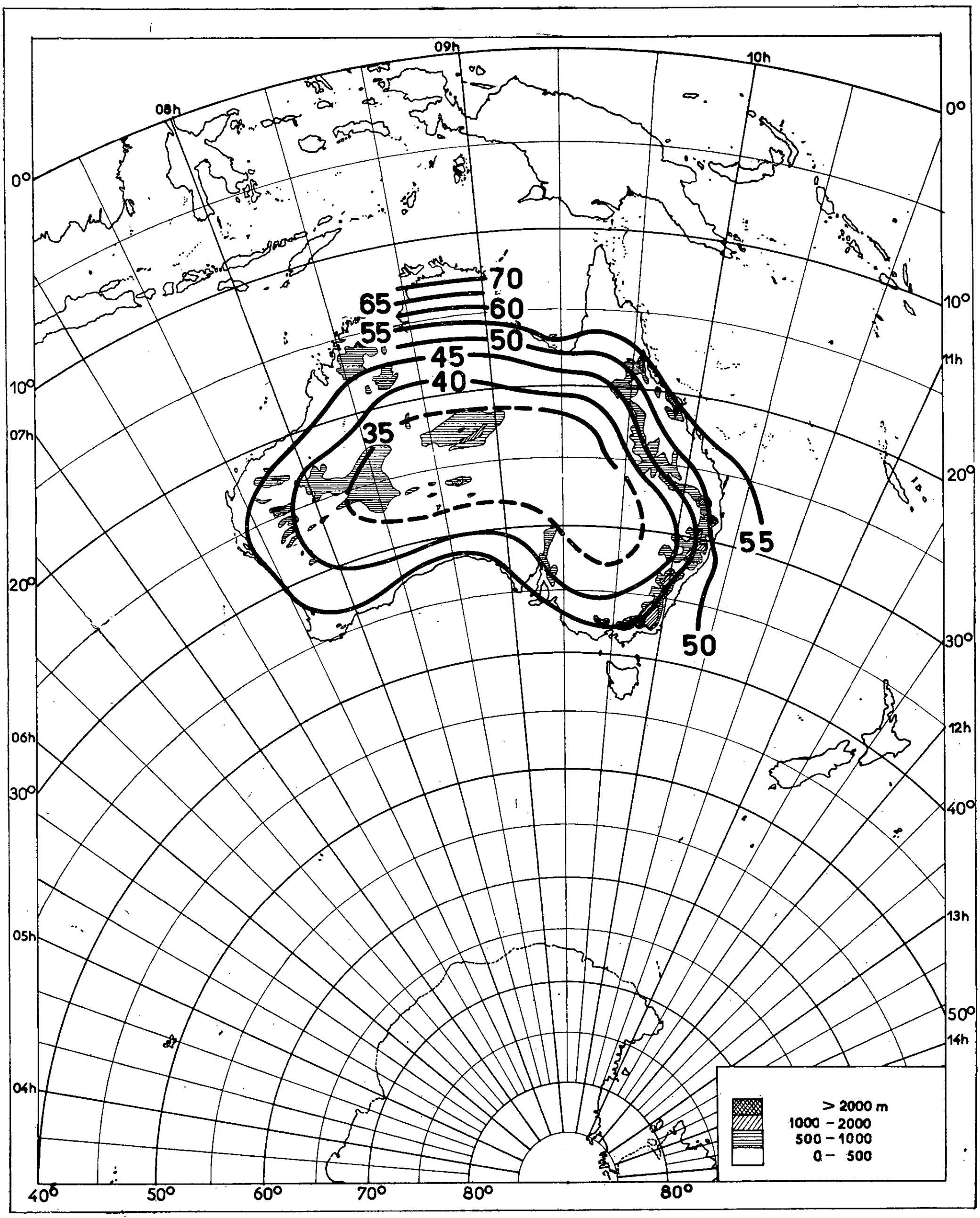

FIGURE 34

Iso —ΔN chart for the South Pacific sector for the month of November, 0400 hrs UT.

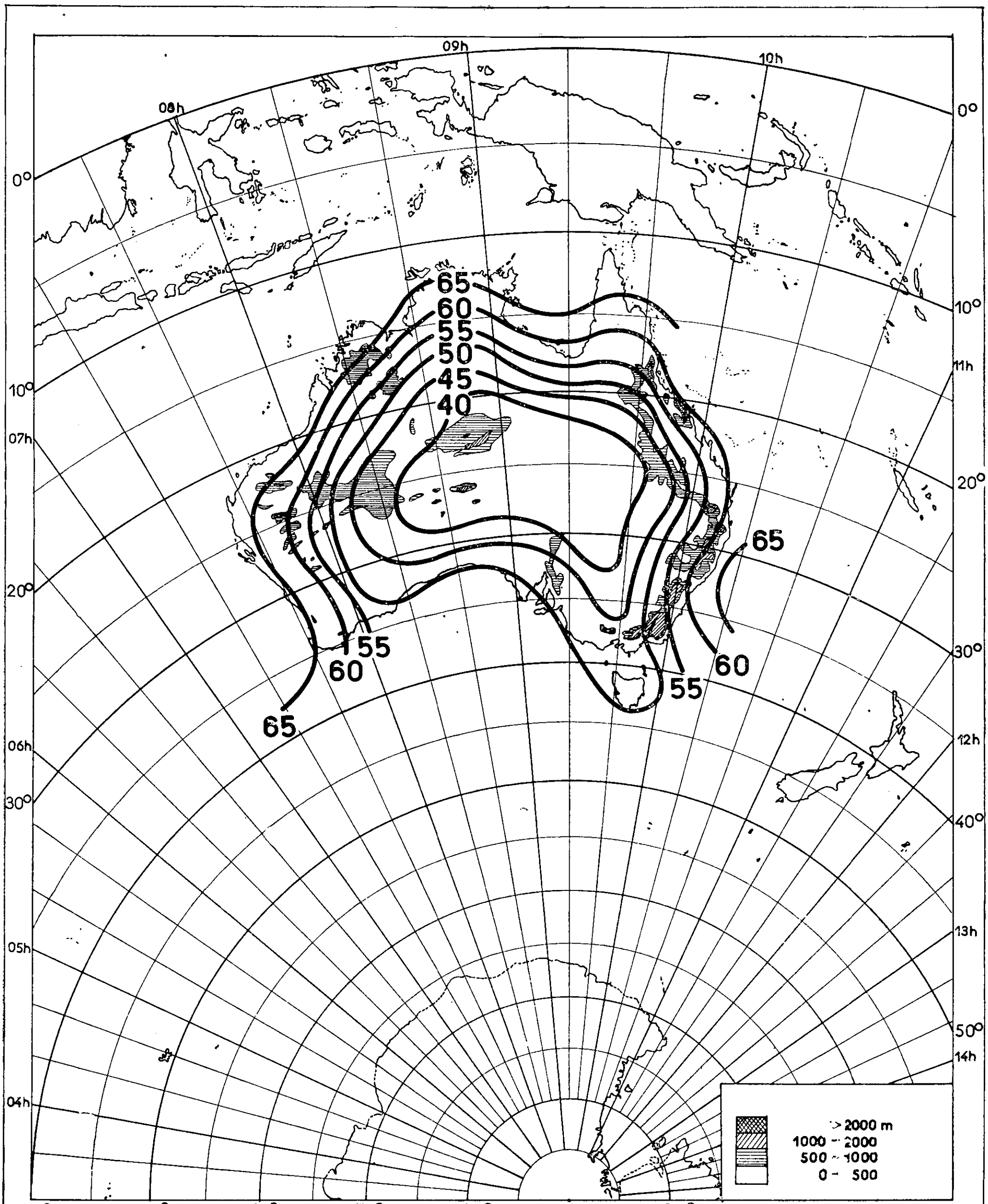

FIGURE 35

Iso —ΔN chart for the South Pacific sector for the month of November, 1600 hrs UT.

REPORT 234 *

INFLUENCE OF THE NON-IONIZED REGIONS OF THE ATMOSPHERE ON THE PROPAGATION OF WAVES

(Study Programmes 191(V) and 192(V))

(Geneva, 1963)

1. Introduction

At the Interim Meeting of Study Group V, Geneva, 1962, the attention of the International Working Party established by Report 146, was drawn to the problem of the influence of non-ionized regions of the atmosphere in earth-space wave propagation. The Working Party was re-established under Resolution 2, and is continuing its work.

The following is a preliminary report on some aspects of this subject.

2. Refraction

Published information concerning the ray-bending of electro-magnetic waves as they pass through the atmosphere is not extensive. Measurements using radar techniques have been described [1, 2]. Measurements using a radiometer to observe the apparent position of the sun are also described [3] and observations of the variability of refraction have been made using phase techniques [4].

Analytical studies of refraction, considering measurements made by the Weather Bureau of the variations of refractive index with altitude [5], have been made and these have been studied as a function of the surface values of the refractive index N_s. In [6] and [7], it has been shown that N_s is a good parameter to use for predicting refraction through the atmosphere. There has, however, been some doubt expressed as to the applicability of N_s to equatorial regions [8]. The equivalent gradient may also be employed to determine bending, but the computation of this parameter is difficult, because a knowledge of the variation of refractive index with altitude is required.

3. Absorption

3.1 Oxygen, water vapour, rain and clouds are known to absorb radio waves for frequencies above 100 Mc/s [9 to 22 inclusive].

Water vapour absorption has a resonant peak at the frequency 22·23 Gc/s, and oxygen absorption has peaks at 60 Gc/s and 120 Gc/s. Fig. 1, derived from an appraisal of the above work, shows the absorption γ_{oo} and γ_{wo} in db/km for both oxygen and water vapour, as determined for standard conditions of temperature and pressure and for a surface value of absolute humidity equal to 10 gm/m³*. For the range of absolute humidity likely to occur in the atmosphere, the absorption in db/km is approximately proportional to the quantity of water vapour. The total gaseous absorption A_a, over a line-of-sight path may be given by:

$$A_a = \gamma_{oo}\, r_{eo} + \gamma_{wo}\, r_{ew}\ (db)$$

where r_{eo} and r_{ew} are effective distances of the path through the atmosphere. The effective distance for oxygen absorption, r_{eo}, is approximately the distance a radio wave travels through an atmosphere of constant density, given in Fig. 1, extending upward from the ground to

* This Report was adopted unanimously.
* 10 gm/m³ is approximately equal to 7·6 gm/kg.

a height of 4 km with a vacuum above. The effective distance for water vapour absorption, r_{we}, is approximately equal to the corresponding distance through the reference atmosphere which is 2 km thick.

3.2 The attenuation of radio waves caused by suspended water droplets and rain usually exceeds the combined absorption due to oxygen and water vapour and becomes increasingly serious at frequencies above 3 Gc/s. The attenuation is due, both to absorption of energy in the droplets and to scattering of energy out of the beam of the antenna.

In practice, it has been found convenient to express the attenuation due to rain as a function of the precipitation rate, R_r, which depends on both the liquid water content and the velocity of fall of the drops. This velocity depends on the size of the drops. There is little evidence that rain with a known rate of fall has a unique distribution of drop-size, and the problem of estimating the attenuation of radio waves caused by the various forms of precipitation is quite difficult.

The total absorption, A_r, due to rainfall over a path length r_0, can be estimated by integrating the differential rain absorption, $\gamma_r\ (r)\ dr$, along the direct path between the two mutually visible antennae, or along horizon rays, for transhorizon propagation:

$$A_r = \int_0^r \gamma_r\ (r)\ dr (\text{db})$$

Having fitted empirically an arbitrary mathematical function to the theoretical results given by [14, 23], the rate of absorption by rain γ_r, may be expressed in terms of the rainfall rate, R_r in mm/hr as:

$$\gamma_r = K\ R_r^{\alpha} (\text{db/km})$$

for frequencies above 2 Gc/s, where the functions K and α are given in Figs. 2 and 3.

Along any given radio path, the rainfall rate varies with altitude and with the horizontal direction and this requires a determination of its statistics including its variation from place to place. This knowledge permits the determination of an effective distance, for use with the curves in Figs. 2 and 3.

3.3 For clouds consisting entirely of small droplets or ice particles (diameters less than 0·001 cm) and fogs, it is possible to express the attenuation in terms of the total quality of the liquid water per unit volume. Thus, the absorption within such a cloud or fog can be written as:

$$A_c = K_1\ M (\text{db})$$

where A_c is the total absorption attenuation within the cloud, K_1 is an attenuation coefficient, values of which are given in Table I and M is the liquid water content of the cloud in gm/m³. This table indicates the manner in which the attenuation varies with both frequency and temperature and also shows the effects of the differing dielectric properties of ice and water.

4. Sky-noise temperature

The non-ionized region of the atmosphere is a source of noise radiation [15]. Fig. 4 shows the sky-noise temperature due to oxygen and water vapour for various angles of elevation and for frequencies between 1 and 100 Gc/s. In estimating antenna temperatures, the antenna pattern and radiation from the earth's surface must also be considered [24].

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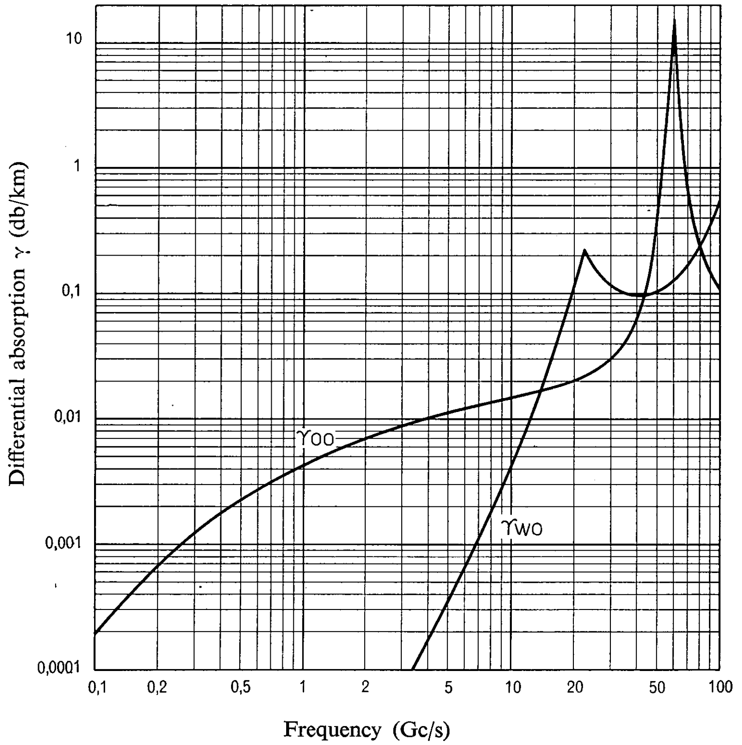

FIGURE 1

Surface values γ_{00} and γ_{w0} of absorption by oxygen and water vapour

Pressure: 760 mm Hg

Temperature: 20° C

Water vapour density: 10 g/m³ ≈ 7·6 gm/kg

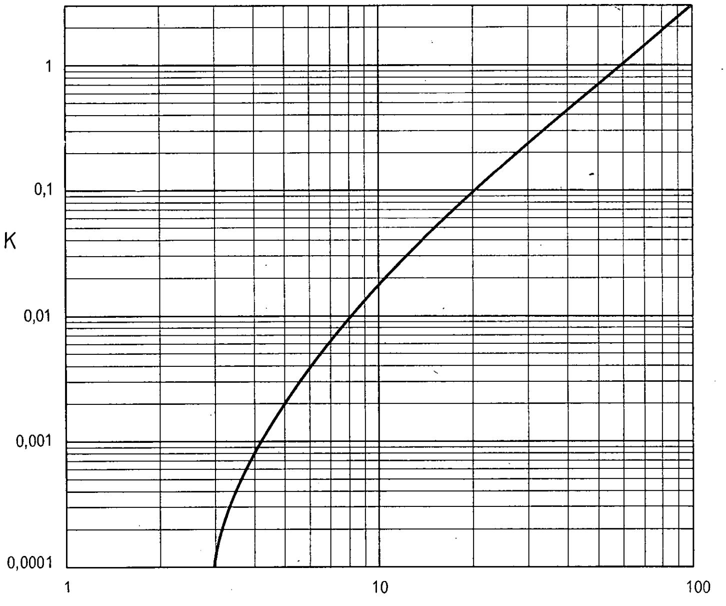

FIGURE 2

Absorption by rainfall: variation of K with frequency

where $\gamma_r = KR_r^{\alpha}$ (db/km), and R_r is the rainfall rate (mm/hr)

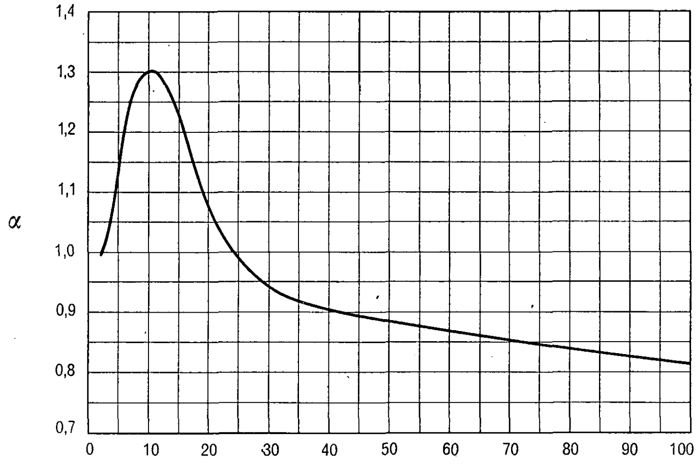

FIGURE 3

Absorption by rainfall: variation of α with frequency
where $\gamma_r = KR_r^{\alpha}$ (db/km), and R_r is the rainfall rate (mm/hr)

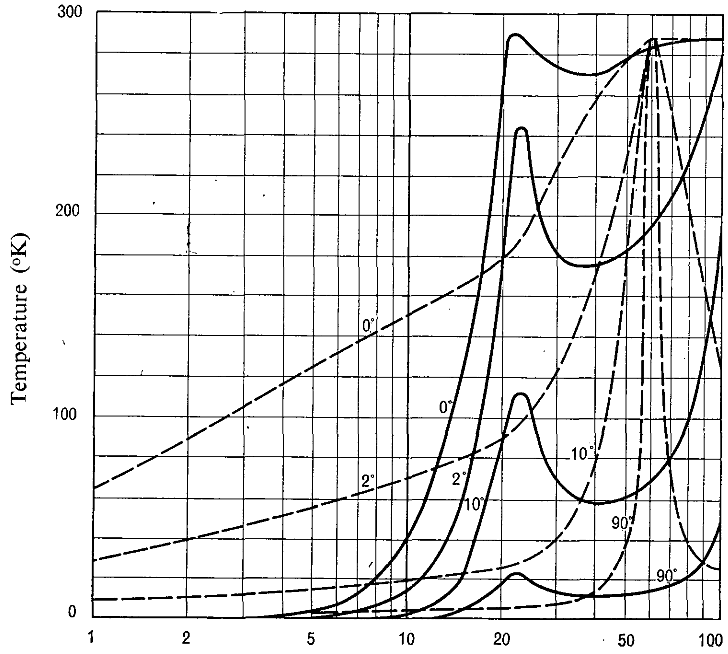

FIGURE 4

Sky-noise temperature due to absorption by oxygen and water vapour
(The angle of elevation above the horizon is indicated on each curve)
Surface pressure: 760 mm Hg
Surface temperature: 20° C
Water vapour density: 10 g/m³

——— water vapour
– – – – oxygen

REPORT 235 *

EFFECTS OF TROPOSPHERIC REFRACTION AT FREQUENCIES BELOW 10 Mc/s

(Warsaw, 1956 — Geneva, 1963)

In the ground-wave propagation curves in Recommandation 368, as is explained in its Annex, no account is taken of tropospheric refraction, whereas in the C.C.I.R. Atlases of ground-wave propagation curves for frequencies above 30 Mc/s [1, 2], the effect of a linear decrease of refractive index with height has been allowed for by the use of an equivalent radius of the earth equal to 4/3 times the real radius. Even at these higher frequencies, it is important to remember that the refractive index of the troposphere does not decrease linearly with height, but eventually approaches the value of unity for free space. Thus, although it is justifiable to assume a 4/3 earth's radius as far as the rate of attenuation with distance is concerned, with increasing height the curves overestimate the field-strength, and instructions are given in the second Atlas for finding the correction factor for a given profile of refractive index, in particular for an exponential law of the type assumed for the basic reference atmosphere in Recommendation 369.

At frequencies below 10 Mc/s, the height-gain effects become small at moderate heights and it was partly for this reason that the ground-wave propagation curves have been made to refer only to the case in which both terminals are on the ground. On the other hand, below about 3 Mc/s, the range of height entering into the determination of the rate of attenuation of field-strength with distance around the earth has extended to the region where the refractive index of the troposphere begins to depart seriously from the value corresponding to a linear decrease with height appropriate to the use of a 4/3 earth's radius. Thus the rate of attenuation of field-strength with distance around the earth no longer corresponds to the use of an atmosphere in which the refractive index decreases linearly to indefinitely great heights.

While at the upper limit of 10 Mc/s for the ground-wave propagation curves in Recommendation 368, it is still nearly correct to use an equivalent radius of 4/3 times the real radius of the earth for both terminals on the ground, the troposphere can have very little effect at the lower limit of 10 kc/s, where the range of height entering into the determination of the rate of attenuation of field-strength with distance around the earth extends to many kilometres above the earth.

There is thus a transition that becomes marked at about 3 Mc/s and almost complete at 10 kc/s, from the use of a 4/3 earth's radius at 10 Mc/s to the use of the real radius of the earth at 10 kc/s. It has long been realized that this transition must occur, as is shown by the existence of the appropriate Study Programme 246 A (V).

Progress in this study has, however, been slow for two reasons: first because of the difficulty of handling the mathematical analysis when the relevant eigen-value equation contains a law of variation of refractive index such as the exponential form proposed, and secondly, because with decreasing frequency, the ionosphere becomes a dominant factor in propagation to great distances, as is pointed out in § 6 of the Annex.

It has been suggested that the degree to which tropospheric refraction modifies ground-wave propagation at frequencies below 10 Mc/s can be investigated experimentally. Such results as have been obtained in this way have in general been inconclusive. It is difficult over a land path to be certain that any effects observed are due to the troposphere and not to inhomogeneities of the

* This Report, which replaces Report 45, was adopted unanimously.

earth constants, or because the conductivity is actually greater than the value assumed in using the curves for comparison with the measured results.

Even over a sea path, where the conductivity is well defined, the ionosphere can produce an appreciable effect at mid-day at distances where the troposphere may be expected to produce a marked increase in signal, though there is some evidence of significant tropospheric refraction at frequencies as low as 1500 kc/s at distances of 200 km or more (see Doc. 176 (France) of Warsaw, 1956).

The conclusion had been reached that there was not much likelihood that the curves could be materially improved on the basis of such experiments. It also appeared that the whole subject was somewhat academic in view of the limited use of such ground-wave propagation curves when the effect of the ionosphere is taken into account, as indicated in § 6 of the Annex.

However, with the advances that have been made at low frequencies in the use of pulse techniques and high radiated powers with the consequent development of new navigational aids, the whole emphasis of the study has been revised. The possibility envisaged, in § 6 of the Annex, of isolating the ground-wave has become of major importance and for this reason the use of pulse techniques has been introduced prominently into the revised form of the study given in Study Programme 246 A (V).

It now appears that further experiments, at least over long sea paths, using pulse techniques may well help to resolve the nature of tropospheric refraction at frequencies below 10 Mc/s. Such experiments are in fact in progress, but no detailed results are as yet available. It may be pointed out that, in comparing the results with the values given by the curves, the important feature is not the absolute value of the field-strength at a given distance, which will depend upon such factors as the estimated radiated power, but the law of attenuation with distance.

At sufficiently great distances where the first term of the residue series in the diffraction formula is predominant, the decrease of field-strength with distance will be effectively exponential, giving an attenuation which may be expressed in db/km. It is this rate of attenuation, which is given primarily by the solution of the eigen-value equation in the mathematical statement of the problem, and which forms the simplest measure of the effect of tropospheric refraction on ground-wave propagation. The secondary problem of computing the absolute values of field-strength can be handled when the fundamental eigen-value equation has been solved.

The mathematical analysis is intimately concerned with the study of the height-gain function from which the eigen-value equation is derived. In § 5 of the Annex, the importance of height-gain effects is stressed, in connection with high-flying aircraft using navigational aids depending on ground-wave propagation by the use of pulse techniques.

Even assuming that the mathematical analysis of the problem had been completed, the inclusion of height-gain effects in the curves would be a formidable task. It would involve the production of an Atlas large in size compared with the existing Atlases [1, 2] and this is a sufficient reason for not including such height-gain effects at the present time.

Nevertheless, the mathematical technique for computing height-gain values is well advanced, even for refractive index profiles such as the experimental one [3, etc.], and when the problem of solving the basic eigen-value equation in its generalized form has been completed, the production of height-gain curves for frequencies below 10 Mc/s can be carried out with the aid of modern computing methods.

Some work that shows promise is in hand on the solution of the eigen-value equation. It confirms, for instance, that the effect of the troposphere is still marked on a frequency of 1500 kc/s as the limited experimental evidence suggests. However, it is too early to anticipate the full results of this analysis.

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REPORT 236 *

INFLUENCE OF IRREGULAR TERRAIN ON TROPOSPHERIC PROPAGATION

(Geneva, 1951 — London, 1953 — Warsaw, 1956
— Los Angeles, 1959 — Geneva, 1963)

The technical aspects of the problem of propagation over irregular terrain may be usefully considered from two viewpoints, as given in §§ 1 and 2 below.

1. Propagation between two specified points with an arbitrary intervening distance and heights above the ground, with an arbitrary intervening terrain profile, and through an arbitrary atmosphere

It is seen that, in addition to being a direct solution of the point-to-point communication problem, the adequate treatment of this problem also provides indirectly the solution of most problems of interest to C.C.I.R.

In most cases of propagation over land, the general roughness of the ground, including the effects of vegetation and man-made obstructions, causes an attenuation of waves passing over it. This may be allowed for by a "terrain factor", which must be included in addition to the transmission loss over smooth earth, given in the C.C.I.R. Atlases. Such a factor will be useful at frequencies, say, above 100 Mc/s and has been stated to be about 10 db at 200 Mc/s [1, 23]. It will depend upon the radio frequency and also on the terrain roughness, as determined, for example, by the standard deviation of heights about their mean value.

This procedure is inadequate for paths containing large irregularities, such as hills and mountain ridges, which have to be considered in terms of diffraction. The path can be treated as passing over a succession of crests, which may be replaced by knife-edges or

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* This Report, which replaces Reports 140 and 144, was adopted unanimously.

cylinders, according to the sharpness of the crests. The case of a single knife-edge may be solved in terms of Fresnel integrals. The case of several knife-edges may be expressed by multiple integrals of Fresnel type, and with two knife-edges the integration can be carried out [1, 2]. The integrals are more difficult to manage in complex cases, and an approximate method [3, 4] is available for any number of successive knife-edges.

Theoretical studies have been made of the ground effects on diffraction by a knife-edge, an escarpment, and a cliff at a coast line [5]. For a cliff at the coast, the rate of change of the relative phase with distance from the coastline becomes larger as the height of the cliff increases and is sometimes much more than that without a cliff.

On long paths, tropospheric-scatter may occur well above a mountain ridge, and the scattered and diffracted waves must be combined. With transmitting and receiving antennae elevated above the surrounding terrain, there can be waves reflected both before and after diffraction [6]. When a wave passes close to the ground, there is an additional transmission loss due to finite ground conductivity [7].

Mountain ridges can effectively reduce both the transmission loss and the fading below the values to be expected in the absence of the obstacle. This occurs when the direct path is non-optical, but both transmitter and receiver can be seen from the top of the mountain. The phenomenon is known as obstacle gain [15, 17]. When using this term quantitatively, it must be stated whether it refers to gain relative to the calculated field over a homogeneous spherical earth, where only diffraction and standard atmospheric refraction are involved (propagation curves of the C.C.I.R. Atlases), or whether scattering and super-refraction are considered as well (curves of Recommendation 370). The latter case occurs when it is possible to compare propagation over two neighbouring paths of comparable distances and antenna heights, one of which has a mountain ridge which causes knife-edge diffraction and the other is clear of obstacles. Measurements made under such conditions have confirmed that such gains do occur [8, 9, 10, 12, 15, 17].

The measured values of transmission loss and the lobe structure, which may be measured by raising the receiving antenna, agree well with values calculated by diffraction theory for paths lending themselves to simple calculation [6, 12].

It is found that when the field strength obtained is high, it is relatively stable and the fading is slight, whereas in a region where the field is normally weak, it fluctuates very much with variations in refractive index [11, 12, 13, 14, 15]. Since the high values of field strength are produced by the addition in phase of fields received over several paths, relatively large effects of the troposphere on the individual components are required to produce an appreciable change in the resultant field. Conversely, the weaker fields, which are produced by partial cancellation of the individual field components, are greatly affected by changes in these components. This conclusion is supported by the fact that the high field strengths become less stable as the frequency is increased from band 8 (VHF) to band 10 (SHF) [11]. It would appear that the VHF (metric) band is more suitable than the higher frequencies for communication by waves diffracted over mountain ridges.

It will be further noted, that the direction of arrival of the strongest signal need not be the direction of the great-circle path between the transmitter and the receiver. This is most noticeable when the receiving station is very near to the diffraction ridge (a few kilometres). This indicates that, in estimating the quality of transmission across a mountain ridge, consideration must be given, not only to the profile of the terrain in the great circle path, but also to the diffraction or scattering properties of the ridge outside this plane. However, if the mountain obstacle is only a little removed from the great-circle path, it no longer introduces an appreciable gain [12].

For propagation over high mountain ridges, a large part of the path may be above the regions of the troposphere in which rapid changes in the index of refraction occur. Also, there may be marked differences in the weather on the two sides of a mountain ridge, so that the conditions which give rise to fading may occur only on one half of the path at a time.

Both of these factors may limit the effects of the troposphere on the individual components of the diffracted wave and tend to minimize the fading which occurs at a receiving point where a high value of field strength is found [12, 13, 14, 16]. While all these investigations are yielding very useful results, it is clearly necessary that studies should be continued in those countries which have the desired topographic features, so that the radio paths under investigation include mountain ridges.

2. The statistical description of the fields expected from a broadcasting station at various locations along a circular arc at a given distance

As a practical matter, the atmosphere, as well as the characteristics of the ground, will vary with time, so that the ground-wave field strength may also be expected to vary with time. As a consequence, § 1 also involves the statistical description of the fields.

It is convenient for most engineering applications to consider simply the cumulative distribution of the received fields with time, i.e., to indicate the fields exceeded for various percentages of time on the specified point-to-point propagation path [17, 18, 19, 20].

In this paragraph, the statistical description of the fields involves both time and receiving location as variables, and in practice the shape, as well as the median value, of the cumulative distributions with time will vary with location even with the distance fixed [21, 22, 23, 24, 25, 26].

As soon as a satisfactory solution has been obtained of the problem given in § 1, then it can be considered that the problem in this paragraph is also solved, since one can use statistical sampling methods to determine the separate cumulative distribution with time, at a large number of locations along an arc at a constant distance from a broadcasting station. Each of these locations will correspond to a different profile of the terrain. It should be noted that, cumulative distributions of the fields need not be determined at closely spaced locations along the arc, since this will result in a redundancy of information by virtue of the correlation of the received field strengths at closely spaced locations (see Report 228).

The statistical cumulative distribution of fields with time and location as described above may be predicted theoretically, or measured. When resort is made to the use of measurements given in this paragraph, one must face the difficulty that it is more or less impracticable to give anything more than a few distributions with location which will be representative, for example, of locations in gently rolling terrain, locations in small villages, locations in large cities, etc. For this reason, it is most desirable that suitable prediction formulae be developed so that they may be used to allow for the effects of the actual terrain encountered in particular situations.

When this information on field strength is used, for example, by the I.F.R.B., in examining frequency allocations, it is necessary to consider for point-to-point circuits (§ 1), the cumulative distribution with time of the ratio of the useful to interfering field strength, or when a directional antenna is used, the ratio of the wanted and unwanted powers available at the receiver. This involves an appropriate combination of the separate cumulative distributions with time for the two propagation paths from the useful and interfering transmitters. In making this combination, it is sometimes important to consider the correlation in the variations with time of the useful and interfering field strengths; for example, since the useful and interfering field strengths will usually change diurnally and seasonally in the same direction, the cumulative distribution in time of their ratio will extend over a somewhat smaller range than if this correlation did not exist. An interference-free point-to-point service may be considered to exist when the ratio of the available wanted-to-unwanted powers exceeds a predetermined value for a specified percentage of the time.

For interference to a broadcasting station from some other transmitter, we may use the statistical sampling method and determine the cumulative distribution of the ratio of wanted-to-unwanted powers at a large number of locations in the intended service area of the wanted station. In this way, we may determine the percentage of locations which will receive an interference-free service.

It should be noted that the above method of analysis automatically makes the appropriate allowance for the fact, that locations which are undesirable for reception of the wanted signal, are often also subject to a weak interfering signal.

In a series of measurements made in the United Kingdom [27], mass plots were made of field strength against distance without regard to direction, and curves were drawn through the medians. These more recent results support the existing curves of Recommendation 370.

Measurements made in Poland [28], in a town and the surrounding rural area, show an attenuation of about 12 db in the centre of the town, but beyond the town the signals increase again to values approximately the same as for purely rural paths.

Measurements in very irregular terrain have been made in the Czechoslovak S.R. In particular, preliminary results have been obtained on the changes in polarization of radio waves in relation to the degree of roughness of terrain, from small irregularities to mountainous regions [29, 30].

It appears from the above discussion given in §§ 1 and 2, that a satisfactory solution of any frequency allocation problem may be obtained when it is possible to determine the cumulative distribution with time of the ratio of the wanted-to-unwanted powers available at the receivers, corresponding to the two irregular terrain paths between the receiving locations to the wanted and unwanted transmitters. At distances where the scattered field may be an important component of the wanted or unwanted signal, these scattered fields must be combined appropriately with the ground-wave.

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REPORT 237 *

INVESTIGATION OF MULTI-PATH TRANSMISSION THROUGH THE TROPOSPHERE

(Study Programme 57 (V))

(Warsaw, 1956 — Geneva, 1963)

A theoretical investigation has been carried out in Italy, on the propagation between two points at the ends of a path which is non-optical for normal atmospheric conditions, taking into account the fact that in Italy a state of super-refraction frequently occurs at heights of less than 500 m above sea level. Doc. 351 of Warsaw, 1956, is an abstract of a published paper** on this subject, in which it is pointed out that under conditions of super-refraction, the effective curvature of the earth becomes concave, with the result that there may be three points of reflection of the waves

* This Report, which replaces Report 51, was adopted unanimously.
** SACCO, L. Il Collegamento Radio in Regime Superrefrazione Atmosferica. *Alta Frequenza*, 6 (December, 1955), pp. 436-469.

transmitted between transmitter and receiver. Under these conditions, the cœfficient of divergence is transformed into one of convergence, which, under particular conditions, results in the possibility of focusing of the waves arriving at the receiver. The paper describes the parameters necessary for calculating the field resulting from the interference between the direct ray and the reflected rays with the aid of the " abac " annexed to Doc. 352 of Warsaw, 1956.

Docs. 330 and 366 (Japan) of Warsaw, 1956, describe experiments performed with a multiray measuring device with a frequency sweep of 3850 ± 250 *Mc*/s, and also a useful method of extracting the mean signal level and its variance from a mass of observations. It is suggested that statistical values of the amplitude ratio ρ and the path difference l, obtained independently, are not suitable for assessing distortion due to multipath transmission. It is more appropriate to use the product ρl * in designing microwave multi-channel radio-relay systems. If the quantity ρl is known, the amount of distortion due to multipath transmission can be estimated from the magnitude of the fading, which can be easily measured. This deduction was confirmed by the results of experimental tests made during the summer, when multipath transmission was expected to occur most frequently.

In Doc. V/30 (Japan) of Geneva, 1962, the statistical distribution of the amplitude ratio ρ, the path difference l and the spread of the arrival angle $\delta\theta$ are measured on a 62 km inland path and a 79 km sea path. The frequency sweep was from 5·65 Gc/s to 6·42 Gc/s. The 50% value of the amplitude ratio was between 0·35 and 0·65 and the 50% value of the path difference l amounted to a few cm under normal propagation conditions and up to 80 cm, when abnormally long path differences where observed on the sea path. The corresponding 50% values of $\delta\theta$ were 0·07 on the inland path and 0·1° on the sea path. In 1% of the time $\delta\theta$ exceeded a value of 0·6°.

Some information relating to §§ 4 and 5 of the Study Programme has resulted from tests carried out in the United Kingdom, using a frequency of 4 Gc/s on two oversea paths, 58 km and 88 km long respectively. Observations on diversity reception and selective fading were made, and the results illustrate some of the effects of multipath transmission at micro-wavelengths.

New tests are presented in Doc. V/35 (United Kingdom) of Geneva, 1962. Vertical space diversity measurements at 4 Gc/s over a sea path of 60 km, carried out over a period of several years show the influence of seasons and the effect of small and extremely large antenna spacings (9 m to 162 m). The large antenna spacings were needed to reduce substantially fading caused by oversea duct formation and resulting ray-defocusing effects. Even the largest antenna spacings were sometimes not adequate to provide vertical space diversity on short oversea paths.

Doc. V/44 (France) of Geneva, 1962, shows that for much longer links (about 200 km), which are still within line-of-sight, a vertical diversity spacing of only 20 m may be sufficient.

It is clearly necessary for more extensive investigations to be made on all aspects of this Study Programme and for further tests to be carried out for longer periods and over a variety of paths in different parts of the world.

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* ALBERSCHEIM W. J. and SCHÄFER, J. P. Echo distortion in the FM transmission of frequency-division multiplex. *Proc. IRE* 316 (March, 1952).

REPORT 238 *

RADIO TRANSMISSION UTILIZING INHOMOGENEITIES IN THE TROPOSPHERE (COMMONLY CALLED " SCATTERING ")

(Study Programme 139 (V))

(Los Angeles, 1959 — Geneva, 1963)

It is well known that under conditions of standard refraction (corresponding to the use of an increased earth radius), the transmission loss at frequencies above 30 Mc/s increases rapidly beyond the horizon in accordance with diffraction around a spherical earth, but that when it has increased some tens of decibels in excess of the free-space value, the rate of attenuation with distance falls to a much smaller value. Measurable signals thus persist out to great distances. At these distances, the signal level is very variable, however, the spread of measured values can be fitted by an exponential curve giving a rate of attenuation of about 0·1 db/km. Useful ranges of 300 km or more are commonly obtained. At still greater ranges, the rate of increase becomes even less, but, by the use of exceptionally high effective radiated power, ranges up to about 1000 km have been achieved.

These signals, while varying in amplitude, are persistent, and are to be distinguished from those much stronger signals which occasionally occur at these rangs. These much stronger signals are known to be due to special conditions, for example those in which ducts are formed in the troposphere, or at the lower frequencies, by reflection from abnormal ionospheric layers, and are considered in other studies.

The variable nature of the long range signals has led to the suggestion that they arise from irregularities in the refractive index of the troposphere. Various physical mechanisms have been proposed to explain this trans-horizon propagation. The observed fading characteristics can be explained by the addition of a number of component signals which come from different parts of the atmosphere and add incoherently to give a noise-like signal. Direct observation of the troposphere has revealed enough irregularity of refractive index to explain the magnitude of the received signals. There is an undoubtable tendency for these irregularities (eddies and small layers) to be extended horizontally. Meteorological theories have attempted to define the mechanism of generation of the irregularities, but radio experiments have not yet succeeded in finding which is the most successful. However, all theories are united in predicting that propagation is highly directive in the forward direction.

It has been found useful to make statistical radio studies of existing communication links to predict the performance of other links. Both slow and rapid variations of field strength are observed. Slow fadings are ascribed to overall changes in refractive conditions in the atmosphere. The median amplitude is distributed approximately log-normally with a typical r.m.s. deviation of some 6 db. The largest variations of transmission loss are often seen on paths, for which the receiver is located just beyond the diffraction region, whilst at extreme ranges the variations are less. The slow fading is not strongly dependent on the radio frequency. The rapid fading has a frequency of a few cycles per minute at lower frequencies and a few cycles per second at UHF. The superposition of a number of variable incoherent components would give a signal

* This Report, which replaces Report 148 and terminates Study Programme 139, was adopted unanimously.

whose amplitude was Rayleigh distributed and this is found to be nearly true when the distribution is analyzed over periods of up to five minutes. If other types of signal form a significant part of that received there is a modification of this distribution. Sudden, deep and rapid fading has been seen when a frontal disturbance passes over a link. Reflections from aircraft can give pronounced rapid fading.

In temperate climates, monthly median transmission losses tend to be lower in the winter than in the summer, differences ranging from 6 to 26 db have appeared in the literature. Oversea paths are more likely to be affected by super-refraction and elevated layers than land paths and so give greater variation. Diurnal variations are often met. Climate affects signal strength. Reports 231 and 233 study this question.

The effect of fading on a communication system can be reduced by the use of diversity reception, using two or more signals which fade more or less independently, owing to the difference in path, frequency or time interval. Signals from two receiving antennae spaced normally to the path and separated by 25 wavelengths or more are commonly used. It is also possible to have frequency diversity and angle diversity using multiple feeds and a common reflector. Polarization diversity is unlikely to be of practical use since polarization is found to be well preserved, while the transmission loss does not seem to depend on whether vertical or horizontal polarization is used.

The combined gain of transmitting and receiving antennae may be less than the sum of their plane-wave gains. Some papers indicate that this occurs when the beam-widths of the antennae are smaller than that over which signals could be scattered if omnidirectional antennae were used. This apparent drop in gain is termed " gain degradation " or " antenna-to-medium coupling loss ". It begins to be apparent when the combined gain is of the order of 30 to 40 db. The amount of loss increases with increasing antenna gain and with path length.

Differential delays between components of the scattered signal result in signal distortion equivalent to restricting the bandwidth available for modulation. Certain papers indicate that this bandwidth is theoretically inversely proportional to the cube of the distance, and increases with increasing antenna gain. In practice, it is to be expected that the available bandwidth is sufficient for many purposes. The difficulties of obtaining adequate signal-to-noise ratio are much more resttrictive.

The siting of terminals of trans-horizon links requires some care. The antennae beams must not be obstructed by nearby objects and the overall requirement is that the antennae should be directed at the horizon. If the antenna beams are tilted upwards by as little as 0·5° there may be a loss of the order of 10 db, probably due to the increased angle through which the radiation must be scattered.

Theory and experiment in scatter propagation have made further progress during the interim period 1959-1962. Docs. V/7 (F.P.R. of Yugoslavia), V/17 (F.R. of Germany), V/23 (U.S.A.), V/32 (Japan), V/39, V/40 and V/41 (France) of Geneva, 1962 present new aspects in scatter theory (Doc. V/7), new experimental results on the frequency dependence of transmission loss, on fading rate, on space diversity (Doc. V/17), frequency diversity (Doc. V/41) and azimuth angle diversity (Doc. V/32), new experimental evidence of the meteorological effects on trans-horizon propagation in different climates (temperate, equatorial, Saharan) have led to the conception of a new parameter, which seems to be specially adequate to give good correlation with transmission loss (Doc. V/39). Studies of frequency diversity at 3400 Mc/s over a 320 km link, show large time variation of the diversity distance between several Mc/s and several tens of Mc/s (Doc. V/41). Doc. V/23, on tropospheric wave propagation loss prediction, gives methods of predicting long-term median values of transmission loss, based on the radio atmosphere, on current scatter theories and ultimately on a very large sample of experimental data. A method of prediction, depending only on distance and frequency, gives sufficient reliability in many cases. Another method of prediction is given in Doc. V/71 (France). This method is based on the transmission loss during the most unfavourable month in different climates.

More general methods, but still of empirical character, depend on a greater number of parameters besides distance and frequency, e.g. the terrain profile, and lead to reliable results in more complicated individual cases. Continuous comparison of measurements and prediction methods were a constant guide in developing the curves, tables and nomograms of the methods. It is thought that they can serve as a preliminary but efficient guide in predicting the cumulative distribution of hourly median values of transmission loss expected in point-to-point tropospheric communication at frequencies above 30 Mc/s.

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REPORT 239 *

VHF AND UHF PROPAGATION CURVES IN THE FREQUENCY RANGE FROM 40 Mc/s TO 1000 Mc/s

Broadcasting and mobile services

(Los Angeles, 1959 — Geneva, 1963)

1. Introduction

This Report gives details of the construction of the propagation curves in Recommendation 370 and also suggests a method for computing the field strength over mixed land-sea paths. The Report is divided into four parts. The first section treats the development of the propagation curves for distances beyond the horizon; the second deals with the derivation of the curves for distances within the normal horizon; the third discusses the effects of terrain irregularities on the curves; and the last section considers propagation over mixed land-sea paths.

Results of field-strength measurements have been made available by many Administrations, and these have been combined in the production of these propagation curves. These curves were developed at a Meeting of C.C.I.R. Experts, Cannes 1961, to prepare for the European VHF/UHF Broadcasting Conference, Stockholm, 1961.**

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* This Report, which replaces Report 145, was adopted unanimously.

** It must be emphasized that the curves are based on data obtained mainly in temperate climates and should be used with caution in other climates.

The following definitions are pertinent to this Report:

1.1 The field strengths have been adjusted to correspond to a power of 1 kW radiated from a half-wave dipole.

1.2 The height of the transmitting antenna is defined as its height over the average level of the ground between distances of 3 and 15 km from the transmitter, in the direction of the receiver.

1.3 The receiving antenna height is defined as the height above local terrain.

2. Beyond-the-horizon distances

The long-term data for distances beyond the horizon were separated into VHF and UHF classes. Figs. 1, 2, and 3 show the average curves which were derived from the data.

Fig. 1 shows the average curves for VHF propagation at the greater distances and incorporates a very large amount of data on many land paths, together with about a dozen sea paths around the British Isles. The average heights of the transmitting and receiving antennae were about 300 m and 10 m respectively. The technique in developing curves for transmitting antennae at other heights is to assume that the field strength is a function of the distance between horizons only. Then, the field strength at a distance X km from the transmitter, for a transmitting antenna at a height h_1 m, would be obtained from the 300 m curves at an equivalent distance of $(X + 70 - 4 \cdot 1 \sqrt{h_1})$ km. This procedure may be used for distances beyond the horizon.

A similar set of curves are shown in Fig. 2, for propagation over land in the UHF range. Here again, the curves represent the average of a great amount of data for many land paths, representing many areas of the world. As above, curves for transmitting antennae at other heights may be developed by assuming that the field strength depends only on the distance between the horizons.

Fig. 3 shows field, strength curves for oversea paths at greater distances. The only data available, relating to oversea propagation at the greater distances, are for the North Sea and Mediterranean areas. The curves of Fig. 3 are based on measurements over a number of paths in the North Sea area over a period of about 18 months. Limited measurements of the median value of field strength in the Mediterranean are in good agreement. There is evidence, however, that the field strengths exceeded for small percentages of time in the Mediterranean are even greater than those experienced in the North Sea area.

The field strengths exceeded for small percentages of the time are not expected to be sensitive to appreciable changes in the height of the transmitting antenna; and the field strengths exceeded for 50% of the time may be adjusted for transmitting antennae at other heights, by again assuming that the field strength beyond the horizon depends only upon the distance between the horizons.

3. Within-the-horizon distances

Propagation curves for distances within the normal horizon were developed by comparing the data obtained from many mobile surveys and a number of long-term measurements at fixed locations for short path lengths, with theoretical propagation curves for a smooth earth at the appropriate frequencies and antenna heights. The variation in field strength with frequency proved to be relatively minor and the data was separated into VHF and UHF classes, as was done for the beyond-the-horizon distances.

Fig. 1 of Recommendation 370 shows the field strength exceeded for 50% of the time at VHF. The curves within the normal horizon distances were derived by comparison with the theoretical corresponding curves for a smooth earth. These curves were then merged smoothly into the corresponding family of curves for distances beyond the horizon, as described in the previous section. Fig. 1 thus includes portions of field-strength curves within the horizon and beyond the horizon, as well as intermediate portions which are the result of merging the within-horizon and beyond-horizon curves.

Figs. 2 and 3 of Recommendation 370 show the field strengths exceeded for 10% and 1% of the time, respectively, at VHF. The derivation of these curves was very similar to those of Fig. 1. The assumption was made that time fading is negligible at short distances, so that the median curves of Fig. 1 may be used as a guide at short distances and merged with the appropriate 10% and 1% curves from Fig. 1.

A set of field strength versus distance curves was derived for the UHF in similar fashion. These are shown as Figs. 6, 7 and 8 of Recommendation 370.

4. Influence of irregularities in the terrain

The influence of irregularities in the terrain increases with frequency. It is therefore, more important in the UHF (bands IV and V) than in the VHF (bands I, II and III) *. The parameter Δh is used to define the degree of terrain irregularity. It is the difference in the heights exceeded for 10% and 90% of the terrain over propagation paths in the range 10 km to 50 km from the transmitter (see Fig. 5 of Recommendation 370). All of the curves for propagation over land refer to the kind of rolling irregular terrain found in many parts of Europe and North America, for which a value of Δh of 50 m is considered representative.

If one could visualize an ideal experiment in which long-term recordings are made at a large number of locations, then the distribution of time medians for each and every site will result in a location distribution such as Fig. 4 of Recommendation 370 for VHF over the typical rolling terrain for a Δh of 50 m.

It is further assumed that the change in the range of variation, i.e., the slope, of this location distribution is approximately unaffected by the roughness of the terrain at VHF, so that the distribution of Fig. 9 of Recommendation 370 may be assumed to apply for most practical values of Δh.

At UHF, typical location distributions for various values of Δh are shown in Fig. 9 of Recommendation 370; the changes in the range of variation cannot be assumed to be negligible.

Not only does the range of variation of the location distribution increase with the terrain roughness, but also the average received field strengths are reduced as the terrain becomes rougher — i.e. Δh becomes greater. Again, this effect increases with frequency. Measurements indicate that the following corrections are appropriate for UHF for distances up to 100 km.

TABLE I

Δh (m)	Attenuation correction factor (db)
$\leqslant 50$	— 10
50	0
100 — 200	10
200 — 400	20

* See Annex II, § 2 of Recommendation 370.

In the above, the attenuation correction factor should be subtracted from the UHF field-strength curves for the required Δh. For distances greater than 200 km, the attenuation correction factor is assumed to be half the number of decibels shown in the above Table I for the same roughness of terrain.

For distances between 100 and 200 km, the corrected propagation curves for the two distances may be merged.

For Band III, the attenuation factor (in db) used at UHF should be halved. No attenuation correction factors are proposed at this time for lower frequencies.

The propagation curves in Recommendation 370 are the result of merging the appropriate curves.

ANNEX

PROPAGATION OVER MIXED LAND AND SEA PATHS

Although there is little evidence of any large difference between propagation over sea and over land in bands I, II and III, except for the small percentages of time, there is an appreciable difference at frequencies in bands IV and V.

When the path is over a mixture of land and sea, then an estimate must be made of the effect on the received signal of the mixed path. An attempt has been made to determine the attenuation from an all-sea path when the path is a mixture of land and sea, based on experimental measurements made in the United Kingdom on mixed paths.

From these measurements, curves have been drawn showing the decrease in field strength, relative to the value for an all-sea path in accordance with the distance from:

— the receiver point to the coast, as shown in Fig. 4 *a*;

— the transmitter site to the coast, as shown in Fig. 4 *b*;

It should be noted that the corrections are zero if the coastal boundary is within the radio horizon from the receiving or transmitting antennae (for heights of 10 m and 300 m respectively). The total corrections must not exceed 45 db, 31 db or 22 db for the 1%, 5% or 10% time values respectively, because these corrections would reduce the field strength values to those for an over-land path of the same total length.

When there are more than two land/sea intersections along a propagation path, i.e. with one or more intervening portions of land, the calculation of field strength should normally be made as follows:

— the curves of Fig. 4 *b* should be applied to the land-sea intersection nearest to the transmitter;

— the curves of Fig. 4 *a* should be applied to the sum of the length of all the remaining land portions of the propagation path.

Application of the method for the determination of field strength over mixed land and sea paths may lead to an erroneous result in certain special cases, where either the length of a sea portion of the path is short or the percentage of the total path that is over sea is small. In such cases, the method should be used with extreme caution and only after consultation between the Administrations concerned.

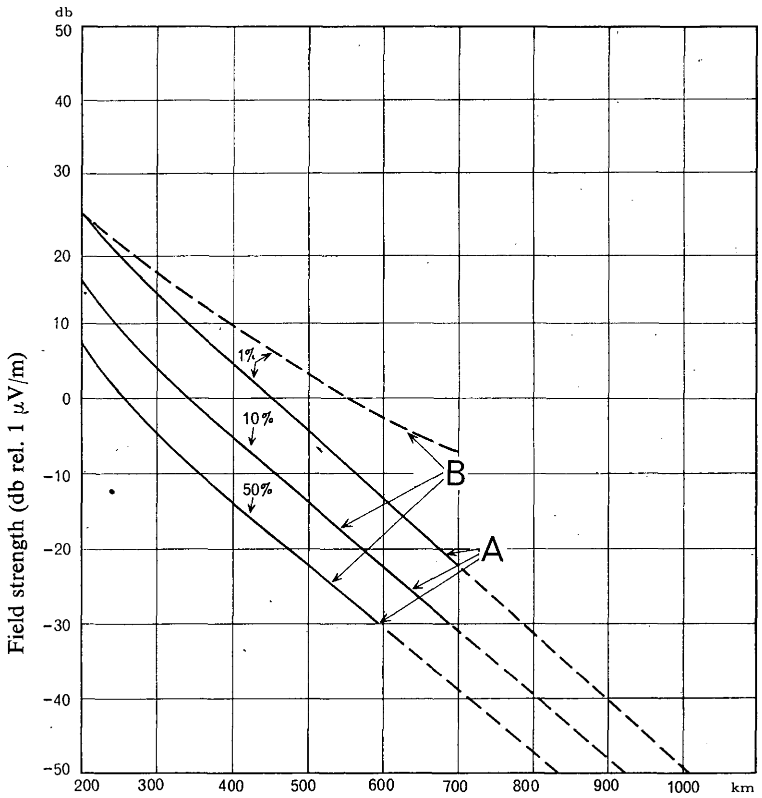


FIGURE 1

Field-strength (db rel. 1 μV/m) for 1 kW e.r.p.

Bands I, II, and III. For the percentages of the time shown on the curves; for 50% of the receiving locations; $h_1 = 300$ m; $h_2 = 10$ m.

Curves A: land
Curves B: North sea.

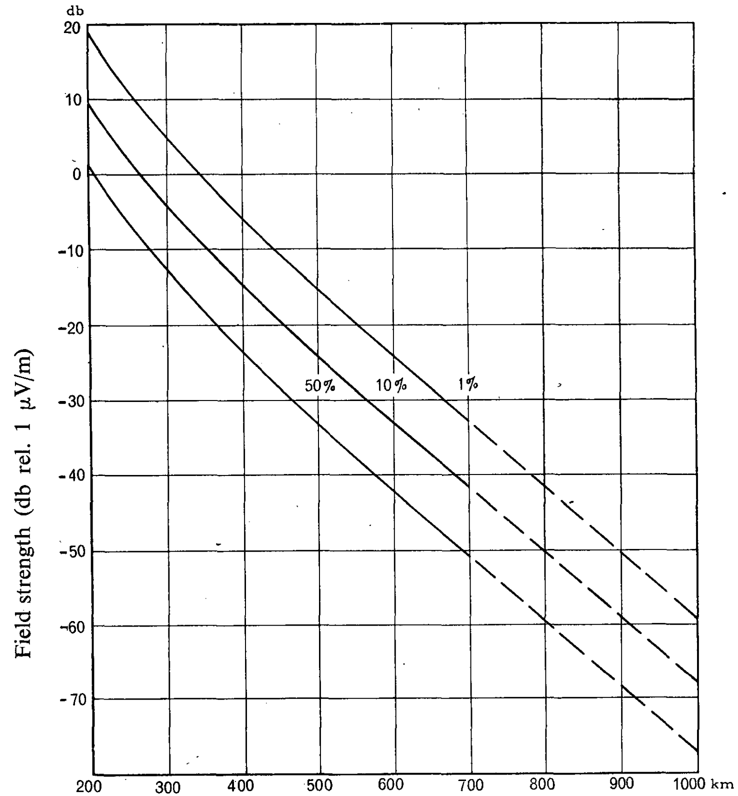


FIGURE 2

Field-strength (db rel. 1 μV/m) for 1 kW e.r.p.

Bands IV and V. For the percentages of the time shown on the curves; for 50% of the receiving locations; $h_1 = 300$ m; $h_2 = 10$ m
Land

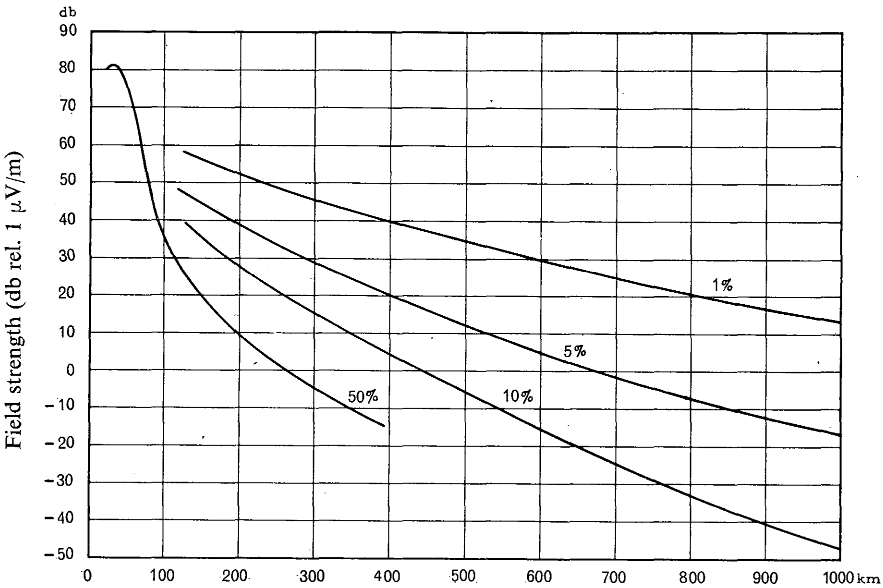
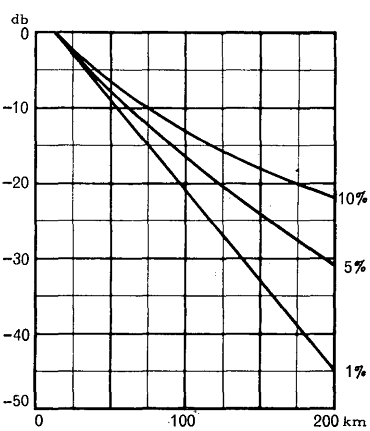


FIGURE 3

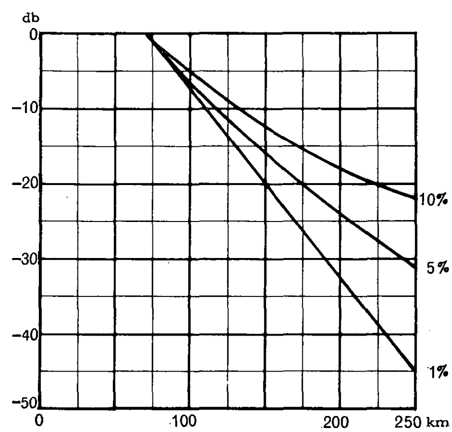
Field-strength (db rel. 1 μV/m) for 1 kW e.r.p.

Bands IV and V. For the percentages of the time shown on the curves; for $h_1 = 300$ m; $h_2 = 10$ m
Sea



Distance from receiver to coast (km)

FIGURE 4*a*



Distance from transmitter to coast (km)

FIGURE 4*b*

FIGURE 4

Corrections to be applied to oversea curves when path is partly overland

REPORT 240 *

PROPAGATION CURVES FOR VHF/UHF BROADCASTING IN THE AFRICAN CONTINENT

(Geneva, 1963)

1. Introduction

It is now well known, that radio field-strengths depend upon climatic conditions. The C.C.I.R. curves (Recommendation 370) refer primarily to temperate continental climates and will therefore only apply in limited regions of the African continent. Although data for other types of climate are somewhat sparse, it is possible to give an estimate of the modifications to the above C.C.I.R. curves required to make them applicable, at least approximately, to other parts of Africa.

2. African climates

For convenience Africa, has been divided into regions, as shown in Fig. 1, each of which corresponds to a fairly well defined type of climate. The classification is as follows:

1. Temperate (Mediterranean)
2. Desert (Saharan)
3. Sub-tropical (continental)
4. Sub-tropical (maritime)
5. Equatorial
6. Temperate (continental)

It should be noted that these divisions are somewhat arbitrary and that the classification of radio climates is not necessarily the same as that of meteorological climates even though the terminology is comparable. Furthermore, it is clear that the boundaries between the various regions will be ill-defined; and guidance on the estimation of propagation conditions for paths near to a boundary or covering more than one climatic region, can be obtained from Report 233. A precise definition of these climates depends on an average of available data. In the preparation of propagation curves, some random path-to-path differences have undoubtedly been ascribed to climatic differences. Each set of curves is, however, the best estimate available at present.

3. Presentation of curves

Figs. 2 to 37 present curves of field strength as a function of distance for the VHF/UHF broadcasting bands, and give for 50% of receiving locations the field strength exceeded for at least 50%, 10% and 1% of the time. The curves have been drawn for a power of 1 kW radiated from a half-wave dipole **. In using these curves for practical planning, the general considerations contained in Annexes I and II to Recommendation 370 and in Report 233 may be considered applicable.

* This Report was adopted by correspondence without reservation.

** Each figure also shows the free space field strength, $E = 106{\cdot}9 - 20 \log_{10} d$, d being expressed in kilometres.

When a transmission path crosses one of the climatic boundaries, interpolation may be made between the curves corresponding to the two regions proportionally (in db) according to the fractions of the path contained in each of the regions.

With respect to the VHF bands (450–1000 Mc/s), the experimental data contained in Doc. V/45 (France) of Geneva 1962, and the curves of Doc. 231 (France) of Geneva 1963, were normalized and extrapolated by theoretical methods, taking into account information about meteorological conditions in Africa.

The curves corresponding to the UHF band (Figs. 20–37) have been drawn for a frequency close to 700 Mc/s, considered representative of the whole of the band 450-1000 Mc/s, since the available experimental results are insufficient to justify separate predictions for different frequencies in the band.

With respect to the VHF band (40–250 Mc/s), experimental data for Africa are even less numerous. Measurements have been made by the French Administration at a frequency close to 100 Mc/s, but only along the west coast of Africa between approximately the 10th and 22nd parallels. The estimates for the VHF band were deduced from radiometeorological considerations and comparisons with data from other regions of the world.

It must be especially emphasized as regards curves for the VHF band (Fig. 2–19) that they apply only to propagation by tropospheric mechanisms. Particularly in equatorial regions, propagation by way of the ionosphere is important at the lower frequencies in the VHF band. It is therefore likely that higher field strengths will occur at long ranges, more often at frequencies below about 60 Mc/s than is indicated by the curves in this Report; and this factor must be borne in mind in planning broadcasting for such frequencies.

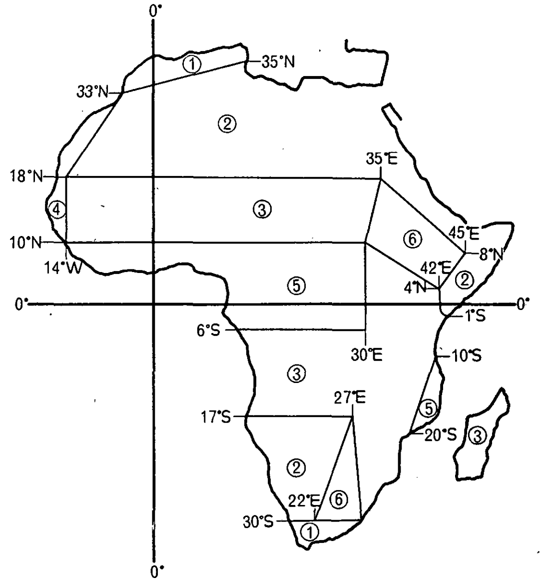
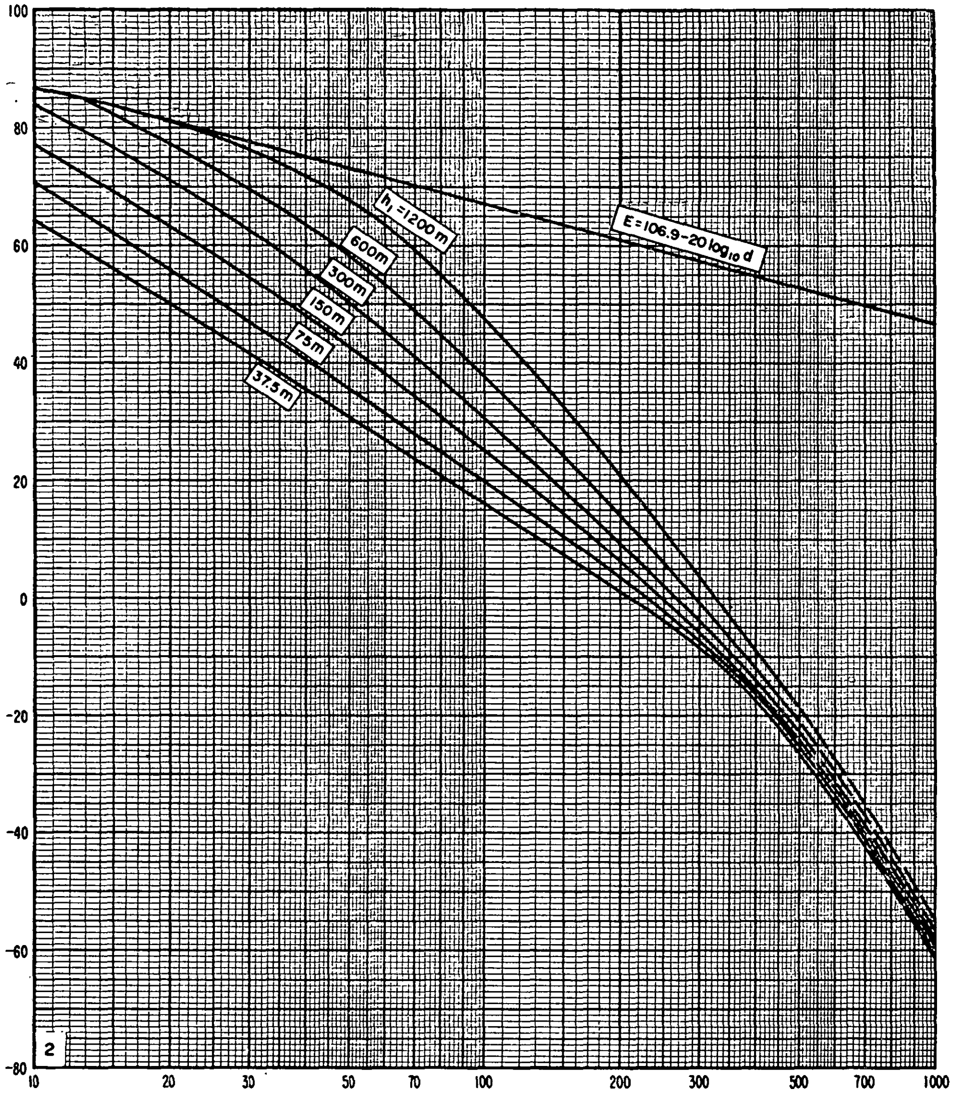


FIGURE 1

Types of climate referred to in the Report

1. Temperate (Mediterranean)
2. Desert (Saharan)
3. Sub-tropical (continental)
4. Sub-tropical (maritime)
5. Equatorial
6. Temperate (continental)



Distance (km)

FIGURE 2

Values of E (50,50) for a temperate (Mediterranean) climate

Frequency: 40–250 Mc/s
h_1: as indicated on the curves
h_2: 10 m

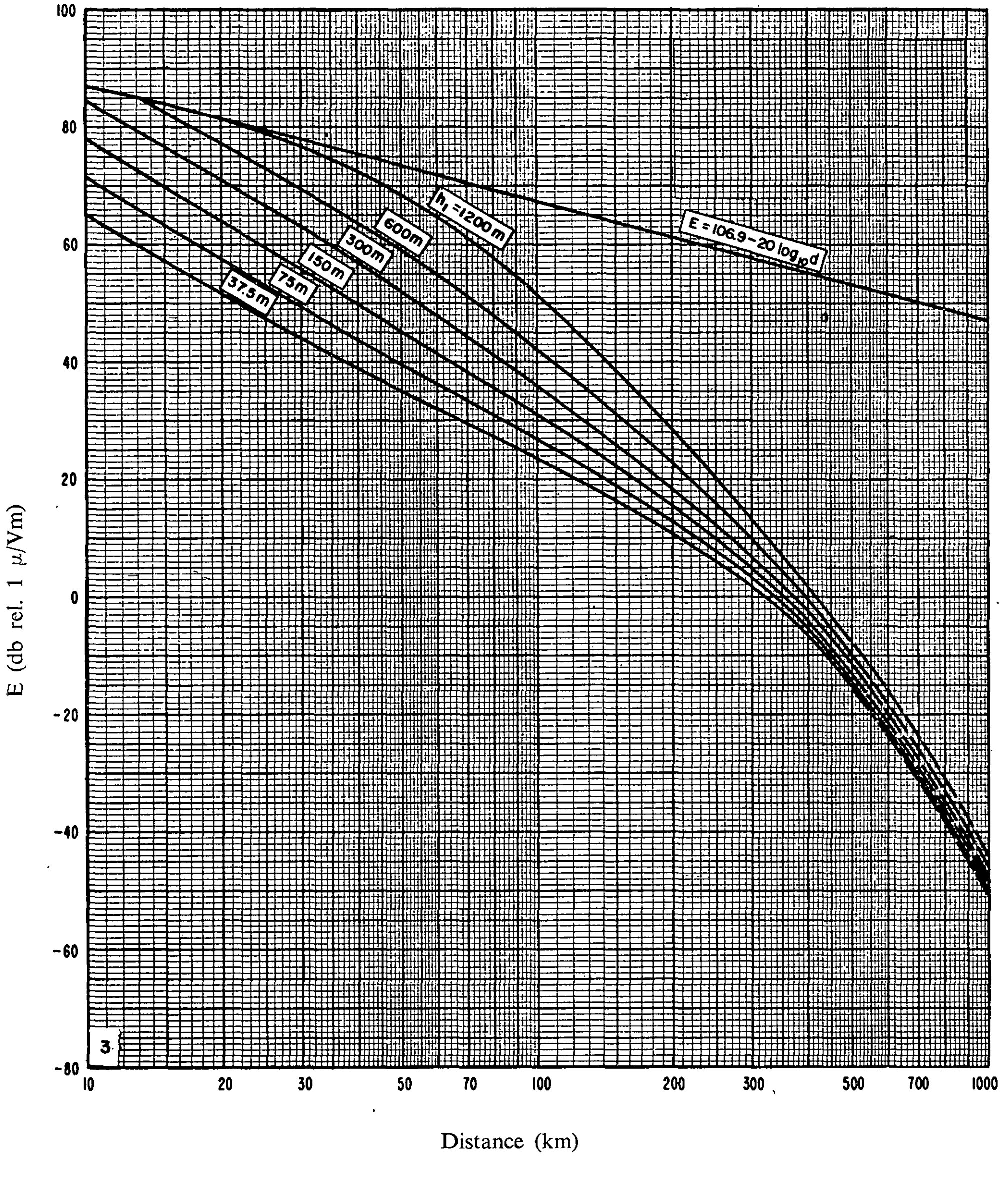


FIGURE 3

Values of E (50,10) for a temperate (Mediterranean) climate

Frequency: 40–250 Mc/s
h_1: as indicated on the curves
h_2: 10 m

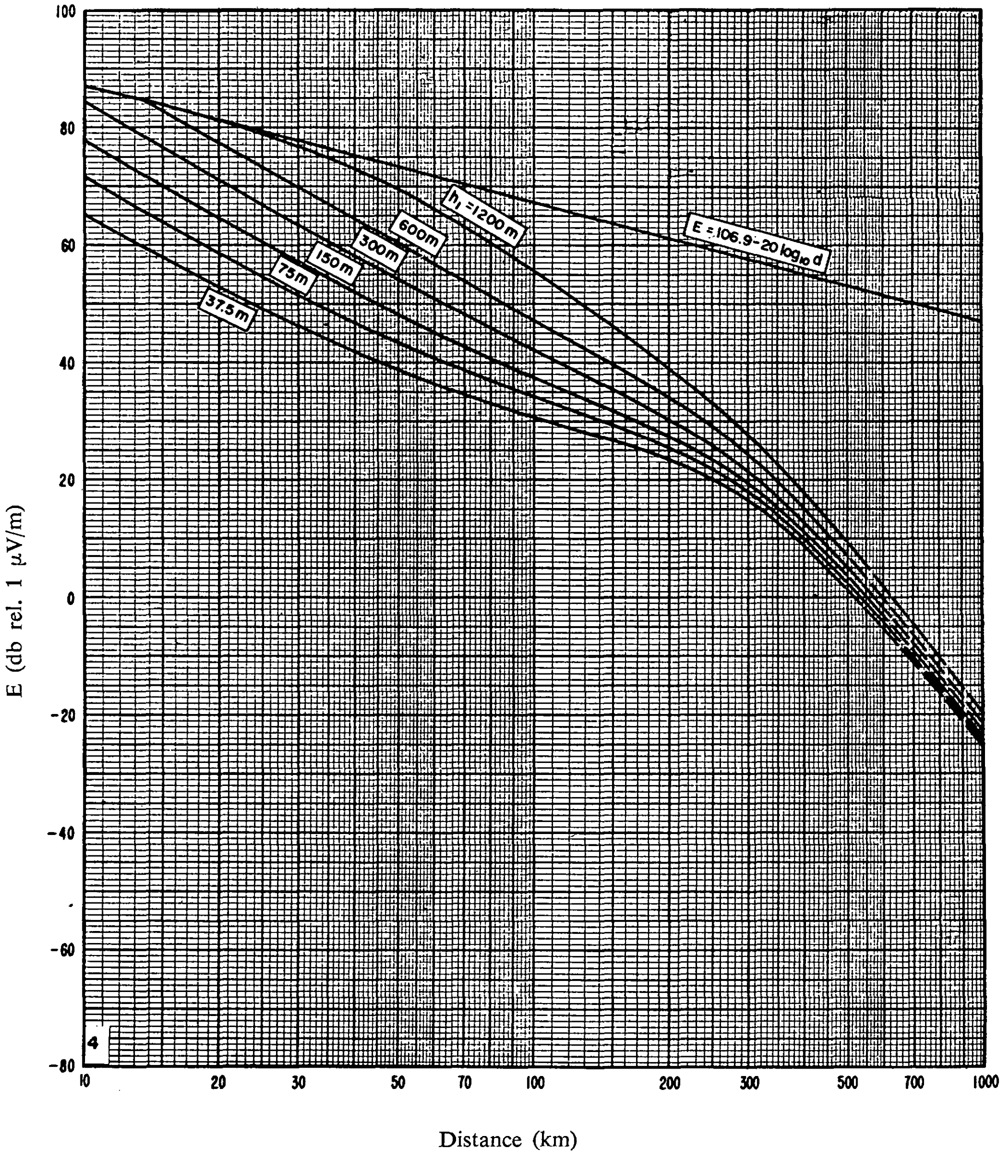


FIGURE 4

Values of E (50,1) for a temperate (Mediterranean) climate

Frequency: 40–250 Mc/s
h_1: as indicated on the curves
h_2: 10 m

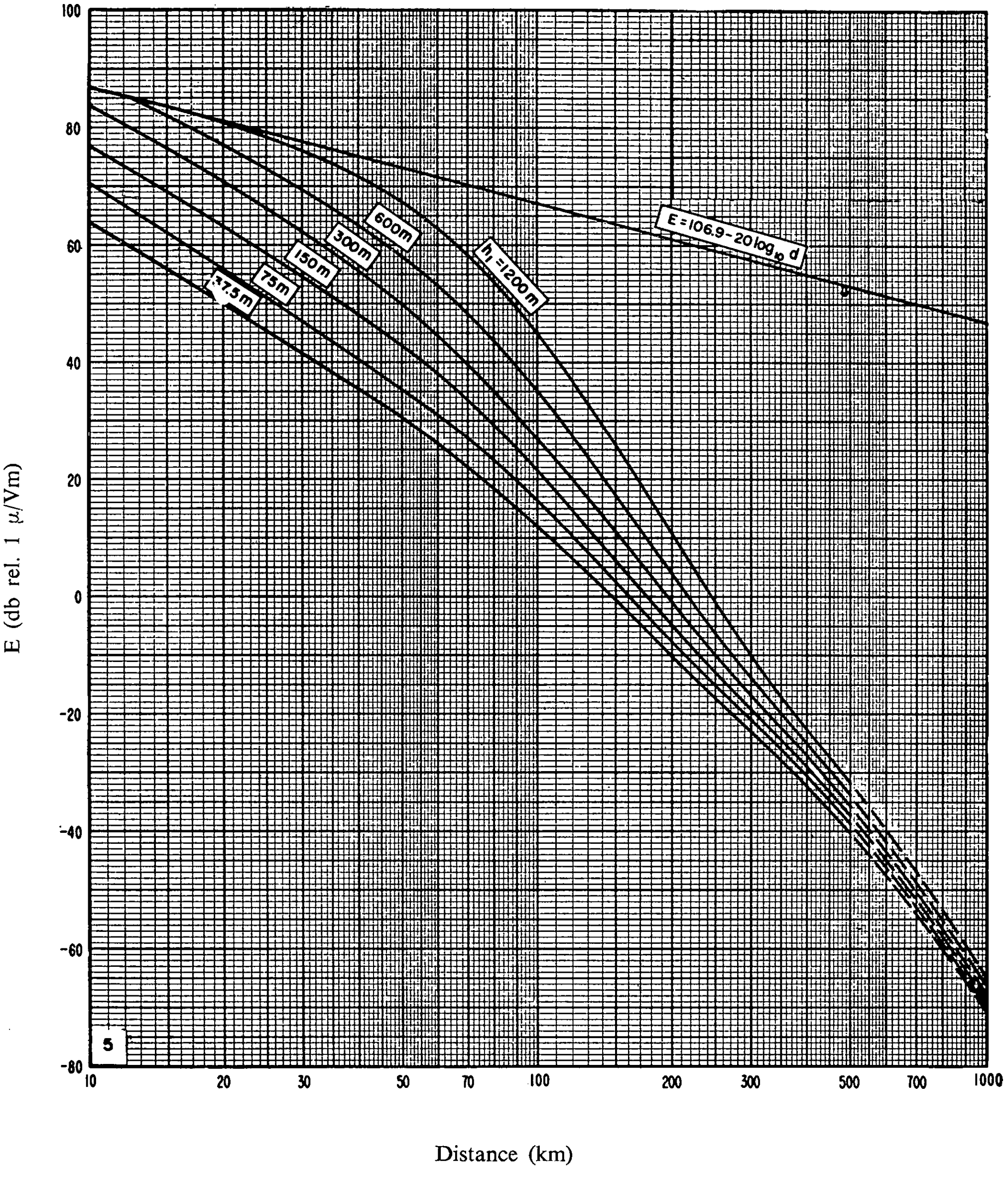


FIGURE 5

Values of E (50,50) for a desert (Saharan) climate

Frequency: 40–250 Mc/s
h_1: as indicated on the curves
h_2: 10 m

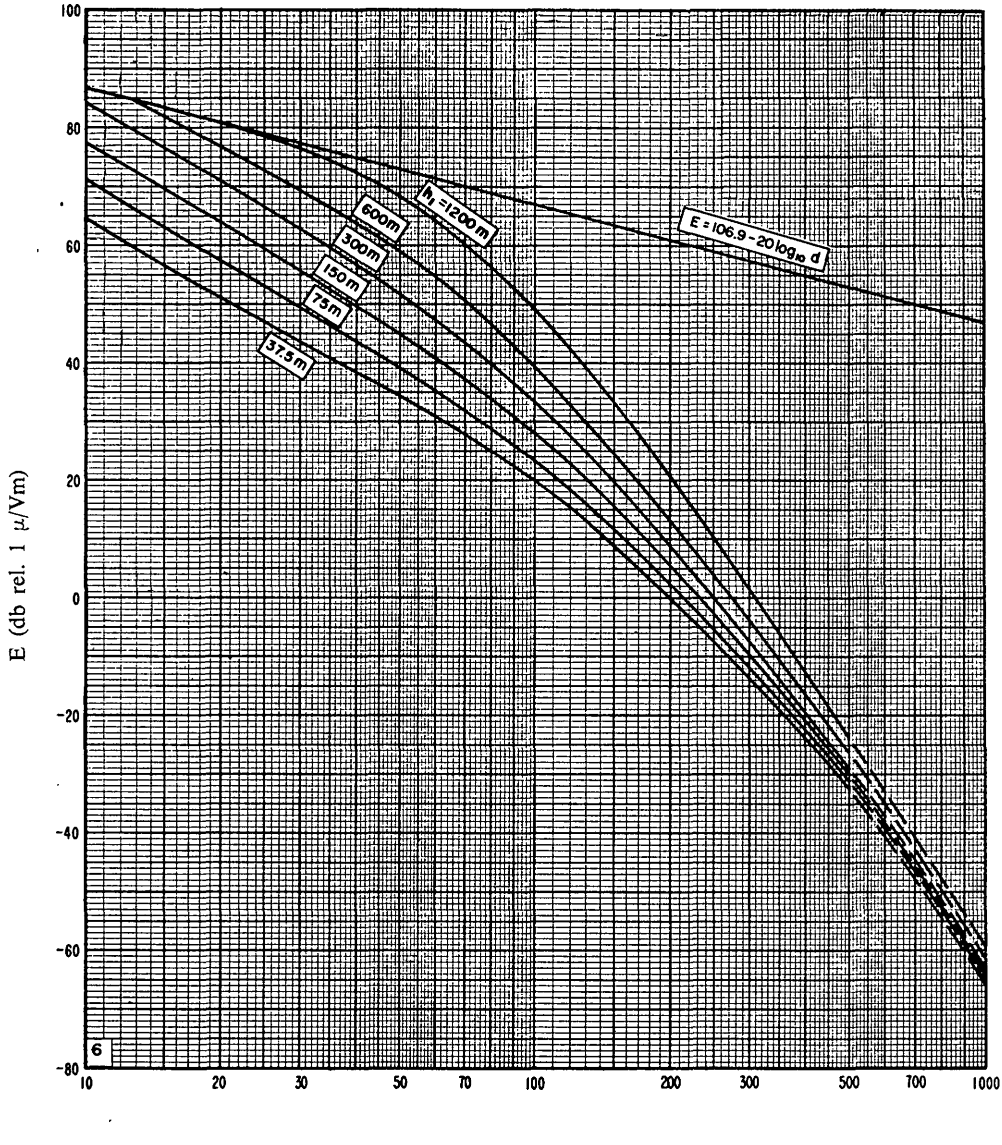


FIGURE 6

Value of E (50,10) for a desert (Saharan) climate

Frequency: 40–250 Mc/s
h_1: as indicated on the curves
h_2: 10 m

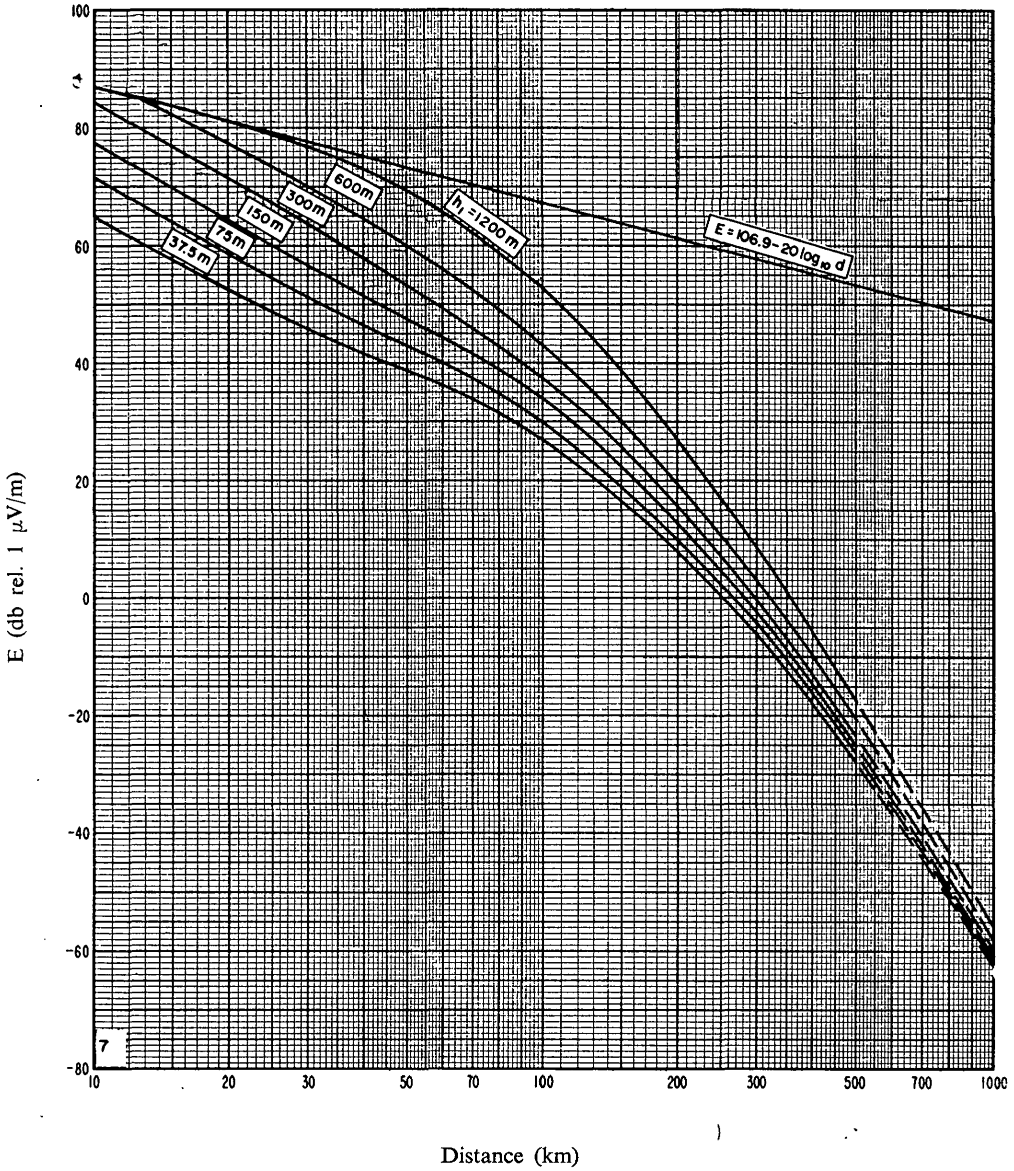


FIGURE 7

Values of E (50,1) for a desert (Saharan) climate

Frequency: 40–250 Mc/s
h_1: as indicated on the curves
h_2: 10 m

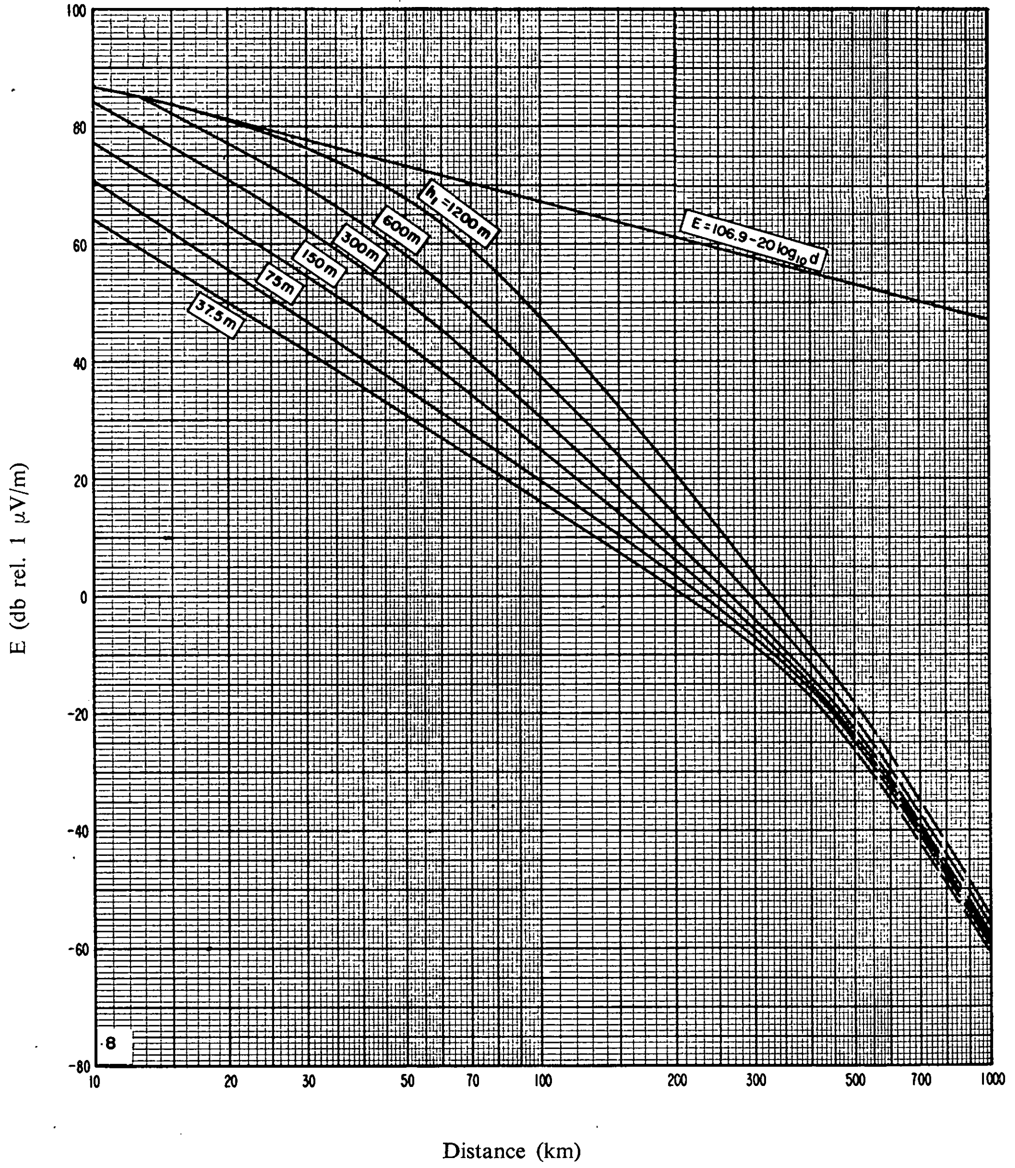


FIGURE 8

Values of E (50,50) for a sub-tropical (continental) climate

Frequency: 40–250 Mc/s

h_1: as indicated on the curves

h_2: 10 m

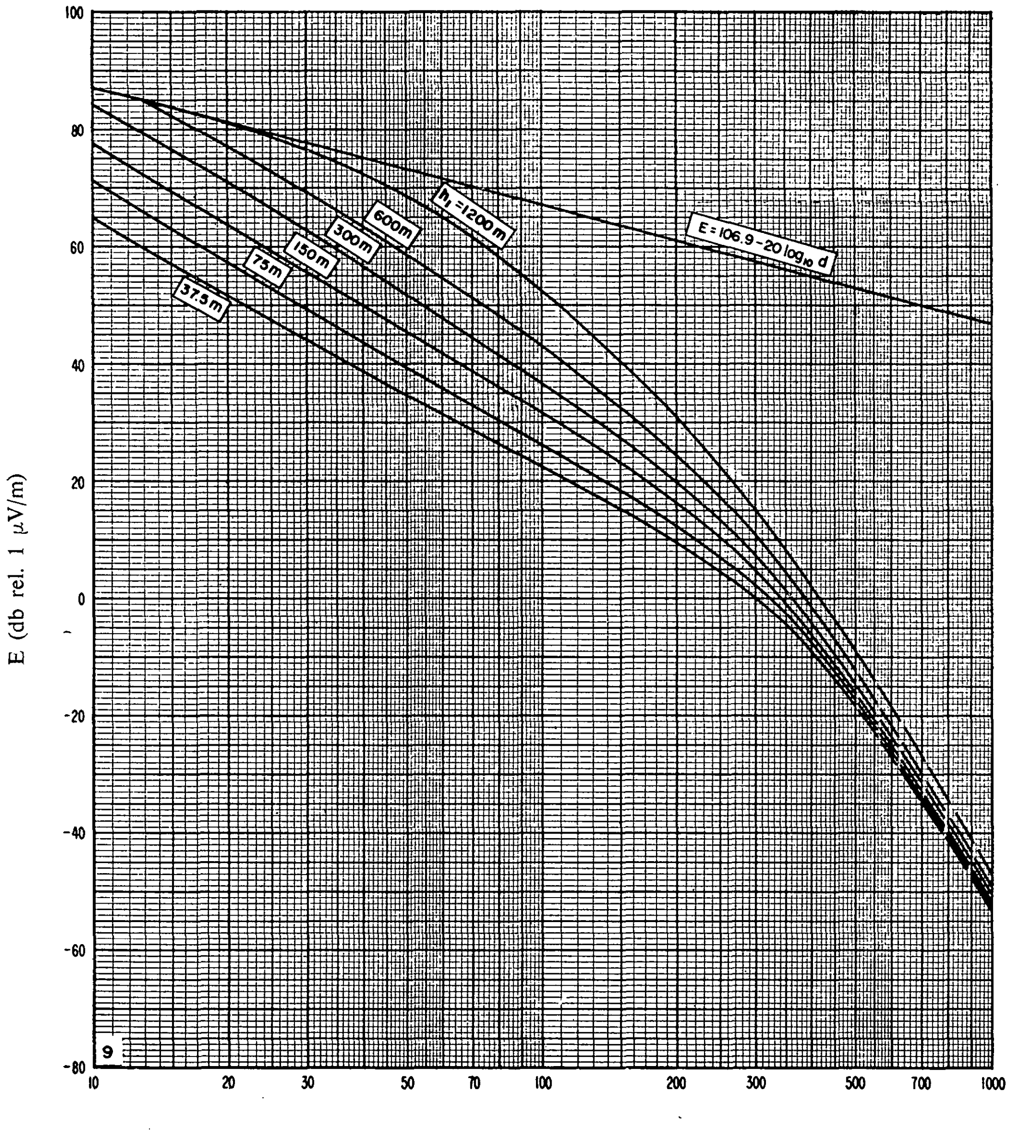
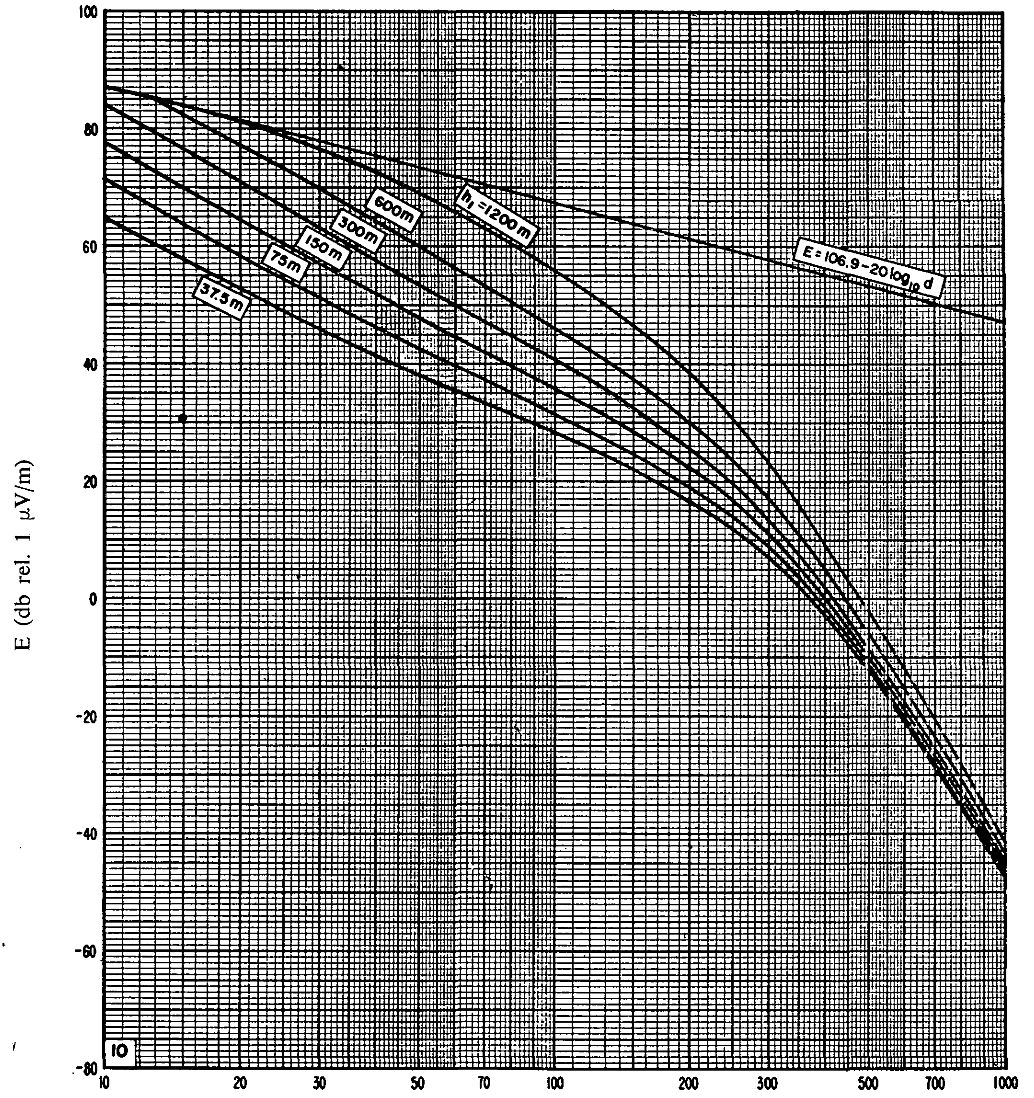


FIGURE 9

Values of E (50,10) for a sub-tropical (continental) climate

Frequency: 40–250 Mc/s
h_1: indicated as on the curves
h_2: 10 m



Distance (km)

FIGURE 10

Values of E (50,1) for a sub-tropical (continental) climate

Frequency: 40–250 Mc/s
h_1: as indicated on the curves
h_2: 10 m

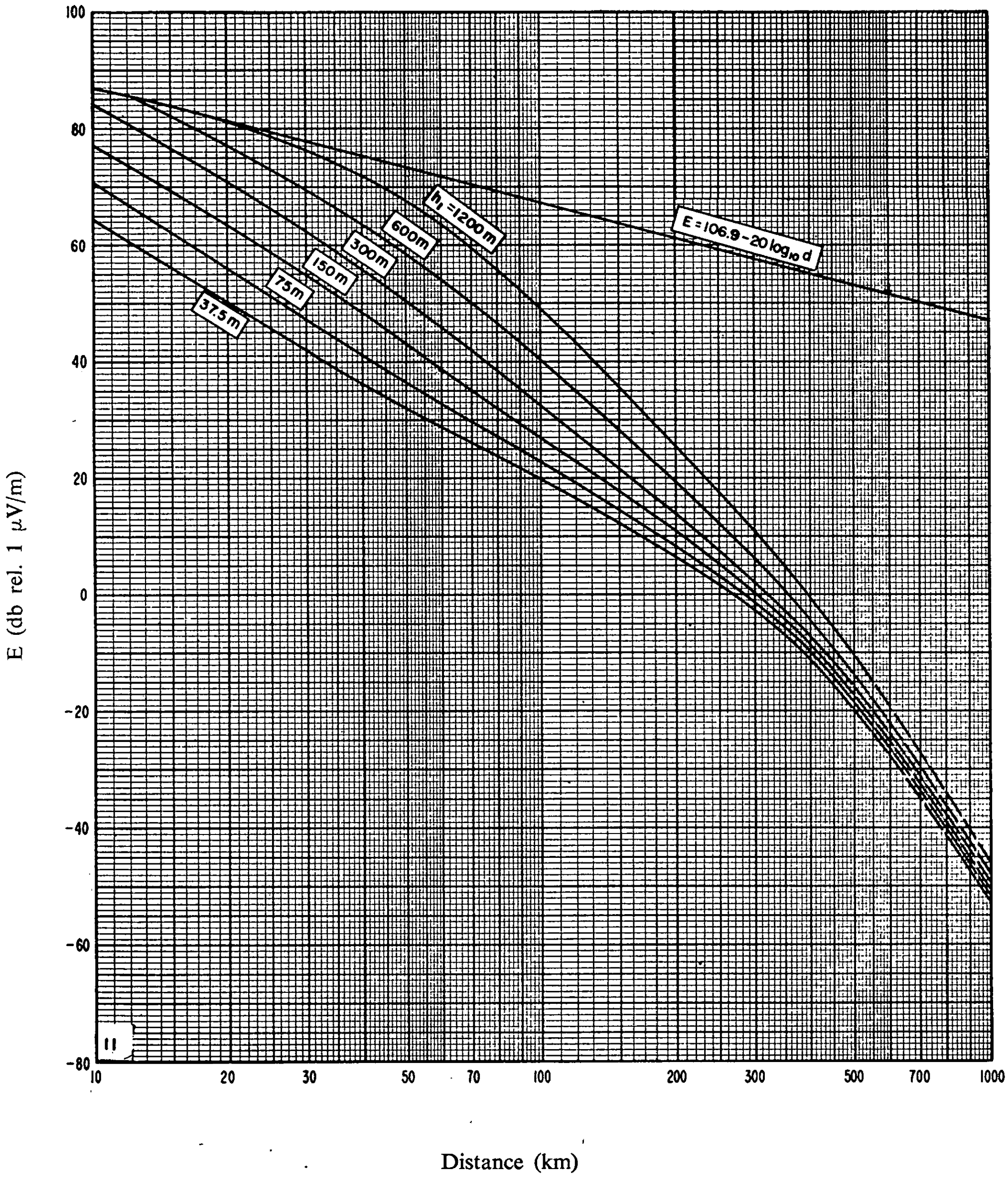


FIGURE 11

Values of E (50,50) for a sub-tropical (maritime) climate

Frequency: 40–250 Mc/s

h_1: as indicated on the curves

h_2: 10 m

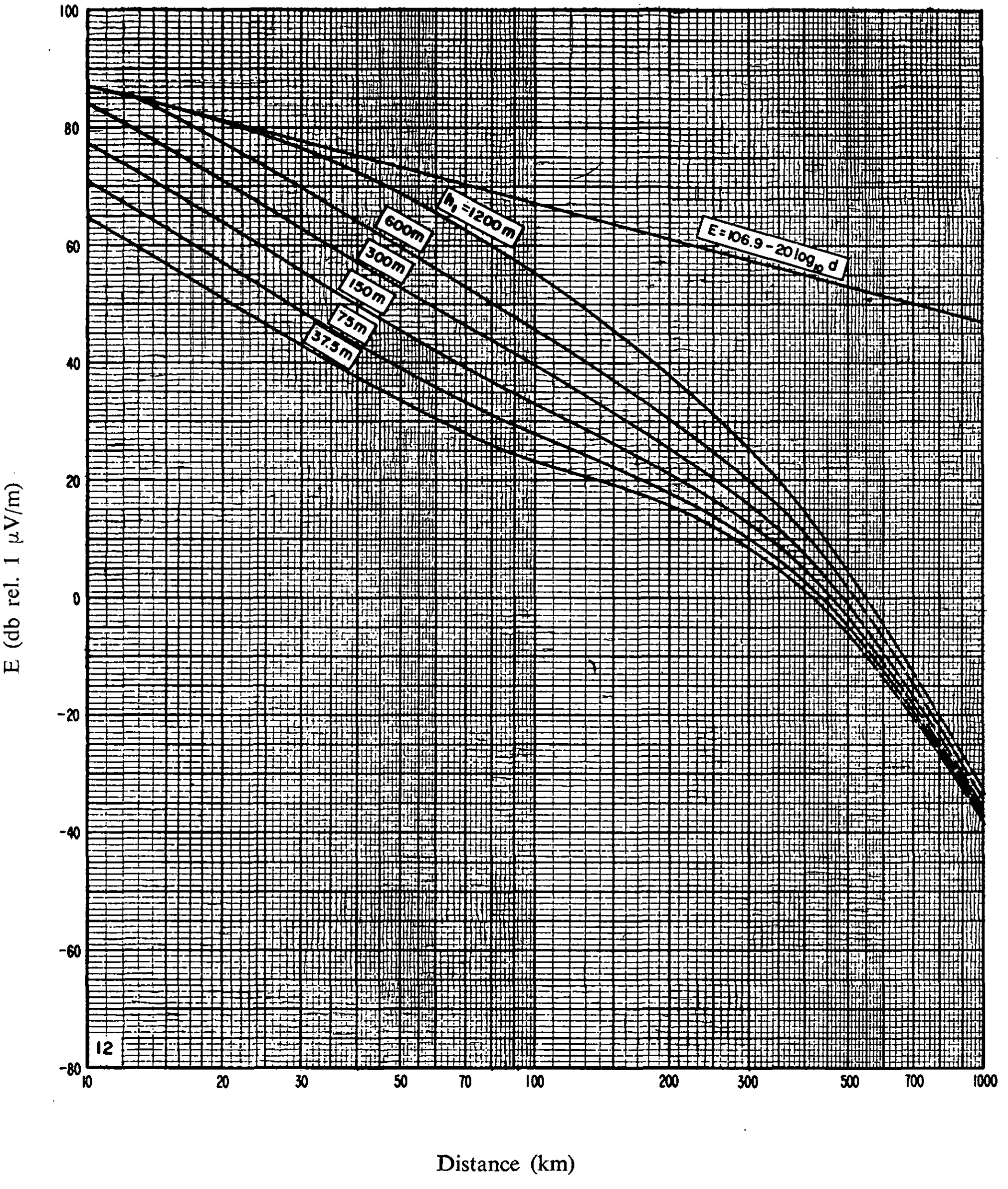


FIGURE 12

Values of E (50,10) for a sub-tropical (maritime) climate

Frequency: 40–250 Mc/s

h_1: as indicated on the curves

h_2: 10 m

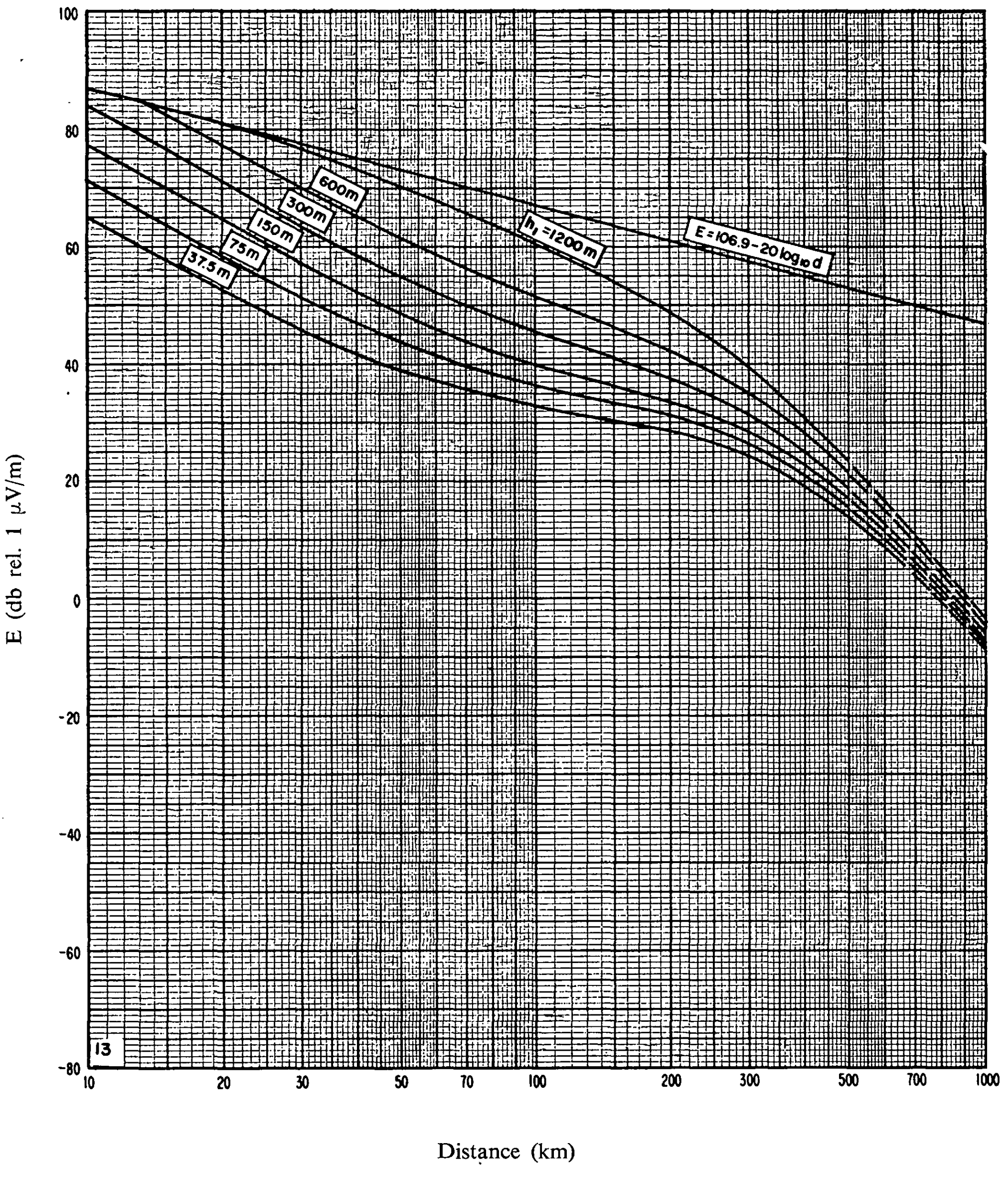


FIGURE 13

Values of E (50,1) for a sub-tropical (maritime) climate

Frequency: 40–250 Mc/s
h_1: as indicated on the curves
h_2: 10 m

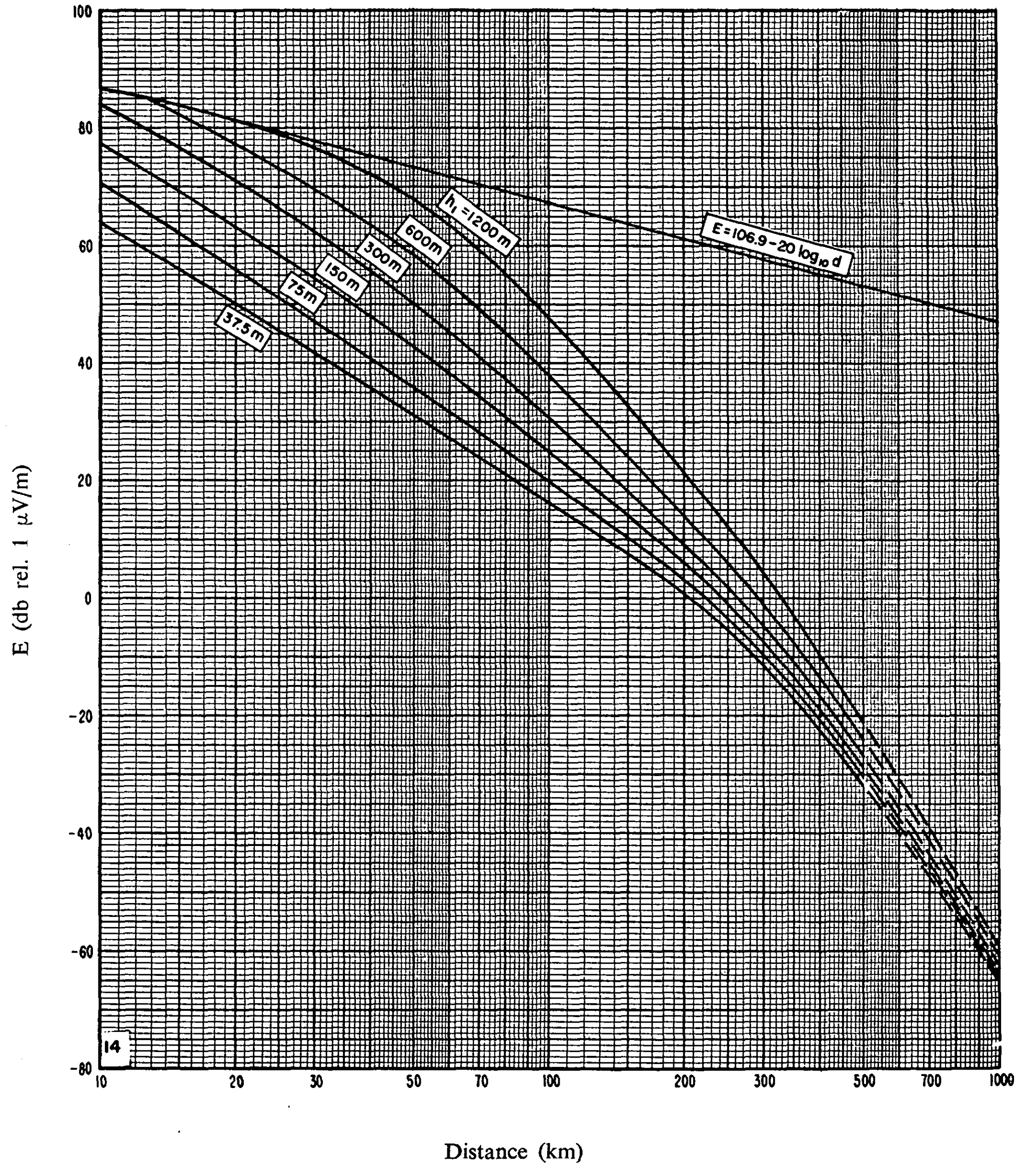


FIGURE 14

Values of E (50,50) for an equatorial climate

Frequency: 40–250 Mc/s
h_1: as indicated on the curves
h_2: 10 m

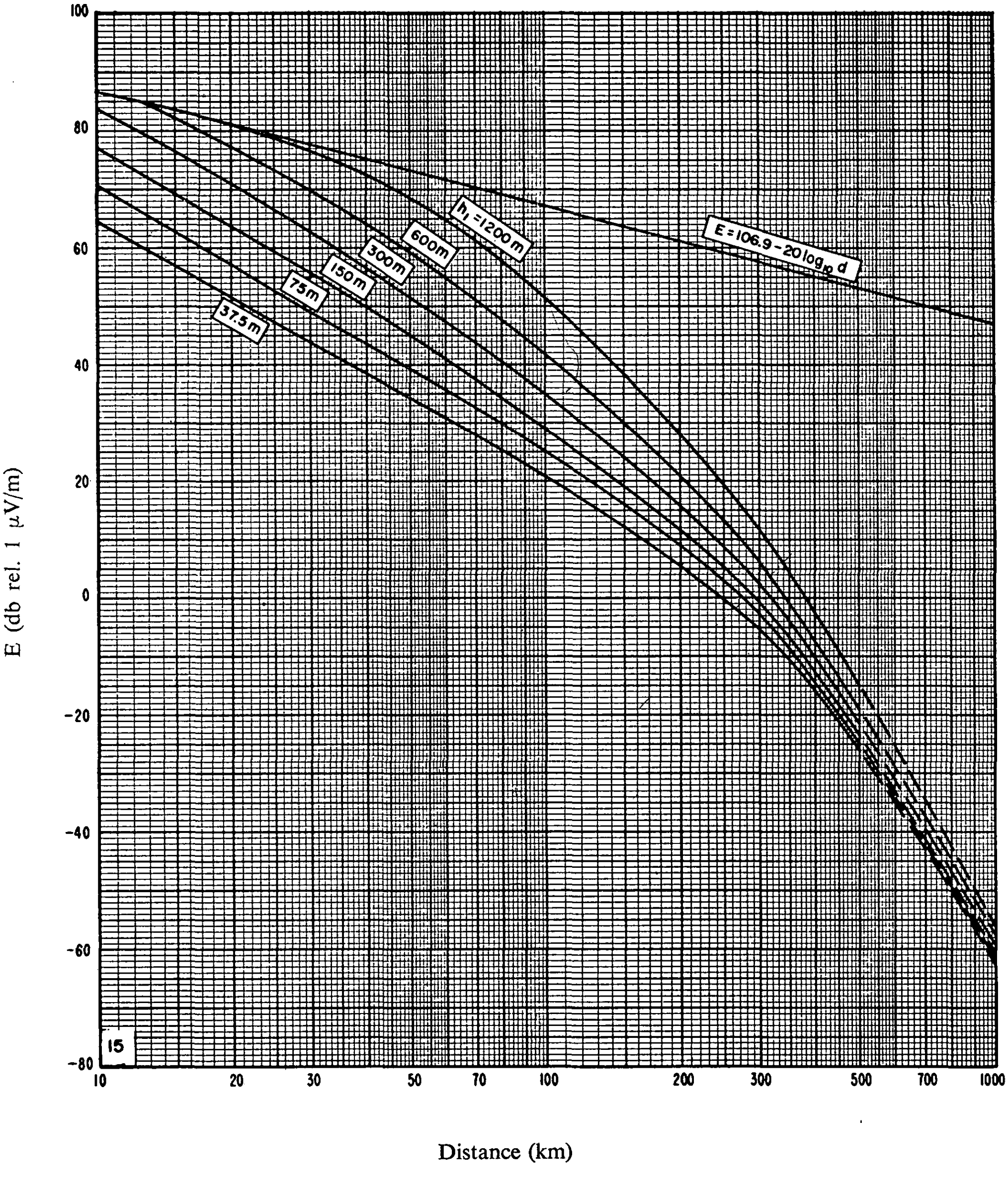


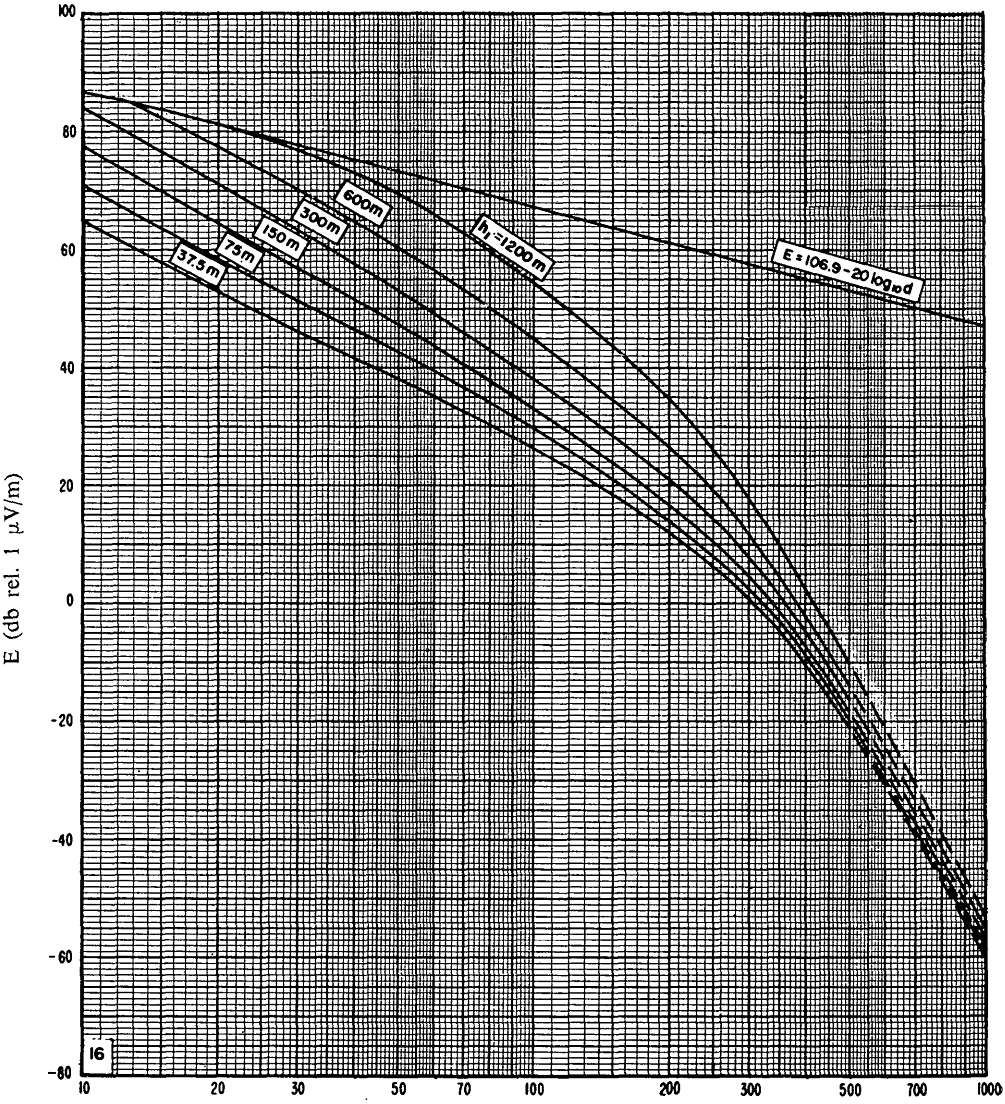
FIGURE 15

Values of E (50,10) for an equatorial climate

Frequency: 40–250 Mc/s

h_1: as indicated on the curves

h_2: 10 m



Distance (km)

FIGURE 16

Values of E (50,1) for an equatorial climate

Frequency: 40–250 Mc/s

h_1: as indicated on the curves

h_2: 10 m

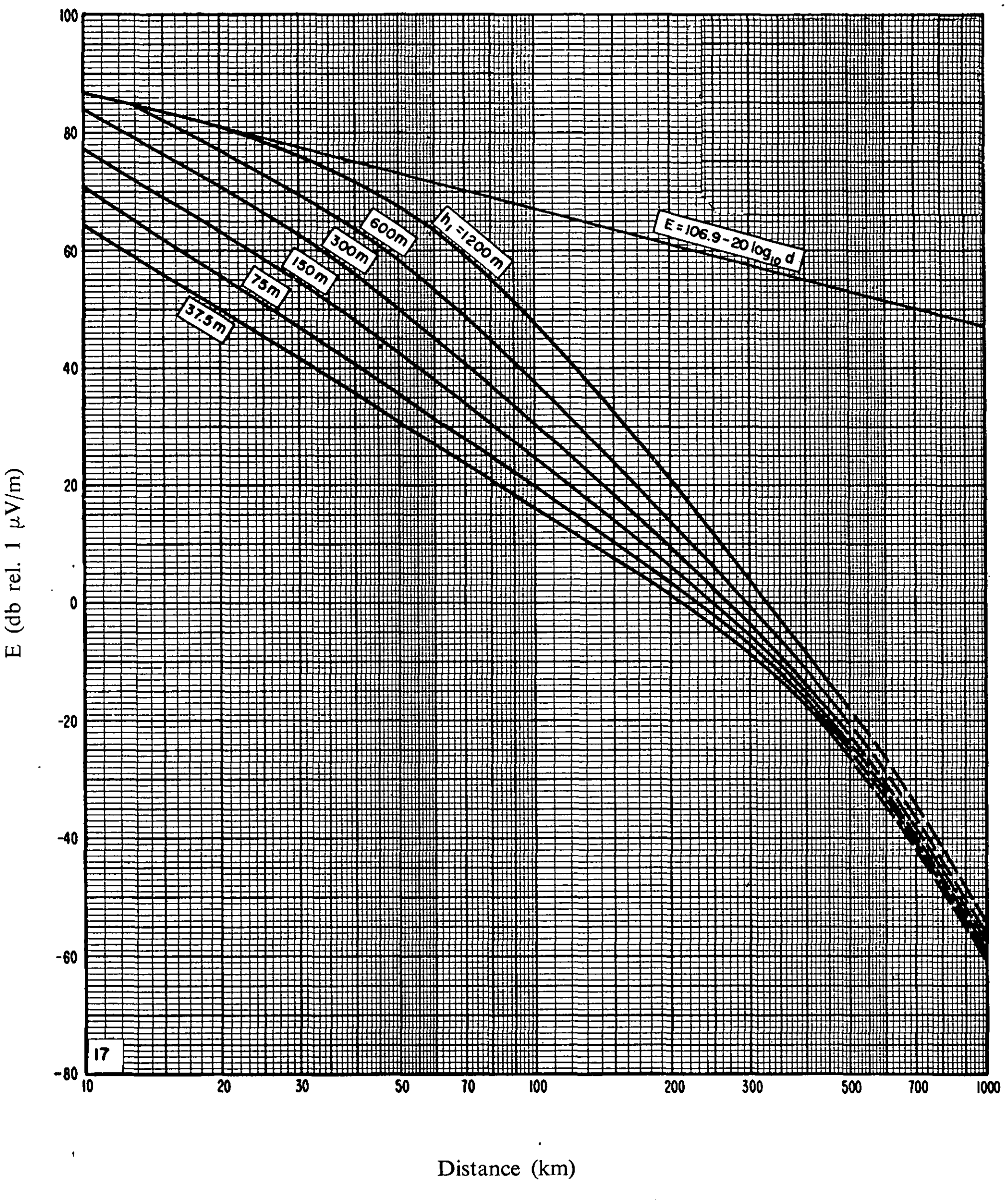


FIGURE 17

Values of E (50,50) for a temperate (continental) climate

Frequency: 40–250 Mc/s

h_1: as indicated on the curves

h_2: 10 m

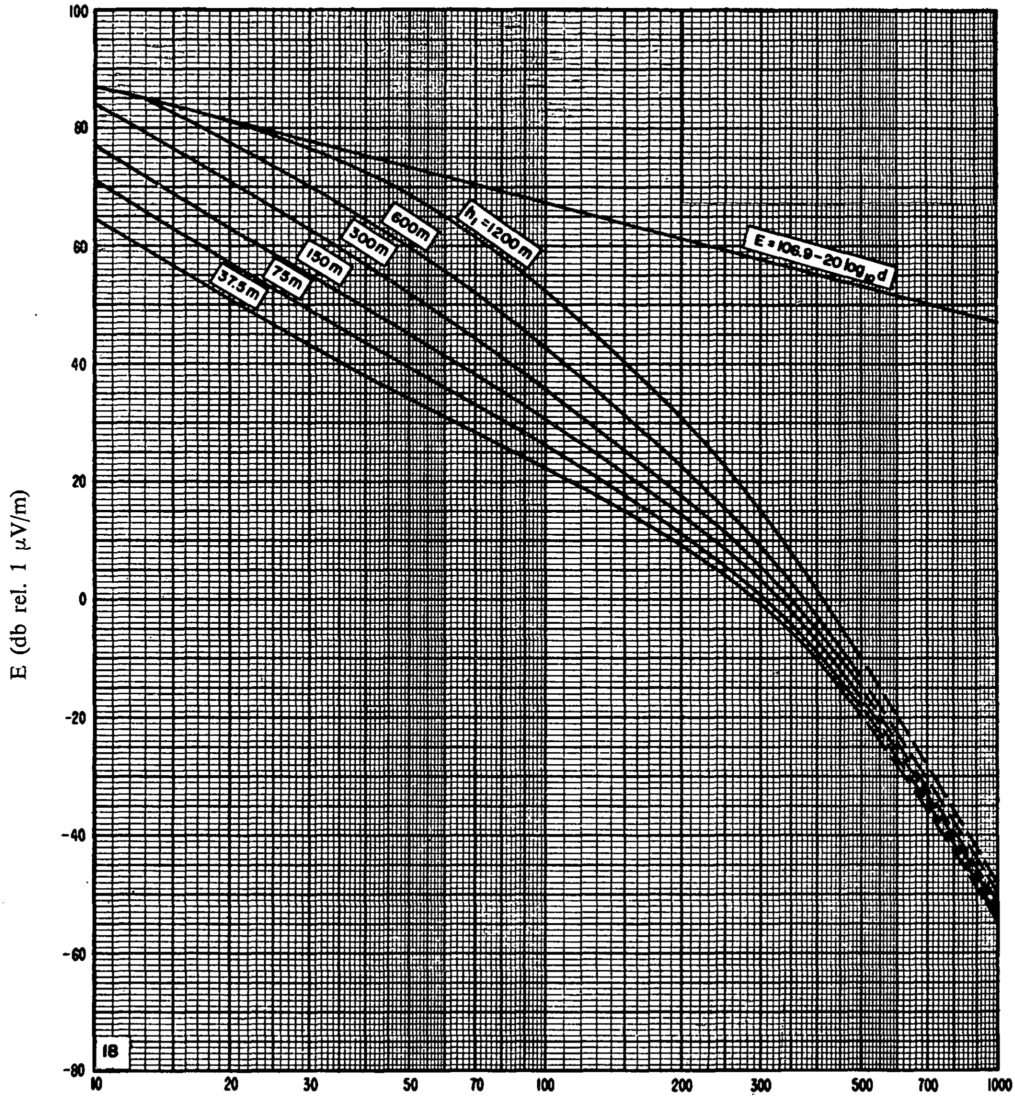


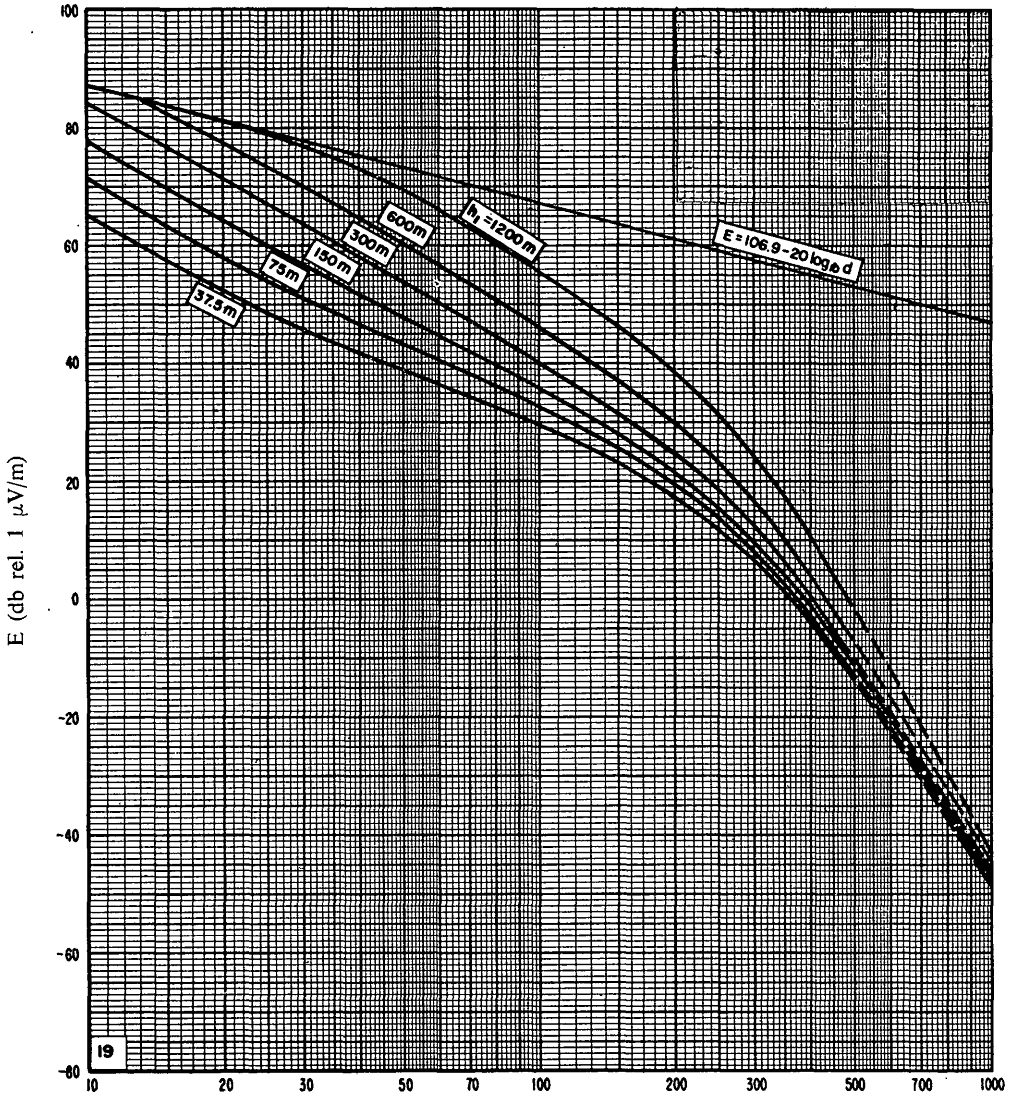
FIGURE 18

Values of E (50,10) for a temperate (continental) climate

Frequency: 40–250 Mc/s

h_1: as indicated on the curves

h_2: 10 m



Distance (km)

FIGURE 19

Values of E (50,1) for a temperate (continental) climate

Frequency: 40–250 Mc/s

h_1: as indicated on the curves

h_2: 10 m

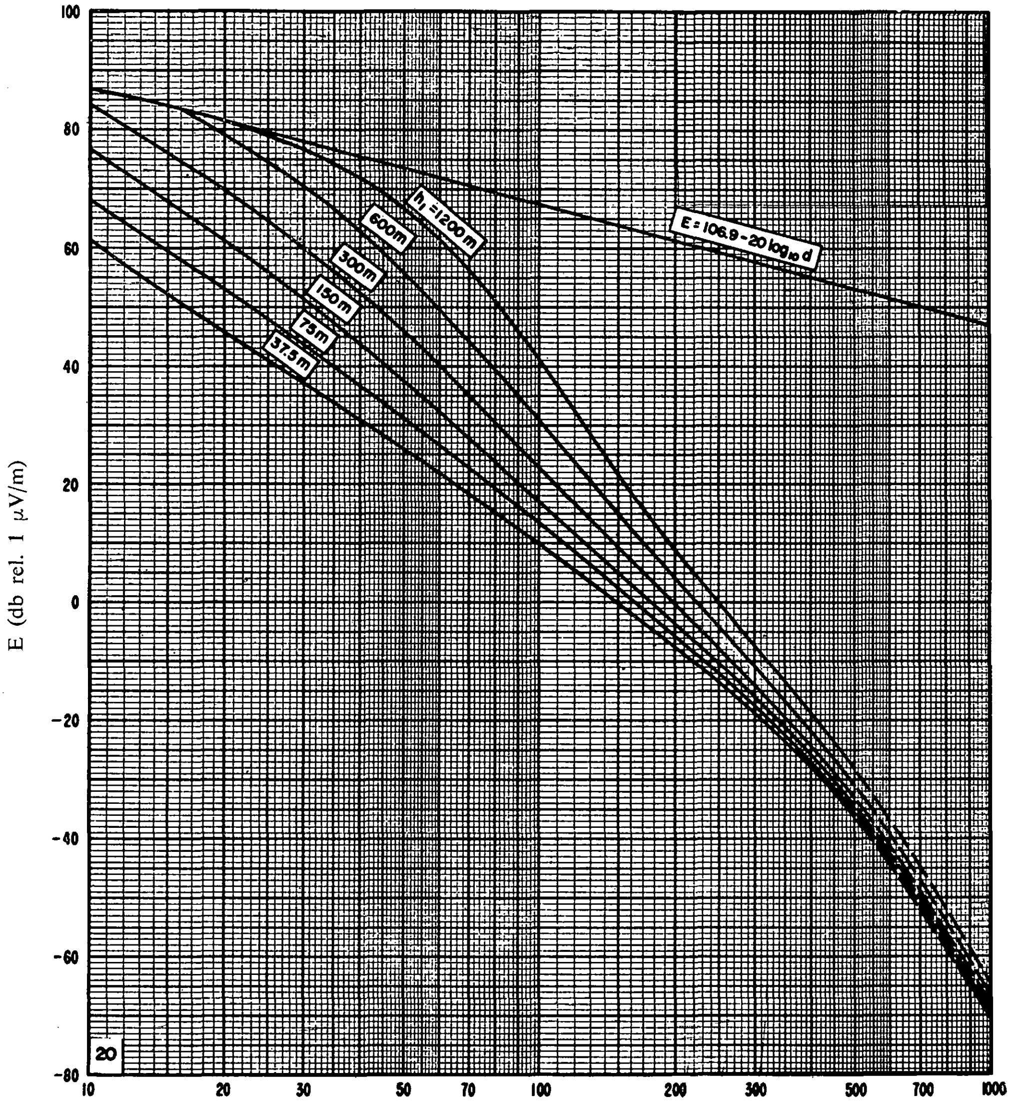


FIGURE 20

Values of E (50,50) for a temperate (Mediterranean) climate

Frequency: 450–1000 Mc/s

h_1: as indicated on the curves

h_2: 10 m

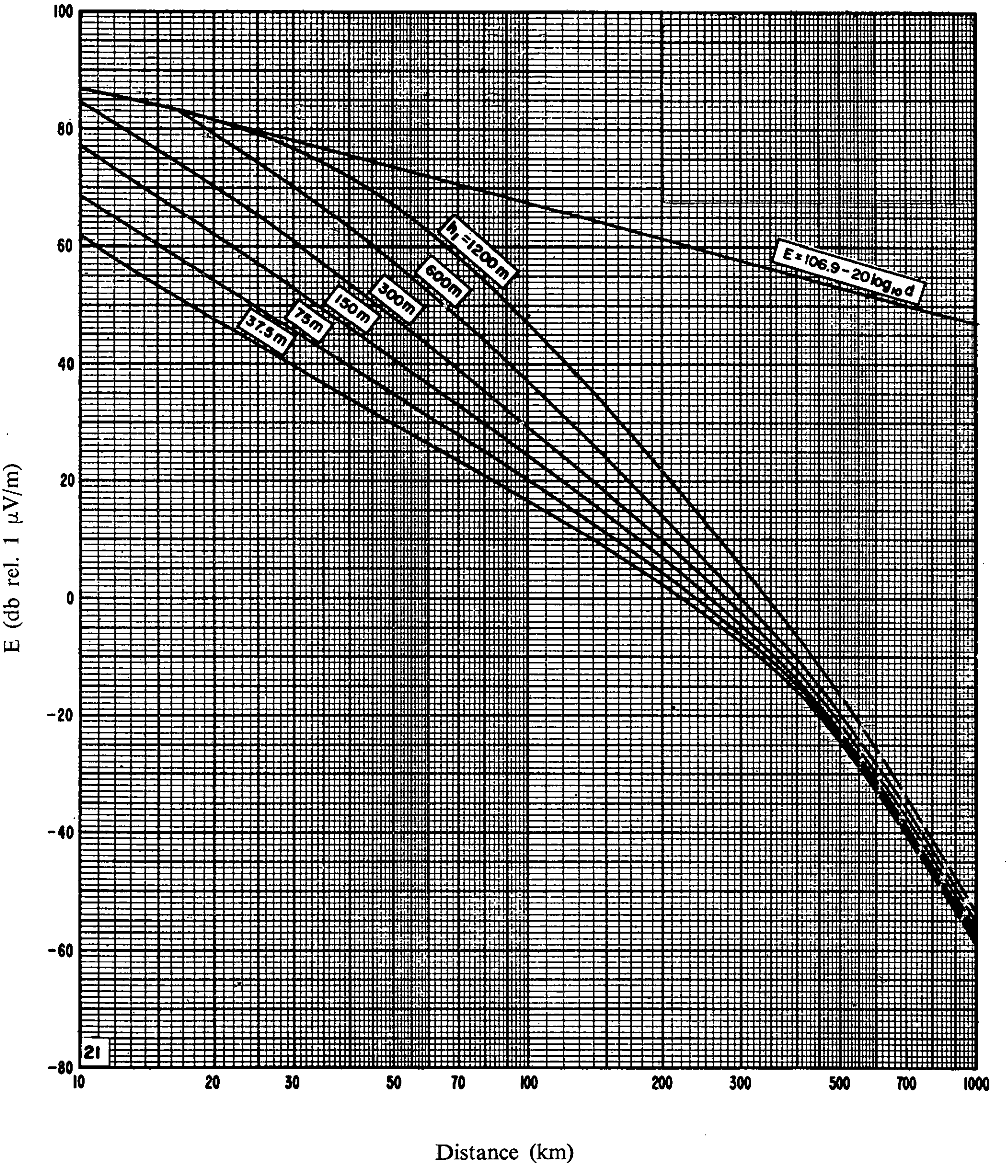


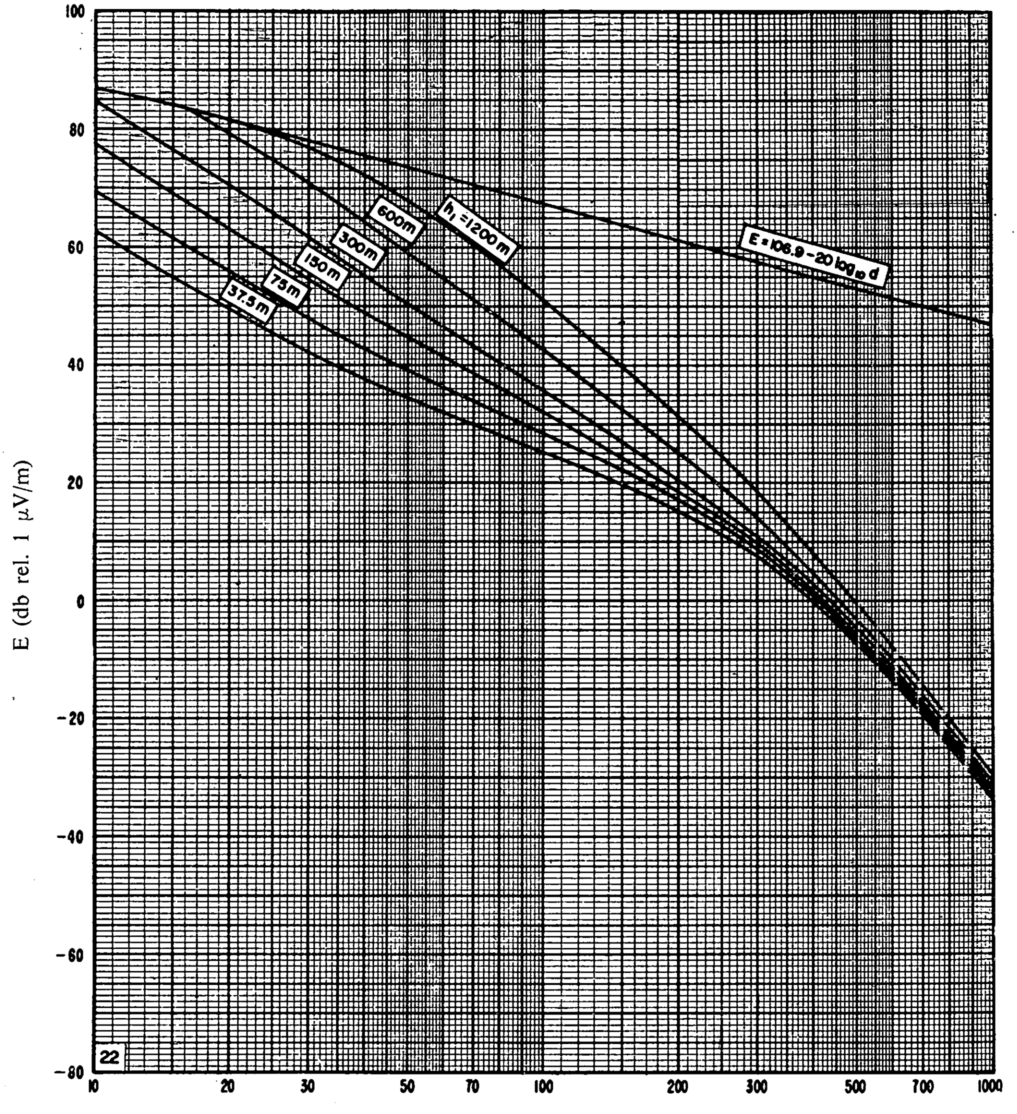
FIGURE 21

Values of E (50,10) for a temperate (Mediterranean) climate

Frequency: 450–1000 Mc/s

h_1: as indicated on the curves

h_2: 10 m



Distance (km)

FIGURE 22

Values of E (50,1) for a temperate (Mediterranean) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

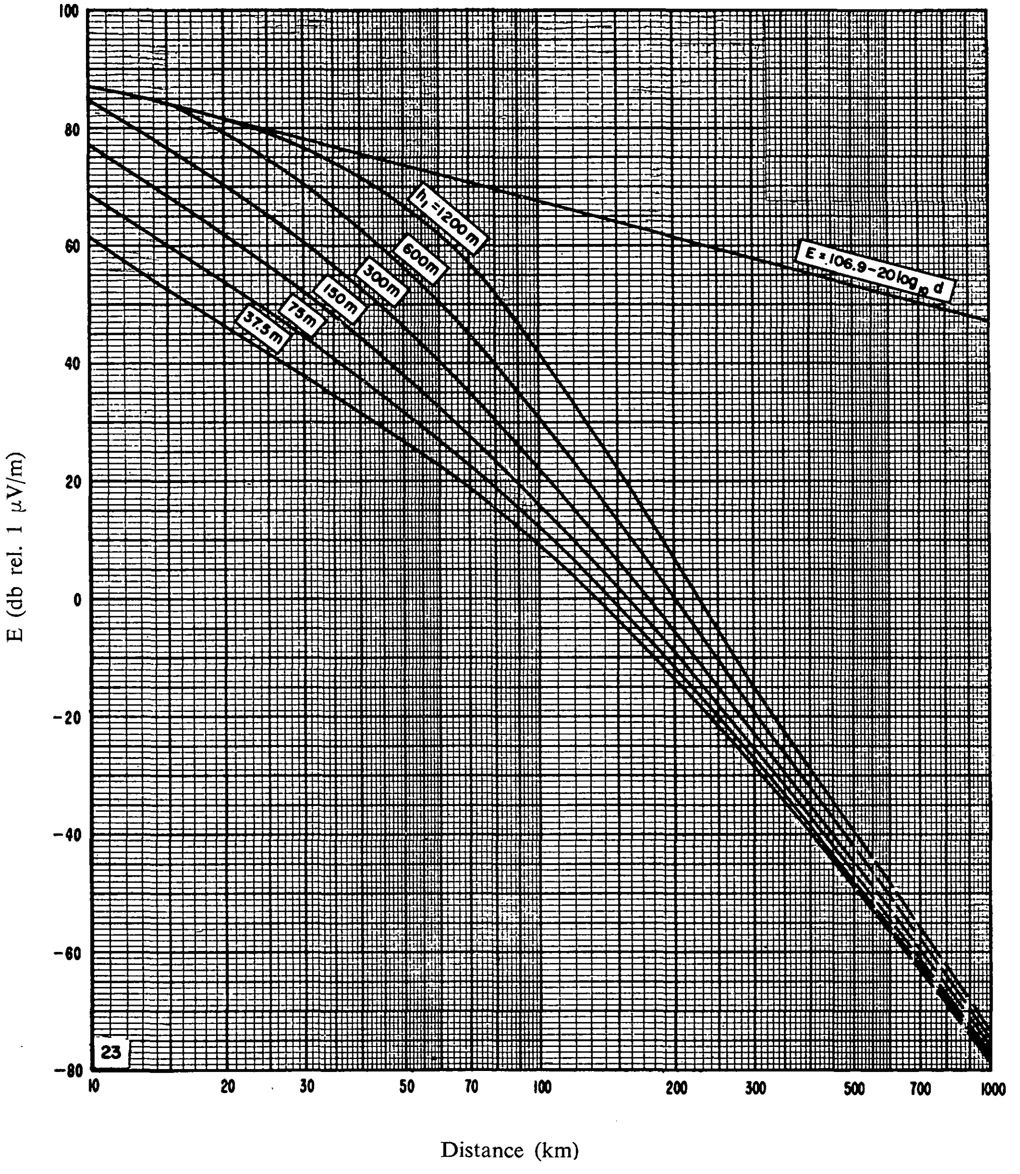


FIGURE 23

Values of E (50,50) for a desert (Saharan) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

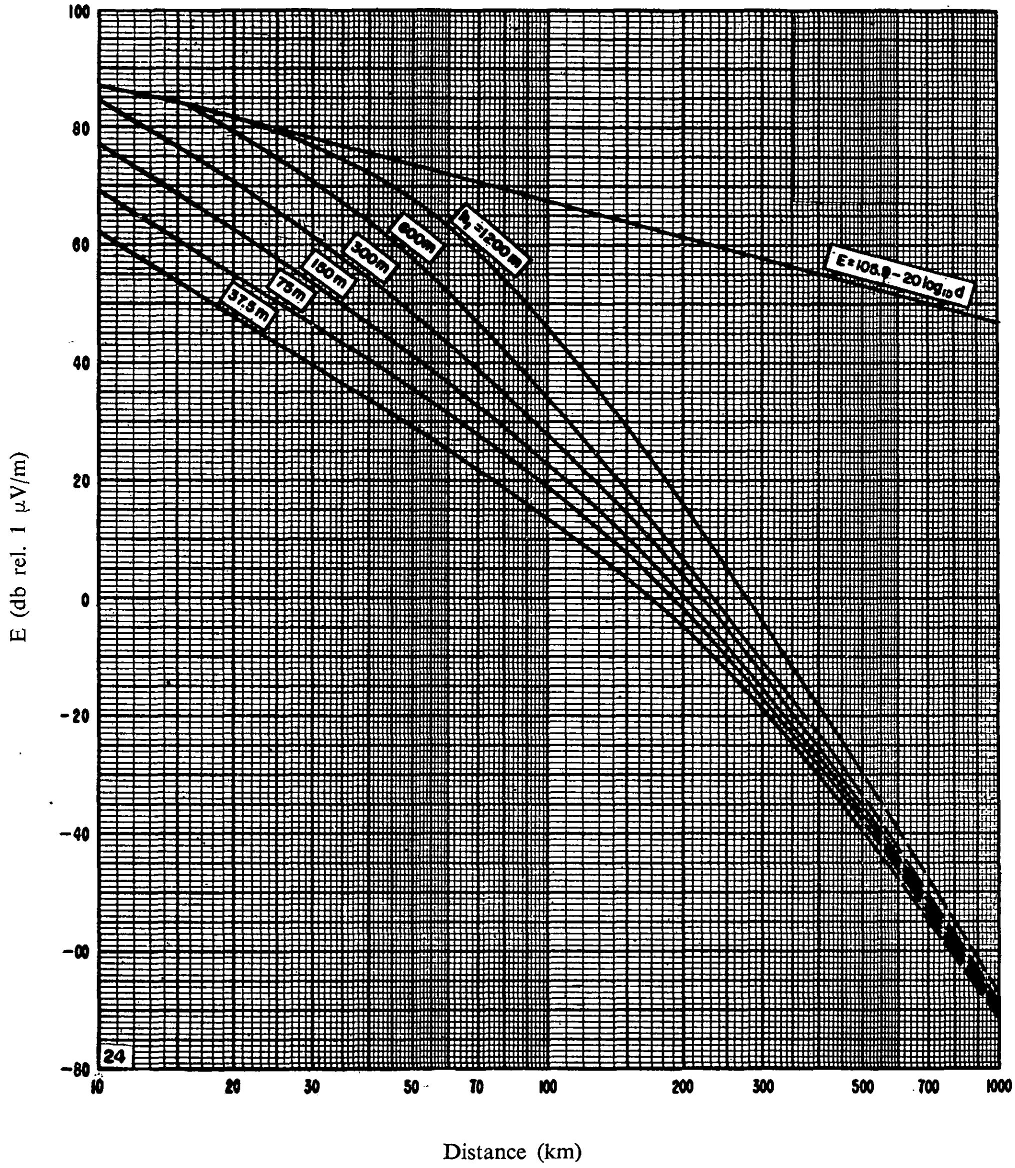
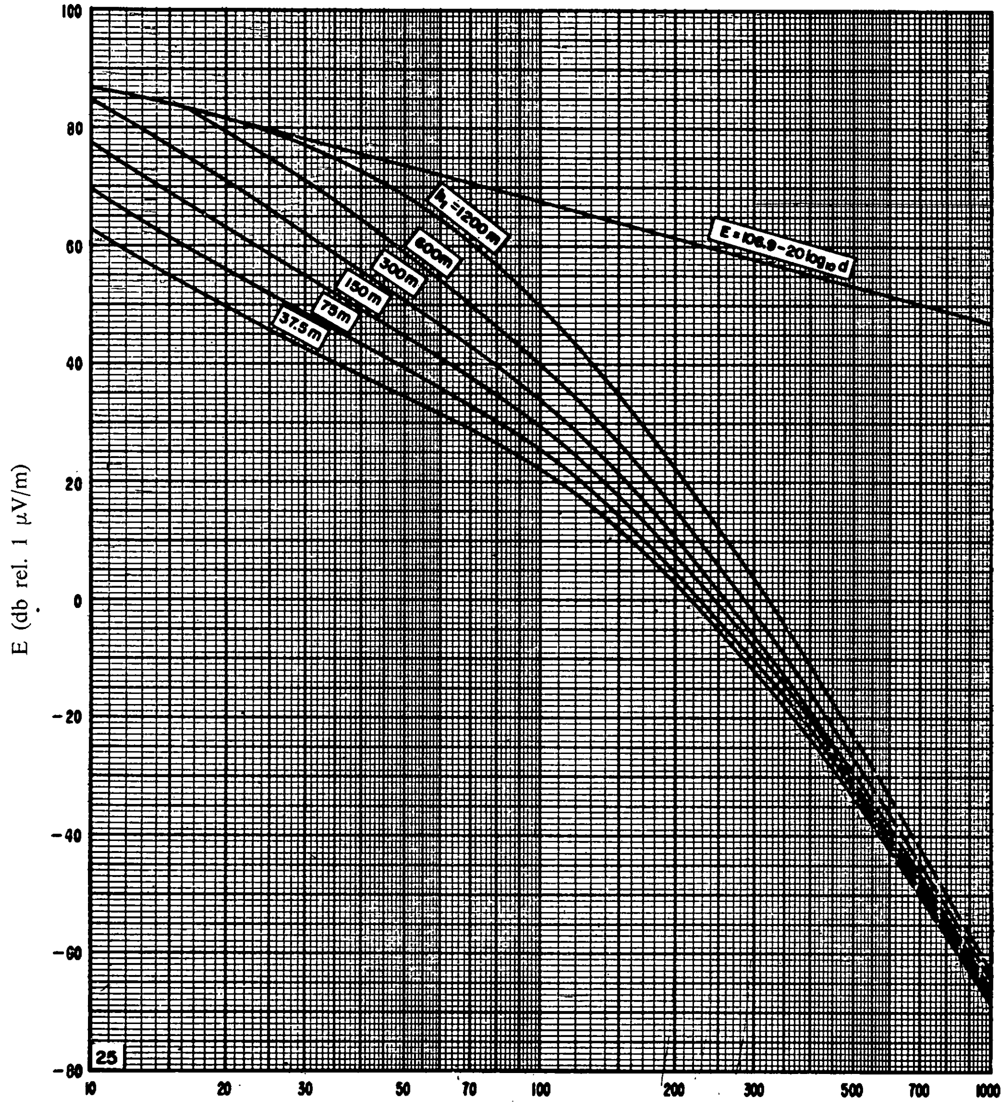


FIGURE 24

Values of E (50,10) for a desert (Saharan) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m



Distance (km)

FIGURE 25

Values of E (50,1) for a desert (Saharan) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

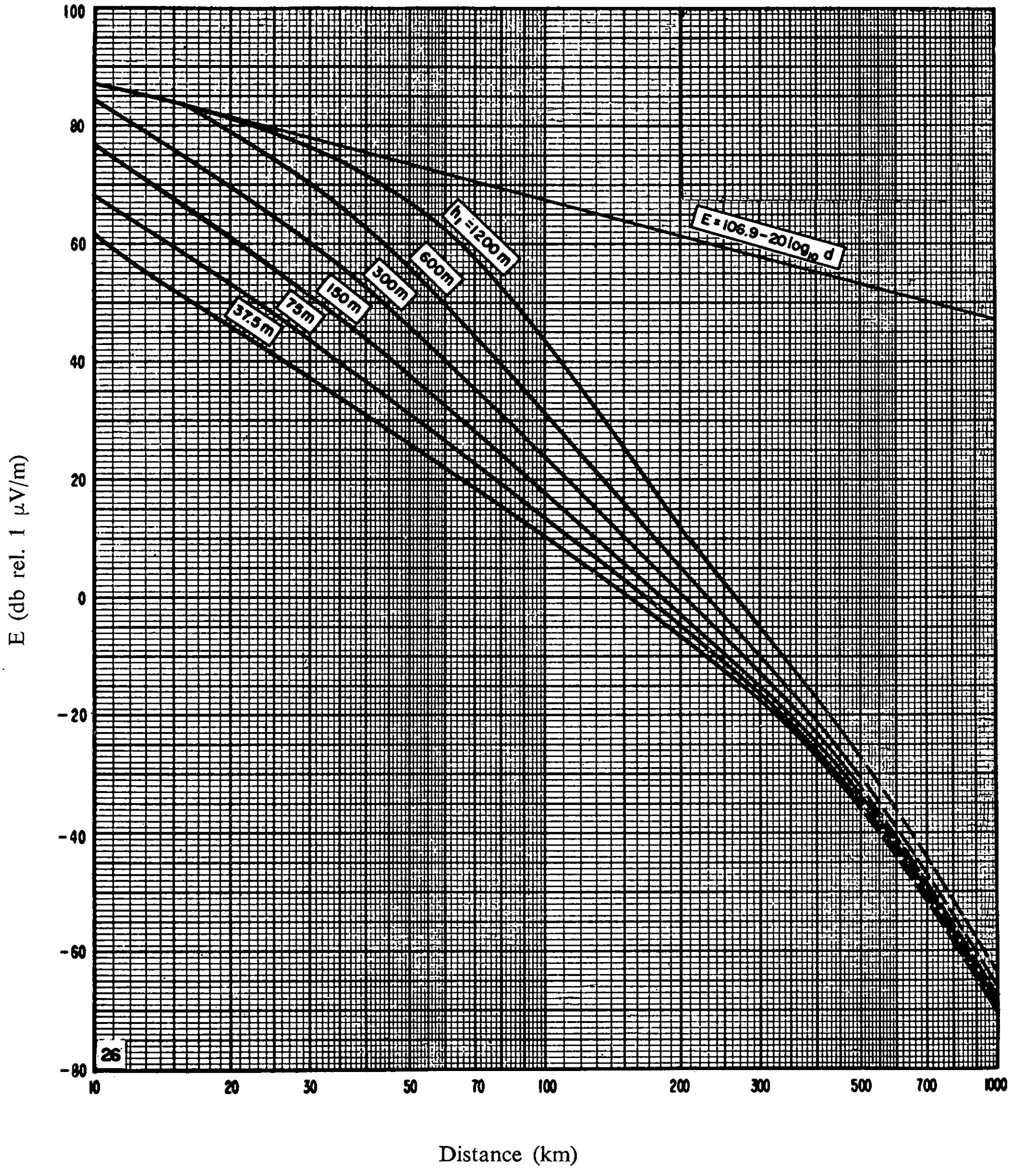
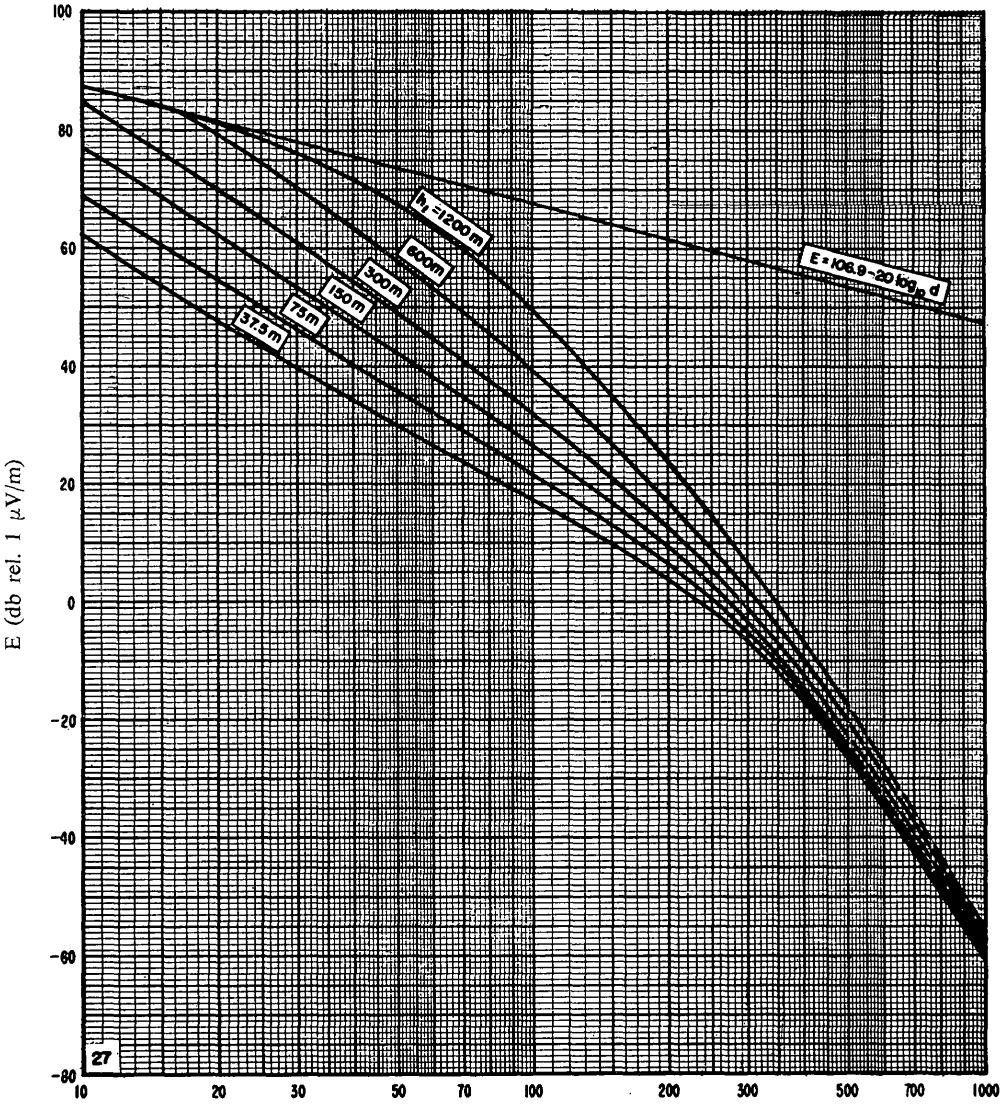


FIGURE 26

Values of E (50,50) for a sub-tropical (continental) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m



Distance (km)

FIGURE 27

Values of E (50,10) for a sub-tropical (continental) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

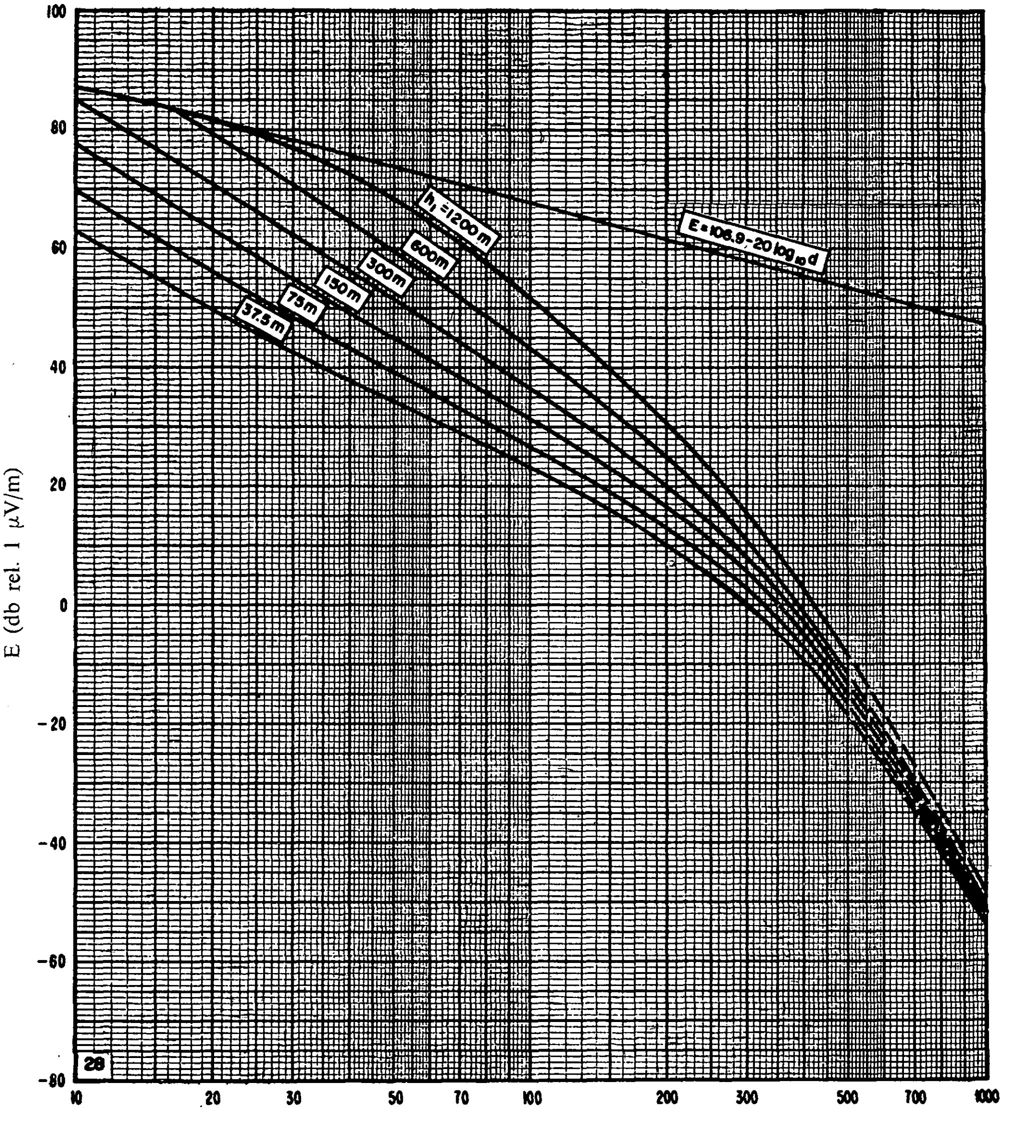


FIGURE 28

Value of E (50,1) for a sub-tropical (continental) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

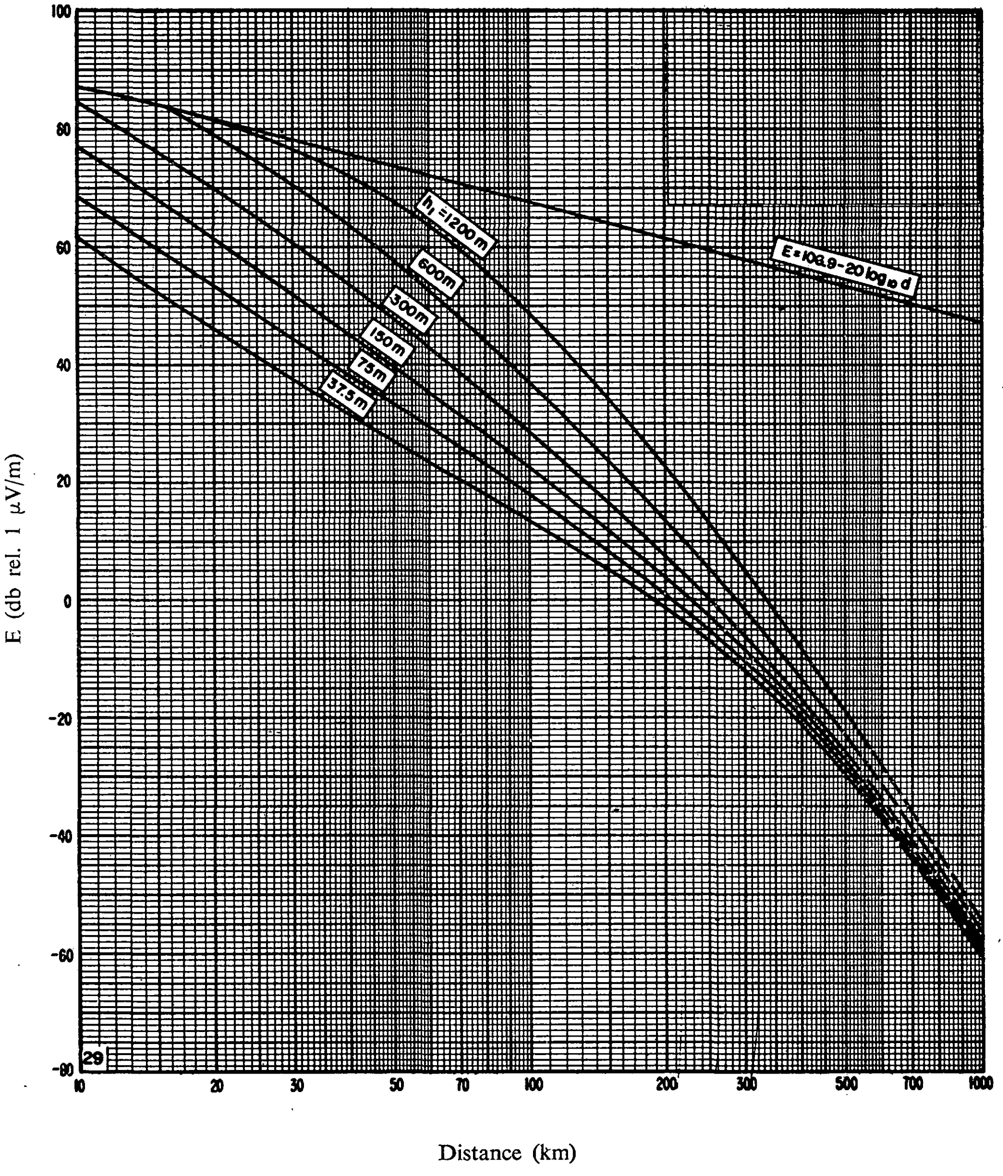


FIGURE 29

Values of E (50,50) for a sub-tropical (maritime) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

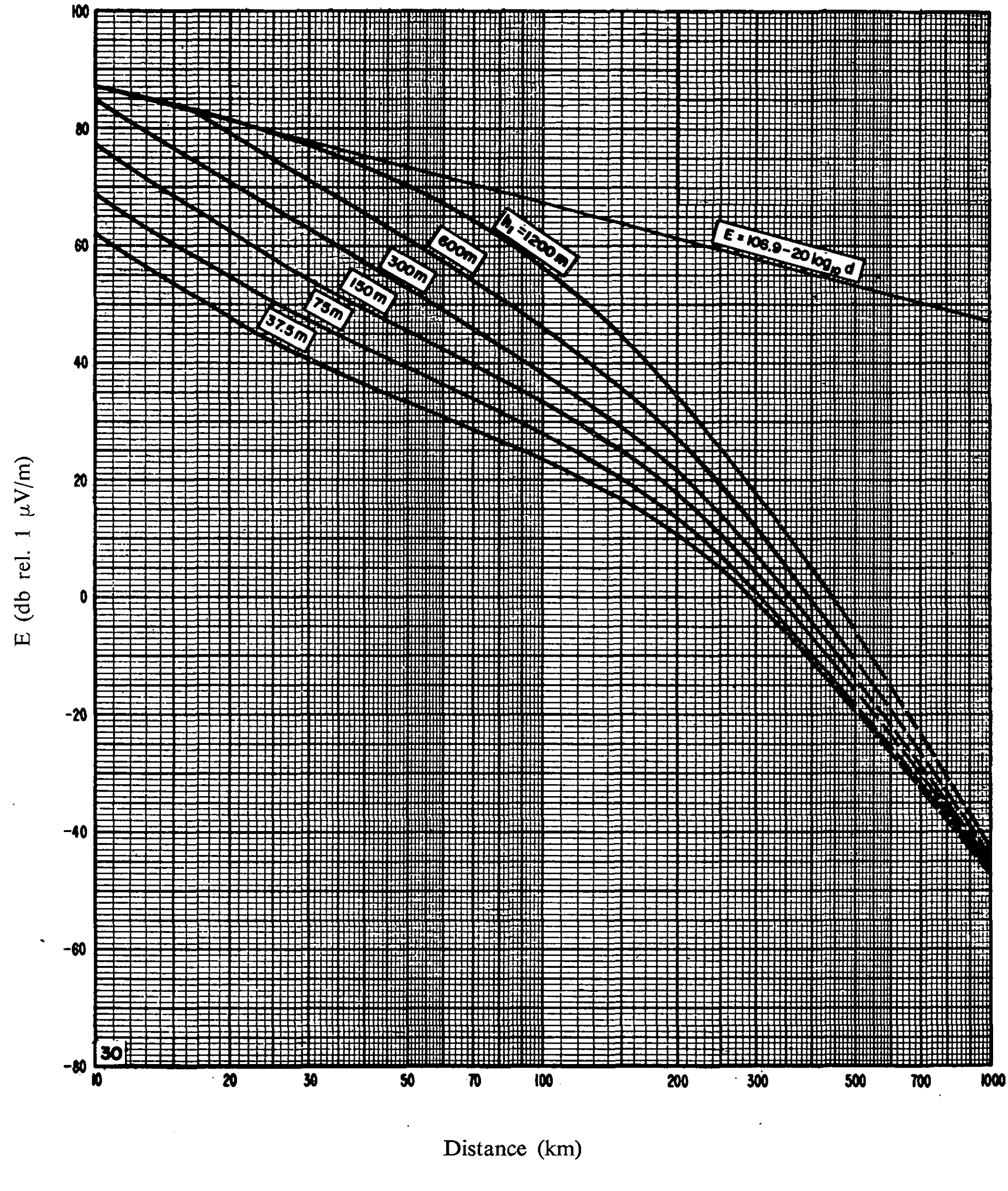


FIGURE 30

Values of E (50,10) for a sub-tropical (maritime) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

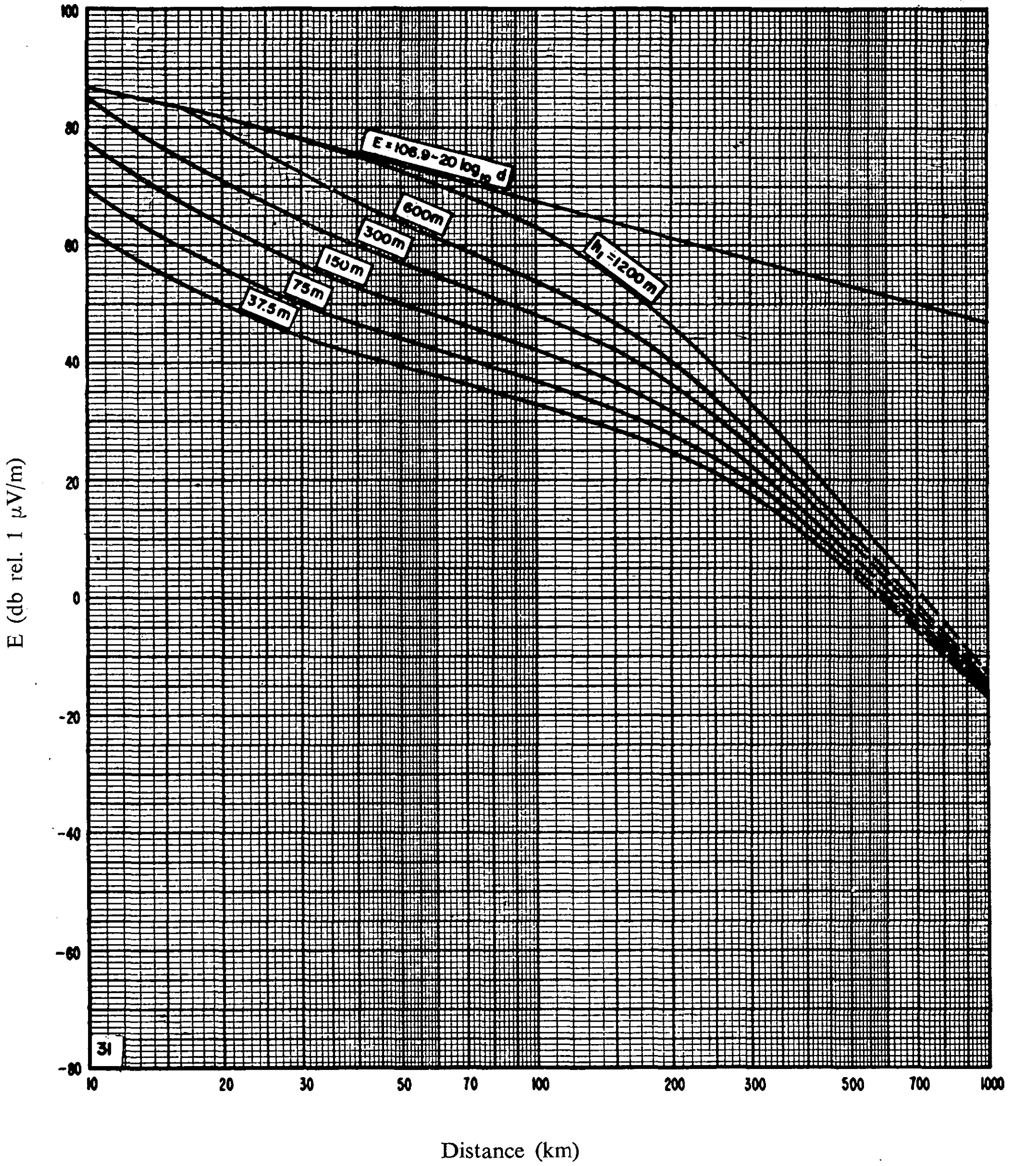


FIGURE 31

Values of E (50,1) for a sub-tropical (maritime) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

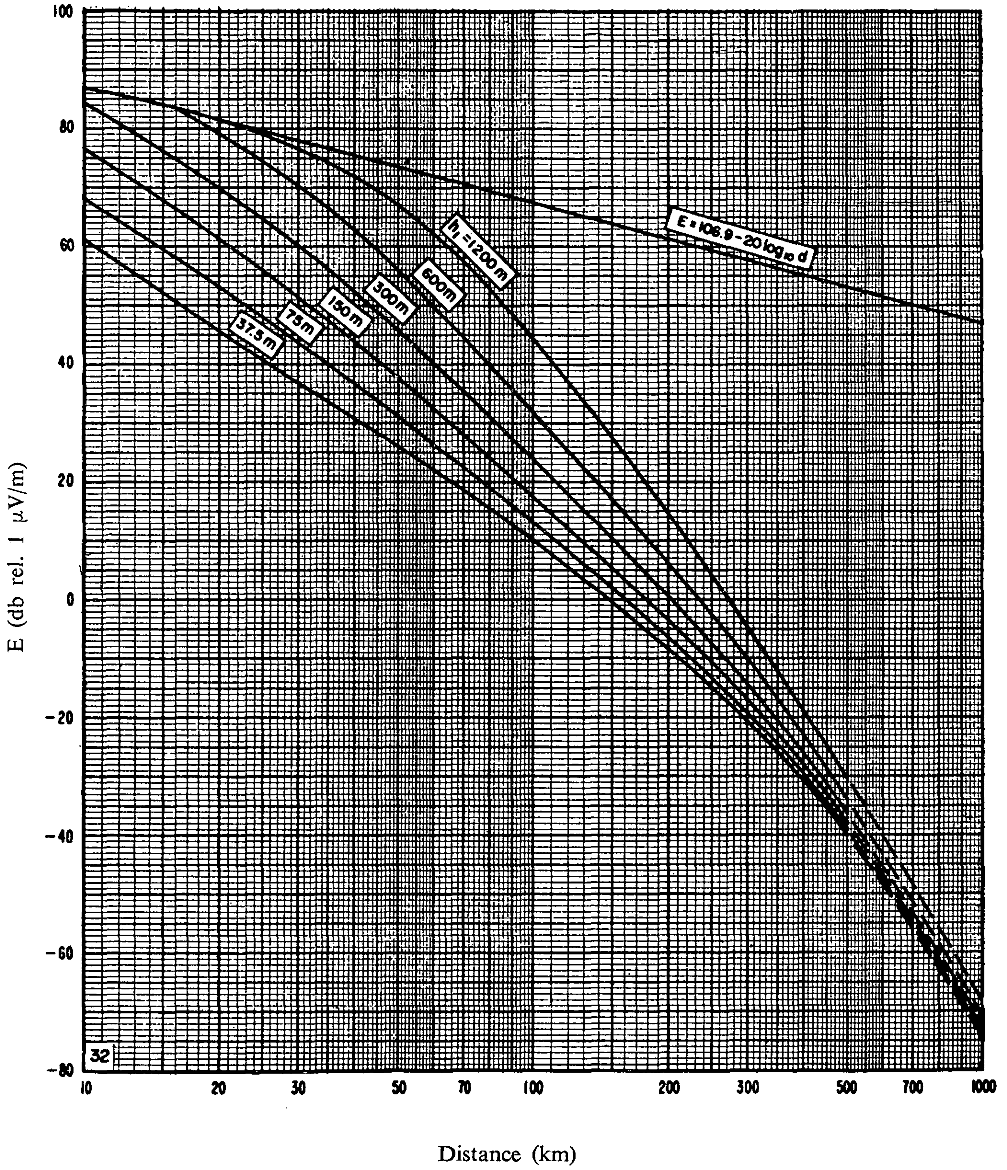


FIGURE 32

Values of E (50,50) for an equatorial climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

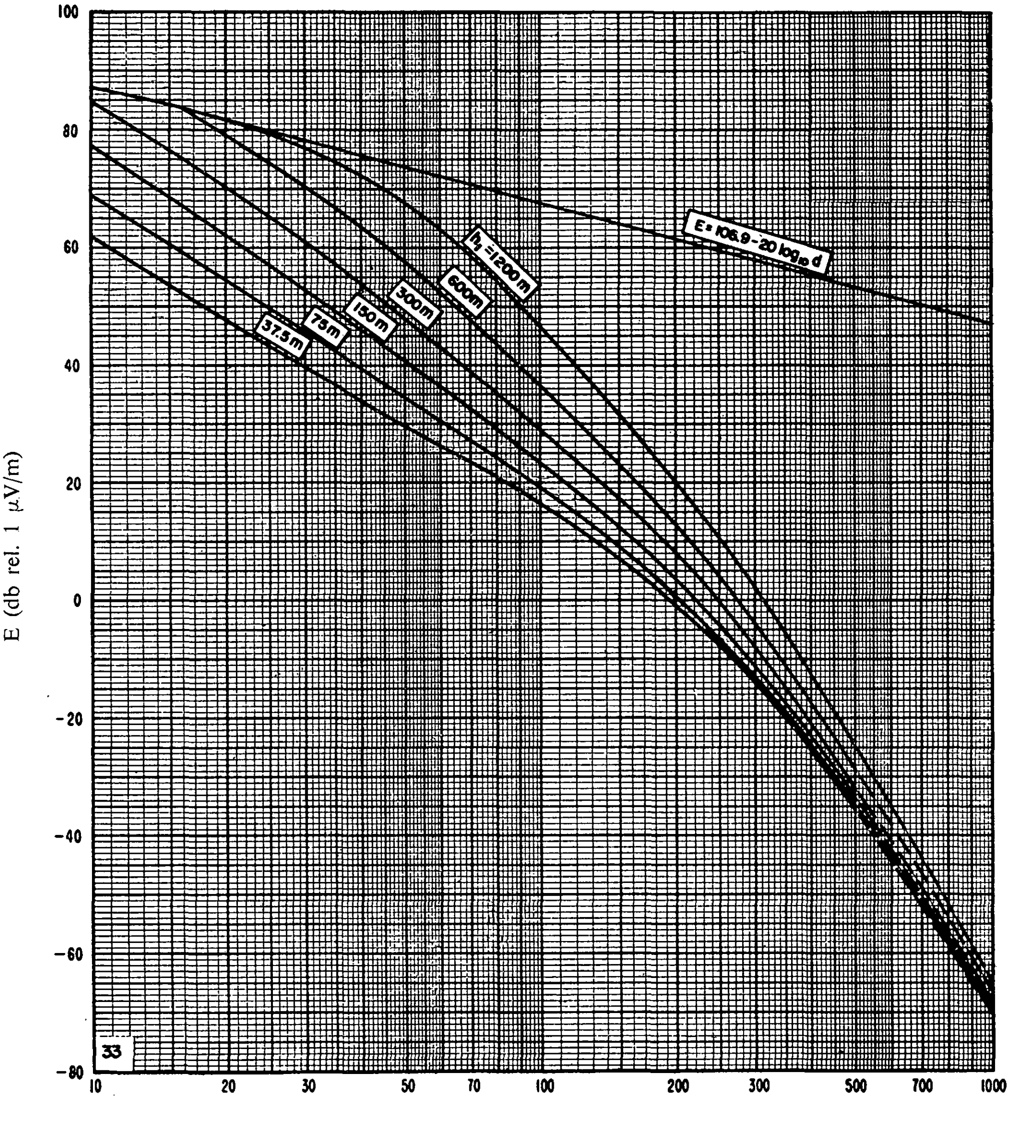


FIGURE 33

Values of E (50,10) for an equatorial climate

Frequency: 450–1000 Mc/s

h_1: as indicated on the curves

h_2: 10 m

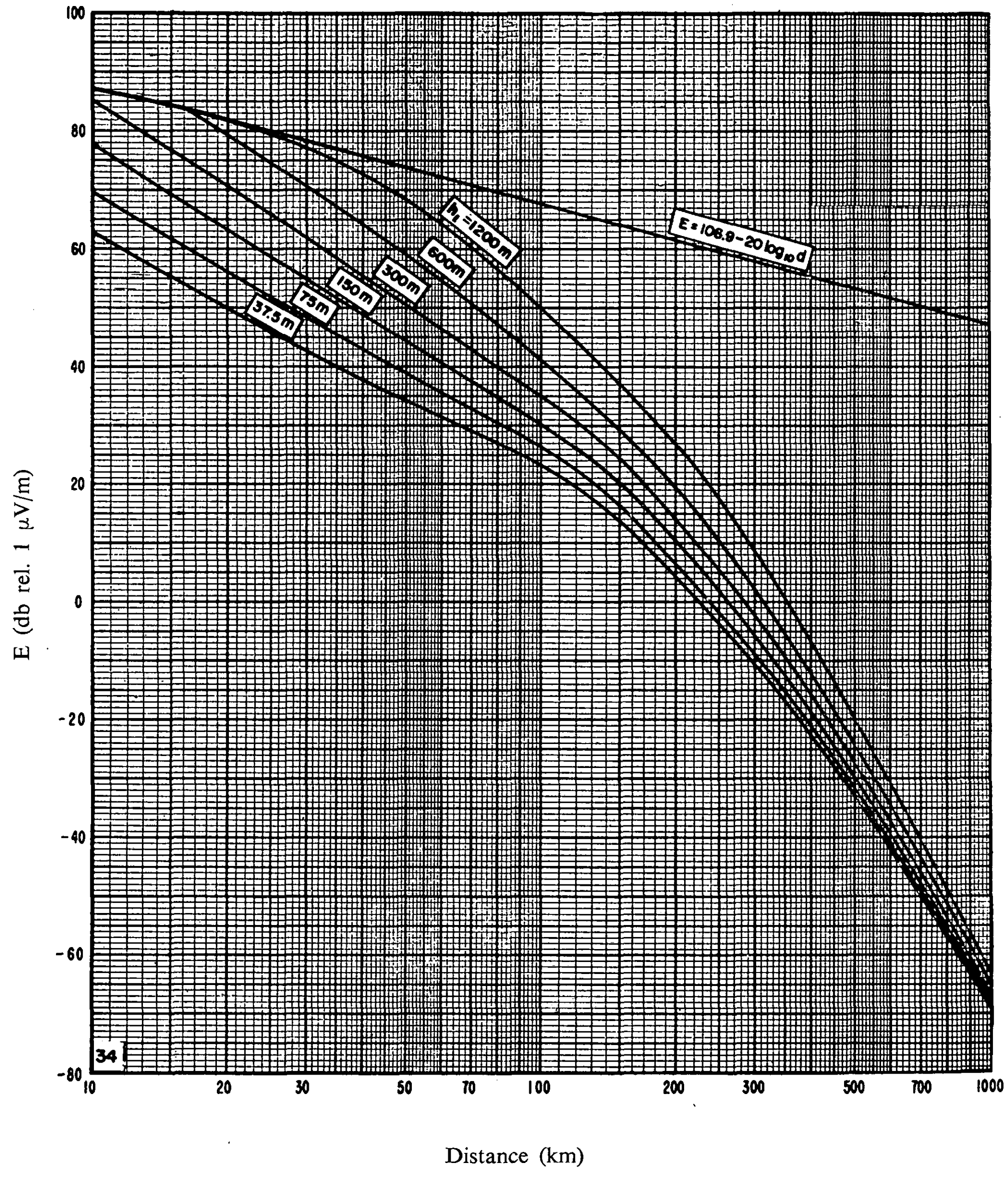


FIGURE 34

Values of E (50,1) for an equatorial climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

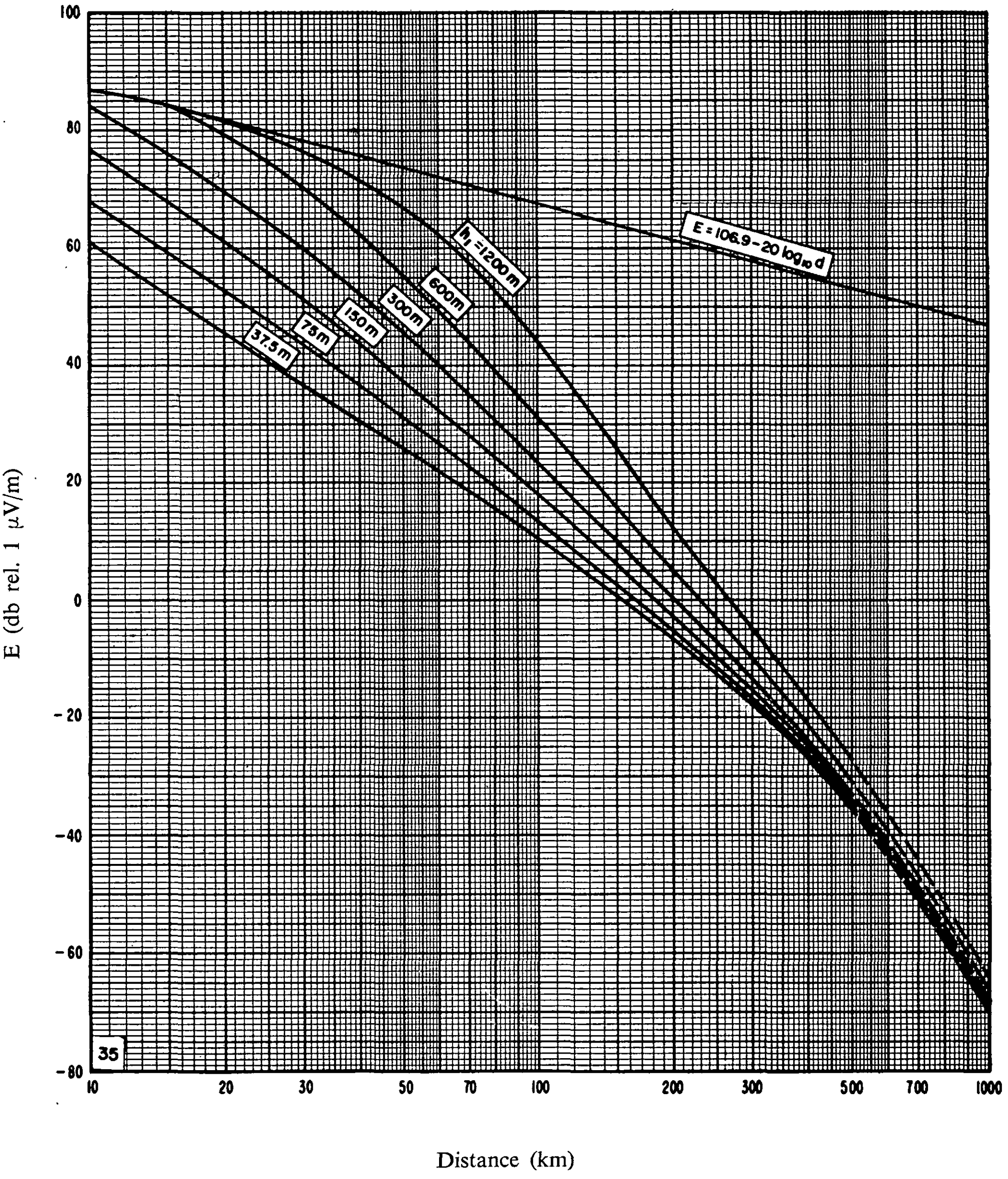


FIGURE 35

Values of E (50,50) for a temperate (continental) climate

Frequency: 450–1000 Mc/s

h_1: as indicated on the curves

h_2: 10 m

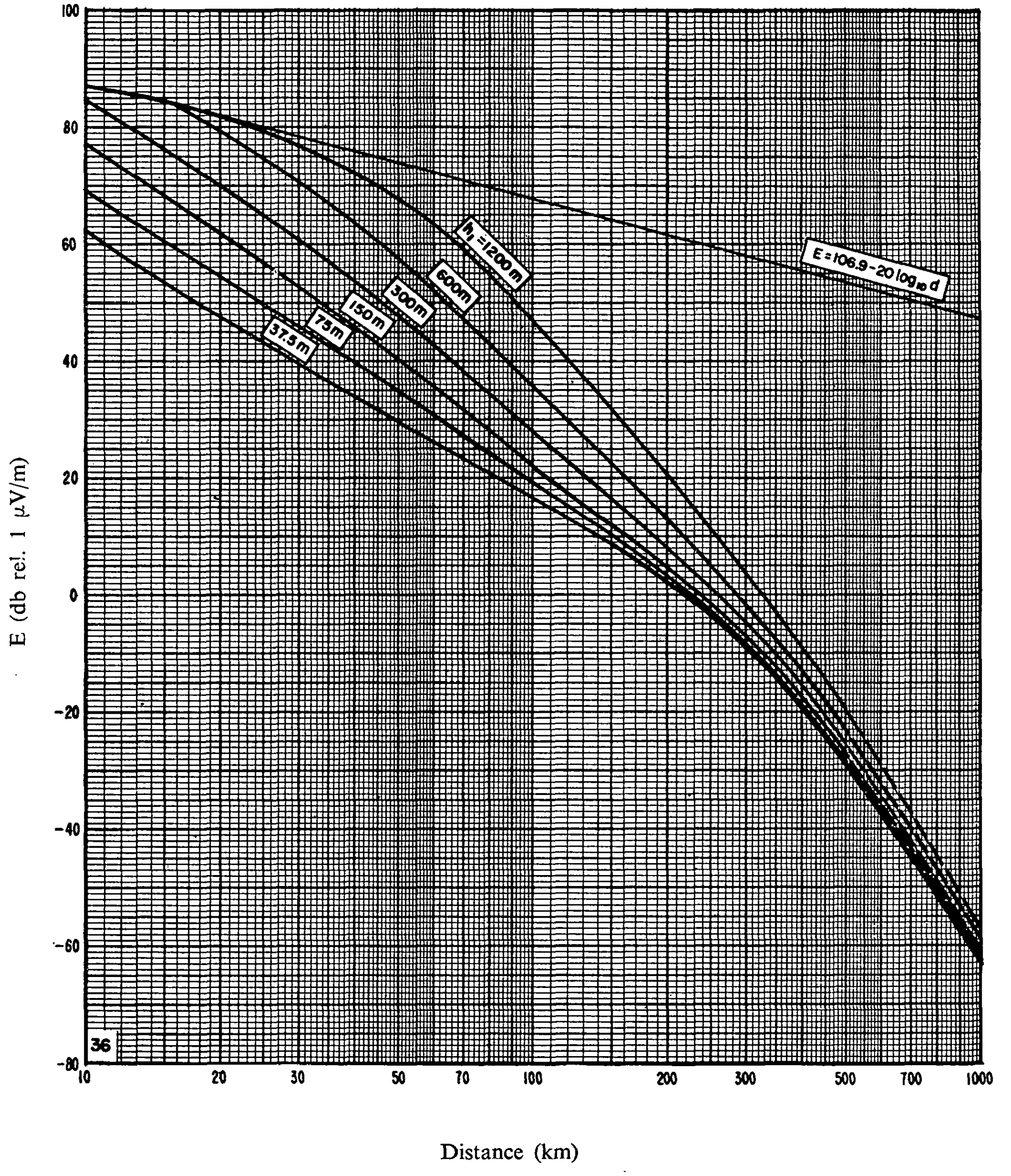


FIGURE 36

Values of E (50,10) for a temperate (continental) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

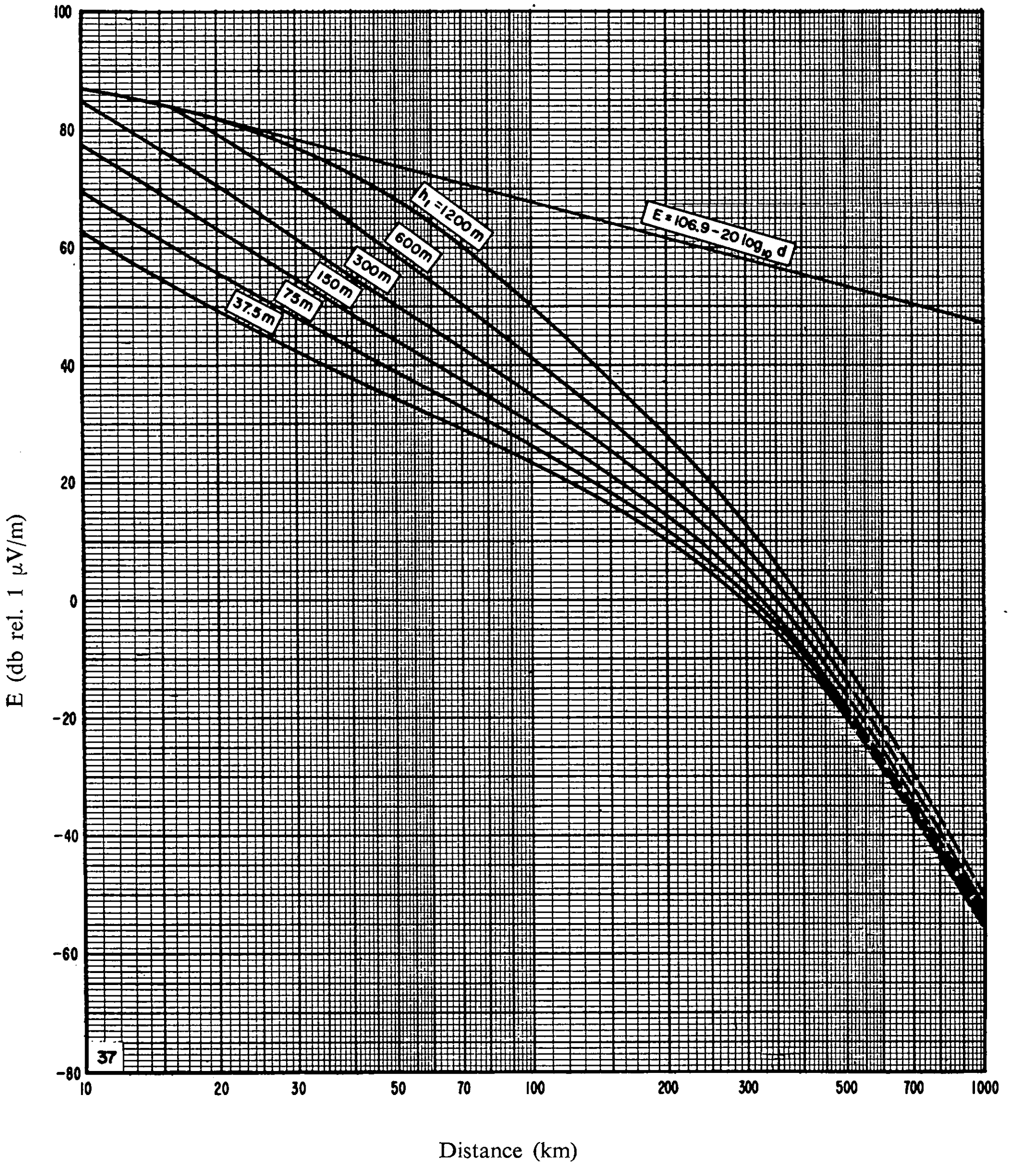


FIGURE 37

Values of E (50,1) for a temperate (continental) climate

Frequency: 450–1000 Mc/s
h_1: as indicated on the curves
h_2: 10 m

REPORT 241 *

PROPAGATION DATA REQUIRED FOR RADIO-RELAY SYSTEMES

(Study Programmes 185 A (V) and 185 B (V))

(Los Angeles, 1959 — Geneva, 1963)

A large amount of data relevant to Study Programmes 185A(V) and 185B(V) has now been accumulated in response to Administrative Circular AC/63. These results of tests performed by a number of Administrations, over paths of widely differing lengths in widely different climatic regions are believed to be of considerable value to designers of radio-relay systems, and copies of the data may be obtained from the C.C.I.R. Secretariat. The results are divided into two sections, within the same volume, one section containing data for paths where the angular distance is negative (" line-of-sight " paths), the other containing data for paths where the angular distance is positive (" beyond-the-horizon " paths). The volume is entitled: " Propagation data obtained in radio-relay systems (C.C.I.R. Study Programmes 185A(V) and 185B(V))."

It remains important that further data should be obtained, especially in regions other than the Temperate Zone, and Administrations are urged to make measurements to provide such data.

Attention is drawn to the fact that the data submitted will not be usable unless the following parameters at least, are given: path length, frequency, antenna gain, angle of elevation of the horizon at each terminal for an effective earth-radius factor of 4/3 (for beyond-the-horizon paths) and time-constant of the recording instrument.

REPORT 242 **

PROPAGATION DATA REQUIRED FOR RADIO-RELAY SYSTEMS

Cumulative distribution of the length of individual time intervals during which the path attenuation exceeds a given level

(Study Programmes 185 A (V) and 185 B (V))

(Geneva, 1963)

1. Introduction

In contradiction to optical range propagation, where the field strength is fairly constant, scatter field-strengths vary continually between wide limits. For practical reasons, it is very useful to know how often deep fades occur, and what their duration will be.

Both the fading rate and the duration of fading are governed essentially by two factors, the rapidity of fading and the given level below which the signal will fall.

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* This Report, which replaces Report 143, was adopted unanimously.

** This Report was adopted unanimously.

All characteristic quantities related to fading, in particular the rate and duration of fades, are of a statistical nature. They are characterized by their mean values, their median values or, more accurately, by their statistical distribution. A distinction, based on the length of the interval of observation, should be made between long-term and short-term statistics. Short-term statistics are confined to intervals for which the fading may be considered to be stationary, that is to say neither the field-strength nor the rapidity of fading exhibit a definite trend.

It is desirable in analyzing data to use the longest period of time for which the fading may be considered to be stationary, since this will improve the accuracy of the results. Experience has shown that this longest period of time may be as long as one hour, although somewhat shorter periods of time may sometimes be used advantageously in the UHF band. The use of analysis periods less than 30 min in the VHF band or less than 10 min in the UHF band is undesirable, since the use of such short periods leads to large fluctuations in the results obtained in successive time intervals.

Long-term statistics cover periods from several months up to years. Their results will be influenced by long-term variations in the median levels of field strength and in the rapidity of fading.

2. *Short-term statistics are* treated first in this contribution. The frequency of short-term fadings may be calculated, using the methods of Rice [1]. We may start from the fact, verified by experiments, that during short-term intervals of up to one hour the scatter field-strength obeys Rayleigh's distribution law:

$$P(r) = \exp\{-0 \cdot 693 r^2\} \tag{1}$$

where

$$r = E/E_m \tag{2}$$

is the ratio of field-strength to its short-term median value. $P(r)$ is the probability that the level r will be exceeded.

According to Rice, the number of downward passings per second of the level r is:

$$N(r) = 2 \cdot 95 f_s r \, . \exp\{-0 \cdot 693 r^2\} \tag{3}$$

The average fading rate f_s is a measure of the fading rapidity. It is defined by the power spectrum $g(f)$ of the fading phenomenon:

$$f_s^2 = \int_0^\infty f^2 g(f)\, df \Big/ \int_0^\infty g(f)\, df \tag{4}$$

where f_s is in fades per second, and is connected with the number of upward crossings of the median value N_m by the relationship:

$$N_m = 1 \cdot 475 f_s \tag{5}$$

Statistics of f_s may easily be obtained by measuring N_m.

The average duration of a fading period $\bar{t}$ may be obtained from (1) and (3), giving:

$$\bar{t}(r) = [1 - P(r)] \, / \, N(r) \tag{6}$$

To assess the reliable performance of a circuit, it is not sufficient to know the average duration of fading, $\bar{t}$, because in practice there is considerable spread of duration of fades around this average value. Extensive measurements of fading lengths were carried out over a number of paths and at different frequencies. The measuring equipment consisted of an electronic short-period measurement set with a recorder connected to it. The shape of the short-period distributions $\Pi(t)$ thus gained were but slightly dependent on the working frequency, the range and the given measuring level. In all cases, nearly perfect log-normal distribution functions resulted, with identical values of standard deviation for the logarithm of the duration of fading, t. The natural dependence of the median value, t_m, of the fading duration on the average fading frequency, f_s, may be eliminated by plotting the distribution of, $t.f_s$. The value, t_m, is then only a function of the given measuring level. Fig. 1 shows this distribution of fading durations, $t.f_s$, measured for various levels of R,

where $$R = 20 \log r \text{ (db)}.$$

When f_s is known, the distribution of fading duration t may be obtained from these distribution curves for any value of level below the median value of the field-strength. It should be noted from these curves, that 98 % of all fading lengths occuring in a short-term interval, lie between $0 \cdot 2\ t_m$ and $5\ t_m$. The arithmetic mean t resulting from t_m is:

$$\bar{t} = 1 \cdot 31\ t_m \tag{7}$$

3. *Long term statistics* may be obtained from the long-term distributions of the hourly median values of field-strength and of the average fading frequency, f_s. A wealth of recorded field-strength data is available. The paths investigated in the Federal Republic of Germany, irrespective of range and operational frequency, always yielded the same long-period distribution as shown in Fig. 2. The field-strengths (db rel. 1μV/m), were reduced to their long-term median value. Experience shows that this curve may be regarded to be at least representative for Central Europe.

Unfortunately, such extensive and reliable statistical data, for the fading frequency, f_s, do not yet exist. The analysis had, in consequence, to be based on the results of fading frequency measurements obtained over a single path (Wrotham — Krefeld, 100 Mc/s, 430 km) and over a few months only. Fig. 3 shows the distribution of f_s thus obtained, related to the corresponding long-term median value, f_{sm}. It may be supposed that more extensive measurements, on the other operational frequencies, would not yield results much different from the given curve.

The long-period median value, f_{sm}, is dependent on the operational frequency. A large number of measurements gave:

$$f_{sm} = 2 \cdot 5 \times 10^{-4} f \tag{8}$$

where f_{sm} is in fades/s. and f is in Mc/s.

There seems to be a slight dependence on the path length, but this effect could not be established as yet beyond doubt; so probably it may be safely neglected.

From the distribution in Fig. 3, the arithmetic mean. $\bar{f}_s$, is calculated:

$$\bar{f}_s = 1 \cdot 53\, f_{sm} \tag{9}$$

The long-period mean value, N, of the fading frequency may be calculated from (3), by means of the distributions plotted in Figs. 2 and 3, and formula (8), giving:

$$\overline{N}/\bar{f}_s = \int (N/f_s)\, dP \tag{10}$$

where P is the distribution of the median values of the field-strength given in Fig. 2. Numerical evaluation of this integral yields the curve in Fig. 4, from which the quantity $\overline{N}/\bar{f}_s$ may be found for any value of measuring level. R_0 (db) indicates the distance between the measuring level and the long-term median level of field-strength.

In a similar way, the long-term distribution $\Pi(t)$ of the fading duration was obtained from its short-term distribution. The calculation yielded the distribution curves in Fig. 5. The product $t.f_{sm}$ was plotted instead of t in a manner analogous to Fig. 1. 98 % of all fading durations lie between $0 \cdot 04$ and 25 times the long-period median value. Hence, the duration of fading exhibits a very wide spread over extended periods of time.

For practical applications of these results, it is essential to use formulae (8) and (9) and Figs. 4 and 5. First, the long-period median value f_{sm} of the median fading frequency, is calculated from the operational frequency by means of (8), and then the mean value, $\bar{f}_s$, is obtained from (9). Then Figs. 4 and 5 will yield the long-period mean value $\overline{N}$ of the fading rate and the long-period distribution Π of the duration of the fading.

Although the analysis given in this Report is confined to the results to be expected on radio-relay systems at large ranges beyond the radio horizon, involving only the scatter mode of propagation, it has been shown in several of the papers published in Proc. IRE (Oct. 1955), that this method of analysis of fading is also useful at the shorter ranges, where the received field arrives at the receiver via two modes of propagation and has both a relatively steady diffracted component and a rapidly varying Rayleigh-distributed scatter component.

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2. GROSSKOPF, J. and FEHLHABER, L. Häufigkeit und Dauer einzelner Schwundeinbrüche bei troposphärischen Scatterstrecken (Frequency and duration of individual deep fades over tropospheric-scatter links). *NTZ*, **2**, 71 (1962).

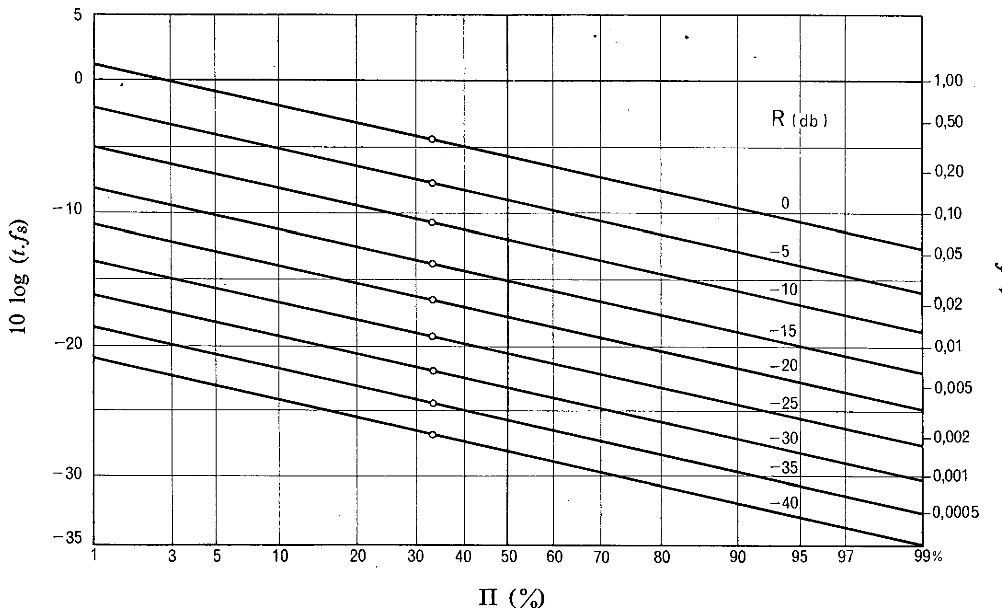

FIGURE 1

Short-term distributions of the duration of fading for departures of R from the median value

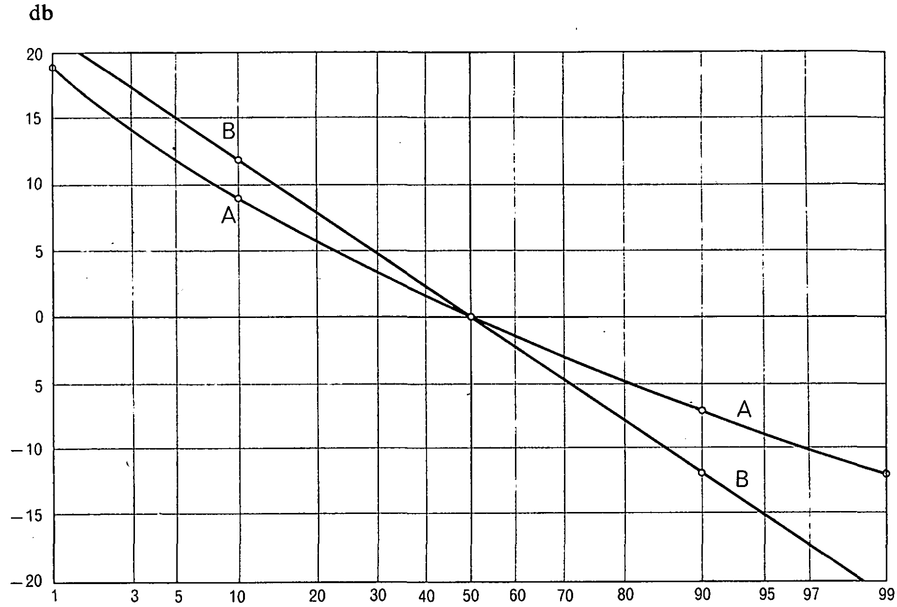

FIGURE 2

Long-term distributions of the scatter field-strength

(Resulting from long-term recordings on different paths:
up to 450 km long, and at frequencies between 100 Mc/s and 2 Gc/s)

Curve A: hourly median values

Curve B: instantaneous values

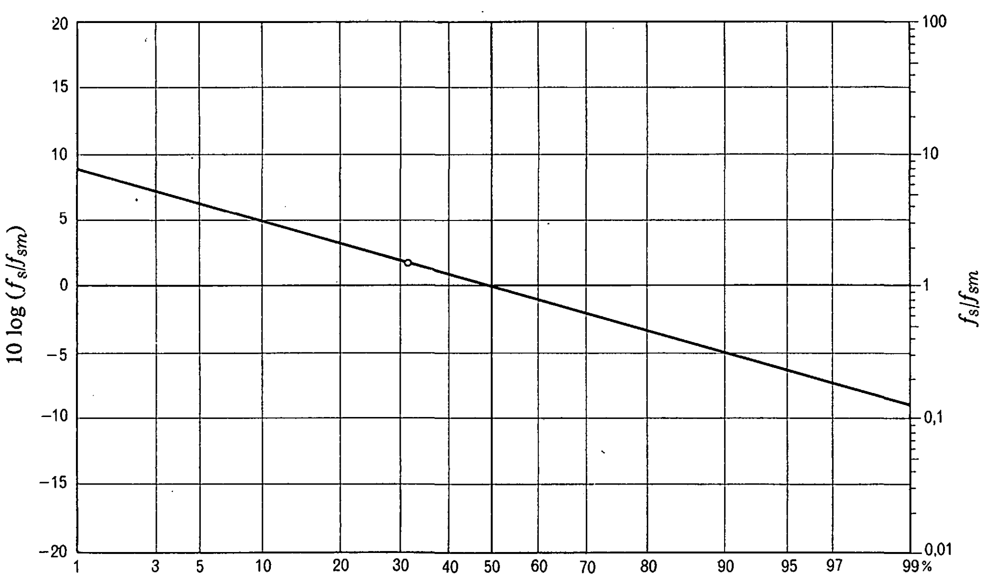

FIGURE 3

Long-term distribution of the mean fading-frequencies

(Wrotham-Krefeld, 100 Mc/s, 430 km, recorded during a few months of 1956)

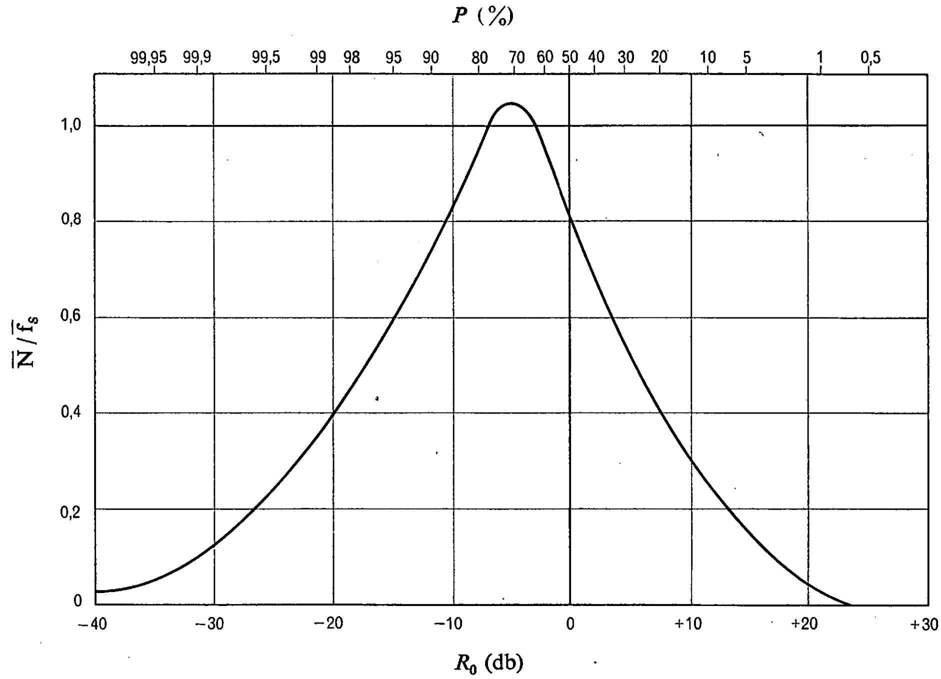

FIGURE 4

Mean number of times that the signal was below certain levels (long-term mean values)

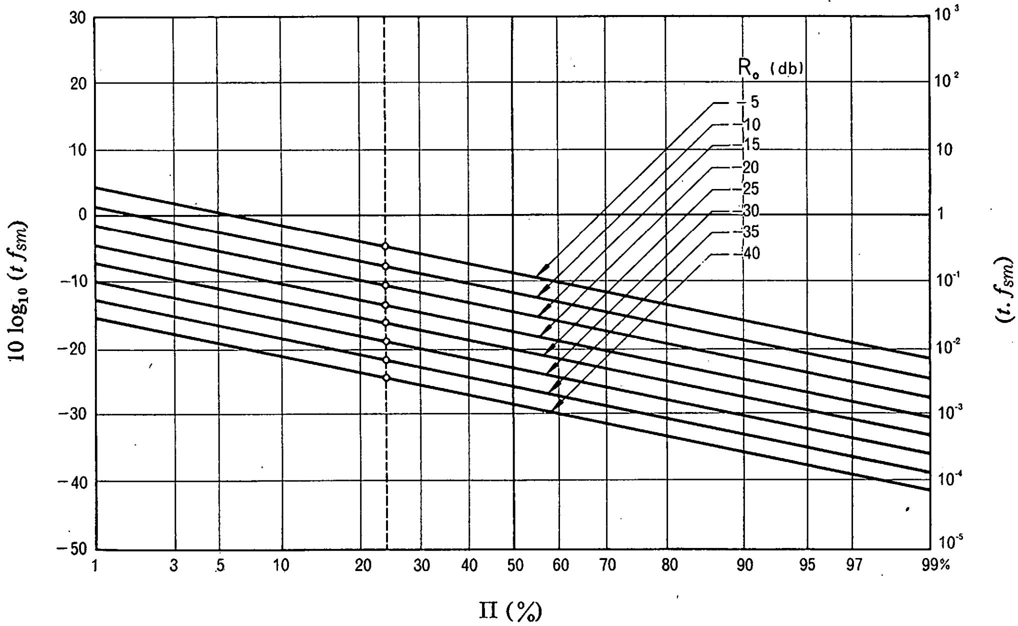

FIGURE 5

Long-term distribution of fading durations for different levels, R_0 (db), relative to the long-term median value of the field strength

REPORT 243 *

TROPOSPHERIC-WAVE PROPAGATION CURVES FOR APPLICATION TO INTERFERENCE PROBLEMS IN THE RANGE FROM 1 TO 10 Gc/s

(Study Programmes 185 A (V) and 185 B (V))

(Geneva, 1963)

1. The curves given in Figs. 1 and 2 have been prepared primarily for use in assessing the mutual interference that may arise on overland paths between the ground stations of satellite radiocommunication services and other terrestrial radio services operating on the same or adjacent frequency channels. However, they may also be used for other interference problems arising in the range from 1 to 10 Gc/s.

   Fig. 1 gives the transmission loss between isotropic antennae for the frequency 4 Gc/s. Fig. 2 gives the corrections that should be applied to the curves in Fig. 1 (for distances greater than 100 km), to determine the transmission loss between isotropic antennae for other frequencies in the range from 1 to 10 Gc/s.

2. The curves in Figs. 1 and 2 have been derived from measured data obtained in temperate and sub-tropical regions, and apply particularly to paths over relatively smooth earth, where the antennae are respectively of the order of 50 m and 15 m above ground level. The parts of the curves for distances greater than about 150 km can be used for paths over relatively smooth earth and for other antenna heights as follows:

   To obtain the transmission loss at a distance of x km from the transmitter, for transmitting and receiving antennae heights of h_1 and h_2 m, the curves should be read for a distance of $x + 45 - 4{\cdot}1\ (\sqrt{h_1} + \sqrt{h_2})$ km.

3. The portions of the curves between 50 and 100 km are based on comparatively few data and should be used with extreme caution. They are indicated by interrupted lines.

4. It is emphasized that, although these curves are based on data obtained from long-term measurements over many paths, they represent only average path conditions and may give rise to substantial errors when estimating the transmission loss over a particular path. Methods for the more accurate prediction of path loss are to be considered by the International Working Party established under Resolution 2 and these will be reported on in due course.

Note. — Attention is also drawn to Report 244 prepared by the International Working Party (Opinion 4).

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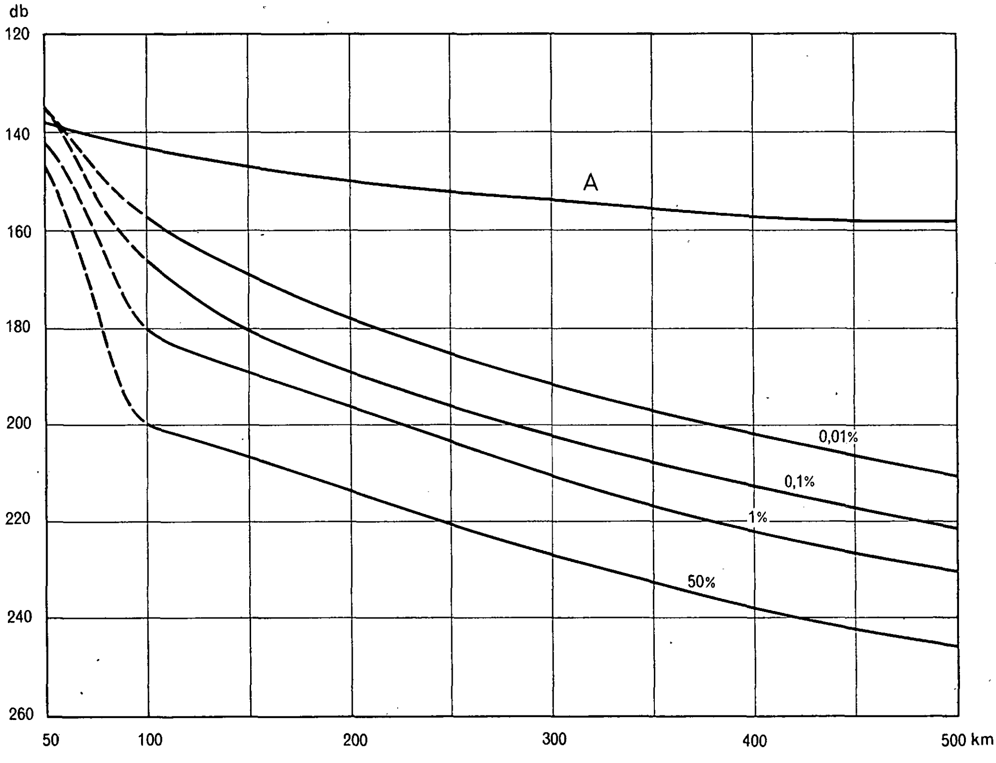
* This Report was adopted unanimously.



Distance (km)

FIGURE 1

Transmission loss (db) between isotropic antennae (basic transmission-loss), not exceeded for the proportions of the time indicated on the curves (Overland path at 4 Gc/s)

Curve A: free-space propagation

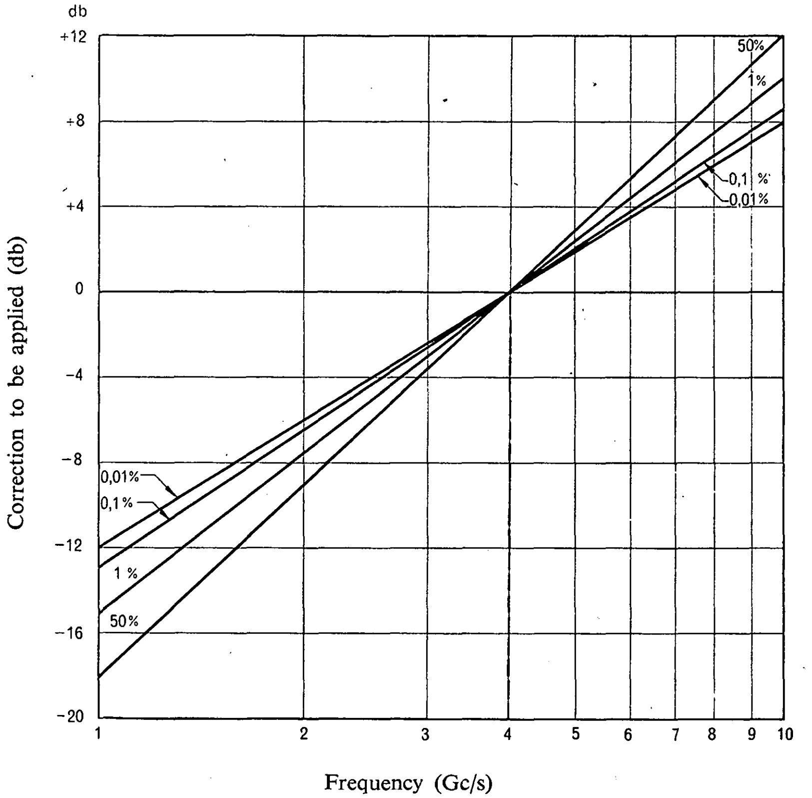


FIGURE 2

Correction (db) for frequency, to be applied to the curves in Fig. 1, for the proportions of the time indicated on the curves

Note: The correction curve for 0·01% of the time is also applicable to the curve for free-space in Fig. 1

REPORT 244 *

ESTIMATION OF TROPOSPHERIC-WAVE TRANSMISSION LOSS

(Geneva, 1963)

1. Introduction

Study Programmes 185A(V), 185B(V) and 190(V) state requirements for radio propagation data and their analysis for frequencies from 40 Mc/s to at least 20 Gc/s for use in the planning of radio-relay systems and in the determination of the possibilities of frequency sharing between radio-relay systems, including space and terrestrial telecommunication systems. Much of these data has been obtained in the past and is, at present, being furnished in response to the request by the Director, C.C.I.R. in A/C 63. Various Administrations have suggested methods for the estimation of transmission loss, both within and beyond the horizon over a wide range of frequencies and for various climates [1, 2, 3, 4, 5].

An International Working Group has been established to continue the work of collecting and analyzing data in accordance with Resolution 2. This preliminary report summarizes data available at present in the frequency range 40 Mc/s to 10 Gc/s, supplied by a number of Administrations. It gives provisional procedures for the estimation of tropospheric wave transmission loss and its variability for a variety of climates.

Certain Administrations have agreed that the procedure described in § 2 is useful for the prediction of tropospheric transmission loss: one of the references [1] contains an account of a comprehensive and detailed method of computation on which this procedure is based. Another method is described in § 3. Unanimous agreement has not been obtained on the best methods to use in all circumstances, and it is clear that more work remains to be done to enable the International Working Group to arrive at a more complete report.

It is desirable that the various Administrations interested in this problem should make comparisons between their own experimental data and the prediction methods mentioned in this Report, and eventually with any other methods, and that they should present their conclusions to the International Working Group through the Director, C.C.I.R., prior to the XIth Plenary Assembly.

No existing method can provide accurate predictions in all circumstances, and for specific point-to-point paths, errors as much as several tens of decibels can exceptionally occur in the estimation of the transmission loss not exceeded for 0·1% and 0·01% of the time (the very high field strengths). However, it must be pointed out that measurements must be made over a very long period of time, if substantially better empirical predictions are to be provided.

2. Free-space propagation

Recommendation 341 and Report 112, relate the available power, P, from the receiving antenna, the total radiated power, P_r, the transmission loss, L, the basic transmission loss, L_b, and the path antenna gain, G_p, as follows:

$$P = P_r - L \tag{1a}$$

$$L_b = L + G_p \tag{1b}$$

* This Report was adopted unanimously.

The attenuation relative to free space, A, is defined as:

$$A = L_b - L_{bf} \text{ db}, \tag{2}$$

$$L_{bf} = 32 \cdot 446 + 20 \log f_{M/cs} + 20 \log r_{km} \tag{3*}$$

where L_{bf} is the basic transmission loss in free space, and r is the straight-line distance between antennae.

For links between earth stations and spacecraft, it is important to know the attenuation relative to free space, $A(p)$, between the earth station and space station as a function of time availability p, range r_0, frequency f, and the angle of elevation, θ_0; the example, shown in Fig. 1, was drawn for $\theta_0 = 0 \cdot 3$ radians and for an atmosphere in which the earth temperature is 20° C, the pressure is 760 mm of mercury, and the water vapour density is 7·6.gm/kg with a total rainfall of 1 m per year.

In free space, ignoring absorption, the calculated transmission loss is:

$$L = L_{bf} - G_t(\hat{r}) - G_r(\hat{r}) \text{ db}, \tag{4}$$

where $G_t(\hat{r})$ and $G_r(\hat{r})$ are free space transmitting and receiving antenna power gains in a direction $\hat{r}$ for the same polarization.

2.2 *Effects of the ground*

For a smooth, perfectly conducting surface, the attenuation relative to free space is

$$A = -6 - 10 \log \sin^2(\pi \Delta r/\lambda) \text{ (db)} \tag{5}$$

where λ is the radio wavelength and $\Delta r = r_1 + r_2 - r_0$ is the difference between direct and ground-reflected ray paths shown on Fig. 2. An effective earth radius, a, rather than the real earth's radius was used to allow for average refraction of radio rays in Fig. 2. Fig. 3 shows a as a function of $N_s = (n_s - 1) \times 10^6$, where n_s is the radio refractive index of the atmosphere at the surface of the earth.

For small grazing angles, ψ, and with antennae h_1 and h_2 (km) above the earth where rays r_1 and r_2 make equal angles of incidence and reflection,

$$\Delta r \approx 2h'_1 h'_2/d \tag{6}$$

where h'_1 and h'_2 are the antenna heights above a plane tangent to the earth at the point of reflection.

For equal antenna heights over a spherical earth of effective radius, a:

$$\Delta r = d(\sec \psi - 1). \tag{7}$$

The greatest distance $d = d_0$ for which $A = 0$ may be obtained graphically from the relation

$$2h_1^2/d_0 - h_1 d_0/(2a) + d_0^3/(8a^2) = \lambda/6 \tag{8}$$

as determined from the condition that the sum of the direct and ground-reflected waves shall be equal to the free space field.

Let θ_h represent the angle of elevation of the direct ray r_0 relative to the horizontal at the lower antenna, h_1, assume that $h_1 \ll h_2$, $h_1 \ll 9a\psi^2/2$, and that ψ is small. Then,

$$\Delta r \approx 2h_1 \approx \sin \Psi \approx h_1 \left[\sqrt{\theta_h^2 + 4h_1/3a} + \theta_h\right] \tag{9}$$

where θ_h may be either positive or negative. For $\theta_h = 0$, $d_1 \approx 2h_1/(3\psi)$.

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* Equation such as (3) may conveniently be expressed in the form of a nomogram (see Fig. 16).

A propagation path with a single isolated terrain feature, which is the horizon for both terminals, may often be considered as having a single diffracting knife edge between the terminals as illustrated in Fig. 4, from which the diffraction attenuation relative to free space, $A(v)$ may be obtained, either for line-of-sight paths ($v < 0$), or for trans-horizon paths ($v > 0$).

An approximate formula for determining diffraction attenuation relative to free space, A, over a smooth earth for horizontal polarization is

$$A = G(x_0) - F(x_1) - F(x_2) - 20{\cdot}67 \quad \text{(db)}. \tag{10}$$

The functions $G(x_0)$ and $F(x_{1,2})$ and an auxiliary function $\Delta(x_{1,2})$ are plotted in Fig. 5.

$$x_0 = dB_0\,;\ x_1 = d_{Lt}\,B_0\,;\ x_2 = d_{Lr}\,B_0\,;\ B_0 = 1.607 f^{1/3}\,C_0 \tag{11}$$

$$C_0 = (8497/a)^{1/3},$$

where $d_{Lt} \approx \sqrt{2h_{te}}$ and $d_{Lr} \approx \sqrt{2h_{re}}$ are distances from each antenna to its smooth earth radio horizon. The error in A will be less than 1 db if

$$x_0 - x_1\,\Delta(x_1) - x_2\,\Delta(x_2) > 320 \text{ (km)} \tag{12}$$

This assumes that terms beyond the second in the residue series may be neglected, and that the second term is much less than the first.

Just beyond the radio horizon of a transmitter, the dominant propagation mechanism for more than half the time is usually diffraction. Well beyond the horizon, the dominant mechanism is usually forward scatter, especiallv during times of day and seasons of the year when strong ducts and elevated layers are rare.

2.3 *Forward scatter*

The long-term median basic transmission loss (i.e. the transmission loss between isotropic antennae) due to forward scatter is approximately:

$$L_b(50) = 30 \log f - 20 \log d + F(\theta d), \tag{13}$$

where $F(\theta d)$ is shown in Fig. 6*a* and 6*b* as a function of the product θd for the following types of climate:

1. Continental temperate (data from France, Federal Republic of Germany, and U.S.A.);
2. Maritime temperate, overland (data from U.K. and Japan);
3. Maritime temperate, oversea (data from U.K. and Japan);
4. Maritime sub-tropical, overland (data from West Coast of Africa);
5. Maritime sub-tropical, oversea (data from West Coast of Africa);
6. Desert (Sahara);
7. Equatorial (data from Congo and Ivory Coast);
8. Continental sub-tropical (Sudan).

The angular distance, θ, is the angle between radio horizon rays in the great circle plane containing the antennae and d is the distance (km) between antennae. [1].

2.4 *Transmission loss variability*

The performance of a radio service and the feasibility of frequency sharing between services, depend on signal-to-noise and signal-to-interference ratios. As a general rule, adequate service over a radio path requires protection against noise when propagation conditions are poor, and requires protection against interference from co-channel or adjacent channel signals when propagation conditions are good. Note that *minimum acceptable* ratios depend on the particular types of fading exhibited by wanted and unwanted signals and noise, as well as upon the demodulation and coding schemes used. These ratios do not vary in time unless the type of fading changes. *Available* ratios, on the other hand, depend upon the strength of available signals and noise, and do vary in time. Consequently, a distinction is made between the rapid " phase interference fading ", associated with multipath phenomena and the slow diurnal and seasonal changes, or " long-term power fading ", associated with changes in average refraction, turbulence, or stratification in the atmosphere.

It is convenient to divide the instantaneous envelope power expressed in dbW into two additive components, one associated with phase interference fading and one associated with long-term power fading. This Report deals only with long-term hourly median transmission losses and their variability with time throughout a year.

To estimate $P(p)$, the value of P exceeded for p % of the time, or $L(p)$, thevalue of L exceeded (100-p) percent of the time, an " effective distance ", d_e, is defined as a function of the propagation path length, d, effective antenna heights h_{te} and h_{re} above the foreground terrain, and the radio-frequency, f in Mc/s:

$$\text{For } d_{so} \leqslant d_{sl} \text{ km}, \quad d_{sl} = 65\,(100/f)^{1/3},$$

$$d_e = 130/[1 + (d_{sl} - d_{so})/d] \text{ km} \tag{14}$$

$$\text{For } d_{so} > d_{sl},$$

$$d_e = 130 + d_{so} - d_{sl} \text{ km},$$

where, $d_{so} = d - \sqrt{18\,000}\, h_{te} - \sqrt{18\,000}\, h_{re}$, is the smooth earth distance between radio horizons, and d_{sl} approximates the distance between horizons when diffraction and forward scatter fields are equal. In this Report, heights and distances are in kilometres, and angles are in radians. $P(p)$ and the corresponding transmission loss $L\,(p)$ are referred to long-term median values $P(50)$ and $L(50)$:

Thus:

$$P(p) = P(50) + y(p) \quad \text{(dbW)} \tag{15a}$$

or

$$L\,(p) = L\,(50) - y\,(\mathrm{p}) \quad \text{(db)} \tag{15b}$$

$$y(p) = y_0\,(p\,,\,d_e)\; g\,(p\,,f) \tag{16}$$

where empirical estimates of the factor g are shown in Fig. 7 and of y_0 in Figs. 8 to 15 for the various climates.

An estimate of the standard error of prediction for any given percentage of the time is given by the formula:

$$\sigma\,(p) = \sqrt{13 + 0{\cdot}12\, y^2\,(p)} \text{ db} \tag{17}$$

3. Summary of an alternative method [2, 3]

The method summarized here was developed following professional experience acquired during the construction of a number of radio-relay systems, both line-of-sight and trans-horizon.

An attempt has been made to reduce the calculations to a minimum and to use the results of experiments wherever possible.

For convenience, there are four separate zones:

— free space;
— zone of interference;
— diffraction zone;
  — from a ridge;
  — from the curvature of the earth;
— " scatter " zone;

A series of nomograms is used [3] for the first three zones, an example of which is given in Fig. 16.

For the fourth zone, the procedure is as follows:

3.1 *Method used in the " scatter " zone*

The object of the calculation is to determine the loss not exceeded for 99% of the time in the worst month of the year; other theoretical and experimental considerations make it possible to estimate values of the loss not exceeded for at least 50%, 10%, 1% etc. of the time. The accuracy of the calculations generally diminishes with the percentage.

Having determined the equivalent distance * by a study of the profile of the path traced for an earth radius of 8500 km, reference is made to the curves in Fig. 17 prepared for a frequency of 1 Gc/s for different climates. The loss between isotropic antennae is thus obtained for the climate considered.

For any frequency between 200 and 4000 Mc/s, the correction read on Fig. 18 is added to the preceding loss. In this way, the loss not exceeded for 99% of the time is obtained for the frequency and climate chosen.

If it is required to know this loss for any percentage of the time, the standard deviation is obtained from Fig. 19 and a log-normal law is taken to represent the monthly distribution of slow variations.

For interference, it may be interesting to know the month during which the smallest loss (high field) occurs. The difference between the worst month and the best month may be found experimentally for 99% levels and for different climates; however, details of this procedure are not given here. The loss not exceeded during any percentage of the best month is calculated from the standard deviation as above.

Note 1. — When a system has to be planned by calculation for a climate not listed here, the worst month of the year is ascertained by radiometeorology based on the study of a function M of two parameters: equivalent gradient and stability. These parameters and this function can easily be calculated from nomograms [3]. For engineering a system, confirmatory tests are confined to the worst month of the year; for interference studies, such tests are made during the best month.

If it is impossible to make tests, a known climate is taken as a reference and ΔM is added, representing the difference between the reference climate and the climate for which the project is intended.

Note 2. — The method described here is specifically directed to those C.C.I.R. requirements, which pay special attention to the weak fields during the worst month of the year (calculation of systems), and high fields (assessment of interference).

4. Thermal noise in line-of-sight systems

In the overall estimation of the performance of line-of-sight radio-relay systems, it is important to take into account the effects of thermal noise. This problem has been discussed in Doc. 196 (U.S.S.R.) of Geneva, 1963, and will be considered further by the International Working Group in the preparation of its final report.

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* Here, equivalent distance is defined as the angular distance, θ, times the effective radius of the earth.

5. Conclusions

The proper use of simple prediction methods, such as those outlined in this summary, requires an appreciation of their limitations and of the advantages of more elaborate methods. The aim of the International Working Group will be to produce a comprehensive report which shows:

— how to allow for incompatible transmitting and receiving antenna polarizations in free space propagation;

— how to estimate temporal, spatial, and regional changes in microwave absorption by oxygen, water vapour, rain and clouds under a variety of conditions in the frequency range 0·1–100 Gc/s;

— how to compute an effective ground reflection coefficient which depends on the conductivity, permittivity, roughness, and curvature of the reflecting surface, as well as upon the ratio of the products of antenna voltage gain patterns in the directions of direct and reflected ray paths;

— how to calculate Fresnel zones and what they are used for;

— how to allow for ground reflection effects and phase changes at a knife-edge for single knife-edge diffraction;

— how to proceed continuously from the low attenuation rates, characteristic of this type of diffraction to the opposite extreme of the high attenuation rates experienced just beyond a smooth earth horizon;

— how to estimate path antenna gain and to allow for path asymmetry, frequency gain, and non-standard refraction in estimating transmission loss due to forward scatter.

In addition, methods for estimating the reliability of the detailed point-to-point prediction methods and for calculating the service probability for noise-limited service will be examined.

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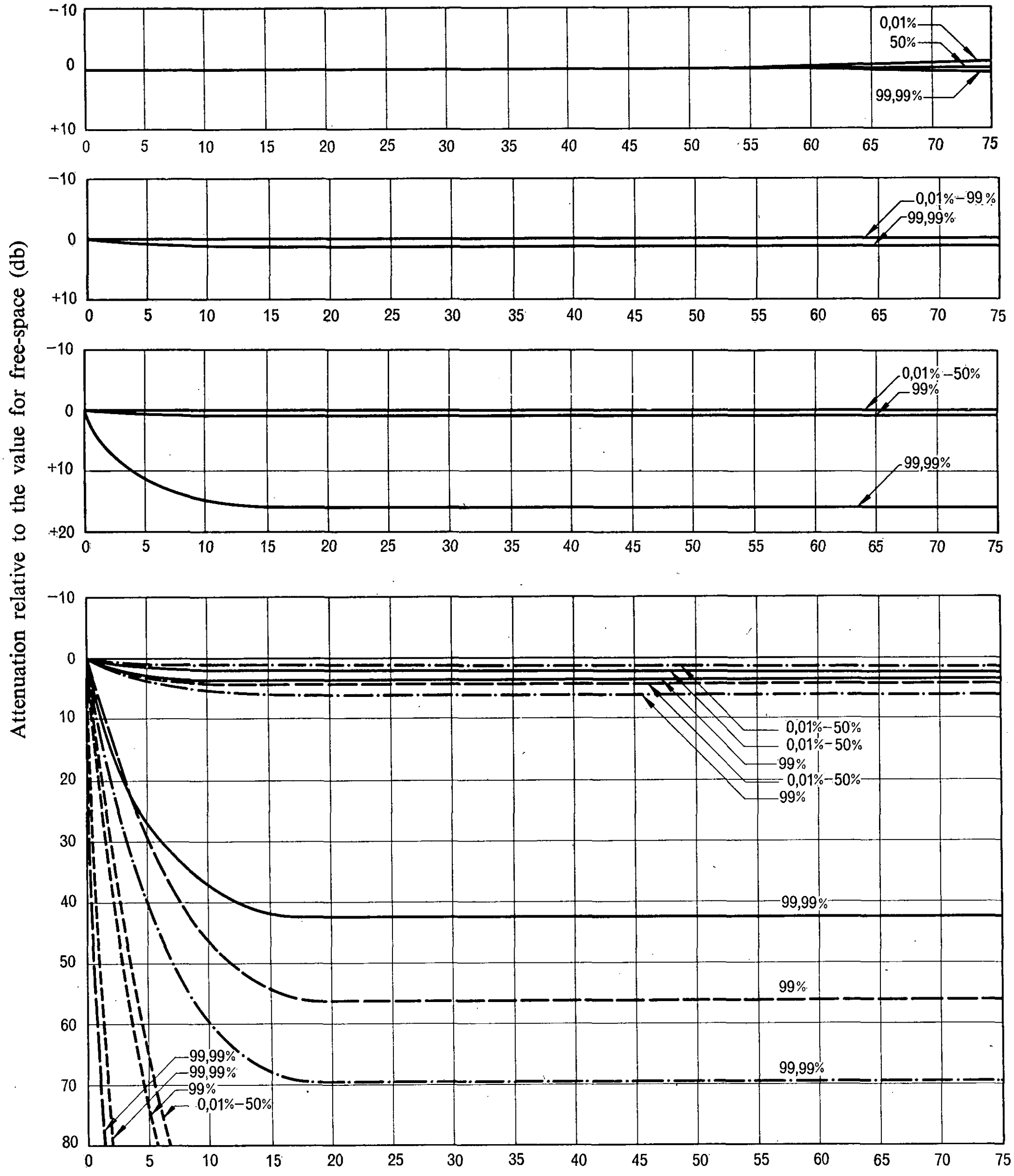
2. C.C.I.R. Doc. V/71 (France) of Geneva, 1962.
3. Note technique No. PR 3104 du Centre National d'Etudes des télécommunications (1962).
4. C.C.I.R. Doc. V/73 (United Kingdom) of Geneva, 1962.
5. National Bureau of Standards Technical Note 101 (1963).



Length of ray-path, r_0, (km)

FIGURE 1

Standard propagation curves for links between earth-stations and spacecraft

($\theta_0 = 0 \cdot 3$ rad., no allowance has been made for ground reflection)

———————— (solid)	2·2 Gc/s
—·—·—·— (dash-dot)	32·5 Gc/s
- - - - - - (dashed)	6·0 Gc/s
— — — — (long dash)	10·0 Gc/s

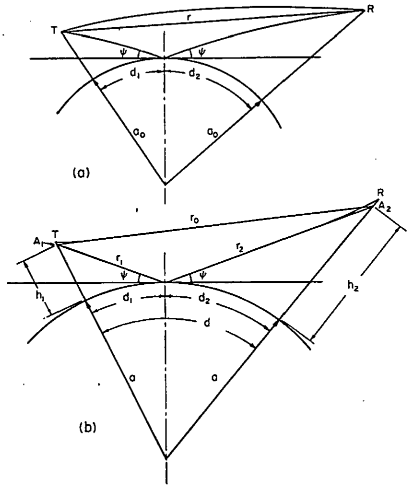


FIGURE 2

Geometrical relationships for within-the-horizon paths

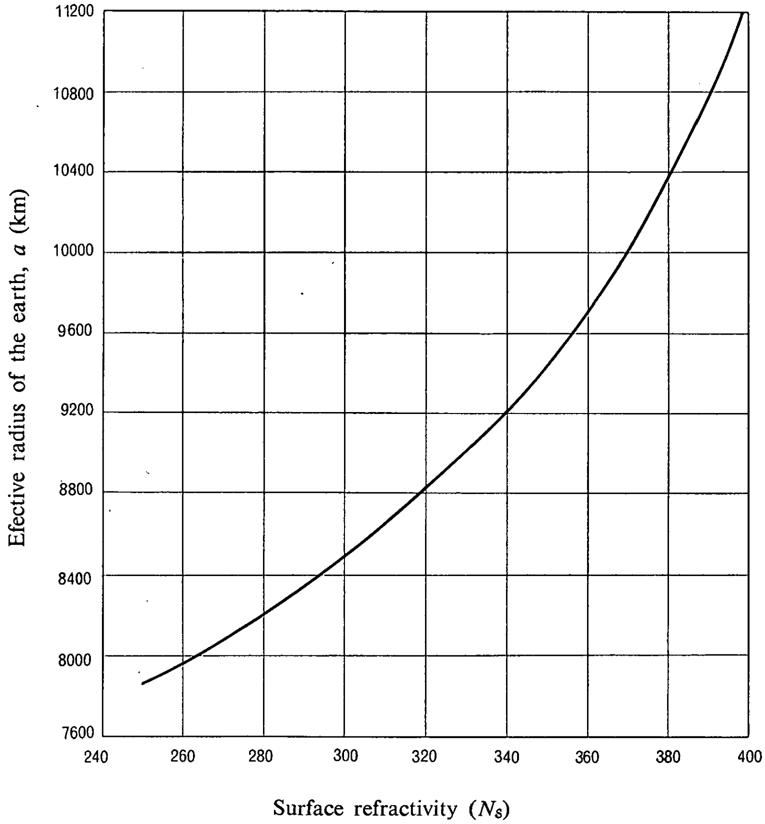


FIGURE 3

Variation of the effective radius of the earth, a, as a function of the surface refractivity, N_S

$$\nu = \sqrt{(2d/\lambda) \cdot \tan \alpha_0 \tan \beta_0}$$

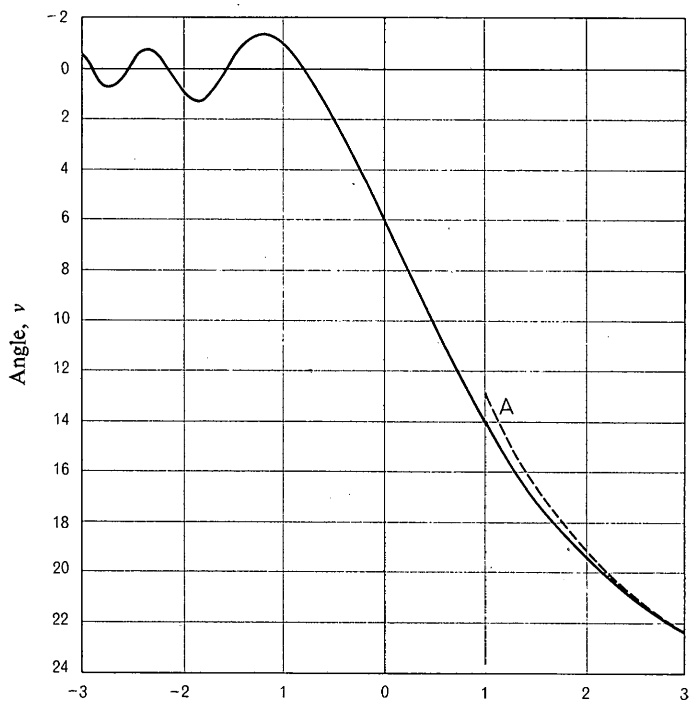


FIGURE 4

Knife-edge diffraction, transmission loss relative to free-space

Curve A: Asymptote, $A(\nu) = 12{\cdot}953 + 20 \log_{10} \nu$

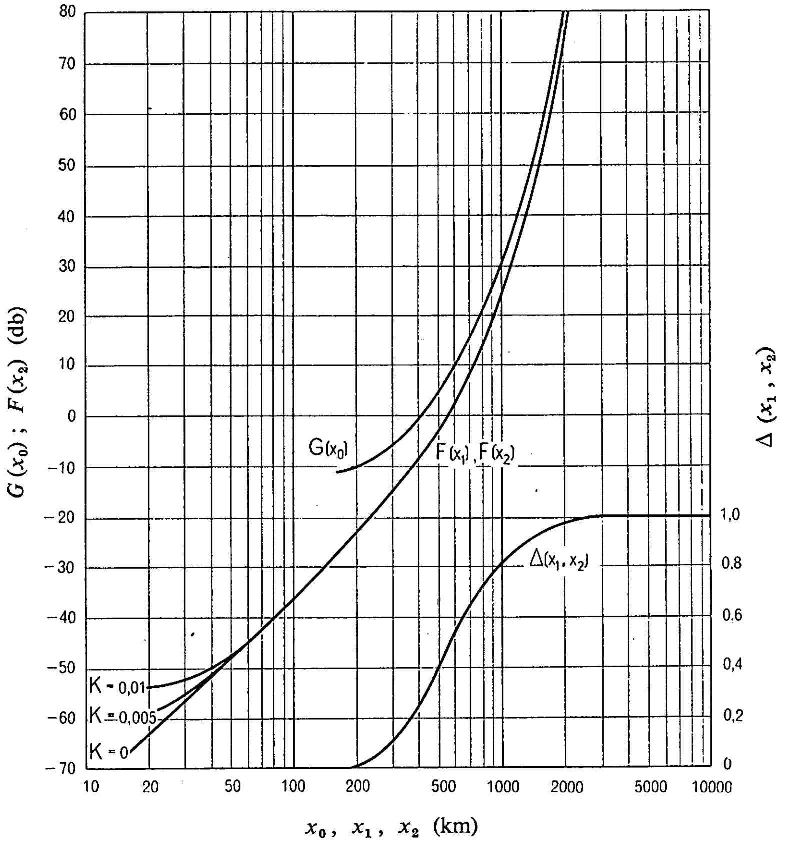


FIGURE 5

Note: For large values of x:

$$F(x) \approx G(x) - 1{\cdot}356,$$

where $G(x) \approx 0{\cdot}0575104\,x - 10\,\log x + 2{\cdot}066$

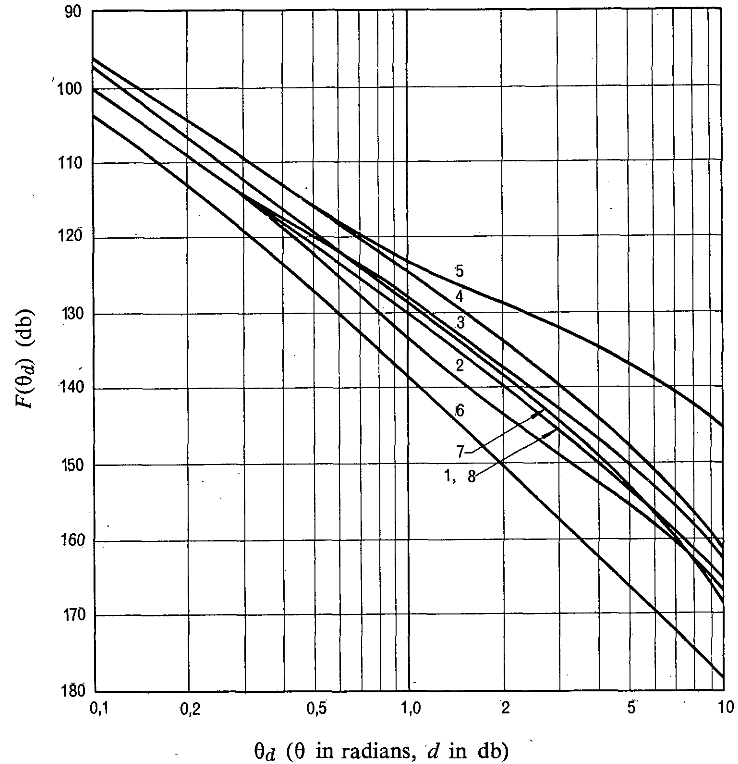


FIGURE 6*a*

The function $F(\theta_d)$ for the types of climate indicated on the curves (see § 2.3)

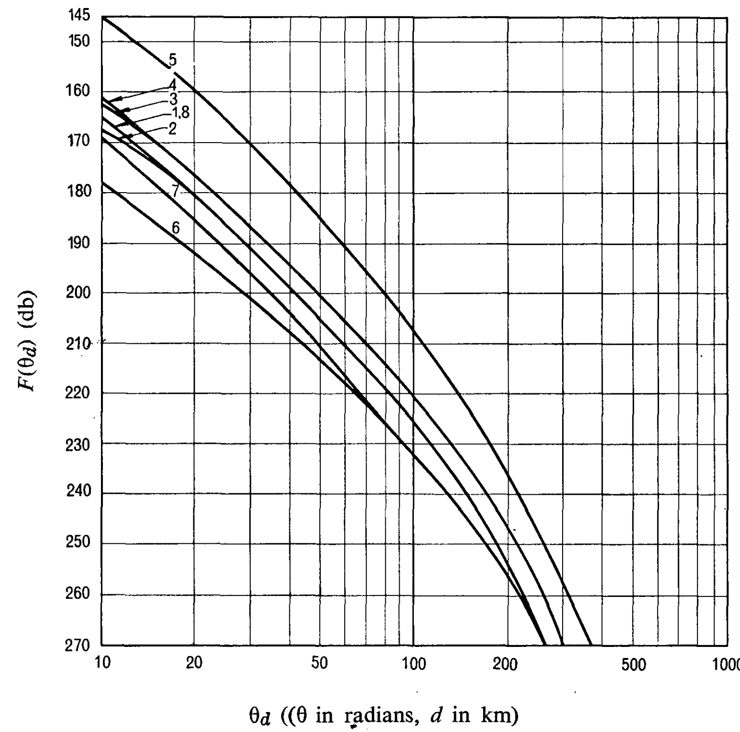


FIGURE 6*b*

The function $F(\theta_d)$ for the types of climate indicated on the curves (see § 2.3)

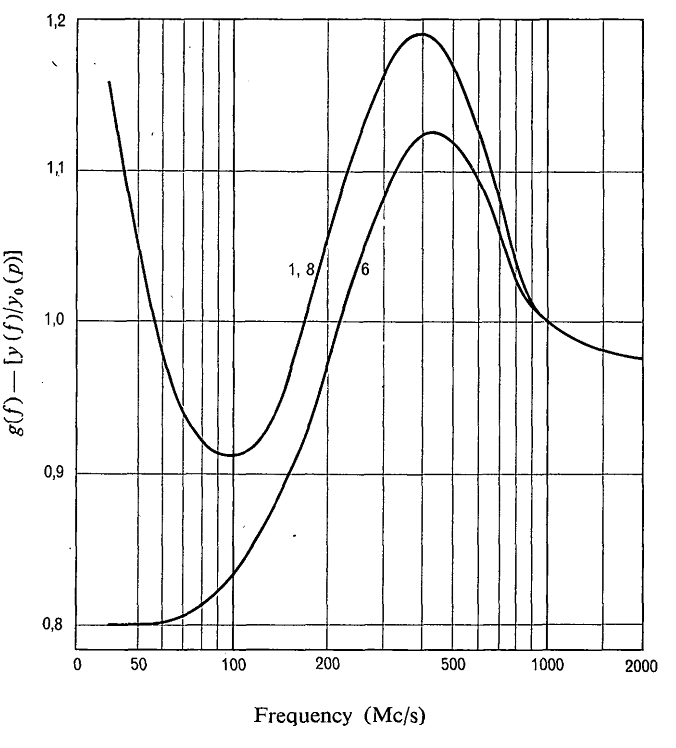


FIGURE 7

The function $g(f)$ — $[y(f) / y_0(p)]$ for the types of climate indicated on the curves (see §2.3)

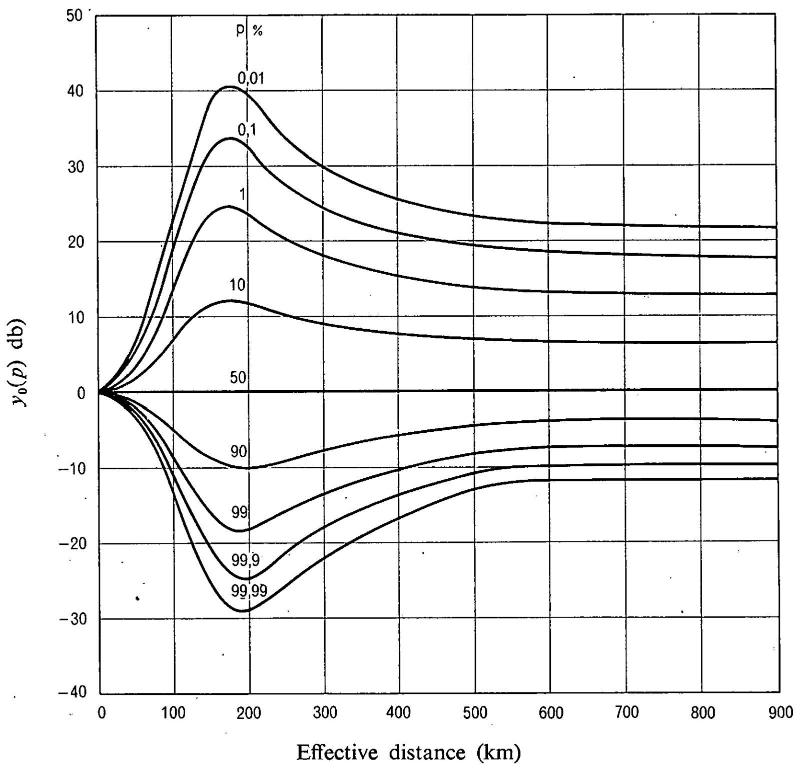


FIGURE 8

Variation of transmission loss with effective distance for a continental temperate climate (Type 1)

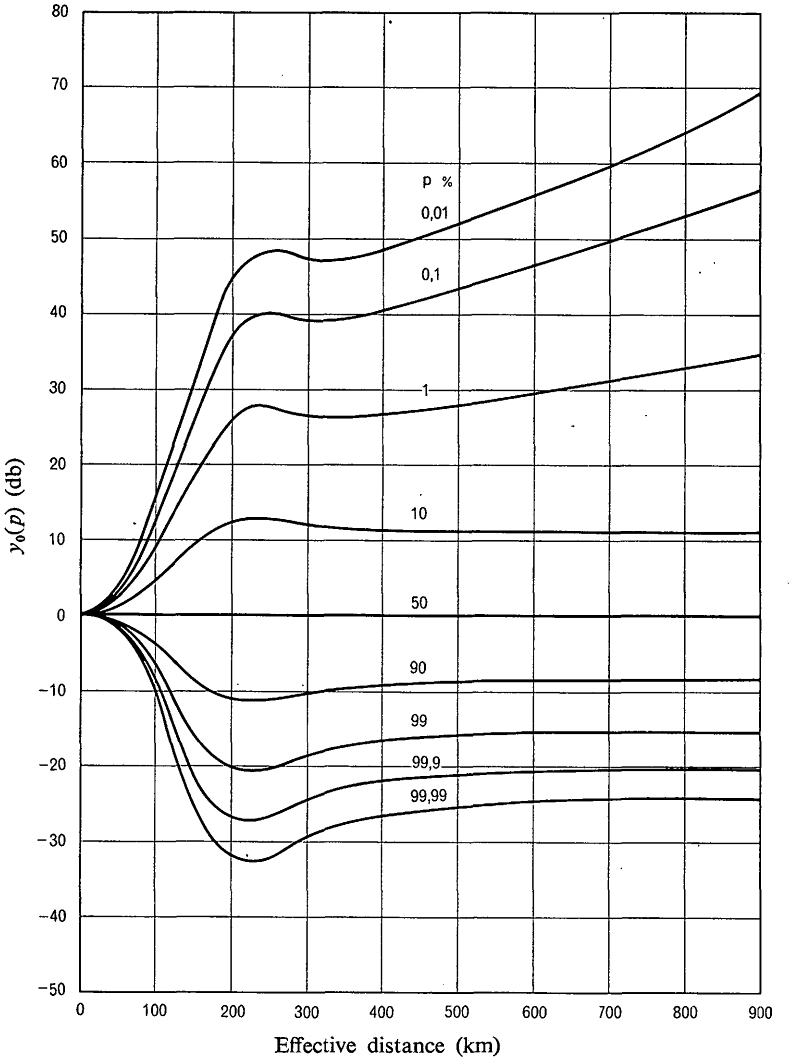


FIGURE 9

Variation of transmission loss with effective distance for an overland path in a maritime temperate climate (Type 2)

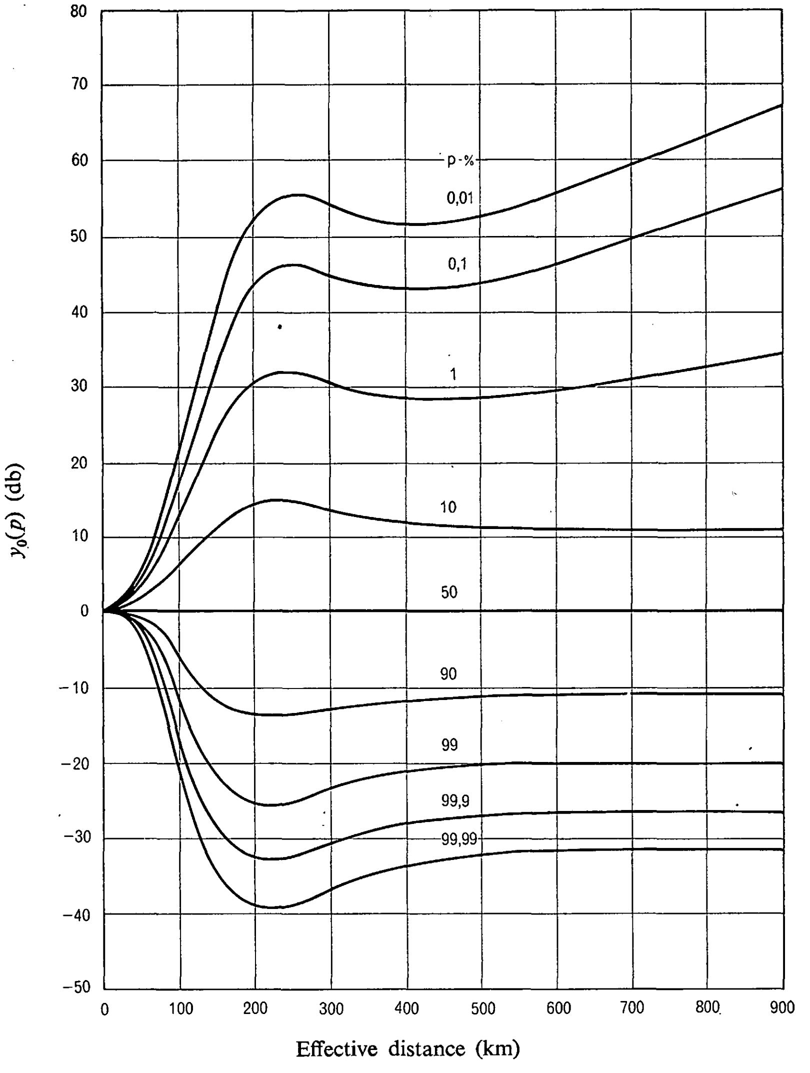


FIGURE 10

Variation of transmission loss with effective distance for an oversea path in a maritime temperate climate (Type 3)

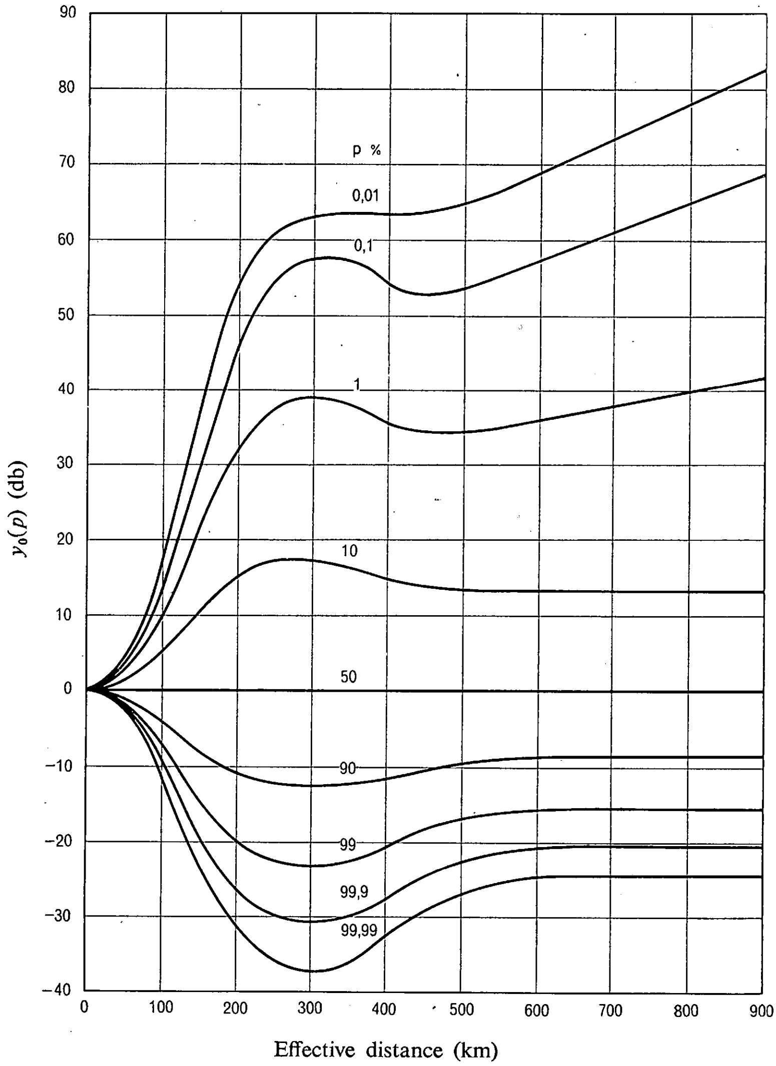


FIGURE 11

Variation of transmission loss with effective distance for an overland path in a maritime sub-tropical climate (Type 4)

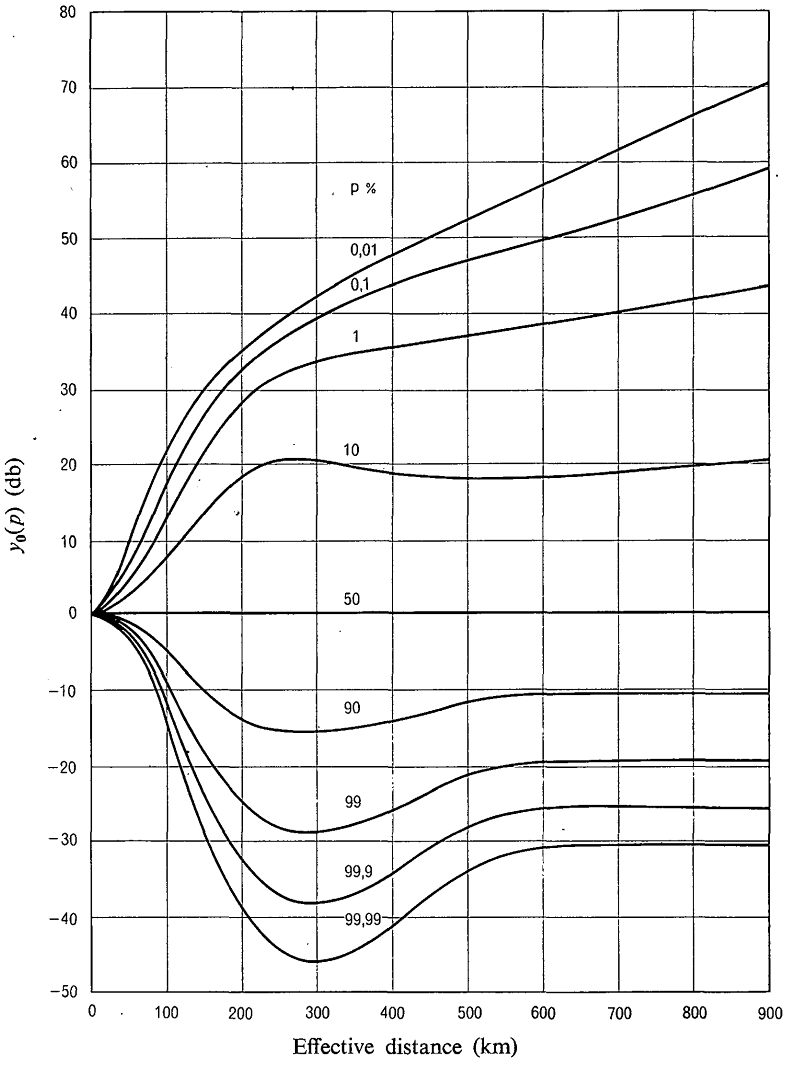


FIGURE 12

Variation of transmission loss with effective distance for an oversea path in a maritime sub-tropical climate (Type 5)

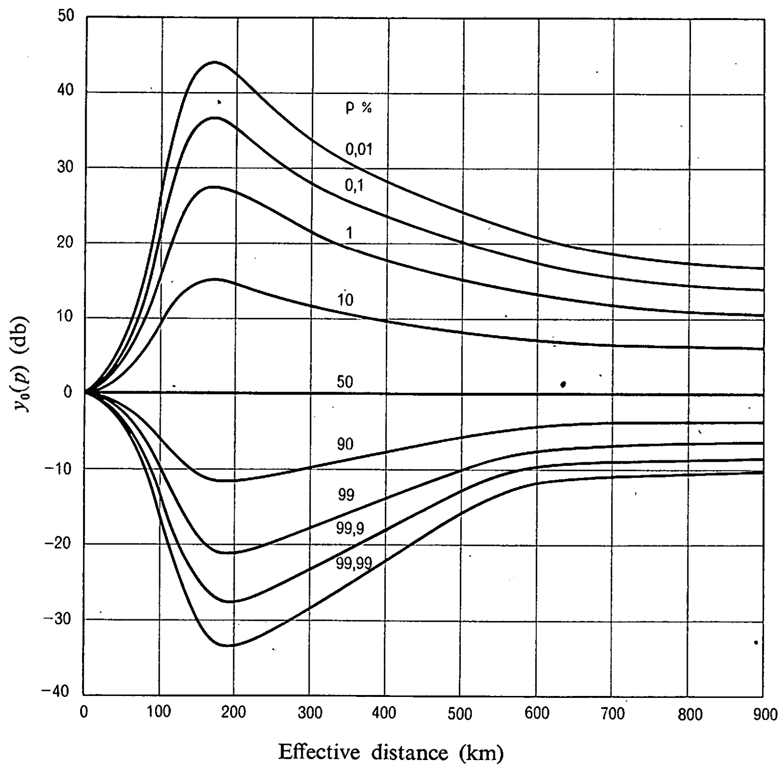


FIGURE 13

Variation of transmission loss with effective distance for a desert climate, Sahara, (Type 6)

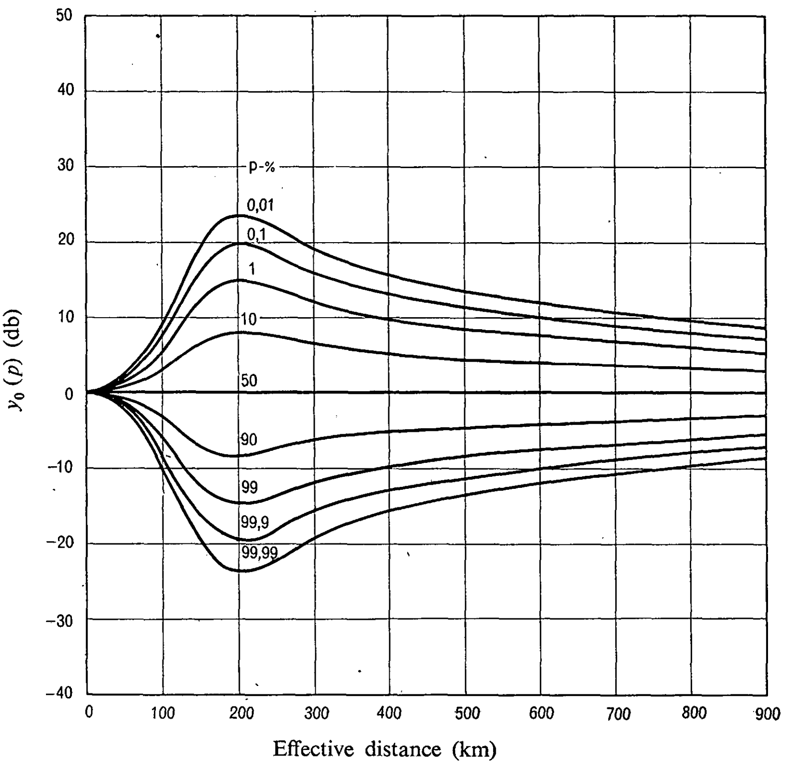


FIGURE 14

Variation of transmission loss with effective distance for an equatorial climate (Type 7)

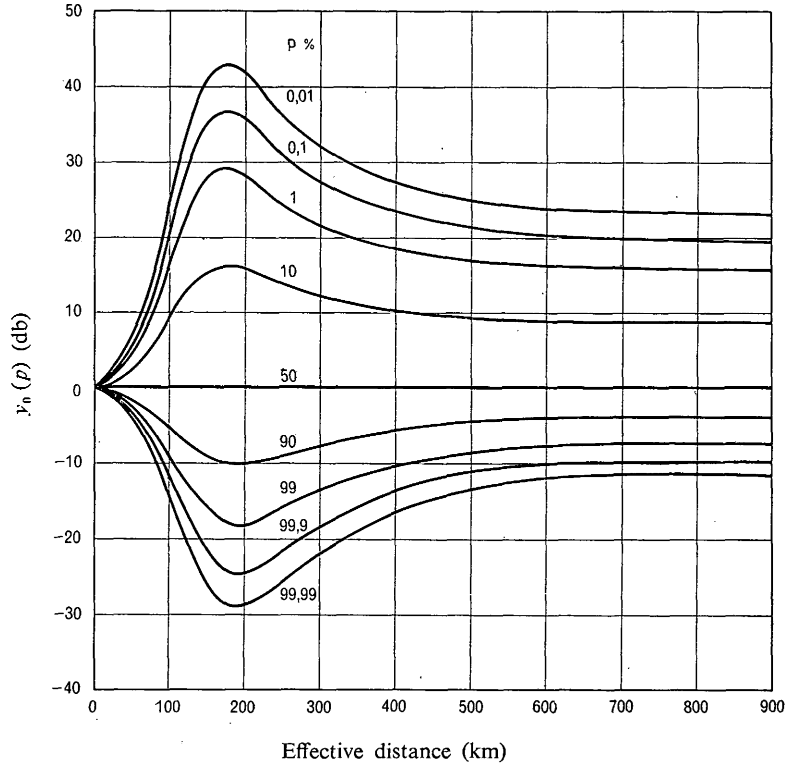


FIGURE 15

Variation of transmission loss with effective distance for a continental sub-tropical climate, Sudan, (Type 8)

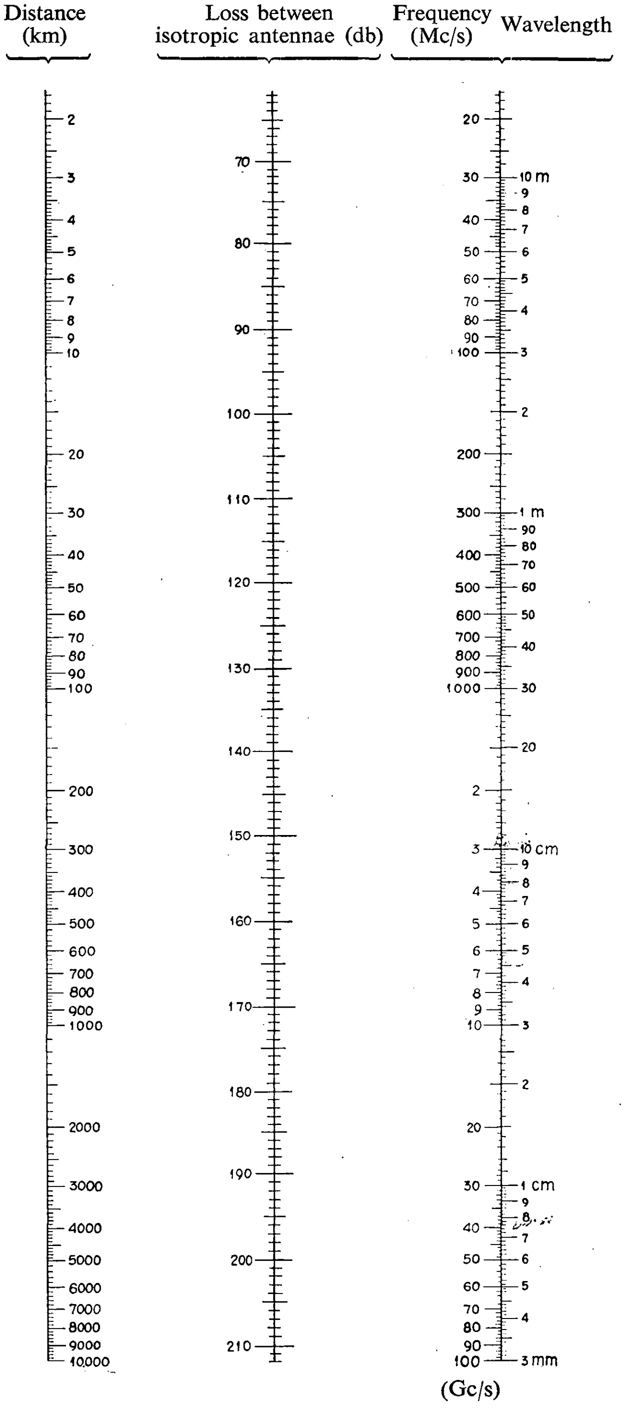


FIGURE 16

Nomogram for the determination of the transmission loss in free-space between isotropic antennae

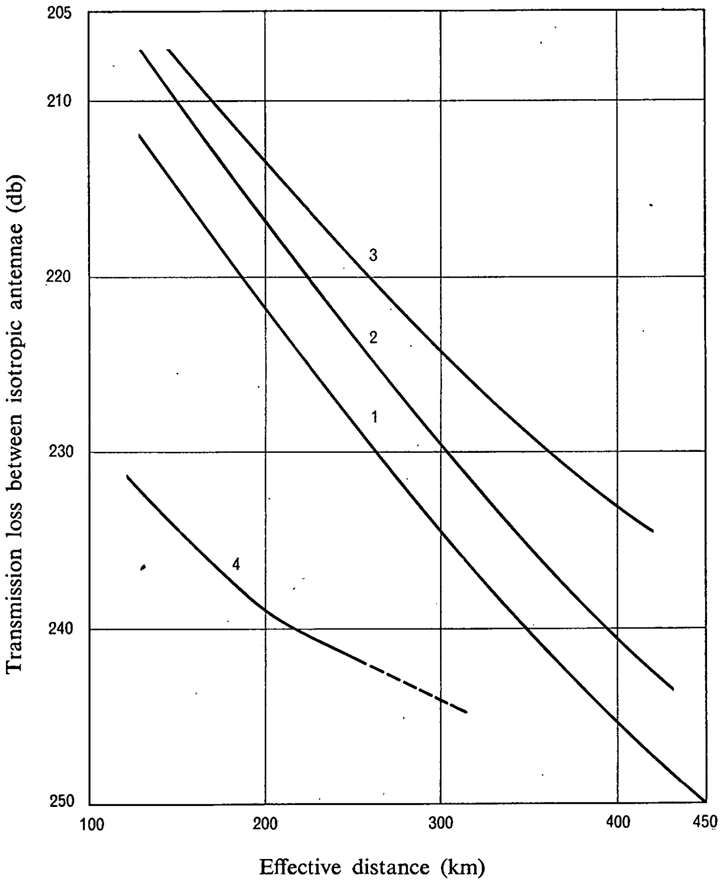


FIGURE 17

Transmission loss, not exceed for 99% of the most unfavourable month, as a function of the effective distance, for the types of climate indicated on the curves (see § 2.3)

(Frequency 1 Gc/s)

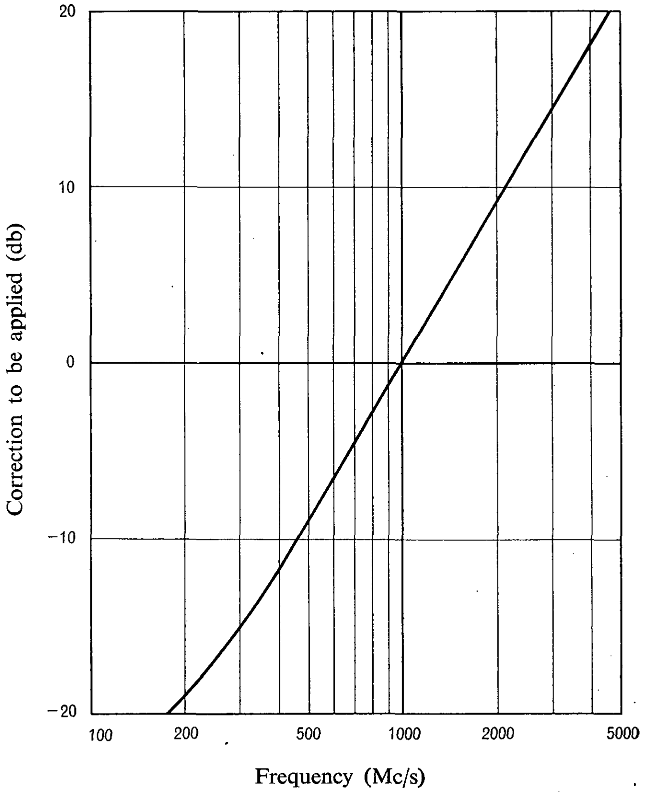


FIGURE 18

Correction (db) to be applied to the values obtained from the curves of Fig. 17, for frequencies other than 1 Gc/s

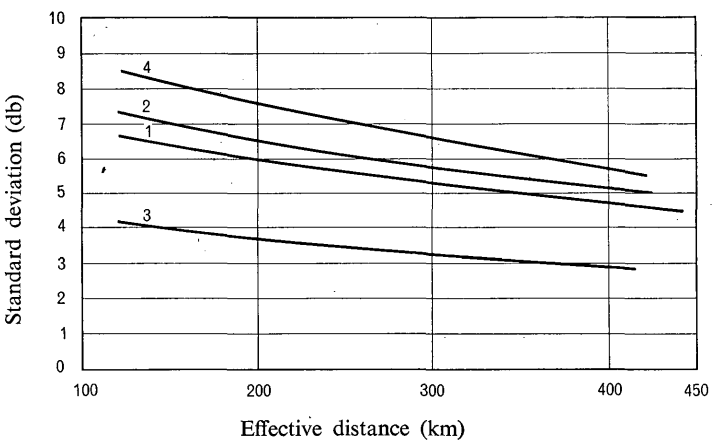


FIGURE 19

Standard deviation as a function of the effective distance, for the types of climate indicated on the curves (see § 2.3)

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STUDY GROUP V

(Propagation over the surface of the earth and through the non-ionized regions of the atmosphere)

Terms of reference

To study all matters relating to the propagation of radio waves over the surface of the earth and through the non-ionized regions of the atmosphere in so far as they concern radiocommunication.

Chairman : Dr. R.L. SMITH-ROSE, C.B.E. (United Kingdom)
Vice-Chairman : Dr. A. KALININ (U.S.S.R.)

INTRODUCTION BY THE CHAIRMAN, STUDY GROUP V

1. Terms of reference

At the IXth Plenary Assembly, Los Angeles, 1959, the terms of reference of Study Group V were revised to include the former work of Study Group IV which is now concerned with space communications. Study Group V thus became responsible for the problems of radio wave-propagation over the ground and through the troposphere.

1.1 To take account of recent developments in space radiocommunications, the title and terms of reference of Study Group V were revised at the Xth Plenary Assembly, Geneva, 1963, as follows:

Title : Propagation over the surface of the earth and through the non-ionized regions of the atmosphere.

Terms of reference : To study all matters relating to the propagation of radio-waves over the surface of the earth and through the non-ionized regions of the atmosphere, insofar as they concern radiocommunications.

2. Summary of proceedings

Six meetings of the Study Group were held in Geneva during the Xth Plenary Assembly. The basis of the studies was the report of the Interim Meeting, Geneva, 1962, with its 27 Appendices in the form of revised Recommendations, Reports, Resolutions, Questions and Study Programmes. A large proportion of these Appendices were adopted with few, and if any, minor modifications: the remainder were considered for revision in the light of new knowledge obtained between the Interim and Plenary meetings, and submitted in new documentation.

3. Measurement of field strength

A revised Report was prepared on the technique of measuring field-strength, with particular reference to the needs of the VHF and UHF broadcasting services. The Report discusses the various methods of measurement, the precautions necessary to obtain reliable results, and the best means of presenting these results for the benefit of the engineer.

4. Ground-wave propagation

For a study of ground-wave propagation over different parts of the surface of the earth, a knowledge of the electrical properties of this surface is essential. A revised Report reviews the various methods of measuring these properties, while another discusses the application of the results to wave propagation over an inhomogeneous earth. A third Report indicates the extent to which our knowledge of the influence of irregular terrain on the propagation of short waves has been advanced.

5. Influence of the troposphere on propagation

5.1 *Sound broadcasting and television*

For some years past, one of the main activities of the Study Group has been to produce reliable curves, showing the relationship between field strength and distance for the various frequencies and conditions encountered in the planning of broadcasting services in the VHF and UHF bands. These curves were revised and extended by a Committee of Experts which met at Cannes in 1961; and later in the same year, they were adopted by the European VHF/UHF Broadcasting Conference, Stockholm, 1961. The curves, with only minor revisions, were formally adopted by the C.C.I.R. at Geneva, 1963; and they are available for use by mobile, as well as broadcasting, services, using frequencies in the range of 40 to 1000 Mc/s.

5.2 *Broadcasting in Africa*

In anticipation of a forthcoming conference to consider the planning of broadcasting services for the African continent, a preliminary set of field-strength/distance curves has been prepared, taking account of the widely varying meteorological and ground conditions in different parts of Africa. It is intended that these curves, which were prepared at the urgent request of I.F.R.B., should be revised as the, at present, scanty knowledge of propagation conditions in that country is supplemented by future quantitative measurements.

5.3 *Point-to-point radio-relay links*

The Study Group gave considerable attention to the assessment, on a statistical basis, of the performance of radio-relay links, and their protection from mutual interference. One of two Reports adopted describes comprehensive methods for estimating tropospheric-wave transmission loss, while the other gives provisional field-strength/distance curves for the frequency range 1 to 10 Gc/s. The latter were prepared primarily for use in estimating the mutual interference between space and terrestrial communication systems.

5.4 *Radiometeorology*

All the investigations conducted in this subject, must take account of the wide, and frequently rapid variations in meteorological conditions. Steady progress is evident towards a better understanding of the effect of these conditions on the propagation of radio waves through the earth's atmosphere. In accordance with the change of title recorded above, a new report is concerned with certain specific matters of interest in propagation between the earth and vehicles in space, through the outer, non-ionized regions of the atmosphere. In such cases, absorption of the waves and natural noise are of great interest at centimetre, and shorter, wavelengths.

6. General

In addition to the preparation of Reports as referred to above, the existing Questions and Study Programmes were revised in the light of advancing knowledge, so that the future work of the Study Group may be of the greatest assistance in the development of broadcasting and point-to-point services including, as appropriate, the extension of these to space communications.

Resolutions were adopted providing for the setting up of two International Working Groups; the first under the chairmanship of Dr. J.A. Saxton (United Kingdom) to deal with propagation curves; and the second under Mr. Misme (or other nominee of France) to study radiometeorology.

OPINION 4 *

RADIO TRANSMISSION UTILIZING INHOMOGENEITIES IN THE TROPOSPHERE (COMMONLY TERMED "SCATTERING")

(Warsaw, 1956)

The C.C.I.R.,

CONSIDERING

(a) that experiments have already shown the possibility of using frequencies in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands for transmission by tropospheric-scatter propagation to distances well beyond the horizon;

(b) that the use of such frequencies over such distances may tend to reduce the rate of expansion of services in other frequency bands;

IS UNANIMOUSLY OF THE OPINION

that the attention of Administrations and of the I.F.R.B. should be drawn to the potentialities of the frequencies in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands for fixed services over distances well beyond the horizon by means of tropospheric-scatter propagation and should be invited to keep in touch with developments in this field (see Study Programme 139).

OPINION 5 **

INFLUENCE OF THE TROPOSPHERE ON FREQUENCIES USED FOR TELECOMMUNICATION WITH AND BETWEEN SPACECRAFT

(Los Angeles, 1959)

The C.C.I.R.,

CONSIDERING

(a) that communication between the earth and spacecraft is now a practical possibility;

(b) that the troposphere influences the characteristics of the received signals and the apparent positions as observed by radio methods;

IS UNANIMOUSLY OF THE OPINION

that U.R.S.I. should be asked the following Question:

1. what effect does the troposphere have on the propagation through it of radio waves of all frequencies? Particular attention should be paid to:
   - the attenuation of the waves;
   - any variations in the direction of propagation:

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* This Opinion was formerly designated "Resolution 24".
** This Opinion was formerly designated "Resolution 40".

2. what frequencies of transmission from spacecraft will produce the most useful information on the troposphere as a supplement to that obtainable by other methods?

QUESTION 185(V) *

PROPAGATION DATA REQUIRED FOR RADIO-RELAY SYSTEMS

(London, 1953 — Warsaw, 1956 — Los Angeles, 1959)

The C.C.I.R.

CONSIDERING

(a) that, in the planning of a communication network, it is necessary to define the overall system performance achieved for given percentages of time;

(b) that designers of radio systems in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands require to know, from the point of view of sustained satisfactory operation, the tropospheric propagation characteristics and the resulting path attenuation that is exceeded for a low percentage of the time for each particular frequency band over the working range, which may extend from well within the optical range in line-of-sight systems to several times the optical range in tropospheric-scatter systems;

(c) that the planning of systems requires a knowledge of the seasonal distribution curves of such propagation characteristies;

(d) that, from the point of view of interference beyond the normal range, it is necessary to know the value of path attenuation likely to be exceeded for a large percentage of time, at distances up to several times the working range;

(e) that the system bandwidth may be limited by multipath propagation effects;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what is the distribution with time of the values of path attenuation in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands, and particularly the values likely to be exceeded for 99·9%, 99%, 50%, 1%, 0·1% and 0·01% of each month of the year;

2. what is the cumulative distribution of the length of individual time intervals, during which the path attenuations exceed each of the levels described in § 1, for a representative month of each season;

3. to what extent are these distributions dependent upon the length of path, the geographical region and the type of terrain over which the path passes, and for optical paths, the terrain clearance;

4. what limitations on the bandwidth of transmission are imposed by the propagation medium?

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* This Question replaces Question 136.

STUDY PROGRAMME 185 A (V)

PROPAGATION DATA REQUIRED FOR LINE-OF-SIGHT RADIO-RELAY SYSTEMS

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that, in planning a communication network, it is necessary to define the overall system performance achieved for given percentages of the time;

(b) that designers of radio systems in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands require to know, from the viewpoint of sustained satisfactory operation, the tropospheric propagation characteristics and the resulting transmission loss (see Recommendation 341), that is not exceeded for a large percentage of the time for each particular frequency band over the working range, which may extend from several tens of kilometres up to more than 200 km for certain links between elevated sites;

(c) that the planning of systems requires a knowledge of the seasonal distribution curves, as functions of time, of the transmission loss for the most unfavourable season or month;

(d) that, for interference studies, it is necessary to know the quasi-minimum value of the transmission loss;

(e) that the bandwidth of the system may be limited by the effects of multipath propagation;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what is the distribution in time of the values, relative to free-space of the received power-level reached, in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands, for each month of the year. The recording should be performed with an instrument having a time constant of less than or equal to one second;
2. what are the levels for given percentages of time corresponding to the most unfavourable month, the most favourable month and those corresponding to the whole year;
3. to what extent do the distributions found depend on the path length, the climate, the nature of the terrain over which the path passes and the clearances of the antennae;
4. to what extent can the distributions found be described by simple statistical laws;
5. what limitations are imposed on transmission by the effects of multipath propagation and how may these be overcome;
6. what limitations on the use of the system are imposed by solar noise and noise from other external sources?

Note. — To meet the needs of Study Group IX, priority should be given to measurements to establish the magnitude of interfering fields at 6 and 11 Gc/s, with antennae representative of practical systems, over representative paths and at longer distances.

STUDY PROGRAMME 185 B (V)

PROPAGATION DATA REQUIRED FOR BEYOND-THE-HORIZON RADIO-RELAY SYSTEMS

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that in the planning of a communication network it is necessary to define the overall system performance achieved for a given percentage of the time;

(b) that designers of radio systems in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands require to know, from the viewpoint of sustained satisfactory operation, the tropospheric propagation characteristics and the resulting transmission loss, that is not exceeded for a large percentage of the time for each particular frequency band, over the distance corresponding to the service range, which may extend from about 200 km to more than 500 km;

(c) that the planning of systems requires a knowledge of the distribution curves, as functions of time, of the transmission loss for the most unfavourable month of the climatic zone under consideration;

(d) that, for interference studies, it is necessary to know the quasi-minimum value of the transmission loss;

(e) that the bandwidth of the system may be limited by the nature of the mode of propagation employed;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. what is the distribution in time of the basic transmission loss (see Recommendation 341) in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands, for each month of the year (the value of the path antenna gain being specified). The recording should be performed with an instrument having a time constant of one minute * and especial importance should be attached to the quasi-maximum and quasi-minimum values of the transmission loss or field-strength;

2. what are the levels for given percentage of time corresponding to the most unfavourable month, the most favourable month and those corresponding to the whole year;

3. which are the hours of the day for which the greatest transmission loss may usually be expected;

4. what is the distribution in time of the fluctuation of the level of the received signal about its hourly median value **, when the recording is made with a time constant as short as possible;

5. how do the distributions depend on the climatic zone in which the path under consideration is located, and which distinct climatic zones should be taken into consideration ***;

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* Other time constants may be used, should it appear desirable, but in all cases the time constant used should be specified.

** Other periods of time may be used to define the median value, but these periods should be stated.

*** In view of the paucity of data relating to propagation in climates other than temperate, Administrations are urged to give special attention to the collection of data relating to other types of climate.

6. how do the distributions found depend on the frequency, the distance between the stations, the angle of elevation of the antennae at each terminal and on the nature of the terrain over which the path passes;

7. to what extent can these distributions be described by simple statistical laws;

8. what limitations on the bandwidth of the system are imposed by the propagation process employed (diffraction, partial reflection, scattering, etc.);

9. what limitations on the use of the system are imposed by the effects of solar noise, and noise from other external sources?

Note. — The results of these studies should be presented in the form given in Administrative Circular AC/63.

QUESTION 246(V) *

GROUND-WAVE PROPAGATION

(Stockholm, 1948 — Warsaw, 1956) — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that under some conditions of propagation, the ground over which the wave passes has a major influence on the propagation characteristics;

(b) that, in this connection, it is desirable to include the effect of the troposphere, insofar as it can be represented by a simple profile of refractive index with height;

(c) that information on the electrical characteristics of the ground can be obtained from ground-wave propagation measurements;

UNANIMOUSLY DECIDES that the following question should be studied:

1. how is ground-wave propagation affected by inhomogeneities and small undulations of the ground;

2. how can changes in the electrical constants of the ground be deduced from changes in the field characteristics along the path;

3. how do the values of the dielectric constant, ε, and the conductivity, σ, derived from measurement, depend on the frequency and on such physical factors as vegetation and weather;

4. what are the variations in the phase of radio waves in transmission over the ground;

5. what is the effect, as a function of frequency, of the troposphere (defined by a simple profile of refractive index with height), upon ground-wave propagation and upon the height-gain relationship.

6. what are the effects obtained with vertical and horizontal polarization respectively;

7. what is the effect of large natural and man-made obstacles in diffracting the waves in either the horizontal or vertical plane?

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* This Question replaces Questions 135 and 184.

STUDY PROGRAMME 246 A (V) *

EFFECTS OF TROPOSPHERIC REFRACTION AT FREQUENCIES BELOW 10 Mc/s

(Geneva, 1951 — London, 1953 — Warsaw, 1956 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the ground-wave propagation curves for frequencies below 10 Mc/s, submitted with Recommendation 368 make no allowance for tropospheric refraction;

(b) that the effect of the troposphere is taken into account in the C.C.I.R. Atlases of ground-wave propagation on frequencies above 30 Mc/s, by the use of an effective radius of the earth 4/3 times its real value;

(c) that the effect of tropospheric refraction will decrease with decreasing frequency;

(d) that experimental data and mathematical analyses relating to this subject are described in Report 235;

(e) that allowance for these effects is likely to be important down to frequencies at least as low as 10 kc/s and out to very large distances in connection with the development of navigational aids employing pulse techniques which rely for their accuracy on the ground-wave mode of propagation;

(f) that suitable mathematical models for describing the tropospheric refractive index as a function of height are given in Report 231;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. further measurements of ground-wave field-strengths, including the use of pulse techniques over a sufficiently long path of uniform conductivity, such as a sea path, to determine experimentally the modification of the ground-wave curves required to include the effects of tropospheric refraction at frequencies below 19 Mc/s;

2. interpretation of the mathematical analysis relating to ground-wave propagation to include the effects of tropospheric refraction on frequencies below 10 Mc/s;

3. investigation of the possible influence of tropospheric refraction on the phase of the ground-wave.

STUDY PROGRAMME 246 B (V) **

GROUND-WAVE PROPAGATION OVER INHOMOGENEOUS EARTH

(Warsaw, 1956 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the problem of amplitude and phase variations in ground-wave propagation resulting from the non-uniformity of the electrical constants, both vertically and horizontally, is of great importance in:

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* This Study Programme replaces Study Programme 87.
** This Study Programme replaces Study Programme 135.

— the prediction of the service areas of radio transmitters;
— the accuracy of navigational aids employing low and medium frequencies;
— the effect of coastal refraction in direction-finding measurements;

(b) that the rigorous mathematical analysis so far refers mainly to idealized models including:
— one or more boundaries between regions of different conductivity normal to the path, with possible discontinuities in height;
— horizontal stratification;
— spherical earth;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the refinement of methods for measuring the values of the equivalent dielectric constant, ε, and conductivity σ for a path, for portions of a path, or for local areas for various frequencies below 30 Mc/s;
2. the obtaining of more experimental results for amplitude and phase of the ground-wave along the path, especially in combination with simultaneous measurements of ε and σ;
3. the further development of the mathematical analysis to include arbitrary variations of ε and σ, especially the cases of propagation obliquely to a boundary and of non-horizontal stratification, and also the simultaneous treatment of surface irregularities and inhomogeneous earth constants;
4. the reduction of analytical methods to a form which is convenient for engineering computation, or, alternatively, the comparison of the rigorous results with the results of semi-empirical methods in order to define more closely the limitations of the latter;
5. the further investigation of the utility of the method which deduces the equivalent earth parameters from the measured dispersion of sferics.

STUDY PROGRAMME 57 (V) *

INVESTIGATION OF MULTI-PATH TRANSMISSION THROUGH THE TROPOSPHERE

(London, 1953)

The C.C.I.R.,

CONSIDERING

that, in systems using frequencies about 30 Mc/s, radio waves may travel from a transmitter to a receiver along several paths;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. investigation of time and phase differences occurring in multi-path transmissions;
2. determination of the percentage of time for which given time and phase differences occur respectively;

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* This Study Programme does not refer to any Question under study.

3. statistical analysis of the relative strengths of signals occurring in multi-path transmissions;
4. investigation of the manner in which the quantities measured vary with frequency, over bands of the order of those used in television and wide-band radio and television systems;
5. investigation of the manner in which the same quantities are affected by the use of space-diversity systems.

STUDY PROGRAMME 139 (V) *

RADIO TRANSMISSION UTILIZING INHOMOGENEITIES IN THE TROPOSPHERE (COMMONLY TERMED "SCATTERING")

(Warsaw, 1956 — Los Angeles, 1959)

The C.C.I.R.,

CONSIDERING

(a) that, in various countries, recent experiments, characterized by the use of transmitting and receiving antennae directed towards the same part of the troposphere, have shown that radio signals in the VHF (metric), UHF (decimetric) and SHF (centimetric) bands can be propagated consistently through the troposphere over unexpectedly great distances, and that, beyond the line of sight, fields are found to be much greater than the diffraction theory for a standard radio atmosphere would predict;

(b) that useful signals can be obtained in this manner at distances greater than was formerly expected;

(c) that tropospheric inhomogeneities play an important role in this phenomenon;

(d) that little is known about geographical and topographical influences;

UNANIMOUSLY DECIDES that the following studies should be carried out:

investigation of this new tropospheric propagation phenomenon, in its widest sense, with a view to the extension of knowledge of:

1. the characterisitcs of the signal, in particular signal strength, signal distortion (time delays, bandwidth), fading rates and fading range and their dependence on frequency, range and geographical situation;
2. the influence of meteorological conditions, including water vapour, rain and snow on signal strength;
3. the efficiency of antennae in relation to size and design;
4. the use of space, frequency and polarization diversity for transmission and reception;
5. the application of such diversity techniques for co-channel transmission and reception.

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* This Study Programme, which replaces Study Programme 91, does not refer to any Question under study.

STUDY PROGRAMME 176(V) *

FADING OF SIGNALS PROPAGATED BY THE TROPOSPHERE

(Adopted by correspondence, 1961)

The C.C.I.R.,

CONSIDERING

(a) that the practical requirements of radiocommunication in the troposphere necessitate information, not only on the strength of the received field, but also on

— the amplitude distribution of field-strength,
— the fading frequency,
— the space distribution of field-strength,
— the occurrence of frequency-selective fading;

(b) that the variation in field-strength involves variations in the direction of arrival, as well as variations caused by interference between components of different modes (bending, refraction, scattering) and variations caused by changes in the meteorological conditions;

(c) that the period of field-strength variations may range in duration from

— fractions of a second to fractions of a minute for scatter propagation,
— from one minute to one hour for propagation through inversions,

and that variations with time of day and season of the year may be expected;

(d) that it is important to have as much information as possible concerning the effects of time-, space-, and frequency-diversity reception;

DECIDES

that the following studies should be carried out in the various frequency bands used in radiocommunication by means of the troposphere:

1. the space- and time-distributions (e.g., Rayleigh, normal and log-normal) of fading;

2. the effect of distance on short-period fading;

3. measurement of the power spectra and autocorrelation function to determine the average fading frequency;

4. determination of the manner in which the value of the correlation coefficients between the received voltages on locally spaced antennae depend on the frequency, the time of day, the season of the year and the distance;

5. the monthly and annual distributions of the long-period variations of the hourly-median amplitude, and the manner in which these distributions are dependent on frequency and distance;

6. the manner in which fading-frequency and depth of fading are dependent on the carrier-frequency, the time of day, the season of the year, the geographical location of the path and on meteorological factors;

7. the effects of field-strength variations on different types of receiving systems, such as time-, space-, and frequency-diversity systems;

* This Study Programme does not refer to any Question under study.

8. the influence of selective fading on wide-band systems and on systems employing frequency-diversity;
9. the effects of fading on modulation;
10. the causes of fading.

STUDY PROGRAMME 188 (V) *

INFLUENCE OF IRREGULAR TERRAIN ON TROPOSPHERIC PROPAGATION

(Geneva, 1951 — London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that it is of great importance to pursue studies concerning propagation over irregular terrain;

(b) that propagation over high mountain ridges is proving to be of great practical significance;

(c) that the presence of obstacles on the path may modify, to a large extent, the mean value of the transmission loss as well as the amplitude and duration of fading;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. measurement of the transmission loss over paths containing a single mountain ridge and comparison with the value calculated from diffraction by knife-edge;
2. influence of the existence of several obstacles on the one path;
3. influence of the radius of curvature and of the nature of the soil at the summit of a mountain;
4. attenuation produced by the general roughness of the ground, known as terrain factor, both for the waves in the service area around a transmitter and for waves arriving from a distant transmitter;
5. the local variation of field strength at a given receiving area for, a nearby and distant transmitter, and their correlation as a function of the irregularity of the terrain and of the directions of arrival of the incoming waves;
6. propagation guided along valleys;
7. propagation across valleys;
8. propagation in urban areas;
9. problems associated with the polarization of radio waves, as influenced by the irregularity of the terrain over which they are propagated;
10. variations of phase, as a function of the distance over irregular terrain;

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* This Study Programme, which replaces Study Programmes 89 and 136, does not arise from any Question under study.

11. influence of a substantial mountainous region, below the common volume of the transmitting and receiving beams, in propagation by tropospheric, scatter;

12. conditions for obstacle gain, namely when the signal received over a mountainous path is greater than if the earth were smooth;

13. influence of irregular terrain on both the short-term and long-term variations of transmission loss, especially under the conditions of obstacle gain.

STUDY PROGRAMME 189 (V) *

VHF AND UHF PROPAGATION CURVES IN THE FREQUENCY RANGE 40 Mc/s TO 1 Gc/s

Broadcasting and mobile services

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

that the provisional propagation curves given in Recommendation 370 are based on data obtained mainly in Europe and in North America using transmitting and receiving antennae generally of the order of 300 m and 10 m respectively above ground level and that information is required not only for other regions or areas but for other antenna heights up to 30 000 m;

UNANIMOUSLY DECIDES that the following studies ** should be carried out:

1. continuous field-strength or transmission loss recordings at frequencies between 40 Mc/s and 1 Gc/s over periods of up to several years in as many parts of the world as possible and for distances of up to about 1000 km covering as wide a range of climatic conditions as possible;

2. determination of corrections to the curves in Recommendation 370, to allow for the effects of other conditions of climate, terrain and vegetation. The influence of buildings on reception at low heights also needs study;

3. investigations over paths up to about 2000 km in length, of the effect of changing the height of the transmitting or receiving antenna, bearing in mind that broadcast and land mobile services may wish to use receiving antenna heights anywhere between about 2 and 30 m above ground, while aeronautical mobile services may use antennae at heights of up to about 30 000 m above ground;***

4. particular investigation of the problems of oversea paths and of mixed land and sea paths;

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* This Study Programme, which replaces Study Programmes 137 and 140, does not arise from any Question under study.

** Many of these studies relate closely to Study Programme 190 (V).

*** In this Study Programme, particular attention should be given to the immediate requirements of the aeronautical mobile service in the frequency band 100 to 140 Mc/s.

5. investigations, over various transmission distances between points on the ground, of the effect of using directional antennae and also of using antennae with beams inclined to the horizontal plane, including the inclination which may result from the existence of an elevated or depressed horizon;

6. of the statistical distribution of field strength, as a function of the location of the point of reception within a specified zone;

7. statistical analyses of the results of such experiments according to Recommendation 311, to extend the range of application of the curves of Recommendation 370.

STUDY PROGRAMME 190(V) *

TROPOSPHERIC PROPAGATION FACTORS AFFECTING THE SHARING OF THE RADIO FREQUENCY SPECTRUM BETWEEN RADIO-RELAY SYSTEMS, INCLUDING SPACE AND TERRESTRIAL TELECOMMUNICATION SYSTEMS

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the provisional tropospheric-wave propagation curves, given in Recommendation 370 are mainly applicable to frequency sharing problems associated with the broadcasting and mobile services for frequencies up to 1000 Mc/s;

(b) that there is now an important need to develop accurate methods for the prediction of the interference likely to arise between radio-relay services operating on the same or adjacent channels for frequencies up to about 20 Gc/s;

(c) that a comprehensive and reliable method for the prediction of transmission loss, for both the required and possible interfering paths involved in radio-relay systems is desirable;

(d) that engineering methods are described in Report 209 and its references, for establishing the feasibility of sharing of the spectrum between space telecommunication and terrestrial systems, but further experimental data are required to make the application of these methods satisfactory;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. measurements, for different path lengths and for at least as long as one year, of the cumulative distributions of the hourly median transmission losses for each month of the year;

2. measurements for different path lengths of within-the-hour ** cumulative distributions of signal levels;

3. measurements for different path lengths of the cumulative time duration distributions of fading below specified amplitude levels above and below the hourly ** median level;

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* This Study Programme, which together with Study Programme, 185 B (V), 191 (V) and 204 (VI) replaces Study Programme 172, does not arise from any Question under study.

** Periods of time shorter than one hour will often be useful in the study of phase-interference (short-term) fading and the period of time used should be specified together with the time constant of the equipment.

4. long-term measurements, at appropriate frequencies above 100 Mc/s and up to at least 20 Gc/s, of the cumulative amplitude and fade duration distributions of transmission loss, over representative wanted and unwanted signal propagation paths, between highly directional antennae oriented at various angles in elevation and azimuth away from the directions of maximum path antenna gain; *

5. the transmission loss measurements referred to in § 4 should be related to observations of the location and size of aircraft, hail, or other reflecting objects near the propagation path;

6. development of comprehensive methods for the prediction of transmission loss exceeded for those percentages of the time specified in Study Programme 185 B (V) and comparison of predictions obtained thereby with measured cumulative distributions to determine the standard deviations of the differences between the observed and predicted losses;

7. measurement of the correlation over long periods of time between the hourly median transmission losses on the wanted and unwanted propagation paths with a common terminal;

8. determination of the effects of the common terminal terrain and climate on the correlation between the errors of prediction of the hourly median transmission losses exceeded for various percentages of the time for the wanted and unwanted signal propagation paths;

9. development of antenna design and siting, to minimize unwanted radiation and reception by antennae;

10. where measurements of cumulative distributions of hourly median transmission losses are required, they should be determined for various percentages of the time, including percentages as high and as low as possible, since applications may arise which require the values for 0·01 % and 99·99 % of the time; such determinations should cover an appropriate number of hours of observation with random sampling over the hour, seasons, etc.

RESOLUTION 2 **

TROPOSPHERIC PROPAGATION DATA FOR BROADCASTING, SPACE AND POINT-TO-POINT COMMUNICATIONS

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the curves for broadcasting and mobile services attached to Recommendation 370 should be kept under review in the light of new experimental data;

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* See Recommendation 341.

** This Resolution replaces Resolution 23 and 41.

(b) that there is also a need to know the tropospheric propagation factors affecting the design of radio-relay systems and the sharing of the radio frequency spectrum between them, including space and terrestrial telecommunications systems (see Study Programme 190 (V));

(c) that new data relevant to both § *(a)* and *(b)* are continually becoming available, especially as a result of the request of the Director, C.C.I.R. in Administrative Circular AC/63;

UNANIMOUSLY DECIDES

1. that an international Working Group should be established, to continue the examination of all available data;

2. that the Working Group should propose revisions of Recommendation 370 as these appear desirable;

3. that the Working Group should study methods of determining, as accurately and concisely as possible, the transmission loss * for point-to-point communication systems, which will be readily usable by radiocommunication engineers (see Study Programmes 185A(V), 185B(V) and 190(V) and prepare a report proposing, if possible, recommended methods of radio-propagation calculations;

4. that the Working Group should be composed of members nominated by the Administrations of France, Japan, Federal Republic of Germany, U.S.A., U.S.S.R. and United Kingdom and that the coordination of the work of the Group should be undertaken by the United Kingdom;

5. that the Working Group should work in close collaboration with the international Working Group established under Resolution 3;

6. that, as far as possible, the work of the Group should be conducted by correspondence;

7. that the Working Group should prepare a report prior to the XIth Plenary Assembly of the C.C.I.R.

STUDY PROGRAMME 191 (V) **

TROPOSPHERIC ABSORPTION AND REFRACTION IN RELATION TO SPACE TELECOMMUNICATION SYSTEMS

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that certain constituents of the troposphere, including water vapour, oxygen, rain, snow etc., are known to attenuate radio waves, particularly at frequencies in excess of about 1 Gc/s and also to result in noise radiation at these frequencies;

(b) that the refractive index structure of the troposphere is known to affect the direction of propagation and coherence of the wave front;

(c) that the above factors are important in the design of space telecommunication systems;

* See Report 244 which is a provisional answer to this problem.

** The radiometeorological aspects of this Study Programme, which does not arise from any Question under study, are considered in Study Programme 192(V). The attention of the International Working Party, established under Resolution 2 is drawn to this Study Programme.

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the measurement and development of methods of prediction of the attenuation of radio waves passing through the troposphere, as a function of frequency, angle of elevation, geographic location, time and constituents of the troposphere, including oxygen, water vapour, water droplets, the distribution of the sizes of the drops and rainfall rate, etc.;

2. the measurement and development of methods of prediction of the refraction, scintillation and coherence of the wave front of radio waves passing through the troposphere as a function of frequency, angle of elevation, geographic location and time;

3. the measurement and development of methods of prediction of the noise radiation from atmospheric gases, clouds and precipitation.*

RESOLUTION 3

INFLUENCE OF THE NON-IONIZED REGIONS OF THE ATMOSPHERE ON WAVE PROPAGATION

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the data presented in Report 233 should be kept under review in the light of new measurements;

(b) that there is a need to examine the usefulness of other parameters in radiometeorological studies (see Study Programme 192(V)) for various climates;

(c) that there is a need to know the characteristics of absorption, refraction and sky noise in relation to space telecommunication systems (see Study Programme 191(V));

UNANIMOUSLY DECIDES

1. that an international Working Group should be established, to continue the examination of all meteorological data relevant to the propagation of radio waves through the non-ionized regions of the atmosphere;

2. that the Working Group should propose revisions of Report 233, as these appear desirable;

3. that the Working Group should be composed of members nominated by the Administrations of France, U.S.A., U.S.S.R., Japan, Federal Republic of Germany and the United Kingdom, and that the coordination of the work of the Group should be undertaken by a member of the Administration of France;

4. that the Working Group should work in close collaboration with the International Working Group established under Resolution 2;

5. that, as far as possible, the work of the Group should be conducted by correspondence;

6. that the Working Group should prepare a report prior to the XIth Plenary Assembly of the C.C.I.R.

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* The attention of the International Working Party on Radiometeorology, set up under Resolution 3, is drawn to those aspects of this Study Programme which concern radiometeorology, and to Doc. V/75 of Geneva, 1962, for their comments.

STUDY PROGRAMME 192 (V) *

INFLUENCE OF THE NON-IONIZED REGIONS OF THE ATMOSPHERE ON WAVE PROPAGATION

(Geneva, 1951 — London, 1953, — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the propagation of radio waves is known to be a function of the thermodynamic conditions prevalent in the atmosphere and that numerous relevant measurements have been made;

(b) that the detailed structure of the field in time and space is still insufficiently known and the lack of appropriate measurements makes it impossible to explain the details of radio wave propagation characteristics on the basis of existing theories;

(c) that the propagation studies required for the establishment of a radio circuit of any length, necessitate a statistical knowledge of the propagation medium, that is, of the atmosphere;

(d) that the progress in the investigation of such propagation has already led to Recommendations 369 and 370;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the detailed variations of the refractive index of air with space and time;
2. the development of improved methods for investigating the irregularities in the thermodynamic properties of the atmosphere, with special reference to such instruments as refractometers, thermometers, hygrometers and radar (see Annex, § 1);
3. the statistical and geographical distributions of water vapour, oxygen, cloud, rain, snow, fog, sand, etc. in the atmosphere;
4. the provision, by national telecommunications services, of additional information concerning N_s, N_0 and ΔN, to complete the work on world-wide refractive index climatology of Report 233 (see Annex);
5. the application to radio propagation of radiometeorological parameters other than those listed above;
6. the correlation between the different radiometeorological parameters in various climatological situations and the characteristics of the transmission loss in terms of their median value, their range and rate of variation and the signal distortion encountered;
7. verifications by Administrations and private operating agencies, by means of a large number of detailed and accurate measurements, of the various theories put forward in explanation of propagation.

Note 1. — National Administrations, the U.R.S.I. and other international organizations, should be encouraged to pursue the theoretical and experimental study of the propagation of radio waves through the atmosphere.

* This Study Programme, which replaces Study Programme 138, does not arise from any Question under study.

Note 2. — The above Study Programme has taken into account Recommendations Nos. 4 and 5 of the Aerological Commission of the W.M.O. and should be brought to the attention of the W.M.O. by the Director C.C.I.R., with particular reference to §§ 1, 2 and 3.

ANNEX

1. The thermodynamic measurements, intended for the calculation of the refractive index of the air and its gradient should, if possible, be determined at distances not more than 10 m apart and with an accuracy no less than:

Temperature $\pm\ 0{\cdot}2^{\circ}$ C,
Humidity (mixing ratio): $\pm\ 0{\cdot}1$ gm/kg,

Continuous measurement equipment should preferably be used.

2. The parameter $N = (n-1)\times 10^6$ is given by the formula:

$N = (77{\cdot}6/T)(p + 4810\ e/T)$
n = refractive index of the air,
T = absolute temperature (°K),
e = water-vapour pressure (mb),
p = atmospheric pressure (mb).

The information provided should, if possible, cover a period of at least five years.

It should be assumed that the seasons can be represented by the months of February, May, August and November and the hours of measurement should, whenever possible, be at the even hours, local meridian time. Since the determination of ΔN is dependent upon data from radio-sonde ascents, the times at which these are made must necessarily be used, though every effort should be made to make these measurements as extensive as possible.

3. N_s is the value of N at the surface of the earth. The formula for determining N_0 is given in Report 233. ΔN is the difference between the value of N at a height of 1 km above the surface of the earth and N_s.

LIST OF DOCUMENTS OF THE Xth PLENARY ASSEMBLY CONCERNING STUDY GROUP V

Doc.	Origin	Title	Reference	Other Study Groups concerned
5	Chairman, Study Group V	Report by Chairman of Study Group V (Dr. R. L. Smith-Rose)	—	—
66	United Kingdom	Radio-relay systems for television and telephony	Q. 185 Q. 192 (IX)	IX
128	Sweden	Transmission loss measurements on radio-relay systems	—	—
129	C.C.I.R. Secretariat	Bibliographic references in the volumes of the C.C.I.R.	—	I-XIV
135	Sweden	Comparison between calculated and measured attenuation for eleven scatter links	S.P. 137, 138 and 139	—
153	C.C.I.R. Secretariat	Refinement of I.F.R.B. technical standards	—	I, II, III, VI X, XII, XIII
192	United Kingdom	Atlases of ground-wave propagation curves for frequencies between 30 Mc/s and 10 Gc/s	CCIR Atlas of propagation curves	—
193	United Kingdom	Draft Study Programme to replace Study Programmes 137(V) and 140(V)	Draft S. P.	—
194	United Kingdom	Tropospheric wave propagation curves for application to interference problems in the range 1 to 10 Gc/s	Draft Rec.	—
196	U.S.S.R.	A method of calculating the statistical distribution of the level of thermal noise in the channels of a line-of-sight radio-relay system	Q. 185 (II)	II
207	I.B.T.O.	Depolarization in various types of terrain and in towns	Rep. 122	—
208	I.B.T.O.	Report on the study of propagation in Bands IV and V carried out by the Communications research institute, Prague (Czechoslovak S. R.) and the Rundfunk- und Fernsehtechnisches Zentralamt, Kolberg	S.P. 137, 138 and 140	—
231	France	Beyond-the-horizon propagation curves in Africa	—	—
270	P.R. of Poland	Note by the Administration of P.R. of Poland in reference to the draft recommendation " VHF and UHF propagation curves in the frequency range from 40 Mc/s to 1000 Mc/s "	Draft Rec.	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
283	United Kingdom	Tropospheric propagation factors affecting the sharing of the radio-frequency spectrum between radio-relay systems, including space and terrestrial telecommunications systems	Draft S.P.	—
286	Study Group V	Summary record of the first meeting	—	—
330	Study Group V	Propagation data required for radio-relay systems	Draft Rep.	—
332	Study Group V	Summary record of the second meeting	—	—
340	Sub-Group V-B	Influence of irregular terrain on tropospheric propagation	Draft S.P.	—
356	Sub-Group V-C	Tropospheric propagation factors affecting the sharing of the radio frequency spectrum between radio-relay systems, including space and terrestrial telecommunication systems	Draft S.P.	—
374	Sub-Group V-B	Ground-wave propagation over inhomogeneous earth	Draft Rep.	—
376	Sub-Group V-B	Effects of tropospheric refraction on frequencies below 10 Mc/s	Draft Rep.	—
421	Sub-Group V-C	Tropospheric propagation data for broadcasting, space and point-to-point communications	Draft Res.	—
437	Study Group V	Summary record of the third meeting	—	—
463	Sub-Group V-C	Influence of the non-ionized atmosphere on wave propagation	Draft Res.	—
498	Study Group V	Influence of the non-ionized regions of the atmosphere on the propagation of waves	Draft Rep.	—
520	Study Group V	International Working Group under Resolution 23 — Estimation of tropospheric wave transmission loss	Report	—
536	Study Group V	Summary record of the fourth meeting	—	—
560	Study Group V	VHF/UHF broadcasting propagation curves for the African continent	Draft Rep.	—
585	Study Group V	Summary record of the fifth and last meeting	—	—
629	France	Comments by the French Administration on Doc. 560-Rev.	—	—

Doc.	Origin	Title	Reference	Other Study Groups concerned
2004	Drafting Committee	Ground-wave propagation curves for frequencies below 10 Mc/s	Rec. 368	—
2005	,,	Definition of a basic reference atmosphere	Rec. 369	—
2006	,,	VHF and UHF propagation curves for the frequency range from 40 Mc/s to 1000 Mc/s	Rec. 370	—
2007	,,	Ground-wave propagation	Q. 246	—
2008	,,	Propagation data required for line-of-sight radio-relay systems	S.P. 185A	—
2009	,,	Propagation data required for beyond-the-horizon radio-relay systems	S.P. 185B	—
2010	,,	Effects of tropospheric refraction on frequencies below 10 Mc/s	S.P. 246A	—
2011	,,	Ground-wave propagation over inhomogeneous earth	S.P. 246B	—
2012	,,	Influence of the non-ionized regions of the atmosphere on wave propagation	S.P. 192	—
2013	,,	Investigation of multipath transmission through the troposphere	Rep. 237	—
2014	,,	Amendment to Report 138	Rep. 227	—
2015	,,	Determination of the electrical characteristics of the surface of the earth	Rep. 229	—
2016	,,	Influence of irregular terrain on tropospheric propagation	Rep. 236	—
2017	,,	Measurement of field strength for VHF (metric) and UHF (decimetric) broadcast services, including television	Rep. 228	—
2018	,,	Reference atmosphere	Rep. 231	—
2019	,,	Influence of the atmosphere on wave propagation	Rep. 233	—
2020	,,	Propagation data required for radio-relay systems	Rep. 242	—
2021	,,	Constants in the equation for the radio refractive index	Rep. 232	—
2081	,,	Tropospheric absorption and refraction in relation to space telecommunication systems	S.P. 191	—
2082	,,	Radio transmission utilizing inhomogeneities in the troposphere (commonly called " scattering ")	Rep. 238	—

Doc.	Origin	Title	Reference	Other Study Group concerned
2114	Drafting Committee	Tropospheric propagation factors affecting the sharing of the radio frequency spectrum between radio-relay systems, including space and terrestrial telecommunications systems	S.P. 190	—
2115	,,	Influence of irregular terrain on tropospheric propagation	S.P. 188	—
2176	,,	VHF and UHF propagation curves in the frequency range from 40 Mc/s to 1000 Mc/s	Rep. 239	—
2177	,,	VHF and UHF propagation curves in the frequency range 40 Mc/s to 1 Gc/s	S.P. 189	—
2193	,,	Effects of tropospheric refraction on frequencies below 10 Mc/s	Rep. 235	—
2194	,,	Tropospheric propagation data for broadcasting space and point-to-point communications	Res. 2	—
2233	,,	Ground-wave propagation over inhomogeneous earth	Rep. 230	—
2239	,,	Propagation data required for radio-relay systems	Rep. 241	—
2252	,,	Influence of the non-ionized regions of the atmosphere on the propagation of waves	Rep. 234	—
2253	,,	Tropospheric wave propagation curves for application to interference problems in the range from 1 to 10 Gc/s	Rep. 243	—
2254	,,	Influence of the non-ionized atmosphere on wave propagation	Res. 3	—
2279	,,	Estimation of tropospheric wave transmission loss	Rep. 244	—
2292	,,	VHF/UHF broadcasting propagation curves for the African continent	Rep. 240	—

RECOMMENDATIONS OF SUB-SECTION G.2: IONOSPHERIC PROPAGATION

RECOMMENDATION 313 *

EXCHANGE OF INFORMATION FOR THE PREPARATION OF SHORT-TERM FORECASTS AND THE TRANSMISSION OF IONOSPHERIC DISTURBANCE WARNINGS

(Geneva, 1951 — Los Angeles, 1959)

The C.C.I.R.,

CONSIDERING

(a) that it is important to give Administrations and operating services (navigation and other services using ionosphere-propagated waves, the earliest possible warning of the onset of disturbances to ionospheric-propagation conditions, so that they may arrange their traffic schedules accordingly;

(b) that it is desirable to find an easier method of drawing up a plan for the rational use of frequencies in place of the system based on long-term mean values, when the latter is temporarily unsatisfactory on account of ionospheric disturbances;

(c) that it would therefore be advisable for all organizations publishing ionospheric forecasts to study the technique of forecasting disturbances;

(d) that it is of great importance to take steps to secure the greatest possible accuracy of such forecasts and the maximum of speed in their dissemination;

(e) that, for the exchange and dissemination of propagation information, there are three categories of users: those who make forecasts, those who make operational use of propagation information and those who require the information for scientific research or other purposes; and that, to meet these different requirements, it is desirable to use the most appropriate methods of exchange in each case;

(f) that effective collaboration has been arranged, particularly for the IGY programme, between some Administrations, operating services and the organizations studying the characteristics of the ionosphere and deducing forecasts therefrom;

(g) that provisional codes, prepared by the International Radio Scientific Union (U.R.S.I.) such as the code used in French Ursigrams, or due to organizations such as the Central Radio Propagation Laboratory (C.R.P.L.), the Arbeits-Gemeinschaft Ionosphäre, the Japanese Central Propagation Laboratory and others, have proved their usefulness in the dissemination of information for the preparation of short-term forecast;

UNANIMOUSLY RECOMMENDS

1. that each country, participating in radio propagation research, should designate an official agency for the reception, coordination and exchange of such data and for liaison with corresponding agencies in other countries;

2. that the information required for the preparation of short-term forecasts, should be centralized by the agencies mentioned in § 1, as far as possible, by the most direct means of telecommunication between the centralizing agency and the various scientific institutes for solar, magnetic and other observations;

* This Recommendation replaces Recomendation 59.

3. that, of the data thus assembled, those which are of use for forecasting within 48 hours should be disseminated, in accordance with the U.R.S.I. decisions, by suitable available communication channels;

4. that the other data, of use for the improvement of forecasting technique in general and for other purposes, should be disseminated by ordinary post or airmail; if they deem it of use for the organization of regional forecasts or for scientific research, interested Administrations may organize alone, or preferably collectively, after centralization of information, the dissemination of detailed information by radio;

5. that certain short but regular transmissions, giving short-term warnings of ionospheric disturbances, should be effected by long-range radio stations;

6. that the attention of the U.R.S.I. should be drawn to the advantages of the fullest possible standardization of the codes to be used, either for the short warnings mentioned in § 5, or for the exchange of the limited information mentioned in § 3 or the general information mentioned in § 4;

7. that Administations should be invited to conform to the resulting codes and to make them known to their operating services;

8. that Administrations should invite these services, together with operating agencies, to study the accuracy of the forecasts, to submit records and to make any suggestions which might assist the studies undertaken to improve the methods used;

9. that special attention should be paid to the comparison between the forecasts and the actual behaviour of radio circuits; it is particularly desirable that Administrations should adopt identical methods of assessing the quality of the circuits by using a suitable classification;

10. that it is also desirable that a common method should be adopted to describe ionospheric perturbations, taking account of such factors as the starting time, zone affected, duration and importance of the perturbation;

11. that, where Administrations have provided facilities for the rapid exchange of information for the preparation of short term forecasts of radio propagation, in connection with the IGY, these facilities should be maintained, and if necessary extended in the future.

RECOMMENDATION 371

CHOICE OF SOLAR INDICES FOR IONOSPHERIC PROPAGATION

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that continuous observations of sunspots have been made for a longer period of time than for any other index of solar activity;

(b) that the 12-month running mean sunspot number, R_{12}, is the only index which has, up to now, been sufficiently studied to allow predictions to be made by objective methods;

(c) that the smoothing of the sunspot number, caused by the use of the 12-month running mean, prevents its use for accurate predictions of ionospheric conditions, for dates less than 12 months ahead of the date of the last observed value of R_{12};

(d) that the ionospheric index I_{F_2} can be predicted certainly for dates up to 6, and perhaps up to 12 months ahead of the date of the last observed value of I_{F_2}, and is highly correlated with the monthly-median values of foF2;

(e) that the monthly-mean value of solar radio-noise flux, at wavelengths near 10 cm, Φ, is highly correlated with foE;

UNANIMOUSLY RECOMMENDS

1. that the 12-month running mean sunspot number should be adopted as the index to be used for all ionospheric predictions for dates more than 12 months ahead of the date of the last observed value of R_{12};

2. that the ionospheric index I_{F_2} should be adopted as the index to be used for predicting monthly median values of foF2 and M (3000) F2 for dates, certainly up to 6, and perhaps up to 12, months ahead of the date of the last observed value of I_{F_2}. Caution should be shown in its use at high magnetic latitudes, where experience suggests that the resulting predictions may not be sufficiently accurate;

3. that the monthly-mean value of solar radio-noise flux at wavelengths near 10 cm should be adopted as the index to be used for predicting monthly median values of foE and foF1, for dates, certainly up to 6, and perhaps up to 12, months ahead of the date of the last observed value of Φ.

RECOMMENDATION 372 *

USE OF ATMOSPHERIC RADIO-NOISE DATA

(Geneva, 1951 — London, 1953 — Warsaw 1956 —, Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

that a revision of Report 65 has now been made;

UNANIMOUSLY RECOMMENDS

that in assessing the intensity and other characteristics of atmospheric radio-noise throughout the world, the information contained in Report 322 ** should be used until sufficient new data to justify further revision have been accumulated and made available.

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* This recommendation together with Resolution 8, replaces Recommendation 315.

** Not reproduced in Volume I to VII of the Xth Plenary Assembly, but issued as a separate booklet.

RECOMMENDATION 373 *

MEANING OF MUF

(Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that experience has shown that transmission is often possible above the MUF for waves assumed to have been propagated solely by ionospheric refraction (i.e. without the influence of ionospheric and ground scatter);

(b) that some prediction services use empirical correction factors to take account of this experience when making predictions;

(c) that the World-Wide Soundings Committee of the U.R.S.I. has recommended the use of a standard transmission curve for rapid analysis of ionograms [1];

(d) that lateral deviations from the great circle path have been observed, especially with propagation involving ionospheric and/or ground scatter;

UNANIMOUSLY RECOMMENDS

1. that the term " classical MUF " should be used to designate the highest frequency at which waves can be propagated to a given distance by ionospheric refraction alone. If used without reference to a particular mode of propagation, the term " classical MUF " should imply the highest of the values for the individual modes;

2. that the term " standard MUF " should be used to designate the approximation to the classical MUF, obtained by application of a standard transmission curve [1], to vertical-incidence ionograms and by the use of a distance factor [2];

3. that the term " operational MUF " should denote the highest frequency permitting operation at a given time, between given points, under specified working conditions. The operational MUF is usually higher than the classical MUF as a result of effects such as ionospheric and/or ground scatter;

4. that working conditions should be stated as precisely as possible in connection with the operational MUF, since this quantity depends on the parameters of the system;

5. that for any MUF prediction it should be clearly stated whether it is intended to predict the standard MUF or the operational MUF.**

BIBLIOGRAPHY

1. U.R.S.I. Handbook for ionogram interpretation and reduction, p. 17, Amsterdam, 1961.
2. See, for example. Circular No. 462 of the U.S.A. National Bureau of Standards, 82.

* This Recommendation replaces Recommendation 318.
** See Study Programme 200 (VI).

REPORTS OF SUB-SECTION G.2: IONOSPHERIC PROPAGATION

REPORT 151 *

IONOSPHERIC SOUNDING STATIONS AFTER THE INTERNATIONAL GEOPHYSICAL YEAR (IGY)

(Resolution 26)

(Los Angeles, 1959)

1. In Resolution 26, the C.C.I.R. drew the attention of U.R.S.I. to the desirability of continuing in operation after the IGY certain of the ionospheric stations specially established or continued in operation solely for the IGY programe. The object from the viewpoint of the C.C.I.R. is to improve propagation forecasts.

2. From the U.R.S.I. viewpoint, continued operation of certain IGY ionospheric sounding stations after the IGY, would also be desirable for filling gaps in the present knowledge of ionospheric morphology and disturbances.

3. In many respects, the objectives stated above may be regarded as identical.

4. The U.R.S.I. therefore recommends that as many as possible of the following stations be continued in operation, preferably on a 15-minute basis, for not less than one year after the next minimum of the solar cycle:

Arctic	*Antarctic*	*Equatorial*	*Gap Fillers*
Alert	South Pole	Natal	Tamanrasset
Thule	Little America	Talara	St. Johns
Svalbard	Terre Adelie	Bogotá	Mexico City
Tromsö	Halley Bay	La Paz	Concepción
Bukhta Tikhaya	Syowa (Showa)	Djibouti	Tahiti
Tiksi Bay	and/or	Kodaikanal	São Paulo
Providence Bay	Mawson	Bangui	Tucuman
		Davao **	Kerguelen Is.
			Macquarie Is.
			Marion Is.

5. A more detailed report has been received by C.C.I.R. from U.R.S.I., following a meeting of the U.R.S.I./IGY Committee in July 1958. This report is available and has been circulated as Doc. VI/69 of Geneva, 1958.

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* This Report was adopted unanimously.

** This location is not certain. It is understood that the Philippine Government plans an IGY station at a location to the south of Manila — nearly on the magnetic equator.

REPORT 245 *

PREDICTION OF SOLAR INDEX

(Geneva, 1963)

1. Judging by the results obtained in the past, it appears that there is, as yet, no method whereby it is possible to predict accurately the next sunspot cycle, or more generally, a cycle which has not yet begun. The parameters which appear to be the most useful are the date of the beginning, the time of growth, the maximum value and the time of fall of the cycle. The values of the parameters of the present cycle, the 19th in the Zürich series, diverge widely from those which could have been established by empirical and statistical laws observed over earlier and even recent cycles. The phenomenon of solar activity ought, therefore, to be studied by statistical methods, but more attention ought to be given to solar physical phenomena.

2. Several attempts to predict the parameters of the 20th cycle have been submitted to the C.C.I.R. Unfortunately, the results differ appreciably according to the methods used.

2.1 In Belgium, use has been made of Anderson's [1] observation, that the cycles in the series 1785 onwards and 1919 onwards are very similar; in particular, the current cycle is similar in shape to that which occurred 170 years earlier and its trend has been predicted by means of a linear relation with the earlier cycle [2 and 3]. The method does not make use of physical knowledge or of statistical techniques.

2.2 The French method takes as a starting point, the dates of the minima and maxima from 1610 onwards together with those values of the smoothed sunspot number from 1700 onwards which it has been possible to re-establish. The even and odd cycles were treated separately, since it is known that solar magnetic phenomena have a period equal to two sunspot cycles, but a significant difference was not found. A prediction is made of the parameters of the 20th cycle by recourse to a secondary cycle equal to 16 elementary cycles. The validity of the method ought to be further investigated by a statistical study based on the deviations observed [4].

3. It goes without saying that it is easier to predict the future development of a cycle once it has begun. In the U.S.A., 12-month running averages of relative sunspot number are predicted by means of an objective method, where the first approximation to the prediction of a future value in a cycle is the mean of all past values for that part of the cycle [5]. This estimate is improved by adding to it a correction proportional to the departure of the immediately preceding value of the cycle in question from the mean cycle. The correction factors are determined by the method of least squares and are based on sunspot data for 1834 to 1954 inclusive; the sunsport data of earlier years are rejected on statistical grounds. To predict a given 12-month running average sunspot number, it is recommended to use the mean, corrected by the departure of the preceding year. Prediction beyond the present cycle is not considered possible by objective statistical methods. As soon as a sunspot minimum is identified, this method can be used for the coming eleven years, but with new correction factors which have been re-determined including the observed values for the preceding cycle.

* This Report was adopted unanimously.

REFERENCES

1. ANDERSON, C. N. *Jour. Geo. Res.*, No. 4 (1954).
2. HERRINCK, P. *Acad. Royal. Science* (Belgium), Vol. IV, 6, 1273 (1958).
3. HERRINCK, P. *Nature*, **184**, 51 (1959).
4. HALLEY, P. and GERVAISE, A. M. To be published in " Annales des Télécommunications ".
5. MCNISH, A. G. and LINCOLN, J. V. *Trans. American Geophys. Union*, **30**, 673 (1949).

REPORT 246 *

CHOICE OF BASIC INDICES FOR IONOSPHERIC PROPAGATION

(London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

1. Introduction

1.1 The purpose of this Report is to explain the reasons which determined the choice of indices for ionospheric propagation that are referred to in Recommendation 371. The term " ionospheric propagation ", which was used in Study Programme 150 (VI), has been assumed to refer to those characteristics of the ionosphere that can be measured and which are required for calculations of the MUF on a point-to-point radio service. The most important of these characteristics are the monthly-median values of vertical-incidence critical frequencies, foE and foF2, of the E-and F2-layers, and the MUF factor, M(3000)F2, of the F2-layer. The indices recommended were selected with these parameters in mind. It is not yet possible to recommend indices which would be useful in predictions relating specifically to the *D*- and *Es*-layers.

1.2 If an inspection is made of any index which represents the month to month changes of solar activity, it is clear that the variations of the index with time contain three components:

1.2.1 a fairly regular component, with a period of about 11 years, which represents the well-known cycle of solar activity;

1.2.2 a component which has a quasi-period of about a year, or a little less, which usually appears near the peak of the solar cycle and which lasts for only a year or two;

1.2.3 fluctuations which appear to be erratic, but which may represent rapid changes in solar activity that cannot be resolved when a monthly mean index is used.

2. Sunspot numbers

2.1 The statistical properties of the main component (§ 1.2.1) of the solar cycle, have been a subject of study for many years. In these studies, the 12-month running-mean sunspot number, R_{12}, is nearly always used, because the resultant smoothing considerably reduces the complicated and rapidly varying components (§§ 1.2.2 and 1.2.3), but does not obscure the slowly varying component (§ 1.2.1). In statistical studies designed to facilitate predictions

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* This Report, which replaces Report 162, was adopted unanimously.

of an index, it is obviously desirable to have as much information as possible about the past behaviour of the index; an important advantage of using sunspot numbers as the basis for an index is, that a longer series of reliable measurements is available for them than for any other type of solar observation.

2.2 In view of the long series of observations of sunspots, and of the fact that the statistical prediction methods which are available at present refer to R_{12}, there appears to be no better alternative index to R_{12} for use in circumstances where predictions are required for dates more than about 9 months ahead. The definition of R_{12} which is preferred is:

$$R_{12} = \frac{1}{12}\left[\sum_{n-5}^{n+5} R_k + \tfrac{1}{2}\,(R_{n+6} + R_{n-6})\right]$$

in which R_k is the mean value of R for a single month k, and R_{12} is the smoothed index for the month represented by $k = n$.

2.3 There are two main disadvantages in the use of R_{12} as an index.

2.3.1 The most recent available value of R_{12} is necessarily centred on a month, at least six months earlier than the present time. Hence, a prediction of R_{12}, which refers to a month n months ahead, requires an extrapolation of the R_{12} series at least $n+6$ months ahead of the last available measured value.

2.3.2 If R_{12} is used as an index, it is not possible to make any attempt to predict the shorter term variations in solar activity, because the amplitude of these variations is considerably reduced, or even completely obscured, by the smoothing which is inherent in R_{12}.

2.4 The accuracy of a prediction of an ionospheric parameter will be increased, if an allowance can be made for the presence of any shorter term variations which may be present. Since such predictions require a monthly unsmoothed index, it seems desirable that such indices should be provided for the E-and F2-layers. The recommended indices are described in §§ 3 and 4.

3. E-layer

3.1 Evidence presented by Kundu [1] shows that the monthly-mean flux of solar radio-noise at wavelengths of about 10 cm is more closely correlated to monthly mean values of foE than the noise at other wavelengths. Investigations made by Minnis and Bazzard [2] and by Eyfrig [3] show that the mean correlation coefficient between the E-layer character figure and solar noise flux at 10·7 cm is very high: 0·95 at Slough, and 0·985 at Lwiro where the effects of geomagnetic distortion are smaller than at Slough.

3.2 Flux measurements at 10·7 cm have been made at Ottawa from 1947 onwards. They have been described by Medd and Covington [4] and no better index for use in making E-layer predictions up to about nine months ahead can be foreseen at present.

4. F-layer

4.1 The correlation between monthly mean values of foF2 and several possible indices has been discussed by Minnis and Bazzard [5], who have presented evidence which shows that the index I_{F_2} is more closely correlated with foF2 than any other available index; the mean coefficient of correlation in a sample was 0·986. The index I_{F_2} is based on measurements of foF2 at 10 long-established ionospheric observatories and monthly values of I_{F_2} are available from 1938 onwards (see Annex I).

4.2 In view of the high correlation with foF2 and the long series of earlier values, I_{F_2} appears to be the best index at present available for making predictions of foF2 up to about nine months ahead. To calculate I_{F_2} for a given month, it is necessary to have the monthly median noon values of foF2 at the ten observatories together with statistical data relating to past measurements at the observatories. These statistical data have been made available to the C.C.I.R. (see Annexes II and III), and air mail or telegraphic services are recommended to ensure rapid transmission of the latest monthly values of foF2 to the C.C.I.R.

5. Miscellaneous

5.1 In § 2.2, R_{12} is recommended for use when predictions are required for dates more than about nine months ahead. For dates less than nine months ahead, the indices referred to in §§ 3.2 and 4.2 are preferred. The figure of nine months ought not to be taken as a rigid boundary in making this decision, but is intended to represent, approximately, the maximum extrapolation of an unsmoothed monthly index which can be achieved with acceptable accuracy.

5.2 Japanese and other laboratories now make regular measurements of solar noise-flux at wavelengths of about 10 cm and eventually it will be possible, after allowing for small systematic differences, to convert measurements made at one place into the equivalent value at another. For the present, however, the Ottawa data ought to be regarded as the reference data in the present context.

5.3 In principle, there is no reason why additional stations should not be included in the calculation of I_{F_2}, provided reliable foF2 data are available for at least one complete solar cycle. It is unlikely, however, that the addition of new stations would increase the correlation of I_{F_2} with foF2, but it would slightly decrease the small statistical fluctuations which arise when a median value is determined from ten values only.

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ANNEX I

THE IONOSPHERIC INDEX I_{F2}

Month	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
January	110	138	71	65	49 (1)	16	7	26	38	135	126	125	122	55	40	16	2	5	76	154	172	159	142	67	24	14
February	122	98	73	51	46 (1)	15	2	22	76	148	114	142	110	49	38	8	—2	10	89	150	162	162	135	61	32	14
March	134	94	84	49	54 (1)	27	18	25	99	142	122	144	112	50	30	2	—2	2	119	151	161	151	111	66	50	18
April	130	101	90	37	56 (1)	26	2	35	107	160	154	158	120	68	21	13	2	8	135	154	176	154	121	61	46	16
May	125	130	80	33	55 (2)	18 (1)	—6	37 (1)	109	178	158	158	125	84	12	6	—6	19	138	168	184	167	126	58	54	23
June	130	128	84	46	28 (1)	18 (1)	2	58	103	150	174	140	124	74	27	2	—14	27	122	166	168	166	124	64	44	10 (3)
July	146	119	93	56	25 (1)	16	4	48	108	173	157	137	94	72	30	7	—8	41	124	168	151	145	113	60	35	
August	150	113	100	65	21	26	20	48	130	166	154	140	80	66	34	2	0	34	157	166	191	161	117	84	21	
September	137	150	104	66	29	5	14	49	121	179	156	174	66	72	30	6	—10	48	184	182	208	166	155	60	27	
October	117	133	95	58	23	—4	20	74	126	174	147	162	67	65	10	—1	—10	64	183	195	206	143	118	54	30	
November	129	113	84	51	21	—2	4	61	137	175	142	157	56	57	14	—4	—7	68	175	184	189	133	109	36	22 (3)	
December	126	86	59	50	22	4	11	46	142	156	144	156	56	56	14	—13	—15	85	182	178	182	151	96	24	10	

Note 1. — Except for the years 1938-1941, the index values are based on the stations listed by Minnis and Bazard. *J. Atmos. Terr. Phys.*, **18**, 297, (1960), but excluding San Francisco.

Note 2. — From 1942 onwards, index values based on data from less than 9 stations are indicated thus:

(1) stations
(2) 7 stations
(3) 6 stations (provisional)

Note 3. — The information relating to November 1962 onwards was received after the closure of the Xth Plenary Assembly.

ANNEX II

1. The index I_{F_2} is based on the monthly median noon values of foF2 at

Canberra	Godley Head	Tokyo
Churchill	Huancayo	Washington
Delhi	Puerto Rico	
Fairbanks	Slough	

2. The regression line of the monthly-mean noon foF2 and the three-month weighted-mean sunspot number R_3 has been calculated for each month of the year using all the available data up to 1957 or 1958. These lines can easily be reproduced by using the values of foF2 for $R_3 = 0$ and 150, which are given in Annex III. The value of R_3 for month n is defined by:

$$R_3 = \frac{1}{2}\left[R_n + \frac{1}{2}(R_{n+1} + R_{n-1})\right]$$

3. For any given measured value of foF2, the appropriate regression line can be used to give the corresponding value of R_3-which will be referred to as R_3. The value of I_{F_2} for a month is the median value of all the available values of R_3.

ANNEX III

MONTHLY MEDIAN VALUES OF 100 × foF2 FOR $R_3 = 0$ AND 150
(foF2 is in Mc/s)

Station	January		February		March		April		May		June		July		August		September		October		November		December	
R_3	0	150	0	150	0	150	0	150	0	150	0	150	0	150	0	150	0	150	0	150	0	150	0	150
Canberra	590	918	575	1024	572	1151	642	1275	573	1142	510	1051	488	1015	509	1051	568	1078	610	1000	640	894	644	855
Churchill	463	1167	450	1068	411	920	397	760	449	673	464	662	439	650	450	673	445	773	488	981	532	1180	515	1148
Delhi	704	1386	758	1450	900	1514	991	1473	848	1312	754	1157	729	1182	784	1252	918	1341	930	1388	764	1392	723	1308
Fairbanks	400	1044	424	1013	405	826	405	695	442	625	450	614	419	633	425	620	429	656	458	836	480	1032	445	999
Godley Head	570	885	574	957	583	1103	570	1273	496	1162	443	1074	430	1079	445	1027	494	974	575	968	684	956	650	845
Huancayo	668	1280	748	1283	720	1317	712	1268	624	1102	575	1025	553	958	583	1046	658	1136	775	1178	883	1307	812	1292
Puerto Rico	616	1172	710	1313	813	1368	832	1360	798	1218	745	1151	666	1128	710	1115	805	1212	890	1264	775	1208	684	1102
Slough	530	1217	510	1242	475	1167	480	988	510	823	503	770	472	773	475	768	490	881	569	1126	558	1293	532	1253
Tokyo	648	1248	722	1365	810	1437	762	1374	610	1128	575	930	542	947	546	1000	618	1117	800	1312	750	1315	675	1167
Washington	574	1298	584	1289	507	1260	488	1029	470	801	494	686	455	690	469	747	530	951	660	1200	678	1272	664	1225

REPORT 247 *

IDENTIFICATION OF PRECURSORS INDICATIVE OF SHORT-TERM VARIATIONS AND EVALUATION OF THE RELIABILITY OF SHORT-TERM FORECASTS OF IONOSPHERIC PROPAGATION CONDITIONS

(Opinion 6)

(Los Angeles, 1959 — Geneva, 1963)

1. Identification of precursors indicative of short-term variations of ionospheric propagation conditions

During and since the International Geophysical Year (IGY), there have been several advances towards more successful forecasting of sudden-commencement geomagnetic storms and associated disturbances of ionospheric propagation that are prevalent during periods of sunspot maximum. Some of these have occurred, or been recognized, since Report 153 [1] was prepared.

For instance, instead of relying solely on the occurrence of a solar flare of optical importance 3 or 3+ to predict a storm within 2 to 3 days of the flare [2], the probability of having made a successful forecast of disturbance can be increased, if the type of solar radio-emission accompanying the solar flare is also taken into account. Dodson [3] first showed that there is a strong relationship between most major solar outbursts at 200 Mc/s before flare maximum, that were followed by a " second part " and geomagnetic disturbances occurring two or three days later. This was confirmed by Sinno [4], who showed that the greater the second part, the greater the ensuing magnetic disturbance. Warwick [5], also confirmed this geomagnetic result, using 18 Mc/s solar bursts, which preceded maxima of Sudden Cosmic Noise Absorption (S.C.N.A.).

It has also been demonstrated that the central meridian passage of " radio noisy " regions at 169 Mc/s can be associated with a following geomagnetic disturbance [6]. These regions are identified by interferometric methods. Several studies have been made to establish the spectral type of solar radio-emission associated with geomagnetic disturbance. One to two days after Type II bursts (slow drift), there is an appreciable probability of geomagnetic disturbance, especially if the Type II burst occurs in association with an optical flare [7]. A greater probability of disturbance is associated with the occurrence of Type IV continuum [8 and 9]. This is the continuum sometimes associated with Type II bursts, but first recognized by Boischot on his 169 Mc/s records.

All the above solar-geomagnetic relationships are enhanced, if a polar-cap absorption event is observed within six hours of the large optical flare accompanied by major radio outbursts of Type IV. These are the absorption events recognized by Bailey [10] and by Reid and Collins [11] on VHF scatter circuits, and by Reid and Leinbach [12] on riometers in northern latitudes. The occurrence of polar-cap absorption events is strongly related to the presence on the sun of a region of enhanced radio emission at metric (or longer) wavelengths [13]. These events precede the disturbance by 18 hours or more and are probably the most reliable terrestrial precursors of important disturbances to ionospheric radio propagation so far recognized. A valuable review and bibliography is given by Obayashi and Hakura [14].

* This Report, which replaces Report 153, was adopted unanimously.

A new method of detecting solar flares has been described by Mitra [15, 16]. The field-strength of a distant long-wave transmitter is recorded continuously. Sudden increases in signal (SIL), have been found to correspond to the observations of solar flares. There is close statistical agreement between the characteristics of the optical flare and those of the SIL. Study of short-term forecasts of ionospheric storms by the use of SIL is in progress.

A correlation has been found between the intensity of cosmic radiation at ground level and magnetic disturbances. Legrand [17] found that a " pre-fall " in the total cosmic radiation was usually followed by a large increase in magnetic activity in the course of the following three to five days.

In the U.S.S.R., effective short-term forecasts have been based on synoptic charts of Δ foF2, Δf_{min} and —fEs$>$ 4 Mc/s [18, 19, 20]. This system necessitates a rapid interchange of ionospheric information from a network of stations, especially in high latitudes. Equally important is the need for a considerable increase in absorption-measuring stations, especially in high latitudes, for providing up-to-date data on which reliable short-term absorption forecasts can be based. Studies have also been made in the U.S.S.R. of the changes in the magnetic and electric fields of sunspot groups and attempts have been made to use the results in the short-term forecasts.

In the field of infra-sonics there are travelling atmospheric pressure waves, with periods from 20 to 60 s and pressure amplitudes from about 1 to 8 dynes/cm², which have been recorded by Chrzanowski *et al* [21], at a microphone station located at Washington, D.C., during intervals of high geomagnetic activity. There is evidence that the origin of the disturbance can be localized by infra-sonic direction-finding techniques.

Finally, preliminary results from the experiments in the space-probe " Pioneer V " [22, 23], indicate that " real " time reporting of observations made in space could indicate the presence of solar particle streams and magnetic disturbances before they reach the earth. Rothwell and McIlwain [24] and Arnoldy, Hoffman and Winckler [25], have written on satellite observations made during magnetic storms.

Thus, progress has been made in the short-term forecasting of sudden-commencement geomagnetic storms and the related radio-propagation disturbances. The need is apparent for a continuation of the rapid interchange of observations from the 24-hour optical and radio-noise patrols of the sun, which were begun during the IGY. The distribution system established during the IGY continues, but every effort should be made to ensure that the patrol observations are continued or restarted, and that they are interchanged promptly.

During the next few years, it is desirable that more research be concentrated on discovering the reasons for the 27-day recurrence patterns of geomagnetic activity that appear most strongly during the declining phase of the solar cycle. Ochs and Beckmann [26, 27] found that disturbances tended to recur, even at sunspot maximum, although the recurrence period was not constant at 27 days, but varied from 27 to 31 days. At present, once a recurrent pattern has been established, geomagnetic and ionospheric conditions repeat after an interval of about 27 days and this enables forecasts to be made.

2. Usefulness and reliability of short-term forecasts

Progress in the improvement of short-term ionospheric disturbance forecasts depends to a considerable extent on the adoption by various Administrations of uniform methods of evaluating the success of such forecasts. The large number of factors involved in radio propagation quality encourages the diversity of evaluation techniques that now exist. This Report is intended to draw the attention of the various Administrations to this problem.

2.1 Tests of the usefulness of the U.K. and U.S.A. forecasts in 1953 and 1956 were carried out in the United Kingdom according to the formula:

$$M = (x - ky)/S$$

where

M is a measure of the usefulness of short-term forecasts,

x is the number of storm days for which correct forecasts were issued,

y is the number of quiet days for which storm forecasts were issued (i.e., false alarms),

S is the total number of storm days,

k is an arbitrary constant, depending on how the traffic handling capacity of the system is affected by a storm and on the degree of traffic interruption, which results from unnecessary action taken following the receipt of a false alarm. (United Kingdom experience suggests that $k = 0 \cdot 5$ is a reasonable value).

The results lead to the following conclusions:

— when the 27-day recurrence cycle in ionospheric disturbances is prominent, the accuracy of the short, medium and long-term forecasts is good enough to warrant their use in making decisions on handling traffic in a radiocommunication system;

— during parts of the solar cycle, when disturbances tend to be non-recurrent, the medium and long-term forecasts are not accurate enough for operational use. The statistical distribution of correct and incorrect forecasts is close to that which would be expected to occur by chance and this seems to imply that the precursors used were not reliable;

— the short-term (1 to 6 hour) forecasts are always accurate enough to justify their use. This is probably due, in part, to the influence of the actual circuit conditions observed at the time of issue of the forecast.

The index M is designed to measure the usefulness of a set of short-term predictions in a radiocommunication organization. On the other hand, the index R, which is referred to in § 2.2 is based on purely statistical considerations. When the accuracy of a set of predictions is low, the index R gives an over-optimistic estimate of the usefulness of the predictions from the point of view of the communications engineer. Further details of this comparison between M and R are given by Minnis [28].

2.2 The Administration of Japan reported, that encouraging results were obtained with forecasts based on an association of magnetic storm with simultaneous occurrence of a solar flare and a solar radio noise outburst at 200 Mc/s. The following formula was developed to assess the reliability of the forecasts:

$$R = A^2/S_1 \, S_2$$

A is the number of storm days forecast correctly,

S_1 is the number of storm days forecast,

S_2 is the number of actual storm days.

The forecasts were based on the relations between the occurrence of magnetic storms and the importance of any solar flares and 200 Mc/s solar noise bursts which were associated with them. Forecasts were made using as a criterion 60% probability of occurrence of a storm and, for the period 9 May–31 December 1956, $R = 0 \cdot 39$; for 70% probability, $R = 0 \cdot 27$, [29]. The choice of radio warning criteria has been discussed by Shibata [30].

2.3 At the C.R.P.L. in the U.S.A., radio propagation quality, both forecast and observed, is expressed on a scale of 1 (unusable) to 9 (excellent). A forecast is considered to be a success when it differs from the observed figure by not more than one unit. The ratio of successes to total number of forecasts, in terms of percentage, has been computed for 1954 and 1958. Periods observed to have been quiet and disturbed are analyzed separately.

Six-hour forecasts issued one hour in advance and whole-day forecasts issued 1 to 4 days in advance achieved the following results:

Ratio of successes to total forecasts

(%)

Forecast	Six-hour		Whole-day	
	Quiet	Disturbed	Quiet	Disturbed
1954	98·5	88·0	90·1	77·4
1958	91·1	87·1	89·7	53·3

It is desirable, in evaluating any set of forecasts, to note that the correct forecasting of a deterioration in propagation quality is of greater inherent value than correctly forecasting the continuance of an existing situation.

2.4 Some relationships have been studied between Special World Intervals declared by the IGY World Warning Agency and subsequent observations of magnetic or propagation disturbances. Such relationships need to be interpreted with particular, care since the declarations of Special World Intervals had different objectives and limitations, as compared with the usual propagation disturbance forecasts. A U.S.S.R. study has shown that, while the need still continues for improved methods of forecasting disturbances, the intensified observations during the IGY Special World Intervals have provided valuable data for further study.

2.5 The Administration of France reported that prior to May, 1957, only about 50% of disturbances were anticipated, but between May, 1957 and March, 1958, 11 out of 16 (68%) were anticipated using forecasts based upon comparisons of data on the solar chromosphere, the intensity and localization of solar radio noise, and the intensity of cosmic rays.

3. Diurnal distribution of the times of onset of ionospheric disturbances and stability of foF2 during disturbed conditions

In the U.S.S.R., statistical studies of ionospheric disturbances have been made which show that disturbances usually commence during night hours. Thus, " forbidden " intervals for storm commencements have been found for every ionospheric station in the U.S.S.R. These results have enabled short-term forecasts to be made more accurately [31]. Studies of the rapid changes of foF2 during the storms showed that the F2-layer is sufficiently stable to permit useful extrapolation of values of foF2 a few hours in advance.

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REPORT 248 *

AVAILABILITY AND EXCHANGE OF BASIC DATA FOR RADIO PROPAGATION FORECASTS

(Study Programme 200(VI) and Recommendation 313)

(Geneva, 1951 — London, 1953 — Warsaw, 1956 —
Los Angeles, 1959 — Geneva, 1963)

1. Introduction

Propagation of radio signals in the range 3 to 30 Mc/s is practicable over any but the shortest distances, mainly because of the possibility of obtaining ionospheric and ground reflections which result in small values of attenuation. Satisfactory communications for a given circuit can generally be obtained, if the operating frequency lies between a lower (LUF) and an upper (operational MUF) frequency limit. These are determined by ionospheric characteristics. The operational range of frequencies has been found to be even more restricted with some forms of high capacity communications systems.

Since only a limited range of frequencies can be used, it is desirable to have, as far in advance as possible, information on the probable values of these upper and lower limits as well as short-term forecasts and disturbance warnings. Collectively, these predictions (long-term) and forecasts (short-term) and disturbance warnings provide information for planning and operating personnel, that can be utilized in making the most economical use of the limited resources of equipment and frequency spectrum. The long and medium-term predictions are indicative of representative ionospheric conditions, so that it is extremely useful to operating personnel to be warned of impending ionospheric disturbances in order that traffic can be rerouted, instructions can be issued in advance to cover temporary adjustments in the normal operating frequency, and the performance of other systems affected by the ionosphere can be assessed.

2. Available data for radio-propagation forecasts

2.1 *Long-term predictions*

Organizations in several countries now prepare predictions of ionospheric conditions from one month up to twelve months in advance (see Annex); for general planning purposes, predictions for a complete solar cycle are also made by some organizations. These predictions are for representative ionospheric conditions. The information is usually issued in the form of charts which are applicable to any part of the world and are available forin terchange between the organizations undertaking this service.

2.2 *Forecasts of disturbances*

Organizations in several countries now prepare forecasts of ionospheric disturbances from a few hours to twenty-seven days in advance (see Annex). These forecasts are supplemental to the long-term predictions, since the occurrence of ionospheric disturbances, which cannot be forecast for long periods in advance, may modify considerably the frequency range within which satisfactory operation can be maintained on a particular circuit. Operating organizations have shown interest in these short-term forecasts to such an extent that they are now being regularly transmitted by radio at scheduled times (see Annex).

* This Report, which replaces Report 160, was adopted unanimously.

2.3 *Working documents for long-term predictions*

The following documents are sources of MUF, FOT and field-strength data, for use with predicted sunspot numbers in making long-term predictions for any part of the world:

— Australian I.P.S. Contour Maps, 1947 and 1951;

— I.F.R.B. technical standards, published by the International Telecommunication Union (1955-1959);

— United States of America NBS Technical Note 2. " World maps of F2 critical frequencies and maximum usable frequency factors ", April 1959;

— United States of America NBS Technical Note 2-2. " Supplementary world maps of F2 critical frequencies and maximum usable frequency factors ", October 1960;

— Japanese Radio Research Laboratories (Tokyo, Japan). " World maps of F2 critical frequencies and maximum usable frequencies for 4000 km ", August 1958;

— British Radio Research Station, Slough, England. " Predictions of radio wave propagation conditions for the sunspot-minimum epoch 1954-1955 ", April 1954;

— British Radio Research Station, Slough, England. " Standard charts of radio-wave propagation conditions for the sunspot maximum epoch ", July 1959.

Some of the above-mentioned data were produced when there was considerably less basic information and understanding of the physical properties of the ionospheric than exist now, so that discretion should be exercised in their use.

3. Exchange of basic data used in short-term forecasts

3.1 For many years, scientific information of direct interest to those concerned with ionospheric forecasts and disturbances has been broadcast by certain countries, in programmes known as Ursigrams arranged by the International Scientific Radio Union. These programmes provide a means of exchange of summary information required within 48-hours, after its collection, for the preparation of short-term forecasts and similar urgent purposes. These exchanges are made through regional networks, composed of observatories, laboratories, communications agencies and regional centres. The regional centres in turn exchange, once a day, summaries of information on solar flares, sudden ionospheric disturbances, solar corona and radio emission, sunspots, ionospheric and magnetic activity, as well as forecasts. It should be noted that during and since the International Geophysical Year, a plan has been in operation for the rapid, world-wide dissemination of similar information. The regional warning centres (RWC) in France, Federal Republic of Germany, Netherlands, Japan and U.S.S.R. collect data in their regions and forward them by telegraph to the World Warning Agency (near Washington, D.C., U.S.A.) which has also collected data from its region. The World Warning Agency makes the final decision, having advice available from the other centres, whether or not to declare a world-wide ALERT (issued shortly after an exceptional solar or geophysical event has occurred or started) or an SWI — Special World Interval — (periods during which many geophysical stations carry out special observing programmes). These decisions are distributed throughout the world to scientific stations participating in the programme by various rapid means, in particular over the meteorological teleprinter networks coordinated by the W.M.O.

3.2 Types of data exchanged among the various regional centres are those concerning solar flares, solar corona, solar radio emission, cosmic rays, critical frequencies of the ionosphere, ionospheric disturbances, terrestrial magnetism and radio propagation quality. Data are collected and transmitted in simple synoptic codes. Complete sets of codes may be obtained from the Secretary General, U.R.S.I., 7 Place Emile Danco, Uccle, Brussels 18, Belgium.

The regional centres from which details may be obtained concerning data and schedules of broadcasts and/or reports are listed in the Annex.

3.3 The Annex lists the centralizing agencies, which have been designated by their respective Administrations, for the reception, coordination, liaison and exchange of information relating to radio propagation.

ANNEX

LIST OF ORGANIZATIONS CONCERNED WITH THE EXCHANGE OF DATA AND THE ISSUING OF FORECASTS OF PROPAGATION CONDITIONS

A: an agency for the general exchange of information on propagation;

RC: a regional centre for the rapid exchanges of data required for short-term forecasts of disturbances;

L: the organization issues long-term predictions. The periods ahead for which predictions are made are shown (in months);

S: the organization issues short-term forecasts of disturbances;

WDC: designated as a world data centre beginning with the IGY

Country	Organization	Address	A	RC	L	S
Argentina	L.I.A.R.A.	Secretaría de Marina, D.E.N. L.I.A.R.A. Av. Lib. Gral. San Martín No. 327 Vicente López República Argentina	×		1	
Australia		Officer-in-charge, International Section, P.M.G.'s Department, Treasury Gardens, Melbourne, C.2. Tel. address: Gentel, Melbourne.	×			
	I.P.S.	Ionospheric Prediction Service, Sydney, New South Wales Tel. address: IPSO, Sydney		×	3	×
Belgium		Chef du Service du Rayonnement, Institut Royal météorologique, 3, Avenue Circulaire, Uccle, Brussels	×			
Brazil	C.T.A.	Centro téchnico de Aeronáutica, S. José dos Campos, São Paulo	×		1	
	I.P.M.	Instituto de Pesguisos de Marinha, Ministerio de Marinha, Rio de Janeiro			1	

Country	Organization	Address	A	RC	L	S
China	R.W.R.L.	Radio Waves Research Laboratories, Directorate General of Telecommunication, P.O. Box No. 84, Taipei, Taiwan	×		×	
Spain		Departamento de Servicios Técnicos de Telecomunicación, División General de Correos y Telecomunicación, Madrid	×			
United States	C.R.P.L.	Central Radio Propagation Laboratory, National Bureau of Standards, Boulder, Colorado. (WDC)	×		6	×
		North Atlantic Radio Warning Service, Box 178, Fort Belvoir, Virginia		×		× (1)
		North Pacific Radio Warning Service, Box 1119, Anchorage, Alaska		×		× (1)
	R.C.A. Inc.	R.C.A. Incorporated, 66, Broad Street, New York City				×
France	C.N.E.T.	Centre national d'études des télécommunications, 196, rue de Paris, Bagneux (Seine) Tel. address: Gentelabo, Paris	×	×		× (2)
	D.P.I.	Centre national d'études des télécommunications, Château de la Martinière, Saclay (Seine-et-Oise)	×	×	6	
India		The Secretary, Radio Research Committee, National Physical Laboratories, Hillside Road, New Delhi	×		3	
		Kodaikanal Observatory				×
Italy		Istituto Nazionale di Geofisica, Città Universitaria, Roma. Tel. address: Geofisica, Roma. (All messages should begin with the word " Ionosphere ")	×			

(1) Warnings also radiated from WWV and WWVH.
(2) Warnings radiated from Pontoise.

Country	Organization	Address	A	RC	L	S
Japan	R.R.L.	Radio Research Laboratories, Ministry of Posts & Telecommunications, Kokubunji, Tokyo (WDC)	×	×	3	× (1)
Mexico *	S.C.T.	Dirección general de Telecomunicaciones, Estación de radiosondes ionosferico, Xole y Universidad, Mexico, (12) D.F.	×			
New Zealand		Carter Observatory (Wellington)				×
Netherlands		Afdeling " Ionosfeer en Radioastronomie ", Kortenaerkade 12, The Hague	×			
		P.T.T. Receiving Station, Nederhorst-den-Berg		×		
Federal Republic of Germany	F.T.Z.	Fernmeldetechnisches Zentralamt (Arbeitsgemeinschaft Ionosphäre), Rheinstrasse, 110, Darmstadt. Tel. address: Ionosphäre, Darmstadt	×	×	3	×
United Kingdom	R.R.S.	Director, Radio Research Station, Slough, Buckinghamshire. Tel. address: Radsearch, Slough (WDC)	×		6	
Switzerland		Division Radio et Télévision, Direction Générale des P.T.T., Speichergasse, 6, Bern .	×			
Republic of South Africa	C.S.I.R.	Telecommunications Research Laboratory, Department of Electrical Engineering, University of Witwatersrand, Johannesburg	×		1	
U.S.S.R.	IZMIRAN	Scientific Research Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Moskovskaya Obl., P/O Vatutenki, Izmiran (WDC)	×	×	12 and 1	× (2)

(1) Warnings radiated from JJY.
(2) Warnings radiated from RDZ and RND.
* Information received after the closure of the Xth Plenary Assembly.

REPORT 249 *

PULSE TRANSMISSION TESTS AT OBLIQUE INCIDENCE

(Study Programme 197 (VI))

(Los Angeles, 1959 — Geneva, 1963)

During the past decade, considerable development of the technique of probing the ionosphere at oblique incidence has occurred [1 to 15], and progress continues to be made both in equipment techniques and in understanding of ionospheric phenomena. A number of detailed investigations have been reported by various Administrations in Report 163 (Los Angeles, 1959). The following documents report further activities. Doc. VI/16 (Federal Republic of Germany), VI/37 (U.S.A.), VI/56 (Canada) and VI/59 (United Kingdom) of Geneva 1962.

We shall exclude from this Report those topics which are covered in a separate report concerning techniques which use scattering from the earth's surface (see Report 261, §1). Thus, the present Report concerns chiefly experiments in which pulse equipment is located at both ends of the propagation paths. Equipment for operational use in this way is now offered by several manufacturers.

Although single-frequency, fixed-direction transmissions reveal more information about ionospheric modes than CW transmissions, even more information and easier interpretation is attainable by sweeping the transmitter and receiver frequency in synchronism. The problem of synchronization is greatly eased by stepping from one frequency to the next, rather than by sweeping continuously.

1. Sweep-frequency and step-frequency results at HF and VHF

1.1 The existing theories of propagation seem to be adequate for calculating MUF for distances up to several hundred kilometres. Oblique incidence pulse tests in Canada [16], France [17], Federal Republic of Germany [18], and in the U.S.A. [19, 20] indicate that the classical MUF is observed to be 3 to 10% higher than the standard MUF for paths up to about 4000 km.

1.2 It is observed that for high latitude paths, the summer day MUF may often be determined by the one-hop F1 (Pedersen ray) mode. For long paths, the one-hop F2 (Pedersen ray) is the principal mode under certain conditions over a wide range of latitudes. For certain distances, the E and F1 layers determine the MUF, especially in summer daytime during periods of low solar activity.

1.3 For north-south paths, the frequency difference between the two magneto-ionic components is reported not to differ appreciably from that at vertical incidence. However, east-west paths in the U.S.A. show a decrease in separation between the classical MUF's for the ordinary and extraordinary modes as the path length increases. The separation at 2400 km is about 0·2 Mc/s [21].

1.4 A study of pulse amplitudes at frequencies near the MUF for a 2370 km east-west path in the U.S.A. indicates that " MUF focusing " amounts, on the average, to no more than about 6 db [21].

* This Report, which replaces Report 163, was adopted unanimously.

2. Off-great-circle observations at HF

The propagation can usually be considered to be confined to the greatcircle route joining the two stations. On the other hand, experiments using scanning antennae have shown that, often this is not so, for example:

2.1 scatter from the ground at one side of the great-circle route is often detectable when the great-circle signal is absent [22 to 31];

2.2 non-uniform distribution of ionization associated with the aurora causes off-great-circle propagation [32, 33].

3. Application to practical HF communication links

This method of probing the ionosphere is easily and directly applied to the problem of two fixed stations attempting to agree upon the best choice of frequency [16, 33, 34, 35, 36, 37]. In this case, it would be advisable to employ the same (or similar) antennae as customarily used for the communication circuit. A classical MUF may be distinguished for each mode of propagation and compared with the operational MUF. The relative time delay between active modes that are present at any given frequency is observable [38, 39].

4. Oblique-incidence pulse measurements at LF

" Loran-C " is an existing navigation system using pulse propagation at 100 kc/s. The instrumentation uses gating and sampling techniques to identify a cycle of the ground-wave portion of the signal and to measure coherently the phase of the 100 kc/s. Similar techniques have been used at great ranges to measure phase, amplitude and dispersion in times of arrival of pulses propagated by the sky-wave. This system can provide excellent time synchronization over great ranges, and it would be possible to measure accurately HF propagation delays by using this time synchronization at both ends of the propagation paths [40].

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REPORT 250 *

LONG-DISTANCE IONOSPHERIC PROPAGATION WITHOUT INTERMEDIATE GROUND REFLECTION

(Los Angeles, 1959 — Geneva, 1963)

1. It is now well established that there are modes of propagation by means of the regular ionospheric regions, by which HF and VHF radio waves can travel to great distances in or below the ionosphere, over low absorption paths, without intermediate ground reflection. The distances in question extend from the classical geometrical limit of single-hop out to 10 000 km.

Modes of propagation which are now recognized include:

— high-angle single-hop Pedersen ray;
— ionospheric ducting between E- and F-regions;
— equatorial F-region ionization trough.

2. the high-angle Pedersen ray has been observed for some years on North American [1] and on transatlantic paths [2, 3] and provides explanation for frequent communication on frequencies well above the standard MUF.

3. Some theoretical work has been carried out on the various modes of propagation possible by way of ducting between the E- and F-regions including the suggestion of some cases of non-reciprocity [4].

4. Long-range trans-equatorial propagation has been observed, and explanations have been proposed, following studies of the ionization gradient in the equatorial F-region trough [5, 6]. It is suggested that both layer tilt and scattering processes may affect this type of long distance propagation. It is theoretically possible for a ray deflected through an ionization gradient, to emerge from the ionosphere, travel in a straight line above the earth's surface, re-enter the ionosphere and then undergo further refraction.

5. The proposed mechanism of a series of internal ionospheric reflections or refractions is attractive for explaining round-the-world echoes which, under certain conditions, show remarkably low dispersion and attenuation between successive echoes [7, 8].

6. Ionospheric soundings from a satellite [9, 10], have shown the existence of significant ionization clouds above the F-region height of maximum density. These may be responsible for some long-distance propagation without intermediate ground reflection and at frequencies above the standard MUF.

7. It is hoped that future ionospheric sounding satellites may spend part of their time in the ionized regions to advance the study of duct modes of propagation [11].

* This Report, which replaces Report 164, was adopted unanimously.

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REPORT 251 *

INTERMITTENT COMMUNICATION BY METEOR-BURST PROPAGATION

(Study Programme 196 (VI))

(Los Angeles, 1959 — Geneva, 1963)

1. Introduction

The subject of VHF propagation by reflections from columns of ionization produced by meteors (meteor trails), has been referred to in Report 259, where signals inadvertently so transmitted were considered in terms of their ability to cause interference. It is now clear that this propagation mode can be used for communications. Experimental single-channel two-way telegraph circuits have been operated in the 30 to 40 Mc/s frequency range over distances of 600 to 1300 km with transmitter powers of 1 to 3 kW. One-way transmissions of voice and facsimile have also been made with transmitter powers of 1 kW and 20 kW respectively.

2. Summary of available information

2.1 Relatively little information is available on the geographical distribution of the meteors important in this mode of transmission and of their preferred directions. Some data exist on the distribution of meteor-ionization over parts of Canada, the Federal Republic of Germany, the United Kingdom and the United States. Data from other areas are needed.

* This Report, which replaces Report 157, was adopted unanimously.

2.2 Theoretical computations indicate that, for a given transmitter power, the average information rate of an intermittent system can increase with increasing bandwidth.

2.3 Experimental results have indicated the possibility of useful transmission, in bandwidths up to 100 kc/s, for time intervals of the order of 1 s and duty cycles of the order of 5 %.

2.4 Reflections from meteor ionization-trails are highly dependent upon path geometry. This characteristic results in propagation which is dependent on geographical location, path orientation, operating frequency and time. Optimum conditions usually occur a few (5 to 10) degrees off the great circle path.

2.5 The signal energy is of the order of 10 db higher than with ionospheric-scatter. This suggests the use of meteor-burst propagation for mobile and airborne installations (requiring less power and antenna gain). Meteor-burst propagation may also be useful in geographical regions where ionospheric scatter losses are unusually high, for example in some equatorial regions.

2.6 Meteor-burst propagation, is subject to black-outs during periods of unusually high D-region absorption, such as polar cap absorption. Simultaneous tests at 10·41 Mc/s and 41·3 Mc/s show that this effect is greatly reduced at the higher frequency. However, the duty cycle is also reduced at the higher frequency.

2.7 Very few data are available at frequencies above 50 Mc/s.

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Some general references on the characteristics of meteors are:

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Characteristics of special interest to radio transmission are summarized in:

3. Villard, O. G. et al. The role of meteors in extended-range VHF propagation. *Proc. IRE*, **43**, 1473 (October, 1955).
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which contain numerous references to earlier work. Most of an issue of the Proceedings of the IRE was devoted to this subject (*Proc. IRE*, **45**, (December, 1957)).

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REPORT 252 *

ESTIMATION OF SKY-WAVE FIELD-STRENGTH AND TRANSMISSION LOSS BETWEEN THE APPROXIMATE LIMITS OF 1·5 AND 40 Mc/s

(Study Programme 198(VI))

(Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

1. Introduction

Since improved methods of estimating sky-wave field-strength and transmission loss are of a great practical importance to the various administrations, and to the I.F.R.B., an International Working Party for this task was established by Study Group VI in Warsaw, 1956. The initial task of this International Working Party (Dr. Lépéchinsky, France, Chairman) was the evaluation of RPU-9 [1], which was being extensively used in lieu of NBS circular 462 [2] and which forms the basis of I.F.R.B. technical examinations. During the work of this International Working Party, 1956-1962, several other Administrations presented prediction methods for consideration, e.g. the Union of Soviet Socialist Republics. [3]; the United Kingdom [4]; the Federal Republic of Germany [5, 6] and Japan [7]. In addition to these methods, India has since developed a method for tropical areas [8] and Canada has a method for the Northern latitudes [9, 10].

The methods of RPU-9 have also been recently modified to conform with the concept of transmission loss (C.C.I.R. Recommendation 241) expanded to consider auroral and polar cap circuits and adapted to electronic computers [11].

Although the International Working Party had already concluded at an early stage that RPU9 was in general more satisfactory than NBS circular 462 the fact that several other methods are now available makes it desirable to modify the initial task of the Working Party. Resolution 7 revises the task to develop a composite method and continues a measurement programme to assist in its development.

2. Summary of major factors

Since there appears to be reasonable agreement among the methods with regard to most of the factors involved in propagation at frequencies below the MUF, it should not be difficult to find suitable compromises for these factors. In arriving at such compromises, the simplicity of the resulting method and its amenability to use with computers should be kept in mind. The general problem of calculating the transmission loss for ionospheric sky-wave propagation may be summarized as follows:

2.1 For frequencies below the classical MUF, and distances less than about 4000 km, the modes of propagation are relatively simple and reasonably well understood. Calculation of transmission loss may be based upon propagation via the classical modes in the plane of the great circle path, taking due account of deviative and non-deviative absorption, and the vertical angles of departure and arrival, together with the corresponding gains of the transmitting and receiving antennae in the great circle plane.

* This Report, which replaces Reports 152, 155 and 156, was adopted unanimously.

2.2 For frequencies below the classical MUF and distances beyond about 4000 km, experimental evidence shows that the mode structure often becomes very complex, and deviations from the great circle path may occur, especially at the longest distances, so that there are grounds for doubt that a calculation based upon conventional great circle modes is warranted or necessary. However, in the continuing absence of sufficient information, it may, for the time being, be acceptable to make calculations for these longer distances in terms of classical modes with the expectation that the results would be reasonably accurate in most cases. On the other hand, it would be simpler and perhaps sufficiently accurate, simply to take the absorption as proportional to the distance, as is done for long distances in the method of NBS circular 462, and to use values of the propagation angles based directly on observation. Further investigation of the nature of very long-distance propagation is necessary before the best approach can be selected.

An important consideration in practical calculations of transmission loss or field strength is the continuity of the calculated values considered as a function of distance. If the use of different procedures for intermediate and long distances results in a discontinuity at the transition distance, it might be preferable to adopt a single calculation procedure for both distance ranges.

2.3 For frequencies above the classical MUF over the shorter distances, one-hop sporadic-E, and the laterally deviated 2-hop F2 mode with ground-scatter, are the most important modes for relatively low transmission loss propagation. Of these, sporadic E seems to be more important. The Japanese method gives a first approximation for the calculation of the transmission loss via these modes [7, 12]. Meteors afford occasional short-lived bursts of strong signal, and for frequencies just above the classical MUF, continuous propagation of relatively low transmission loss may be afforded by the combination of forward scattering by irregularities in the D/E region and ordinary reflection by the F2-layer. However, these modes are not believed to be of sufficient importance at the shorter distances for consideration at present. Direct forward scatter from D-region irregularities affords continuous propagation at frequencies well above the classical MUF, but the transmission loss is rather high.

2.4 At distances well beyond 4000 km, relatively low transmission loss propagation may usually be observed, well above the normal classical great circle MUF (i.e. the classical MUF reckoned without taking account of extra-long Pedersen-ray hops). At frequencies not too far above this MUF, the propagation may take place via:

- multi-hop classical modes laterally deviated via ground side-scatter into regions of higher classical MUF;
- direct or side-scattered multi-hop sporadic-E modes;
- the combination of D/E scatter and classical reflection;
- the extra-long Pedersen-ray hop.

There is some evidence that this last is probably not important beyond about 6000 km.

3. Recent work on sky-wave absorption using pulse techniques

3.1 *Doc. VI/69* (France) of Geneva, 1962, reports on a series of regular observations made at Domont (France) and Bangui (Central Africa). Tables of monthly median values are given, from which it appears, that at frequencies of about 3 Mc/s, the noon absorption at the equator is roughly 25 % higher than the summer values at about 49°N.

3.2 *Doc. VI/106* (U.S.S.R.) of Geneva, 1962, is an abstract of a widespread analysis of noon measurements made at 2 Mc/s by 22 stations all over the world. The result is described by a formula containing three terms relative to solar control, increased absorption in the equatorial belt and in the polar regions. The coefficients of these three terms have been determined separately for magnetically quiet and disturbed days. Numerical values and further details are to be published.

3.3 Doc. VI/18 (Federal Republic of Germany) of Geneva, 1962, reports on more than three years of multi-frequency observations at about 48° N. The contributions of (non-deviative) D- and (deviative) E-regions have been separated by taking into account the particular conditions found with reflections from Es-layers. Monthly median tables of both contributions are given. Whilst the diurnal variation is due to the combination of both the deviative and non-deviative contributions, their seasonal variations are rather different. The D-layer absorption undergoes only slight seasonal changes, because the winter anomaly fills up a large part of the expected winter minimum. The E-absorption, however, has a considerable seasonal effect, higher summer values being caused by a lowering of the layer height. Pulse measurements made at two places in Germany and at one near Paris, have shown besides, a high degree of correlation of the corresponding monthly medians. Another measurement campaign at Tsumeb (South-West Africa) was made on two frequencies; a very important seasonal variation of the absorption is reported from this place (19° S).

3.4 Doc. VI/22 (Federal Republic of Germany) of Geneva, 1962, reports on pulse measurements carried out between the U.S.A. and Germany. A statistical analysis of the amplitudes of the different multiple-hop signals gave higher values for 3 × F and 4 × F than for 2 × F and 5 × F paths. The results for 2 × F is explained in terms of deviative absorption and blanketing.

3.5 India has developed a formula for the frequency dependence and diurnal variation of ionospheric absorption in tropical areas on the basis of ionospheric absorption observed on vertical incidence pulse-transmissions since 1954 [13].

4. Recent work on sky-wave propagation

4.1 Four contributions describe new theoretical investigations.

Doc. VI/93 (F.P.R. of Yugoslavia) of Geneva, 1962, which is a mainly theoretical contribution, considers a model layer containing sub-stratifications, so that losses are introduced not by collison absorption processes alone, but also by partial reflections.

Doc. VI/18 (Federal Republic of Germany) of Geneva, 1962, splits the absorption term into a non-deviative and a deviative one, taking account, in a particular manner, of reflections obtained from the Es layer; these latter are less influenced by deviative absorption than are reflections from higher reflection levels.

Doc. VI/53 (Japan) of Geneva, 1962, gives details of a field strength calculation method which applies to off-great circle propagation by ground (side) scatter. Two attenuation terms are used. The first one provides for ionospheric absorption on the two sections of the indirect path; it is given as a function of f/MUF_c, by an empirical law, MUF_c being the value of MUF (4000) obtained at a control point 2000 km distant from the related terminal and f being the frequency. The second term is a ground-scatter loss supposed to be proportional to the scattering azimuth angle. A similar method, containing the first term only is applied for normal great circle propagation.

Doc. VI/22 (Federal Republic of Germany) of Geneva, 1962, refers to a former German contribution (Doc. VI/30 of Geneva, 1958), where a semi-empirical field-strength formula depending on MUF had been established. It is understood that in this way the different scatter effects are taken into account, including loss by scatter effects at frequencies below the classical MUF.

4.2 Doc. VI/106 (U.S.S.R.) of Geneva, 1962, proposes a world-wide description of absorption by a formula containing two extra terms, which take account of increased absorption in the equatorial belt and in the polar region respectively.

4.3 Three contributions give statistical comparisons between calculated and measured values of field strength.

Doc. VI/64 (United Kingdom) of Geneva, 1962, gives a method of making field-strength measurements using transmitters employed on long-distance circuits. Additional material has been supplied to the Working Party, set up under Resolution 48, in which such measurements of field strength are compared with calculations based on RPU9. In general, the measured values of field strength are considerably lower than the calculated ones, in particular during night-time conditions; differences go up to 20 db. It must be mentioned here, that the maximum antenna gain has been introduced into the calculations, since the true angle of elevation was unknown; correction for this influence should certainly tend to reduce the difference.

Doc. VI/53 (Japan) of Geneva, 1962, gives a few examples of a long series of observations showing good agreement with values calculated by the Japanese method. It must be emphasized, however, that this method uses a deviative absorption term obtained empirically. Additional information has been supplied to the Working Party, set up under Resolution 48.

Doc. VI/22 (Federal Republic of Germany) of Geneva, 1962, compares transatlantic field-strength values at 15 and 20 Mc/s with calculations made by a semi-empirical method [14]. The ratio of the field strengths at 20 and 15 Mc/s has a diurnal variation with values greater than unity during the day and less than unity at dawn. According to the above-mentioned theory, the value of the field strength at night should be lower in winter, when the MUF is lower than in summer. Another test of the theory has been made by deducing a field-strength curve at 15 Mc/s from the curve observed at 20 Mc/s. Agreement between this deduced curve and the values at 15 Mc/s observed independently is good to within a few decibels (standard deviation).

4.4 India has developed a method for calculating sky-wave field strength in the tropical regions. It is reported that, for tropical broadcasting services, this method gives the closest agreement with measured field strengths when compared with other prediction methods [15].

4.5 The Swiss P.T.T. station at Chatonnaye has continuously recorded the receiver input voltage of the frequencies 2·5, 5, 10, 15, 20 and 25 Mc/s of the standard frequency station WWV, Beltsville, Maryland, U.S.A., since 1950 [16].

5. Conclusions

5.1 The calculation of field strength or of transmission loss at frequencies below the classical MUF and at distances less than about 4000 km, must take account of the different possible modes of propagation and their vertical angles of departure and arrival in the great circle plane. At the shorter distances, deviative absorption may be important as well as non-deviative absorption. Theory predicts that, near the limits of one-hop propagation, horizon focusing should decrease the spatial attenuation. In practice, however, it does not seem to be an important effect.

5.2 For longer distances, at frequencies below the classical MUF, the actual propagation modes are less well understood. There is some practical justification, therefore, for the use of a simplified calculation of the transmission loss at these distances. A simplified method for estimating high-frequency transmission loss at night has been furnished by the Japanese Administration [17].

5.3 At frequencies above the MUF, methods for estimating the transmission loss for sporadic-E propagation and laterally deviated multi-hop F2 propagation, involving ground side-scatter, have been furnished by the Japanese Administration. For long distances, at frequencies in the vicinity of and above the classical MUF, the Federal Republic of Germany has furnished a semi-empirical method [14]. Interested Administrations should check both of these methods and report on their applicability and accuracy.

5.4 It is highly desirable that there be a reliable method, readily adaptable to machine computation, for each of the various propagation situations (i.e. below and above the classical MUF, and at both short and long distances).

5.5 Administrations are requested to give some thought to the feasibility of constructing a " C.C.I.R. method " applicable to some, if not all, of the propagation situations and should provide the Chairman of the International Working Party with details of prediction methods used within their Administrations, with emphasis on techniques which are considered especially applicable.

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REPORT 253 *

SYSTEMATIC MEASUREMENTS OF SKY-WAVE FIELD-STRENGTH AND TRANSMISSION LOSS AT FREQUENCIES BETWEEN THE APPROXIMATE LIMITS OF 1·5 AND 40 Mc/s

(Study Programme 198(VI))

(Geneva, 1963)

1. Introduction

Field-strength measurements ** in the frequency band between 1·5 and 40 Mc/s are required to provide the International Working Party, set up under Resolution 7, with experimental data to compare with the values of field strength derived from the various methods of prediction under consideration. This Report is intended as a guide to Administrations and Organizations on the possible methods for obtaining and presenting the required experimental data. It is emphasized that the need for these experimental data is urgent.

Those which already have experimental data, that can be used by the International Working Party, are invited to forward their data to the Working Party through the Director, C.C.I.R. as soon as possible. It would be of great assistance to the Working Party if the data could be presented in accordance with the suggestions made in §4 of this Report.

2. General considerations

The organization of the work for obtaining these experimental data falls naturally into two parts:

— selection of suitable transmissions and the location of receiving stations;

— recording and compilation of data, in a form suitable for comparison with calculated values of field-strength.

Ideally, the methods of transmission and reception should be of a standard type and for this reason, it was originally proposed that the transmitters should be those in use for standard-frequency transmissions since they provide a service 24 hours per day and are effectively radiating a continuous wave of carefully controlled frequency and power from a standard omnidirectional antenna. Some key receiving stations were also proposed having special reference to the possibility of locations in the countries participating in the work of the International Working Party.

It has been found, however, that the standard-frequency transmissions are not of sufficient power to provide adequate field strength for measurement purposes at great distances, moreover, under these conditions, there is serious mutual interference due to frequency sharing between these transmissions. It is therefore necessary to contemplate the use of more powerful transmissions and the possibility of using the transmissions on existing broadcasting or point-to-point services needs to be considered.

However, many organizations are experienced in making field-strength measurements, so that it should be possible to obtain reliable data that can be compared with less uncertainty than is implied in predicting day-to-day and hour-to-hour variations of field strength. Thus, data in which the absolute value of field strength may be somewhat doubt ful as compared with those obtained on a standard set, may yet provide valuable information on diurnal

* This Report was adopted unanimously.

** In this Report, the term " field-strength " is considered to include the term " transmission loss " where appropriate.

variations of field strength that would be differently predicted according to the method used. Some of these difficulties can possibly be avoided by converting field strength to transmission loss, as discussed in Report 112.

3. Provision of transmissions

Resolution 7 envisages the cooperation of Administrations and organizations in the provision of transmissions. Such cooperation would obviously be subject to the limitations imposed by the normal working schedules of the transmitters in question, although the possibility of using such transmitters at special times on standard omnidirectional antennae could be explored.

However, organizations have been asked, in C.C.I.R. Circular AC/57, to give full details of those transmitters which they consider would be suitable, especially as regards their knowledge of the radiation polar-diagram in both the horizontal and vertical directions. As a guide, it is desirable, in long-distance propagation, to have a vertical polar diagram approximating to that of a standard short vertical radiator for angles of elevation less than 20°.

It is also necessary to rely upon the organization to choose transmitters the antenna characteristics of which are known with sufficient accuracy, either by actual measurement or from design data and a knowledge of the suitability of the site.

In addition, they are invited to consider the possibilities of making field-strength measurements of the distant transmitters used for their point-to-point telephone or telegraph service. Some of the advantages of this are:

— no special transmissions are required;

— reception is mainly free of interference, provided the bandwidth of the measuring set is no greater than of the receiver normally in use for the reception of traffic;

— full details of the transmissions are recorded in the logs of the commercial receiving station.

4. Receiving stations and recording techniques

The need should be stressed for a coordinated programme of measurements and the presentation of the results in a uniform manner so that they may be comparable. It may be desirable that at certain key stations, prepared to make special measurements, e.g. of angles of arrival, there should be uniformity with regard to recording speeds, scales, etc.

However, many organizations are already equipped to make field-strength measurements, using their own choice of time-constants, recording meters, calibration techniques, etc., and they would not necessarily be prepared to replace their existing facilities by a standard equipment. Since it will be their responsibility to analyze their own records, the use of standard equipment will not be of paramount importance.

It is suggested, however, that the standard receiving antenna should be a small loop or a short vertical rod, for which the vertical polar diagram does not differ materially from that of an ideal Hertzian dipole over the range of angles involved in long-distance transmission.

In any measuring equipment, the quantity measured is a voltage at some specified point, usually the input terminals of the receiver. The problem is then to relate this voltage to the value of the field-strength existing at the antenna. Even with the standard antenna, the conversion of field strength refers only to the vertical component of the electric field and some assumption must be made with regard to the randomness of the polarization of the incident wave system.

Some organizations are equipped to make measurements using special antenna systems, such a rhombic arrays, designed for specific circuits to improve signal-to-noise ratios and to enable measurements to be made under conditions where a simple antenna would be unusable. It is difficult to interpret the results obtained on an extended antenna system in the presence of a complex field built up of several waves incident at different angles, but measurements made with such antennae may be acceptable for the purpose in hand if they can be related consistently to those that would be obtained at the same time on a standard antenna. These relationships would have to be examined by the organizations concerned and applied by them in the reduction of their records to the standard form of hourly median values of field strength.

In general each measuring station is requested in AC/57 to prepare from the analysis of its own records the hourly median values and then to tabulate them with the monthly median values for each hour. A suggested form for presentation of the results is given by the Table in the Annex. The actual method of measurement in each case should be stated.

It is realized that continuous recording may be impraticable and that measurements may only be made at certain times of day and days of the week, but it is hoped that even so some useful information on monthly median values may be obtained for at least some hours of the day.

Although the field strength predictions are meant to refer to average propagation conditions, readings which correspond to obviously abnormal conditions, e.g. auroral effects or during times of sudden ionospheric disturbances and severe magnetic storms, should be included in the estimate of the monthly median values. Such readings in the Table of hourly medians should be indicated by some suitable notation. The Annex gives details of a typical method of obtaining the required information from point-to-point telegraph and telephone transmissions.

ANNEX I

A METHOD FOR MAKING FIELD-STRENGTH MEASUREMENTS OF TRANSMITTERS USED ON POINT-TO-POINT TELEGRAPH AND TELEPHONE SERVICES

1. As an example relating to point-to-point telegraph and telephone services, a brief description follows of the method in use by one organization.

2. Measurement of field strength

Field-strength measurements are made at a measuring station using a communications receiver adapted for the purpose. A self-supporting vertical rod antenna, 4 m long, feeds a wideband amplifier, which in turn is connected to the communications receiver by a buried 75 Ω coaxial cable. The equipment is calibrated against a field-strength measuring set, when both sets are receiving signals from a portable transmitter several hundred yards away. The receiver is operated with charge and discharge time constants of 20 s.

A pen recorder is used with a chart speed of one inch per hour. Calibration marks are shown on the charts at intervals, thus allowing the field strength to be read directly in db relative to 1 μV/m.

The measurements are made on multi-channel independent-sideband transmissions with suppressed carriers and the groups of individual channels may not be symmetrical about the carrier frequency. The receiver bandwidth is adjusted so that it includes all the sidebands transmitted and the actual bandwidth used depends on the type of multi-channel signal being transmitted, e.g., a receiver bandwidth of 1·2 kc/s might be used for a transmission consisting of two telegraph channels and bandwidth of 8 kc/s for a transmission consisting of two 3 kc/s telephone channels together with two telegraph channels.

3. Analysis of field-strength records

In analysing the field-strength records, the hourly values are first extracted from the recorder charts and tabulated. From the tabulated values, the median, upper decile and lower decile values can be derived for each hour. It has been found that at this stage of the analysis, it is imperative to check the recorder chart against the receiving station logs, to ensure that the recorded field strengths do, in fact, refer to the correct transmission and not to noise or interference. It may happen that the level of interference is not high enough to affect reception at the receiving station and, in such a case, there will probably be no reference to interference in the station logs. The interfering signal will only be detected by the presence of a residual signal after the wanted transmission has ceased. It has been found from the records obtained so far that this condition does not occur very often. When it does occur, the readings for that day for the particular frequency concerned must be discarded.

To compare the recorded field strengths with the values obtained by calculation, using any of the existing methods, the recorded values are reduced to the value F_s corresponding to the incident sky-wave field strength for a power of 1 kW radiated from a short vertical antenna. The value of F_s is obtained from the formula:

$$F_s = F_m - (P_t - L) - G_t - H \tag{1}$$

where:

$\left.\begin{array}{l} F_s = \text{sky-wave field-strength,} \\ F_m = \text{measured field-strength, which is a resultant of the sky-wave} \\ \quad \text{and ground reflected waves,} \end{array}\right\}$ (db rel. 1μV/m)

P_t = transmitter power (db rel. 1 kW),

G_t = transmitter antenna gain relative to the gain of a short vertical antenna * on the surface of a perfectly conducting earth,

L = loss due to transmitter mismatch, antenna mismatch and feeder loss, A typical value for this is 3 db,

H = height-gain factor.

A typical height-gain factor of —1 db allows for the fact that the measured value is the resultant of the direct and ground reflected rays, whereas the calculated value normally refers to the incident sky-wave. This factor assumes wave-arrival angles of 10°–15° relative to the ground and reflection from ground of good conductivity ($\varepsilon = 10$, $\sigma = 3 \times 10^{-2}$ mhos/m), for a vertically polarized wave. The height-gain factor will vary with frequency and wave-arrival angle, but the variations can be neglected over the range of frequencies and angles likely to be encountered in the course of these measurements. The height-gain factor would differ somewhat from the -1 db given above, if the ground conductivity were different.

4. Presentation of results

A possible form of presentation is given in Table I, which contains the minimum data needed. Further useful information would include the count number and the notation used to describe the conditions attaching to individual readings.

* If an isotropic antenna is used as the reference, G_t would be increased by 4·8 db.

TABLE I

MEASUREMENTS OF HIGH FREQUENCY FIELD STRENGTH * MEASURING STATION

CIRCUIT: *Transmitter* .... *Receiver* .... *Distance* .... (km)

TRANSMITTER DETAILS: *Power* .... (kW) *Feeder and mismatch losses* .... (db) *Antenna gain* .... db rel. short vertical antenna

Frequency .... (Mc/s) *Year* .... *UT* .... *Month* ....

Day of month	Hour of day								
	0000	0100	0200	0400		2000	2100	2200	2300
1									
2									
3									
.									
.									
.									
.									
29									
30									
31									
Median									
Upper decile									
Lower decile									

* The figures in this table are the hourly median values of measured field strength. The field strength of the incident sky-wave for a radiated power of 1 kW is obtained from Equation (1) in § 3 of Annex I.

ANNEX II

At the date of presentation of this Report, the following Administrations have replied to AC/57:

Japan, which has designated Hiraiso Radio Wave Observatory as a measuring station and Koganei transmitting station (Standard Frequency Station, call sign JJY) as a transmitting station and has given some details on the receiving equipment and the measured data so far obtained.

India, which has designated Delhi as a measuring station.

Australia, which has designated the monitoring centre in Melbourne as a measuring station and has given details on high-frequency radiotelegraph services operated by their Oversea Telecommunications Commission.

France, which has designated the international monitoring centre (Centre de contrôle international des émissions) in Noiseau as a measuring station and the standard frequency transmitting station (Station émettant des fréquences étalon), Paris-Bagneux (FFH) as a transmitting station.

Federal Republic of Germany, which has designated Fernmeldtechnisches Zentralamt at Darmstadt as a measuring station and has indicated some details of their programme of measurements.

Ethiopia, which has indicated that it has no monitoring equipment for carrying out such measurements, but has expressed interest in possible participation.

Monaco, which has indicated that it cannot, at present, participate in the measurement campaign.

Moreover, the *United Kingdom* delegation to the Xth Plenary Assembly has communicated the information to the Working Party that the B.B.C. is prepared to make measurements at its monitoring station at Tatsfield and has given details of the scope of the work it can undertake, and that the G.P.O. is already obtaining records at the receiving station at Banbury in accordance with the method outlined in Annex I. Field-strength data are also available from measurements, made in Singapore by the D.S.I.R.

REPORT 254 *

MEASUREMENT OF ATMOSPHERIC RADIO-NOISE

(Study Programme 154)

(Los Angeles, 1959 — Geneva, 1963)

1. Networks of noise measuring stations

The network of stations for the measurement of noise power, using the ARN-2 recorder, is substantially the same as described in Report 165 (Los Angeles, 1959); equipment for 15 stations was provided by the United States and for one by India [1]. Some stations have been equipped for the measurement of other noise parameters. Measurements of more detailed statistical parameters of the noise structure, from which the noise power can also be deduced, have been made at many other stations. A full account of the measurement programme has been prepared by U.R.S.I. and published [2]. Some systematic differences, up to 4 db at some frequencies, have been observed in the values of noise power obtained by different techniques on the same site. These are still under investigation [3]. A few measurements have continued using the older aural techniques [4].

The data obtained during the last few years have been used in the preparation of Report 322.

* This Report, which replaces Report 165, was adopted unanimously.

2. Measurement of statistical characteristics

Measurements of amplitude probability distribution of atmospheric noise have been made at many locations [2], and the data have been used in Report 322. It has been shown that allowance can be made for the noise structure in estimating required signal-to-noise ratios.

3. Measurements with directional antennae

Measurements have been made with directional antennae of the type used in high-frequency, long-distance communication. The results have not been studied sufficiently for a full report to be made, but some preliminary information is contained in Report 322.

4. Lightning-flash counters and direction-finding networks

The object of lightning-flash counter observations, in so far as they are required for noise studies, is to determine the numbers of lightning discharges occurring per unit area of the earth's surface, in different places and at different times. Although the expansion of counter networks has proceeded rather slowly, further experience has been gained in their use, and in the comparison between the C.C.I.R. type and other types. Data from the so-called E.R.A. type, which has been used extensively, can be correlated with the C.C.I.R. type, provided that a suitable sensitivity has been used. Experiments have been made with a counter operating on the high-frequency energy from atmospherics, but no experience has yet been gained on the relationship between the results and those from C.C.I.R. counter. [5]

Experiments in England [6] and others, reported in a C.C.I.R. document from Sweden [7], have resulted in different estimates of the effective range of the C.C.I.R. counter, and further investigation is required. However, the more precise evaluation of this quantity need not delay the collection of further data which will show at least the relative values in different geographical locations.

A report to the C.C.I.R. by the Working Group on lightning flash counters [8] shows correlations between counter data and low-frequency noise levels. For example, the antenna noise-factor F_a resulting from atmospheric noise in a large equatorial storm area, is given approximately by:

$$F_a = 150 + 10 \log_{10} n \text{db} .$$

at 13 kc/s, where n is the number of discharges counted per hour with the C.C.I.R. counter There is evidence that corresponding relationships can be found for higher frequencies, when the different propagation conditions are allowed for.

Although a large volume of data from atmospherics direction finding networks exits, no reports are to hand which show how these data could be used in noise studies. The problems involved are considerable, but, since these networks are potentially capable of providing information leading to knowledge of the noise generated in oceanic areas, where adequate networks of lightning-flash counters cannot be established, early attention should be given to a study of whether the potentialities are likely to be realized in practice.

5. Intensity and nature of noise from individual discharges

Atmospherics from near storms have been recorded, in such a way that the effects of propagation can be allowed for, and an energy spectrum derived, which is effectively a characteristic of the source alone [9, 10, 11]. The spectrum has been used, in conjunction with lightning-flash counters and propagation data, to give estimates of integrated noise at certain locations. [8]) These have been compared with measured noise intensities and the agreement is sufficiently close to justify further investigation of this method of approach.

6. Methods of presenting statistical data on noise

The short-term and long-term statistical variations of noise have been studied and methods for taking them into account in assessing the interference to radio services have been proposed in Report 322.

7. Atmospheric noise in relation to other types of interference

Some results of studies of man-made interference are contained in Report 258.

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REPORT 255 *

BASIC PREDICTION INFORMATION FOR IONOSPHERIC PROPAGATION

(Study Programme 200 (VI))

(Los Angeles, 1959 — Geneva, 1963)

1. Prediction of the oblique-incidence classical MUF from vertical-incidence data

In Recommendation 373, the " classical MUF " is defined as " the highest frequency at which waves can be propagated to a given distance by ionospheric refraction alone ", while the " standard MUF " is defined as " the approximation to the classical MUF obtained by

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* This Report, which replaces Report 161, was adopted unanimously.

application of a standard transmission curve to vertical-incidence ionograms and by the use of a distance factor ". Many Administrations have prediction methods in which charts of, for example, the standard F2-zero-MUF and the standard F2-4000-MUF based on vertical-incidence data are presented. Two types of prediction errors can occur in deriving the classical MUF for a given distance from these methods. Firstly, there are errors in computing the standard charts, due to such factors as sparseness of data used in preparing them, the interpolation methods used to estimate the position in the solar cycle (i.e., the index to be used), and so forth. Secondly, there is a class of errors due to differences between the standard MUF and the classical MUF. An example of this latter type is the case where a standard MUF is predicted from vertical-incidence data taken at the mid-point of a 1-hop F2 path and this value does not agree with the classical MUF observed by oblique sounders located at the terminals of the path.

A study of errors of the first kind has been made by the C.C.I.R. Secretariat [1]. The ten prediction methods compared in this study use the two-control-point method, excepting [1 H] which uses the geometrical reflection-point method. Figs. 1 and 2 give the arithmetic mean and standard deviation of the various methods for the Paris-Tananarive path for June, sunspot number = 125 and December, sunspot number = 5. As can be deduced from these figures, different prediction methods may give widely different values of the standard MUF. Analysis showed that the mean of the absolute values of deviation about the mean of the results of the various prediction methods is about 9·7%.

In most 1-hop paths, the differences between the standard and classical MUF (errors of the second kind) will be small. Where steep horizontal ionization gradients and inhomogeneities in ionization occur in the transmission path, the difference can be large. Examples of this are given by [2, 3], where exceptionally high values of the ratio of the classical MUF to the standard MUF are attributed to non-symmetrical paths.

2. The ratio of operational MUF to standard MUF

Some information concerning the ratio of operational MUF to standard MUF has been collected during past years by the Federal Republic of Germany, the United Kingdom, Belgium, the P.R. of Poland, the U.S.S.R., the Secretariat of the C.C.I.R. and the Radio-Suisse, S.A. [1 and 4 to 8]. This information, summarized in Tables I and II, is as yet insufficient for deriving general conclusions as regards exact values of the ratio in every case. However, some tendencies can be indicated.

The ratio of the operational MUF to the standard MUF tends to be higher for night-time than for day-time conditions. For medium latitudes, the corresponding ratio in summer, for both day and night, seems to be lower than for night conditions in winter. The highest values of this ratio, for middle and high latitudes, usually occur in winter at the time of lowest standard MUF. The ratio tends to increase for circuits passing near the auroral zones.

The difference between operational MUF and standard MUF can be explained by various phenomena, such as scattering in the E and F regions, off-great circle propagation, propagation without intermediate ground reflections, etc. [9 to 16]. Since up to the present no quantitative method for evaluation of these factors has been adopted, it is proposed to calculate the values of standard MUF and to apply correction factors determined by experiments. An additional factor could be the error in the standard MUF charts.

3. Representation of ionospheric data

The main problem with ionospheric data, is to derive from records at unevenly spaced stations a continuous function of latitude, longitude and time, dispensing with artificial zone boundaries. This problem is simplified by first considering the local time as fixed. The results can readily be transformed to UT.

For those having ready access to a computer, the most convenient representation is such as to allow the ionospheric parameter concerned to be computed rapidly for any place at any time. Solutions of propagation problems may then be completed in the computer without reference to any charts.

Charts will however be found more convenient in many cases. For communications between points in low or moderate latitudes the most useful representations employ a rectangular grid, with longitude as abscissa and latitude as ordinate. The values of the parameter concerned are represented by means of contours. Separate charts are needed for a series of values of UT.

If one or both terminals are at high latitude, polar representation is more convenient. Gnomonic projection has the advantage that all great circles become straight lines.

4. The effect of ionization in the E-region

Little difficulty is encountered in introducing the effect of the regular E-layer into prediction methods. Sporadic E, however, is more of a problem. Except in the equatorial sporadic-E zone, its occurrence can be predicted only on a statistical basis. In a multi-hop path, partial or total reflection by sporadic-E can occur at several points along each ray path. Examples of the importance of including sporadic-E in predictions are given in [6]. A method which incorporates the tropical-Es layer has been described by Kift [17].

5. Introduction of propagation modes and layer tilts

Certain MUF prediction methods take modes of propagation into account explicitly, for example, the French [1.H], the German [15] and the Canadian methods [18]. These methods can be expected to give results generally lower than two-control-point methods in some paths compared by the C.C.I.R. Secretariat, but it is not certain that they refer to the same conditions. Recent work in the United Kingdom [17] suggests that a usable frequency range should be computed for each active mode rather than a single range between an electron-limited MUF and an absorption-limited LUF.

Prediction methods cannot yet treat the case where ionization and layer tilts cause the angle of arrival to differ from the angle of departure. Ray trajectories for such situations have been computed.

6. Effect of working conditions

The ratio of operational MUF to standard MUF largely depends on the type of service and the effective radiated power. The required minimum field strength seems to be the main factor in determining this ratio [9 to 16]. Generally, the most exacting type of service is associated with the lowest values of this ratio. For some circuits, the method of calculation of the standard MUF by the two-control-point method gives values of standard MUF closer to the operational MUF than the method using every reflection point.

Fig. 3 shows an example of curves of operational MUF and LUF calculated from measurements of WWV frequencies [8]. There are four levels of receiver input corresponding to an intensity range of 60 db, each reduced for an 1 kW e.r.p.. It is suggested that the 0 db curve corresponds to classes of service such as A1 and the +20 db curve (+40 db in winter at night) to services such as A7A and F6 with time-division multiplex.

7. Transmission by propagation off the great-circle path

Some information and references are given in Report 249.

8. Anticipated day-to-day spread in MUF

From independent analyses, it is apparent that the ten percentile of the MUF dispersion is close to 0·85 of the mean standard MUF (i.e. the present FOT). It appears that this value is dependent on various factors, including seasonal and solar effects, and varies between approximately 0·72 and 0·90.

Typical day-to-day spreads in operational MUF have been measured [8], for many conditions (solar activity, season and time of day), e.g. Fig. 4. The lower decile of the operational MUF, i.e. for 90% security, is the FOT, according to the classical definition, but it is found that this does not give the highest receiver input. It appears that the classical definition of FOT applied to operational MUF does not give the optimum frequency for traffic: this is actually midway between the median operational MUF and LUF.

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TABLE I

MINIMUM RATIO OF OPERATIONAL MUF TO STANDARD MUF *

No.	Winter				Summer				Remarks
	06–09 *	09–15	15–18	18–06	03–06	06–18	18–21	21–03	
1		1·10 1·15 1·30 1·20 1·18		1·13 1·14 1·45 1·30 1·40					Comparison was made with standard MUF from actual ionosonde data
2	1·00–1·42	1·10	1·00	1·24–1·76	1·19–1·21	1·19–1 28	1·05	1·05–1·24	
3	1·15 1·07 1·00	1·07 1·07 1·25	1·15 1·15 1·07	1·00 1·20 1·09 0·94 1·20 1·09 0·92 1·10 0·99 1·00 0·94	1·00 1·15 1·07	1·15 1·07 1·07	1·00 1·00 1·00	1·04 1·04 1·00 0·98 1·01 0·97 0·98 0·98 0·92 0·81 0·92	Prediction corrected for measured sunspot number
4			1·28 1·14	1·56–1·81 1·14–1·66	1·11 1·00–1·22	0·96–1·17 0·86–1·10	1·00–1·15 1·00–1·08	1·14–1·22 0·96–1·24	Comparison was made with predicted values of standard MUF (see Table II)
5	1·00–1.55 1·36–2.23 1·37	1·00 1·06	0·88–1·20 1·00–1·30	0·90–1·30 1·30–1·55 1·00–1·28 1·35–1·38					
6	1·58 1·39	1·11 0·95	1·31 1·08	1·48 1·40	1·45 1·06	1·16 1·03	1·12 1·04	1·23 1·07	

* The times referred to are the local times at the mid-point of the paths.

TABLE II

DETAILS OF ORIGIN OF DATA IN TABLE I

No.	Doc. (Geneva, 1962)	Country or organization	Circuit	Sunspot number	Type of service	Power class ERP (kW)	Method of calculation for standard MUF and maps used
1	VI/23	F.R. of Germany	New York-Frankfurt	125 125 100	MUX Teleprinter Morse	100–150 100–150 100–150	Reflection points, Es not considered, Rawer's interpolation method [19]
			Lima-Hamburg Osaka-Hamburg	125 125	Teleprinter MUX	100–150 100–150	
2	VI/63	United Kingdom	North Atlantic	150	Broadcasting	Not indica.	Control points; measurements, Es not considered
3	VI/65	Belgium	Washington-Brussels	10 75 150	Standard frequency (WWV)		Control points; ORPL zone maps [1. I], Es considered
			New-York-Brussels	10 75 150	FSK Teleprinter	100–150	
				10 75 150	FSK-TDM-MUX 4 channels	100–150	
				10 75 150	FSK-FDM-Telegr., 4-channel TOR	100–150 p.e.p.	
4	VI/71	P.R. of Poland	Washington-Warsaw	125 100	Standard frequency (WWV)	Not indicated	Control points; CRPL zone maps [1. I] Es not considered
5	VI/92	C.C.I.R.	Bern-Buenos Aires Bern-Washington Frankfurt-Melbourne Geneva-Tokyo	40 40 40 40	Not indicated	100 100 Not indicated	Control points; CRPL zone maps [1. I] Es not considered
6	198 (Geneva, 1963)	Radio-Suisse, S.A.	Washington-Geneva	5 104-127	Standard frequency (WWV)		Control points; CRPL zone maps [1. I] for summer R = 104–127, otherwise UT charts [1. E, 1. F]

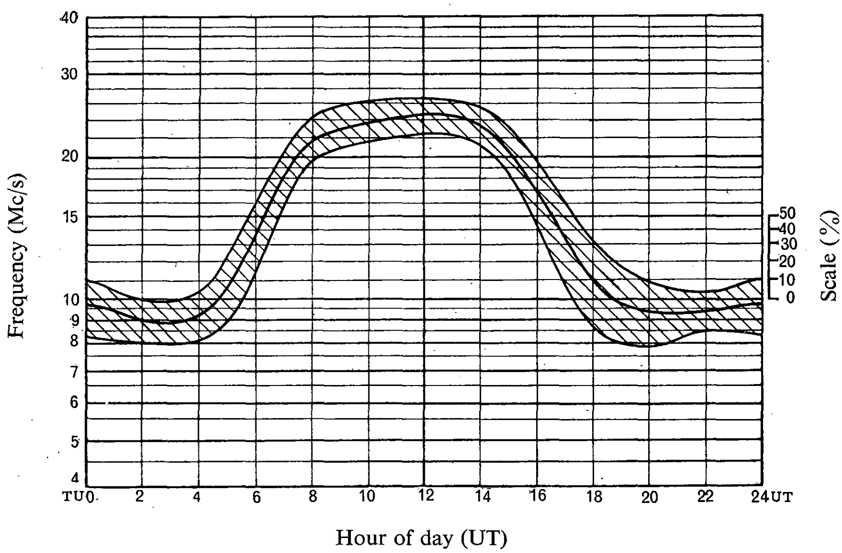


FIGURE 1

Path: Paris-Tananarive; Month: December; Sunspot number: 5

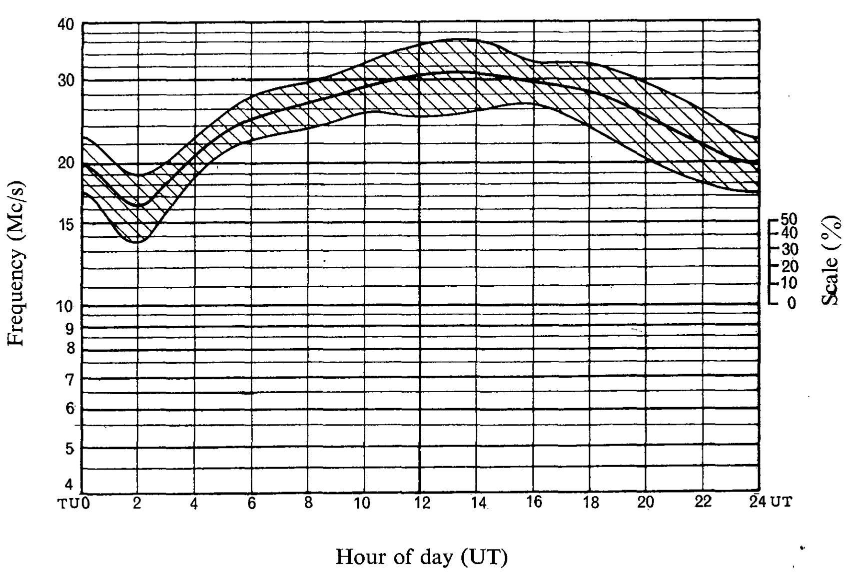
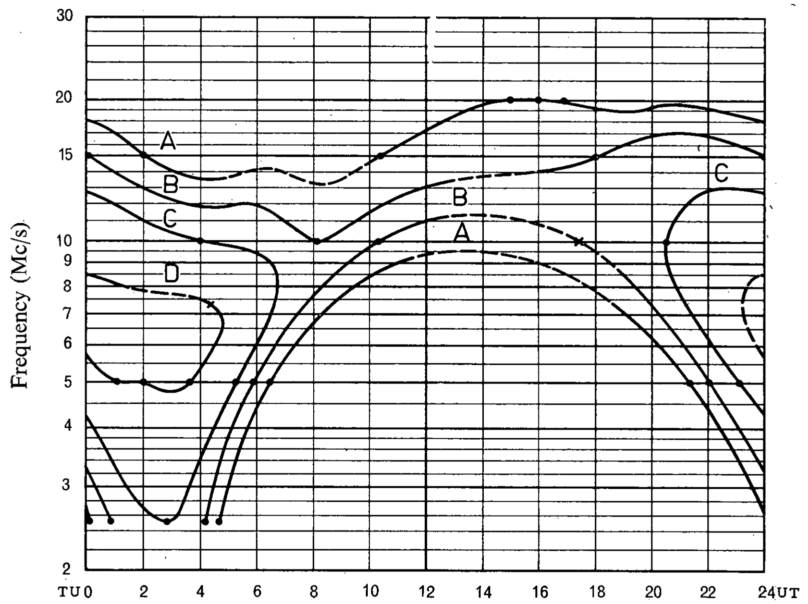


FIGURE 2

Path: Paris-Tananarive; Month: June; Sunspot number: 125



Hour of day (UT)

FIGURE 3

Intensity contours for the operational median (50%) MUF+LUF and median for:
Path: Beltsville (Washington)—Chatonnaye (Berne); Distance: 6650 km; Month: July; Year: 1954; Sunspot number R_{12}: 5

Taken from recordings of WWV at 2·5, 5, 10, 15, 20 and 25 Mc/s of the input to the receiver (μV) with the transmitter power reduced to 1 kW. Transmitting antenna: non-directional.

Curve A: 0·1 μV (0 db)
B: 1 μV (+20 db)
C: 10 μV (+40 db)
D: 100 μV (+60 db)

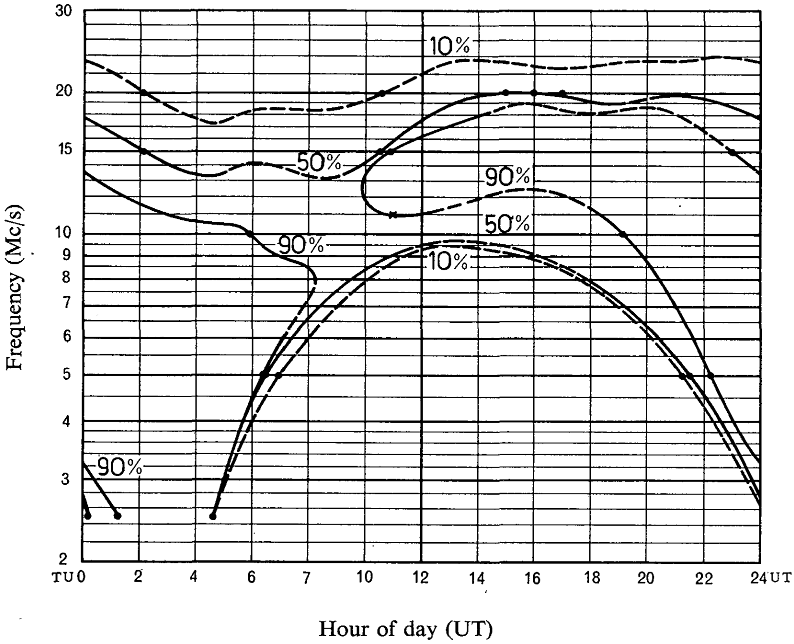


FIGURE 4

Upper decile (10%), median (50%) and lower decile (90%) values of the operational MUF + LUF for the Path: Beltsville (Washington)—Chatonnaye (Berne); Distance 6550 km; Month: July; Year: 19ç4 Sunspot number R_{12}: 5

Taken from recordings of WWV at 2·5, 5,10, 15, 20 and 25 Mc/s for a minimum input of 0·1μV to the receiver, with the transmitter power reduced to 1 kW. Transmitting antenna: non-directional; receiving antena: directional.

REPORT 256 *

MEANING OF MUF

(Recommendation 373)

(Geneva, 1963)

The definitions of the three terms given in Recommendation 373 are an attempt to differentiate clearly between the most common usages of the general term MUF. This Report is intended to anticipate most of the questions which users may put.

1. *The operational MUF* is determined by circuit operation itself under conditions which are thereby specified precisely without auxiliary experiments. Working conditions should be stated as precisely as possible when referring to operational MUF. All pertinent details of the actual system should be given, including power output, class of emission and information rate.

For many systems, the effective limit of operation depends on the ambient noise level and can frequently be identified with a minimum required field-strength (or maximum transmission loss). In these cases, the operational MUF is the highest frequency at which the incident field-strength reaches this limiting value.

It concerns propagation in the real ionosphere, in which irregularities in ionization, scattering, and partial reflection at steep gradients of ionization-density frequently occur. It commonly refers to propagation by whatever mechanism, layer or mode, gives the highest permissible frequency.

Particular system limitations (for example when high fading-rates cannot be tolerated), could make the operational MUF less than the classical MUF, but in practice, in most applications, the operational MUF is found to be equal to, or higher than, the classical MUF.

2. The intention of the *classical* theory of *MUF* was originally to determine a limiting frequency as a function of distance, or more simply of angle of elevation at departure, such that higher frequencies would penetrate the ionosphere and escape into space, while lower frequencies would be reflected back to the earth.

The classical MUF is independent of power and is calculable, in principle, by ray optics in the presence of the magnetic field of the earth. It is also measurable by oblique-incidence pulse transmissions where calculations are too difficult. It refers to the frequency at which the upper and lower refraction traces are seen to merge on the ionogram. However, account is not taken of the nose extension when observed on the ionosonde records, since neither its cause nor its effect are as yet known. The lower ray gives an apparent reflection over a small area. The upper (Pedersen) ray follows closely the level of maximum density and may, under certain conditions, reach to extraordinary distances, up to 7000 km, in a single hop. Those cases where the lower ray is cut off by the earth's curvature could be designated as " classical Pedersen ray MUF ".

Effects due to small ionization irregularities (such as are observed as " spread-F " or " spread-E " in ionograms), scattering and partial reflections are not considered in the deter-

* This Report was adopted unanimously.

mination of the classical MUF. However, larger scale irregularities (commonly referred to as " layer tilts ") and the anisotropy caused by magneto-ionic double-refraction are included. Therefore the ray path which determines the classical MUF is not necessarily along the great circle.

3. *The standard MUF* is a standard analytical approximation to the classical MUF. It is found by combining numerical data obtained from soundings with a simplified analytical solution of the oblique-incidence refraction problem. The basic ionospheric parameters used generally for the F2-layer are foF2 and M(3000)F2. The latter factor is found by applying a transmission curve for 3000 km (defined by convention) to the ionogram. This curve takes partial account of the curvature of the ionosphere, but not of the magneto-ionic double refraction. The transformation to distances other than 3000 km is then made by applying standard distance factors. Both procedures are based on particular assumptions concerning the vertical profile of electron density. Thus, the number of the parameters taken into account at the experimental determination of the classical MUF is considerably reduced.

The most valuable result obtained is, that if the earth's magnetic field is neglected, the path of a ray in a horizontally-stratified, ionized medium above a flat earth, at any frequency, can be related element by element to that of a vertically incident ray at a frequency equal to the product of the frequency of the oblique ray and the cosine of the angle of departure of the oblique ray (measured from the vertical). This result, modified by an approximate correction for the earth's magnetic field and for the curvature of the earth, is the basis of the standard transmission curve.

The main approximations made are:

— the assumption that the percentage change in refractive index (a function of electron density) in a distance of a wavelength is very small;

— the full effect of the magnetic field of the earth is not completely taken into account. In particular the lateral separation of ordinary and extraordinary rays, in combination with the earth's curvature, *prevents* propagation rigorously along a great-circle path, except along a magnetic meridian. Furthermore, the doubly refracting properties of the medium lead to coupled propagation of two rays wherever two of the four vector propagation constants are approximately equal, and the theory of this phenomenon is as yet incomplete;

— the net deviation of a ray by underlying layers of the ionosphere is frequently ignored;

— the curvature of the ionosphere introduces difficulties as yet incompletely resolved;

— the effect of collisions between electrons and ions and neutral particles on the propagation path is usually ignored. However, it becomes of paramount importance, under conditions of coupled propagation as described in the second point of this list of approximations;

— the nature and effects of tilts are incompletely understood, and their consideration is often omitted.

A consequence of the first of these is that ionospheric scattering is omitted. The same is true for ground scattering. Some particular types of ray propagation are omitted, such as the Pedersen ray (see § 2).

Some of the above approximations tend to result in a calculated MUF less than the classical MUF, and in most cases less than the operational MUF observed.

The MUF calculated from foF2 and M (3000) F2 is always standard.

4. *The control-point method* was instituted to simplify calculations and to take empirical account of some of the discrepancy between the operational MUF and that calculated formerly for long transmission paths. Oblique pulse experiments have since shown that there is no

physical basis for this method and that consideration of the several possible modes of propagation is more accurate. Some Administrations feel, however, that for the particular case of high-power circuits, the control-point method can be used to give a rough approximation to an operational MUF.

REPORT 257 *

QUESTIONS SUBMITTED BY THE I.F.R.B.

(London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

1. Although the C.C.I.R. is still not in a position to supply full answers to the three questions contained in the Annex below, progress has been made since the IXth Plenary Assembly and some positive measures have been taken, with a view to obtaining information on which answers may eventually be based.

2. Study Programme 200 (VI) and its related Report 255 make clear the reasons why Question (*a*) below cannot, at present, be answered fully. Problems regarding methods of presentation and interpolation, for instance, indicate that there are many problems involved in the production of MUF predictions.

However, Resolution 10 calls for the establishment of an International Working Party to prepare a provisional atlas representing world-wide ionospheric characteristics, including the MUF. The terms of reference of this Working Party concern the standard MUF**, but it should be recognized that it is the operational MUF for the service concerned that is needed for the revision of the master FOT curves mentioned in Question (*a*). Report 255 includes some suggestions, and gives, in its Annex, some preliminary values of operational MUF which could be useful for estimating possible interference.

It may be noted that, to the extent that the operational MUF depends upon a minimum required field-strength (or maximum allowable transmission loss), the answer to Question (*a*) depends upon the answer to Question (*b*) below. Resolution 11 asks that interested Administrations make available operational data on fade-in and fade-out times. Such data will be useful for determining factors relating the operational MUF to the classical or to the standard MUF.

3. As regards Question (*b*), the Working Party referred to in Resolution 48, has been carrying out its tasks, and has reported periodically to the Chairman of Study Group VI. Report 252 is the most recent Report reflecting the present state of progress in this respect. It now appears from the theoretical and experimental data for temperate latitudes, so far available, that the methods of prediction contained in Report RPU-9 and in Doc. 744 (U.S.S.R.) of Warsaw, 1956, as a general rule provide values of field strength which are lower and closer to the measured values than those obtained by the methods of Circular 462. Resolution 7 and Report 253 are designed to continue the work of the Working Party and to provide it with adequate material. Study Programme 198(VI) is also important in this connection. An Administrative Circular AC/57, dated 9 March, 1962, has been issued by the Director, C.C.I.R., inviting Administrations to participate in the campaign of field-strength measure-

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* This Report, which replaces Report 150, was adopted unanimously.
** See Recommendation 373 and Report 256 for definitions and discussion of MUF terminology.

ments set up by the Working Party. Report 253 gives further details, regarding the appropriate measurement techniques.

4. As regards Question (*c*), which is covered by Study Programme 206(VI), Report 264 is considered to contain information superseding that on which the Cairo curves were based.

ANNEX

QUESTIONS SUBMITTED BY THE I.F.R.B.

Ionospheric propagation

*Question (*a*)*

What modification, if any, should be made to the master FOT curves used by the Mexico City High-Frequency Broadcasting Conference, to take account of experience acquired in subsequent years?

*Question (*b*)*

What is the best method of calculating the field-strength produced by a transmitter working on frequencies above 1500 kc/s by means of ionospheric propagation (distances up to 25 000 km)?

*Question (*c*)*

What modification, if any, should be made to the C.C.I.R. long and medium-wave propagation curves adopted at Cairo in 1938? In particular, they appear to need extension:

(i) as a function of magnetic latitude;

(ii) as a function of season;

(iii) as a function of solar activity.

Note: In revising and extending these curves, attention should be paid to distances less than 500 km (to allow, for example, for the evaluation of the effect of special vertical transmitting antennae designed to reduce fading in the outer part of the service area) and to distances beyond 2000 km (to allow for the evaluation of interference between regions).

REPORT 258 *

MEASUREMENT OF MAN-MADE RADIO-NOISE

(Study Programme 153)

(Geneva, 1963)

Radio-noise of man-made origin is often the basic limitation to radio reception, particularly in urban areas. It may be of importance even at isolated receiving locations at certain times of day and frequencies. Although many studies have been made of the radio-frequency interference, resulting from individual nearby sources, very few measurements have been made, at greater distances, of the composite man-made noise resulting from many sources. Furthermore, the

* This Report was adopted unanimously.

measurements on individual sources have been made using quasi-peak meters, and the results are difficult to compare with the atmospheric noise-power values contained in Report 322.

To alleviate somewhat this problem, measurements of noise power from the world-wide network sponsored by the U.S. National Bureau of Standards have been analyzed in such a way as to isolate the man-made noise values. This was done by selecting periods of time when atmospheric levels were low. The times selected were in the range 0800–1200 hrs local time during the winter when the predominance of man-made noise was evident at most stations both from aural monitoring and the known behaviour of both types of noise with frequency.

It first became evident and, has since been confirmed at most stations, that man-made noise decreases with increase in frequency at a rate of approximately 28 db for each decade of frequency.

A completely generalized prediction of man-made noise levels throughout the world would require a detailed study of the dependence of these levels on a large number of parameters, many of which are not known. However, using data from the NBS network, certain facts have been deduced.

For purposes of comparison with Report 322, measured values have been normalized to 1 Mc/s. The normalized values of F_{am} * attributed to man-made sources were found to vary, from station-to-station, over the range 43 to 55 db with a median value of 49 db. This median value is 5 db below that given in Report 65, but it is probable that the noise measuring stations are, on the whole, more free from man-made interference than an average commercial receiving station. A more detailed examination confirmed the expectation that higher levels would be measured at stations located closer to populated areas.

REPORT 259 **

LONG-DISTANCE PROPAGATION OF WAVES AT 30 TO 300 Mc/s BY WAY OF IONIZATION BY THE E-AND F-REGIONS OF THE IONOSPHERE

(Study Programme 195 (VI))

(Geneva, 1951 — London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

1. Review of propagation by regular ionization

1.1 *E-layer*

A study of regularly made vertical-incidence measurements indicates, that it is unlikely that transmission of waves of 30 to 300 Mc/s would ever occur by way of the regular E-layer.

1.2 *Fl-layer*

A study of the vertical-incidence measurements indicates, that it is unlikely that transmission of waves of 30 to 300 Mc/s would ever occur by way of the regular Fl-layer, except near noon at maximum solar activity in tropical regions only. Since the F2-layer MUF

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* Expressed in db above thermal noise at 288° K (See Report 322).

** This Report, which replaces Report 149, was adopted unanimously.

values would, under the same conditions, exceed those for the F1-layer, this fact is of little importance. The F1-layer may have an effect on the skip distance of radio waves passing through it and then reflected by the F2-layer.

1.3 *F2-layer*

A study has been made of the vertical-incidence measurements for a number of widely distributed ionospheric stations and, in addition, a considerable amount of observational evidence has been collected from actual transmissions. The data indicate that, during certain seasons of the year at the peak of the sunspot cycle, long-distance transmission by way of the regular F2-layer ionization can occur for a significant fraction of the time in temperate latitudes on waves of up to about 50 Mc/s. In the low latitudes (between geomagnetic latitudes, 20° N and 20° S), however, such transmission can occur on waves of up to 60 Mc/s, with almost regular transmission on waves of 30 to 40 Mc/s.

It is clear that, for several years around the solar maximum, intolerable long-range interference may be expected in temperate latitudes on frequencies up to about 50 Mc/s during daylight hours in the equinox and winter seasons. Similarly, for low-latitude stations, particularly in the Far East, intolerable long-range interference may be expected up to about 60 Mc/s. The lowest frequency at which such interference becomes so infrequent as to be negligible is about 60 Mc/s, for stations in temperate latitudes, and about 70 Mc/s for stations at low latitudes. During the sunspot cycle with maximum in 1957-58 even higher frequencies were observed than for the previous maximum. However, sunspot activity during the 1957–58 maximum was the highest which has been observed since the commencement of reliable records in 1749, and this should be borne in mind when anticipating future sunspot activity. Charts of expected F2-layer interference for 1% and 10% of the time are found in Report 109.

World-wide predictions of F2-layer MUF are given in monthly charts published by the C.R.P.L. in the U.S.A., by the D.S.I.R. in the United Kingdom, by C.N.E.T. in France and by other authorities.

2. Propagation by anomalous ionization

2.1 *Sporadic-E ionization*

Because of the nature, transmission by sporadic-E is ordinarily confined to a single hop and is thus limited to a maximum distance of about 2300 km. Since, in the most intense form of sporadic-E ionization, the skip distance, say for 50 Mc/s, is about 650 km, the transmission range is, in practice, restricted to distances between 650 and 2300 km.

Sporadic-E occurs in different forms in different latitudes and it is useful to study sporadic-E in terms of latitude zones. The major zones are the North and South Auroral Zones, the North and South Temperate Zones and the Equatorial Zone. The Auroral and Temperate Zones can be roughly separated by the 15% auroral isochasm (approximate geomagnetic latitude 60° N and 60° S), whereas the demarcation line between the Equatorial Zone and the North and South Temperate Zone may be taken as the $\pm$ 7° isocline of magnetic dip. In the Auroral Zones, sporadic-E is largely a night-time phenomenon without pronounced seasonal variation. In the Temperate Zones, sporadic-E concentrates strongly in the summer months and occurs most frequently between 0600 and midnight, local time, with a broad daytime maximum and frequently a secondary peak between 1700 and 2200 hours. This type is very often opaque in daytime, but more transparent at night. The type of sporadic-E peculiar to the Equatorial Zone is nearly transparent, and is a very regular, and a strictly daytime phenomenon with high maximum frequency.

There is also considerable variation in sporadic-E within a given zone. In the North Temperate Zone, for instance, sporadic-E appears to occur several times as frequently in the region around Japan as compared with the United States for the same magnetic latitude (as observed at oblique incidence at 50 Mc/s.) In addition, in the low latitude areas of the Temperate Zone, sporadic-E seems to occur more frequently than in the high latitude areas. Work is in progress, for example, in Japan, on the prediction of oblique-incidence field strength of sporadic-E reflections with regard to temporal distribution and frequency dependence in these zones.

In terms of Γ, the excess loss over free-space, three mechanisms may be roughly distinguished by the following levels:

$\Gamma \leqslant 45$ db specular reflections from sporadic-E (appears like a layer reflection);

45 db $< \Gamma <$ 70 db scattered reflections from sporadic-E;

$\Gamma >$ 70 db sporadic-E masked by normal D-scatter.

For oblique-incidence paths, particularly with wide-beam antennae, the incidence of sporadic-E as predicted for the mid-point of the path may be somewhat increased by off-path reflections.

The predicted world distribution of sporadic-E has been indicated in world charts published by C.R.P.L. in the U.S.A., by D.S.I.R. in the United Kingdom, C.N.E.T. in France and by other authorities.

2.2 *Meteoric ionization*

Studies have been made in Canada, the Federal Republic of Germany, the United Kingdom, the United States and elsewhere, of the reflections which occur from meteor trails. Report 251 gives a bibliography on this subject. The matter of meteor-burst communication is dealt with separately in Study Programme 196 (VI).

2.3 *Ionization of other kinds*

The studies indicate that there may, at times, occur bodies of ionization at virtual heights different from those of any of the recognized ionospheric layers. Such ionization patches may occasionally give rise to reflections of waves in the 30 to 300 Mc/s range, the principal case being that of reflection from the edges or sides of magnetic-field aligned patches which occur within or near the Auroral Zone. Such reflections may constitute a source of interference to stations working on waves in the 30 to 300 Mc/s range.

Reflections have been observed via the F-region, at frequencies appreciably above the F2-MUF but at intensity levels well below free-space. These reflections have been observed in the Far East, in South America and in Africa and appear to be a phenomenon of high sunspot years. The equinoctial months appear to be favoured.

2.4 *Trans-equatorial propagation*

Recent studies indicate that strong transmissions can occur, particularly during high sunspot years, over long North-South paths spanning the magnetic equator. Most observations have been made by radio amateurs at a frequency of 50 Mc/s for paths of the order of 4000-9000 km; paths between South America — North America, Africa — Europe, and Japan — Australia have been noted.

3. **Table of the main causes of interference to stations working at frequencies between 30 to 300 Mc/s**

Cause of interference	Latitude Zone	Period of severe interference	Approximate highest frequency with severe interference (Mc/s)	Approximate frequency above which interference is negligible (Mc/s)	Approximate range of distances affected (km)
Regular F-layer reflections	Temperate	Day, equinox-winter solar cycle maximum	50	60	E-W paths 3000–6000 or N-S paths 3000–10000
	Low	Afternoon to late evening, solar cycle maximum	60	70	
Sporadic-E reflections	Auroral	Night	70	90	500–2000
	Temperate	Day and evening Summer	60	90	
	Equatorial	Day	60	90	
Sporadic-E scatter	Low	Evening through midnight	60	90	Up to 2000
Reflections from meteoric ionization	All	Particularly during showers	May be important anywhere in the range		Up to 2000
Reflections from magnetic field aligned columns of auroral ionization	Auroral	Late afternoon and night			
Scattering in the F-region	Low	Evening through midnight, equinox	60	80	1000–4000
Special trans-equatorial effects	Low	Evening through midnight	60	80	4000–9000

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REPORT 260 *

IONOSPHERIC-SCATTER PROPAGATION

(Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

1. Introduction

Considerable experience has been gained since the first high-speed communication circuits employing ionospheric-scatter propagation came into regular service in 1953. The circuits already operating during the low sunspot minimum of 1954 above latitude 40°N in the U.S.A. have now been supplemented by operational and experimental links which

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* This Report, which replaces Report 158, was adopted unanimously.

extend the range of observation from the tropics to the Arctic and through a period of solar activity with an unprecedently high maximum (1957–1958).

New terminal equipment has been developed to include, for instance, advances in modulation techniques and in antenna design, and considerable attention has been given to the problem of reliability. Many important features of ionospheric-scatter propagation are now better understood, including the scattering of power away from the receiving antenna by aspect-sensitive meteoric ionization. In the following sections, a series of topics is discussed in the light of recent experience.

2. Geographic distribution of signal intensity

The records show that, without regard to path orientations and the scattering mechanisms, the signal intensities are high, both in a region within about 20° of the magnetic pole, and in the region of the magnetic equator, but that there is a fairly deep minimum at about 20° to 30° from the magnetic equator. In this trough, it appears that for a large fraction of the time, the received signals are those that have been scattered from meteoric ionization. The location of this minimum has been fixed most accurately in the central Pacific Ocean region north of the equator, but it may be assumed that its geographic latitude will be a function of longitude. There is evidence in all latitudes, that certain types of ionospheric irregularities are aligned with the direction of the earth's magnetic field.

3. Influence of the solar cycle

A long-term variation in signal intensity related to the solar cycle would be expected and there is some evidence of it during the daytime. In high latitudes, it appears to show a lag with respect to the sunspot cycle, which suggests a dependence on magnetic disturbance. At times of high solar and magnetic activity, daytime median-signal intensities are higher by several decibels than during the minimum of the solar cycle. The differences are not constant, but vary with the path, time of day and season. The weaker signal intensities seem to be less dependent on solar activity, in accordance with the suggestion that they are representative of conditions when meteoric ionization plays a relatively important part in the scattering process.

In middle latitudes the results are similar, though the effects of magnetic disturbances are less noticeable. The solar cycle dependence is far from simple to evaluate quantitatively, since it is complicated in high latitudes, for example, by the effect of absorption which tends to reduce signal intensities selectively at times of high solar and geomagnetic activity. Moreover, its true nature may well be obscured by long-term variations in meteoric ionization unrelated to the solar cycle.

4. Influence of magnetic activity

While extensive analyses of the influence of magnetic activity have been based on the planetary magnetic K-index, other indices, such as the local magnetic indices and the occurrence of blackouts in high latitude ionograms, have also been used. It is important to recognize that the K-index provides a fair measure of solar corpuscular radiation. In high latitudes, for frequencies in the 40 to 50 Mc/s range, it is well established that high K-indices are accompanied by abnormally high signal intensities. For somewhat lower frequencies, the relationship is less clear, because of the increased importance of ionospheric absorption at times of high magnetic activity. In middle latitudes, the relationship is much less striking, as might be expected, since solar corpuscular radiation seldom penetrates to such latitudes.

5. Equatorial ionospheric-scatter

It has been suggested, that the phenomenon of equatorials poradic-E (q — type sporadic-E), could be associated with the equatorial electrojet. At Huancayo, Peru, near the magnetic equator, it has been established by pulse-delay measurements, made simultaneously at vertical and oblique incidence, that there is a detailed correlation in the daytime between local variations of the horizontal component of the earth's magnetic field and the intensity of signals scattered from the part of the lower ionosphere vertically above the magnetic observatory. The scattering sources lie between the heights of 100 and 110 km within which the electrojet occurs. It thus appears, that the structure of the electrojet, especially with regard to the range of latitude over which it extends and the variations in time and space of the irregularities within it, may be studied by radio techniques.

6. F-region scatter

Recent experience in sub-equatorial regions in the central and western areas in the Pacific Ocean has shown, that at times, there is scattering from the F-region of the ionosphere. Although it was felt that this phenomenon might cause trouble, it has in fact raised no serious difficulties in the operation of conventional ionospheric communication links employing E-region scattering. The geographical limits of F-region scattering have not been clearly established, but it has been observed many hundreds of kilometres from the equator.

7. Useful range of frequencies

It is now usually accepted that the useful range of frequencies for communication by the ionospheric-scatter mode of propagation extends from about 30 to 60 Mc/s at the lower end of the VHF band (band 8). The lower limit is set by the increasing ionospheric absorption associated with decreasing frequency during SID and polar cap events and also by the desirability of avoiding interference from signals propagated by reflection between the earth and the F2-layer.

At times, when the circuit is operating on the scatter mode, interference may be caused by transmitters from other directions where the propagation of the F-layer mode is possible. Although mutual interference between the scatter circuit and other circuits may sometimes be mitigated by the use of highly directional antennae, this type of interference can only be satisfactorily avoided by careful planning in the allocation of frequencies.

There is, however, the possibility of self-interference by energy scattered back from the ground and propagated by the F2-reflection mode, especially when this mode is not possible over the direct path between the transmitter and receiver. This situation, in fact, arose at the time of high solar activity and initially, proved troublesome. However, special modulation techniques have now been developed, which have reduced the effects of back-scattering so largely, that it is no longer a source of difficulty for telegraphic communication.

The fundamental limitation to the use of lower frequencies is thus the increasing absorption. At high latitudes, extreme absorption during times of polar-cap absorption can render the circuit unusable for a rapidly increasing fraction of the time, as the operating frequency is decreased. The absorption can be fairly serious for a significant fraction of the time, even in the 30 to 40 Mc/s range, at times of high solar activity, if extreme reliability of operation is sought.

The upper limit of frequency is set mainly by economic considerations. Since, as a rough guide, the signal intensities may be taken as varying inversely as the seventh power of the frequency, for scaled antennae with equal input power, while the cosmic noise intensities vary inversely as about the 2·5 power of the frequency, the signal-to-noise ratio varies inversely as approximately the 4·5 power of the frequency. Thus, at 60 Mc/s it would be about $4 \cdot 5(10 \log_{10} 60/30)$, or 13·5 db less than at 30 Mc/s. Actually, a receiving antenna for 60 Mc/s of the same aperture as for one at 30 Mc/s, based on current practice, would be too directional and would therefore not realize much of the added plane-wave gain relative to a scaled antenna. Even if the figure of 13·5 db should over-estimate the reduction in signal-to-noise ratio by several decibels, which seems unlikely, it will be seen that with further increases in operating frequency the already high costs, if not prohibitive, would render the system less able to compete with the other means of communication available at these higher frequencies.

8. Choice of operating frequencies

The above consideration of the factors which decide the useful range of frequencies suggests that the choice of frequencies for given ionospheric-scatter circuits, may be grouped under three categories of service:

8.1 *Single-frequency circuits in the low part of the range (say 30 to 45 Mc/s)*

Such circuits would be suitable in temperate latitudes for providing reliable telegraph and facsimile services when special antennae and modulation techniques are used to suppress the self-interference from back-scattered multi-path echoes. For amplitude-modulated speech, such provisions are not necessary, as the intelligibility is not seriously affected by this form of interference.

Continuous single-frequency operation, of course, implies the possibility of long range interference by F2-layer propagation, as with HF circuits, and also by sporadic-E reflections. To avoid this latter type of interference, ionospheric-scatter circuits should have their transmitting and receiving terminals separated geographically by at least 2300 km from other circuits capable of causing such interference.

As a rough guide to the probability of interference by F2-layer propagation, Figs. 1, 2 and 3 show contour maps of the maximum frequencies reflected by the F2-layer, which are exceeded for 1% of the time during the December solstice, June solstice and Equinox periods respectively, at sunspot maximum. A circle of radius 2000 km centred on the receiving antenna of an ionospheric-scatter circuit gives the frequencies for which interfering signals can arrive from various directions over a 4000 km path for 1% of the time. The percentage of time is smaller for paths longer or shorter than 4000 km.

8.2 *Single-frequency circuits above 45 Mc/s*

These circuits would be used for services requiring the highest reliability, and which can be of limited channel-capacity or are designed for the high power necessary for greater channel capacity. They have the advantage that the antennae and modulation techniques used can be simpler than those for single-frequency working below 45 Mc/s.

8.3 *Two-frequency circuits*

Particular interest is being taken in two-frequency operation, using one frequency in the 30 to 45 Mc/s range and the other between 45 and 60 Mc/s. This category would contain services requiring the highest obtainable reliability, which are designed for the minimum power needed for normal operation at the lower frequency, but which can work at the higher frequency on greater power, or with reduced transmission capacity, if it is necessary to assure continuity of service through occasional periods of intense absorption, or of interference by long-range F2-layer propagation at the lower frequency.

The need for the higher frequency will be greatest at times of high solar activity, but it would be available at all times, ready to take over from the lower frequency at the onset of difficult conditions. The actual choice of frequencies in the two ranges will depend on geographical location.

9. Modulation techniques and automatic error-correction

Apart from the modulation techniques designed to overcome the effects of self-interference from back-scattering, special frequency-modulation techniques for telegraphy have been adopted to combat the Doppler effects associated with reflections from meteoric ionization. These use time-division rather than frequency-division multiplex, and 16-channel systems of 60 to 100 words per minute are coming into use. Ionospheric-scatter circuits are not economically capable of providing sufficient bandwidth for extensive voice transmission and are not likely to be used for more than one or two speech channels.

Automatic error-correction techniques, which are particularly effective when the natural character error rate is moderately high, can be made highly efficient when applied to telegraph traffic passed over an ionospheric-scatter circuit.

10. Antenna design

The problems of antenna design centre round the need to obtain, for a given available input power to the transmitting antenna, the maximum protection at the receiving antenna against harmful interference from multipath signal components and, to a more limited degree, from other transmitters; and to achieve the best possible signal-to-noise ratio, in view of the inherently high transmission loss associated with ionospheric-scatter propagation.

Large rhombic antennae, which were much used in the original installations, are now disappearing in favour of more compact arrays of less gain and greater beamwidth, but with higher back-to-front ratios. Under conditions of low signal intensity, space-diversity reception is useful. Work in progress in Japan suggests, that with a spacing of 26 wavelengths, the correlation between the signals on the two antennae is small and that by always selecting the stronger of the two signals by a switching device, an improvement of 5 db in the signal-to-noise ratio can be obtained at low signal levels.

11. Effects of meteors

While at present, it is still usual to direct the antennae of an ionospheric, scatter circuit in the great-circle plane to favour the reception of signals scattered from near the mid-point of the path, it is by no means certain that this will continue to be good engineering practice. The importance of scattering from aspect-sensitive meteoric ionization, which is most effective in regions of the ionosphere displaced transversely from the great-circle plane, is now recognized.

The effectiveness of such ionization as a scattering source varies greatly with the time of day, season, meteoric activity, and with path position, length and orientation. By using antennae which take advantage of scattering from meteoric ionization in regions of the ionosphere, other than above the mid-point of the path, the signal-to-noise ratios obtainable can, at certain times, be significantly increased. Such increases may be of particular importance in improving the usability of a circuit at seasons and times of day when the lowest signal-to-noise ratios for scattering from the mid-point region occur.

12. Reliability of ionospheric-scatter circuits

In conclusion, it may be stated that although much remains to be discovered about the mechanism of ionospheric scattering, the technique of communication by the scatter mode has so far progressed that the problems affecting the reliability of the services lie, not in the changing propagation conditions, but in the electrical, mechanical, electronic and human factors that enter into the running and the maintenance of the circuits.

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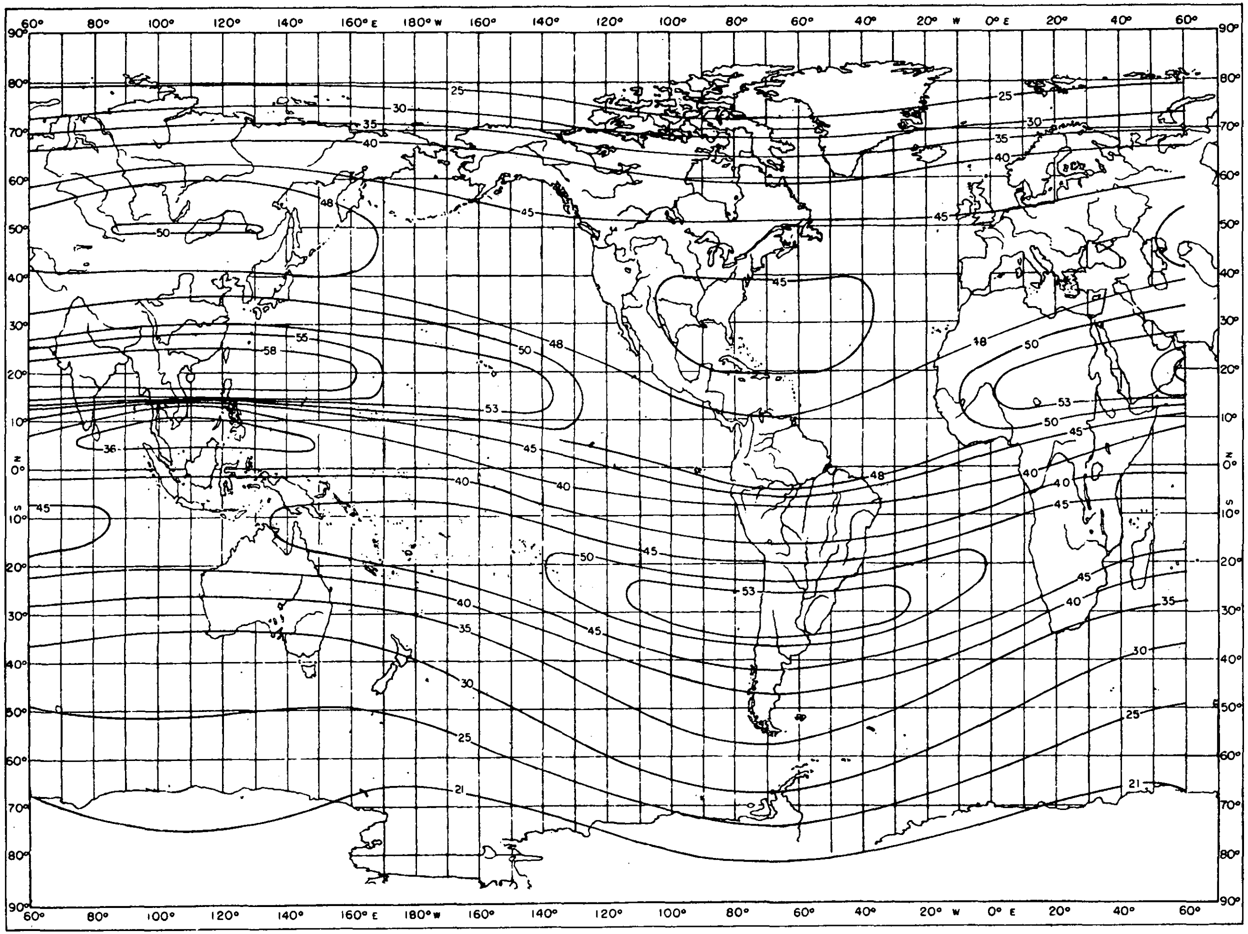

FIGURE 1

F2 4000 MUF exceeded during 1% of hours — December solstice ; sunspot maximum

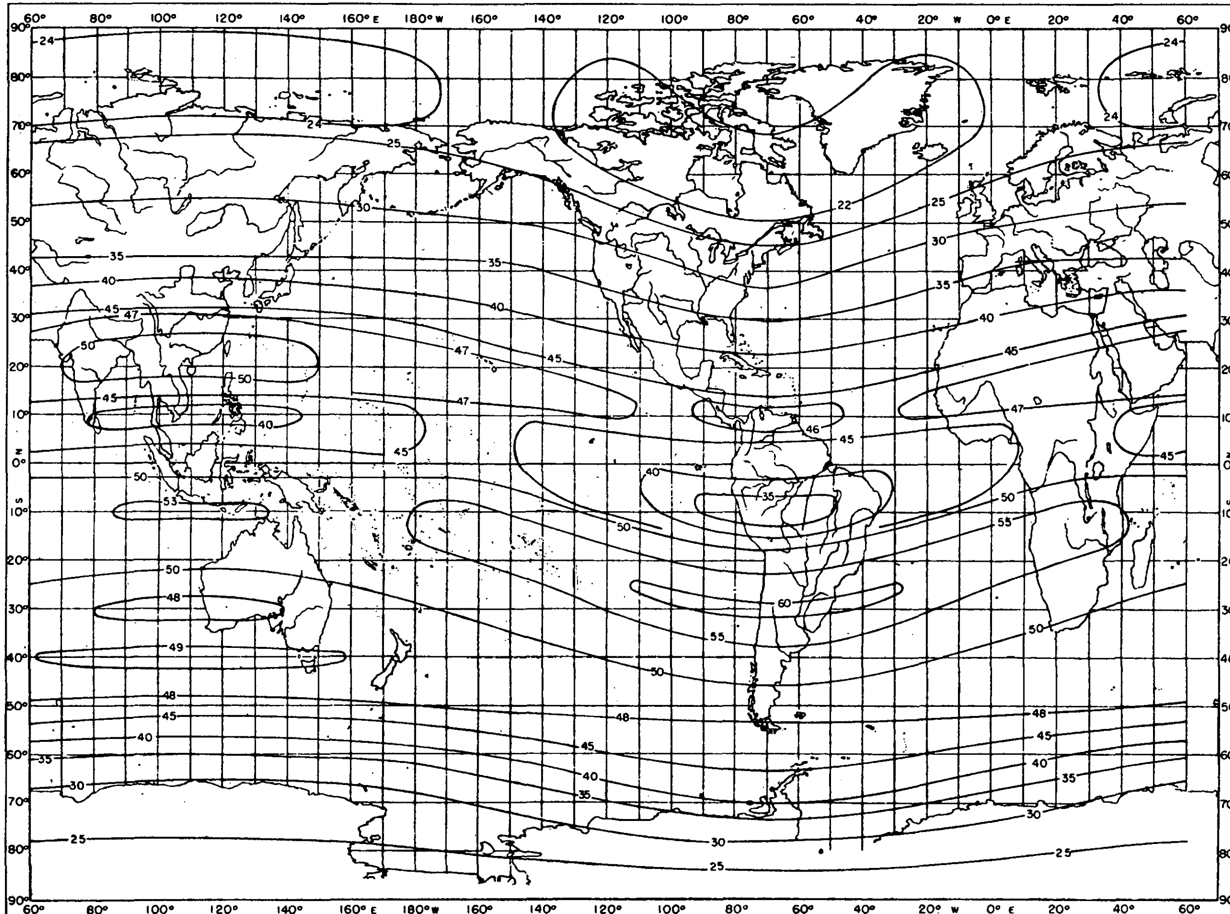

FIGURE 2

F2 4000 MUF exceeded during 1% of hours — June solstice ; sunspot maximum

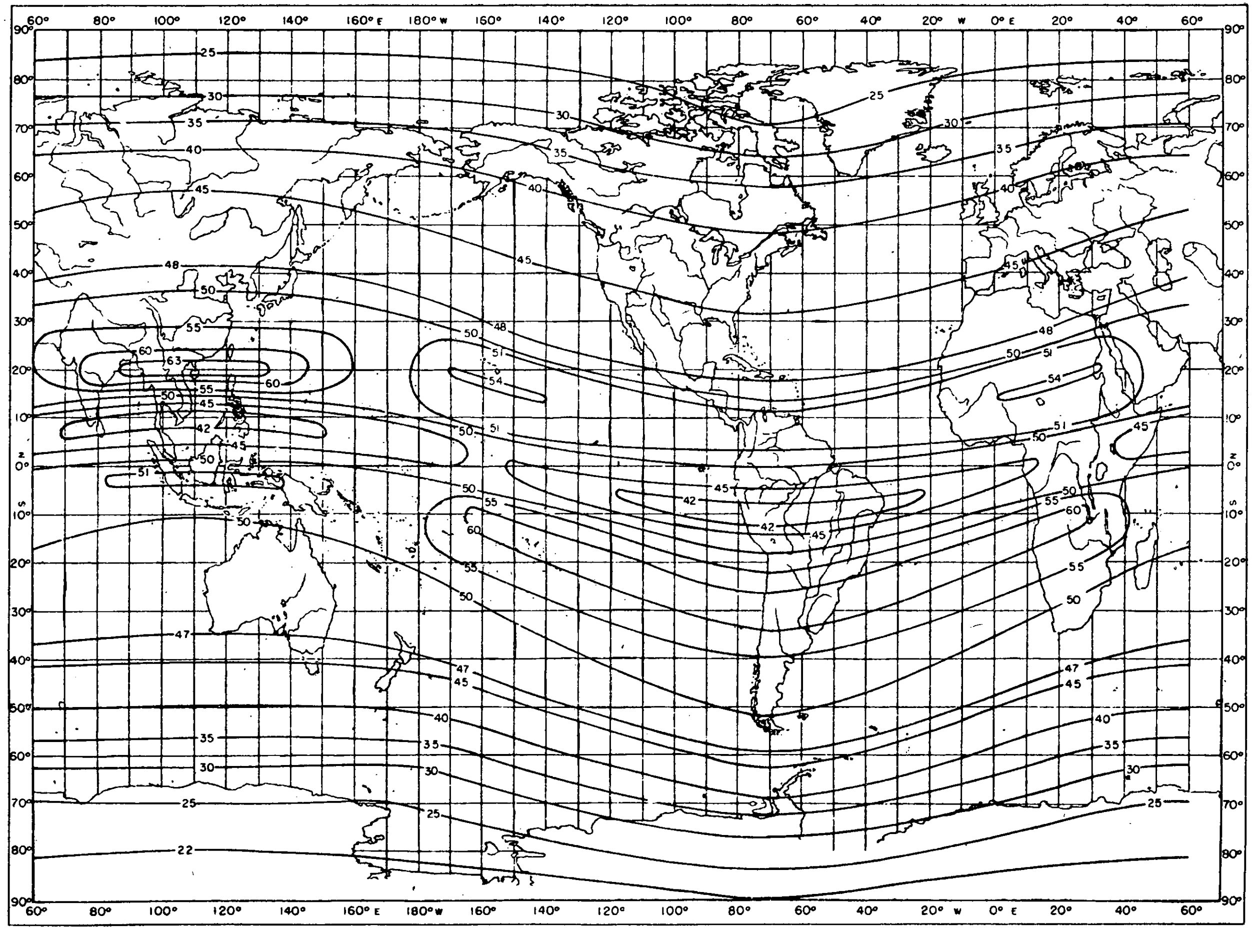

FIGURE 3

F2 4000 MUF exceeded during 1% of hours — Equinox ; sunspot maximum

REPORT 261 *

BACK-SCATTERING

(Study Programme 203(VI))

(Geneva, 1963)

1. Introduction

A radio wave propagated via the ionosphere is partially scattered by the irregularities of the ground or sea, and even to some extent by those of the ionosphere itself. Some of the scattered energy is returned over the same propagation path to the vicinity of the transmitter [1 to 6] and by measuring the time delay of the echo, the slant range to the scattering source may be inferred. By employing a directional antenna rotating slowly around the vertical, the azimuth to the echoing region can be estimated.

If information about ionospheric height is available, the measured slant range of the back-scatter echo may be converted to ground range [7, 8]. Thus, with a single station, the condition of the ionosphere can be determined in all directions from the station, generally to distances of the order of several thousand kilometres [9]. Relatively large pulse widths (1 ms) are typically employed to capitalize on the " time focusing " which occurs just beyond the edge of the skip zone [10, 11]. This method is often called simply " back-scatter sounding ".

An alternative method of measurement is to vary the frequency at a given azimuth, rather than varying the azimuth. This has been called " sweep-frequency back-scatter sounding ", and gives more definite information about the propagation modes present at a given azimuthal direction.

2. Identification of back-scatter sources

To establish the bearing of a back-scatter echo, the combined *azimuthal* directivity of the transmitting and receiving antennae must be sufficient to discriminate against off-bearing echoes.

To estimate the range of back-scatter sources from oscilloscope records, it is necessary to postulate the active modes. Their identification is assisted by a knowledge of the combined *vertical* directivity of the antennae, but unless vertical-incidence data are available, caution is needed in drawing conclusions. In one experiment, however, when the ionospheric height data were not available, the ground range was inferred using an antenna with a vertical pattern split into two distinct lobes: by showing an overlapping of the echoes from these two lobes the phenomenon of focusing has been demonstrated [12].

The focusing effect is characteristic of F-layer echoes near the skip distance, and the probability of occurrence of this effect appears to be greatest in the evening in winter and at night in summer. The absence of focusing can be used to identify Es modes [13]. Another method of identifying Es modes is the use of the azimuth-sweeping back-scatter sounder: motion of isolated Es patches can be traced with surprising ease, and a general westward drift has been noted around 40° north latitude [14 to 19].

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* This Report was adopted unanimously.

This type of sounder occasionally observes slight changes in range of the skip-zone echo, these changes in range being a function of the azimuth. These are consistent with a large-scale single wave of altered F-region ionization, the wave sweeping over the observing station at speeds of the order of 1000 km/hr [20].

3. Practical applications

Back-scatter tests have been carried out at fixed frequencies to determine the usefulness of this technique in the operation of the HF broadcasting service. Service areas deduced from these tests were found to be in better agreement with listener reports than predictions based on vertical-incidence soundings. The echo patterns showed clearly the difference in coverage over the service area on changing the transmitting antenna. Some similar tests have shown that it is possible to estimate, with an accuracy of a few minutes, the fade-out time of signals on a telegraph circuit of average length. [11, 21, 22].

Back-scatter observations have shown that the skip zone of an Indian broadcast transmission was smaller than had been anticipated from consideration of the F-layer alone and this was found to be due to Es propagation [23].

4. Unusual phenomena

Back-scatter experiments have shown long-range echoes out to 10 000 km which are stronger than multi-hop echoes present at the same time at shorter range. They sometimes persist after the multi-hop echoes have faded out. Such long-range echoes, without intermediate ground reflections, are observed primarily during dawn, twilight, or trans-equatorial propagation conditions (see Report 250). They are generally attributed to layer tilts and have been the subject of considerable study [24, 25].

Back-scatter observations have been reported suggesting the existence of an interesting mode of propagation in which an HF signal at a frequency, always somewhat above the penetration frequency of the ionosphere in the direction of the magnetic field, is apparently guided along the field lines [26].

Other work at 40·3 Mc/s has shown echoes with up to 50 ms greater delay than those for E reflections [27]; they involve off-path auroral echoes as well as one- and two-hop F2 ground-scatter reflections from as far as 6000 km. During winter daytime, F2 reflections were nearly always involved.

5. Direct back-scatter from ionospheric irregularities

5.1 *Field-aligned ionization*

Irregularities and gradients have been observed experimentally in the ionosphere, which are capable of giving direct back-scatter echoes at frequencies well above the frequencies normally reflected from the ionosphere by over-dense ionization. The process is an inefficient one. Most of the energy passes through the scattering region, but a substantial echo is nevertheless observable, because of the large volume of scatterers observed instantaneously by the radar. Those echoes have the unique property, that they are strongest when observed from an orientation at right angles to the direction of the earth's magnetic field. An empirical description of the scattering process has been given by Booker [28]. Possibilities of communication by those modes have only partially been explored.

5.2 *Auroral ionization*

Near the auroral zone, the aurora has sufficiently intense scattering properties to scatter HF, VHF, and even UHF radar waves *. These echoes are closely related to the

* A survey of work prior to 1955 is contained in [29, 30, 31, 32].

visible aurora, and have a diurnal variation which is maximum near midnight. The seasonal variation has a maximum at the equinoxes. In addition to a dependence upon the geometry of the magnetic field, the auroral echoes appear to be confined to heights of the order of 100 to 125 km, in contrast to the much greater heights, at which visible light from the auroral rays can be detected. When the E region is sunlit, another type of auroral echo appears [30]. These echoes appear to come from height regions about 10 km in thickness [33] but of great lateral extent.

Even at latitudes far from the auroral zone, HF ground back-scatter equipments have observed distant echoes from auroral ionization, with the aid of ionospheric bending and possibly an additional reflection from the ground [34].

5.3 *Field-aligned ionization at middle latitudes*

HF radars, of the type used for ground back-scatter sounding, regularly observe field-aligned echoes that resemble auroral echoes in many ways but are not so intense and do not correlate with geomagnetic activity. An E-region type, associated with sporadic-E, is distinctly separate from an F-region type associated with spread-F [35]. A 200 Mc/s observation, giving evidence for E-region field-aligned ionization, but possibly being related to meteoric ionization, has been observed over a middle-latitude oblique path [36].

5.4 *Equatorial field-aligned ionization*

In the special case of the magnetic-dip equator, where the magnetic field is parallel to the earth's surface and to the ionosphere stratifications, F-region ionization, associated with spread-F conditions, as registered by a vertical-incidence sounder, actuallyc onsists of field-aligned horizontal irregularities which principally give echoes in the east-west plane through the vertical containing the station [37].

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REPORT 262 *

WHISTLER MODE OF PROPAGATION

(Geneva, 1963)

1. The existence of whistlers was known before the days of radio, since, although a site is needed where man-made noise is very low, their detection requires only the simplest equipment. Early work on the propagation of very low frequencies in the ionosphere, by the extraordinary mode, successfully explained the law of the frequency dispersion of whistlers and was the basis of the generally accepted theory of propagation between conjugate points, defined as the two extremities of a line of force of the earth's magnetic field.

This theory has been verified by cooperative observations, made at locations which are approximately conjugate in the above sense. The experiments were originally carried out on whistlers generated naturally by lightning discharges, and later supplemented by observations on signals made by the use of transmissions from high-power VLF radio stations and propagated by the whistler mode.

Along with this experimental work, has gone the development of the theory of propagation by the whistler mode, but although much progress has been made, it is not yet possible to predict intensities with any certainty, as the factors which control the location and efficiency of the whistler paths are not well understood. The fact that these paths can extend far from the earth, to distances of several earth radii indicates that a measure of ionization must exist out to these distances, and conversely, that a knowledge of the distribution of this ionization is necessary, before the properties of the whistler mode can be closely defined.

2. The whistler mode of propagation is taken into account in Study Programme 201(VI), in view of its potential use as a means of communication, and also because it may provide a path whereby interfering signals can reach a receiver. The study also mentions the possibility of communication, when the terminals of the circuit are not necessarily on the earth, but may be situated somewhere in the duct along the lines of force of the earth's magnetic field, defining the path of the whistler mode. The mode is therefore not purely of scientific interest, though, in the present stage of the study, the emphasis will probably be on the better understanding of the physical factors controlling this mode of propagation.

3. Much of the theoretical and practical study of the whistler mode is being conducted in the United States at Stanford University, Dartmouth College, the Naval Research Laboratory and the Central Radio Propagation Laboratory, particularly with regard to the identification of whistlers at each of two conjugate locations and to the use of high-power VLF radio stations. A transmisssion from NSS (15·5 kc/s) Annapolis, Maryland, was received by the whistler mode near Cape Horn, South America, about 1700 km from the magnetic conjugate point, showing, incidentally, that the area of reception round this point can be quite large. Similarly, tests have been made in New Zealand on NPM (19·8 kc/s) and in Australia on NDT (17·4 kc/s), while in Great Britain some work has been done using GBR (16 kc/s)

* This Report was adopted unanimously.

Important results have been obtained relating to multi-path propagation, split echoes and fading, but poor correlation was found between the times when whistlers were prevalent and when relatively strong signals from NSS were received by the whistler mode.

4. The results of this work have been discussed by the U.R.S.I. and the following details have been supplied in response to Resolution 42 (Los Angeles, 1959). When both terminals are on the surface of the earth it is found that the whistler mode is effective at frequencies at least as low as 400 c/s and as high as 35 kc/s. It has been observed at most locations between geomagnetic latitudes 20° and 80°. There is a well-defined cut-off frequency which is approximately 0·6 of the minimum gyro-frequency along the path. Observations on signals from NSS at middle latitude show, that at night, a one-hop whistler mode exists for more than half the time. On occasion, its strength approaches to within 10 db of the conventional waveguide signal between the earth and the ionosphere. Two-hop whistler-mode signals have been detected at several locations on the east coast of the U.S.A. and of Canada, and on the west coast from NPG (18·6 kc/s). In Great Britain, some evidence of the two-hop whistler mode was found in observations on GBR. In general, two-hop transmission is relatively infrequent at frequencies above 15 kc/s and the signals are much weaker than for the one-hop mode. Little is known about the intensity of daytime whistler-mode signals, but it appears that they are attenuated severely in the D-region of the ionosphere.

Several factors seem to be important in the calculation of intensity, including:

— the polarization and directivity of the radiator,

— the properties of the path between the end-points of the duct in the ionosphere and the terminal points on the ground,

— the transmission coefficient for the propagation through the lower regions of the ionosphere,

— the spatial divergence in the duct,

— multi-path effects resulting from the presence of more than one duct,

— the possible amplification, or absorption, of signal energy through interaction with charged particles in the plasma.

For a terminal point within the ionosphere, consideration must be given to the effect on transmission loss of the behaviour of the antenna in a highly anisotropic dielectric medium. Little information is yet available on this problem and further experiments with rockets and satellites may be required to find the solution. It is perhaps worth noting, that future progress in whistler-mode studies will depend on the extent to which existing high-power VLF transmitters can be made available for the transmission of test signals.

In conclusion, it may be pointed out that there may be a close connection between the whistler-mode of propagation and the recently discovered phenomenon of high-frequency propagation by ionospheric irregularities aligned along the lines of force of the earth's magnetic field. It may well be that the study of the one mode will throw light on the nature of the other.

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REPORT 263 *

FACTORS AFFECTING PROPAGATION IN COMMUNICATIONS WITH SPACECRAFT

(Study Programmes 204(VI) and 205(VI))

(Geneva, 1963)

Two contributions have been given by national Administrations to Study Programme 172** which was adopted by correspondence. Both are concerned with the influences of the ionosphere on communication with spacecraft.

Doc. VI/104 (IV/11) (Canada) of Geneva, 1962, reports on the effect of auroral disturbances on signals at 440 Mc/s reflected from the moon. Whilst the received signal level remained constant to $\pm$ 2 db during such disturbances the fading rates increased by a factor of two or three so that the power spectrum of the CW signals was extended. The most important effect, however, concerned the plane of polarization, which was subject to rapid fluctuations of one radian and more within times of a few minutes.

Doc. VI/86 (IV/6) (Federal Republic of Germany) of Geneva, 1962, reports on systematic observations of Doppler and Faraday effects at 48° N at 20 and 40 Mc/s respectively. Important ionospheric effects have been found in both cases. Deformations of the curve of Doppler frequency as a function of time, due to refraction, were found to be strong in about 40% of all cases increasing considerably the inaccuracy of the determination of the time of the closest approach. Ionospheric scintillation perturbed the regular sequence of Faraday fadings in about 50% of all cases and the Faraday fading was completely absent in 20% of all cases.

The document of the Federal Republic of Germany also reports on theoretical work on the subject. The following list of studies, which should be encouraged, is given:

— field-strength changes near the radio horizon,

— propagation by ionospheric reflection,

— " guided " propagation from a satellite at the antipodal position,

— scintillations and " drop-outs " as a function of geomagnetic latitude,

— " propagation noise " produced under particular ionospheric conditions.

The use of two new concepts is recommended in this context:

1. Description of the overall propagation effects on field strength and transmission loss by the *standard extra-terrestrial diagram*, which is the diagram of an isotropic antenna on the surface of the earth, measured outside the terrestrial ionosphere.

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* This Report was adopted unanimously.

** Study Programme 172 has been replaced by Study Programmes 190(V), 204(VI) and 205(VI).

2. Introduction of a new ionospheric parameter, f_d, which is defined as the *MUF at grazing elevation angle* ; f_d should be deducible from the routine sounding parameters. The propagation conditions are particularly complicated at frequencies below f_d.

REPORT 264 *

PREDICTIONS OF IONOSPHERIC FIELD-STRENGTH OR PROPAGATION LOSS FOR THE FREQUENCY RANGE BETWEEN 150 AND 1500 kc/s

(Study Programme 206(VI))

(Los Angeles, 1959 — Geneva, 1963)

1. Foreword

Study Programme 206 (VI) calls for the continuation of measurements of field strength at frequencies below 1500 kc/s in relation to the revision and extension of propagation curves for the prediction of field strengths in this frequency range. The present Report is restricted to frequencies in the range 150 kc/s to 1500 kc/s, since it has been found desirable to consider frequencies below 150 kc/s separately, as is done in Report 265.

The Report gives the progress already made in this field and suggests future work required to provide propagation curves applicable to all areas of the world; but its special and immediate purpose is to present a set of curves for night-time field strengths for the European Broadcasting Area, based on the results of an extensive measurement campaign carried out by the E.B.U. over many years, as a response to Question (*c*) asked by the I.F.R.B. (See Report 257). It therefore begins with a detailed description of the curves and the method of use, and later refers to the fact that they are supported within quite small limits by a similar measurement campaign started some years later by the I.B.T.O.

Reference is then made to results already obtained in other areas of the world, and some preliminary comparisons are given which indicate some of the differences from the European area which may be established when a further study has extended the use of the propagation curves to other areas, in particular to low latitudes and to the southern hemisphere.

2. European area

2.1 *Introduction*

The nocturnal field strength at low frequencies (band 5) and medium frequencies (band 6) have been the subject of a measurement campaign organized by the European Broadcasting Union from 1952 onwards. Reports concerning the progress of this work and giving certain interim results were submitted to the C.C.I.R. in 1956 and 1958.

The present account is based on field-strength recordings made in the European Broadcasting Area up to the end of 1960, the total duration of which exceeded 45 000 hours. It is intended for forecasting the nocturnal field-strength in this area, such forecasts being necessary to solve any problem relating to the assignment of frequencies **. It does not, therefore, propose to give a scientific explanation of the physical phenomena that underlie

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* This Report which, together with Report 265 replaces Report 154, was adopted unanimously.

** As these predictions are based on data obtained only in the European Broadcasting Area, they do not necessarily apply to other areas.

the variations of the nocturnal field-strength, and it does not seek to justify the methods used; it has been intentionally designed as a working instrument. *

The organization and analysis of the measurements are described in considerable detail in [1].

2.2 *Annual median value of field-strength or propagation loss*

The annual median value of the field-strength can be represented by the following general expression, derived from recordings made using a small loop receiving antenna:

$$F_1 = F_0 + \Delta_A \quad (1)$$

where

$$F_0 = 80 \cdot 2 - 10 \log D - 0 \cdot 00176 f^{0 \cdot 26} D, \quad (1a)$$

D = the distance (km),

F = the frequency (kc/s).

Δ_A in equation (1) is a correction factor for the transmitting antenna, defined as the ratio (db) between the field-strength (μV/m) at a distance of 1 km, in the direction of departure corresponding to reception at a distance D, and the field-strength of 3×10^5 μV/m.

F_1 is then the field-strength (db rel. to 1 μV/m) at the receiving point for a power of 1 kW radiated from the transmitting antenna.

Δ_A includes the effects of the horizontal and vertical polar diagrams of the transmitting antenna, and Fig. 2, calculated on the assumptions of:

— a perfectly conducting plane earth;

— a reflection at a vertical height of 100 km; **

— a lossless, unloaded, vertical antenna at a variable height (h);

gives Δ_A as a function of D. (The discontinuity of the curves at 2200 km corresponds to the distance beyond which there are at least two hops).

Equation (1a) permits the determination of the annual-median value of the hourly-median values of the nocturnal field strength:

— at distances from the transmitter between 300 and 3600 km;

— for frequencies between 150 kc/s and 1500 kc/s.

Fig. 1 shows a family of propagation curves for F_0, computed from equation (1a), for frequencies of 150, 200, 300, 500, 700, 1000 and 1500 kc/s, i.e. for the same frequencies as those used in Recommendation 368 (Ground-wave propagation).

The propagation loss **, corresponding to equation (1a), between the transmitting antenna and a small loop receiving antenna, is given by:

$$L_{po} = 10 \log D + 20 \log f + 0 \cdot 00176 f^{0 \cdot 26} D - \Delta_A - 7 \cdot 75 \quad (1b)$$

The values F_1 and L_{po} are valid for the following conditions:

— a transmitting antenna characterised by Δ_A and a small loop receiving antenna ***;

— the magnetic dip at the mid-point of the path is 61°;

— a sunspot number (Wolf number) $S = 0$ ****;

— the local time at the mid-point of the propagation path is midnight;

— distances D greater than 300 km.

* Administrations are encouraged to examine the methods in the light of information at their disposal, with a view to extending them to other areas.

** The height of 100 km corresponds to propagation via the E-region of the ionosphere, which is usually the case, except occasionally at frequencies approaching 1500 kc/s, for the late hours and for the shorter distances.

** See Recommendation 341 and Report 112.

*** For reception with other types of receiving antenna, equation (1b) may still be used if an additional term of the type ΔA is subtracted to allow for the directional pattern of the receiving antenna in azimuth and elevation. Equation (1) cannot be generalized in a similar way, since the field-strength is independent of the kind of antenna used for its reception.

**** In this Report, the letter S is used instead of R to indicate the annual mean value of the sunspot number (Wolf number). This has been done to avoid confusion with the symbol R, used for the field-strength ratio in § 2.5 of this Report.

The following equations should be used to obtain the annual median values for more general conditions:

$$F_H\,(50) = F_1 + P + \Delta_I + \Delta_H\,(50) - 0{\cdot}02S \tag{2a}$$

$$L_{pH}\,(50) = L_{po} - \Delta_I - \Delta_H\,(50) + 0{\cdot}02S \tag{2b}$$

The symbols in these formulae have the following significance:

F_H (50) is the annual median-value of the vertical electric field-strength (db rel. 1μV/m) at H hours local time at the mid-point of the propagation path, for:

— a transmitting antenna characterised by Δ_A, radiating a power P (db rel. 1 kW);
— a sunspot number, S;
— a magnetic dip, I, at the mid-point of the propagation path.

L_{pH} (50) is the annual median-value of the propagation loss (db):

— at H hours local time;
— at the mid-point of the path;
— between a transmitting antenna characterised by Δ_A and a small-loop receiving antenna;
— for a sunspot number, S;
— for a magnetic dip, I, at the mid-point of the propagation path.

F_1 and L_{po} are the values given by equations (1) and (1b) respectively;

P is the power radiated from the transmitting antenna (db rel. 1 kW);

Δ_I is the correction to be applied to take account of the magnetic dip I, at the mid-point of the propagation path. The value of this correction (db) is given by the curves shown in Fig. 3. The magnetic dip considered is given by the isoclinic lines, obtained by extrapolation of the dip values measured between 1954 and 1956, at the vertical incidence ionospheric sounding stations. These values are contained in the " Ionospheric Stations Manual ", Section III, published by the General Secretariat of the U.R.S.I., Brussels, 1958.
Δ_H (50) is the correction to be applied when the local time H at the mid-point of the path differs from midnight. The value of this correction (db) is given in Fig. 4.
S is the annual mean value of the sun-spot number (Wolf number).

2.3 *Statistical variations of the field-strength or of the propagation loss*

2.3.1 *Distribution of hourly medians*

Observed values, particularly when recorded over short periods of time, may be expected to depart significantly from the long-term values given in this Report.

The curves of Fig. 5 give the order of magnitude of the statistical variations of the hourly medians * of the field-strength, taking into account both the time at the mid-point of the path and the percentage of the nights considered. They make it possible to determine, approximately, the correction that has to be applied to the annual median value, to ascertain the field-strength during a given percentage of the nights of a year. Thus (2a) and (2b) become:

$$F_H(T) = F_H(50) + \delta_H(T) \tag{3a**}$$

$$L_{pH}(T) = L_{pH}(50) - \delta_H(T) \tag{3b}$$

* It is shown in the reference [1] that the long-term distribution of half-hourly medians is very nearly the same as that of the hourly medians.
** Fig. 5 shows the values $\delta_H(T) = \Delta_H(T) - \Delta_H(50)$, where $\Delta_H(T)$ are the values given in [1].

2.3.2 *Distribution within an hour*

In Report 266, it is suggested that the short-term variations (within a half hour or an hour) follow the Rayleigh distribution.

All the statistical variations considered above refer to the hourly median values. To assess, in a more complete fashion, the possibilities of interference, the quasi-maximum value of the field-strength during the course of an hour may well have to be considered.

At any given point of reception, the annual median value of the ratio between the hourly quasi-maximum (10%) value and the hourly median value, varies little from one year to another; this ratio being, however, a function of the distance and the frequency. The study of the median value of this ratio, based on a large number of measurements made during the course of several years shows that it increases with the frequency and that it decreases when the distance increases. Depending upon the distance and the frequency, this value varies between approximately 6 db and 3 db for hectometric waves (band 6) and between 4·5 db and 2 db for kilometric waves (band 5).

However, for distances where single-hop propagation is no longer possible (above about 2000 km), this ratio no longer obeys an obvious law, but its median value remains in general below 6 db for hectometric waves and around 2 db for kilometric waves.

2.4 *Example of a complete calculation of field-strength*

Calculate the probable field-strengths that are exceeded during 50% and 10% of the nights during a year, under the following conditions:

Length of path:	$D = 1500$ km
Magnetic dip at the mid-point:	$I = 66°$
Local time at the mid-point of the path:	$H = 2130$ hr
Wolf number:	$S = 100$
Frequency:	$f = 800$ kc/s
Antenna height:	$h = 150$ m, non-loaded antenna
Radiated power:	$p = 100$ kW

The successive stages of the calculation are as follows:

Stage	Parameters	Fig.	Term calculated	Value (db)	Value (μV/m)
1	$f = 800$ kc/s, $D = 1500$ km	1	$F_0 =$	33	
2	$p = 100$ kW		$P = 10 \log 100 =$	20	
3	$S = 100$		$-0{\cdot}02S =$	—2	
4	$h = 150$ m, $f = 800$ kc/s } $h/\lambda = 0{\cdot}4$	2	$\Delta_A =$	1	
5	$I = 66°$	3	$\Delta_I =$	—1	
6	$H = 2130$	4	$\Delta_H (50) =$	—2	
7			$F_H (50) =$	49	280
8	$T = 10\%$	5	$\delta_H(T) =$	6	
9			$F_H (T) =$	55	560

It is, of course, assumed here that the factors I, D and H have been determined in advance. In particular, the local time H at the mid-point of the path is obtained normally from the clock time (Greenwich Mean Time, Central European Time, or as appropriate) at the point of reception.

A simple process for determining H, consists of transforming first of all the local time at the point of reception into GMT, then in determining the longitude L of the mid-point of the path measured in an easterly direction and, finally, in applying the expression:

$$H = \text{GMT} + L/15 \qquad (4)$$

2.5 *Formula for estimating the wanted-to-unwanted signal ratio R*

At a particular receiving location, at a distance D_u, from the wanted transmitter and at a distance D_n from the unwanted transmitter, the ratio $R(T)$ (db) between the wanted hourly median signal level and the unwanted hourly median signal level exceeded for a percentage T greater than 50% of the hours of a year at the corresponding local times H_u and H_n of the mid-points of the paths may be estimated for a non-directional receiving antenna by means of the following formula:

$$\left.\begin{aligned} R(T) = P_u - P_n + 10\log(D_n/D_u) + 0{\cdot}00176 f_n^{0\cdot 26} D_n - 0{\cdot}00176 f_u^{0\cdot 26} D_u + \Delta_{Au} - \Delta_{An} \\ + \Delta_{Iu} - \Delta_{In} + \Delta_{Hu}(50) - \Delta_{Hn}(50) - \sqrt{\delta_{Hu}^2(T) + \delta_{Hn}^2(100-T) + 2\rho\,\delta_{Hu}(T)\,\delta_{Hn}(100-T)} \end{aligned}\right\} \quad (5)$$

where ρ represents the correlation between the changes in hourly median values for the wanted and unwanted propagation paths.

In the absence of measurements of this factor ρ, it is suggested that it be set equal to 0·5 in using equation (5).

It should be noted that δ_{Hn} and δ_{Hu} always have opposite signs and that the minus sign before the radical in (5) is associated with the practical situation normally encountered where the time availability T of satisfactory service is greater than 50%.

Strictly speaking, equation (5) is applicable only to the extent that a log-normal distribution describes the data. However, for the distributions encountered in practice the formula is an adequate approximation.

2.6 *Combined influence of the hour and the season on the distribution of hourly medians*

Fig. 4 provides a correction of the hourly median as a function of the hour at the mid-point of the path. But this correction term is itself no more than a yearly median derived from results obtained with different frequencies and at all times of the year. The spread of the correction, shown in Fig. 5, is, therefore, very great. Its value can, however, be rendered more precise and its dispersion reduced by bringing to the fore the seasonal factor obtained through statistical study carried out separately for each of a number of frequencies.

A first study has been effected using as a basis recordings made at 845 kc/s throughout the night, over a period of three consecutive years (1959, 1960 and 1961), on the Rome-Wittsmoor, Rome-Darmstadt, Rome-Belgrade and Rome-Tel Aviv paths the length of which varies between 700 and 2200 km. This made it possible to establish the family of curves in Fig. 6, giving the median value of the correction $\Delta_H(50)$ to be made, as a function of the month and the hour, to the field-strength calculated with the method described above. The curves clearly show two seasonal maxima, in March and in September, the latter being the greater. This seasonal effect is quite apparent on each of the paths used to establish the curves.

The present study of data obtained for other frequencies enables it to be assumed already that, for the European Area at least, a similar effect occurs throughout the medium-frequency broadcasting band. However, the completion of this study must be awaited to know whether the seasonal effect depends upon the frequency and the geographical position of the path.

The slight field-strength maximum in the second half of the night, to be seen on Fig. 4, relating to the whole of one year, is also found on each of the curves established each month for the four paths indicated above (845 kc/s), and its position in the course of the night seems to be sensibly independent of the time of sunset.

The final objective of this study is to replace Fig. 4 by several families of curves similar to these giving the values $\Delta_H(50)$ $\Delta_H(90)$ and $\Delta_H(10)$ and valid for the whole medium-frequency band in the European Area. In certain applications, these families of curves might replace all those in Figs. 4 and 5.

2.7 *Other work carried out in the European Area*

Since the E.B.U. contributions which form the basis of this Report were communicated, the I.B.T.O. has submitted a study on the same subject [2].

It is worthy of note that study, based on data collected independently of those used by the E.B.U.* but processed by similar methods, produce closely related results; the yearly median field-strength is given by the formula:

$$F_0 = 81 \cdot 2 - 10 \cdot 56 \log D - 0 \cdot 0018 f^{0 \cdot 262} D \qquad (6)$$

where the symbols and the units are the same as for equation (1*a*):

$$F_0 = 80 \cdot 2 - 10 \log D - 0 \cdot 00176 f^{0 \cdot 26} D \qquad (1a)$$

It should be noted, however, that formula (6) may produce, for high frequencies and long distances, field-strength values 2 db lower than those obtained with formula (1*a*). It is desirable that a study should be made to reveal the source of this slight difference with a view to establishing a single formula which will take account of all the results upon which equations (1*a*) and (6) are based, together with those obtained from further measurements as they become available.

3. Australia

A study of medium-frequency sky-wave characteristics has been conducted by the Australian Broadcasting Control Board since March, 1953. These measurements have been the subject of publications [3] [4] and of a contribution to the work of the C.C.I.R. [5]. The field-strength curves of Fig. 7 are derived from this latter document, which gives the results of these investigations in great detail. The solid curves shown in this figure have been produced from field-strength recordings of one hour's duration centred on the second hour after sunset. They represent the hourly median values exceeded on 50% of the nights for one year. The seasonal variation eliminated by this procedure may be obtained from [5].

Field-strength values F_0 given in db above 1 μV/m have been normalized to an unattenuated field strength of 3×10^5 μV/m at 1 km at the appropriate angle of radiation. The curves of Fig. 7 have been arrived at by applying the correction factors given in Fig. 2 to the measured results obtained with a number of different vertical transmitting antennae. The original median data are spread around the solid curves to within $\pm$ 1·5 db for 90% of the stations observed.

The most outstanding feature of these Australian recordings has been the relatively high level of sky-wave field strength throughout the whole of the sunspot cycle; this level has been about 9 db higher, for 1500 km but less for shorter distances, than that predicted by the curves of Fig. 1. No significant variation of level with frequency is evident except at the low frequency end of the band. More recent results are known to display a general trend towards higher levels at the low frequency end of the band, in keeping with low sunspot activity.

No correction has been made to the original data, to allow for the influence of two high altitude nuclear explosions in the Pacific during August, 1958 [2].

There appear to be two different types of distribution for the quasi-maximum (10%) values. The ratio of the 10% value, exceeded on 10% of the nights to that exceeded on 50% of the nights, is either 3 db or 5·5 db, two different types of distributions being obtained

* The number of hours of recording is smaller for the I.B.T.O. than for the E.B.U., but it covers more frequencies.

for reasons not yet understood. As far as the distribution within an hour is concerned, the ratio of the field strength, exceeded for 10% of the time, to that exceeded for 50% of the time, is found to be 5 db.

The dashed curve in Fig. 7 is based on results from only three broadcasting stations during low sunspot activity and is therefore less accurate than the curves for high sunspot activity. It is expected that these Fo-curves will require some slight modification when more data become available.

4. India

The field-strength of a number of transmitters at frequencies between 550 and 760 kc/s and for path lengths between 350 and 1320 km has been recorded in India since 1959.

Some of the results of these recordings have been submitted to the C.C.I.R. [6]. A yearly mean value of the field strength is given for one path (670 kc/s, 1320 km). This value is about 6 db higher than the corresponding value predicted for the European Broadcasting Area and about 3 db lower than those predicted in Australia, but it should be pointed out that such a comparison has little statistical significance.

5. The United States of America

The FCC standard broadcast curves of yearly median field-strength [7], derived from measurements made in the U.S.A., have been available for many years and considerable use has been made of them in other countries. The measurements refer to a period of low solar activity, and the presentation adopted for the curves is based on the second hour after sunset and shows how they vary with latitude.

Limited comparisons between these curves and those in Fig. 1 indicate that comparable values are obtained when the dependence of the FCC curves upon geographic latitude is translated into terms of geomagnetic latitude.

6. Future work

Reference has already been made to the coordination of the E.B.U. and I.B.T.O. results as further measurements extend the range of the investigation. There is an especial need to relate the propagation curves to low latitudes and to the southern hemisphere, where the comparisons so far made suggest significantly higher values of field strength than are found in the European area. It would be very valuable, for instance, to have results from Africa and from South America, and to know to what extent the curves of Fig. 1 apply to temperate latitudes beyond the European area, e.g. to the region including Japan.

Although, from the point of view of frequency planning and sharing, the problem is to some extent a continental one, so that widely separated areas such as Australia, Europe and the U.S.A. can act independently of one another in the use of medium frequencies, it is clear that valuable information on the dependence of field-strength curves on geographical location can be obtained by comparing measurements made in such areas. Thus, for instance, a re-examination of the records upon the FCC curves were based, may well help in assessing the situation in regions adjoining the European area which come within the consideration of the I.F.R.B.

Resolution 12 proposes the setting up of a small Working Party of experts to study the problem of such comparisons, with a view to establishing the accuracy that is likely to be obtainable in propagation curves extended to cover the other regions of the world as well as the European area to which the curves in Fig. 1 refer.

In this work it should be remembered that measurements of reflection cœfficients made at vertical incidence, as envisaged in Study Programme 206 (VI), and their relation to oblique incidence phenomena, may help in gaining a deeper understanding of the underlying physical mechanism of medium-frequency propagation. In this connection, reference may be made to work being carried out by the Federal Republic of Germany [8]. Measurements made in South West Africa show that the mean night-time attenuation ranges from about 6 db at 1070 kc/s to 17 db at 365 kc/s. Daytime values are much higher, and, one hour before sunset and one hour after sunrise, they may be several times the night value.

It is hoped that the work done in the interim period may enable a Recommendation to be put forward at the XIth Plenary Assembly, for the use of curves such as those in Fig. 1, extended to include all other areas of the world where medium frequency communications are carried out.

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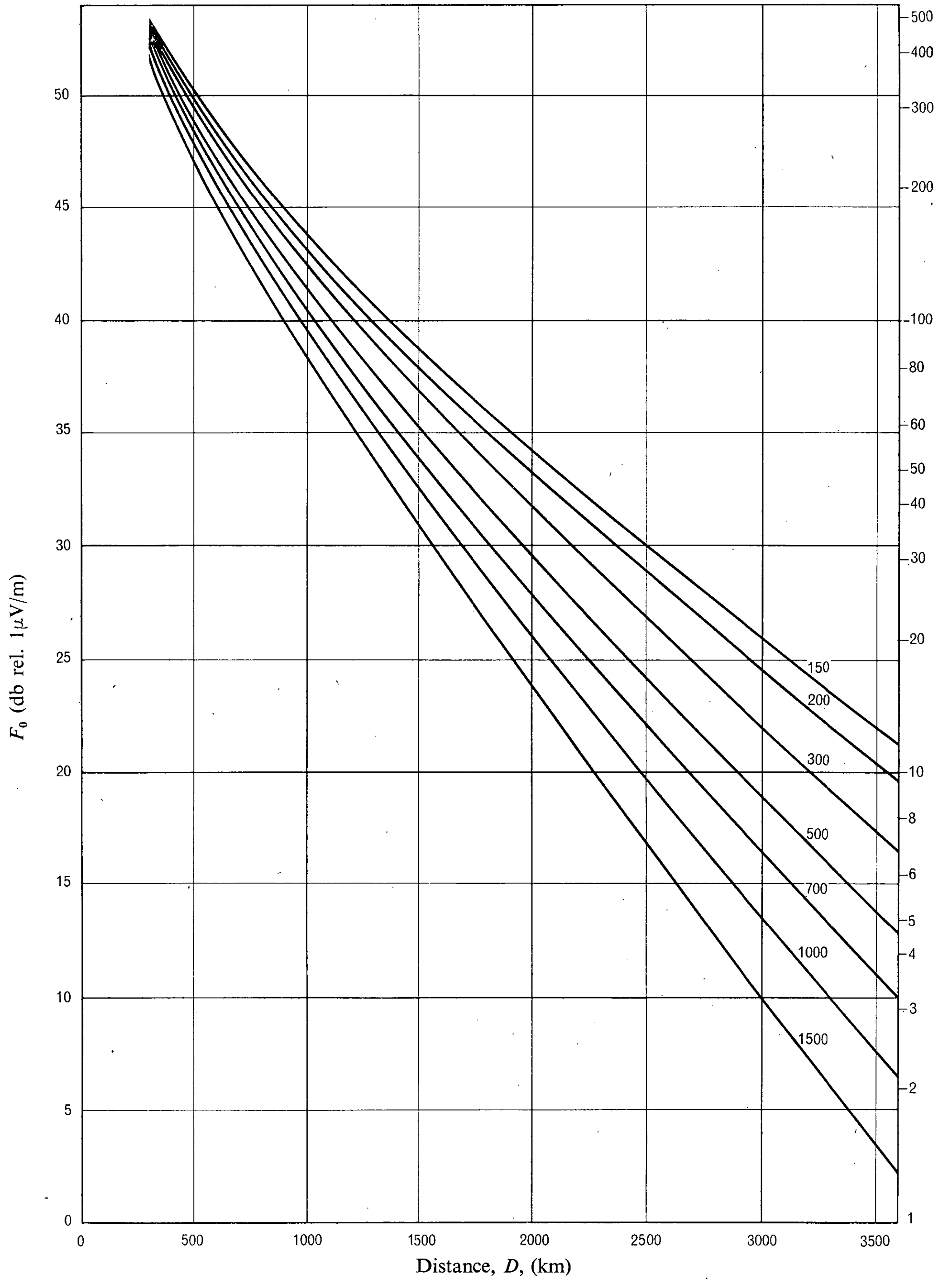


FIGURE 1

Family of basic curves of F_0 to be used to determine the annual median value of the field strength for the frequencies, (kc/s) indicated on the curves

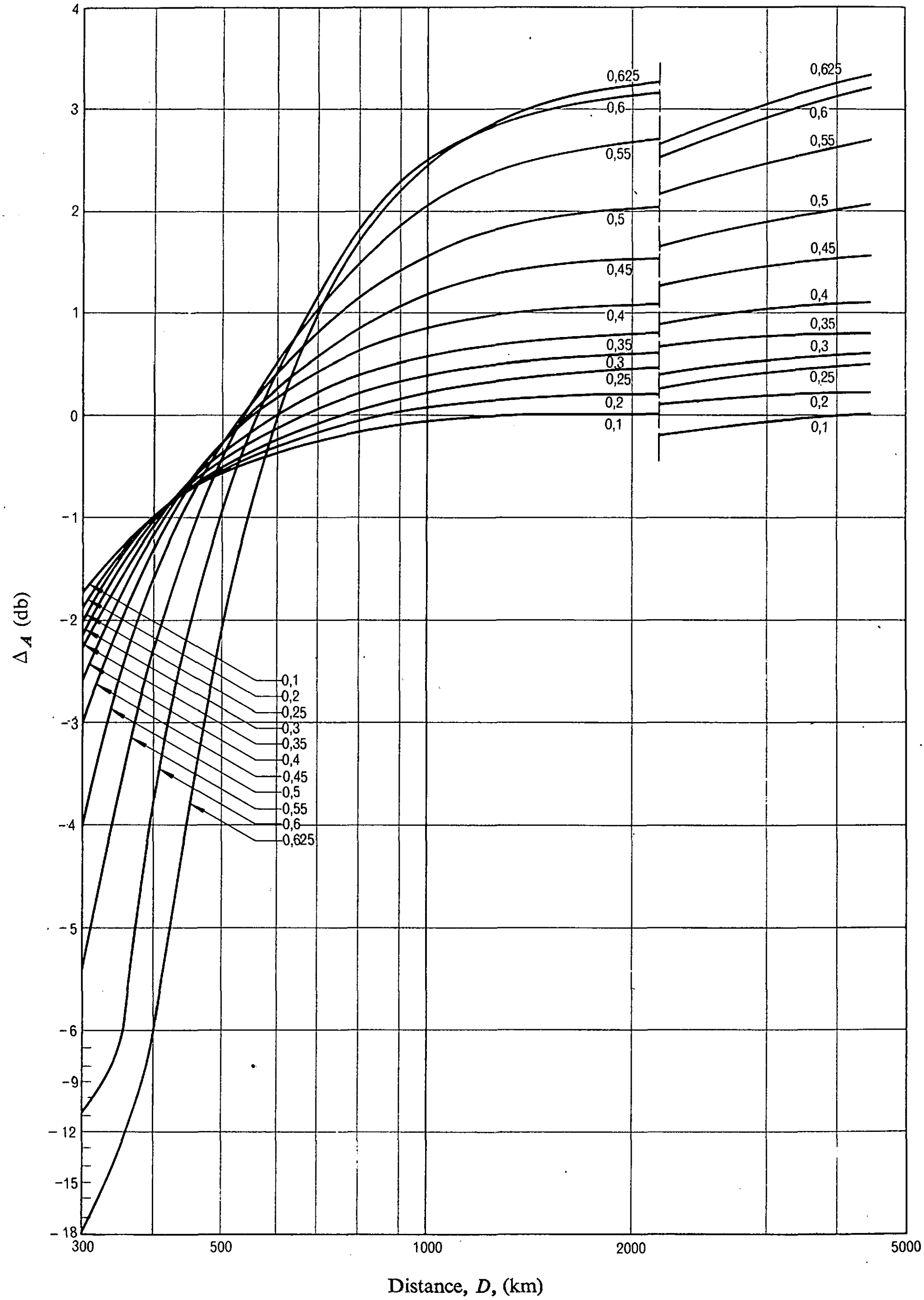
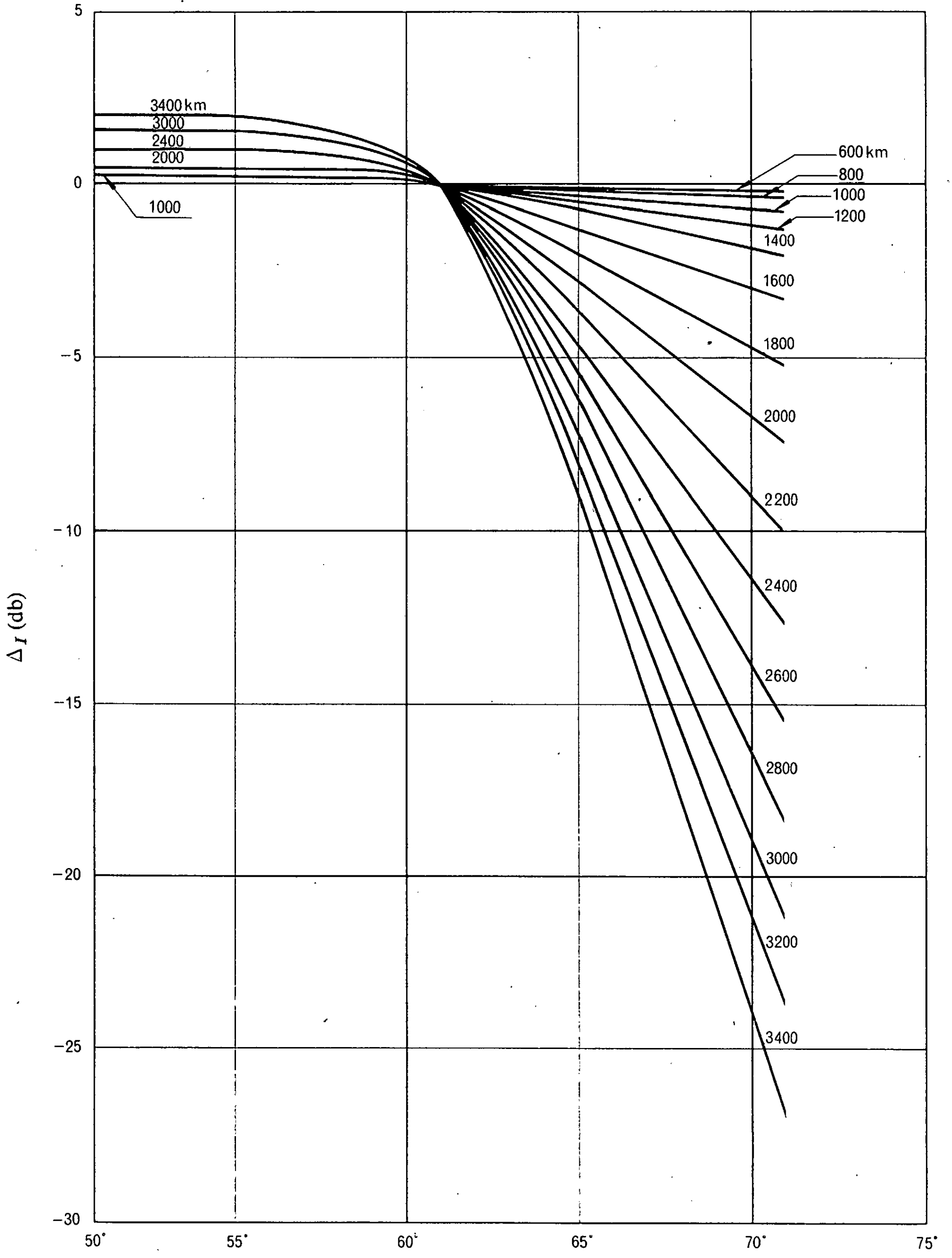


FIGURE 2

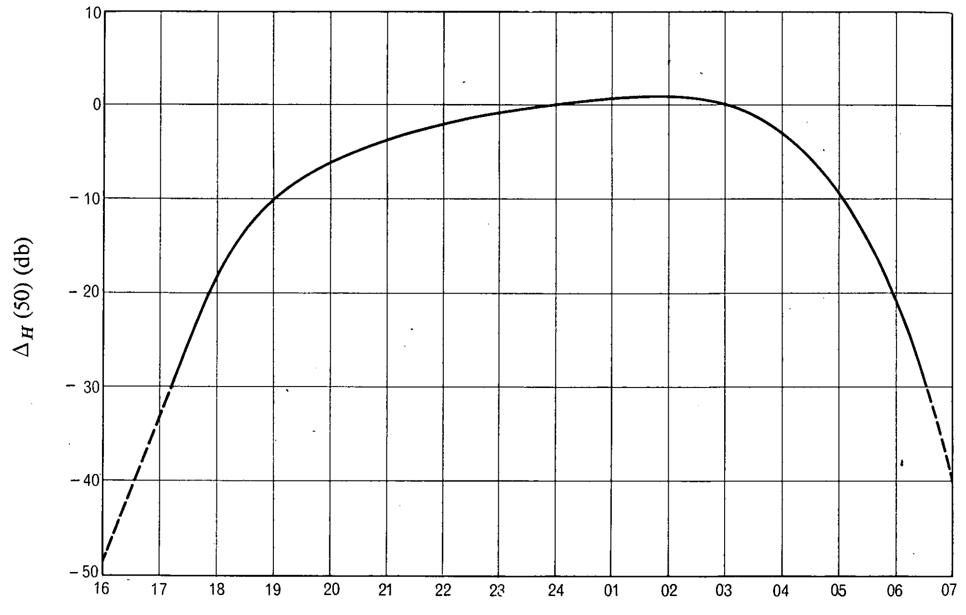
Gain Δ_A of vertical transmitting antennae of various lengths as a function of the distance from the point of reception



Magnetic dip, I (deg.)

FIGURE 3

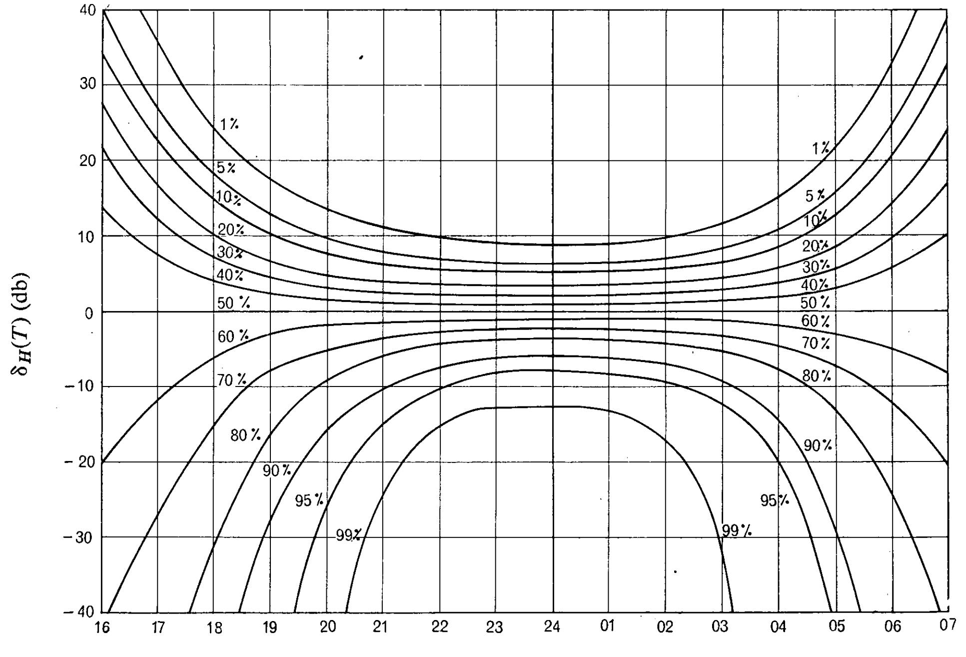
Correction (Δ_I) to be applied to take account of the magnetic dip.



Time at the mid-point of the path (H)

FIGURE 4

Correction $\Delta_H(50)$ to be applied to take account of the time at the mid-point of the path



H

FIGURE 5

Correction $\delta_H(T)$ to be applied to take account of the percentage of the nights of a year

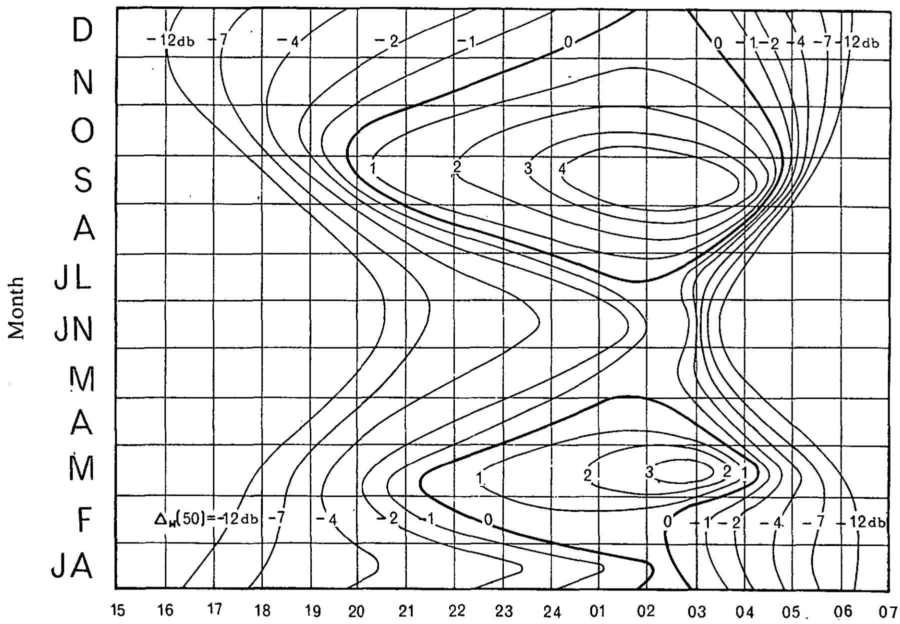


FIGURE 6

Sample correction to be applied to take account of the time at the mid-point of the path H and of the season of the year

(Frequency: 845 kc/s)

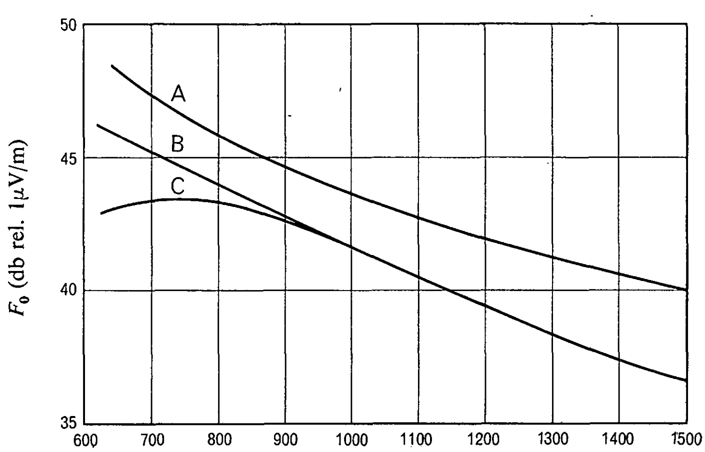


FIGURE 7

Hourly median value of the field-strength exceeded on 50% of the nights for one year, at the second hour after sunset

Curve A: for $10<S<40$ (550 and 1300 kc/s)
B: for $S>80$ (1300 kc/s)
C: for $S>80$ (550 kc/s)

REPORT 265 *

LONG-DISTANCE SKY-WAVE PROPAGATION AT FREQUENCIES BELOW 150 kc/s

(Study Programme 206(VI))

(Los Angeles, 1959 — Geneva, 1963)

Practical radiocommunication began at low frequencies and if it were not for the limited bandwidth available, more extensive use would be made today of frequencies below 150 kc/s. In this frequency range, at distances at which the ground-wave has become too weak to be useful (see Figs. 1 to 5 of Recommendation 368), propagation continues between the earth and the lower boundary of the ionosphere to great distances and is characterized by good reliability and stability. For a given radiated power, increased signal strength is obtained with decreasing frequency, down to 10 kc/s, and the diurnal, seasonal and solar-cycle variations become smaller.

Because of the stability of the propagation, frequencies in this range are useful for navigational systems. In particular, at frequencies above about 100 kc/s, where it becomes practicable to isolate the ground-wave by pulse techniques, highly accurate time systems can be devised. Marine communication makes considerable use of low frequencies, which are also useful for point-to-point services at times of severe ionospheric disturbances to high-frequency circuits.

The propagation is essentially by way of vertical polarization which is well preserved, and an important limitation, which is partly economic, is the need for large antenna installations and high-power transmitters. Another limiting factor is the increasing level of atmospheric noise with decreasing frequency, and thus, apart from the small total bandwidth available in the frequency range, services generally use a fairly narrow bandwidth and hence a low communication rate.

In recent years research has been concentrated on the VLF range and to a lesser extent on the LF range. A survey and an extensive bibliography are available [1], covering both the theoretical and experimental aspects. A useful survey of the conditions in the lower ionosphere governing the propagation of low and very low frequencies has been published [2]. Propagation curves for the VLF range prepared by Wait [3] will be found useful in some practical problems, while propagation data for low frequencies can be found in the work of Belrose and his co-workers [4].

There are many aspects of the propagation of LF and VLF waves which need further study before curves can be prepared extending the existing C.C.I.R. curves to cover long distance propagation below 150 kc/s. In particular, the non-reciprocal effects produced by the earth's magnetic field and the problems introduced by changes in the conductivity of the earth along the path may be mentioned. Much of the theoretical work has been based on idealized models of the ionosphere and further experimental work needs to be done to relate it to practical conditions.

It is probably premature to organize a world-wide programme of field-strength measurements, and as a first step it has been suggested that two or three experts in this field should form an informal working party to examine the large amount of literature already available, with a view to advising the C.C.I.R. whether such a programme should be undertaken (Resolution 13).

* This Report, which together with Report 264 replaces Report 154, was adopted unanimously.

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REPORT 266 *

FADING OF SIGNALS PROPAGATED BY THE IONOSPHERE

(Study Programme 148)

(London 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

1. Introduction

Experience has shown that information concerning the mean value of the received signal is not sufficient for planning radiocommunication systems. The variations in time which occur as random short-term variations, irregular long-term variations and more or less periodic variations, collectively described as fading, also have to be taken into consideration. This fading has a decisive influence on the performance of radiocommunication systems. Hence, it is essential to know the severity and rapidity of fading to be able to specify power requirements for transmitting installations, the most efficient and economical diversity systems for receiving installations and the necessary protection ratios to guard against interference.

2. Causes of fading

It is considered that fading is caused by the following phenomena:

— changes in absorption,
— focusing and defocusing,
— changes in polarization,
— multi-path propagation.

Consequently, distinction should be made between:

— absorption fading,
— focusing fading,
— polarization fading,
— multi-path fading.

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* This Report, which replaces Report 159, was adopted unanimously.

Experimental separation of these fading components is extremely difficult; however, some useful deductions can be made with the aid of plausible suppositions. In general, long-period fading is assigned to absorption processes, whereas short-period fading will be due to polarization and multi-path effects. Focusing fading probably falls between these two groups.

However, detailed studies of the causes of fading and the relative importance of the various contributory phenomena are felt to fall within the province of the U.R.S.I. (see Opinion 10).

3. Characteristic sampling periods for various types of fading

While it would be highly desirable to restrict the number of different categories of fading, this is not always possible. In fact, the number of different categories, into which it is desirable to classify fading phenomena, depends upon the objectives for any particular analysis. Thus, short-period statistics of the order of several minutes are most useful for describing multi-path, selective fading, performance of diversity combiners and error correction coding equipment. These statistics may be obtained by sampling from stationary processes, the duration of which may range from a few minutes to one hour or more. On the other hand, hourly medians and their standard deviation, over periods of the order of a month, or even a year, are of greater significance than the short-term distribution in determining system power requirements, since such data present more clearly the full range of variations encountered on a circuit. It has long been recognized that there are quasi-periodic variations, introduced by diurnal changes in the ionosphere, the period of rotation of the sun, and certain characteristic changes of geomagnetic variables. For application to the telecommunication system analyses of the C.C.I.R., it is usually expedient to exclude the effects of these variables from the long-term variance, since they will have very nearly the same influence on both the wanted and unwanted received signals and will, therefore, not affect the wanted-to-unwanted signal ratio to any appreciable extent.

It is thus evident that sampling periods of HF circuits should not be established arbitrarily nor fixed at a single value. Instead, a number of sampling intervals of different lengths should be chosen, sufficient to demonstrate all the different fading characteristics that would be of interest to system designers. Having stated the complexity associated with fading phenomena at HF, it is nevertheless imperative to reach at least temporary agreement concerning appropriate sampling intervals over which fading phenomena are to be studied.

4. Severity and rapidity of short-period fading

4.1 *Severity of fading* [1 to 13 and 21 to 23]

The statistical method of describing the severity of fading is the only useful one. Fading can be characterized by a distribution function obtained empirically. This function indicates the percentage of time that a given signal level has been exceeded. As emphasized earlier, no standard interval can be chosen to differentiate sharply between short-period and long-period statistics. However, in the light of various investigations performed in this field (see Docs. 13 (Japan), 76 (Japan) and 475 (U.S.S.R.) of Warsaw, 1956), a relatively short interval, varying from say, 3 minutes to an hour or more, depending on the radio-frequency and the characteristics of the propagation path, seems to be reasonable to describe short-period fading. Further studies along this line are considered desirable.

The distribution function associated with short-period fading has been the subject of numerous theoretical analyses. Several authors have suggested the following probability density function for the very general case of a superposition of a strong constant field and a large number of secondary fields with random amplitudes and phases;

$$\mathrm{d}P = 2v/v_{rms}^2 \; I_o\left(2vv_c/v_{rms}^2\right) \exp\left\{-\left(v^2 + v_c^2\right)/v_{rms}^2\right\} \mathrm{d}v \tag{1}$$

where

v = received signal-envelope voltage,

v_c = signal envelope-voltage of the constant component,

$I_o\,(x)$ = modified Bessel function of order zero.

As v_c becomes vanishingly small, the above function approaches the Rayleigh distribution given by

$$\mathrm{d}P = \left(2v/v_{rms}^2\right) \exp\left\{-v^2/v_{rms}^2\right\} \mathrm{d}v \tag{2}$$

whose cumulative distribution is

$$P\,(v > v_o) = \int_{v_o}^{\infty} \left(2x/v_{rms}^2\right) \exp\left\{-x^2/v_{rms}^2\right\} \mathrm{d}x = \exp\left\{-v_o^2/v_{rms}^2\right\} \tag{3}$$

The Rayleigh distribution, expressed in terms of the instantaneous power p, available from the receiving antenna is given by:

$$P\,(p > x) = \exp\left\{-x/\bar{p}\right\} \tag{4}$$

where $\bar{p}$ denotes the mean of the available power.

The distributions described above are all based on the assumption of a large number of component vectors present simultaneously with random relative phases. Theoretical discussions have also been held for the case of a finite number of vectors with random relative phase [13]. For example, when two vectors with equal amplitudes and random relative phase are added together, the probability distribution of their resultant is given by:

$$P\,(v > v_o) = 1/\pi \text{ arc cos } \left[\left(v_o^2 - v_{rms}^2\right)/v_{rms}^2\right] \tag{5}$$

This particular distribution, while rarely encountered in practice, can give rise to fading conditions more severe than those described by the pure Rayleigh distribution.

In addition to the above statistical distribution, which is bound to certain theoretical assumptions (stationary processes, random motion of secondary radiators), there are other statistical distribution functions worth considering, because they contain several arbitrary parameters to which values may be assigned to fit the measured data.

In this connection, mention should be made of the m-distribution [1, 2 and 24] which has the probability density

$$\mathrm{d}P = [(2m^m\, v^{2m-1})/\Gamma\,(m)\,\Omega^m] \exp\left\{-mv^2/\Omega\right\} \tag{6}$$

where

v = envelope voltage of receiver signal,

m, Ω = parameters,

$\Omega = v_{rms}^2$

$m \geqslant 1/2$

This distribution is identical with the χ^2 distribution often used for probability calculations and statistics. For $m = 1$, it reduces to the Rayleigh distribution function already mentioned. Measurements have revealed that the parameter m varies as a rule between 0·9 and 1·8. It should be noted that for larger values of m, the severity of fading is decreased.

Finally, the following possible distribution functions are worthy of mention:

— the normal distribution, which characterizes the variations of the instantaneous radio-frequency voltage, $v_i = v \sin \omega t$, having a Rayleigh distributed envelope voltage v:

$$\mathrm{d}p = \left(1 / v_{rms} \sqrt{\pi}\right) \exp \left\{- v_i^2 / v_{rms}^2\right\} \mathrm{d}v_i \,, \tag{7}$$

— the log-normal distribution, which approximately represents the long-term distribution of the transmission loss or field strength, expressed in db:

$$\mathrm{d}P = \left(1 / \sqrt{2\pi}\, \sigma_V\right) \exp \left\{- V^2 / 2\sigma_V^2\right\} \mathrm{d}V \tag{8}$$

where

$$V = 20 \log v$$

The simplest method of characterizing empirical distributions by a more or less large number of parameters is the indication of levels. A distribution can, for instance, be characterized by stating the levels exceeded for 50%, 90% and 10% of the time. For the distributions given by multi-parameter laws, there is always the risk of extrapolations that may not be jusified.

The measured results hitherto found in the HF range, can be summarized as follows:

With short analysis intervals (3 to 7 min), distribution functions similar to the Rayleigh distribution seem to predominate. With high signal levels, the variance of the distribution seems to fall below the Rayleigh value. Considering the theoretical formula given by (1), this can be explained by the preponderance of a constant specular reflection. On the other hand, it is considered by some workers, that when high signal levels predominate, analysis intervals longer than 7 min may be required, for an approximation to a Rayleigh distribution to be obtained. In general, however, during these longer analysis intervals (about 30 min or 60 min), the distribution curves seem to follow the log-normal law rather than the Rayleigh. The fading range is often defined as the difference between the values of the signal level (in db above 1 μV/m), exceeded for 10% and 90% of the time, and is on the average, given by:

$$(V_{10} - V_{90}) = 13 \pm 3{\cdot}2 \text{ (db)}$$

It should be noticed that although the form of the distributions may differ from that of Rayleigh, this observed fading range is very close to the value of 13.4 db expected for the Rayleigh distribution.

A relatively small number of the measured distributions do not show a log-normal, but rather an S-shaped distribution. This would indicate that there were several propagation modes present during the time interval concerned.

4.2 *Rapidity of fading* [16, 17 and 19]

The rapidity of fading can be characterized in different ways. A nearly complete description of fading is given by an auto-correlation function in time or by the corresponding power spectrum. The auto-correlation function of a stationary process, $U = U(t)$, varying in a random manner with time, is defined by the equation:

$$R(\tau) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} U(t) \,.\, U(t + \tau)\, \mathrm{d}t \tag{9}$$

where $U(t)$ may denote a signal level in any convenient units, such as voltage, power or decibels. It is, of course, essential to specify the units employed.

From the above, we can calculate the power spectrum of the process

$$G(f) = 4 \int_0^{\infty} R(\tau) \,.\, \cos (2\pi f \tau)\, \mathrm{d}\tau \tag{10}$$

The relation between $G(f)$ and the Fourier spectrum $F_T(f)$ is given by:

$$G(f) = \lim_{T\to\infty} \frac{1}{T} F_T(f) F_T^*(f) \tag{11}$$

where

$$F_T(f) = \int_{-T}^{T} U(t) \exp\{i2\pi ft\} \, dt. \tag{12}$$

Hence, the frequency spectrum of the fading process may be obtained with the aid of the auto-correlation function which is relatively easy to determine. With certain theoretical assumptions (Maxwell distribution of the velocities of the secondary radiators), a Gaussian curve is to be expected for the auto-correlation function:

$$R(\tau) = R(0) \exp\{-\tau^2/\tau_o^2\} \tag{13}$$

However, it is questionable whether this assumption is often justified. Therefore, the possibility of other auto-correlation functions should also be taken into consideration.

Because of the lack of suitable equipment for measuring the auto-correlation function, these functions of fading have, hitherto, been determined only on a very limited scale. Other more readily obtainable parameters are used for characterizing the rapidity of fading. While these do not represent as complete a description of fading as auto-correlation functions, they nevertheless provide useful information concerning fading rates. There is, first of all, the fading rate defined as the number of positive crossings per unit time through any specified level.

When the signal fades according to (1), the fading rate through the level v is given by:

$$N(v) = \left(\sqrt{4\pi}\, f_s\, v/v_{rms}\right) \exp\left[-\left(v_c^2 + v^2\right)/v_{rms}^2\right] I_o\left(2v_c\, v/v_{rms}^2\right) \tag{14}$$

where:

I_o = modified Bessel function of order zero,

f_s = mean frequency of fading (defined below).

In the special case of the Rayleigh distribution, we can introduce the median value v_m obtaining:

$$N(v) = 2{\cdot}95\, f_s\, (v/v_m) \exp\{-0{\cdot}693\, v^2/v_m^2\} \tag{15}$$

where, if

$$v = v_m, \text{ it follows}$$

$$N(v_m) = 1{\cdot}47\, f_s$$

This proportionality is also valid, at least approximately, for other amplitude distributions.

The r.m.s. fading frequency f_s, which is used in (14) and (15) can also be determined from the auto-correlation function. The square of the r.m.s. value of the fading frequency is given by:

$$f_s^2 = \overline{f^2} = \frac{\int_0^\infty f^2 G(f)\, df}{\int_0^\infty G(f)\, df} = \frac{1}{4\pi^2 R(0)} \left. \frac{d^2 R(\tau)}{d\tau^2} \right|_{\tau=0} \tag{16}$$

The fading rapidity is closely connected with the derivative of the received signal amplitude. Consequently, a measure of the fading rapidity can also be obtained by electronic differentiation of the received signal. The following expression is then defined as the fading rapidity:

$$S = \frac{1}{\bar{v}} \left| \frac{d\bar{v}}{dT} \right|$$

The number of maxima of the received signal envelope amplitude per unit time may also be used as a measure of the fading rapidity. The relationship between the number Z of these maxima and f_s is given by $Z = 2 \cdot 52\ f_s$ for the Rayleigh distribution. Hence f_s may be determined from counts of the maxima.

Until now, the United States of America and the United Kingdom were the only countries performing a reasonably large number of investigations with the help of auto-correlation functions, studies in the United States being carried out at 50 Mc/s (ionospheric scatter), and in Britain at 6 to 18 Mc/s. Values of τ measured in the United Kingdom, on the assumption that the auto-correlation function satisfied (13), were between 0·7s and 3·5s. Some Indian auto-correlograms show clear quasi-periodic components.

Fading rates through the field-strength level exceeded for 90% of the time, were primarily measured in the Federal Republic of Germany by recording WWV (15 Mc/s). The fading rates varied between 6 and 16 (per min), their mean value being 11·25 (per min). Investigations by means of electronic differentiation of the received signal amplitude were performed on the same test link. For 50% of the time, the derivatives were above 3·5 db/s and for 10% of the time above 8·5 db/s.

Lack of sufficient data has, up to the present, prevented any clear dependence of fading on carrier frequency or distance to be established. Furthermore, the time of day, the season and the activity of the sun do not seem to have any clearly observable influence. More thorough investigations in this field appear desirable.

5. Long-period variations [14, 15]

For those long-period variations which are neither periodic nor quasi-periodic, again only statistical techniques for analyzing the data can be meaningfully used. Although one often assumes, for the sake of simplicity, a log-normal distribution for the long-period random variations, this is by no means always valid. A great number of distributions, whether measured over one month, one sun rotation or one year, are more complex than the simple log-normal distribution. In voluminous statistics from the Federal Republic of Germany, covering a total of 28 rotations of the sun, 50% of the distribution curves of a sun rotation were log-normal. About 25% could be split up into two log-normal populations, each valid over a different region of signal strengths; while the remainder could only be reduced to the log-normal distribution by splitting up into an even larger number of partial populations. However, it remains doubtful whether physical processes could be used to explain such complex splittings. The fading range, V_{10}-V_{90} was, on the average, about 20 db. This corresponds to a standard deviation of 8 db and is thus in agreement with the results of similar measurements in the U.S.S.R. Splitting up the data into different time blocks shows that during the night, the fading range is considerably greater than during the day. Hence, there seems to be a positive correlation between high field-strengths and large variability. Conversely, there is positive correlation between low field-strengths and small day-to-day variations. If there is a dependence on frequency, the effect is apparently caused by changes of the MUF. Radio paths crossing polar areas with high absorption show large variations of the hourly median values. The standard deviation is $\sigma = 10$ db.

The long-period distributions seem to be strongly influenced by the geographical position of the transmission path as well as the time in the sunspot cycle. This was to be expected. Further experience in this field is most desirable.

6. Diversity problems [2, 18, 20]

Of the various diversity techniques that can be used to reduce the influence of fading on the quality of reception, viz., space diversity, frequency diversity, polarization diversity, time diversity, only space diversity reception has been fairly thoroughly investigated.

Based upon a simple, but probably unrealistic, model of scatter theory, the spatial correlation function is often assumed to be Gaussian, viz:

$$\rho(d) = \exp\left\{-d^2/2\chi^2\right\} \tag{17}$$

where d is the separation distance perpendicular to the plane of propagation, and χ the so-called structure size. At the distance $d = \chi$ the correlation is stil l0·61. In practice, the value $\chi\sqrt{2}$ would be more suitable, at which distance $\rho(d) = 0{\cdot}37$. Experience and theory show that the optimum diversity effect is, for all practical purposes, already obtained at this distance, so that the expression " separation distance " or " correlation distance " seems to be justified for this parameter.

Since the Gaussian function representation of the spatial correlation is bound to special theoretical assumptions, it does not always agree with the measured results.

Theoretical studies, based on the *m*-distribution, gave time distributions for various diversity systems with uncorrelated and correlated signals.

In the United Kingdom, tests were made in the frequency range 6 to 18 Mc/s over distances of 2000 to 17 000 km, which indicated that the structure size χ, for space diversity was between 150 and 400 m, i.e., separation distances of 210 to 560 m, which correspond to 10 to 25 wavelengths.

In the United States, the average separation distance found for 540 kc/s was $29{\cdot}4\ \lambda \pm 17{\cdot}1\ \lambda$. At 85 kc/s, the United States succeeded in splitting up fading into two types, with fading periods of 7 min. and 1·5 min, and in determining the separation distances associated with these types to be 5 km for 7 min fading and 1 km for 1·5 min fading.

These findings were confirmed by recordings in the Federal Republic of Germany of the station WWV transmitting on 15 Mc/s. In addition, it was revealed that the separation distances required when specular reflection at the ionosphere is predominant are much greater than with scatter. Most frequently, cases were observed where the recordings suggested pure scatter, but where examination of the spatial correlation suggested a mixture of weak specular reflexion as well as scatter.

The same investigations showed, that separation distances transverse to the direction of propagation (15 λ for $\rho(d) = 0{\cdot}5$), are only half as large as those along the direction of propagation (30 λ for $\rho(d) = 0{\cdot}5$). Thus, for space diversity operation, antennae are almost always set up side-by-side instead of one behind the other. For pure scatter, when the operating frequency was above the MUF, the separation distance decreased to 1 to 2 λ for $\rho = 0{\cdot}5$. With normal reflected radiation, the separation distance turned out to be of the order of 100 λ and practically independent of frequency. The separation distances decreased with increasing distance between transmitter and receiver.

The improvement in reception to be achieved by space diversity has been studied in the United Kingdom, and the United States of America. When the correlation between the received signals on the two antennae approached zero, the 99·9% level was raised by 14 to 15 db. For $\rho = 0{\cdot}61$, the improvement was still 13 db, i.e., it was almost as good

Polarization diversity in the frequency range 6 to 18 Mc/s was studied in the United Kingdom. The antennae were at the same location, but arranged to respond to waves with mutually perpendicular polarization. The result was the same as that obtained with an equivalent spaced antenna separation of 240 to 480 m. Polarization diversity is, therefore, an effective means for improving HF reception under fading conditions. It is particularly useful where want of room prohibits the setting up of antenna systems suitable for space diversity.

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REPORT 322

REVISION OF ATMOSPHERIC RADIO-NOISE DATA

This Report, which replaces Report 65, was adopted by correspondence.

Because of its length, this Report has been published separately.

STUDY GROUP VI

(Ionospheric propagation)

Terms of reference:

To study all matters relating to the propagation of radio waves through the ionosphere, in so far as they concern radiocommunication.

Chairman: Dr. D.K. Bailey (U.S.A.)
Vice-Chairman: Dr. E.K. Smith (U.S.A.)

INTRODUCTION BY THE CHAIRMAN, STUDY GROUP VI

1. The position with regard to questions or special problems affecting new countries

Study Group VI, in dealing with the technical problems associated with radiocommunication by means of the ionosphere, has become increasingly aware of the need for presentation, on a world-wide basis, of much ionospheric information in a form suitable for application to communications (including broadcasting). In particular, the Study Group is now aware of a number of special problems associated with the tropical regions in which most of the new countries lie. The present position is given below under a series of specific topics:

2. The prediction of MUF (maximum usable frequency)

The prediction of MUF between two given points on the earth's surface has been under study in many countries for nearly a quarter of a century. During this time, and especially since the IGY, a great deal of ionosonde and other information of a more practical kind has been accumulated and studied, and prediction services exist in several countries. The Study Group is now engaged in the production of a C.C.I.R. atlas of ionospheric characteristics which will allow users in all parts of the world to estimate the MUF for a particular requirement as a function of time of day, season and level of solar activity. This work is in the hands of an International Working Group, established under Resolution 10. Report 256 should also be noted. Particular attention is being paid to the low latitudes.

The successful completion of Report 246 on ionospheric indices, and the satisfactory position indicated by such texts as Recommendation 232 and Resolution 4, and Study Programme 193(VI), will facilitate this work considerably.

3. The prediction of sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 Mc/s.

A long-standing International Working Group has been studying this problem (see Recommendation 177 (Warsaw, 1956) and Resolution 7). The production of a C.C.I.R. method for use throughout the world has proved difficult, but much useful preliminary work has been done. The recent reorganization of the International Working Party, as indicated in Resolution 7, is expected to lead to the early production of a method of calculation suitable for provisional adoption by the C.C.I.R. As with MUF, particular attention will be paid to low latitudes.

4. The prediction of sky-wave field strength at frequencies below 1·5 Mc/s.

Study Group VI has now embarked on a systematic programme, designed to replace the old Cairo Curves (1938), of night-time sky-wave field strength as a function of distance, geographical position and local time. The original curves were applicable to middle and high latitudes primarily in the European area. They are known to be quite inapplicable to tropical latitudes, and are probably inapplicable in middle latitudes, not only in the southern hemisphere, but also in northern regions in longitudes far removed from Europe. For the European region, the Cairo Curves have now been replaced by the propagation curves contained in Report 264. An International Working Party has been established by Resolution 12 to prepare similar information for other parts of the world, and particularly for the tropics and southern hemisphere temperate and sub-tropical regions.

The problem of producing propagation curves for long-distance propagation at frequencies below 150 kc/s is to be reviewed by an informal Working Party, established by Resolution 13. The matter of the detailed organization of the production of such curves will await the report of this Working Group. However, the low and very-low frequencies are of less immediate concern to new countries in low latitudes, because of the high background levels of atmospheric radio-noise, especially in Africa.

5. Atmospheric radio-noise

The limitations imposed by the background of atmospheric radio-noise are particularly severe in many tropical regions, and are therefore of concern to a number of new countries. An extensive revision of Report 65 (Report 322) is now being prepared for publication. Recommendation 372 recommends that the Report be used until such time as further revision seems desirable. The revised Report takes account of much new observational material from various parts of the world including the tropics.

6. Lightning-stroke counters

The C.C.I.R., (through Study Group VI), has designed and tested simple electronic devices for counting nearby lightning strokes, and has approved one of particular design. It has strongly urged Administrations, primarily through the W.M.O., to operate such devices and report the results, so that they may be used to improve the present noise maps.

7. New Question

The existence of special problems of HF radiocommunication associated with the equatorial ionosphere has been recognized in Quetion 248 (VI). Such effects as equatorial flutter fading, which can be a very severe difficulty for several new countries, are clearly included within the scope of the Question.

8. Relations with other Study Groups

Study Group VI has certain subjects for study which bear some relation to the work of Study Groups IV (Space systems) and XII (Tropical broadcasting). These subjects are likewise of interest to new countries.

OPINION 6 *

IDENTIFICATION OF PRECURSORS INDICATIVE OF SHORT-TERM VARIATIONS OF IONOSPHERIC PROPAGATION CONDITIONS

(Study Programme 93(VI))

(Los Angeles, 1959)

The C.C.I.R.,

CONSIDERING

(a) that increased efficiency in many practical uses of ionospheric radio propagation would result if reliable identification of precursors of variations in propagation conditions could be made;

(b) that such identification is most important for ionospheric storms;

(c) that solar phenomena appear to be an important source of precursors;

IS UNANIMOUSLY OF THE OPINION

that the U.R.S.I. should be asked the following Question:

what solar events or other phenomena may be used for reliable prediction of short-term variations in ionospheric radio-propagation conditions, particularly ionospheric storms?

RESOLUTION 4

DISSEMINATION OF BASIC INDICES FOR IONOSPHERIC PROPAGATION

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that R_{12}, I_{F2} and Φ have been recommended as indices for use in ionospheric propagation (see Recommendation 371);

(b) that it is desirable to make available to Administrations the most recent observed and predicted values of these indices;

UNANIMOUSLY DECIDES

1. that the Director, C.C.I.R., should be requested to make arrangements:

1.1 to obtain the most recent data on sunspot numbers and solar noise-flux at 10 cm wavelength which are necessary for the calculation of R_{12} and the monthly-mean value of Φ;

1.2 to obtain the monthly-median values of ionospheric data which are necessary for the calculation of I_{F2};

1.3 to calculate the monthly values of R_{12}, Φ and I_{F2};

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* This Opinion was formerly designated " Resolution 45 ".

2. that the values of these indices should be published in the " Telecommunication Journal ", together with any predictions of the indices, and the estimated prediction errors, made by those Administrations which have had special experience in the prediction of ionospheric parameters or solar activity;

3. that the Director, C.C.I.R., should make arrangements for the dissemination of this information by more rapid methods to those Administrations which require it;

4. that the organizations which are at present responsible for the basic solar and ionospheric data, used in the production of the indices, should be urged to continue to make the necessary observations and to forward them to the Director, C.C.I.R.

OPINION 7

PREDICTION OF INDICES OF SOLAR ACTIVITY

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that solar activity, as defined by various numerical indices based on observations of solar phenomena, has an important influence on the ionosphere, and hence on radiocommunications affected by the ionosphere;

(b) that the methods of predicting the future trend of solar activity now depend mainly on statistical studies of the series of sunspot numbers;

IS UNANIMOUSLY OF THE OPINION

that the International Astronomical Union should be asked the following Question:

is it possible to improve the accuracy of predictions of solar activity, in particular of sunspot numbers, by making use of recent advances in the knowledge of solar physics?

QUESTION 247 (VI)

CHOICE OF BASIC INDICES FOR IONOSPHERIC PROPAGATION

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

that Recommendation 371 defines certain indices of solar activity and recommends their use;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what indices of solar activity can be devised which would be preferable to those recommended;

2. what are the best indices for the prediction of:

2.1 D-layer absorption at HF;

2.2 the D-layer reflection characteristics at MF and lower frequencies?

STUDY PROGRAMME 193 (VI) *

PREDICTION OF SOLAR INDEX

(Warsaw, 1956 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the sun is the primary cause of many geophysical phenomena, in particular, of the formation of the ionosphere and of most of its variations;

(b) that the gradual waxing and waning of solar activity, with intervals of approximately eleven years between maxima, corresponds closely with many slowly varying indices of geophysical activity

(c) that the slowly varying component of solar and geophysical activity can be estimated from many solar indices, based on optical and radio measurements, by geomagnetic measurements and ionospheric soundings;

(d) that the reliable prediction of such parameters is of the utmost importance to radio propagation work;

(e) that autocorrelation techniques have been studied in various countries;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. predictions by all published autocorrelation, or quasi-autocorrelation, methods should be compared with one another and with the results of subsequent observations for recent years; these comparisons should be continued on a current basis;

2. more detailed examination of those combinations of autocorrelation, empirical and other methods which may yield more accurate predictions.

STUDY PROGRAMME 194 (VI) **

IDENTIFICATION OF PRECURSORS INDICATIVE OF SHORT-TERM VARIATIONS OF IONOSPHERIC PROPAGATION CONDITIONS AND METHODS FOR DESCRIBING IONOSPHERIC DISTURBANCES AND THE PERFORMANCE OF RADIO CIRCUITS

(London, 1953 — Warsaw, 1956 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that it is desirable to have an index, or indices, suitable for short-term forecasts of ionospheric disturbances;

(b) that long-term indices for ionospheric propagation are not satisfactory for indicating short-term variations in the ionosphere;

(c) that ionospheric propagation disturbances may result from either corpuscular or photon radiation from the sun;

* This Study Programme, which replaces Study Programme 100, does not arise from any Question under study.
** This Study Programme, which replaces Study Programme 93, does not arise from any Question under study.

(d) that a correlation has been found between short-term variations of ionospheric propagation conditions and certain indices of magnetic phenomena and solar eruptions;

(e) that it is desirable to have forecasts of ionospheric disturbances, expressed in terms which are at the same time meaningful to operators of ionospheric communications systems, and appropriate for use in the subsequent evaluation of the reliability of the forecasts;

(f) that the application of ionospheric disturbance forecasts varies widely with the type of radio circuit in question;

(g) that it is desirable that the forecasts issued by different agencies should be expressed in a way which facilitate comparison between them;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the possibility of selecting particular kinds of solar observations or observations of other phenomena, such as geomagnetic activity, cosmic rays, whistlers, etc., which can be made objectively, and which may be usefully employed for short-term predictions of ionospheric propagation conditions;
2. the possibility of describing ionospheric disturbances in terms comparable with the forecasts;
3. the possibility of establishing a common method for the description of ionospheric disturbances, for use in forecasting and verification, taking account of such factors of the disturbance as: starting time, areas affected, movement, change of size, duration and magnitude;
4. the possibility of defining indices, which describe the intensity of ionospheric disturbance for each of a series of equal short intervals and which might be combined into an estimate of the importance of the disturbance for the whole period;
5. the relationship between the characteristics of the disturbance, as described by the common method (see § 3), and the expected performance of radio circuits of various kinds;
6. the possibility of defining a more objective scale of the importance of sudden ionospheric disturbances, for example, by studying changes in the mean field-strength of atmospherics in the frequency band 20 to 40 kc/s.

RESOLUTION 5

IMPROVEMENT IN THE NETWORK OF IONOSPHERIC SOUNDING STATIONS

(Report 151)

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that a network of ionospheric sounding stations is necessary for the production of basic data for ionospheric propagation predictions and for subsequent comparisons with the performance of radio services;

(b) that the increasing importance of earth-space communications will require continued collection of the information derived as a matter of routine, together with possible increases and changes;

(c) that the existing network of ionosphericsounding stations provides synoptic information which is important for scientific studies such as those of interest to U.R.S.I.;

(d) that, for radiocommunications, it is important that large geographical gaps in the network, whether in latitude or longitude, be avoided;

UNANIMOUSLY DECIDES

1. that Administrations should take all possible steps towards continuation of the ionosonde network, giving special attention to the filling of large gaps in the geographical coverage;

2. that continuation of the interchange of basic data through World Data Centres and other established channels should be encouraged;

3. that arrangements should be made for the international exchange of new information now becoming available through " topside " soundings;

RESOLUTION 6

USE OF SATELLITE-BORNE IONOSONDES IN ORBITS ABOVE THE F2-PEAK (TOPSIDE SOUNDERS) FOR THE STUDY OF IONOSPHERIC PROPAGATION

(Report 151)

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that ionospheric sounders, carried in orbiting earth-satellites, provide a means for mapping foF2 with high geographical resolution;

(b) that such satellite-borne sounders provide a relatively convenient means for mapping foF2 over inaccessible parts of the earth, such as oceanic and polar regions;

(c) that representations of ionospheric conditions can probably be markedly improved when these new basic data become available;

(d) that the reliability of long-term prediction of ionospheric characteristics for communication purposes should therefore increase;

UNANIMOUSLY DECIDES

1. that Administrations involved in satellite programmes should place all possible emphasis on this new method of ionospheric sounding;

2. that other Administrations should cooperate in this work through the operation of other telemetering stations on the ground;

3. that the basic data on foF2, obtained from satellite-borne sounders, should be interchanged on the same principles as those from ionospheric soundings from the ground.

STUDY PROGRAMME 195 (VI) *

PROPAGATION BY WAY OF SPORADIC-E AND OTHER ANOMALOUS IONIZATION IN THE E- AND F-REGIONS OF THE IONOSPHERE

(Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that sporadic-E propagation may play an important role in HF communications out to great distances and, frequently, in the lower part of the VHF band, up to distances of about 2300 km;

(b) that sporadic-E data from ionosondes do not provide adequate statistics for the prediction, for oblique paths, of the field strength of the received signal or of the transmission loss;

(c) that data on propagation by sporadic-E and other abnormal ionization obtained from continuous-wave recordings, and from fixed frequency pulse measurements at oblique incidence, provide statistical data of the type needed by engineers;

(d) that with continuous-wave observations, it is frequently very difficult to separate sporadic-E from other anomalous ionization in the E- and F-regions and from tropospheric propagation effects;

(e) that the path configuration plays an important part in those modes of propagation, where reflections from field-aligned ionization seem to occur, as for example, auroral-type phenomena;

(f) that, whilst it may be possible to exploit these anomalous modes, they are also a potential source of interference;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. field-strength or transmission loss of signals propagated by abnormal modes in the E- and F-regions at frequencies in the upper part of the HF band and the lower part of the VHF band. In analyzing the measurements, attention should be paid to:
   - — separation of the effects of the different modes of propagation;
   - — influence of frequency, distance, time of day, season and solar cycle;
   - — the effects of field-aligned ionization;
   - — the vertical and azimuthal angles of arrival of the different abnormal modes;
   - — characteristics of the terminals, such as antenna gains and directivities, site configuration, receiver characteristics and calibration procedures, transmitter power, and transmission-line losses;

2. comparison, where possible, of the results so obtained with data obtained by means of ionosondes (for example, foEs);

3. preparation of simple world-wide and regional charts of received signal level relative to free-space, or of transmission loss, at suitable frequencies for those abnormal modes which are found to be significant.

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* This Study Programme, which replaces Study Programme 143, does not arise from any Question under study.

STUDY PROGRAMME 196 (VI) *

INTERMITTENT COMMUNICATION BY METEOR-BURST PROPAGATION

(Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that meteor-burst propagation has been demonstrated to be a feasible means of intermittent communication in the lower part of the VHF band over a useful range of distances extending from a few hundred kilometres to somewhat more than 2000 km;

(b) that the extensive propagation data now available have not yet been demonstrated to be adequate for the design of efficient systems using this mode of propagation;

(c) that, while experimental systems using this mode of propagation provide propagation data, the data thus obtained are not always capable of general application;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the determination of the statistical parameters of the received signals required for the proper design and operation of intermittent communication systems;
2. the dependence of the diurnal and seasonal variation of these signal parameters for given system parameters upon;
   - — geographical location,
   - — path orientation,
   - — solar and geomagnetic activity;
3. the influence of the system parameters such as frequency, gain, directivity and orientation of the antennae on the parameters of the received signals;
4. the problems arising from interference both to and from other transmissions due to meteor-burst propagation, Es-reflections, and F-layer reflections at times of high solar activity.

STUDY PROGRAMME 197 (VI) **

PULSE TRANSMISSION TESTS AT OBLIQUE INCIDENCE

(Geneva, 1951 — London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that both fixed-frequency and variable-frequency pulse test transmissions have been made with both experimental and commercial equipment;

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* This Study Programme, which replaces Study Programme 146, does not arise from any Question under study.

** This Study Programme, which replaces Study Programme 151, does not arise from any Question under study.

(b) that the use of oblique-incidence pulse transmissions would be of great assistance in the study of many problems in ionospheric propagation of direct concern to the C.C.I.R.;

(c) that, in particular, such test transmissions enable separation of propagation into individual modes, so that the range of frequencies usable for each mode may be delineated and the corresponding intensity, direction of arrival and delay time at the receiver are measurable;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the various modes of propagation and their frequency limits in relationship to:

1.1 standard MUF calculations for the respective modes;

1.2 operational MUF on circuits operating simultaneously on the same path;

2. loss compared to free space or transmission loss of various modes, with a view to explaining observed loss on operating circuits.

3. investigation of off-great circle modes of propagation by measurements of direction of arrival of the individual modes;

4. the occurrence of the one-hop Pedersen ray propagation at various distances beyond about 4000 km and in various parts of the world, with particular reference to the propagation of waves to very great distances without intermediate ground-reflection;

5. the effect of Es reflections, F-region spread echoes and abnormal absorption on oblique pulse transmissions;

6. the relation of oblique pulse transmissions to vertical incidence soundings at appropriate points along the transmission path;

7. other factors which are appropriate to oblique pulse measurements including:

— the nature of fading,

— focusing,

— reciprocity,

— magneto-ionic double refraction,

— vertical angle of arrival.

RESOLUTION 7 *

SKY-WAVE FIELD STRENGTH AND TRANSMISSION LOSS AT FREQUENCIES BETWEEN THE APROXIMATE LIMITS OF 1·5 AND 40 Mc/s

(Study Programme 198 (VI))

(Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the estimation of sky-wave field strength and transmission loss at frequencies above 1·5 Mc/s is of great practical importance;

* This Resolution replaces Resolution 48.

(b) that a single method of estimation, based on the best technical information, is required by the I.F.R.B. in the treatment of frequency notifications;

(c) that, of the methods available within the various Administrations, each is likely to offer certain advantages;

(d) that to develop a single method based on the best technical information, it will eventually be necessary to make extensive comparisons with experimental data;

UNANIMOUSLY DECIDES

1. that the Working Party, originally set up by Recommendation 177, should continue and should consist of experts from Administrations and organizations concerned with this problem (e.g.):

United States of America
France
United Kingdom
Japan
Federal Republic of Germany
India
Czechoslovak S.R.
U.S.S.R. and
I.F.R.B.;

2. that these Administrations and organizations should submit the name of their expert to the Chairman of Study Group VI through the Director, C.C.I.R.;

3. that the Chairman, Study Group VI should appoint a Chairman for the Working Party from among the experts so named;

4. that the Working Party may invite the assistance of experts from other Administrations and from international organizations;

5. that the Working Party should develop:

5.1 as soon as possible, a simple provisional method adapted to computers of modest capacity;

5.2 a detailed, provisional method suitable when circuit parameters are more fully known;

6. that Administrations and international organizations should make available to the Working Party, through the Director, C.C.I.R., any existing reliable field-strength measurements made in a manner consistent with the provisions of Report 253;

7. that the Administrations, Members of the C.C.I.R., should continue measurements of field strength and radiated power of transmitters, with a view to a comparison of the methods with experimental data;

8. that, in view of the great amount of work involved in the comparison of the results of calculations by the various methods with experimental data, the Administrations, Members of the C.C.I.R., should render all possible assistance to the Working Party, such as assisting in making calculations for circuits under study;

9. that since the work on measurements of field strength will require much time, during which continuous coordination will be needed, the task of the Working Party should be conducted by correspondence, as well as by meetings;

10. that the C.C.I.R. Secretariat shall collaborate with the Working Party, for example, by collecting and collating material submitted by Administrations and organizations and preparing summaries for the Working Party.

STUDY PROGRAMME 198 (VI) *

ESTIMATION OF SKY-WAVE FIELD-STRENGTH AND TRANSMISSION LOSS FOR FREQUENCIES BETWEEN THE APPROXIMATE LIMITS OF 1·5 AND 40 Mc/s

(Geneva, 1951 — London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

that present methods of estimating sky-wave field-strength and transmission loss are not always sufficiently accurate;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. detailed theoretical investigations of long distance ionospheric propagation;
2. improvements in methods of estimation, taking into account for example, off great-circle propagation, ground scatter and the influence, not only of the strength of the magnetic field of the earth, but also of its direction relative to the direction of propagation;
3. improvements in the estimation techniques for paths traversing the equatorial or the auroral zone, and for the short paths, up to 800 km, involved in tropical broadcasting;
4. improvements in the estimation of night-time attenuation;
5. statistical comparisons between the calculated and measured values of the field-strength or transmission loss, taking into account the values of the propagation parameters for the period of comparison, as well as the influence of the actual polar diagrams of the antennae;
6. measurements of absorption from both vertical and oblique incidence pulse transmissions on a number of frequencies especially in regions of high absorption;
7. application of the temporal variations of the absorption of extraterrestrial noise and of field strengths of signals received from spacecraft.

Note : In making these studies, reference should be made to Study Programmes 148 (VI), 195 (VI), 197 (VI) and 203 (VI).

RESOLUTION 8 **

REVISION OF ATMOSPHERIC RADIO-NOISE DATA

(Geneva, 1951 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the information in Report 322 *** requires continual revision;

* This Study Programme, which replaces Study Programmes 144 and 145, does not arise from any Question under study.
** This Resolution, together with Recommendation 372, replaces Recommendation 315.
*** Report 322 will be published as a separate booklet.

(b) that improved equipment now in operation should provide a continually increasing amount of data available for such revision;

(c) that, before any further revision of Report 322 can be undertaken, there is a need for coordination of these data;

(d) that the new data should make possible further extension of the scope and improvement in the accuracy of Report 322;

UNANIMOUSLY DECIDES

1. that the Working Group on atmospheric radio-noise, designated by the Chairman, Study Group VI, should continue to collect data from all sources relevant to Report 322;

2. that material submitted to the Working Group should be in a form which facilitates comparison with Report 322, more specifically, such data should include values of mean noise-power and of more detailed short-term characteristics, and should show whether:

2.1 that the relative noise-intensities at different locations suggest that the noise contours should be amended;

2.2 that the relative noise-intensities at different frequencies suggest that the frequency curves should be amended;

2.3 that the ratios of the upper and lower decile values to the median value should be amended;

2.4 that the curves of probability distribution of the measured amplitudes should approximate closely to one of the relevant family of idealized curves presented in Report 322;

3. that the Working Group should keep the data under continual review and should formulate proposals for a further revision of Report 322 when it appears opportune.

RESOLUTION 9

WORLD DISTRIBUTION AND CHARACTERISTICS OF ATMOSPHERIC RADIO-NOISE

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that Report 65 has been used as a source of information on the geographical distribution and temporal variations of the mean power of atmospheric radio-noise;

(b) that a programme of measurements, carried out since the preparation of Report 65, has made available improved information, not only on the noise power, but also on other characteristics of the noise which are required in estimating the extent to which it interferes with radio services;

(c) that this information has been studied by the Working Group established under Recommendation 315 * and has been incorporated in a new Report designed to replace Report 65;

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* Replaced by Resolution 8.

UNANIMOUSLY DECIDES

1. that the Director, C.C.I.R., in consultation with the Chairman, Study Group VI and the Working Group on atmospheric radio noise (see Recommendation 315 *), should arrange for the adoption by correspondence of the revision of Report 65 ** which has been prepared by the Working Group;

2. that the Director, C.C.I.R. should then arrange for the publication, at as early a date as possible, of this Report, together with the comments, if any, by Administrations.

STUDY PROGRAMME 199 (VI) ***

MEASUREMENT OF ATMOSPHERIC RADIO-NOISE

(Geneva, 1951 — London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the atmospheric noise data in Report 322 ** are available for provisional use;

(b) that this Report now contains information on the short-term amplitude probability distributions of noise and on prediction uncertainties, in addition to improved information on the noise-power distribution over the world, as received on a short vertical grounded antenna;

(c) that these and other characteristics of the noise are known to be important in determining the interference to radio services;

(d) that additional measurements are required for further revision of this Report and to extend its scope;

(e) that a knowledge of the distribution of lightning discharges, the power radiated by them and the influence of propagation is valuable in estimating the intensity and properties of radio noise;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the world distribution of noise power, either directly or by deduction from other characteristics, with the existing or an augmented network of stations;

2. the other characteristics of the noise already described in Report 322;

3. the measurements, at stations with suitable facilities, of atmospheric noise on types of directional antennae in common use for radiocommunication, and the correlation of the results with information on the distribution of thunderstorms;

4. the frequency of occurrence of lightning discharges throughout the world:
   - — by the use of networks of counters designed to record local discharges;
   - — by the use of direction-finding networks designed to locate thunderstorms at a distance;

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* Replaced by Resolution 8.

** It is intended that this long Report (Report 322) should not appear in the printed documents of the Xth Plenary Assembly.

*** This Study Programme, which replaces Study Programme 154, does not arise from any Question under study.

5. the intensity and nature of the noise from individual lightning discharges and the influence of propagation;

6. the distributions, over short periods of time for which the statistics are stationary, of the durations of noise impulses and of the intervals between them; these distributions should be measured as a function of threshold;

7. the study of the power spectrum, or the corresponding autocorrelation function, of the waveform of the noise envelope;

8. the further development of methods of using statistical data on the characteristics of noise, in addition to its mean power, for use in assessing the interference to radio services;

9. the relative importance of atmospheric noise, as compared with other types of interference, as a limiting factor in radiocommunication.

RESOLUTION 10

BASIC LONG-TERM IONOSPHERIC PREDICTIONS

(Study Programme 200 (VI))

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that many Administrations are now convinced of the need of a continuous world-wide representation of ionospheric parameters;

(b) that Study Programme 200 (VI) calls for a study of the extent to which basic prediction material could be improved by different methods of presentation and interpolation (e.g., by the use of world charts in UT or by automatic interpolation methods);

(c) that Study Programme 200 (VI) also calls for a statistical examination of the day-to-day variation in MUF in terms of season, solar cycle, location etc., so that practical methods may be devised whereby this factor can be introduced into monthly predictions;

(d) that procedures exist* which automatically include, by virtue of functional properties, the representation of ionospheric propagation parameters on the basis both of UT and of Local Time;

(e) that such procedures provide continuous interpolation among observational data, and can allow for the observed variations with solar activity, time and geographical position, as well as for physical laws which influence the ionization;

(f) that a procedure, based mainly on objective methods of numerical analysis, now exists for the analysis and presentation of ionospheric parameters, such as foF2 and M (3000)F2, as determined by the world-wide ionosonde network*;

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* A selection of references bearing on this point will be found in the bibliography.

UNANIMOUSLY DECIDES

1. that a small Working Party of experts should be formed, to draw up specifications for a provisional C.C.I.R. atlas, representing world-wide ionospheric characteristics, for the purpose of assisting radiocommunications, and to organize its production and presentation;
2. that this Working Party should give careful consideration to the employment of means of data analysis, having a maximum practicable degree of objectivity without neglecting physical considerations, especially in regions suspected of presenting anomalies;
3. that this Working Party should contain about six expert members, to be nominated from among Administrations known to be active in this field;
4. that participating Administrations should make known to the Director, C.C.I.R., the name, and address for purposes of direct correspondence, of their expert, member not later than 1 June, 1963;
5. that the Chairman, Study Group VI should appoint a chairman from among the experts who are thus nominated;
6. that the I.F.R.B. and the Secretariat of the C.C.I.R. should be invited to participate in the Working Party.

ANNEX

1. As a guide to the Working Party to be set up under the terms of this Resolution, it is suggested that the first report should contain 32 charts, depicting for example, the world-wide distribution of the quantities foF2 and MUF(4000)F2, for the following combinations of parameters:
   - four values of UT, namely 0000h, 0600 h, 1200 h, and 1800 h;
   - two months, namely June and December;
   - two values of Index, one low and one high, say 5 and 125.
2. Any member of the Working Party, who has or knows of, a suggestion for taking into account some special ionospheric features of a particular geographical region, should send a statement to the Chairman, defining the limits of the region concerned and indicating the physical reason necessitating the suggested special treatment. Suitable mathematical formulae for representing variations within the region may facilitate taking account of the special ionospheric features in a computer programme.
3. A meeting of the Working Party should be arranged when the work by correspondence has advanced to a point which makes it necessary.

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1. Rawer, K. Note on the longitude effect in the F-region. *Atmos. and Terr. Phys.*, 3, 123-124 (1953).
2. Jones, W. B. and Gallet, R. M. The representation of diurnal and geographic variations of ionospheric data by numerical methods. *Telecommunication Journal*, **29**, 5, 129-149, (May, 1962).
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4. Sandoz, O. A., Stevens, E. E. and Warren, E. S. The development of radio traffic frequency prediction techniques for use at high latitudes. *Proc. IRE*, **47**, 681-688 (May, 1959).
5. Eyfrig, R. W. The effect of the magnetic declination on the F2 layer (to be published in *Annalen der Geophysik*, 1963).

RESOLUTION 11 *

BASIC PREDICTION INFORMATION FOR IONOSPHERIC PROPAGATION

(Study Programme 200 (VI))

(Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the objectives of Study Programme 200 (VI) have not yet been attained;

(b) that the I.F.R.B. has made known its urgent need for:

— the most reliable data available at the present time on the median F2 MUF, for application on a world-wide scale;

— information which will assist in identifying those circuits for which operational results differ appreciably from MUF predictions;

UNANIMOUSLY DECIDES

1. that interested Administrations should make available to the I.F.R.B., by way of information or for purposes of consultation, operational data on radio circuits, especially those for which it appears, from operational experience or from monitoring observations for instance, that divergences of practical importance exist between basic predictions and operational results;

2. that these data should comprise statistics of fade-in and fade-out times and should indicate the effects of factors other than propagation conditions (for example, frequency changes made for operational reasons);

3. that, in principle, all relevant details of the working conditions should be stated;

4. that the information should be transmitted to the I.F.R.B. through the Chairman, Study Group VI and the Director, C.C.I.R.

STUDY PROGRAMME 200 (VI) **

BASIC PREDICTION INFORMATION FOR IONOSPHERIC PROPAGATION

(London, 1953 — Los Angeles, 1959 — Geneva 1963)

The C.C.I.R.,

CONSIDERING

(a) that the production of basic predictions for ionospheric propagation involves problems which are not yet fully solved;

(b) that, nevertheless, extensive practical use is made of predictions by radio operating services and Administrations***;

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* This Resolution replaces Recommendation 316.

** This Study Programme, which replaces Study Programme 149, does not arise from any Question under study.

*** See Report 255.

(c) that the application of basic prediction information, as supplied to various Administrations and centres, to specific operational problems, has revealed occasional large discrepancies between predictions and operational results, even though the solar activity may have been correctly forecast. These discrepancies may be attributed to such causes as:

— different interpretations placed upon the basic ionospheric observations;

— different methods of converting basic ionospheric observational data into predictions;

— inadequate understanding and lack of research concerning the role played by the E-, Es-and Fl-layers, for the actual modes of propagation and for the effects of ground and ionospheric scatter;

— the need for suitable methods of interpolation in the preparation of basic world predictions especially for regions from which no ionosonde data are available;

— differences in the statistical significance of the ionospheric and operational data sampled, and in the methods of assessing the circuit performance of the various classes of service;

(d) that the distinction between operational, standard and classical MUF* is not yet familiar to many users.

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the suitability of present methods for predicting oblique-incidence MUF from vertical data for both short and long paths;

2. the ratio of operational MUF to standard MUF so that a correction factor dependent on system parameters such as power, type of service, and information rate could be introduced into predictions wherever it is needed;

3. the extent to which basic prediction data could be improved by different methods of interpolation;

4. the role played by ionization in the layers of the E-region for both short and long paths;

5. practical methods of introducing into predictions such subjects as propagation modes, the related angles of arrival and departure, and the effects of ionospheric-layer tilts;

6. propagation off the great-circle path;

7. a statistical determination in terms of season, solar cycle, location, etc. of the day-to-day variation of both standard and operational MUF so that practical methods may be devised whereby this factor can be introduced into monthly predictions.

OPINION 8

HIGH-FREQUENCY PROPAGATION BY DUCTING ABOVE THE F2-REGION PEAK

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that propagation of high-frequency waves may be possible along ionization ducts aligned with the earth's magnetic field;

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* See Recomendation 373.

(b) that such propagation may be useful as a means of providing communication but, on the other hand, may be capable of causing interference;

IS UNANIMOUSLY OF THE OPINION

1. that the attention of Administrations should be drawn to:
   - the possibilities of the propagation of both wanted and unwanted HF signals, along ionization ducts aligned with the earth's magnetic field, especially at times of high solar activity;
   - the desirability of determining, for example, by further experiments, involving observations at magnetically conjugate points, whether this phenomenon is of potential importance to communications;
2. that the U.R.S.I. should be invited:
   - to comment on the possible practical importance of high-frequency propagation along field-aligned ducts;
   - to advise on the type of experiment that might be carried out by Administrations having suitable facilities.

QUESTION 248 (VI)

SPECIAL PROBLEMS OF HF RADIOCOMMUNICATION ASSOCIATED WITH THE EQUATORIAL IONOSPHERE

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

that HF radiocommunications for paths which cross or follow close to the magnetic equator are known to experience certain difficulties associated with the equatorial ionosphere;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the phenomena peculiar to ionospheric propagation at or near the magnetic equator;
2. what are the effects of these phenomena on radiocommunication as a function of:
   - class of emission,
   - antenna characteristics,
   - frequency,
   - geographical location, orientation and length of propagation path,
   - time of day, month and phase of solar cycle;
3. what are the physical mechanisms involved? *

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* The Director, C.C.I.R. is requested to transmit this text to the U.R.S.I. for comment, drawing particular attention to §3.

STUDY PROGRAMME 153 (VI) *

MEASUREMENT OF MAN-MADE RADIO-NOISE

(Los Angeles, 1959)

The C.C.I.R.,

CONSIDERING

(a) that man-made radio-noise is frequently the limiting factor in the reception of radio signals over a wide frequency range, particularly during daylight hours, when atmospheric noise is low;

(b) that the dynamic characteristics, as well as the geographical, time and frequency dependence of man-made radio-noise are entirely different from those of atmospheric noise;

(c) that information on the relative importance of atmospheric and man-made radio noise is needed for future revisions of Report 322;

(d) that previous measurements of man-made noise have largely been concentrated on the individual sources, the principal objective being the reduction in noise rather than a determination of the composite effect throughout given areas;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the investigation of the level of composite man-made radio-noise, as a function of geographic location, frequency, and time of day;
2. the investigation of the statistical characteristics of composite man-made radio-noise, as a function of the above variables, during short-time intervals as well as for day-to-day variation;
3. the determination of the correlation of man-made radio-noise levels with population density, industrial activity, electric power consumption, and other factors;
4. the determination of the types of measurement most significant for the evaluation of the interference potential of man-made radio-noise for different types of service, for example, peak, quasi-peak, r.m.s. voltage, average envelope voltage, average logarithm, and probability distribution of the amplitudes.

STUDY PROGRAMME 201 (VI) **

WHISTLER MODE OF PROPAGATION

(Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that ionospheric propagation by the so-called " whistler mode ", frequently permits reasonably efficient propagation at frequencies below about 30 kc/s, along paths lying approximately along the lines of the earth's magnetic field and therefore extending far out into space beyond the region of maximum ionization in the ionosphere;

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* This Study Programme does not refer to any Question under study.

** This Study Programme, which replaces Study Programme 141, does not arise from any Question under study *(b)* that such propagation can, under certain conditions, provide a means of communication, but on the other hand can produce harmful interference;

(c) that understanding of the mechanism of the whistler mode of propagation is still very imperfect;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the potential usefulness of the whistler mode for communication;
2. the interference potentialities of signals propagated by the whistler mode;
3. the calculation of field-strength or transmission loss for waves propagated by the whistler mode, for various positions of the terminal points of the path relative to the earth and the ionosphere — e.g. on the surface of the earth and in or above the ionosphere;
4. further development of the mathematical analysis.

STUDY PROGRAMME 202 (VI) *

IONOSPHERIC-SCATTER PROPAGATION

(Geneva, 1951 — London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that many aspects of ionospheric-scatter propagation remain for study even though fully designed communication systems are in regular use as a result of knowledge gained from experimental ionospheric-scatter links;

(b) that several links are available for further experimental work;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the dependence of short-term fluctuations and of the diurnal and seasonal variations of the hourly median received signal-intensity upon:
   — geographical location,
   — path orientation,
   — solar and geomagnetic activity,
   — occurrence of Es ionization,
   — meteoric ionization,
   — meteorological factors;
2. the characteristics of the received signal, such as multi-path and Doppler-shifted components, entailing the development of special modulation techniques to obtain the maximum useful bandwidths and information rates;

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* This Study Programme, which replaces Study Programme 147, does not arise from any Question under study.

3. the influence upon the multipath characteristics and the intensity of the received signal of:
   — antenna directivity,
   — antenna plane-wave gain,
   — antenna orientation,
   — path length,
   — frequency,
   — ionospheric and ground characteristics;

4. the use of diversity methods to reduce the short-term variations of received signal intensity;

5. the methods of reducing to a minimum, e.g. by an appropriate selection of frequencies, the interruption to ionospheric-scatter circuits caused, for instance, by polar cap absorption;

6. the problems arising from the occurrence of Es-reflections and of F-layer reflections at times of very high solar activity, with special reference to interference both to and from other transmissions.

STUDY PROGRAMME 203 (VI) *

BACK-SCATTERING

(Geneva, 1951 — London, 1953 — Warsaw, 1956 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that back-scatter phenomena yield direct information at the transmitting station of the performance of the frequency used, of the modes of propagation, and of the effectiveness of various antennae for a given service;

(b) that, nevertheless, because of losses of energy (particularly from the scattering process but also from the varying path attenuation), the absence of echoes from a particular range, with present techniques and sensitivity, does not necessarily indicate that communication with a station at that range is impossible;

(c) that back-scatter phenomena confirm that the operational MUF may exceed the classical MUF;

(d) that, nevertheless, if the skip-distance is varying with azimuth, and the beamwidth is more than a few degrees, appreciable errors can be made in measurements of skip-distance;

(e) that there are indications that long-distance back-scatter, although coming predominantly from the ground, may be received from ionospheric regions, and that, in consequence, large errors in measurement may be produced:

(f) that the back-scatter plan position indicator (PPI), is especially suitable for studying the movement of Es-clouds;

(g) that back-scatter phenomena can be of assistance in identifying the modes of propagation of pulse signals at oblique incidence;

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* This Study Programme, which replaces Study Programme 152, does not arise from any Question under study.

(h) that back-scatter studies have proved useful in investigating certain types of long-range propagation previously observed on communication circuits, whereby waves appear to travel to great distances without intermediate ground reflections;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. discrimination between the various back-scatter sources on the ground or in the E-, F- and auroral regions;

2. the use of back-scatter technique, at both fixed and sweep frequencies, to supplement the information obtained by oblique-incidence pulse transmissions;

3. field-strength measurements, to determine the back-scattering coefficient as a function of frequency, the nature of the scattering source and angle of incidence at the scattering source;

4. determination of the incident field at the scattering zone from the back-scatter coefficient, as derived from the field strength measurements made near the transmitting site;

5. investigation by back-scatter technique of the formation and movement of localized areas of Es;

6. determination from back-scatter measurements of actual propagation conditions within the limited range, resulting from considerable loss of energy due to the scattering process and to varying path attenuation;

7. determination of the relative effectiveness of antennae, for application within the limited range referred to in § 6;

8. investigation, by back-scatter measurements, of unusual types of propagation, for example:
- — the absence of echoes between the one-hop and two-hop focusing zones;
- — the persistence of long-range echoes (often after the fade-out of the single- and multi-hop echoes);

9. investigation, by back-scatter measurements, of focusing effects and the characteristics of irregularities in the ionosphere.

STUDY PROGRAMME 204 (VI) *

CHARACTERISTICS OF THE IONOSPHERE AFFECTING SPACE TELECOMMUNICATION SYSTEMS

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that the ionosphere affects the propagation of radio waves, at all frequencies, transmitted through it;

(b) that it may be possible to share parts of the radio-frequency spectrum among terrestrial systems, spacecraft-to-spacecraft systems and systems involving communication between earth stations and spacecraft;

* This Study Programme, which together with Study Programmes 190(V) and 205(VI), replaces Study Programmes 172 and 173 and Question 217, does not arise from any Question under study.

(c) that uncoordinated frequency sharing, between completely independent frequency allocations for sub-ionospheric and spacecraft-to-spacecraft communication services, cannot yet be accepted owing to the lack of necessary data on the minimum isolation afforded by ionospheric phenomena;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. measurement and development of methods of prediction of the attenuation, refraction and scintillation of radio waves passing through the ionosphere, as functions of frequency, direction of propagation, angle of elevation, and ionospheric parameters;
2. measurement and development of methods of prediction of the relative influences of Doppler and Faraday effects.

STUDY PROGRAMME 205 (VI) *

EFFECTS OF RADIO-NOISE IN SPACE ON COMMUNICATIONS WITH SPACECRAFT

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that radio noise is an important element in radiocommunications with spacecraft;

(b) that little is known of this noise in the ionosphere and in space;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. measurement of the noise in the ionosphere and in space from:
   — cosmic sources;
   — lightning discharges and other terrestrial sources;
2. development of methods of prediction of noise in the ionosphere and in space from:
   — cosmic sources
   — lightning discharges and other terrestrial sources.

OPINION 9 **

EFFECTS OF THE IONOSPHERE ON RADIO WAVES USED FOR TELECOMMUNICATION WITH AND BETWEEN SPACECRAFT BEYOND THE LOWER ATMOSPHERE

(Los Angeles, 1959)

The C.C.I.R.,

CONSIDERING

(a) that communication between the earth and artificial earth satellites is now a practical reality;

(b) that, while VHF and UHF emissions are likely to be used for many such communication

* This Study Programme, which together with Study Programmes 190(V) and 204(VI), replaces Study Programmes 172, 173 and Question 217, does not arise from any Question under study.

** This Opinion was formerly designated " Resolution 47 ".

purposes, the ionosphere will nevertheless have some influence on the character of the received signals and on apparent positions as observed by radio methods;

(c) that the study of the effects of the ionosphere on such communications may be facilitated by comparison of HF signals with VHF and UHF signals, since the ionospheric effects are larger on the lower frequencies;

(d) that, in particular, the ionosphere above the F2-layer peak, which cannot normally be studied with radio waves of terrestrial origin, will have some influence on such communications;

(e) that magneto-ionic double refraction, in particular, can cause changes in the state of polarization;

IS UNANIMOUSLY OF THE OPINION

that U.R.S.I. should be asked the following Question:

1. what effect does the ionosphere have on the propagation through it of radio waves of all frequencies; particular attention should be paid to:
   — the attenuation of the waves,
   — any variations in the direction of propagation,
   — changes in the state of polarization;

2. what frequencies of transmission from artificial earth satellites will provide the most useful information on the ionosphere, as a supplement to that obtainable by ionospheric sounding from terrestrial observatories?

RESOLUTION 12

LONG-DISTANCE SKY-WAVE PROPAGATION FOR FREQUENCIES BETWEEN 150 kc/s AND 1500 kc/s

(Study Programme 206(VI))

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that considerable interest exists (see Report 257), regarding the use of low-and medium-medium-frequency field-strength curves for the various areas of the world;

(b) that as the work so far done in response to Study Programme 206(VI), refers mainly to the European Area (see Report 264), the results do not necessarily apply to low latitudes* or to middle latitudes, both in the southern hemisphere and in other parts of the northern hemisphere;

UNANIMOUSLY DECIDES

1. that a Working Party should be set up, including experts from the Administrations and organizations referred to in Report 264 (Australia, U.S.A., India, E.B.U., I.B.T.O. and the I.F.R.B.), which are already concerned with the measurement of medium-frequency field strengths;

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* These areas are a matter of special urgency in view of the African Low-Frequency and Medium-Frequency Broadcasting Conference to be held in 1964.

2. that these and other interested Administrations and organizations should submit the names of their experts as soon as possible to the Chairman of Study Group VI through the Director, C.C.I.R.;

3. that the Chairman, Study Group VI, should appoint a chairman for the Working Party from the experts so named and inform the Director, C.C.I.R. of the appointment;

4. that the Working Party should invite assistance from other Administrations favourably placed geographically with respect to the areas referred to in §(*b*);

5. that the Working Party should be asked to report to the next meeting of Study Group VI on:
   - the accuracy with which low- and medium-frequency field-strengths can be calculatec for the various areas of the world and particularly for low latitudes as a matter of urgency;
   - the information needed to achieve such accuracy in the provision of propagation curves of sky-wave field-strengths for frequencies between 150 kc/s and 1500 kc/s for these areas. these areas.

RESOLUTION 13

LONG-DISTANCE SKY-WAVE PROPAGATION AT FREQUENCIES BELOW 150 kc/s

(Study Programme 206(VI))

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that there is a continuing interest in the propagation of low and very low frequencies in connection, not only with communications, but more especially with standard-frequency and time services as well as navigational systems employing pulse, phase comparison or direction-finding techniques;

(b) that, although action has been taken to produce long-distance sky-wave propagation curves for frequencies between 150 kc/s and 1500 kc/s (see Resolution 12 and Reports 257 and 264), there is a need for such curves for frequencies below 150 kc/s for distances at which the sky-wave predominates, but the information so far available in C.C.I.R. documents is not sufficient to serve as a basis for the establishment of such curves;

UNANIMOUSLY DECIDES

1. that two or three experts should be invited by the Chairman, Study Group VI, through the appropriate Administrations to constitute an informal Working Party:
   - to study the relevant information available from all convenient sources;
   - to draw up a report for consideration at the next meeting of Study Group VI, indicating if possible whether the existing information is sufficient for the establishment of long-distance sky-wave propagation curves for frequencies below 150 kc/s, or whether further studies or the establishment of an appropriate programme of field-strength measurements would be desirable;

2. that the Chairman, Study Group VI should arrange for one of the members of the working party to act as Chairman to organize the work by correspondance;

3. that the Chairman, Study Group VI should advise the Director, C.C.I.R. of this appointment.

STUDY PROGRAMME 206(VI) *

LONG-DISTANCE SKY-WAVE PROPAGATION AT FREQUENCIES BELOW 1500 kc/s

(Geneva, 1951 — London, 1953 — Los Angeles, 1959 — Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that new night-time propagation curves and formulae for the European area are given in Report 264;

(b) that, nevertheless, it is not yet possible to supply Administrations and the I.F.R.B. with complete answers regarding night-time propagation for frequencies below 1500 kc/s applicable to all areas and in particular at low latitudes;

(c) that information is also needed for daytime propagation at distances for which the sky-wave predominates;

(d) that there is a continuing interest in the propagation of low and very low frequencies in connection, not only with communications, but more especially with standard frequency and time services, as well as navigational systems employing pulse, phase-comparison or direction-finding techniques;

(e) that while progress is being made in understanding the characteristics of the ionosphere relevant to sky-wave propagation at frequencies below 1500 kc/s, the mathematical analysis has been confined largely to ideal cases that are not sufficiently representative of practical conditions;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the continuation of measurements at vertical and oblique incidence at frequencies below 1500 kc/s, by Administrations and by laboratories having suitable facilities;

2. the determination of the physical conditions in the lower ionosphere responsible for the reflection of low and very low frequencies, with particular reference to the possibility of reflections ocurring simultaneoulsy at more than one height;

3. the dependence of the diurnal and seasonal variations in the sky-wave upon:
   - — geographical location, with particular attention to transpolar paths and antipodal regions;
   - — path orientation, including the influence of the earth's magnetic field;
   - — solar and geomagnetic indices, with particular reference to the amplitude and phase consequences of the SID's and polar blackouts;
   - — orientation of the path with respect to the day-night line;

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* This Study Programme, which replaces Study Programme 142, does not arise from any Question under study.

4. the development of the mathematical analysis, to apply more closely to the general conditions of long-distance propagation in which the ionization, the direction of the earth's magnetic field, and ground conditions (including inhomogeneities and irregularities of terrain) vary along the propagation path;

5. the effect of variable propagation conditions along the path, upon the phase and amplitude, with special reference to standard-frequency and time services, as well as to navigational systems at low- and very-low frequencies;

6. revision and extension of the night-time propagation curves and formulae in Report 264, as further measurements become available, especially for other areas and in low latitudes;

7. the possibility of establishing curves and formulae for daytime propagation at distance, for which the sky-wave is predominant,

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OPINION 10

FADING OF SIGNALS PROPAGATED BY THE IONOSPHERE

(Geneva, 1963)

The C.C.I.R.,

CONSIDERING

(a) that a special International Working Party was set up under Resolution 49 *, to consider those aspects of the phenomena of fading which are of interest to the C.C.I.R.;

(b) that the understanding of the basic processes involved in fading, will greatly assist in the formulation of measures to counteract its effects;

IS UNANIMOUSLY OF THE OPINION

that the U.R.S.I. should be asked the following question:

1. what are the basic phenomena which give rise to fading of radio signals propagated through the ionosphere, including:
   - changes in absorption,
   - focusing and de-focusing,
   - changes in polarization,
   - multipath propagation;

2. what is the relative importance of each of these factors in the fading process; and what are the distinctive features of the fading associated with each of these factors;

3. what experimental techniques can be employed to distinguish between the different types of fading, including:
   - absorption fading,
   - focusing fading,
   - polarization fading,
   - multipath fading?

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* This Resolution has been deleted.

STUDY PROGRAMME 148 (VI) *

STUDY OF FADING

(London, 1953 — Los Angeles, 1959)

The C.C.I.R.,

CONSIDERING

(a) that the practical requirements of radiocommunication necessitate not only information on the median received field-strength of radio transmissions, but also:

— data on the amplitude distribution and rapidity of field-strength variations (with respect to the speed of transmission),

— effects of equipment time constants,

— selective fading,

and that this information is essential to Study Groups III, X and XII in assessing the allowances for fading;

(b) that field-strength variation involves phenomena of focussing, of variation in direction of arrival, of interference by components of a single mode, between different modes, and between the various magneto-ionic components, as well as of variations of ionospheric absorption and of scattering phenomena;

(c) that variations of field-strength may, as a first approximation, be divided into three types:

— irregular short-period variations, assumed in general to result from interference and focussing, with an apparent period of occasionally as much as several minutes and dependent to a certain degree on the frequency. These variations should be allowed for in the assessment of a *fading safety factor ;*

— irregular variations of periodicity large compared with the case above. i.e., hourly, daily or from one day to another, which may be due to fluctuating absorption or to prolonged large scale focussing or which may result from variations of arrival angle and polarization. Allowance for them should be made in the assessment of an *intensity fluctuation factor ;*

— regular variations with time of day, season and solar activity, to which are added the variations of the two above types;

(d) that it is important to have as much information as possible concerning the effects of fading on time, space, frequency and polarization diversity reception;

UNANIMOUSLY DECIDES that the following studies should be carried out for the various frequency bands used in radiocommunication by means of the ionosphere:

1. the space and time distributions (for example, Rayleigh, normal and log-normal) of short-period field-strength variations, ranging from less than 10^{-4} s, to as much as several minutes. Such results may also be measured as space and time correlations, and as power spectra;

2. the time distribution of the duration of fades for different levels of the field-strength relative to the median;

3. the severity of day-to-day variations of hourly median field-strengths, i.e., for time intervals of one hour;

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* This Study Programe, which replaces Study Programme 66, does not refer to any Question under study.

4. the extent to which the above variations are dependent upon season, solar activity and geographical location;

5. the effects produced by field-strength variations on different receiving systems, such as time, space, frequency and polarization diversity systems;

6. the mechanisms which produce field-strength variations;

7. the extent to which any of the above studies are affected under modulation conditions;

8. the effects of selective fading on very closely adjacent frequencies (e.g., approximately 20 kc/s and less).

Note. — The above studies should be undertaken both from a theoretical and experimental viewpoint. When appropriate, consideration should be given to the time constants and other characteristics of the measuring equipment.

LIST OF DOCUMENTS OF THE Xth PLENARY ASSEMBLY CONCERNING STUDY GROUP VI

Doc.	Origin	Title	Reference	Other Study Groups concerned
6	Chairman, Study Group VI	Report by Chairman of Study Group VI (Dr. D. K. Bailey)	—	—
89	Sub-Group VI-A	Choice of basic indices for ionospheric propagation — Draft Report	Rep. 162	—
95	India	Ionospheric absorption at Delhi	S.P. 145	—
96	India	Observation of scatter-echos on high-power pulsed transmissions	S.P. 152	—
98	India	Best method for calculating the field-strength produced by a tropical broadcasting transmitter	Q. 154 (XII) S.P. 144	XII
99	India	Study of fading	S.P. 148	—
101	India	Identification on precursors indicative of short-term variations of ionospheric propagation conditions	S.P. 93	—
129	C.C.I.R. Secretariat	Bibliographic references in the volumes of the C.C.I.R.	—	I-XIV
136	Canada	Basic prediction information for ionospheric propagation	S.P. 149 Rep. 161	—
142	Federal Republic of Germany	Basic prediction information for ionospheric propagation — Interpolation problems relative to ionospheric predictions	S.P. 149, § 3	—
153	C.C.I.R. Secretariat	Refinement of I.F.R.B. technical standards	—	I, II, III, V, X, XII, XIII
162	India	Atmospheric radio-noise over tropical land masses	S.P. 154 Res. 51 Q. 155 (XII)	XII
182	Sweden	Local lightning flash counters	Res. 51	—
183	Sweden	Practical experience with the C.C.I.R. lightning counter	Res. 51	—
198	Radio-Suisse	Study of sky-wave propagation at frequencies between approximately 1·5 and 40 Mc/s for the estimation of field-strength — Basic prediction information for ionospheric propagation — Meaning of MUF — Quality index for radio circuits	S.P. 144 S.P. 149	—
204	E.B.U.	Radio propagation at frequencies below 1500 kc/s	S.P. 142	—

Doc	Origin	Title	Reference	Other Study Groups concerned
209	I.B.T.O.	Study of long-wave and medium-wave ionospheric propagation during night-time	S.P. 142	—
236	India	Measurement of atmospheric radio noise	Rec. 315 S.P. 154 Q. 155 (XII)	XII
271	U.R.S.I.	Long-distance directivity of HF antennae	Circ. AC/55	III, X
272	Federal Republic of Germany	Corrigendum to Doc. V/22 — Study of sky-wave propagation on frequencies between approximately 1·5 and 40 Mc/s for the estimation of field-strength	S.P. 144, § 5	—
303	Sub-Group VI-E	Basic long-term ionosopheric predictions	Draft Opinion	—
304	Study Group VI	Summary record of the first meeting	—	—
348	Study Group VI	Identification of precursors indicative of short-term variations and evaluation of reliability of short-term forecasts of ionospheric propagation conditions	Draft Rep.	—
387	Study Group VI	Summary record of the second meeting	—	—
434	Sub-Group VI-B	Long-distance ionospheric propagation without intermediate ground reflection	Draft Rep.	—
435	Sub-Group VI-B	Back-scattering	Draft Rep.	—
436	Sub-Group VI-B	Basic prediction information for ionospheric propagation	Draft Rep.	—
476	Study Group VI	World distribution and characteristics of atmospheric radio-noise	Draft Res.	—
501	Sub-Group VI-C	Estimation of sky-wave field-strength and transmission loss between the approximate limits of 1·5 and 40 Mc/s	Draft Rep.	—
506	Sub-Group VI-C	Systematic measurements of sky-wave field-strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 Mc/s	Draft Rep.	—
512	Study Group VI	Summary record of the third meeting	—	—

Doc	Origin	Title	Reference	Other Study Groups concerned
513	Sub-Group VI-G	Systematic sky-wave field-strength measurements on frequencies between the approximate limits of 1·5 and 40 Mc/s	Rec. 317	—
514	Sub-Group VI-G	Radio propagation at frequencies below 150 kc/s	Draft Rep.	—
519	Study Group VI	Measurement of atmospheric radio-noise	Draft Rep.	—
552	Sub-Group VI-C	Estimation of sky-wave field-strength and transmission loss for frequencies between the approximate limits of 1·5 and 40 Mc/s	Draft S.P.	-
553	Sub-Group VI-C	Study of sky-wave field-strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 Mc/s	Draft S.P.	
559	Sub-Group VI-G	Long-distance sky-wave propagation at frequencies below 150 kc/s	Draft Res.	—
562	Sub-Group VI-G	Long-distance sky-wave propagation for frequencies between 150 kc/s and 1500 kc/s	Draft Res.	—
565	Study Group VI	Summary record of the fourth meeting	—	—
572	Sub-Group VI-G	Predictions of ionospheric field-strength or propagation loss for the frequency range between 150 and 1500 kc/s	Draft Rep.	—
582	Study Group VI	Summary record of the fifth meeting	—	—
589	Study Group VI	Special ionospheric propagation effects in equatorial regions	Draft Q.	—
609	Study Group VI	Summary record of the sixth meeting	—	—
630	Study Group VI	Summary record of the seventh and last meeting	—	—
2022	Drafting Committee	Basic prediction information for ionospheric propagation	Res. 11	—
2023	,,	Meaning of MUF	Rec. 373	—
2024	,,	Choice of solar indices for ionospheric propagation	Rec. 371	—

Doc	Origin	Title	Reference	Other Study Groups concerned
2025	Drafting Committee	Use of satellite-borne ionosondes in orbits above the F2-peak (topside sounders) for the study of ionospheric propagation	Res. 6	—
2026	,,	Fading of signals propagated by the ionosphere	Op.10	—
2027	,,	Improvement in the network of ionospheric-sounding stations	Res. 5	—
2028	,,	Predictions of indices of solar activity	Op. 7	—
2029	,,	Revision of atmospheric noise data	Res. 8	—
2030	,,	Dissemination of basic indices for ionospheric propagation	Res. 4	—
2031	,,	High-frequency propagation by ducting above the F2-region peak	Op. 8	—
2032	,,	Choice of basic indices for ionospheric propagation	Q. 247	—
2033	,,	Identification of precursors indicative of short-term variations of ionospheric propagation conditions and methods for describing ionospheric disturbances and the performance of radio circuits	S.P. 194	—
2034	,,	Predictions of solar index	S.P. 193	—
2035	,,	Whistler mode of propagation	S.P. 201	—
2036	,,	Radio propagation at frequencies below 1500 kc/s	S.P. 206	—
2037	,,	Propagation by way of sporadic-E and other anomalous ionization in the E-and F-regions of the ionosphere	S.P. 195	—
2038	,,	Intermittent communication by meteor-burst propagation	S.P. 196	—
2039	,,	Ionospheric-scatter propagation	S.P. 202	—
2040	,,	Basic prediction information for ionospheric propagation	S.P. 200	—
2041	,,	Pulse-transmission tests at oblique incidence	S.P. 197	—
2042	,,	Back-scattering	S.P. 203	—

Doc	Origin	Title	Reference	Other Study Groups concerned
2043	Drafting Committee	Measurement of atmospheric radio-noise	S.P. 199	—
2044	,,	Long-distance propagation of waves of 30 to 300 Mc/s by way of ionization by the E-and F-regions of the ionosphere	Rep. 259	—
2045	,,	Availability and exchange of basic data for radio-propagation forecasts	Rep. 248	—
2046	,,	Predictions of solar index	Rep. 245	—
2047	,,	Measurement of man-made radio noise	Rep. 258	—
2048	,,	Factors affecting propagation in communications with space vehicles	Rep. 263	—
2049	,,	Meaning of MUF	Rep. 256	—
2083	,,	Ionospheric-scatter propagation	Rep. 260	—
2099	,,	Effects of radio-noise in space on communications with space vehicles	S.P. 205	—
2101	,,	Characteristics of the ionosphere affecting space-telecommunication systems	S.P. 204	—
2102	,,	Intermittent communication by meteor-burst propagation	Rep. 251	—
2103	,,	Pulse transmission tests at oblique incidence	Rep. 249	—
2104	,,	Fading of signals propagated by the ionosphere	Rep. 266	—
2105	,,	Whistler mode of propagation	Rep. 262	—
2106	,,	Choice of basic indices for ionospheric propagation	Rep. 246	—
2108	,,	Basic long-term ionospheric predictions	Res. 10	—
2192	,,	Identification of precursors indicative of short-term variations and evaluation of reliability of short-term forecasts of ionospheric propagation conditions	Rep. 247	—
2255	,,	Use of atmospheric noise data	Rec. 372	—
2282	,,	Long-distance ionospheric propagation without intermediate ground reflection	Rep. 250	—

Doc	Origin	Title	Reference	Other Study Groups concerned
2283	Drafting Committee	Questions submitted by the I.F.R.B.	Rep. 257	—
2293	,,	Back-scattering	Rep. 261	—
2294	,,	Basic prediction information for ionospheric propagation	Rep. 255	—
2319	,,	Estimation of sky-wave field-strength and transmission loss between the approximate limits of 1·5 and 40 Mc/s	Rep. 252	—
2320	,,	Systematic measurements of sky-wave field-strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 Mc/s	Rep. 253	—
2338	,,	World distribution and characteristics of atmospheric radio noise	Res. 9	—
2339	,,	Long-distance sky-wave propagation at frequencies below 150 kc/s	Rep. 265	—
2340	,,	Sky-wave field-strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 Mc/s	Res. 7	—
2364	,,	Long-distance sky-wave propagation for frequencies between 150 kc/s and 1500 kc/s	Res. 12	—
2365	,,	Measurement of atmospheric radio-noise	Rep. 254	—
2366	,,	Estimation of sky-wave field-strength and transmission loss for frequencies between the approximate limits of 1·5 and 40 Mc/s	S.P. 198	—
2367	,,	Long-distance sky-wave propagation at frequencies below 150 kc/s	Res. 13	—
2368	,,	Predictions of ionospheric field-strength or propagation loss for the frequency range between 150 and 1500 kc/s	Rep. 264	—
2386	,,	Special problems of HF radiocommunication associated with the equatorial ionosphere	Q. 248	—

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