INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

C.C.I.R.

DOCUMENTS OF THE

XIth PLENARY ASSEMBLY

OSLO, 1966

VOLUME II

PROPAGATION

Published by the
INTERNATIONAL TELECOMMUNICATION UNION
GENEVA, 1967

INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

C.C.I.R.

DOCUMENTS OF THE

XIth PLENARY ASSEMBLY

OSLO, 1966

VOLUME II

PROPAGATION

Published by the
INTERNATIONAL TELECOMMUNICATION UNION
GENEVA, 1967

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

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

Questions and Study Programmes allocated to Study Group V (Propagation over the surface of the earth and through the non-ionized regions of the atmosphere) — Opinions and Resolutions of interest to this Study Group

Lists of documents

Recommendations of Sub-section G.2: Ionospheric propagation

Reports of Sub-section G.2: Ionospheric propagation

Questions and Study Programmes allocated to Study Group VI (Ionospheric propagation) — Opinions and Resolutions of interest to this Study Group

Lists of documents

DISTRIBUTION OF THE TEXTS OF THE XIth PLENARY ASSEMBLY OF THE C.C.I.R. AMONG VOLUMES I-VI

- Volumes I to VI of the documents of the XIth Plenary Assembly contain all the C.C.I.R. texts at present in force.
- For Questions and Study Programmes, the final (Roman) numeral indicates the Study Group to which the text has been assigned. The plan on page 5 shows the Volume in which the various texts of that Study Group can be found.
- Recommendations, Reports, Opinions and Resolutions which have been amended by the XIth Plenary Assembly, have retained their original number, followed by the indication 1 (e.g.: Recommendation 326-1), which is not shown in the Table below. Further details on the numbering system appear in Volume VI.

1. Recommendations

Number	Volume	Number	Volume	Number	Volume
45	III	237	I	313	II
48, 49	V	239	I	314	IV
75–77	III	240	III	325–334	I
80	V	246	III	335–349	III
100	III	258	III	352–367	IV
106	III	261, 262	V	368–373	II
136	V	264–266	V	374–379	III
139, 140	V	268	IV	380–406	IV
162	III	270	IV	407–421	V
166	III	275, 276	IV	422, 423	III
168	II	279	IV	425	III
182	III	281–283	IV	427–429	III
205	V	289, 290	IV	430–433	I
212	V	297–300	IV	434, 435	II
214–216	V	302	IV	436–443	III
218, 219	III	304–306	IV	444–446	IV
224	III	310, 311	II	447–451	V

2. Reports

Number	Volume	Number	Volume	Number	Volume
19	III	175–194	I	292–295	V
32	V	195–198	III	297–316	V
42	III	200–203	III	318–320	III
79	V	204–219	IV	321	I
93	III	222–224	IV	322	(1)
106, 107	III	226	IV	323–335	I
109	III	227–239	II	336–339	II
111, 112	III	241–266	II	340	(1)
122	V	267	III	341–344	II
130	IV	269–273	III	345–373	III
134	IV	275–282	III	374–397	IV
137	IV	283–290	IV	398–412	V
				413–415	(1)

(1) Published separately.

3. Opinions

Number	Volume	Number	Volume	Number	Volume
1, 2	I	12–14	IV	21	III
3	IV	15–17	V	22, 23	II
11	III	19	V	24–30	III
				31	V

4. Resolutions

Number	Volume	Number	Volume	Number	Volume
1	III	12, 13	II	26, 27	VI
2-4	II	14–16	III	30, 31	II
7, 8	II	19, 20	III	32	V
10	II	21–23	I	33-36	VI
		24	VI		

ARRANGEMENT OF VOLUMES I TO VI OF THE DOCUMENTS OF THE XIth PLENARY ASSEMBLY OF THE C.C.I.R.

(Oslo, 1966)

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	Sound broadcasting and Television (Section E, Study Groups X, XI and XII and the C.M.T.T.).
Volume VI	List of participants. Minutes of the Plenary Meetings. Resolutions of a general nature. Reports to the Plenary Assembly. List of documents in numerical order.

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 XIth 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.

TABLE OF CONTENTS OF VOLUME II

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)

QUESTIONS AND STUDY PROGRAMMES ASSIGNED TO STUDY GROUP V (PROPAGATION OVER THE SURFACE OF THE EARTH AND THROUGH THE NON-IONIZED REGIONS OF THE ATMOSPHERE); OPINIONS AND RESOLUTIONS OF INTEREST TO THIS STUDY GROUP

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

---

* Published separately.

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

RECOMMENDATION 168-1

PRESENTATION OF ANTENNA RADIATION DATA

(1953 - 1956 - 1966)

The C.C.I.R.,

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 radiocommunications;

(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 linearly in terms of relative radiated power or field strength;
2. that, for highly directional antennae, it is often desirable to graduate the patterns linearly in decibels;
3. 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*;
4. 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 *Ed*, 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 wavelength, or to the distance at which the measurements are made, the limit of the product *Ed* 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, with an indication of the sense of this polarization.

---

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

RECOMMENDATION 310-1

DEFINITIONS OF TERMS RELATING TO PROPAGATION IN THE TROPOSPHERE

(1951 - 1959 - 1966)

The C.C.I.R.,

CONSIDERING

that it is well known that the propagation of waves of frequencies greater than 30 MHz 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.	*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.
5.	*Relative humidity*	Ratio of the existing water vapour pressure to that for saturation at the same temperature, generally expressed as a percentage.
6.	*Refractive index* (n)	Ratio of the speeds of radio waves in vacuo to the speed in the medium under consideration.
7.	*N (refractivity)*	One million times the amount by which the refractive index exceeds unity.
8.	*N-unit*	A unit in terms of which N (refractivity) is expressed.
9.	*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.
10.	*Refractive modulus*	One million times the amount by which the modified refractive index exceeds unity.
11.	*M-unit*	A unit in terms of which refractive modulus is expressed.
12.	*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).
13.	*Standard radio atmosphere*	For tropospheric propagation: an atmosphere having the standard refractive modulus gradient.

	Term	Definition
14.	*Basic reference atmosphere*	An atmosphere in which N (refractivity) decreases exponentially with height (see Recommendation 369–1).
15.	*Standard refraction*	The refraction which would occur in a standard radio atmosphere (see Fig. 1).
16.	*Sub-refraction*	Refraction for which the refractive modulus gradient is positive and greater than standard (see Fig. 1).
17.	*Super refraction*	Refraction for which the refractive modulus gradient is less than standard, may become zero and may increase negatively (see Fig. 1).
18.	*Tropospheric propagation*	Propagation through the troposphere by any mechanism, several of which are defined below.
19.	*Standard propagation*	The propagation of radio waves over a smooth spherical earth of uniform electrical characteristics under conditions of standard refraction in the atmosphere.
20.	*Radio horizon*	The locus of points at which direct rays from the antenna become tangential to the earth's surface, taking into account the curvature due to refraction.
21.	*Effective radius of the earth*	Radius of a hypothetical spherical earth for which the distance to the horizon, assuming rectilinear propagation is the same as that for the actual earth enveloped in an atmosphere having a constant vertical gradient of refractive index. (For the standard atmosphere, the effective radius is 4/3 that of the true radius.)
22.	*Tropospheric radio-duct*	A quasi-horizontal layer in the troposphere between the boundaries of which radio energy of a sufficiently high frequency is substantially confined and propagated with abnormally low attenuation.
23.	*Ground-based duct (Surface duct)*	A tropospheric radio-duct in which the lower boundary is the surface of the earth.
24.	*Elevated duct*	A tropospheric radio-duct in which the lower boundary is above the surface of the earth.
25.	*Duct thickness*	The difference in height between the upper and lower boundaries of a tropospheric-radio duct.
26.	*Duct height*	The height above the surface of the earth of the lower boundary of an elevated duct.
27.	*Trapped propagation*	Propagation within a tropospheric-radio duct. Several modes of propagation (as in wave-guide theory) may exist.
28.	*Trans-horizon propagation*	A generic term for propagation over paths extending beyond the normal radio-horizon. It may include a variety of mechanisms such as non-directional scatter and specular reflection towards the receiver.
29.	*Tropospheric-scatter propagation*	Propagation involving scattering from many inhomogeneities and discontinuities in the refractive index of the atmosphere, generally characterized by attenuation which increases rapidly in directions away from the incident direction.
30.	*Precipitation-scatter propagation*	Propagation by scattering from precipitation particles.
31.	*Multipath propagation*	Propagation by way of a number of transmission paths.

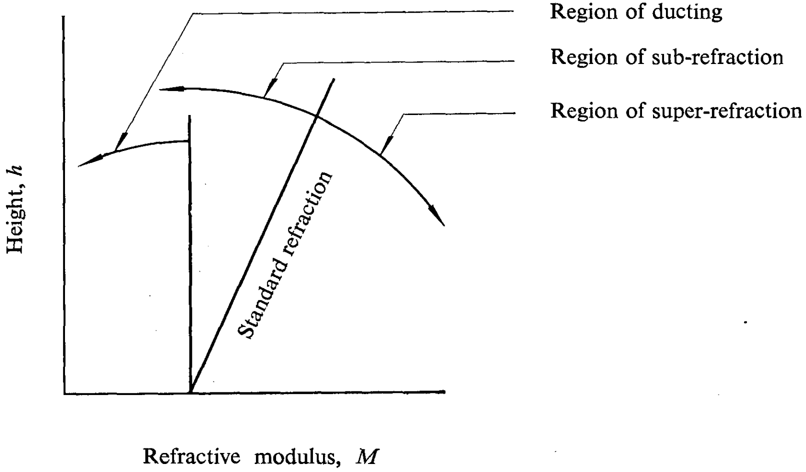


FIGURE 1

M-curves

RECOMMENDATION 311 *

PRESENTATION OF DATA IN STUDIES OF TROPOSPHERIC-WAVE PROPAGATION

(1953 - 1956 - 1959)

The C.C.I.R.,

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 MHz;

(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), Warsaw, 1956, or in Doc. V/28 (France), 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 should 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.

---

* 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 analyse 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-strength 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

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

For abscissae $x = 0$, $x \longrightarrow \infty$ and $x \longrightarrow -\infty$, 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:

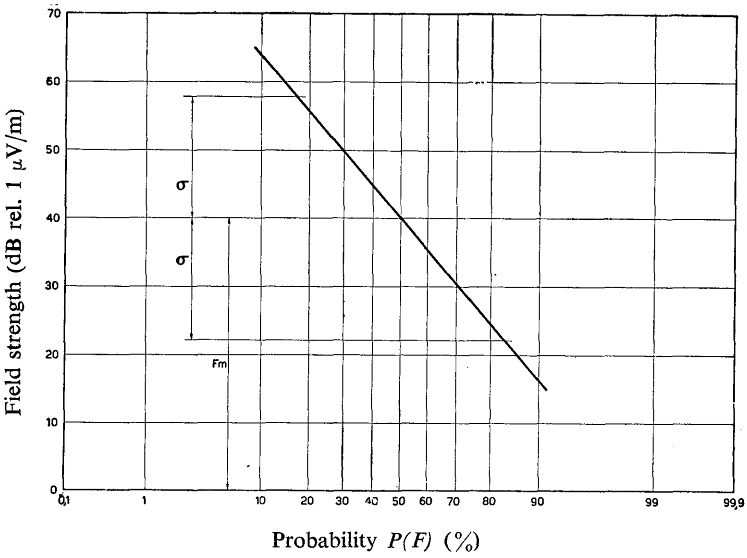
$$P(F) = \frac{1}{\sigma\sqrt{2\pi}} \int_{F}^{\infty} \exp\left(-(f-F_m)^2/2\sigma^2\right) df$$

$P(F)$ 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 MHz

(Question 246)

(1951 - 1959 - 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 MHz under the conditions stated.

---

* This Recommendation replaces Recommendation 307.

ANNEX

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

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

1. they refer to a smooth homogeneous earth;

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

3. 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 kHz and 2 MHz and for distances of less than about 2000 km. However, under conditions where the sky-wave is comparable with, or even greater than, the ground-wave, the curves are still applicable when the effect of the ground-wave can be separated from that of the sky-wave, by the use of pulse transmissions, as in some forms of direction-finding systems and navigational aids.

---

* *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.

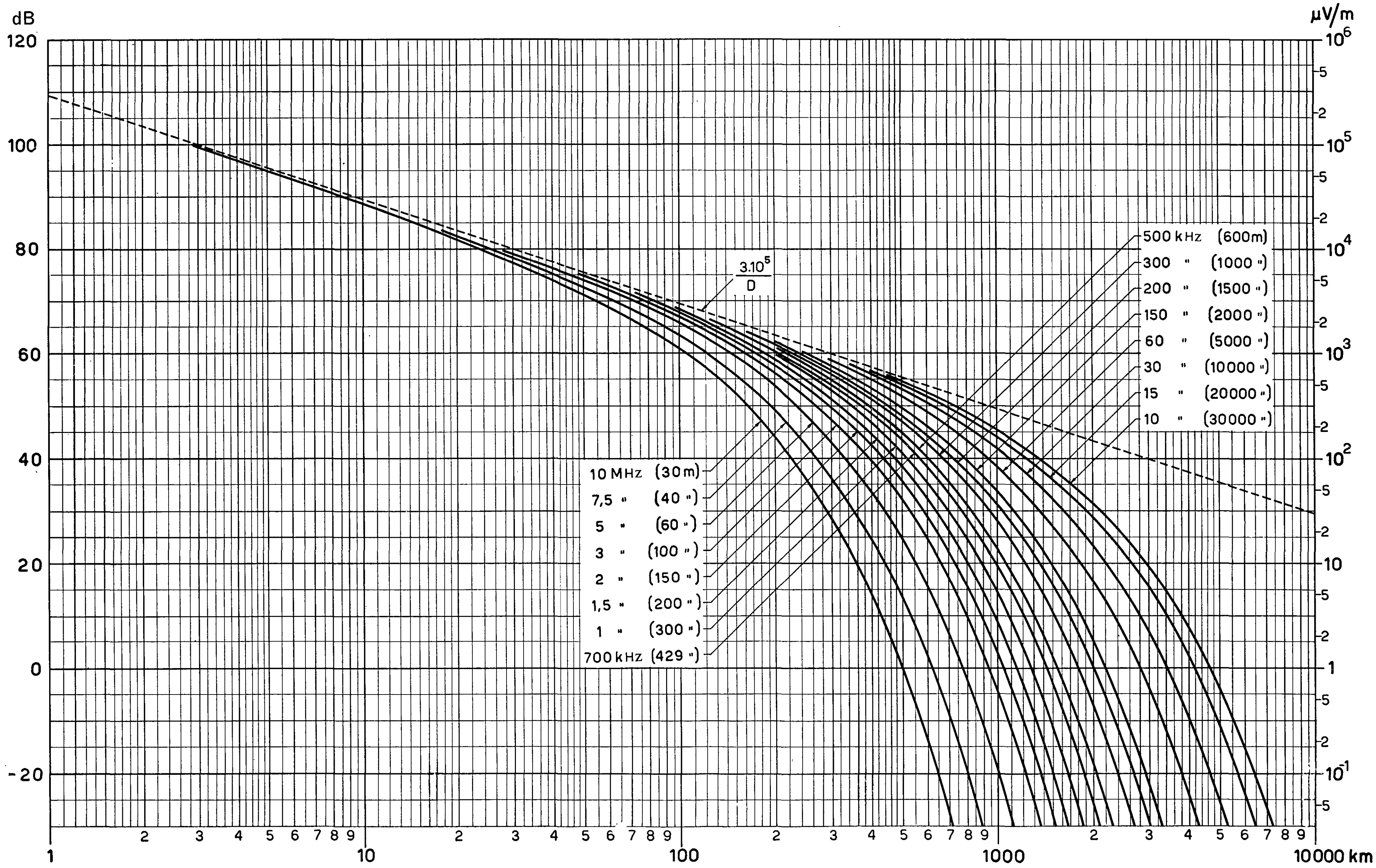


FIGURE 1

Ground-wave propagation curves; Sea, σ = 4 mho/m, ε = 80

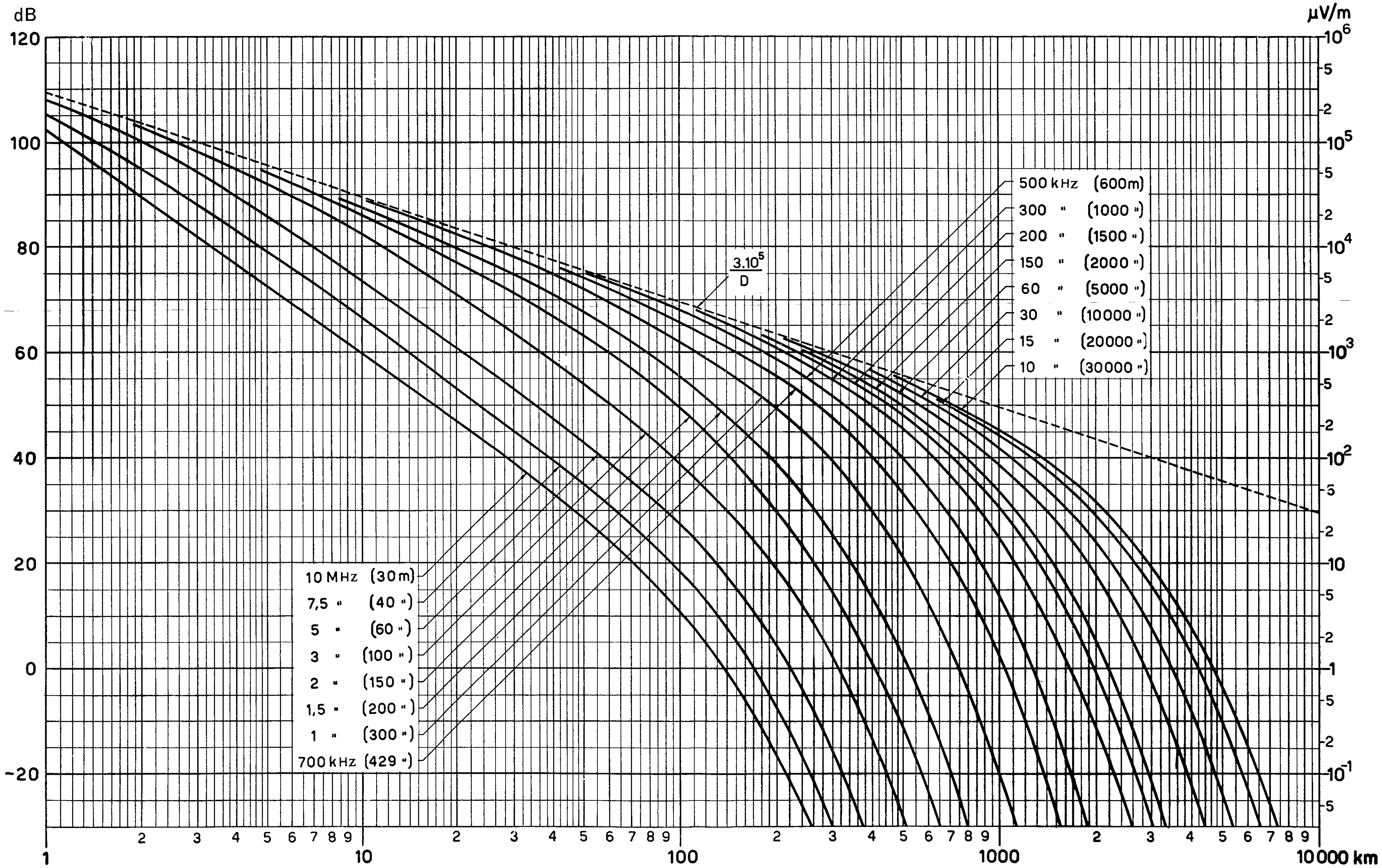


FIGURE 2

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

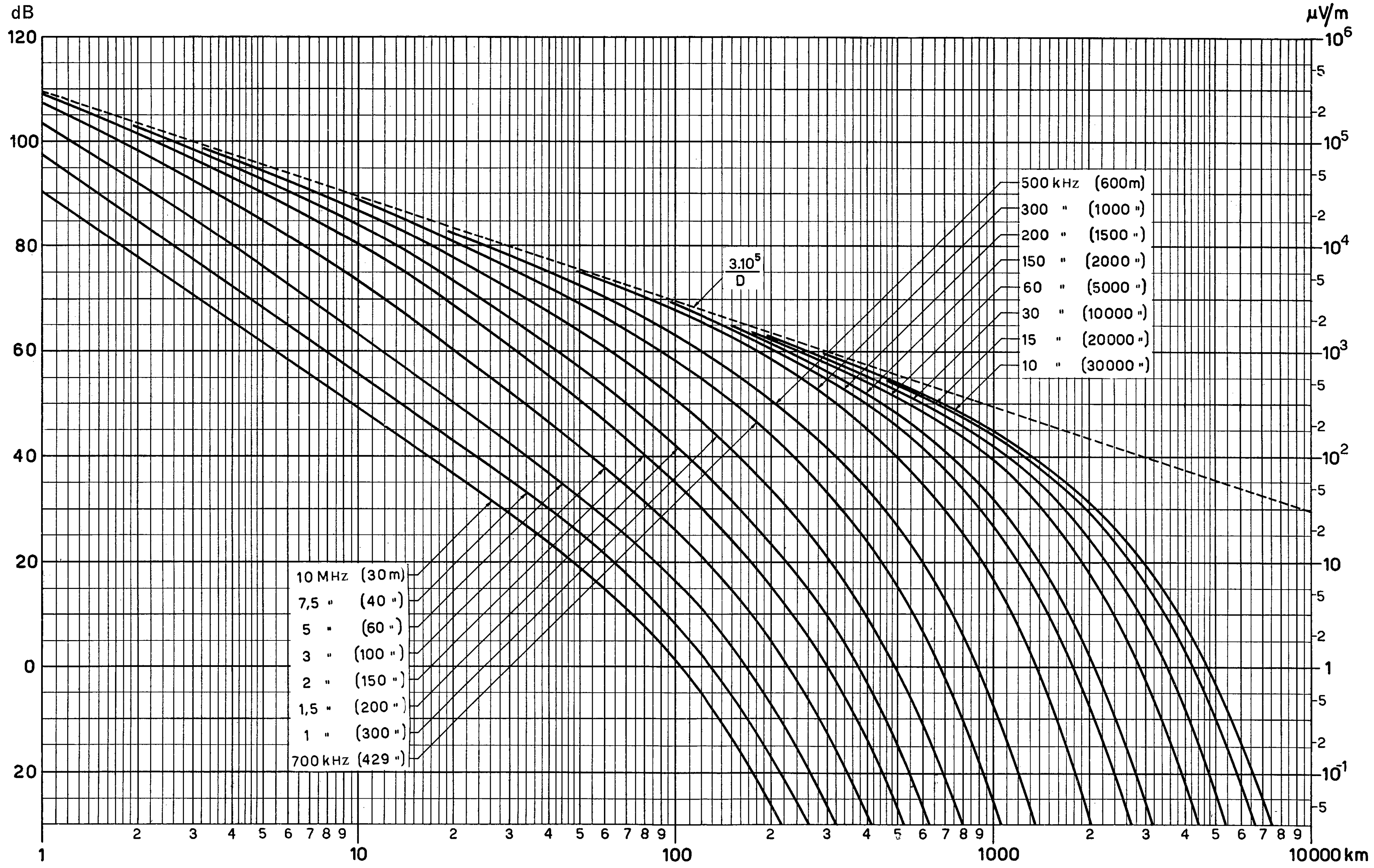


FIGURE 3

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

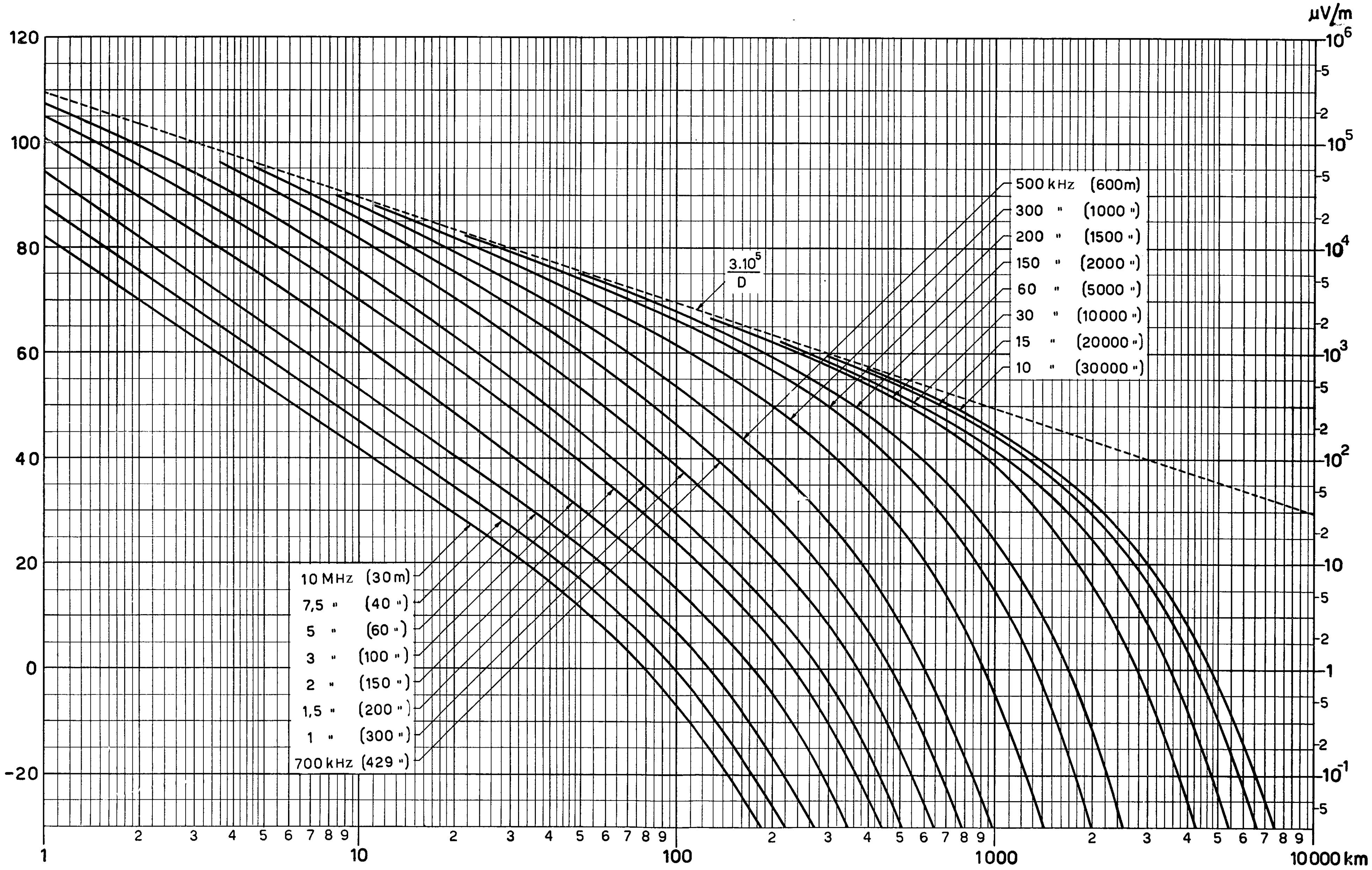


FIGURE 4

Ground-wave propagation curves; Earth, $\sigma = 3\times10^{-3}$ mho/m, $\varepsilon = 4$

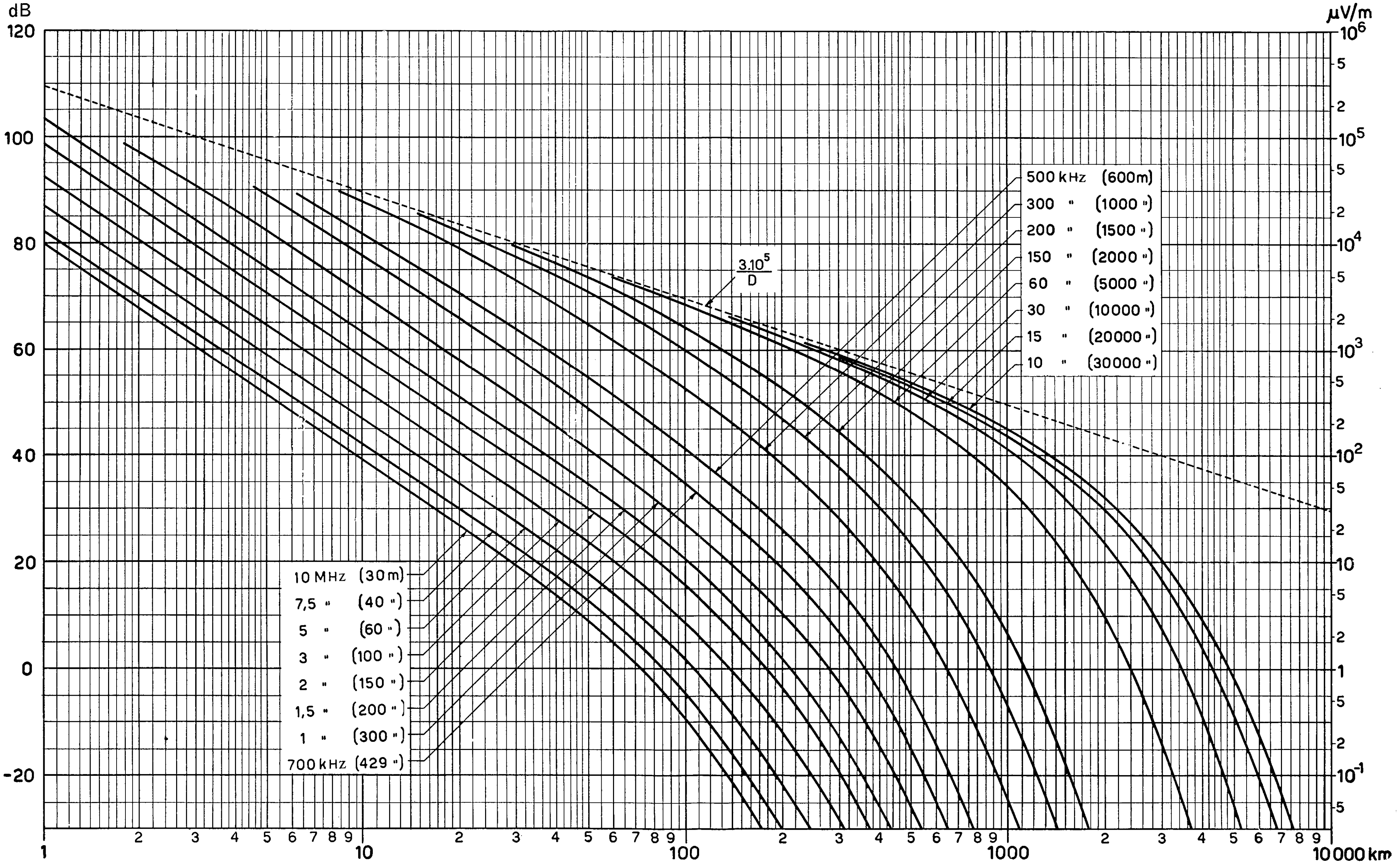


FIGURE 5

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

RECOMMENDATION 369-1

DEFINITION OF A BASIC REFERENCE ATMOSPHERE

(1959 - 1963 - 1966)

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 231-1);

UNANIMOUSLY RECOMMENDS

that the basic reference atmosphere be defined by the relationship:

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

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

Note. — The gradient of the refractive index of this atmosphere at ground surface 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 370-1

VHF AND UHF PROPAGATION CURVES FOR THE FREQUENCY RANGE FROM 30 MHZ TO 1000 MHZ *

Broadcasting and mobile services

(1951 - 1953 - 1956 - 1959 - 1963 - 1966)

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;

---

* It must be emphasised 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.

(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;

(c) that the annexed curves are based on the statistical analysis of a considerable amount of experimental data (see Report 239–1);

UNANIMOUSLY RECOMMENDS

1. that the revised curves given in Annexes I and II be adopted for provisional use *, for the following conditions:

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 height of the receiving antenna is defined as the height above local terrain.

1.4 A parameter Δh is used to define the degree of terrain irregularity; it is the difference in heights exceeded by 10% and 90% of the terrain in the range 10 km to 50 km from the transmitter (see Fig. 7).

1.5 The effect of changing the receiving antenna height is discussed in Report 239–1, § 4.2;

1.6 A method for determining field strengths over mixed land and sea paths is described in Report 239–1.

ANNEX I

VHF BANDS (30 - 250 MHz)

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. 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 sea paths as well as land paths in the North Sea area. The 1% time values for sea paths in the North Sea area are given in Fig. 4. 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 land distances greater than about 700 km, obtained by extrapolation of these curves (dashed lines), should be used with caution.

3. 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. 5.

---

* 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.

Propagation curves for broadcasting in the African Continent are given on pages 343-379 of the Final Acts of the African VHF/UHF Broadcasting Conference, Geneva, 1963.

Neither the curves of Figs. 1, 2 or 3, nor the distribution curve of Fig. 5, can be assumed to apply accurately in very hilly or mountainous regions. In band III, and for such terrain, one should use the attenuation correction factor (dB), given in Fig. 8 (*a*).

4. 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, $\Delta N \approx -40$, 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 those 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.

5. VHF 1% (time) curves for mixed land and sea paths for a transmitting antenna at a height of 300 m are shown in Fig. 6. It was assumed, in constructing the curves, that the land sections of the path on either side of the sea section were equal. For other situations, estimates of mixed, path field strengths should be made, in accordance with the method described in Report 239-1.

ANNEX II

UHF BANDS (450 - 1000 MHz)

1. Figs. 9, 10 and 11 show the field strengths exceeded at 50% of the locations and for 50%, 10% and 1% of the time respectively for land paths. 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 as shown in Fig. 8 (*b*).

2. The field strengths given in Figs. 9, 10 and 11 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. 12.

3. Figs. 13, 14, 15 and 16 show field strengths exceeded at 50% of receiving locations in coastal regions for 50%, 10%, 5% and 1% of the time respectively. They relate to propagation in the North Sea and Mediterranean areas, the values for the greater distances being based on measurements in the North Sea area. Limited measurements of the median value of field strength in the Mediterranean area are in good agreement. There is evidence, however, that the field strengths exceeded for small percentages of the time in the Mediterranean area are greater than those experienced in the North Sea area.

4. These curves are based on long-term values (several years), 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), field strengths may occur which greatly exceed those given in Figs. 9-16 inclusive.

5. Figs. 17 (*a*) and 17 (*b*) show 1% and 10% curves for mixed land and sea paths for a transmitting antenna at a height of 300 m, assuming the land sections of the path on either side of the sea section are equal. For other situations, estimates of mixed-path field strengths should be made in accordance with the method described in Report 239–1.

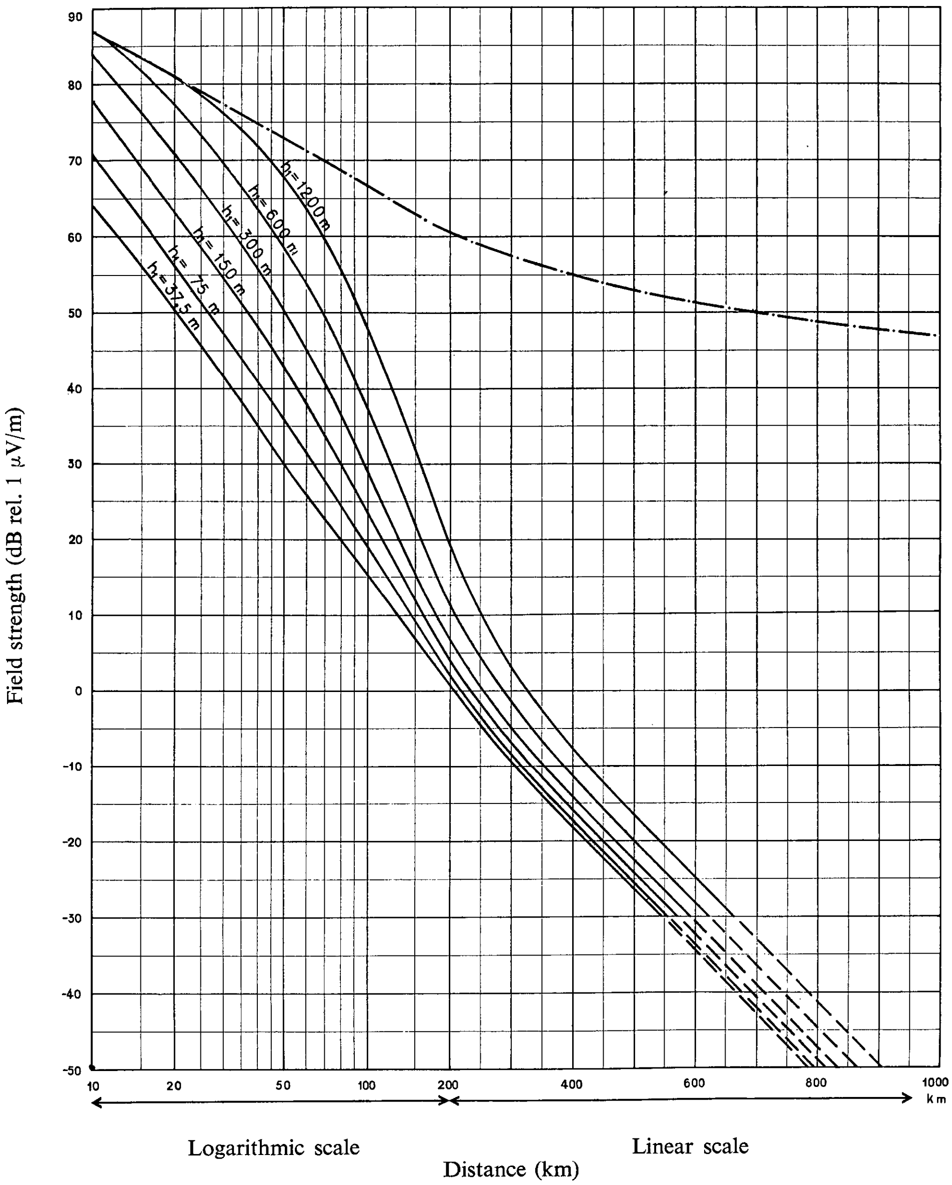


FIGURE 1

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

Frequency: 30–250 MHz (Bands I, II and III); Land and North Sea; 50% of the time; 50% of the locations; h_2 = 10 m.

—·—·—·—·— Free space

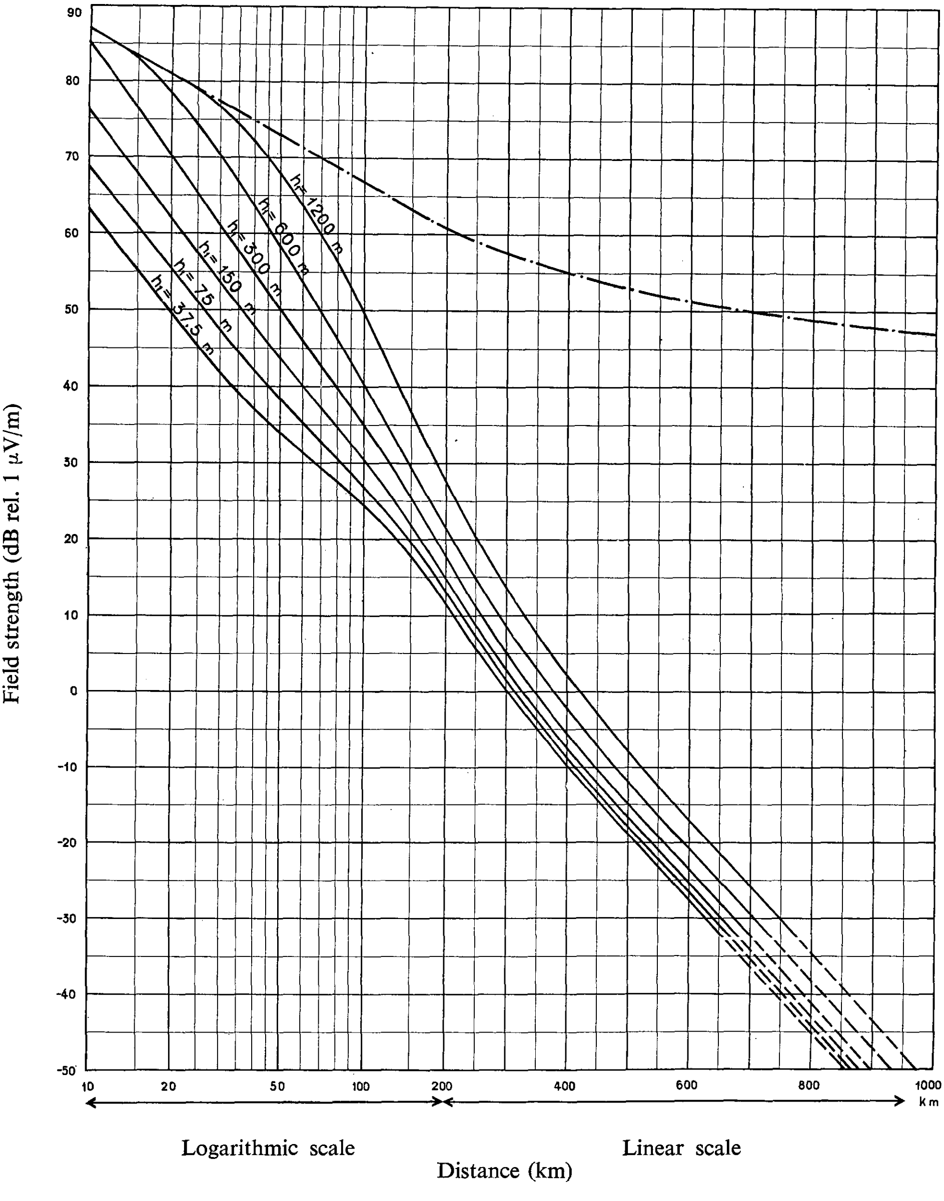


FIGURE 2

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

Frequency: 30–250 MHz (Bands I, II and III); Land and North Sea region, 10% of the time; 50% of the locations; h_2 = 10 m.

—·—·—·—·— Free space

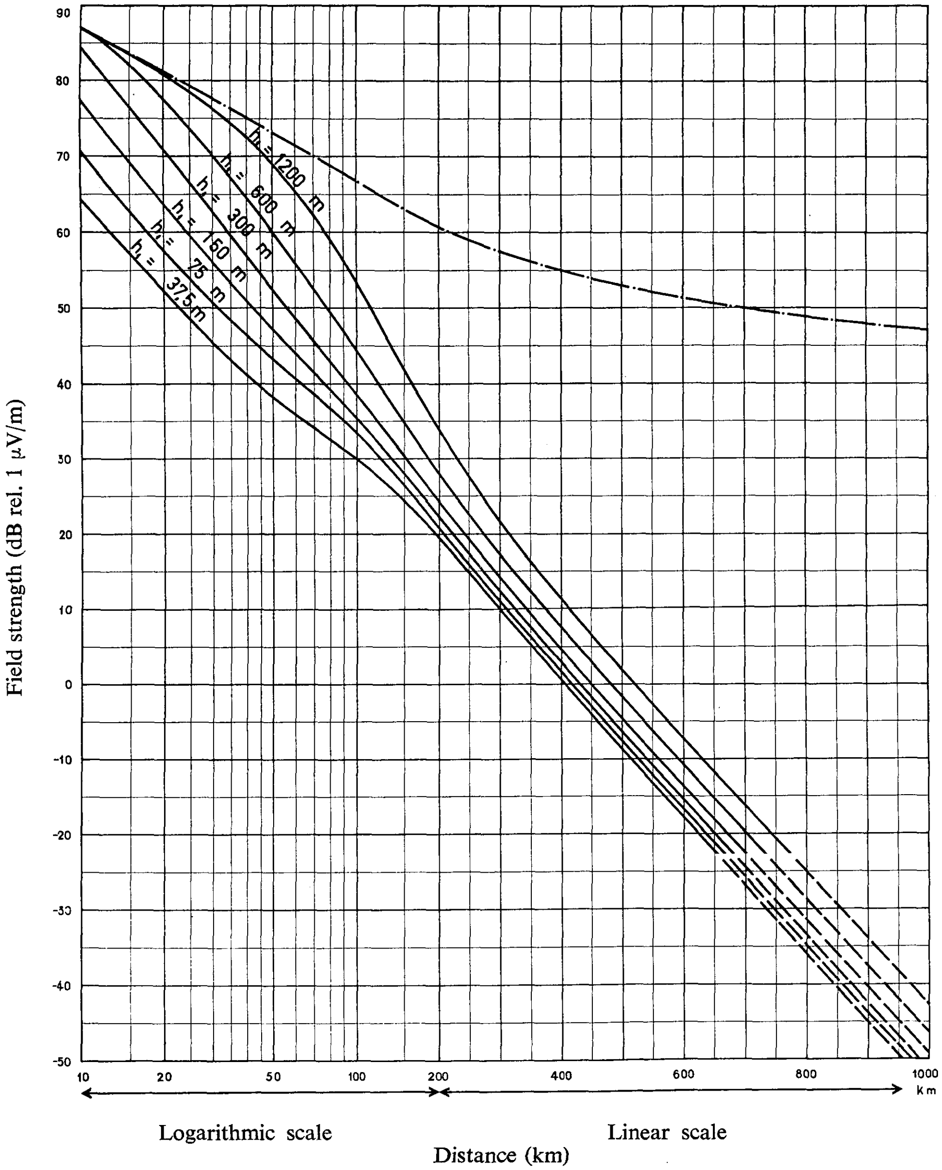


FIGURE 3

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

Frequency: 30–250 MHz (Bands I, II and III); Land; 1% of the time;
50% of the locations; h_2 = 10 m.

—·—·—·— Free space

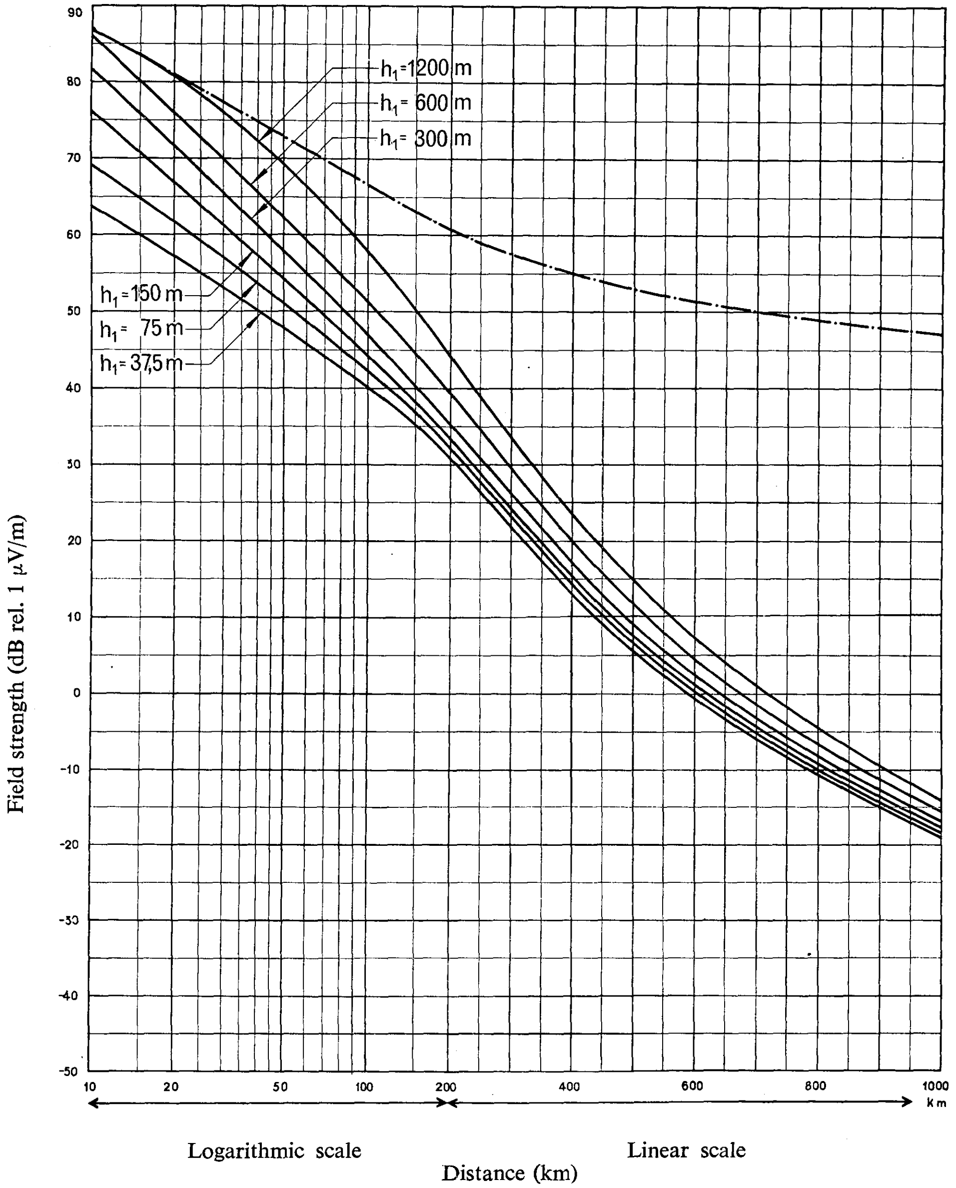


FIGURE 4

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

Frequency: 30–250 MHz (Bands I, II and III); North Sea; 1% of the time; 50% of locations; h_2 = 10 m.

—·—·—·—·— Free space

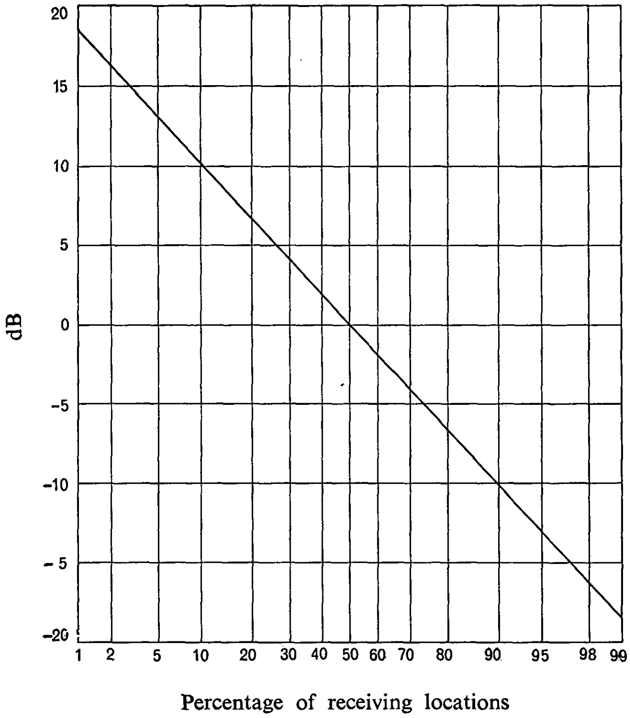


FIGURE 5

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

Frequency: 30–250 MHz (Bands I, II and III)

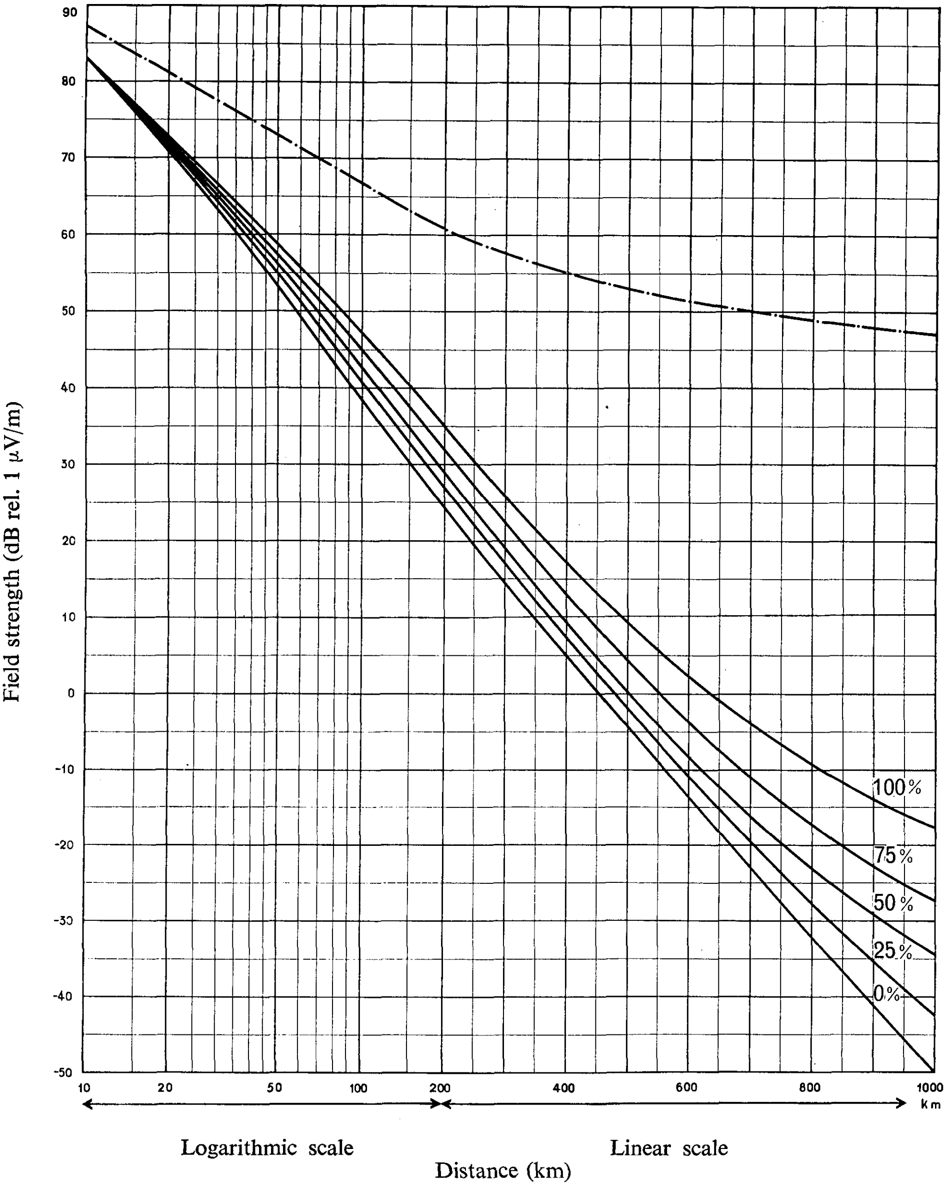
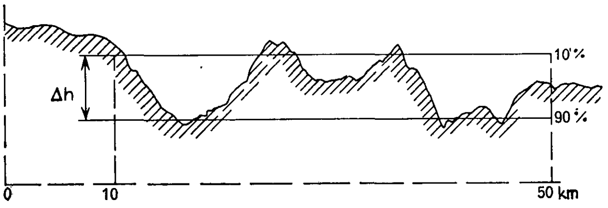


FIGURE 6

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

Frequency: 30–250 MHz (Bands I, II and III); Mixed land and sea (North Sea area); 1% of the time; 50% of locations; h_2 = 10 m; h_1 = 300 m.
(Best fit curves for indicated percentage of path over sea).

—·—·—·—·— Free space



Transmitter

FIGURE 7

Definition of the parameter Δh

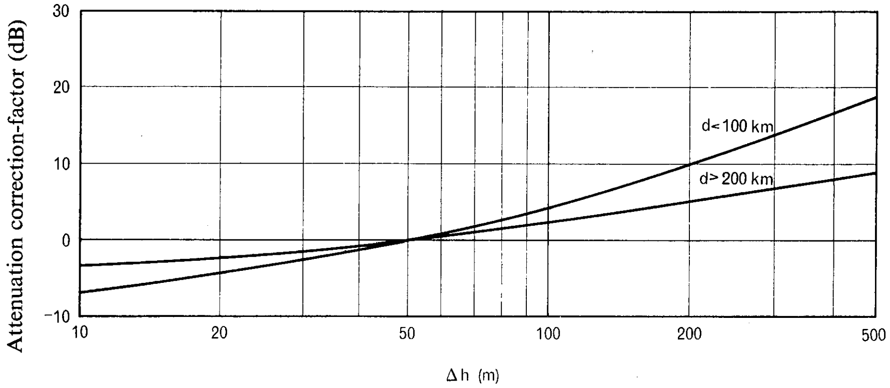


FIGURE 8 *(a)*

Attenuation correction-factor as a function of Δh for frequencies 150–250 MHz (Band III)

(Parameter d represents the distance from transmitter)

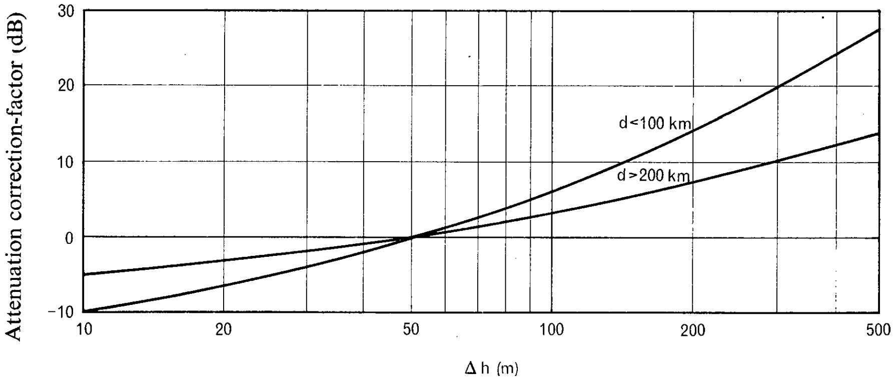


FIGURE 8 *(b)*

Attenuation correction-factor as a function of Δh for frequencies 450–1000 MHz (Bands IV and V)

(Parameter d represents the distance from transmitter)

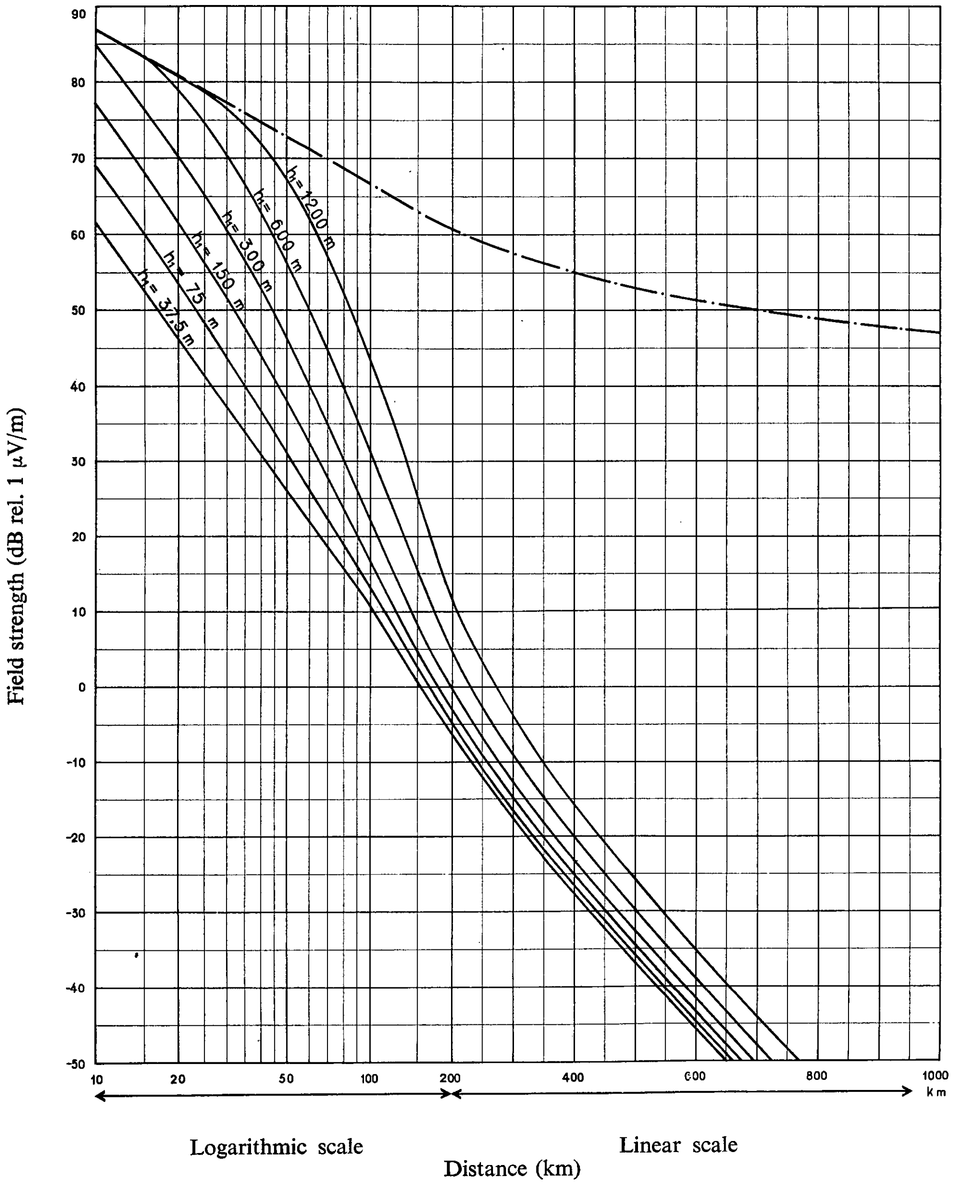


FIGURE 9

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

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

—·—·—·—·— Free space

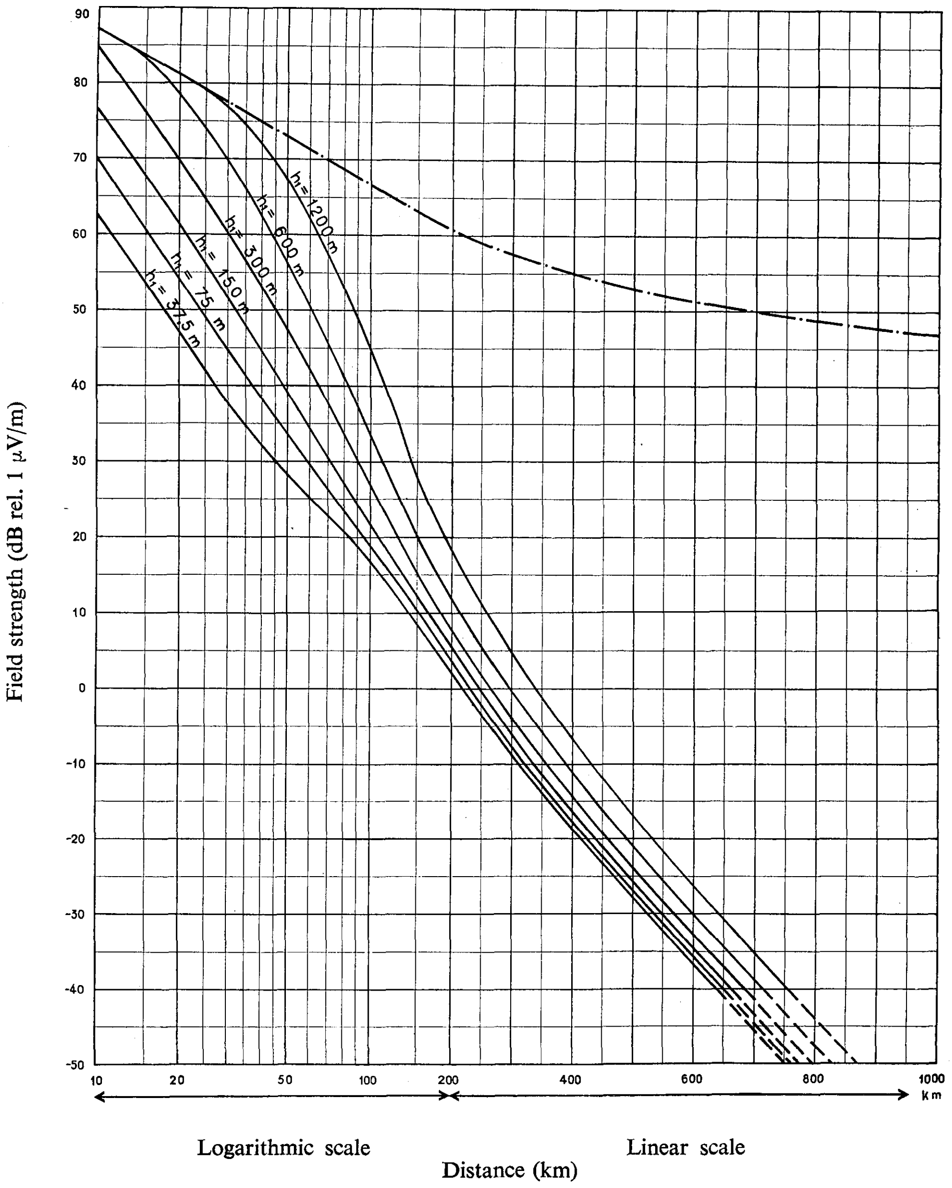


FIGURE 10

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

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

—·—·—·—·— Free space

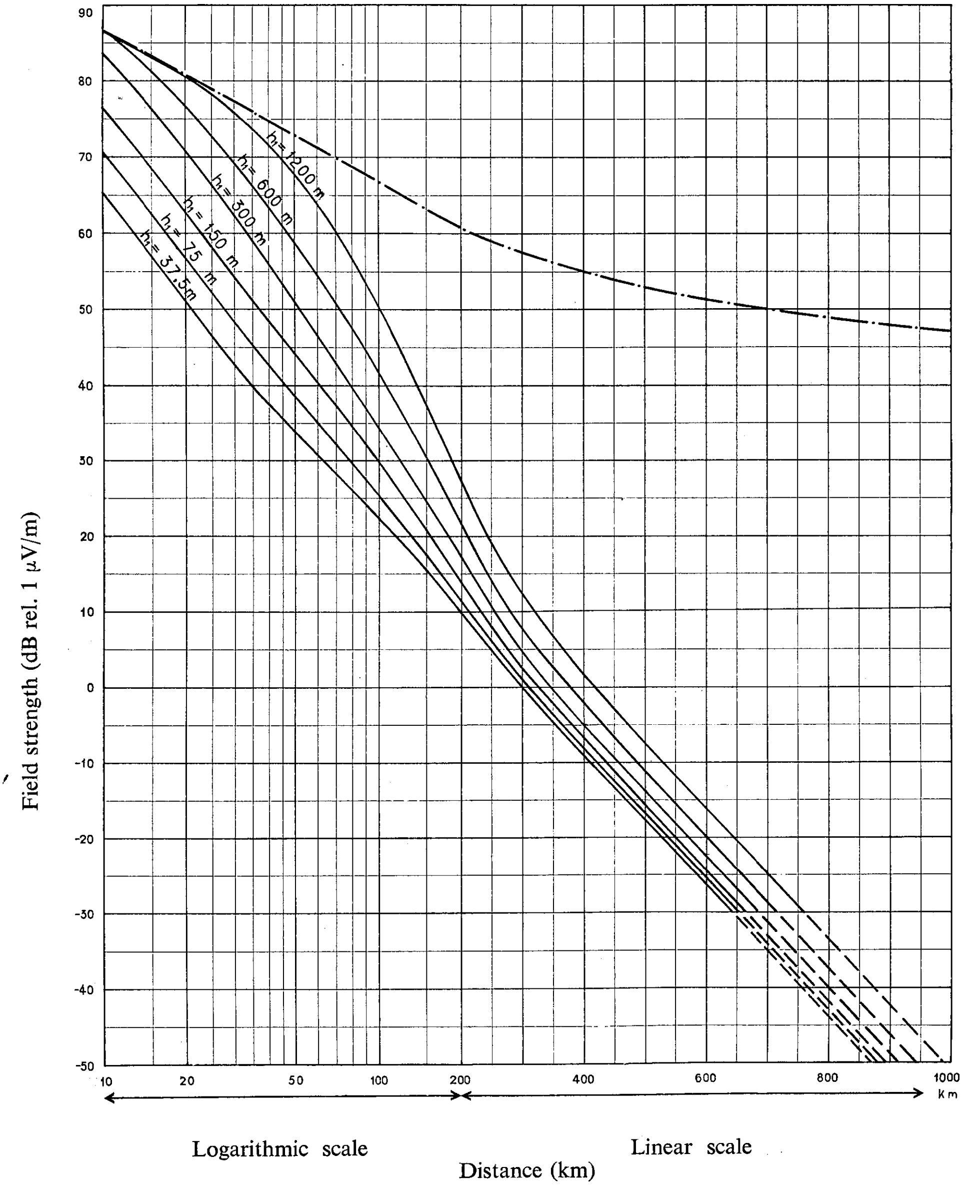
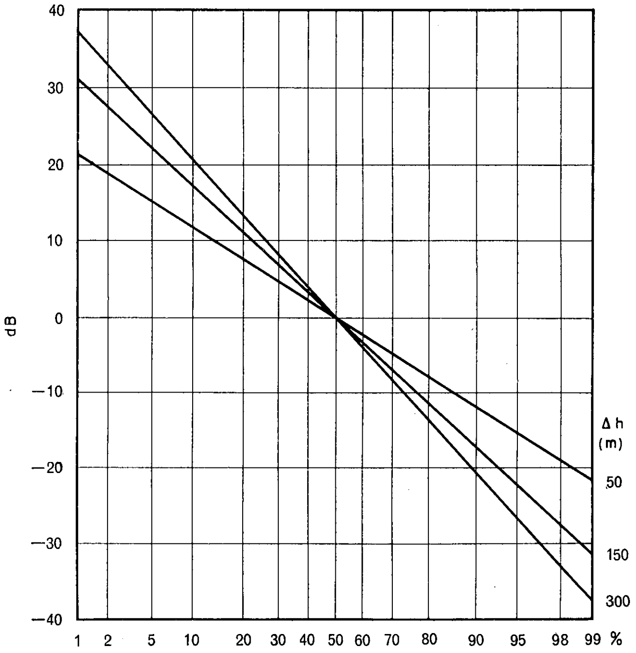


FIGURE 11

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

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

—·—·—·—·— Free space



Percentage of receiving locations

FIGURE 12

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

Frequency: 450–1000 MHz (Bands IV and V)

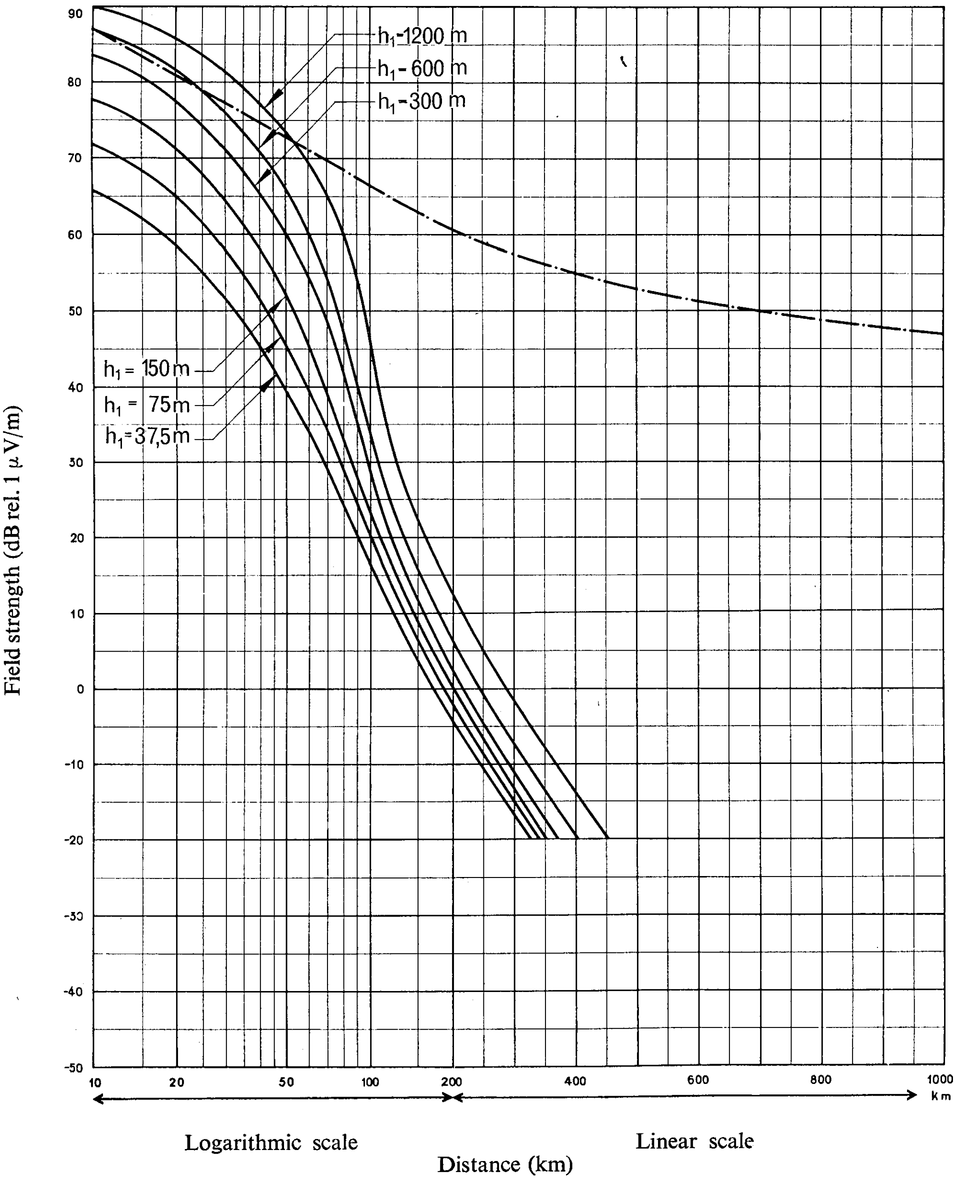


FIGURE 13

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

Frequency: 450–1000 MHz (Bands IV and V); North Sea; 50% of time; 50% of locations; h_2 = 10 m; Δh = 50 m.

—·—·—·—·— Free space

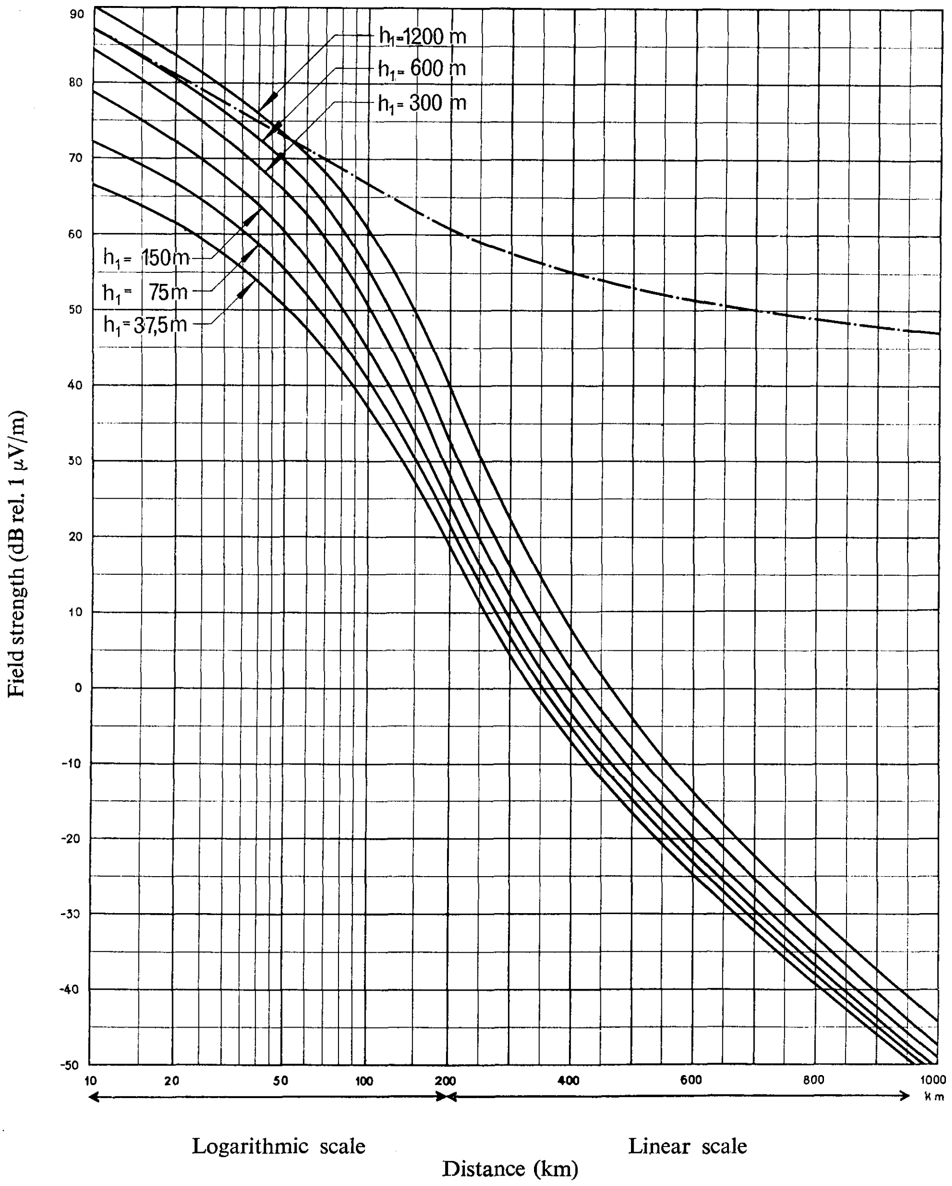


FIGURE 14

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

Frequency: 450–1000 MHz (Bands IV and V); North Sea; 10% of time; 50% of locations; h_2 = 10 m.

—·—·—·—·— Free space

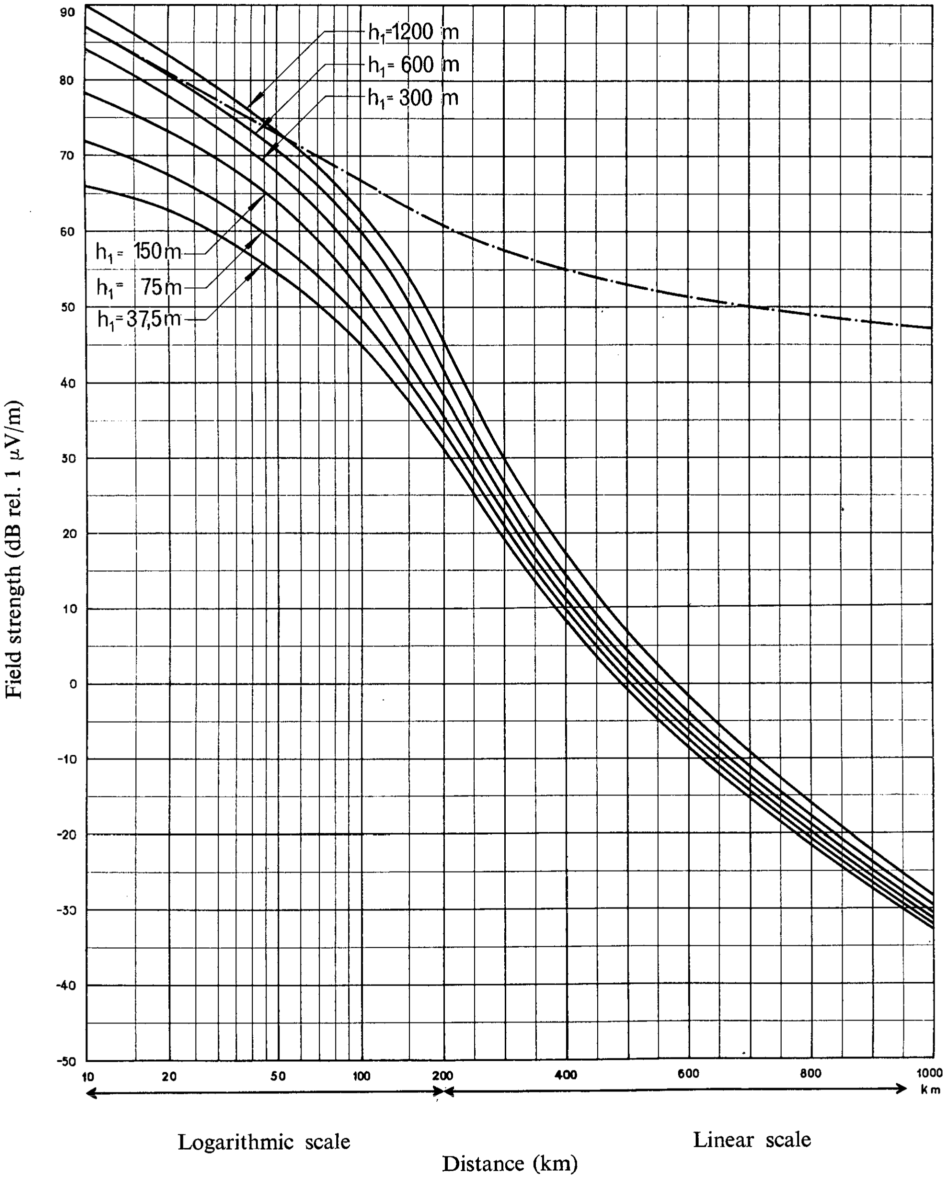


FIGURE 15

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

Frequency: 450–1000 MHz (Bands IV and V); North Sea; 5% of time; 50% of locations; h_2 = 10 m.

—·—·—·—·— Free space

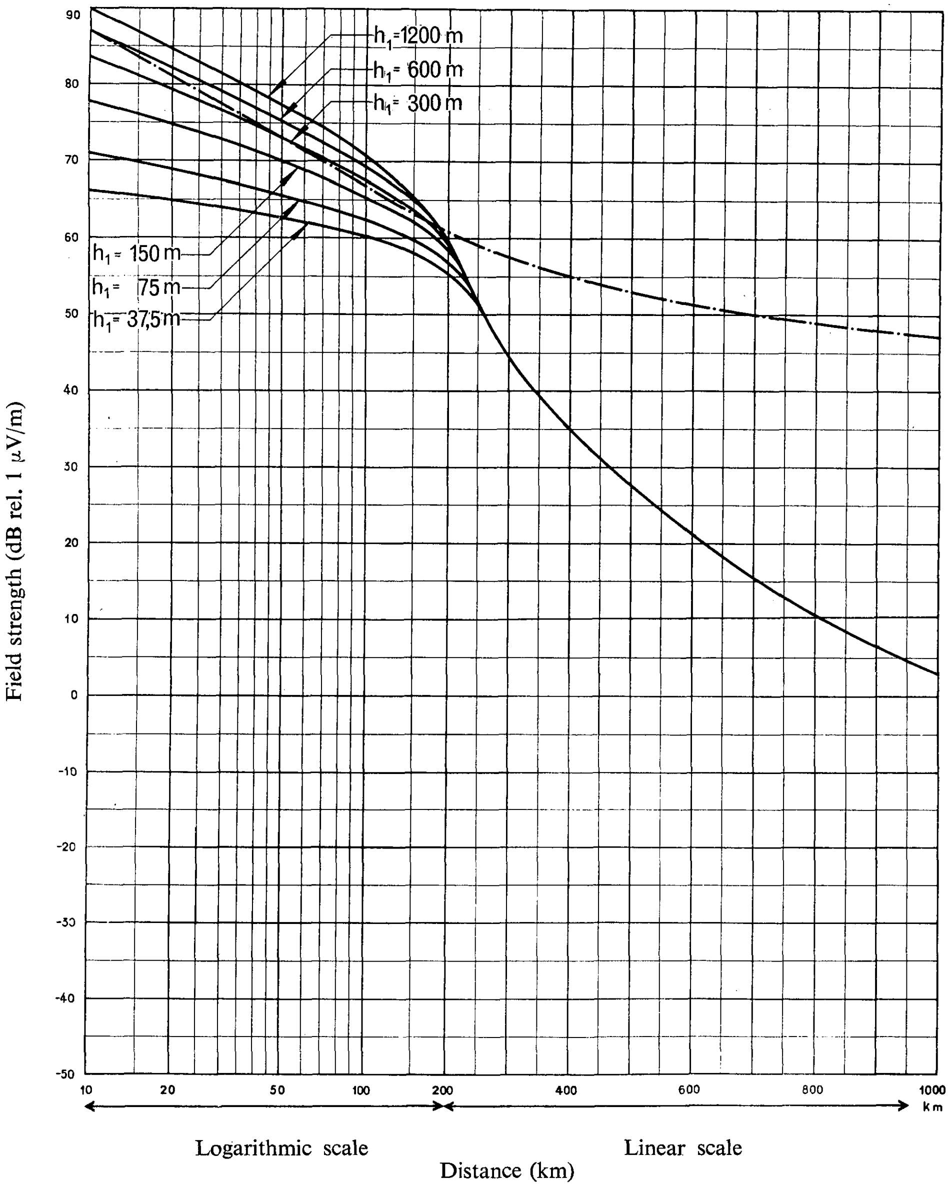


FIGURE 16

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

Frequency: 450–1000 MHz (Bands IV and V); North Sea; 1% of time; 50% of locations; h_2 = 10 m.

—·—·—·—·— Free space

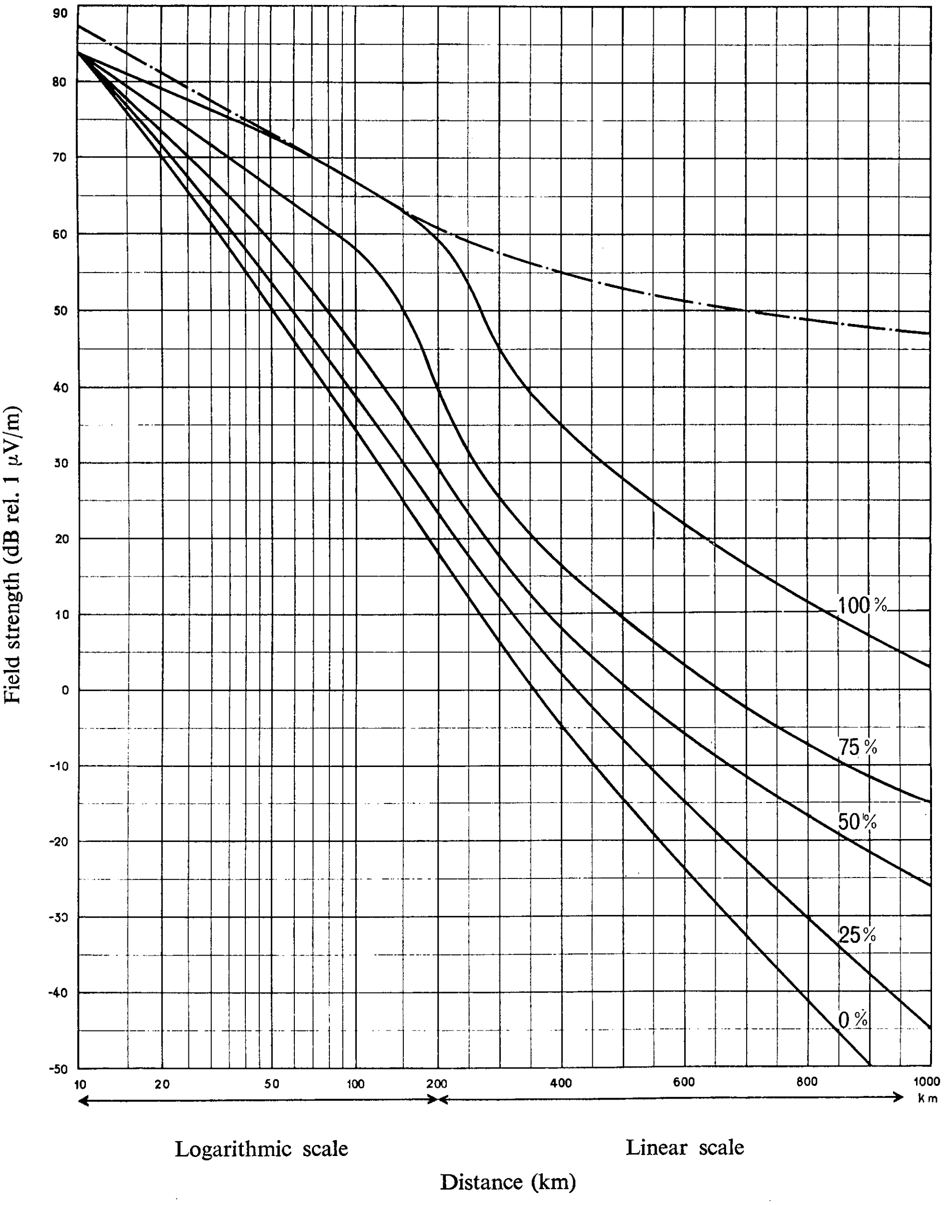


FIGURE 17*(a)*

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

Frequency: 450–1000 MHz (Bands IV and V); Mixed land and sea (North Sea area); 1% of time; 50% of locations; h_2 = 10 m; h_1 = 300 m.
(Best fit curves for indicated percentage of path over sea)

—·—·—·—·— Free space

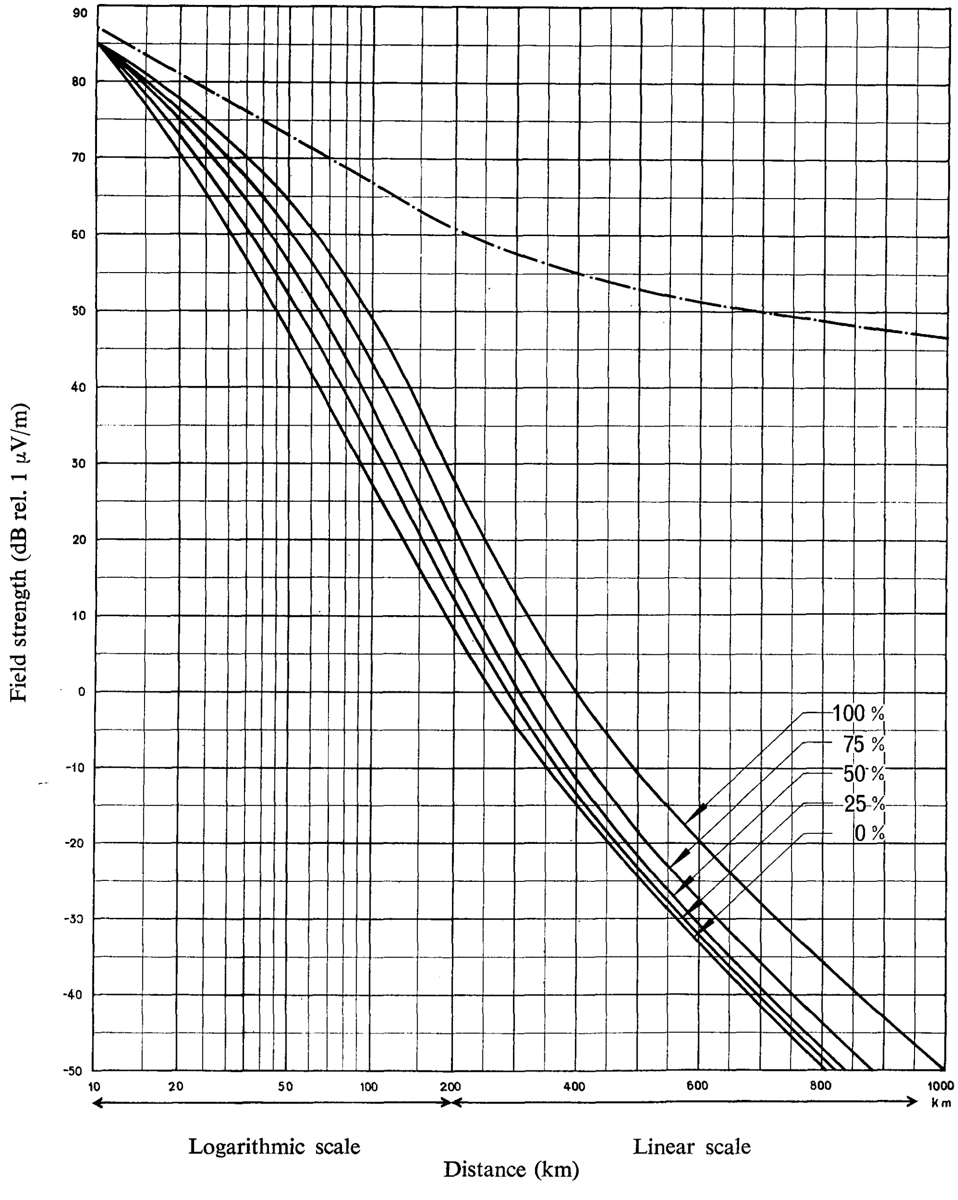


FIGURE 17*(b)*

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

Frequency: 450–1000 MHz (Bands IV and V); Mixed land and sea (North Sea area); 10% of time; 50% of locations; h_2 = 10 m; h_1 = 300 m.
(Best fit curves for indicated percentage of path over sea)

—·—·—·—·— Free space

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

REPORT 227 *

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

(1959 - 1963)

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 MHz, 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

---

* 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.

the top. Most loops are multi-turn, although some instruments employ single-turn loops. Rod antennae cannot be effectively shielded from magnetic fields and, in this frequency range, are normally operated in an unbalanced manner with the rest of the instrument and power supply acting as ground.

Above about 30 MHz half-wave dipoles [7, 8, 9] are generally employed, although they are sometimes used in portable field-strength equipment as low as 18 MHz 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 standards are 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 228–1.

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 on 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- line 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 megahertz, disturbing effects from underground cables do not usually have to be considered, but at frequencies much below 2 MHz, 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 polarised 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 MHz 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 differ 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 field strength 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 MHz, 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 having 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 sub-multiples 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 1 GHz, the power flux-density (field intensity) may be measured in watts (or sub-multiples) 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 the bandwidth and this leads to the unit of microvolts per metre per kilohertz (or microvolts per metre in a 1 kHz 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 (± dB)	Minimum field strengh at which this accuracy is obtained (μV/m)
10 - 30 kHz	2	10 (1)
30 - 300 kHz	2	5 (1)
300 - 3000 kHz	2	2 (1)
3 - 30 MHz	2	2 (1)
30 - 300 MHz	2	2
300 - 3000 MHz	3	5 (2)
3 - 30 GHz	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. Recommendation 378–1 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 a 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 advisable 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 advisable 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 MHz, 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 circuit:

— cathode-ray oscillograph at the output of the radio-frequency or intermediate-frequency 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 organisations, and these are listed in Table II.

TABLE II

Frequency range (MHz)	Bandwidth at 6 dB down (kHz)	Charge time constant T_c (s)	Discharge time constant T_d (s)	Mechanical time constant T_m (s)
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 (3)	0·160 (3) 0·600 (2)	0·160 (1)
25–300	120 (1) 150 (2)	0·001 (3)	0·550 (1) 0·600 (2)	0·1 (1)

(1) C.I.S.P.R. [1].
(2) A.S.A. [2].
(3) Used by both the above 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 bandwidth (the average power is proportional to the bandwidth). 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 logarithm 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 signal [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 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/m^2) 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 length, 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).

BIBLIOGRAPHY

1. Specification for C.I.S.P.R. Radio interference measuring apparatus for the frequency range 0·15 Mc/s to 30 Mc/s *C.I.S.P.R. Report 302.*

   Specification for C.I.S.P.R. Radio interference measuring apparatus for the frequency range 25 to 300 Mc/s. *C.I.S.P.R. Report 303.*

2. Proposed American standard specifications for radio-noise and field-strength meters.

   ASA C 63.2 - 0·015 to 30 Mc/s
   ASA C 63.5 - 25 to 400 Mc/s

3. Proposed American standard on methods of measurement of radio influence voltage and radio influence field (radio noise)

   ASA C 63.4 - 0·015 Mc/s to 25 Mc/s
   ASA C 63.3 - 25 Mc/s to 400 Mc/s

4. *I.E.C. Report Sc.*, 12-1.
5. GREENE, F. M. Calibration of commercial radio strength meters at the National Bureau of Standards. *NBS Circular*, 517 (December, 1951).
6. MCPETRIE, J. S. and SAXTON, J. A. Theory and experimental confirmation of calibration of field-strength measuring sets by radiation. *Journal I.E.E.*, **88**, Part III, 11 (1941).
7. CHAPIN, E. Field-strength measurements. *F.C.C. Report L.D. 6.3.1.*
8. TERMAN, F. E. and PETTIT, J. M. *Electronic Measurements*, McGraw-Hill, Chapter XI (1951).
9. SMITH-ROSE, R. L. Radio field-strength measurement. *Proc. I.E.E.* (Radio and Comm.), **96**, Part III (January, 1949).
10. SMITH, W. B. Recording sky-wave signals from broadcast stations. *Electronics*, **21**, 112 (November, 1945).
11. CRICHLOW, W. Q. and SPAULDING, A. D. A graphical method of obtaining amplitude-probability distribution from statistical moments of atmospheric radio noise, presented at Joint Meeting U.R.S.I.-IRE (October 20-22, 1958), at Penn. State University.
12. WATT, A. D. *et al.* Performance of some radio systems in the presence of thermal and atmospheric noise. *NBS Journ. of Research*, Part **B** (July, 1959).
13. Recommended practice for measurement of field intensity above 300 Mc/s from radio-frequency industrial, scientific and medical equipments. *A.I.E.E.*, 950 (April 1951).
14. WIND, M. *Handbook of Electronic Measurements*, Vol. II, Chapter VIII, Polytechnic Institute of Brooklyn, Inter-science Publishers.
15. Standards on radio wave propagation measuring methods. *Supplement to Proc. IRE*, Vol 30, **7**, Part II (1942).
16. NORTON, K. A. Transmission loss in radio propagation (I and II):

    Part I — *Proc. IRE*, **41** (January, 1953).

    Part II — *NBS Technical Note* 12 (June, 1959), Office of Technical Services, U.S. Department of Commerce, Washington 25 D.C.

17. *Proc. U.R.S.I. XIIth General Assembly*, Boulder, Colo.; Vol. XI, Part. 4, Commission IV.

    — Report No. 254: What are the most readily measured characteristics of terrestrial radio noise from which the interference to different types of communications systems can be determined, 9.

    — Recommendation No. 1 and Annex to Recommendation No. 1: Measurement of atmospheric noise, 99.

18. C.C.I.R. Report 65. Revision of atmospheric radio noise data.
19. DIAMOND, H., NORTON, K. A. and LAPHAM, E. G. On the accuracy of radio field-intensity measurement at broadcast frequencies. *Jour. of Res. of the NBS*, **21**, 795-818 (December, 1938).
20. NORTON, K. A. System loss in radio wave propagation. *NBS Journ. of Res.*, D (July, 1959).

REPORT 228-1 *

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

(1959 – 1963 – 1966)

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 provided with a given quality of service;

1.2 it should take into account significant variations with times;

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 conditions, 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 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 an unsatisfactory 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/μV/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 fulfil 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.

On the other hand, when the height of the transmitting antenna is such, that the field strength varies non-linearly with height above the ground for the frequency band concerned, it is desirable to measure the field strength at various heights up to at least 20 m [8].

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.

However, when using directional receiving antennae, it is sometimes insufficient to measure only the strength of the sound signal to determine the coverage of a transmitter for both vision and sound.

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 MHz*

Normally, below 100 MHz, 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 MHz. 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 location, 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 of the direction from which the maximum signal arrives, if other than the direction of the transmitter.

2.8 *Measurements at frequencies above 100 MHz*

At frequencies above 100 MHz, 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. 1μV/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 location 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 variation 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 and distance for a television station operating in the 54 MHz to 88 MHz 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 shown, that would be expected to have a field strength in excess of 57 dB rel. 1 μV/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.

BIBLIOGRAPHY

1. Report to the Federal Communications Commission of Committee 5.3 of the Television Allocation Study Organization (TASO) (March, 1959).

2. Volumes I and II of the Report of the ad-hoc Committee for the evaluation of the radio-propagation factors concerning the television and FM broadcasting services in the frequency range between 50 and 250 Mc/s. Federal Communications Commission, Mimeograph 36830 (May, 1949) and Mimeograph 54382 (7 July, 1950).

3. KIRBY, R. S. Measurement of service area for television broadcasting. *Trans. IRE*, PGBTS-7, **23** (February, 1957).

4. NORTON, K. A., STARAS, H. and BLUM, M. Statistical approach to the problem of multiple radio interference to FM and television service, *Trans. IRE*, AP-1, **43** (February, 1952).

5. Kirby, R. S. and Capps, F. M. Correlation in VHF propagation over irregular terrain. *Trans. IRE,* AP-4, 1, **72** (January, 1956).

6. Kirby, R. S., Dougherty, H. T. and McQuate, P. L. VHF propagation measurements in the Rocky Mountain Region. *Trans. IRE,* PGVC-6, **13** (July, 1956).

7. Kühn, U. Ausbreitungsuntersuchungen über unterschiedlichem Gelände in den Frequenzbändern I, II und III (Propagation investigation of the effect of various types of terrain in the frequency bands I, II and III), *Techn. Mitt. BRF* (DDR) (February and May, 1958).

8. Gentile, G. Measurement of field strengths at frequencies above 30 MHz — Method used by the RAI Monitoring Centre at Monza. *E.B.U. Review* **97**-A (June 1966).

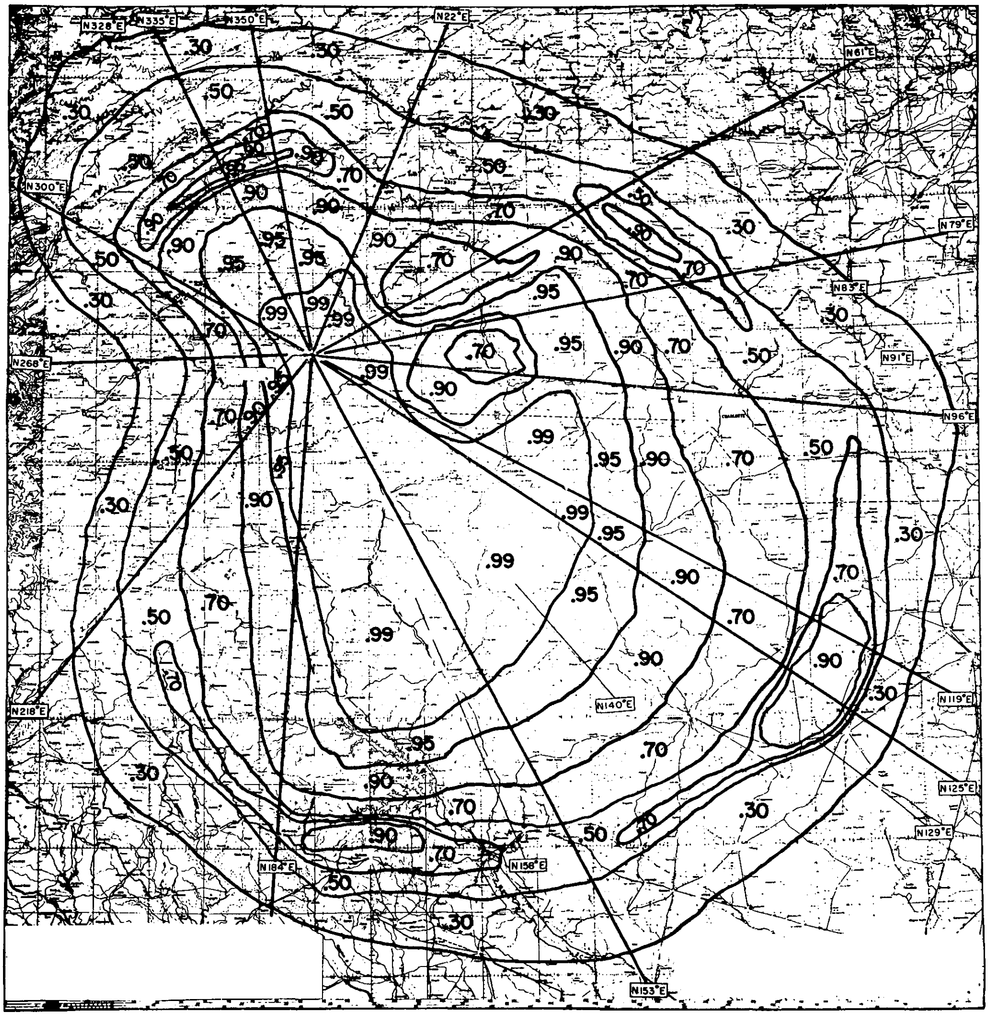


Figure 1

The concept of service probability

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

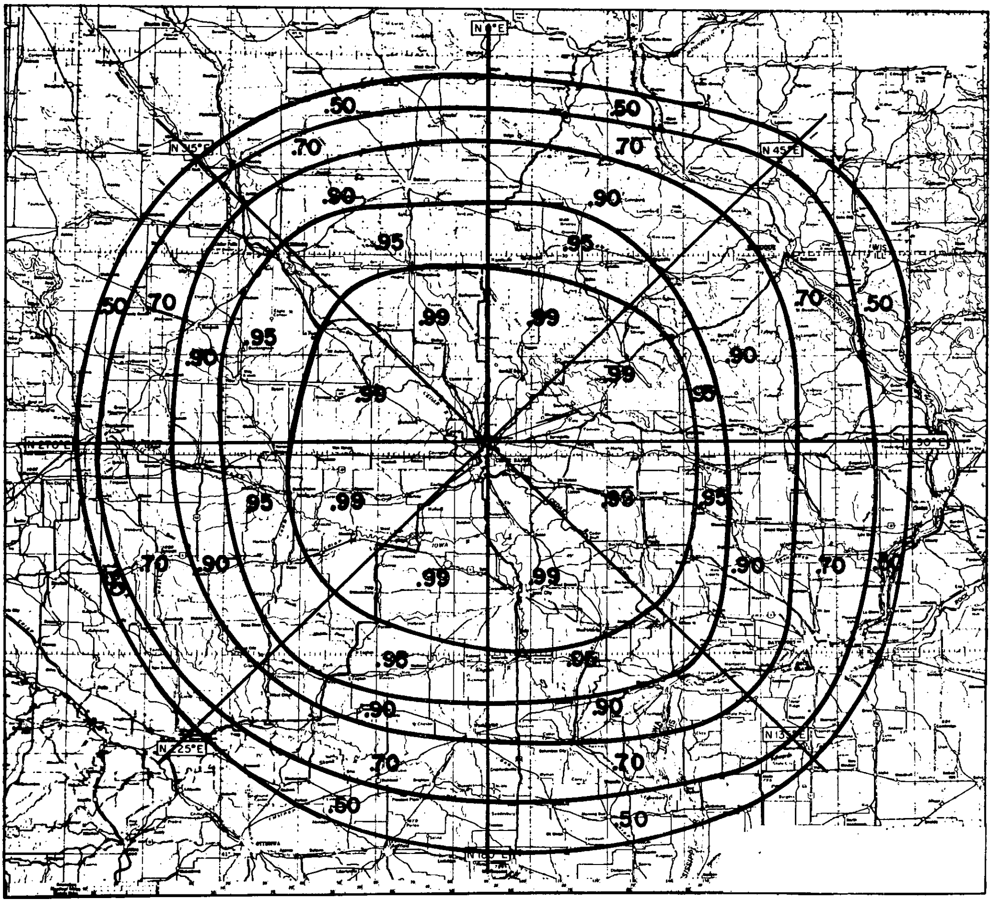


FIGURE 2

The concept of service probability

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

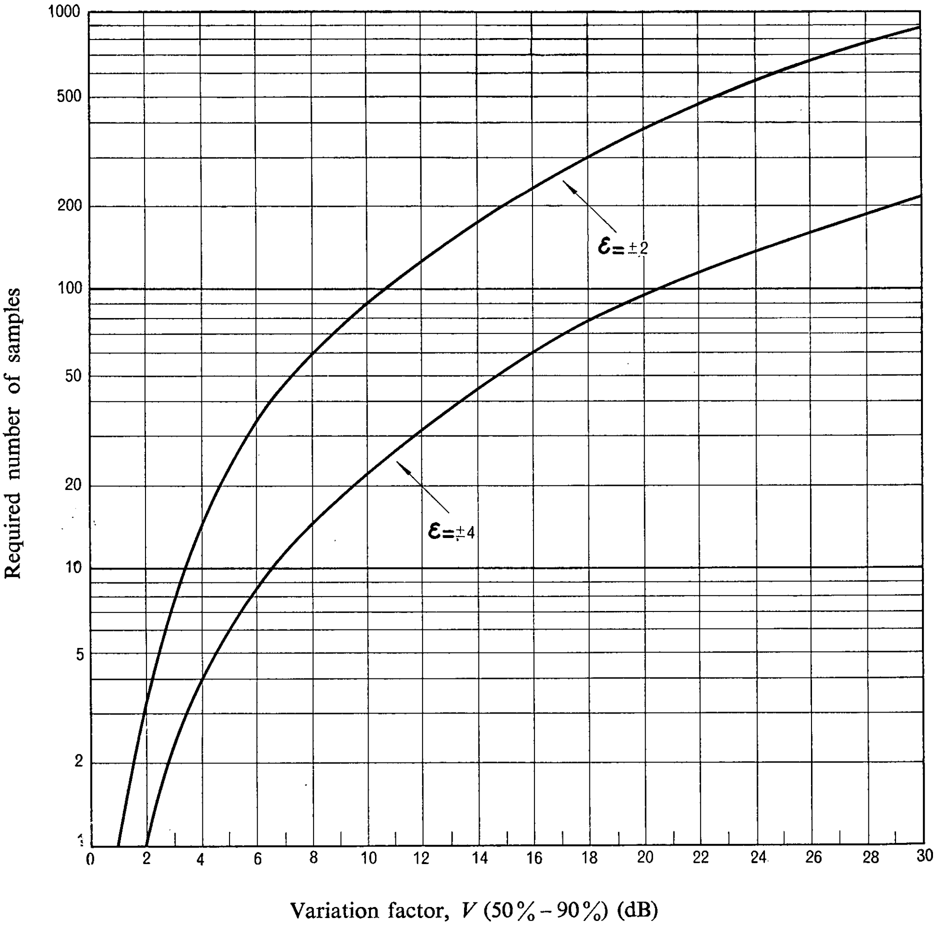
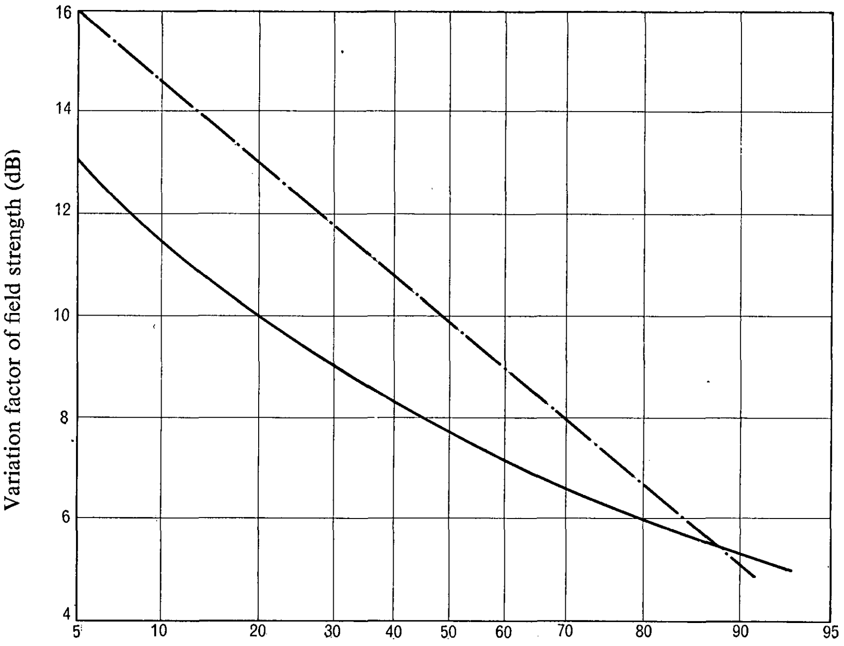


FIGURE 3

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



Percentage of towns in which variation factor exceeds the ordinate

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

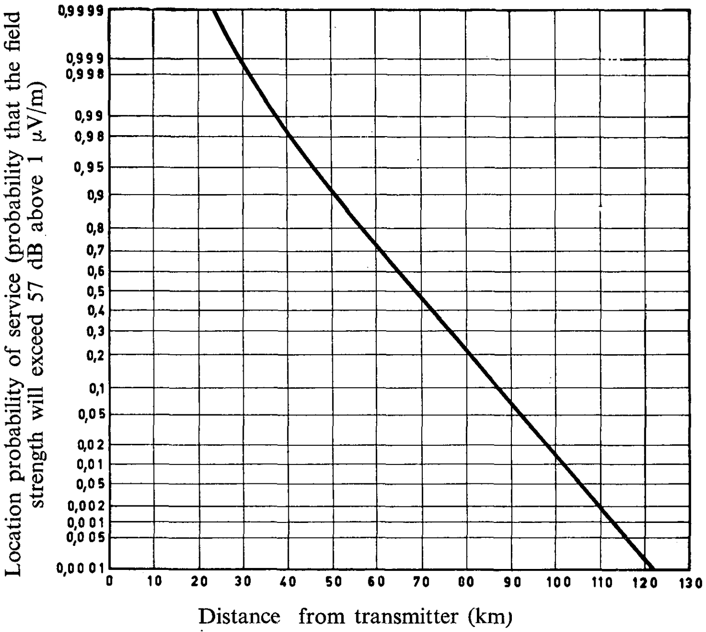


FIGURE 5

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 MHz band

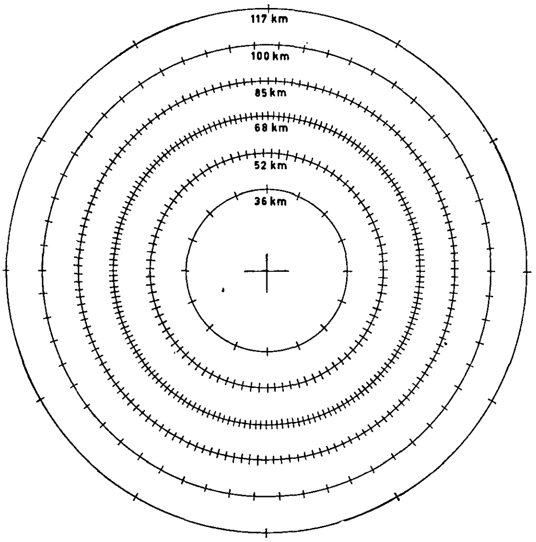


FIGURE 6

Possible arrangement of measurement sites 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

(Question 1/V)

(1959 - 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 dielectric 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 MHz, λ is the free-space wave-length in metres, and the time factor $\exp(j\omega t)$ is assumed. It may be noted that the displacement and the conduction current densities are 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 (MHz)
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 kHz to 10 MHz, δ has the values shown in Table II. It will be seen that at frequencies of 10 MHz 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 MHz, may be very much greater for a vertically-polarized wave than for a horizontally-polarized wave (Doc. V/24 (Federal Republic of Germany), 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 kHz to 10 MHz.

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), Geneva, 1962). It is reported that careful use of this method allows measurement of earth constants over a range of frequencies from 100 kHz to 40 MHz (Doc. V/1 (Federal Republic of Germany), 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 *Measurements of ground-wave attenuation*

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

4.5 *Attenuation with depth below the surface*

The ground 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 *Measurements of phase-change*

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 kHz because of the small angles of tilt which occur. In view of the dependence of the tilt on height above the surface, the usefulness of this method is restricted to frequencies below about 40 MHz (Doc. V/1 (Federal Republic of Germany), 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), Geneva, 1962). See also Report 236–1).

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 the ground

Frequency	Depth δ(m)		
	$\sigma = 4$ mho/m $\varepsilon = 80$	$\sigma = 10^{-2}$ mho/m $\varepsilon = 10$	$\sigma = 10^{-3}$ mho/m $\varepsilon = 5$
10 kHz	2·5	50	150
100 kHz	0·80	15	50
3 MHz	0·14	5	17
10 MHz	0·08	2	9

BIBLIOGRAPHY

Relating to § 3

1. SMITH-ROSE, R. L. The electrical properties of soil for alternating currents at radio frequencies. *Proc. Roy. Soc. A.* **140**, 359 (1933).
2. SMITH-ROSE, R. L. The electrical properties of sea-water for alternating currents. *Proc. Roy. Soc. A*, **143**, 135 (1933).
3. SMITH-ROSE, R. L. Electrical measurements on soil with alternating currents. *J.I.E.E.*, **75**, 221 (1934).
4. WAIT, J. R. Propagation of radio waves over a stratified ground. *Geophysics*, **18**, 416 (1953).
5. FEINBERG, E. On the propagation of radio waves along an imperfect surface. *J. of Phys. U.S.S.R.*, **8**, 317 (1944).
6. BARFIELD, R. H. The attenuation of wireless waves over land. *J.I.E.E.*, **66**, 204 (1928).
7. BARFIELD, R. H. and MUNROE, G. H. The attenuation of wireless waves over towns. *J.I.E.E.*, **67**, 253 (1929).
8. C.C.I.R. Doc. V/24 (Federal Republic of Germany), Geneva, 1962.
9. WAIT, J. R. Geofisica Pura e Applicata, **28**, 47 (1954).
10. WAIT, J. R. The propagation of electromagnetic waves along the earth's surface. *Proc. Symposium on electromagnetic waves*, Pub. **6**, Math. Research Center, U.S. Army (1961).

Relating to § 4

11. FELDMAN, C. B. The optical behaviour of the ground for short radio waves. *Proc. IRE*, **21**, 764 (1933).
12. GISH, O. H. and ROONEY, W. J. Measurements of resistivity of large masses of undisturbed earth. *Ter. Magn. and Atmos. Elect.*, **30**, 161 (1925).
13. WHITEHEAD, S. and RADLEY, W. G. Experiments relating to the distribution of alternating electric currents in the earth and the measurement of the resistivity of the earth. *Proc. Phys. Soc.*, **47**, 589 (1935).

14. Wait, J. R. and Wahler, A. M. On the measurement of ground conductivity at VLF. *NBS, Report No. 5037.*

15. Smith-Rose, R. L. and Barfield, R. H. On the determination of the directions of the forces in wireless waves at the earth's surface. *Proc. Roy. Soc. A*, **107**, 587 (1925).

16. Barfield, R. H. Some measurements of the electrical constants of the ground at short wavelengths by the wave-tilt method.

17. Gill, E. W. B. A simple method of measuring electrical earth constants. *Proc. I.E.E.*, **96**, 141 (1949).

18. Galligioni, G. Ground conductivity measurements in Italy. *Alta Frequenza*, **20**, 119 (1951).

19. Effective radio ground-conductivity measurements in the United States. *NBS Circular 546* (1954).

20. Vice, R. W. A. Survey of ground wave propagation conditions in South Africa. *Trans. S.A.I.E.E.*, **45**, 139 (1954).

21. Norton, K. A. The propagation of radio waves over the surface of the earth and in the upper atmosphere. *Proc. IRE*, **24**, 1367 (1936).

22. Pressey, B. G., Ashwell, G. E. and Fowler, C. S. The measurement of the phase velocity of ground-wave propagation at low frequencies over a land path. *Proc. I.E.E.*, **100**, Pt. III, 73 (1953).

23. McPetrie, J. S. A determination of the electrical constants of the earth's surface at wavelengths of 1·5 and 0·46 metres. *Proc. Phys. Soc.*, **46**, 637 (1934).

24. McPetrie, J. S. and Saxton, J. A. Determination of the electrical properties of soil at a wavelength of 5 metres (Frequency 60 Mc/s.) *J.I.E.E.*, **90**, Part III, 33 (1943).

25. Grosskopf, J. Über das Zennecksche Drehfeld im Bodenwellenfeld eines Senders (On Zenneck's rotating field in the ground-wave field of a transmitter). *Hochfrequenzetechn. u. Elektroakustik. (HFT)*, **59**, 72 (1942).

26. Grosskopf, J and Vogt, K. Über die Messung der Bodenleitfähigkeit (On the measurement of ground conductivity). *Telegr., Fernspr., Rf. u. Fernseh-Technik. (TFT)*, **29**, 164 (1940).

27. Grosskopf, J. and Vogt, K. Zur Messung der Bodenleitfähigkeit (On the measurement of ground conductivity). *TFT*, **31**, 22 (1942).

28. Grosskopf, J. and Vogt, K. Der Zusammenhang zwischen der effektiven Bodenleitfähigkeit und der Ausbreitungsdämpfung (The relation between the effective conductivity of the ground and propagation attenuation). *HFT*, **62**, 14 (1943).

29. Grosskopf, J. Über Bodenleitfähigkeitsmessungen in Schleswig-Holstein (Measurements of ground conductivity in Schleswig-Holstein). *Fernmeldetechn. Zeitschrift*, **2**, 211 (1949).

30. Grosskopf, J. Zur Ausbreitung von Mittelwellen über inhomogenes Gelände (On the propagation of medium waves over non-homogeneous terrain). *Fernmeldetechn. Zeitschrift (FTZ)*, **3**, 118 (1950).

31. Grosskopf, J. and Vogt, K. Ausbreitungsmessungen über inhomogenem Boden (Measurements of propagation over non-homogeneous terrain). *HFT*, **60**, 97 (1942).

32. Grosskopf, J. Die Ausbreitung elektromagnetischer Wellen über inhomogenem Boden (The propagation of electromagnetic waves over non-homogeneous terrains). *HFT*, **62**, 103 (1953).

33. Grosskopf, J. and Vogt, K. Der Einfluss von Bodeninhomogenitäten auf die Funkbeschickung (The effect of inhomogeneity of the ground in radio direction-finding errors and its correction to zero). *Nachrichtentechn. Zeitschrift (NTZ)*, **9**, 349 (1956).

34. Grosskopf, J. and Vogt, K. Zur Höhenabhängigkeit des Zenneckchen Drehfeldes (On the dependence of Zenneck's rotating field on height). *HFT*, **62**, 172 (1943).

35. Grosskopf, J. Das Strahlungsfeld eines vertikalen Dipolsenders über geschichtetem Boden. (The radiation field of a vertical-dipole transmitter on stratified soil). *HFT*, **60**, 136 (1942).

36. Grosskopf, J. and Vogt, K. Die Messung der elektrischen Leitfähigkeit bei geschichtetem Boden (The measurement of electrical conductivity on stratified soil). *HFT*, **58**, 52 (1941).

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

38. C.C.I.R. Doc. V/1 (Federal Republic of Germany), Geneva, 1962.

39. Argirović, M. A new method and equipment for the measurement of the electrical constants of the earth. *Telekomunikacije* (in Serbo-Croat), **6**, 1 (1957).

40. Godzinski, Z. The surface impedance concept and the structure of radio waves over real earth. *Proc. I.E.E.* Part C, Monograph 108, 362-373 (September, 1961).

41. Tomankiewicz, T. and Stasierski, L.
    - *(a)* The wave-tilt method of determining the electrical properties of the earth. (Reports of the Institute of Telecommunications, Warsaw, Poland), No. 2 (1966).
    - *(b)* Determination of ground-wave attenuation from measurements of the electrical properties of the earth (Reports of the Institute of Telecommunications, Warsaw, Poland), No. 2 (1966).

42. Wait, J. R. and Howe, H. H. Amplitude and phase curves for ground-wave propagation. *NBS Circular* 574 (1956).

43. Johler, J. R., Kellar, W. J. and Walters, L. C. Phase of the low radio-frequency ground-wave. *NBS Circular 573* (1956).

44. Walters, L. C. Johler, J. R. and Lilley, C. M. Amplitude and phase of the low and very low radio-frequency ground-wave. *NBS Technical Note* No. 60 (1960).

45. Johler, J. R. A note on the propagation of certain LF pulses utilized in a radionavigation system. *NBS Technical Note* No. 118 (1961).

46. Johler, J. R. and Walters, L. C. Propagation of a ground-wave pulse around a finitely conducting spherical earth from a damped sinusoidal source current. *Trans IRE,* PGAP, *AP-7,* 1 (1959).

47. Johler, J. R. and Lilley, C. M. Ground conductivity determinations at low radio frequencies by an analysis of spheric signatures of thunderstorms. *J. Geophys. Res.*, **66**, 3233 (1961).

48. Levy, B. R. and Keller, J. B. Propagation of electromagnetic pulses around the earth. *Trans IRE,* PGAP, *AP-6,* 56 (1958).

49. Novikov, V. V. Propagation of a radio pulse over the surface of a plane homogeneous earth. *Vestnik Leningradskogo universiteta, Seria fiziki i khimii, No. 10,* **2**, 16 (1960).

50. Wait, J. R. Transient fields of a vertical dipole over a homogeneous curved ground. *Can. J. Res.*, **34**, 27 (1956).

51. Wait, J. R. The transient behaviour of the electromagnetic ground-wave over a spherical earth. *Trans. IRE,* PGAP, *AP-5,* 198 (1957).

52. Wait, J. R. A note on the propagation of the transient ground-wave. *Can. J. Phys.*, **35**, 1146 (1957).

REPORT 230 *

GROUND-WAVE PROPAGATION OVER INHOMOGENEOUS EARTH

(Question 1/V)

(1956 - 1959 - 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

---

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

** Study Programme 135 has been replaced by Question 1/V.

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.

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 of 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 computation 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 earth 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 coastline. It is similarly difficult to check the theory of wave propagation parallel to a boundary by field-strength measurements along a coastline.

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, which is a factor 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 depend, 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 laboriousness 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.

BIBLIOGRAPHY

A. Theoretical investigations of propagation over inhomogeneous earth

1. Investigations of propagation of radio waves, edited by B. A. Vvedensky, a symposium. Published by *Ac. Sci. U.S.S.R.*, Moscow-Leningrad (1948) (in Russian).
2. FEINBERG, E. L., ALPERT, J. L. and GINZBURG, V. L. Theory of ground-wave propagation over earth surface; Radio wave propagation, *GITTL*, Moscow Part I, Chap. IX, 184 (1953) (in Russian).
3. MONTEATH, G. D. Application of the compensation theorem to certain radiation and propagation problems. *Proc. I.E.E.*, Part IV, **98**, 23 (1951).
4. CLEMMOW, P. C. Radio propagation over a flat earth across a boundary separating two different media. *Phil. Trans. Roy. Soc.* A, **246**, 1 (1953).
5. BREMMER, H. The extension of Sommerfeld's formula for the propagation of radio waves over a flat earth to different conductivities of the soil. *Physica*, **20**, 441 (1954).
6. FURUTSU, K. Propagation of electro-magnetic waves over a flat earth across a boundary separating different media and coastal refraction. *J. Radio Res. Lab.* (Tokyo), **2**, 1 (1955).
7. FURUTSU, K. Propagation of electro-magnetic waves over a flat earth across two boundaries separating three different media. *Ibid.*, **2**, 239 (1955).
8. FURUTSU, K. Propagation of electro-magnetic waves over the spherical earth across boundaries separating different earth media. *Ibid.*, **2**, 345 (1955).
9. SENIOR, T. B. A. Radio propagation over a discontinuity in the earth's electrical properties: I and II Coastal Refraction. *Proc. I.E.E.*, Part C, **104**, 43, 139 (1957).
10. WAIT, J. R. Mixed path ground-wave propagation: 1. Short distances. *J. Res. N.B.S.*, **57**, 1 (1956).
11. WAIT, J. R. and HOUSEHOLDER, J. Mixed-path ground-wave propagation: 2. Larger distances. *Ibid.*, **59**, 19 (1957).
12. WAIT, J. R. Amplitude and phase of the low-frequency ground wave near a coastline. *Ibid.*, **58**, 237 (1957).
13. GODZINSKI, Z. The use of equivalent secondary sources in the theory of ground-wave propagation over an inhomogeneous earth. *Proc. I.E.E.*, Monograph No. 299 R (April, 1958), republished in *Proc. I.E.E.*
14. KALININ, Yu. K. and FEINBERG, E. L. Ground-wave propagation over the surface of an inhomogeneous spherical earth. *Radiotech. and Elektron*, **3**, 1122 (1958) (in Russian).
15. KALININ, Yu. K. Diffraction of radio waves over the surface of an inhomogeneous spherical earth. *Ibid.*, **3**, 1274 (1958) (in Russian).
16. HOUTSMULLER, J. Ground-wave propagation. *Mixed path. Tijdschr. Nederl. Radiogen* (to be published).
17. C.C.I.R. Doc. IV/2 (United Kingdom), Geneva, 1958.
18. WAIT, J. R. The propagation of electromagnetic waves along the earth's surface. *Proc. Symposium on electromagnetic waves*, **6**, Math. Research Center, U.S. Army (1961).
19. WAIT, J. R. On the theory of mixed-path ground-wave propagation on a spherical earth. *J. Research NBS*, ***65D***, 401 (1961).

B. Theoretical investigation of propagation over stratified ground

1. GROSSKOPF, J. Das Strahlungsfeld eines vertikalen Dipolsenders über geschichtetem Boden (The radiation field of a vertical dipole over stratified ground). *Hochfr. und El. Ak.*, **60**, 136 (1942).
2. BREKHOVSKIKH, L. M. The field of a point source in a stratified medium. *Bull. Ac. Sci., U.S.S.R., phys. ser.*, **13**, 505 (1949) (in Russian).

3. Wait, J. R. The field of a line source of current over a stratified conductor. *Appl. Sci. Res.*, Sect. B, **3**, 279 (1953).
4. Wait, J. R. Radiation from a vertical electric dipole over a stratified ground. *Trans. IRE*, Vol. AP-1, 9 (1953).
5. Wait, J. R. and Fraser, W. C. G. Radiation from a vertical dipole over a stratified ground (Part. II). *Ibid.*, Vol. AP-3, 144 (1954).
6. Wait, J. R. Theory of electromagnetic surface waves over geological conductors. *Geofisica Pura Appl.*, **28**, 47 (1954).
7. Wait, J. R. Radiation from a vertical antenna over a curved stratified ground. *J. Res. NBS.*, **56**, 237 (1956).
8. Pavinsky, P. P. and Kozulin, Yu. N. The field of a vertical magnetic dipole over a two-layer medium, *Geofisika* (published by the University of Leningrad), **134** (1956) (in Russian).
9. Kozulin, Yu. N. The field of a vertical magnetic dipole over a two-layer medium. Computation of functions *T(p, Z)*. *Ibid.*, 158 (in Russian).
10. Brekhovskikh, L. M. Waves in stratified media (published by the *Ac. Sci. U.S.S.R.*, Moscow) (1957) (in Russian).

C. Theoretical investigations of propagation over irregular and inhomogeneous earth

1. Feinberg, E. L. Propagation of radio waves over a real surface. *Ref.* A.1, 97 (in Russian).
2. Furutsu, K. On the multiple diffraction of electro-magnetic waves by spherical mountains. *J. Radio Res. Lab.* (Tokyo), **3**, 331 (1956).
3. Furutsu, K. Wave propagation over an irregular terrain (I), (II), (III). *Ibid.*, **4**, 135, 349 (1957), **6**, 71 (1959).
4. Wait, J. R. On the theory of propagation of electromagnetic waves along a curved surface, *Can. J. Phys.*, **36**, 9 (1958).
5. Kalinin, Yu. K. Perturbation of the field of a plane radio wave by inhomogeneity of the surface of the earth. *Radiotechn. i Electron.*, **3**, 557 (1958) (in Russian).
6. Bremmer, H. Applications of operational calculus to ground-wave propagation in particular to long waves. *Proc. IRE.*
7. Bremmer, H. Encyclopedia of Physics, edited by S. Flügge, Springer, Berlin, **16**, Sect. 68-73, 531 (1958).
8. Furutsu, K. Effect of ridge, cliff and bluff at coastal line on ground waves (to be published; see Doc. V/26 and V/27, Geneva, 1962).

D. Theoretical investigations of pulse propagation over inhomogeneous earth

1. Wait, J. R. Propagation of a pulse across a coast line. *Proc. IRE*, **45**, 1550 (1957).
2. Lowndes. J. S. A transient magnetic dipole source above a two-layer earth. *Quart. J. Mech. Appl. Math.*, **10**, 79 (1957).
3. Doherty, R. H., Hefley, G. and Sinfield, R. J. Timing potentials of Loran-C. *Proc. IRE*, **49**, 1959 (1961).
4. Grumet, A. Penetration of transient electromagnetic fields into a conductor. *J. Appl. Phys.*, **30**, 682 (1959).
5. Johler, J. R. A note on the propagation of certain LF pulses utilized in a radio navigation system. *NBS Technical Note* No. 118 (1961).
6. Johler, J. R. and Walters, L. C. Propagation of a ground-wave pulse around a finitely conducting spherical earth from a damped sinusoidal source current. *Trans. IRE*, PGAP, *AP*-**7**, 1 (1959).
7. Johler, J. R. and Silley, C. M. Ground conductivity determinations at low radio frequencies by an analysis of sferic signatures of thunderstorms. *J. Geophys. Res.*, **66**, 3233 (1961).
8. Keilson, J. and Row, R. V. Transfer of transient electromagnetic surface waves into a lossy medium. *J. Appl. Phys.*, **30**, 1595 (1959).
9. Levy, B. R. and Keller, J. B. Propagation of electromagnetic pulses around the earth. *Trans. IRE*, PGAP, *AP*-**6**, 56 (1958).

10. Novikov, V. V. Propagation of a radio pulse over the surface of a homogeneous flat earth. *Vestnik Leningradskogo universiteta, Seria fiziki i Khimii* No. 10 (Issue 2), **16** (1960).
11. Perkeris, C. L. and Altermann, Z. Radiation from an impulsive current in a vertical antenna placed on a dielectric ground. *J. Appl. Phys.*, **28**, 1317 (1957).
12. van der Pol, B. On discontinuous electromagnetic waves and the occurrence of a surface wave. Electromagnetic wave theory symposium, *Trans. IRE*, PGAP, *AP*-**4**, 288 (1956).
13. Wait, J. R. Transient fields of a vertical dipole over a homogeneous curved ground. *Corr. J. Res*, **34**, 27 (1956).
14. Wait, J. R. The transient behaviour of the electromagnetic ground wave over a spherical earth. *Trans. IRE*, PGAP, *AP*-**5**, 198 (1957).
15. Wait, J. R. A note on the propagation of the transient ground wave. *Can. J. Phys.*, **35**, 1146 (1957).

E. Paper with geographical presentations facilitating practical computations

1. Furutsu, K. and Koima, S. The calculation of field strength over mixed paths on a spherical earth. *J. Radio Res. Lab.* (Tokyo), **3**, 391 (1956).
2. See also [A. 6, A. 7, A. 10, A. 11, A. 13 and C. 1].
3. C.C.I.R. Doc. 18 (New Zealand), Los Angeles, 1959.

F. Semi-empirical methods

1. Grosskopf, J. and Vogt, K. Der Zusammenhang zwischen der effektiven Bodenleitfähigkeit und der Ausbreitungsdämpfung (The relationship between the effective ground conductivity and the propagation loss). *Hochfr. und El. Ak.*, **62**, 14 (1943).
2. Grosskopf, J. Zur Ausbreitung von Mittelwellen über inhomogenes Gelände (On the propagation of medium waves over an inhomogeneous terrain). *Fernmeldetechn. (FTZ)*, **3**, 118 (1950).
3. Millington, G. Ground-wave propagation over an inhomogeneous smooth earth. *Proc. I.E.E.*, Part. III, **96**, 53 (1949).
4. Millington, G. and Isted, G. A. Ground-wave propagation over an inhomogeneous smooth earth. Part. 2. Experimental evidence and practical implications. *Ibid.*, **97**, 209 (1950).
5. Kirke, H. L. Calculation of ground-wave field strength over a composite land and sea path. *Proc. IRE*, **37**, 489 (1949).
6. Pressey, B. G., Ashwell, G. E. and Fowler, C. S. The measurement of the phase velocity of ground-wave propagation at low frequencies over a land path. *Proc. I.E.E.* Part III, **100**, 73 (1953).
7. Suda, K. Estimation of medium-wave field strength over mixed paths. C.C.I.R. Doc. 140 and 232 (Japan), London (1953).
8. Godzinski, Z. A comparison of Millington's method and the equivalent numerical distance method with the theory of ground-wave propagation over an inhomogeneous earth. *Proc. I.E.E.*, Part C Monograph No. 318 R (December, 1958) (to be published later under 106 C).
9. Latmiral, G. Radiation of horizontal antenna and measurement of electrical constants of the earth. *Alta Frequenza*, **7**, 509 (1938).
10. Sacco, L. and Barzilai, G. On the measurement of electrical constants of the earth at very high frequencies. *Rassegna delle Poste e delle Telecomunicazioni*, **9**, 597 (1940).
11. Argirović, M.
    - *(a)* Propagation of electromagnetic waves over an inhomogeneous earth. *Elektrotechnički Vjesnik*, **8-9**, 225-231 (1951);
    - *(b)* Méthode générale de calcul des conductivités du sol hétérogène. *Ann. Télécom.*, **8**, 212-224 (1953);
    - *(c)* Variations de la constante de phase de l'onde de sol. *Onde Electr.*, **35**, 687-691 (1955);
    - *(d)* Propagation de l'onde de sol sur trajets mixtes (Doc. 221, Warsaw, 1956).
12. Argirović, M. The influence of the conductivities in the interior of the earth on radio propagation curves (Serbo-Croat), *Telekomunikacije*, 3 (1961).
13. Godzinski, Z. The surface impedance concept and the structure of radio waves over real earth. *Proc. I.E.E.*, Part C, **108**, 362 (1961).
14. Tomankiewicz, T. and Stasierski, L. Determination of the ground-wave attenuation from measurements of the electrical characteristics of the earth. *Prace Instytutu Lacznosci* (Reports of the Institute of Telecommunications, Warsaw, P.R. of Poland) No. 2 (1966).

REPORT 231-1 *

REFERENCE ATMOSPHERES

(Question 2/V)

(1959 - 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 or 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:

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

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

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

---

* This Report was adopted unanimously.

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. In temperate climates, the average values of N_s vary from about 310 to 320 and ΔN from about —38 to —42. One may thus define an average atmosphere as one in which $N_s = 315$ and $\Delta N = -40$, so that:

$$n(h) = 1 + 315 \exp-(0{\cdot}136h) \times 10^{-6} \qquad (7)$$

In this atmosphere, the gradient of the refractive index at the surface corresponds to a value of k of 1·38. If extensive radio-sonde data are available, so that a good determination can be made of the average difference 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 profiles of mean refractive-index 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.

Should more precise determination of $n(h)$ be required, one may refer to the extensive tabulations available in [6], where for each month of the year, world-wide charts are presented in terms of its dry air and water vapour components.

BIBLIOGRAPHY

1. MISME, P. Essai de radioclimatologie dans le Nord de la France (Radioclimatological tests in Northern France). *Annales des télécommunications*, T. 13, Vol. 11-12 (1958).
2. BEAN, B. R. and THAYER, G. D. On models of the atmospheric radio refractive index. *Proc. IRE*, **47**, 740-755 (1959).
3. DU CASTEL, F. and MISME, P. Eléments de radioclimatologie (Elements of radioclimatology). *Onde Electrique* (December, 1957).
4. LANE, J. A. The radio refractive index gradient over the British Isles. *Jour. Atmos. and Terr. Phys.* Vol. 21, 157-166 (1961).
5. BEAN, B. R., FEHLHABER, L. and GROSSKOPF, J. Die Radiometeorologie und ihre Bedeutung für die Ausbreitung der m-, dm- und cm-Wellen auf grosse Entfernungen (Radiometeorology and its significance in the propagation of metric, decimetric and centimetric waves over long distances). *NTZ*, **1**, 9 (1962).
6. BEAN, B. R., CAHOON, B. A., SAMSON, C. A. and THAYER, G. D. A world-wide atlas of radio refractive index. Monograph No. 1, Environmental Sciences Services Administration, U.S. Government Printing Office, Washington, D. C. (1966).

REPORT 232 *

CONSTANTS IN THE EQUATION FOR THE RADIO REFRACTIVE INDEX

(Question 2/V)

(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 233-1.

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 has been 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.

Bibliography

1. Bean, B. R., The refractive index of air. *Proc. IRE*, 50, **3**, 260-273 (March, 1962).

---

* This Report was adopted unanimously.

REPORT 233-1 *

INFLUENCE OF THE NON-IONIZED ATMOSPHERE ON WAVE PROPAGATION

Ground-ground propagation

(Question 2/V)

(1959 - 1963 - 1966)

1. Introduction

After discussing the influence of the atmosphere on propagation and the choice of radio-meteorological parameters, this Report gives charts of refractive-index characteristics for use in practical propagation problems.

Propagation problems in which the atmosphere is involved can be classified in several different ways:

1.1 *As a function of the factor to be measured*, e.g. a distance, an angle, or a transmission loss:

- measurement of a distance involves direct consideration of the air index in the form of an integral:

$$l = \int_S n \, \mathrm{d}s$$

  in which l is the electrical length of the path S, n is the refractive index at any point on this path, and $\mathrm{d}s$ is an increment of length along the path;

- measurement of an angle brings in the gradient of the refractive index since the curvature of a path one point is directly proportional to the gradient of the index at that point;

- transmission loss in propagation beyond the line-of-sight involves consideration of certain radio-meteorological factors, such as the gradient of the refractive index and the stability of atmosphere.

1.2 *As a function of the angle at which the atmosphere is traversed*

If the path traverses the atmosphere at a relatively large angle of elevation, for example, in a link with a satellite, the atmosphere intervenes only as a corrective term in relation to propagation in a vacuum. This term is low for high angles of elevation and becomes difficult to assess accurately for small angles (which are avoided as far as possible for this reason). A simple model of an atmosphere is generally sufficient to evaluate this correction.

If the path remains permanently in the low layers of the atmosphere (for example, a radio-relay link), the atmosphere plays an overriding role, especially in the case of beyond the line-of-sight links (other than by diffraction), which would not be possible if the atmosphere did not exist. If a model of the atmosphere could be envisaged in this case, it would be completely different from the preceding one.

---

* This Report was adopted unanimously.

2. Correlation between propagation beyond the line-of-sight and radiometeorological 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 kilometer 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.

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 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].

Correlation has also been remarked between observed field strength and the values of refractive index at the surface [15 and 16]; however, this is apparently true only when a good correlation has been established between the vertical gradient of the refractive index (e.g. ΔN) and the value of this index at the surface [2, 12, 13, 14]. The refractive index at the surface is easier to determine from the existing statistical meteorological data than is the gradient of the index; the latter requires radio-sonde measurements, which are usually performed only at specific 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. In temperate climates, the month corresponding to the highest transmission loss has been found to be the same as that corresponding to the lowest values of N_s.

If, in these regions, the yearly variation of the monthly mean values of N_s is small (less than 10 to 15 N), good correlation between the propagation loss variation and the monthly mean value of N_s is not necessarily to be expected.

In other climates, the available evidence of correlation is inconclusive. Some measurements give good correlation [17, 18]; others give poor correlation [19]. In the latter cases, the correlation appears to be good except at that time of the year when N_s is larger than approximately 350. Caution should be used in applying this value as a world-wide criterion, however. The limited amount of field-strength data available for the southern United States in summer, when N_s is larger than 350, shows correlation with N_s at about the same level as in the winter months. In one such study [21], where regressions were run on the annual cycles of monthly mean N_s and monthly median field strength, the mean correlation coefficient for 9 paths, where N_s averages about 360 to 370 during the summer was 0·70, and the other 11 paths, with N_s generally much less than 350, showed a mean correlation of 0·69. It would appear that the cause of the breakdown in correlation noted in other areas of the world is too complex to be represented by such a simple parameter as N_s, and probably lies in vertical air-mass characteristics (e.g. subsidence).

It has been found that N_s is often useful for predicting regional, seasonal and diurnal variations in transmission loss, but it is of limited value for predicting them in tropical and equatorial regions.

It is, therefore, considered necessary that further studies should be undertaken in regions of the world with diverse climates.

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 refraction of radio waves passing through the troposphere [18, 20]. 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 [20]. The value of refractive index at the surface in general gives good correlation with the refraction for angles of elevation of 1° or more, but for angles of elevation less than ½° the vertical gradient must be taken into account. Further studies are necessary for very small angles of elevation (under 1°), since it is not clear that a meaningful correction can be made in this case under all climatic conditions.

In addition to the mean value of ΔN, it may be useful to know the gradient distribution law in the vicinity of the ground.

A knowledge of these variations is important for determining the likelihood of interference between stations and the atmospheric ducts which might disturb line-of-sight links.

It does not seem feasible to prepare world-wide charts of the equivalent gradient or of the stability parameters referred to above, but world-wide charts have been prepared, both for the vertical gradient and for the refractive index at the surface, for 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 Question 2/V, on a world-wide scale, of the correlation between all the parameters indicated above, and the variations in radio propagation.

By way of information, it may be mentioned that, if ΔA is equal to the variation of the monthly median propagation loss in dB, $\Delta(N_s)$ the variation in the monthly mean of N_s in N-units, $\Delta(\Delta N)$ the variation of the monthly median ΔN in N-units, α_1 and α_2 coefficients of proportionality in corresponding units, the following can often be written:

$$\Delta A = \alpha_1 \Delta(N_s) \qquad \text{and} \qquad \Delta A = \alpha_2\, \Delta(\Delta N)$$

It has been found experimentally that:

α_1 = 0·2 in the United States and Japan,
= 0·6 in France and the Federal Republic of Germany.

Doc. V/45 (U.S.S.R.), Geneva, 1965, shows that α_1 varies with distance:

α_2 = 0·5 in the United States and Japan,
= 0·9 in France, but in some years no proportionality was observed between ΔA and $\Delta(\Delta N)$,

α_2 has not been measured in the Federal Republic of Germany and the U.S.S.R.

The validity of these proportionalities has not been established in the United Kingdom.

Values of α_1 and α_2 are not available for other countries.

3. 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.

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_o.

The purpose of this procedure is to reduce the difficulty of mapping N_s, and since there can be no " correct " value of N_o, a certain amount of arbitrary choice may be made in the process to be used. However, for N_o to be perfectly representative, at a given location, it is necessary and sufficient that the exponential law for $N(h)$ should be applicable. A single exponential function, with a fixed constant for calculating N_o, is used.

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. However, the inhomogeneity of data for certain inter-tropical regions indicates that it is doubtful whether the exponential, or any other elementary function, will prove applicable in these particular areas [14].

Figs. 1 and 2 show isopleths of the mean value of N_o for February and August respectively and Fig. 3 shows the area where $N_o > 350$ (annual mean value).

Note. — In view of the scale of the charts, the number of measurement points, and the methods of calculation, the uncertainty in the N_s values which can be obtained is of the order of a few N-units in temperate regions to perhaps 10 in intertropical areas. The Administration of the United States has done more detailed work for its territory [22].

4. Charts of ΔN

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

$$\Delta N = N_s - N_1$$

in which N_s is the value of N at the surface, and N_1 is the value of N at 1 km above the surface. Due to the opening of a great number of new stations in areas formerly having very sparse coverage (primarily during and since the I.G.Y.), it is now possible to prepare world-wide charts of ΔN.

5. Preparation of the charts of ΔN

Averaged upper-air weather data are published monthly in the W.M.O.-sponsored " Monthly climatic data for the world ". Five years of record were selected for 269 stations throughout the world, and the mean monthly values of ΔN were calculated for these by interpolation from the 850 mb data and surface data (in some cases the 700 mb data had to be used, and for U.S.A. stations the 900 mb level was often available). The five year mean values were then calculated for each of the 12 months; the charts prepared from these data appear in Figs. 4–7. Most of the values plotted in the charts were obtained from observations at 0000 UT (in some cases they are averages of two or more observations per day).

Caution should be exercised in attempting to use these charts in mountainous areas.

6. Charts of N-gradient near the surface

It is not yet possible to distribute such charts.

An example of world variations in these gradient distribution laws in the first 100 metres is given in Fig. 8. Although there are not yet enough of these data, preliminary world maps of this gradient exceeded during 10% and 2% of the time have been published [23] and this information is given to radio engineers for information.

Additional caution should be exercised in applying these data to a particular month in a given year, since year-to-year variations in N_s and ΔN, for a given month, may equal or exceed the annual variation of monthly mean values.

BIBLIOGRAPHY

1. SAXTON, J. A. Propagation of metre waves beyond the normal horizon, *Proc. I.E.E.*, Part III (1951).
2. BEAN, B. R. and MEANY, F. M. Some applications of the monthly median refractivity gradient in tropospheric propagation. *Proc. IRE*, 43, **10**, 1419-1431 (October, 1955).
3. TROITSKY, N. V. Fading of ultra-short waves in radio-relay systems. *Elektrosviaz*, **10** (1958).
4. C.C.I.R. Doc. V/24 (Czechoslovak S.R.), Geneva, 1958.
5. MISME, P. Le gradient équivalent: mesure directe et calcul théorique (The equivalent gradient, its direct measurement and theoretical calculation), *Annales des télécommunications*, 15, **92** (1960).
6. BOLGIANO, R. A theory of wavelength dependence in ultra high frequency transhorizon propagation based on meteorological considerations. *Journal of Research of the NBS*, Part D, **3** (May-June, 1960).
7. MISME, P. Corrélation entre le champ à grande distance et un nouveau paramètre radiométéorologique (The correlation between the field strength at a great distance and a new radio-meteorological parameter). *Transactions of PGAP*, AP-6, 3 (1958).
8. MISME, P. Influence du gradient équivalent et rôle de la stabilité atmosphérique dans les liaisons transhorizon au Sahara et au Congo (The influence of the equivalent gradient and the role of atmospheric stability in beyond-the-horizon links in the Sahara and the Congo). *Annales des télécommunications*, 16, **6-5** (1961).
9. C.C.I.R. Doc. V/39 (France), Geneva, 1962.
10. C.C.I.R. Doc. V/57 (U.S.A.), Geneva, 1962.
11. FLAVELL, R. G. and LANE, J. A. The application of potential refractive index in tropospheric wave propagation. *Jour. Atm. and Terr. Phys.*, 24 (1962).
12. MISME, P. Essai de radioclimatologie d'altitude dans le Nord de la France (Test of the radioclimatology of altitude in Northern France). *Annales des télécommunications*, 13, **11-12** (1958).
13. LANE, J. A. The radio refractive index gradient over the British Isles. *Jour. Atm. and Terr. Phys.*, 21 (1961).
14. MISME, P., BEAN, B. R. and THAYER, G. D. Models of the atmospheric radio refractive index. *Proc. IRE*, 48, **8** (August, 1960).
15. PICKARD, G. W. and STETSON, H. T. A study of tropospheric reception at 428 Mc/s and meteorological conditions. *Proc. IRE*, **35** (December 1947).
16. BEAN, B. R. Some meteorological effects on scattered radio waves. *IRE, Trans. on Comm. Systems*, CS-4, **1**, 32-38 (March 1956).
17. ONOE, M. *et al.* Results of experiments of long-distance overland propagation of ultra-short-waves. *Journal of Radio Research Laboratories*, 5, **20** (April, 1958).
18. GRAY, R. E. Refractive index of the atmosphere as a factor in tropospheric propagation far beyond the horizon. Elec. Comm., 36, 60 (1959).
19. BOITHIAS, L. and MISME, P. Limitations on the application of the refractive index at the surface of the earth. *Annales des télécommunications*, 19 (November-December, 1964).
20. BEAN, B. R. and CAHOON, B. A. The use of surface weather observations to predict the total atmospheric bending of radio waves at small elevation angles. *Proc. IRE*, 45, **11** (November, 1957).
21. BEAN, B. R. and CAHOON, B. A. Correlation of monthly median transmission loss and refractive index profile characteristics. *J. Res. NBS*, **65D**, 1 (1961).
22. BEAN, B. R., HORN, J. D. and OZANICH, A. M. Jr. Climatic charts and data of the radio refractive index for the United States and the World. NBS, Monograph 22 (November, 1960; Supt. of Docs. United States Government Printing Office, Washington 25, D.C.).
23. BEAN, B. R., CAHOON, B. A., SAMSON, C. A. and THAYER, G. D. A world-wide atlas of radio refraction index, Monograph No. 1, Environmental Sciences Services Administration, U.S. Govt. Printing Office, Washington, D.C. (1966).

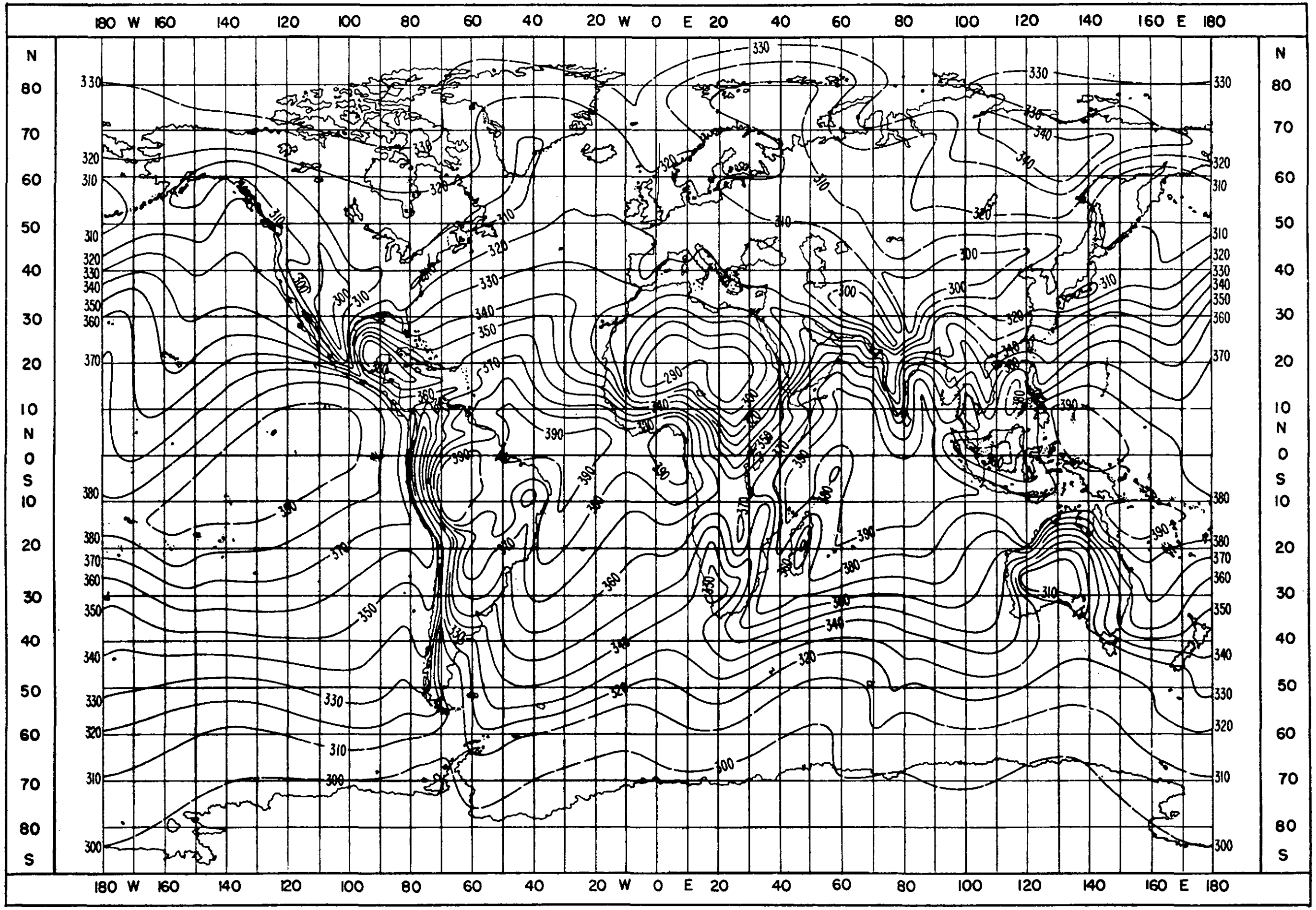


FIGURE 1

World-wide mean value of N_o for February

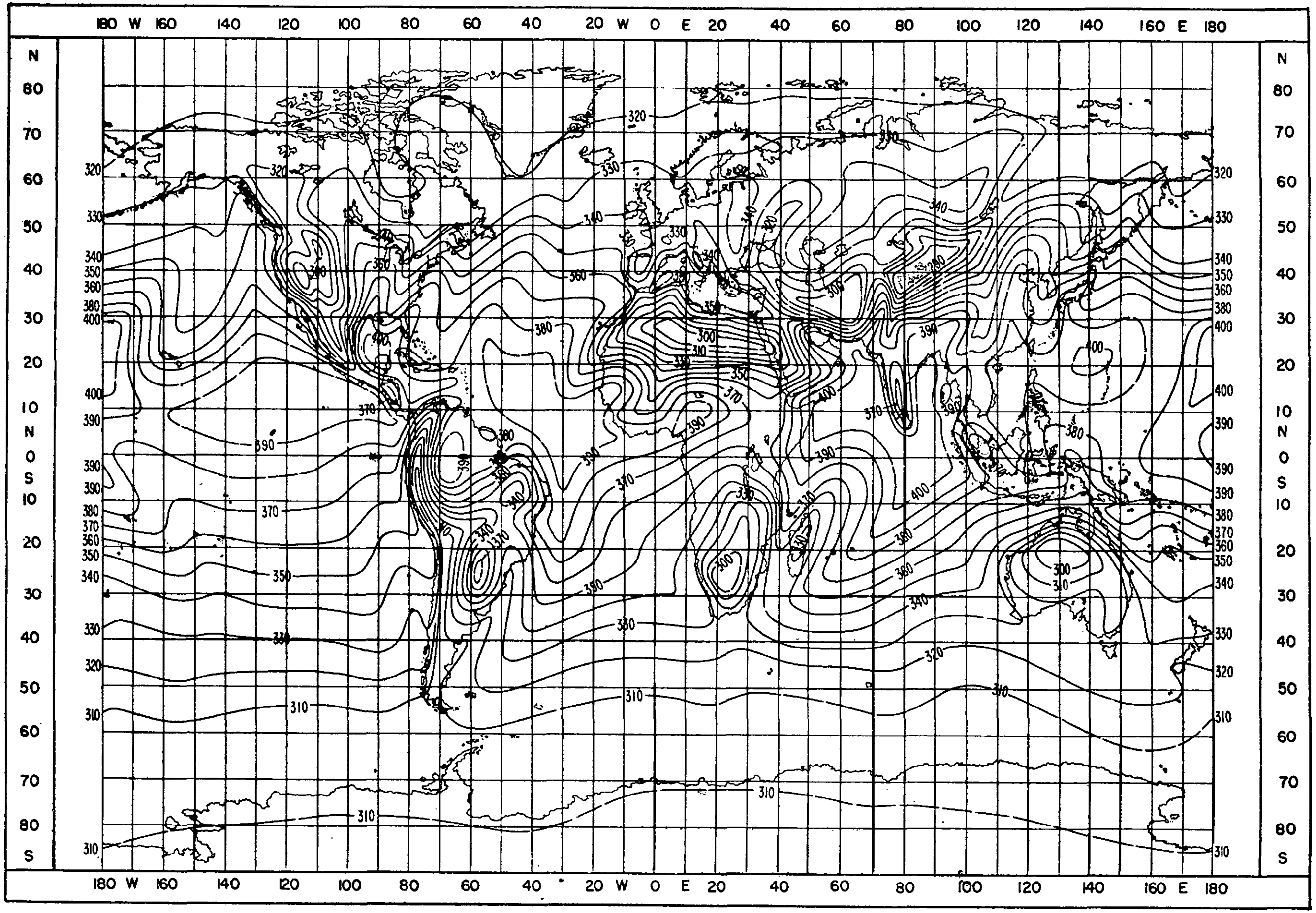


FIGURE 2

World-wide mean value of N_o for August

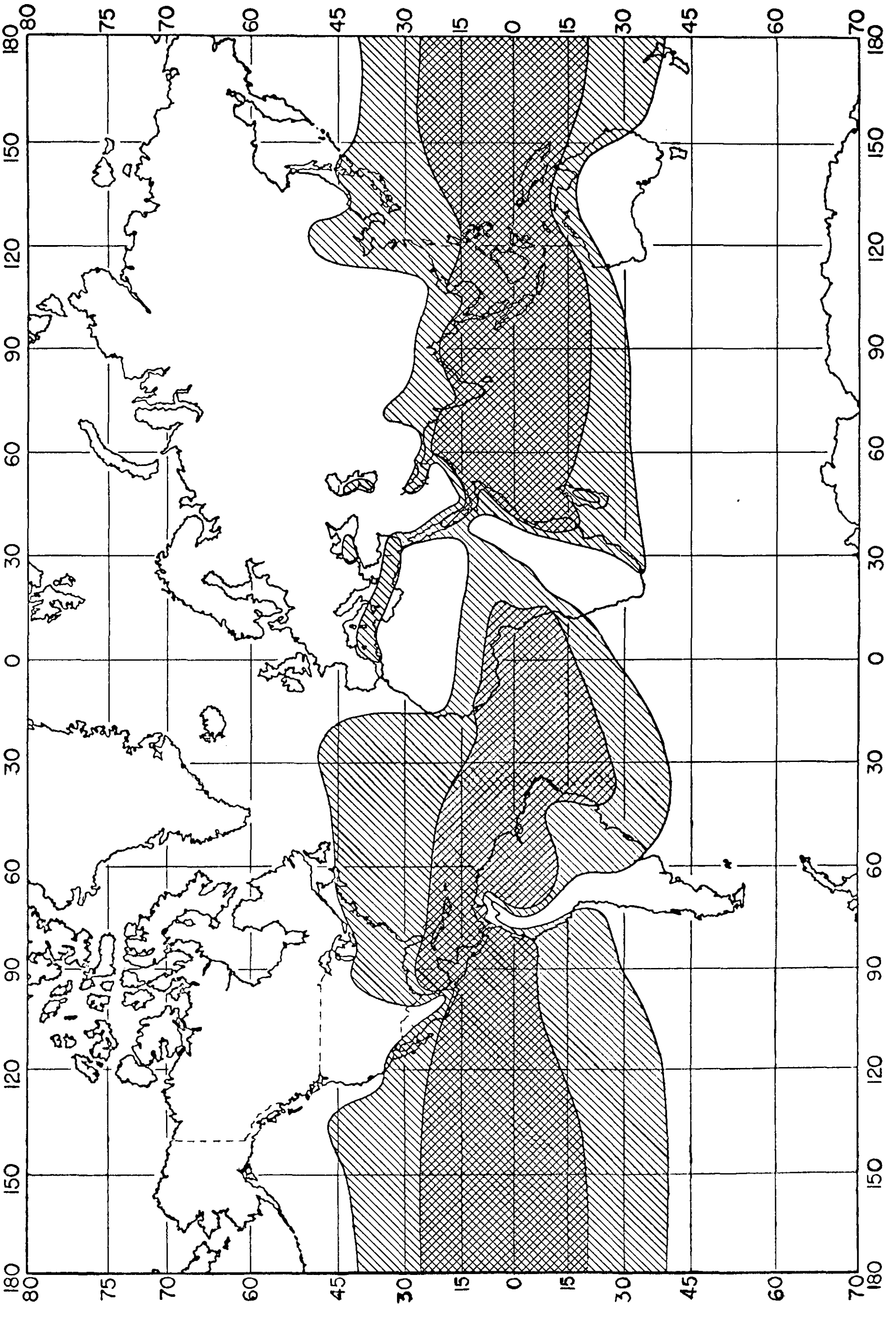


FIGURE 3

▩ Mean monthly $N_s > 350$ N-units during at least one month

▨ Mean monthly value of $N_s > 350$ N- units during all months

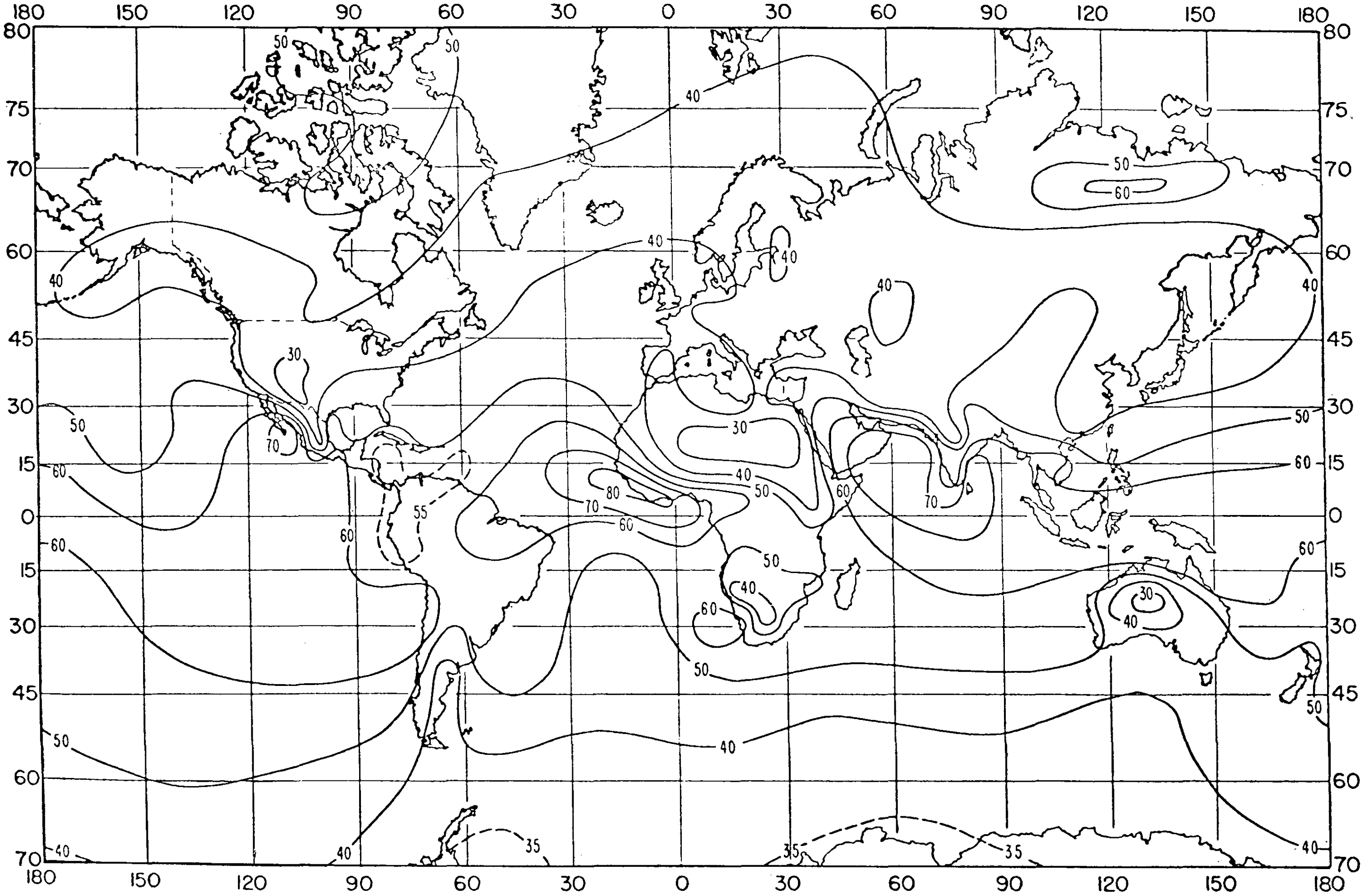


FIGURE 4

Monthly mean values ot ΔN: February

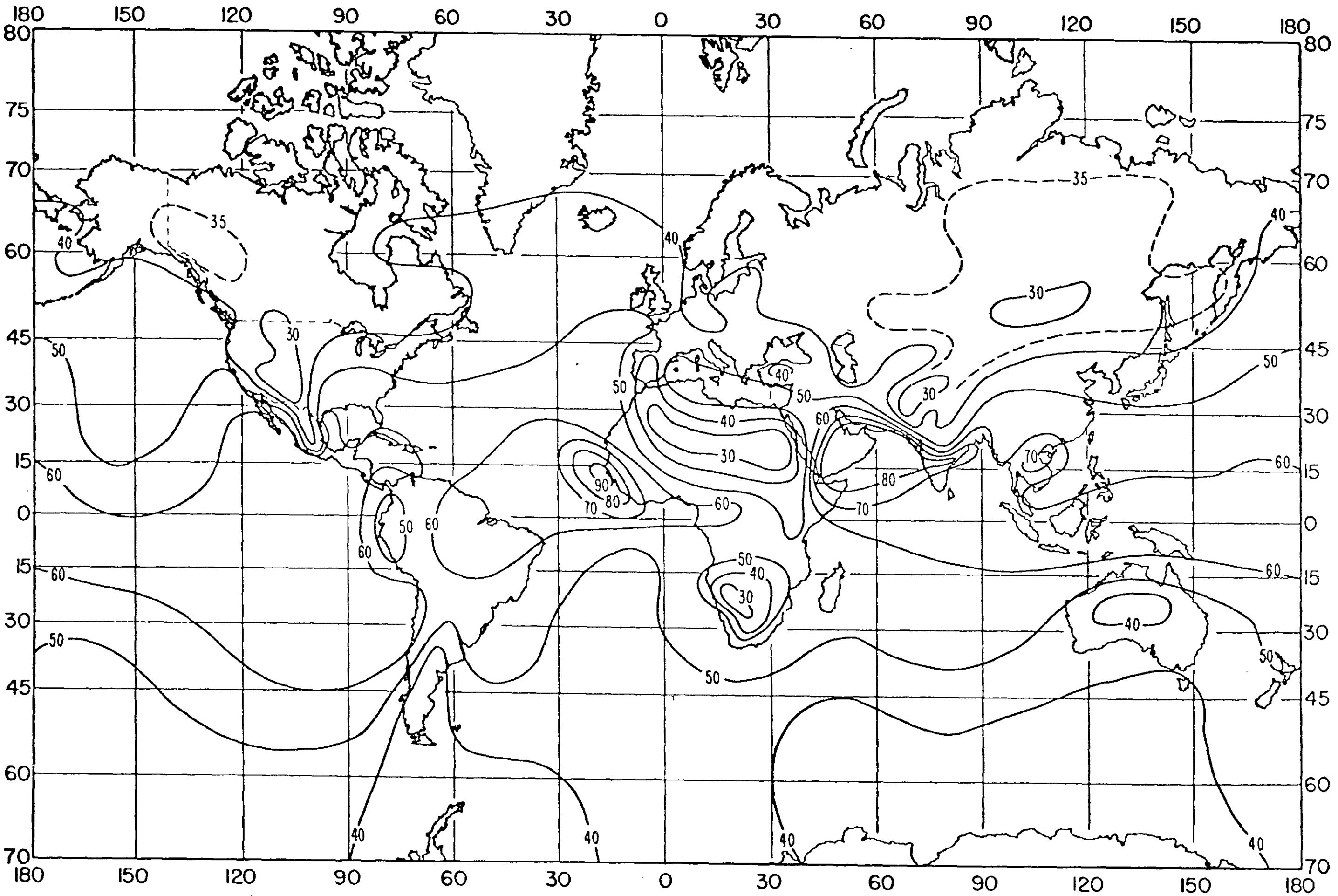


FIGURE 5

Monthly mean values of ΔN: May

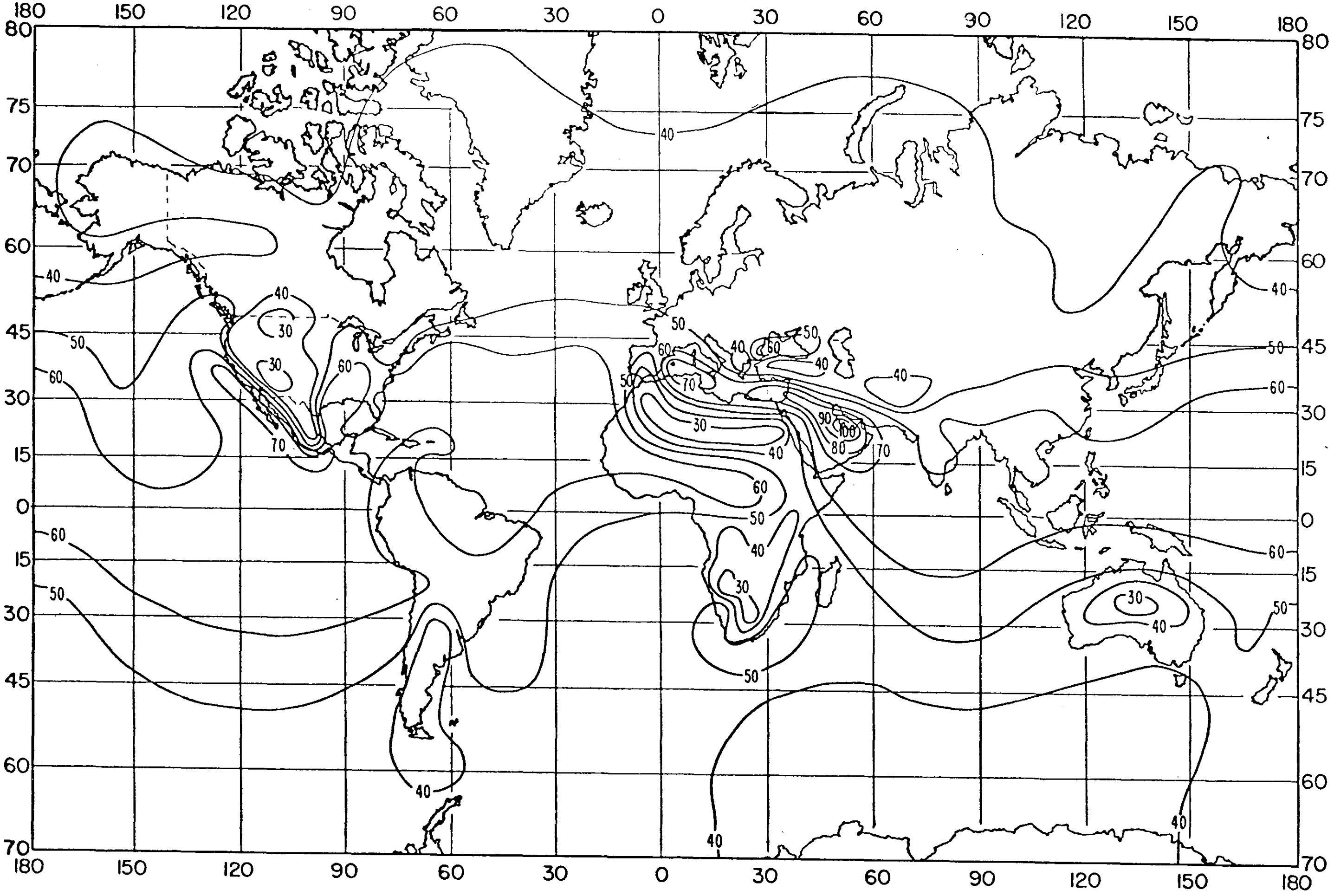


FIGURE 6
Monthly mean values of ΔN: August

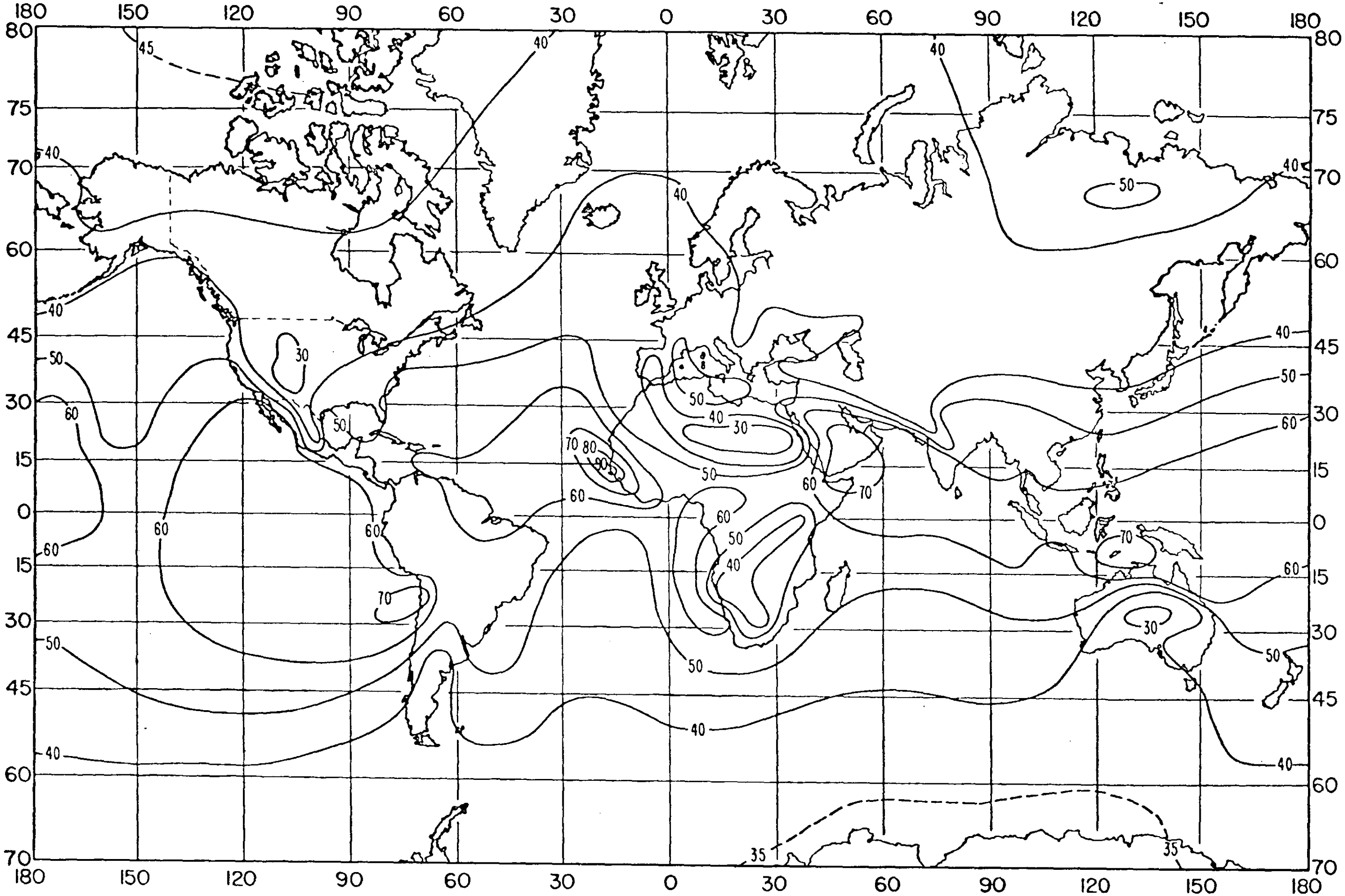
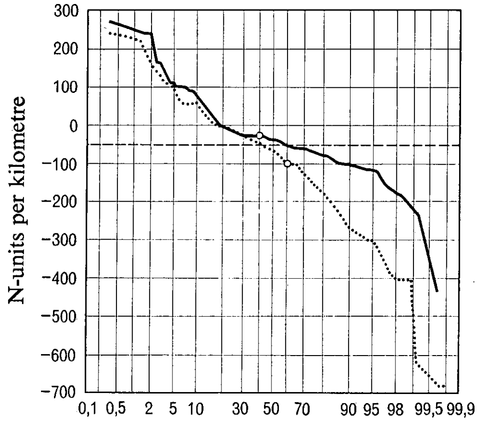


FIGURE 7

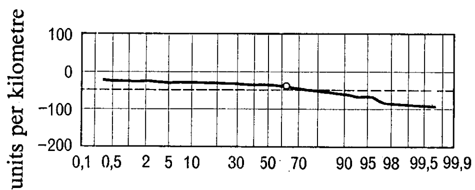
Monthly mean values of ΔN: November



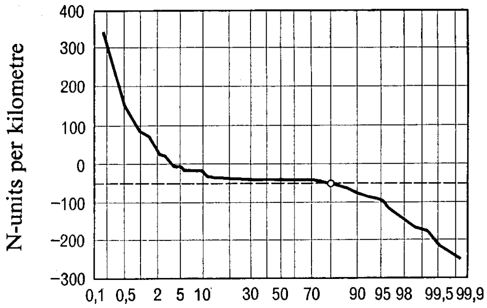
Percentage of time ordinate is exceed de
Nicosia, Cyprus

.... 0000 GMT

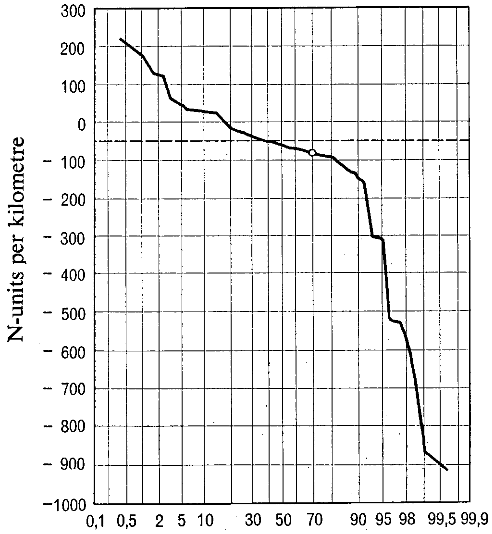
——— 1200 GMT



Percentage of time ordinate is exceeded
Ostersund, Sweden



Percentage of time ordinate is exceeded
New York



Percentage of time ordinate is exceeded
Bangui, Central African Republic

FIGURE 8

Cumulative probability distributions of dN/dh for ground-based 100 m layer

REPORT 234-1 *

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

Earth-space propagation

(Question 2/V, Study Programme 5C/V)

(1963 - 1966)

1. Introduction

In propagation through the non-ionized regions of the atmosphere, spatial variations of refractive index can cause refraction and scattering of radio waves. In addition, atmospheric gases and precipitation give rise to absorption which may be significant at frequencies above about 1 GHz. This Report summarizes the main features of atmospheric absorption and refraction, with special reference to earth-space communications.

2. Refraction

Published information concerning the ray-bending of electromagnetic 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.

It is observed that a large part of the curvature of a radio ray takes place in the most dense and variable part of the atmosphere closest to the surface of the earth. In the case of earth-space propagation, errors in the apparent elevation angle of a satellite due to refraction rapidly decrease as the satellite moves from the horizon to the zenith. As an example, assuming a very large value of N_s ($N_s = 450$, see Report 231-1) in the above models, the elevation angle correction decreases from 32 to 5 milliradians when the elevation angle increases from 0 to 52 milliradians (0 to 3°) [26]. If such a path goes through the atmosphere at altitudes which are always greater than several kilometres as when the earth terminal is at a high altitude, it avoids the dense variable regions of the atmosphere, the total curvature is less and the atmospheric models mentioned above are always usable.

To obtain adequate precision in the calculation of the angle of elevation required, corrections are necessary to allow for the departure from rectilinear propagation. For an error of no more than 10^{-4} radians, for 99·5% of the time, at all angles of elevation less than

---

* This Report was adopted unanimously.

10°, it is necessary to take into account the actual variation of refractive index with height; between 10° and 50° elevation a correction computed from a model given in Report 231-1 is adequate; no correction is required for angles of elevation above 50°.

The required accuracy for pointing an antenna is greater, the smaller the antenna beamwidth. The atmospheric models mentioned above are at times insufficient to determine the direction of antenna pointing; and, under these conditions, the measured values of the refractive index as a function of altitude must be used.

Moreover, the index of refraction has small and rapid variations which are one of the aspects of turbulence. Phase surface distortion due to turbulence-induced refractive index variations has been studied over line-of-sight paths [4]. The design of most radio tracking systems is based on the assumption of a uniform wave front or phase surface, and random phase variations in time and space limit the accuracy that can be achieved with such systems. This turbulence also affects the stability of frequencies transmitted through the atmosphere (Report 271-1). For space-space or earth-space paths at high angles of elevation, rapid variation in the refractive index is generally insignificant.

3. Absorption

3.1 Oxygen, water vapour, rain and clouds are known to absorb radio waves at frequencies above 100 MHz [9 to 30].

Water vapour absorption has a resonant peak at the frequency 22.23 GHz, and oxygen absorption has peaks at 60 GHz and 120 GHz. 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/m^3 (approximately equal to 7.6 gm/kg). 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:

$$A_a = \gamma_{oo} r_{eo} + \gamma_{wo} r_{ew} (\text{dB})$$

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, as given in Fig. 1, extending upward from the ground to 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 GHz. 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_o, 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 trans-horizon propagation:

$$A_r = \int_{0}^{r_o} \gamma_r(r) \mathrm{d}r (\text{dB})$$

Having fitted empirically an arbitrary mathematical function to the theoretical results given by [14, 23, 28], the rate of absorption by rain γ_r, may be espressed in terms of the rainfall rate, R_r in mm/hr as:

$$\gamma_r = K\, R_r^{\alpha} (\text{dB/km}).$$

The frequency dependence of K and α is included in the γ_r/frequency curves of Fig. 2. Fig. 2 should be used with caution in view of the tendency at some frequencies of measured attenuations to exceed the maximum possible theoretical attenuation [28]. Additional difficulty in the use of Fig. 2 arises from the non-uniformity of rainfall rate over an actual transmission path. It has been suggested that further studies of the spatial correlation of rainfall rates may yield a general form of this correlation useful in specifying the reduction in rainfall attenuation over an actual path relative to one with uniform precipitation [27].

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 quantity of the liquid water per unit volume. Thus, the absorption within such a cloud or fog can be written as:

$$A_c = K_l\, M (\text{dB})$$

where A_c is the total absorption attenuation within the cloud, K_l is an attenuation coefficient, values of which are given in Table I, and M is the liquid water content of the cloud in gm/m^3. 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.

TABLE I

One-way attenuation coefficient, K_l, in clouds in dB/km/gm/m^3

(rounded to two significant figures)

Temperature (°C)		Frequency (GHz)			
		33	24	17	9.4
Water cloud	20	0·65	0·31	0·13	0·048
	10	0·68	0·41	0·18	0·063
	0	0·99	0·53	0·27	0·086
	− 8	1·2	0·68	0·34 (extrapolated)	0·11 (extrapolated)
Ice cloud	0	$8{\cdot}7\times10^{-3}$	$6{\cdot}3\times10^{-3}$	$4{\cdot}4\times10^{-3}$	$2{\cdot}5\times10^{-3}$
	−10	$2{\cdot}9\times10^{-3}$	$2{\cdot}1\times10^{-3}$	$1{\cdot}5\times10^{-3}$	$8{\cdot}2\times10^{-4}$
	−20	$2{\cdot}0\times10^{-3}$	$1{\cdot}4\times10^{-3}$	$1{\cdot}0\times10^{-3}$	$5{\cdot}6\times10^{-4}$

3.4 The attenuation caused by snow increases with frequency and may be important at frequencies above 1 GHz, sometimes exceeding the attenuation produced by rain of equivalent rainfall rate.

4. Sky-noise temperature

The non-ionized region of the atmosphere is a source of noise radiation [15, 25]. Fig. 3 shows the sky-noise temperature due to oxygen and water vapour for various angles of elevation and for frequencies between 1 and 100 GHz. In estimating antenna temperatures, the antenna pattern and radiation from the surface of the earth must also be considered [24].

BIBLIOGRAPHY

1. FANNIN, B. M. and JEHN, K. H. A study of radar elevation-angle errors due to atmospheric refraction. *IRE Trans.*, AP-5, 71 (1957).
2. ANDERSON, W. L., BEYERS, N. J. and RAINEY, R. J. Comparison of experimental and computed refraction. *IRE Trans.*, AP-8, 456-461 (1960).
3. ANWAY, A. C. Empirical determination of total atmospheric refraction at centimeter wavelengths by radiometric means. Collins Research Report No. CRR-2425, Collins Radio Company, Cedar Rapids, Iowa (June, 1961).
4. NORTON, K.A., HERBSTREIT, J.W., JONES, H.B., HORNBERG, K.O., PETERSON, C.F., BARGHAUSEN, A.F., JOHNSON, W. E., WELLS, P. I., THOMPSON, M. C. Jr., VETTER, M. J. and KIRKPATRICK, A. W. An experimental study of phase variations in line-of-sight microwave transmissions. NBS Monograph No. 33 (November, 1961).
5. SCHULKIN, M. Average radio ray refraction in the lower atmosphere. *Proc. IRE* 40, 5, 554-561 (May, 1952).
6. BEAN, B. R., THAYER, G. D. and CAHOON, B. A. Methods of predicting the atmospheric bending of radio rays. *NBS Jour. of Res.*, 64D, 5 (1960).
7. BEAN, B. R. and THAYER, G. D. Comparison of observed atmospheric radio refraction effects with values predicted through the use of surface weather observations. *NBS Jour. of Res.*, 67D, 3 (1963).
8. MISME, P., BEAN, B. R. and THAYER, G. D. Models of the atmospheric radio refractive index. *Proc. IRE*, **48**, 8, 1499-1501 (August, 1960).
9. ARTMAN, J. O. and GORDON, J. P. Absorption of microwaves by oxygen in the millimeter wavelength region. *Phys. Rev.*, **96**, 5, 1237-1245 (December, 1954).
10. BEAN, B. R. and ABBOTT, R. L. Oxygen and water vapor absorption of radio waves in the atmosphere. *Geofisica Pura e Applicata*, Milano, **37**, 127-144 (1957).
11. BUSSEY, H. E. Microwave attenuation statistics estimated from rainfall and water vapor statistics. *Proc. IRE*, **38**, 781-785 (July, 1950).
12. CRAWFORD, A. B. and HOGG, D. C. Measurement of atmospheric attenuation at millimeter wavelengths *B.S.T.J.*, **35**, 907 (July, 1956).
13. GUNN, K. L. S. and EAST, T. W. R. The microwave properties of precipitation particles. Quar. J. Roy. Meteorological Soc., London, **80**, 522-545 (1954).
14. HATHAWAY, S. D. and EVANS, H. W. Radio attenuation at 11 GHz and some implications affecting relay system engineering. *B.S.T.J.*, **1**, 73-97 (January, 1959).
15. HOGG, D. C. and SEMPLAK, R. A. The effect of rain and water vapor on sky noise at centimeter wavelengths. *B.S.T.J.*, **40**, 5, 1331-1348 (September, 1961).
16. LANE, J. A. and SAXTON, J. A. Dielectric dispersion in pure polar liquids at very high radio frequencies. Proc. Roy. Soc. A213, 400 (July, 1952).
17. PERLET, A. and VOGE, J. Attenuation of centimetre and millimetre waves by the atmosphere. *Ann. des télécom.*, 8, **12**, 396-397 (December, 1953).
18. STRAITON, A. W. and TOLBERT, C. W. Anomalies in the absorption of radio waves by atmospheric gases. *Proc. IRE*, **48**, **5**, 898-903 (1960).
19. TOLBERT, C. W. and STRAITON, A. W. Experimental measurement of the absorption of millimeter radio waves over extended ranges. *Trans. IRE*, PGAP AP-5, No. 2, 239-241 (April, 1947).
20. VAN VLECK, J. H. Absorption of microwaves by oxygen. *Phys. Rev.*, **7**, No. 7, 413-424 (April, 1947 a).
21. VAN VLECK, J. H. Absorption of microwaves by uncondensed water vapor. *Phys. Rev.*, **7**, No. 7, 421-433 (April, 1947 b).
22. VAN VLECK, J. H. Theory of absorption by uncondensed gases. Propagation of short radio waves, 646-664, McGraw-Hill Book Co., New York, N.Y. (1951).
23. RYDE, J. W. and RYDE, D. Attenuation of centimetre waves by rain, hail, fog and clouds. General Electric Co., Wembley, England (1945).
24. DU CASTEL. Propagation troposphérique et faisceaux hertziens transhorizon (Tropospheric propagation and transhorizon radio-relay systems). Edition Chiron, Paris (1962).
25. CROOM, D. L. Naturally-occurring thermal radiation in the range 1-10 GHz, *Proc. I.E.E.*, 111-113, 967 (1964).

26. Bean, B. R. and Dutton, E. J. Radio meteorology, NBS Monograph No. 92, U.S. Government Printing Office, Washington, D.C. (1966).

27. C.C.I.R. Doc. V/101 (Japan), Oslo, 1966.

28. Medhurst, R. C. Rainfall attenuation of centimetre waves: Comparison of theory and measurement. *Trans. IEEE*, AP-13, **4**, 550-564 (1965).

29. Jevakine, S. A. and Naoumov, A. P. Calculation of the absorption factor of centimetric and millimetric waves in oxygen and in the atmosphere (in Russian) *Radiotechnika i Elektronika*, 10, 6th Edition (1965).

30. Kirdiacheve, K. P. The statistical characteristics of radio measurements of cloudy atmosphere in the 0·8 cm range (in Russian). *Radiotechnika i elektronika*, **10**, 12th Edition (1965).

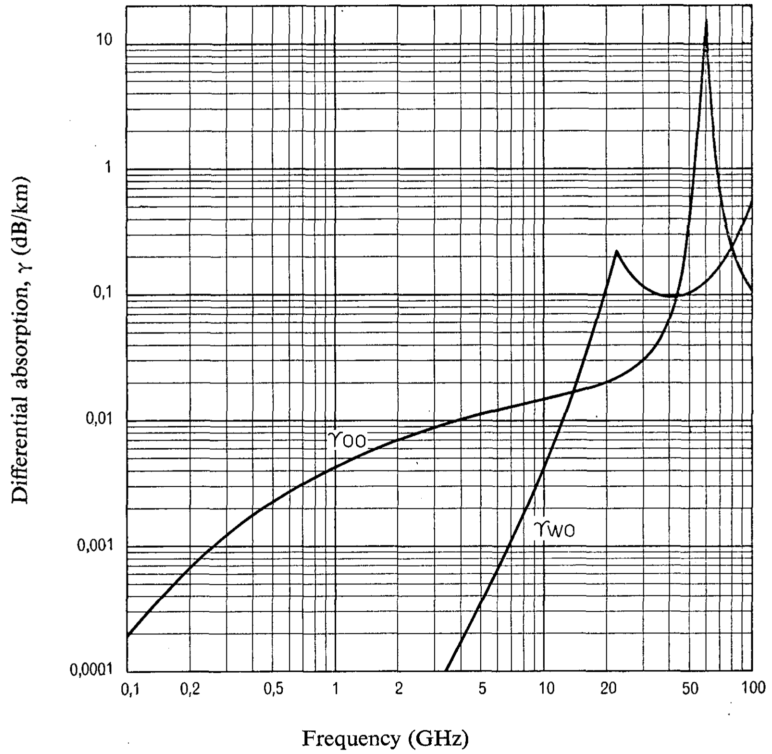
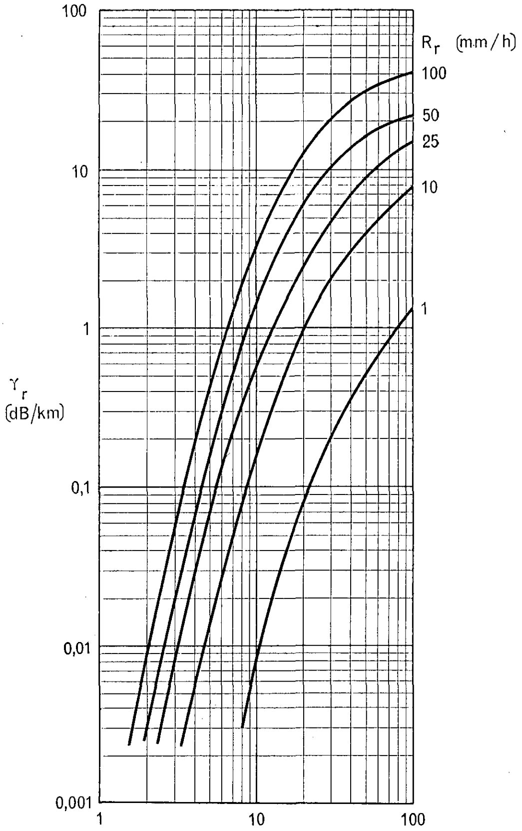


Figure 1

Surface values γ_{OO} and $\gamma_{\omega O}$ of absorption by oxygen and water vapour

Pressure. 760 mm Hg; Temperature: 20° C
Water vapour: 10 g/m³ = 7·6 gm/kg



Frequency (GHz)

FIGURE 2

Variation of γ_r with frequency

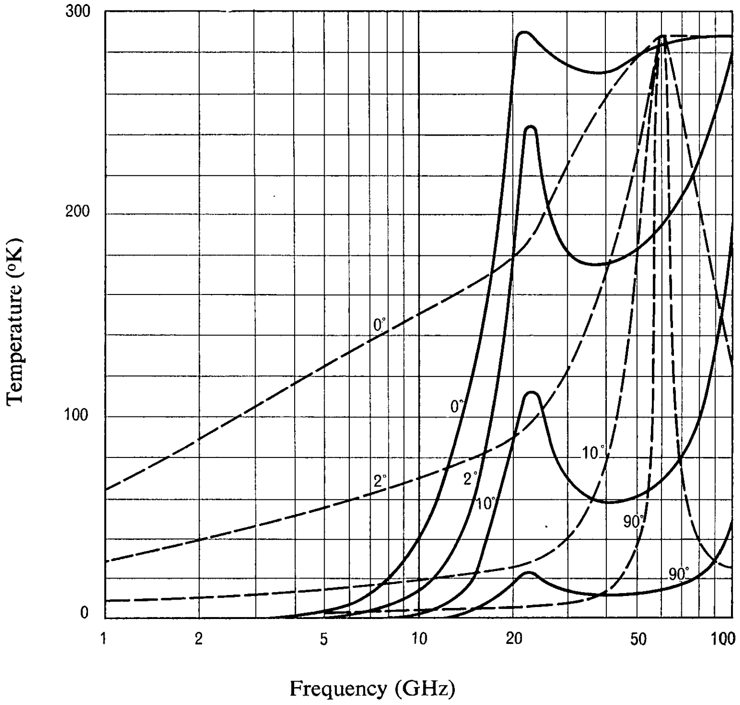


FIGURE 3

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

Water vapour density: 10 g/m^3

Surface temperature: 20° C

———— Water vapour

– – – – Oxygen

REPORT 235 *

EFFECTS OF TROPOSPHERIC REFRACTION AT FREQUENCIES BELOW 10 MHz

(Question 3/V)

(1956 - 1963)

In the ground-wave propagation curves in Recommendation 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 MHz [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 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 369–1.

At frequencies below 10 MHz, 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 MHz, 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 MHz 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 kHz, 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 MHz and almost complete at 10 kHz, from the use of a 4/3 earth's radius at 10 MHz to the use of the real radius of the earth at 10 kHz. It has long been realized that this transition must occur, as is shown by the existence of the appropriate Question 3/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 MHz can be investigated experimentally. Such results as

---

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

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 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 kHz at distances of 200 km or more (see Doc. 176 (France), 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 Question 3/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 MHz. 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 MHz 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 kHz as the limited experimental evidence suggests. However, it is too early to anticipate the full results of this analysis.

BIBLIOGRAPHY

1. C.C.I.R. Atlas of ground-wave propagation curves for frequencies between 30 Mc/s and 300 Mc/s (I.T.U., Geneva, 1955).
2. C.C.I.R. Atlas of ground-wave propagation curves for frequencies between 30 and 10 000 Mc/s (I.T.U., Geneva, 1959).
3. Bremmer, H. On the theory of wave propagation through a concentrically stratified troposphere with a smooth profile. *Part I:* Discussion of the extended W.K.B. approximation. *NBS Journal of Research*, 64 D, 467, 1960. *Part II:* Expansion of the rigorous solution. *Ibid.*, 66 D, 31 (1962).
4. Norton, K. A. System loss in radio-wave propagation. *Ibid.*, 63 D, 53 (1959).
5. Millington, G. Propagation at great heights in the atmosphere, *Marconi Review*, **21**, 143 (1958).
6. Wait, J. R. On the propagation of radio waves in an inhomogeneous atmosphere. *NBS Tech. Note* 24 (1959).

REPORT 236-1 *

INFLUENCE OF IRREGULAR TERRAIN ON TROPOSPHERIC PROPAGATION

(Study Programme 6A/V)

(1951 - 1953 - 1956 - 1959 - 1963 - 1966)

1. Introduction

The object of this Report is to describe in general terms how terrain characteristics affect the propagation of tropospheric radio waves between arbitrary antenna locations over irregular terrain.

1.1 *Electrical characteristics of the surface of the earth*

Propagation over sea or over a smooth or uniformly rough land depends in principle on the electrical constants of the surface of the earth (see Report 229). At sufficiently low frequencies the effect of the conductivity is dominant, while at sufficiently high frequencies it is similarly the permittivity that is dominant. For oversea transmission ($\varepsilon = 80$, $\sigma = 4$ mho/m) the transition occurs between 300 MHz and 3 GHz, while for transmission over " poor " ground ($\varepsilon = 5$, $\sigma = 10^{-3}$ mho/m) and " good " ground ($\varepsilon = 10$, $\sigma = 10^{-2}$ mho/m), the transition ranges are from 1 MHz to 10 MHz and from 5 MHz to 50 MHz respectively.

1.2 *Interaction between the terrain and the troposphere*

Reports 231-1, 233-1, 234-1, 235, 237-1, 238, 243, 244-1 and 285-1 discuss the influence of the troposphere. Many effects of terrain and the troposphere are closely interrelated, but it is convenient to separate them as much as possible. It is observed that an increase in

---

* This Report was adopted unanimously.

atmospheric refraction increases long-distance diffraction or forward-scatter fields but may lead to multipath fading over shorter paths. Increased turbulence of the atmosphere may result in either an increase or a decrease of radio transmission loss, depending on the geometry of a particular path and the dominance of various propagation mechanisms associated with stratification of the refractive-index structure.

1.3 *Comparison between idealizations and terrain factors*

Just beyond the radio horizon of a transmitting antenna, the observed radio fields result from diffraction over ridges, hills, or the bulge of the earth. At one extreme is the case of diffraction over obstacles so high and so isolated that knife-edge diffraction theory gives theoretical results that agree fairly well with observations, as discussed in § 2 of this Report. Field strengths may be near free-space values, showing a low rate of attenuation with distance, d, or angular distance θ, corresponding to the $20 \log \theta + 10 \log d$ law given in Fig. 4 of Report 244–1. At the other extreme is diffraction over a smooth spherical earth. This condition results in low field strengths which are soon exceeded, as one progresses beyond the horizon of a transmitting antenna, by radio-fields produced by reflection from elevated layers or by forward-scatter radio waves.

Theoretical methods have been developed to handle certain idealizations of terrain features, such as bluffs, cliffs, and knife-edge obstacles in a transmission path [1], [3], [4].

But in most cases of propagation over land, it has been found extremely difficult to take into account the roughness and irregularities of terrain features and environmental clutter such as vegetation, buildings, bridges and electric power lines, except in terms of an empirically determined " terrain factor ". Such factors, derived as a function of parameters relating the radio wavelength and path geometry to statistical descriptions of terrain, are discussed in Report 239–1, which is devoted to descriptive propagation statistics applicable to broadcasting and mobile services.

1.4 *Point-to-point prediction and prediction of path-to-path variability*

The most important parameters for distinguishing between great circle path terrain profiles for trans-horizon paths of a given length is usually the angular distance, θ. This is defined as the angle between radio horizon rays in the plane of the great circle containing the antennae, and is the minimum angle of diffraction or angle of scattering unless antenna beams are elevated.

This angle, with effective antenna heights and other parameters mentioned in this Report, is useful for predicting median transmission loss values for point-to-point radio-relay links. The inevitable path-to-path variability of transmission loss among all paths corresponding to a given set of values of frequency, distance, angular distance, and effective antenna heights, is accepted as part of the error of prediction.

Most broadcasting and mobile service applications, on the other hand, correspond to a given set of values of frequency, distance, antenna heights, and parameters describing the terrain and climate. The path-to-path variability corresponding to this set of conditions is part of the prediction instead of being part of the error of prediction.

1.5 *Time availability of service*

It is convenient for most point-to-point applications to predict simply the cumulative distribution in time of received power from wanted and unwanted signal sources, with expected values of cross-correlation [2]. Since wanted and unwanted signal power will usually change diurnally and seasonally in the same direction, the cumulative distribution in time of the wanted-to-unwanted signal ratio will extend over a somewhat smaller range than if this positive 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 time.

2. Diffraction over isolated obstacles

Some paths can be treated as passing over a succession of crests, which may be replaced by knife-edges or 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 the Fresnel-type, and with two knife-edges the integration can be carried out [1]. The integrals are more difficult to manage in complex cases, and an approximate method [5, 6] 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 [7]. For a cliff at the coast, the rate of change of the relative phase with distance from the coast-line 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 [8]. When a wave passes close to the ground, there can arise an additional transmission loss due to finite ground conductivity [3].

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 [9, 10]. 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 370-1). 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 [9, 10, 11, 12, 13, 14].

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 [14].

An investigation into diffraction by multiple ridges has been made on a large number of SHF paths in Japan [15]. An emprical diffraction loss prediction method is given and shown to agree reasonably well with these data. (In a theoretical limiting case where all the ridges coincide, the method will not give the correct answer, however.) It is also demonstrated [15] that the time variability of these signals is proportional both to the total diffraction loss and to the ratio of path length to wavelength.

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 [9, 14]. 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). It would appear that the VHF (metric) band is more suitable than the higher frequencies for communication by waves diffracted over mountain ridges.

Work in the United Kingdom in Band I [16] has shown, that the presence of a large diffracting ridge within 15 km of the receiving site on long tropospheric paths, causes an attenuation which is substantially constant in time; that is, the attenuation is the same for normal and abnormal propagation. With the diffracting ridge close to either terminal, the diffracted signal is stronger that signals due to other propagation mechanisms. With a diffracting ridge nearer the centre of a path, super-refractive atmospheric conditions may, for small percentages of time, lead to considerable enhancement in signal levels, overriding the diffracted signal energy.

Studies at 2 GHz in Japan [17, 18] show that although considerable fading was experienced during the summer, no significant seasonal variation and very little diurnal trend was observed. Multipath distortion, however, shows considerable variation in time, especially in summer, because of sensitivity to deep fades of short duration, and correlates well with the amplitude distribution of the fading. The worst month for multipath distortion does not coincide with that for maximum transmission loss.

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 [14]. 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.

3. The influence of small and medium irregularities in terrain

Most irregularities in a terrain profile are not isolated obstacles [2, 21, 22], free of the influence of nearby hills and valleys. The descriptive analysis of broadcast data reported in Report 239-1 and in Recommendation 370-1 shows that, to a first order of approximation, such irregularities can be characterized by the difference Δh of terrain heights exceeded for 10% and 90% of a propagation path in the range 10 km to 50 km from the transmitter [19]. This parameter Δh is defined in Recommendation 370-1.

Experience has shown, that improved point-to-point predictions, or predictions of cumulative distributions of transmission loss in a broadcaster's service area, may be obtained by the use of additional parameters noted here and in Report 239-1, which summarizes comparisons with data, while this Report brings forward explanations of physical phenomena which support the use of these parameters.

Work in the Federal Republic of Germany and the United Kingdom [20, 22, 23] has shown that an improvement in prediction accuracy may be achieved by including on an empirical basis, the mean slope of the terrain in the vicinity of the receiving point. The principle upon which this work is based is that improved illumination of the receiving point will be obtained, when the direction of arrival of the incident ray makes a greater angle with the local terrain. This reasoning follows firstly from simple geometric ray theory and secondly from the fact that the transmission will have to pass through a shorter scattering path due to buildings and trees etc., when the angle referred to above is large.

A further empirical method has been developed in the People's Republic of Poland [24, 25] which considers the problem from a different standpoint. In this method, the mean wavelength of terrain undulations is taken into account as an additional parameter, the actual terrain being represented by an equivalent sinusoidal model. The basis of this method is the empirical summation of the contributions to the terrain factor by the last few undulations of the sinusoidal model, using a derivation from the Television Allocations Study Organization method [25].

4. Path-to-path correlation

Measurements in the Federal Republic of Germany [26] and in the United Kingdom [27] have shown that when transmitted from adjacent sites, there is found a close correlation between the field strength measured in UHF channels separated in frequency up to 200 MHz. The value of the correlation coefficients is approximately 0·9 in flat terrain and 0·8 in hilly terrain.

Similar measurements in Bands III and V showed that over average terrain the correlation coefficient was still as great as 0·7 even when the ratio of frequencies was 1 to 3. On the other hand, when transmitters are sited at widely different locations, the correlation coefficient between field strengths at a receiving site is close to zero even when there is virtually no frequency separation.

BIBLIOGRAPHY

1. MILLINGTON, G., HEWITT, R. and IMMIRZI, F. S. Double knife-edge diffraction in field strength predictions I.E.E. Monograph 507 E (March, 1962).
2. RICE, P. L., LONGLEY, A. G., NORTON, K. A. and BARSIS, A. P. Transmission loss predictions for tropospheric communication circuits. U. S., NBS Tech. Note 101, Vol. 1, Vol. 2 (May 7, 1965).
3. FURUTSU, K. Wave propagation over an irregular terrain, I, II and III. Journal of Radio Research Laboratories (Japan), Vol. 4, 16 (1957), Vol. 4, 18 (1957) and Vol. 6, 23 (1959).
4. FURUTSU, K. On the theory of radio wave propagation over inhomogeneous earth, *Journ. Res. NBS* **67D** (Radio Prop.) No. 1, 39-62 (January-February, 1963).
5. BAUERMEISTER, E. and KNOPFEL, W. UKW — Feldstärke-Voraussage in gebirgigem Gelände (Prediction of field strength for UHF waves in mountainous terrain). Techn. Hausmitt. N.W.D.R. Jahrgang 4, 67-73 (1952).
6. WILKERSON, R. E. Multiple knife-edge diffraction, to appear in *Journ. Res. NBS* (1966).
7. FURUTSU, K. Effect of ridge, cliff and bluff at a coastline on ground-waves. Journal of Radio Research Laboratories (Japan), Vol. 9, 41 (January, 1962).
8. C.C.I.R. Doc. V/8 (F.P.R. of Yugoslavia), Geneva, 1962.
9. DICKSON *et al. Proc. IRE* (August, 1953).
10. NORTON, K. A. *et al.* Use of angular distance in estimating transmission loss and fading range for propagation through a turbulent atmosphere over irregular terrain. *Proc. IRE,* Vol. 43, 1488 (October, 1955).
11. IWAI, F. *et al.* Radio transmission beyond the line-of-sight, etc. Electrical Communications Laboratory Journal, N.T.T. (Japan), Vol. 8, 1183 (September, 1959).
12. FUKAMI, T. *et al.* Propagation measurements on long mountain diffraction paths, etc. *Electrical Communications Laboratory Journal, N.T.T.* (Japan), Vol. 10, 2430 (December, 1961).

13. C.C.I.R. Doc. V/28 (Japan), Geneva, 1962.
14. Kirby *et al. Proc. IRE,* October, 1955.
15. C.C.I.R. Doc. V/48 (Japan), 1963-1966.
16. C.C.I.R. Doc. V/18 (United Kingdom), 1963-1966.
17. C.C.I.R. Doc. V/29 (Japan), 1963-1966.
18. Okumura, Y. and Hara, M. Long-term properties of UHF path loss and multipath distortion on over-the-horizon radio links using obstacle gain path. *Rev. Elect. Comm. Lab. NTT,* Tokyo **13,** No. 4 (1965).
19. C.C.I.R. Doc. V/38 (O.I.R.T.), 1963-1966.
20. C.C.I.R. Doc. V/24 (F. R. of Germany), 1963-1966.
21. Beckmann, P. and Spizzichino, A. The scattering of electromagnetic waves from rough surfaces, Pergamon Press, London, New York, Paris (1963).
22. Thiessen, P. Über den Einfluss der Geländebeschaffenheit auf die Ausbreitung elektromagnetischer Wellen im Bereich IV. (The influence of irregularities in the terrain on the propagation of electromagnetic waves in Band IV). *Rundfunktechnische Mitteilungen* No. 8; 22-38 (1964).
23. E.B.U. Monograph C, 1965.
24. C.C.I.R. Doc. V/28 (P.R. of Poland), 1963-1966.
25. La Grone, A. H. Forecasting television service fields. *Proc. IRE* **48,** No. 6 (June 1960).
26. C.C.I.R. Doc. V/42 (F. R. of Germany), 1963-1966.
27. Wise, F. H. The influence of propagation factors in UHF television. Television Soc. Journal. V.10, No. 11 (1965).

REPORT 237-1 *

FADING OF SIGNALS DUE TO MULTIPATH TRANSMISSION IN THE TROPOSPHERE

(1956 - 1963 - 1966)

1. Line-of-sight paths

Changes in atmospheric refraction and multipath sometimes cause excessively severe fading on line-of-sight microwave radio links [2, 3, 11]. This fading can be counteracted by employing diversity techniques such as dual frequency-diversity, where the information is transmitted over two channels at different frequencies, or dual height-diversity where two vertically-spaced receiving antennae are used. The gross behaviour of the variation in transmission loss for many paths is explained by means of two relatively simple propagation mechanisms: refraction associated with the time-varying vertical gradient of refractive index and the formation of phase-interference patterns due to diffraction and reflection by the earth's surface and atmospheric refractive-index irregularities [12, 15, 18].

Recent measurements of the vertical refractive-index gradient in the lower layers of the atmosphere show that the range of values is much larger than was previously supposed.

In the United States, at Cape Kennedy, Florida, the vertical gradient was measured in the first 100 m near the surface of the earth. It was found to vary between 230 N/km, which

---

* This Report, which was adopted unanimously, is in response to Study Programmes 57 and 176. The attention of Study Group IX is drawn to this Report as a partial answer to Question 13/IX.

was exceeded during 0·05% of the time, and —370 *N*/km, which was exceeded during 99·9% of the time, which corresponds to *k* ranging between 0·4 and —0·7 (concave earth) [16].

In France, studies carried out in the Paris area in the same part of the atmosphere—the first 100 m near the surface of the earth — produced results very similar to those mentioned above. When the gradient was measured in the first 500 m, however, variations were much less, values ranging from 30 *N*/km (0·05% of the time) to —140 *N*/km (99·8% of the time), which corresponds to *k* ranging between 0·8 and 10 [6].

It must be pointed out, however, that, so far as wave propagation is concerned, extreme values of the index gradient are less important than might be supposed. These extreme values correspond to unusual weather conditions prevailing over a distance which is probably very short, generally less than the length of the radio link. One must therefore consider also the space correlation between the index gradients at two points on the path, but insufficient study has been made of this question. The index gradient measured at one point (especially extreme values) should therefore be used with great caution.

The measurements conducted in the U.S.S.R. [23] have shown that the statistical distribution of the vertical gradient of the refraction index in the 0—200 m layer approaches the normal law for most climatic regions of the U.S.S.R. (except mountainous and coastal regions). The distribution parameters (median value and standard deviation) are different for various climatic regions and depend upon the season of the year.

Rapid changes of the refractive index, within a height range of several tens of metres above the surface of the earth, have also been reported. Such rapid changes of refractive index with height can be a source of multipath propagation [10].

When the atmosphere is sufficiently sub-refractive, the ray paths will be bent in such a way that the earth appears to be in the direct path between transmitter and receiver giving rise to the kind of fading called diffraction fading. This type of fading may be alleviated by installing antennae which are sufficiently high, so that the most severe ray bending will not place the receiver in the diffraction region.

At small gradients of the refractive index the direct ray will, under some circumstances, be interferred with by the ground-reflected ray or other multipath rays. Whether this interference is constructive or destructive will depend on the differential path lengths of the signals which reach the receiving antenna; where the paths contribute in-phase signals, the interference pattern will yield a field-strength maximum and when they are out-of-phase, the pattern will yield a field-strength minimum. The most severe fading occurs when there are two effective components, equal in magnitude and opposite in phase. This kind of fading may be alleviated by the use of diversity systems, since this interference is frequency, time and space selective. Radio links with diversity equipment to combat this type of fading have been built and reported [1, 4, 14] to operate quite satisfactorily.

Under normal conditions and over moderately irregular sea or terrain, one expects a portion of the ground-reflected wave to be scattered away from the propagation path [17]. However, when the atmosphere is super-refractive and the earth appears concave, the reflected wave is enhanced by the convergence of the associated rays.

Methods have been developed for determining the antenna height or frequency separations necessary to provide diversity protection against deep fades. Methods [14, 16] for a two-ray model which make use of the measured variation of the refractive index gradient near the surface of the earth, assume that the received signal consists of a direct and reflected wave of approximately equal amplitudes with phase varying in accordance with the refractive index gradient. A method for the case of atmospheric multipath has been developed and experimentally verified in Japan [24].

2. Beyond-the-horizon paths

When the receiver is located beyond the radio horizon, or the link operates under sub-refractive conditions, many components of the received signal are observed and arrive at the receiver via many paths which are the result of scattering from atmospheric inhomogeneities or partial reflections from elevated layers [5]. When the diffracted wave component of the received signal becomes negligible (e.g. at longer distances from the transmitter), the signal is observed to fade very rapidly when compared to line-of-sight links. This beyond-the-horizon region is treated under the topic of tropospheric-scatter [12, 19, 20].

Scatter propagation over large beyond-the-horizon distance has been studied in the Federal Republic of Germany by measurements of the " correlation distance " (diversity distance) and " fading frequency " [9, 10, 12, 13]. Quantitative measures of these characteristics have been determined from simultaneous field-strength recordings taken with several horizontally and vertically spaced antennae (normally three). From these recordings quantities characterizing the field have been derived. These include:

- space correlation functions in the orthogonal directions;
- time correlation functions;
- cross-correlation functions of the received field strengths on the separate antennae.

In addition, power spectra have been determined in space and time including the determination of the angular distribution of arriving waves (the scatter cone) and the mean frequency of fading, f_s. Similarly, the variation in the frequency-correlation coefficient with path length has been studied [25].

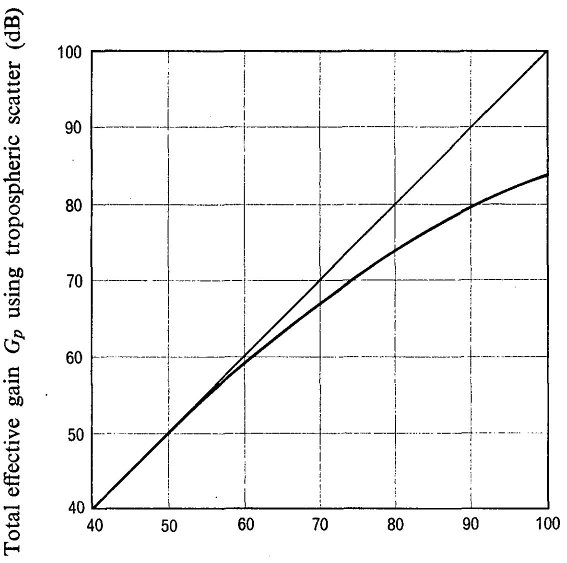
It has been found that, when the antenna beamwidth is larger than the width of the angular distribution of the arriving waves, the structure of the troposphere may be deduced from the spatial pattern of the received field strength. Under conditions where the antenna beamwidth is large, the correlation coefficient of the field received on spaced antennae does not exceed $1/e$ for antenna separation of 8·5 m more than 1% of the time for vertical antenna spacings or more than 2% of the time for horizontal antenna spacings. When the antenna beamwidth is less than the width of the angular distribution of the arriving waves, the correlation distances have been found to increase [9, 10]. Results of the studies also indicate that the space and time correlation functions of the received field are related to the horizontal and vertical motions of the troposphere as determined from wind velocity measurements.

The path antenna gain or total effective antenna gain over a tropospheric scatter circuit has been observed to be practically independent of distance between about 150 and 500 km [21]. Furthermore, the total effective gain, shown in Fig. 1, may be assumed to depend only on the sum of the free-space antenna gains, without large corrections, provided that neither of the free space gains exceeds about 50 dB.

References [22, 26] examine the influence of the path length and the directivity of the transmitting antenna, on the loss in antenna gain in the receiving antenna, and it is shown that this loss in antenna gain is not necessarily distributed equally between the transmitting and receiving antennae.

3. Future studies

Further analysis may be valuable utilizing multiple rays and correlation functions (real and complex) of frequency, time and space [8, 24]. Especially it is desirable to make further studies of fading encountered on typical radio-relay links to establish the range of validity for propagation models such as those described above. These studies should include simultaneous fading measurements at a number of different frequencies, both vertical and horizontal antenna spacings and paths, for a substantial period of time [7]. Particularly important are simultaneous meteorological measurements.



The sum of the free-space antenna gains, $G_t + G_r$ (dB)

FIGURE 1

BIBLIOGRAPHY

1. ALBERTSON, J. N. Space diversity on the microwave system of the Southern Pacific. Wire Radio Commun. 83-87 (Nov. 1964).
2. BATTESTI, J. and BOITHIAS, L. Etudes des sections longues dans les faisceaux hertziens en visibilité (Study of long sections in line-of-sight radio-relay systems). *Annales des télécommunications* (July-August, 1964).
3. BRAUDE, S, Ya., OSTROVSKII, I. E. and SANIN, F. S. Use of the concept of negative equivalent earth radius for estimating strong refraction of radio waves (Russian). Izvest. vyssh. ucheb. zaved, Radiofizika, **4**, 67-73 (1961).
4. CABESSA, R. Réalisation de liaisons par faisceaux hertziens de qualité sur des trajets maritimes en Grèce (Realization of high quality radio-relay links on oversea paths in Greece). *l'Onde Electrique*, **35**, 714-727 (1955).
5. C.C.I.R. Report 238.
6. C.C.I.R. Doc. V/8 (France), Geneva 1965.
7. C.C.I.R. Doc. V/11 (United Kingdom), Geneva 1965.
8. CRAWFORD, A. B. and JAKES, W. C., Jr. Selective fading of microwaves, Bell System Tech., J., **31**, 91-103 (1952).
9. FEHLHABER, L. and GROSSKOPF, J. Untersuchung der Brechzahlstruktur der turbulenten Atmosphäre mit Hilfe einer Korrelationsanalyse des Empfangsfeldes bei Scatterausbreitung (Investigations of the refractive index structure of the turbulent troposphere using a correlative analysis of the received field during scatter transmission). *NTZ*, **2**, 63-70, *NTZ*, **6**, 292-299 (1965).
10. FEHLHABER, L. and GROSSKOPF, J. Zur Deutung der Schwunderscheinungen auf Sichtstrecken im dm und cm Wellenbereich (Contribution to the explanation of fading phenomena on line-of-sight radio links in the decimetric and centimetric bands). Technischer Bericht No. 5578 of Fernmeldetechnisches Zentralamt of Deutsche Bundespost (1 April, 1965).
11. GIUGLIARELLI, G. On the influence of oversea propagation on the transmission of colour television signals. *E.B.U. Review*, 90-A Technical (April, 1965).
12. GROSSKOPF, J. Schwunduntersuchungen im Höchstfrequenzbereich (Investigation of fading in the microwave band) *NTZ* **12**, 590-604 (1961).
13. GROSSKOPF, J., FEHLHABER, L., and WITTKE. Schwundfrequenzmessungen auf der 1850 MHz-Strecke Hochblauen-Darmstadt (Measurement of fading frequency on the 1850 MHz link Höchblauen-Darmstadt). Technischer Bericht No. 5567 of Fernmeldetechnisches Zentralamt of Deutsche Bundespost (15 May, 1963).
14. LEWIN, L. Diversity reception and automatic phase correction *Proc. I.E.E.*, **109 B**, 295-304 (1962).
15. MISME, P. Influence des discontinuités frontales sur la propagation des ondes décimétriques et centimétriques, *Annales des télécommunications*, **12** (1957).
16. NORTON, K. A., HUFFORD, G. A., DOUGHERTY, H. T. and WILKERSON, R. E. Diversity design for within-the-horizon radio-relay systems. NBS, Report 8787 (1965).
17. RICE, P. L., LONGLEY, A. G., NORTON, K. A. and BARSIS, A. P. Transmission loss predictions for tropospheric communication circuits. NBS Tech. Note 101 (1965).
18. SACCO, L. Il collegamento radio in regime superrefrazione atmosferica. Alta Frequenza, **6**, 436-469 (1955).
19. ANGELL, B. C., FOOT, J. B. L., LUCAS, W. J. and THOMPSON, G. T. Propagation measurements at 3840 MHz over a 173 mile path. *Proc. I.E.E.*, **105 B** (1958).
20. GEIGER, G. V., LA FRENAIS, N. D. and LUCAS, W. J. Propagation measurements at 3480 and 9640 MHz beyond the radio horizon, *Proc. I.E.E.*, **107 B** (1960),
21. BOITHIAS, L. and BATTESTI, J. Etude expérimentale de la baisse de gain d'antenne dans les liaisons transhorizon, *Annales des télécommunications* (September-October, 1964).
22. C.C.I.R. Doc. V/46 (U.S.S.R.), 1963-1966.
23. KALININ, A. I. Calculation of radio-relay links (in Russian), published by Sviaz, Moscow, 128-135 (1964).
24. C.C.I.R. Doc. V/102 (Japan), 1963-1966.
25. C.C.I.R. Doc. V/114 (France), 1963-1966.
26. C.C.I.R. Doc. V/108, (U.S.S.R.), 1963-1966.

REPORT 238 *

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

(Study Programme 139)

(1959 - 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 MHz 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 ranges. 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 hertz at UHF. The superposition of a number of variable incoherent components would give a signal whose

---

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

amplitude was Rayleigh distributed and this is found to be nearly true when the distribution is analysed 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 higher in winter than in 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 231-1 and 233-1 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 beamwidths of the antennae are smaller than those 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 restrictive.

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), 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 MHz over a 320 km link, show large time variation of the diversity distance between several megahertz and several tens of megahertz (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 MHz.

BIBLIOGRAPHY

1. *Proc. IRE* (October, 1955).
2. *Proc. I.E.E.*, **105**, Part B (1958).
3. Record of National Symposium on extended range and space communications, *IRE*, Washington (October, 1958).
4. DU CASTEL, MISME, SPIZZICHINO and VOGE. Réflexions partielles dans l'atmosphère et propagation à grande distance (Partial reflections in the atmosphere and propagation at a great distance). Editions de la *Revue d'Optique*, Paris (1960).
5. SHKAROFSKY, I. P. Tropospheric-scatter propagation. Research Report No. 7-200-1, RCA-Victor Co. Ltd., *Res. Labs.*, Montreal, Canada (March, 1958).

REPORT 239-1 *

PROPAGATION STATISTICS APPLIED TO BROADCASTING AND MOBILE SERVICES ON FREQUENCIES FROM 30 TO 1000 MHz

(Study Programme 7A/V)

(1959 - 1963 - 1966)

1. Introduction

This Report gives details of the construction and use of the propagation curves in Recommendation 370-1 and includes descriptive statistics concerning antenna height gain and depolarization phenomena: it also discusses the effects of large cities and of vegetation on propagation. The last section suggests an improved method for computing field strength over mixed land-sea paths.

Report 240 was prepared to supply a need for broadcasting curves showing climatic differences expected within the continent of Africa. When transmitters operating in those frequency bands are put into service, it is hoped that the African Administrations will make available additional data for comparison with these curves.**

---

* This Report was adopted unanimously.

** Propagation curves for broadcasting in the African Continent are given on pp. 343-379 of the Final Acts of the African VHF/UHF Broadcasting Conference, Geneva, 1963.

Report 236–1, as a companion to this Report, discusses the influence of the terrain on propagation and the theoretical basis for some of the parameters used with curves of field strength versus frequency, distance, antenna heights, and type of terrain. Report 228–1 discusses the measurement and descriptive analysis of field strengths for broadcast services and shows how propagation curves may be used to describe effective service areas. For point-to-point transmission loss prediction of long-term medians and time variability, other methods of prediction are usually employed. A compilation of some of these methods being studied by the International Working Group under C.C.I.R. Resolution 2 has recently been published [1].

Results of field-strength measurements have been made available by many Administrations, and these have been combined in the production of these propagation curves [18, 19, 20, 21, 22, 23, 24]. 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, and have been brought up to date in this document.

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, and further subdivided for land and sea paths. Figs. 1, 2 and 3 show the average curves derived from these data.

Fig. 1 shows the curves for VHF propagation at the greater distances and incorporates a very large amount of data over many land and sea paths, obtained with transmitting and receiving antennae at various heights. The data were normalized for a transmitting antenna height of 300 m by assuming that the field strength was a function only of the distance between horizons. By this assumption, the field strength at a distance X km from the transmitter for an antenna height of h_1 m, is the same as the field strength on the curve for a transmitting antenna height of 300 m at a distance $(X+70—4{\cdot}1\sqrt{h_1})$ km. This procedure may be used for distances beyond the horizon, and was applied to the curves of Fig. 1, at 200 km and beyond, to obtain the family of curves appearing in Figs. 1, 2, 3 and 4 of Recommendation 370–1. The near-distance portions of the curves in Fig. 4 of Recommendation 370–1 were drawn to coincide with the land curves at a distance of about 10 km.

A similar set of curves is shown in Fig. 2 for propagation over land at UHF. Here again the curves, which relate to a transmitting antenna height of 300 m, represent the average of a great amount of data for many land paths in many areas of the world. Curves for transmitting antennae at other heights have been developed from these by assuming that the field strength depends only on the distance between horizons, as described in the last paragraph. These are shown in Figs. 9, 10 and 11 of Recommendation 370-1.

Attention should, however, be drawn to measurements made by O.I.R.T. [28] over a period of three years on transmissions over five paths in Central Europe at a frequency of 1100 MHz. An important conclusion from this work is that the variance of the field strength for several paths is considerably greater than that indicated by Recommendation 370–1 and also by Report 244–1. These paths are such that they are particularly influenced by the overlapping effects of more than one propagation mechanism. For example, it was observed that over paths of some 200 km in length the difference between the field strength exceeded for 1% and 50% of the time is of the order of 30 dB, compared with a difference of about 18 dB which would have been expected from the curves of Recommendation 370–1, drawn for a median frequency of about 700 MHz (middle of the bands IV and V).

Fig. 3 shows curves for oversea paths representing the field strength exceeded for 1%, 5%, 10% and 50% of the time in bands IV and V (450—1000 MHz). For distances between 200 and 1000 km, the 50% and 10% curves are normalized for a transmitting antenna at a height of 300 m according to the method described above. Long range data at present available indicate that for small percentages of the time, the received field strength is relatively insensitive to the height of the transmitting antenna. Accordingly, the 1% curve has not been corrected for transmitting antenna height. The 5% curve, which is an interpolation between the 1% and 10% curves, therefore contains approximately half the height gain correction.

Curves for other heights of transmitting antennae in Recommendation 370–1 have been developed for these distances by the methods decribed above. The curves are based on measurements over a number of paths in the North Sea area, each for a period of about eighteen months between November 1958 and September 1964. The measurements were taken at open coastal sites directly overlooking the sea. In order that they may be applicable for the calculation of co-channel interference in coastal towns, where the field strength may be expected to be lower than at the open sites, they incorporate a correction of approximately —7 dB relative to the measured values.

Limited measurements of the median value of field strength in the Mediterranean area are in good agreement. There is evidence, however, that field strengths exceeded for small percentages of the time in the Mediterranean area are greater than those experienced in the North Sea area.

Some observations indicate that for small, but not insignificant percentages of time, perceptible signals may be received from high-power transmitters at distances exceeding 4000 km in tropical regions. For example, a field strength of 0·15 μV/m for an effective radiated power of 1 kW and transmission frequency of 417 MHz was measured at a distance of 4740 km (across the Atlantic Ocean), for approximately 2% of the year [29].

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 were separated into VHF and UHF classes, as was done for the beyond-the-horizon distances.

Fig. 1 of Recommendation 370–1 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 corresponding theoretical 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 of Recommendation 370–1 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 370–1 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 Figs. 2 and 3.

The near-distance field strengths in Fig. 4 of Recommendation 370–1, which shows the 1% (time) oversea VHF curves, were constructed on a corresponding assumption, namely, that the 1% field strength for propagation over land and over sea would not be materially different at a distance of 10 km from the transmitter. The sea curves were consequently merged smoothly with the land curves at this distance.

A set of field strength versus distance curves was derived for the UHF in similar fashion. These are shown as Figs. 9, 10 and 11 of Recommendation 370–1 for overland paths and in Figs, 13, 14, 15 and 16 for oversea paths.

4. Influence of irregularities in the terrain

Random selection of broadcast receiving locations on or near roads and in valleys results in higher values of the median transmission loss than are seen with most carefully selected receiving sites. Terrain roughness first increases the expected or median field strength by breaking up the destructive phasing between direct line-of-sight propagation and radio waves reflected or diffracted by the ground. Then increasing terrain irregularity and terrain clutter will reduce signals due to shadowing, absorption (including attenuation caused by vegetation) and the scattering and divergence or defocusing of diffracted waves. Convergence or focusing and specular reflection also play a part in these multipath phenomena, as does average refraction, turbulence and stratification of the refractive-index structure of the atmosphere.

Two phenomena play a major part in determining the complex standing waves which determine antenna height gain at a fixed distance from a transmitter. With reflection or diffraction from a surface which is sufficiently smooth and sufficiently large, a linear height gain is to be expected for lower heights, and as a receiving antenna is raised above irregularities and clutter, a height gain is to be expected for the quite different reasons mentioned in the preceding paragraph.

Depolarization phenomena are discussed in Report 122 and some recent measurements are discussed below. Here again site selection is of prime importance, either to reject unwanted signals, for instance, or to take advantage of depolarization with diversity: polarization discrimination is better in open country and with high signal levels than when field strengths are low, as at UHF in areas where a receiving antenna is surrounded by obstacles.

It is useful now to discuss some aspects of the problems arising from irregular terrain, vegetation, etc., with special reference to the use of VHF and UHF propagation curves.

4.1 *The parameter* Δh

The influence of irregularities in the terrain increases with frequency. It is therefore of more importance 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. 7 of Recommendation 370–1). 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 median for each and every site will result in a location distribution such as Fig. 5 of Recommendation 370–1 for VHF over 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. 5 of Recommendation 370–1 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. 12 of Recommendation 370–1; 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. Recent measurements in the Czechoslovak S.R. and the United Kingdom confirm that the corrections given in Figs. 8 (*a*) and 8 (*b*) of Recommendation 370–1 apply for distances up to 100 km in bands III, IV and V [2, 3].

In the above, the attenuation correction factor should be subtracted from the field strength for the required value of Δh. For distances greater than 200 km, the attenuation correction factor is also given in Figs. 8 (*a*) and 8 (*b*) of Recommendation 370–1.

For distances between 100 km and 200 km, the correction factor should be linearly interpolated between the two curves referred to above.

No attenuation correction factors are proposed at present for bands below band III.

Recent work has shown the single parameter Δh to be inadequate to define precisely the attenuation correction factor. It has been found, for example, that at any location along transmission paths broadly defined by $\Delta h \approx 50$ m, the median field strength predicted may be in error by more than 20 dB although it is generally within 10 dB, the error in the VHF bands tending to be less than at UHF.

Efforts have been made to improve accuracy by the introduction of further terrain parameters on an empirical basis. These methods are listed below and may be used in cases where the prediction accuracy required is greater than that associated with the use of the parameter Δh alone.

4.1.1 A method developed in the F.R. of Germany [4] in which as well as the r.m.s. value of Δh, the mean slope of the terrain plays an important role in the derivation of the factor.

4.1.2 A method developed in the P.R. of Poland [5] and based upon a modification of the TASO method [6], in which the factor is dependent upon both Δh and the mean wavelength of terrain undulations.

4.1.3 A method developed in the United Kingdom [3] in which factors dependent upon Δh and the mean slope of the terrain are used.

4.2 *Effect of change in the height of the receiving antenna*

4.2.1 *Median values of height-gain factors*

Work by various Administrations [7, 8, 9, 27] shows the height gains which may be expected in changing the receiving antenna height from 3 m to 10 m above ground level. The results may be summarized as follows:

Bands I, II — Median values of height gains are 9 dB to 10 dB in hilly or flat terrain for rural and urban areas.

Band III — Median values of height gains are 7 dB in flat terrain and 4 to 6 dB in urban or hilly areas.

Bands IV, V — Median values of height gains in these bands are very dependent upon terrain irregularity. Fig. 4 shows how the median varies with Δh. In suburban areas, the median is 6 to 7 dB and in areas with many tall buildings 4 to 5 dB.

The above values apply for distances up to 50 km from the transmitter. For distances in excess of 100 km, values should be reduced by 50% (use linear interpolation at intermediate distances).

At any specific location in an area, the actual height gain may differ by many decibels from the median value.

4.2.2 *Ratio between field strength in town and in surrounding areas*

Presently available evidence suggests, that provided receiving antenna heights are sufficiently above the local roof level, the received field strength will be substantially that given by the curves in Recommendation 370–1.

Experience has shown that in bands I and II, no great difference exists between field strengths measured at a height of 10 m in rural or urban areas. In band III [10, 11, 12], field strengths at a height of 10 m in suburban areas are much the same as in equivalent rural areas [10, 12]. Work in the P.R. of Poland showed maximum attenuation in the centre of an urban area as follows: in an urban area of 400,000 people [10, 11], 16 dB at 10 m and 6 dB at 16 m (the average roof level), and in an urban area of 80 000 population [12], 12 dB at 10 m. In heavily built-up areas, the received field strength may be reduced by 6 to 16 dB, dependent upon the character of the buildings in the area. For the UHF bands, recent work in the United Kingdom [13] has shown a median loss of 9 dB for urban areas in southeast England. Experiments made in Italy [30], at metric and decimetric wavelengths in heavily built-up areas, have shown that the additional loss factor depends principally on the density and height of the buildings, on the angle of arrival of the wave at the receiving antenna and on the orientation of the street with respect to the direction of the transmitter from the receiving site.

It is desirable to obtain larger statistical samples for each type of urban situation.

4.2.3 *Interpolation of the field-strength curves for land-mobile services*

The field-strength curves given in Recommendation 370–1 are directly applicable to broadcasting services where the receiving antenna is at a height of 10 m above ground level. For land-mobile services, the receiving antenna will generally be nearer 3 m above ground level and the median received field strength will, in consequence, be reduced.

In rural areas the interpolation is straightforward. The appropriate height-gain factor given in § 4.2.1 should be subtracted from the field strength predicted by the curves. In urban areas the interpolation is more complicated. The appropriate height-gain factor given in § 4.2.1 is subtracted from the field strength predicted by the curves and then a further " terrain clutter " factor must be subtracted for reasons given in § 4.2.2. Total correction factors, to be subtracted from the field strength read from the curves of Recommendation 370–1, are given in Table I.

TABLE I

	Bands I, II	*Band III*	*Bands IV, V*
Rural (dB)	9	7	as given by Fig. 4 for $d < 50$ km,
Urban (dB)	9	11	14

The above values apply for distances from the transmitter up to 50 km. For distance in excess of 100 km the above factors should be reduced by 50%, with linear interpolation for intermediate distances.

4.2.4 *Roof-top versus indoor antennae*

In a recent study [14], the performance of existing roof-top and indoor antennae in New York City was related to both signal strength measurements and subjective determinations of television picture quality. Point-to-point transmission loss distributions were log-normal with standard deviations of 16 and 14 dB, respectively, for roof-top and indoor measurements. Median values for these distributions differed by amounts ranging from 16 to 35 dB depending on the frequency, the type of building, and the type of path. This difference was about 7 dB greater at 570 MHz than at 55 MHz, 10 dB greater for reinforced concrete buildings than for wooden buildings, and 5 dB greater for locations on Manhattan Island than for locations outside Manhattan Island.

4.3 *Depolarization phenomena*

In the band of frequencies between 30 and 1000 MHz, the median value of the polarization discrimination that can be achieved at domestic broadcast receiving sites by the use of orthogonal polarization may be as much as 18 dB, and under these conditions, the values exceeded at 90% and 10% of the receiving sites are about 8 to 10 dB and 29 dB, respectively (see Report 122).

The discrimination is better in open country and worse in built-up areas or places where the receiving antenna is surrounded by obstacles. For domestic installations in densely populated districts, the median value of 18 dB will usually be realized only at roof level, and this value may be reduced to 13 dB or less at street level.

In a recent study at 573·25 MHz [15], the discrimination exceeded at 90% of receiving sites, when a vertically polarized antenna was directed towards a horizontally polarized transmission was 8 dB, taking many types of terrain into consideration. The discrimination exceeded at 90% of receiving locations, with a vertically polarized antenna directed 180° away from the direction of a horizontally polarized transmission, was 22 dB, or 6 dB greater than the front-to-back ratio of the antenna. Discrimination was generally greater in areas where the field strength was high, and lower in conditions of poor reception.

Measurements made in the Federal Republic of Germany [31], at frequencies of 190 and 500 MHz, have given a comparison of both the quality of reception and the received field strength of vertically and horizontally polarized television transmissions. It was shown that the quality of reception with vertically polarized waves was inferior to that with horizontally polarized waves and the difference has been attributed to the effects of buildings and vegetation. At 190 MHz, the field strength over line-of-sight paths was 3 dB lower with vertical than with horizontal polarization; for receiving points in shadow this difference increased to 4·7 dB. For 500 MHz the corresponding values are 0 dB and 1·5 dB. The observed subjective quality of the received pictures was well correlated with these measurements.

Measurements in very irregular terrain have been made in the Czechoslovak S.R. In particular, 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 [25, 27]. When receiving sites were classified according to types of terrain, the depolarization ratio varied over a great range. Representative values are given in Table II.

TABLE II

Depolarization ratio exceeded at 90% of receiving sites in different types of terrain at 570 MHz

Type of terrain	Angle of diffraction (mr)	Ratio (dB)	Median value of attenuation relative to free space (dB)
Suburban area optical to transmitter		18	7
Suburban area in slight diffraction zone	2	13	26
Suburban area in moderate diffraction zone	6	10	31
Town in deep diffraction zone	45-82	4	40
Thickly wooded area (trees in leaf: no obstruction due to terrain)		2	27

The angle of diffraction to each of the receiving areas at which measurements were made is shown in the Table. This is defined as the angle between the line joining the obstacle and the receiving antenna and the extension of the line from the transmitter to the obstacle. Whilst some correlation with diffraction angle is seen to exist, the occurrence of depolarization is in a large measure dependent on the local terrain at the receiving site. A satisfactory parameter for demonstrating a correlation with depolarization ratio is the path attenuation at each of the sites; that is the difference between the free-space field strength calculated for the sites and the median of a number of measured values (of the order of 20) obtained at the sites. The appropriate path attenuations so determined are given in Table II. A plot of depolarization ratio against path attenuation gives a curve with a reasonably small range of scatter except in the case of the last item of the Table, which reflects the important effect of a wooded environment on depolarization.

Other measurements at 520 and 700 MHz [16] have indicated 1 to 2 dB more depolarization for vertical than for horizontal polarization. Table III summarizes these measurements which were made near Heidelberg. Thirty per cent of the observations were in or near built-up areas, and the remaining 70% were evenly distributed over the remaining area.

The effect of frequency and building density proved to be negligible. The data of Table III are classified according to the parameter Δh which indicates the roughness of the terrain.

TABLE III

Nature of terrain	Δh (m)	90% of locations (dB)	50% of locations (dB)
Flat	10	$\geqslant 20$	$\geqslant 30$
Hilly	50	$\geqslant 14$	$\geqslant 27$
Mountainous	200	$\geqslant 0$	$\geqslant 16$

4.4 *Attenuation due to vegetation and buildings*

A recent review [32] shows how the attenuation caused by vegetation and buildings varies with frequency. This review summarizes published data covering a range of vegetation conditions [33, 34, 35, 36, 37, 38] and the results are given in Fig. 5.

Comparative measurements for horizontally and vertically polarized waves have been recorded and, although the difference is not always marked, there appears to be a tendency for the attenuation to be slightly greater with vertical polarization.

5. Mixed land-sea paths

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

When the transmission path is over a mixture of land and sea then an estimate must be made of the effect of the mixed path on received signal.

Since the Xth Plenary Assembly, Geneva 1963, an improved method for calculating the field strength over a mixed land and sea path, well supported by measurements, has been developed in the United Kingdom and removes the restrictions in the previous method. The new method [17] is described by reference to Fig. 6, where the UHF 1% sea and land curves, for a transmitting antenna height of 300 m, are reproduced as curves (*A*) and (*B*) respectively.

Let it be assumed, for the purpose of this example, that the transmission path consists of 200 km over sea and 100 km over land. In making the calculation, the path is traversed in both directions, and the geometric mean of the two computations is taken as the required field strength.

Curve (*A*) in Fig. 6 indicates that the field strength at 200 km is 59·5 dB rel. 1 μV/m. The distance along curve (*B*) at which this field strength is reached is 31 km. This distance is therefore equivalent on the land curve to 200 km on the sea curve, when the field strength is 59·5 dB rel. 1 μV/m. It is assumed that the wave, which has travelled over 200 km of sea, is in the same state as a wave that has travelled the equivalent land distance of 31 km. It will, therefore, continue to be attenuated according to the land curve as it proceeds over the next section of path 100 km long. The equivalent distance of the whole path is thus 131 km, and the field strength at this distance on the land curve is 28·8 dB rel. 1 μV/m.

The process is repeated in the opposite direction. Thus, for 100 km of land, curve (*B*) indicates a field strength of 35 dB rel. 1 μV/m. The equivalent distance on curve (*A*) is 403 km. The equivalent distance of the whole of the path on the sea curve is then 603 km, and the field strength at this distance on curve (*A*) is found to be 21 dB rel 1 μV/m. The mean of the two answers obtained is:

$$E = \tfrac{1}{2}(28{\cdot}8+21) \approx 25 \text{ (dB rel. 1 } \mu\text{V/m)}$$

which is the required field strength.

The procedure for paths containing more than two sections is merely an extension of what has been described.

BIBLIOGRAPHY

1. RICE, P. L., LONGLEY, A. G., NORTON, K. A. and BARSIS, A. P. Transmission loss predictions for tropospheric communication circuits. U.S. Nat. Bur. Stand. Tech. Note 101 (May 7, 1965).
2. C.C.I.R. Doc. V/38 (O.I.R.T.), 1963-1966.
3. E.B.U. Monograph C, 1965.
4. C.C.I.R. Doc. V/24 (F. R. of Germany), 1963-1966.
5. C.C.I.R. Doc. V/28 (P. R. of Poland), 1963-1966.
6. LA GRONE, A. H. Forecasting television service fields. *Proc. IRE* **48** No. 6 (June, 1960).

7. C.C.I.R. Doc. V/4 (U.S.A.), 1963-1966.
8. Uhlen, N. *Tele*, Stockholm 1 (1962).
9. C.C.I.R. Doc. V/39 (O.I.R.T.), 1963-1966.
10. C.C.I.R. Doc. V/34 (P. R. of Poland), 1963-1966.
11. C.C.I.R. Doc. V/35 (P. R. of Poland), 1963-1966.
12. C.C.I.R. Doc. V/51 (P. R. of Poland), Geneva, 1962.
13. C.C.I.R. Doc. V/9 (U. K.), 1963-1966.
14. C.C.I.R. Doc. V/2 (U.S.A.), 1963-1966.
15. C.C.I.R. Doc. V/19 (U. K.), 1963-1966.
16. C.C.I.R. Doc. V/43 (F. R. of Germany), 1963-1966.
17. C.C.I.R. Doc. V/20 (U. K.), 1963-1966.
18. Kühn, U. Ausbreitungsuntersuchungen über unterschiedlichem Gelände in den Frequenzbändern I, II und III (Study of wave propagation over irregular terrain in bands I, II and III). *Technische Mitteilungen B.R.F. (R.D.A.)* (February and May, 1958).
19. Fine, H. UHF propagation within line-of-sight. FCC Report T.R.R., 2.4.12.
20. Saxton, J. A. Basic ground-wave propagation characteristics in the frequency band 50-800 MHz. *Proc. I.E.E.* **101** Part III, 211 (1954).
21. Saxton, J. A. and Harden, B. N. Ground-wave field-strength survey at 100 and 660 MHz. *Proc. I.E.E.*, **101** Part III, 215 (1954).
22. Kirke, H. L. *et al.* A VHF field-strength survey on 90 MHz. *Proc. I.E.E.*, **98** Part III, 343 (1951).
23. Report of Television Allocations Study Organization to the Federal Communications Commission (1959).
24. C.C.I.R. Doc. V/34 (United Kingdom), Geneva, 1962.
25. C.C.I.R. Docs. 207 and 208 (O.I.R.T.), Geneva, 1963.
26. Králík, F., Kühn, U. and Vočadlo, V. Ausbreitungsmessungen bei 480 MHz und 780 MHz im Gebirge der Niederen Tatra (C.S.S.R.) (Propagation measurements at 480 MHz and 780 MHz in the Low Tatra mountains (Czechoslovak S.R.)). *Techn. Mitt. des BRF,* 5, **4**, 174 (December 1961) and *Techn. Mitt. des RFZ*, 6, **1**, 18 (March, 1962).
27. Králík, F., Kühn, U. and Vočadlo, V. Ausbreitung von Dezimeterwellen bei horizontaler und vertikaler Polarisation und Höhenabhängigkeit der Feldstärke im Gebirge (Propagation of decimetric waves with horizontal and vertical polarization and the effect of height on field strength in mountains), *Tech. Mitteilungen RFZ*, Vol. 6, **4**, 162-166 (1962).
28. C.C.I.R. Doc. V/117 (O.I.R.T.), 1963-1966.
29. Misme, P. Propagation transhorizon à très grandes distances au-dessus de l'Atlantique intertropical (Trans-horizon propagation over very long distances over the intertropical Atlantic) *Annales des télécommunications* (1966).
30. C.C.I.R. Doc. V/99 (Italy), 1963-1966.
31. C.C.I.R. Doc. V/121 (F. R. of Germany), 1963-1966.
32. C.C.I.R. Doc. V/89 (United Kingdom), 1963-1966.
33. Saxton, J. A. and Lane, J. A. VHF and UHF reception. *Wireless World* **61**, 229 (1953).
34. Lagrone, A. H. Height-gain measurements at VHF and UHF behind a grove of trees. *IEEE Trans.* **BC-9**, 37 (1953).
35. Lagrone, A. H. and Chapman, C. W. Some propagation characteristics of high UHF signals in the immediate vicinity of trees. *IRE Trans.* **AP-9**, 487 (1961).
36. Herbstreit, J. W. and Crichlow, W. Q. Measurement of the attenuation of radio signals by jungles. *Radio Science* **68D**, 903 (1964).
37. Josephson, B. and Blomquist, A. The influence of moisture in the ground, temperature and terrain on ground-wave propagation in the VHF band. *IRE Trans.* **AP-6**, 169 (1958).
38. Head, H. T. The influence of trees on television field strengths at UHF. *Proc. IRE* **48**, 1016 (1960).

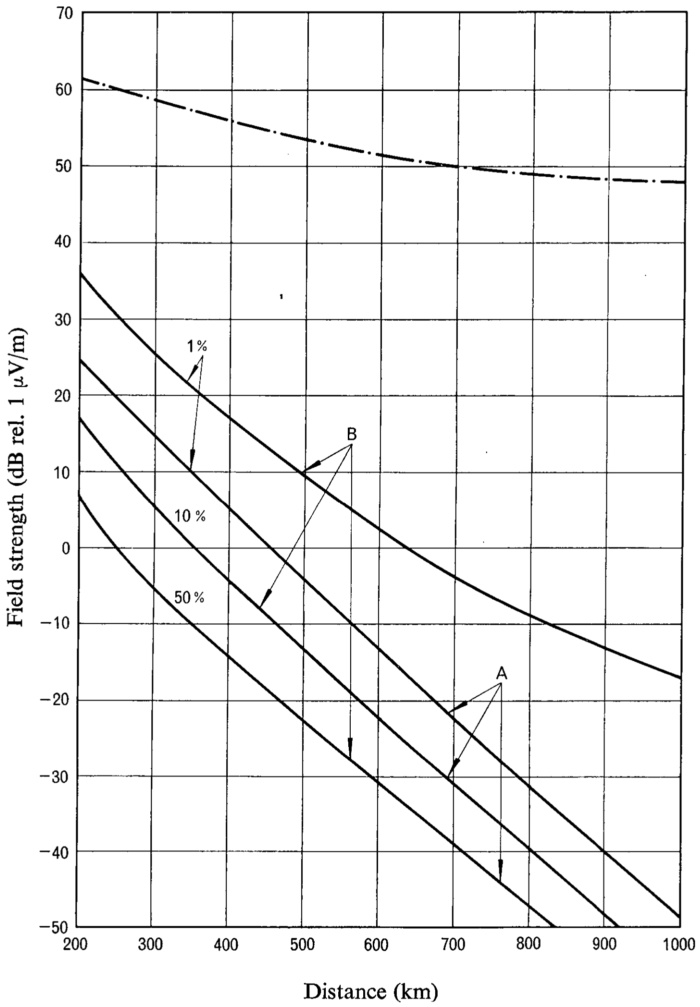


FIGURE 1

Field strength (dB rel. 1 μV/m) for 1 kW e.r.p. Freq. 30 – 250 MHz (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

—·—·— Free space

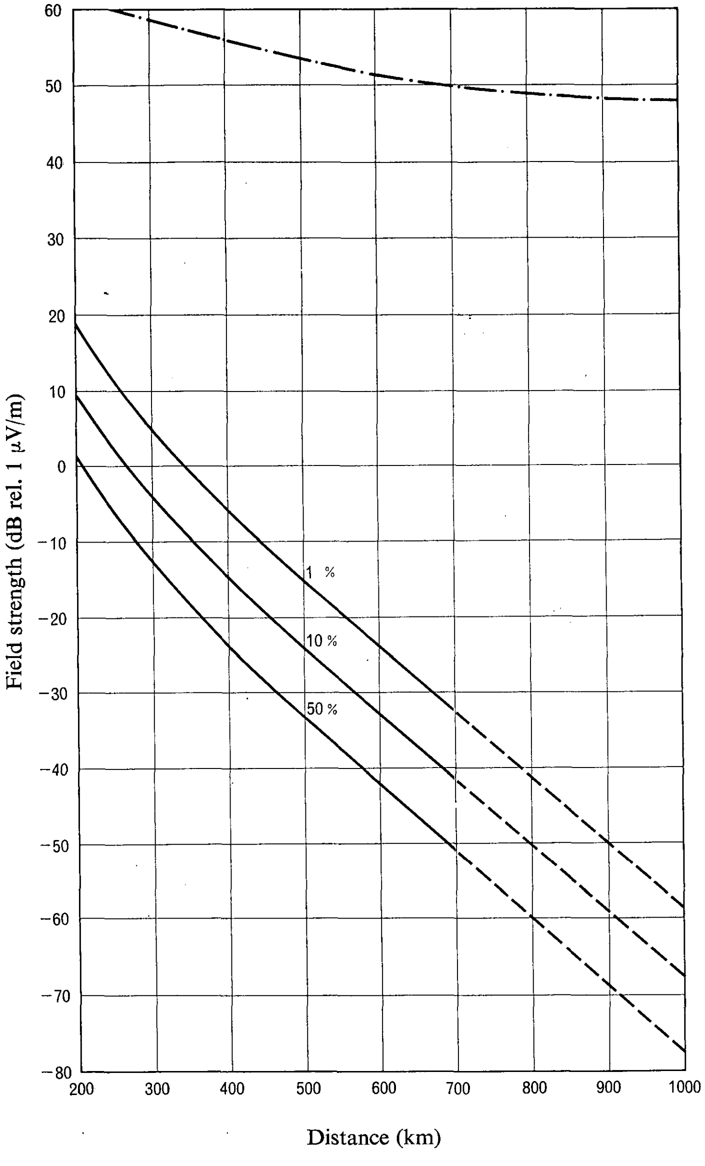


FIGURE 2

Field strength (dB rel. 1 μV/m) for 1 kW e.r.p. Freq. 450 – 1000 MHz (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*

—·—·— Free space

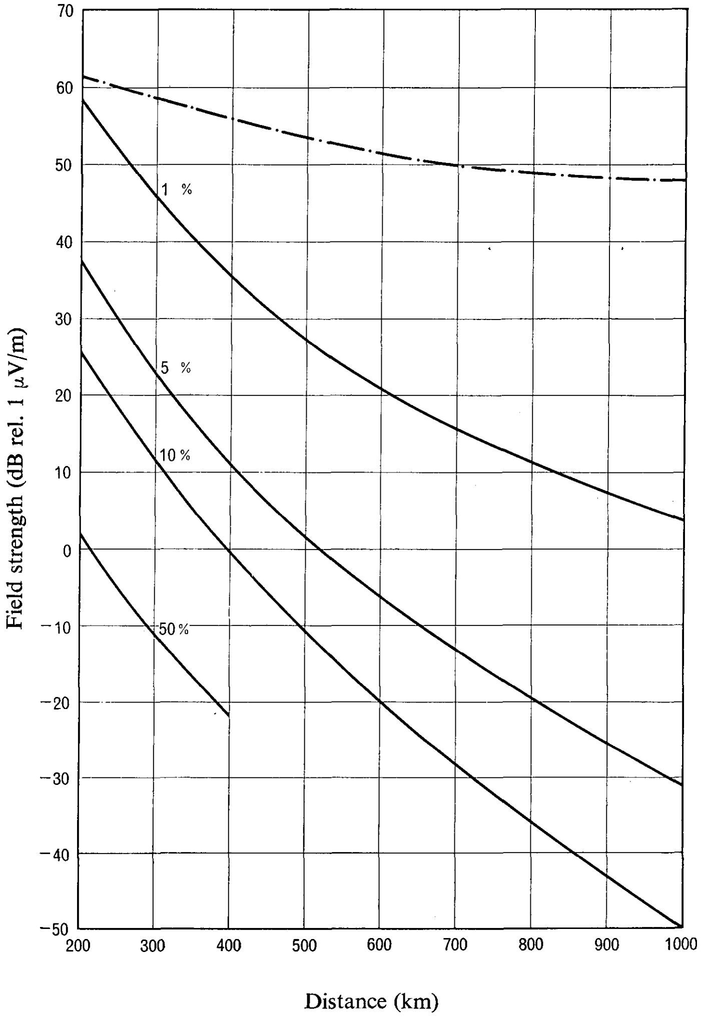


FIGURE 3

Field strength (dB rel. 1 μV/m) for 1 kW e.r.p. Freq. 450 – 1000 MHz (Bands IV and V); for the percentages of time shown on the curves: for 50% of the receiving locations; *h_1 = 300 m; h_2 = 10 m. Sea*

—·—·— Free space

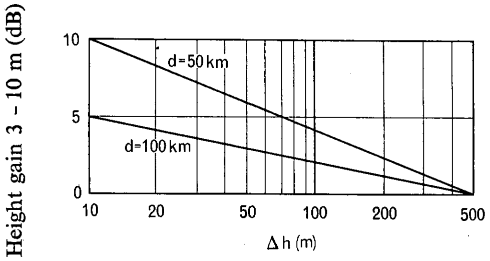
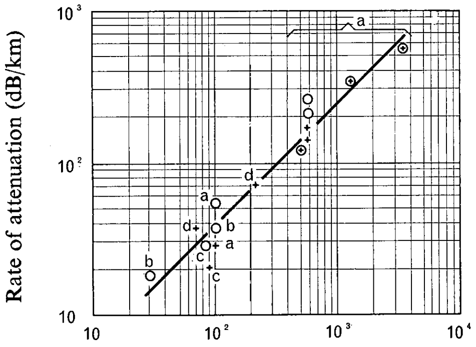


FIGURE 4

Height gain factor 3 – 10 m as a function of Δh for frequency 450 – 1000 MHz (Bands IV and V) parameter d represents distance from the transmitter



Frequency (MHz)

FIGURE 5

Attenuation in woods and undergrowth as a function of frequency

(a)	Trees in full leaf	[33]
(b)	Woods with dense undergrowth	[37]
(c)	Tropical jungle	[36]
(d)	Trees in full leaf	[34]
o	Vertical polarization	
+	Horizontal polarization	

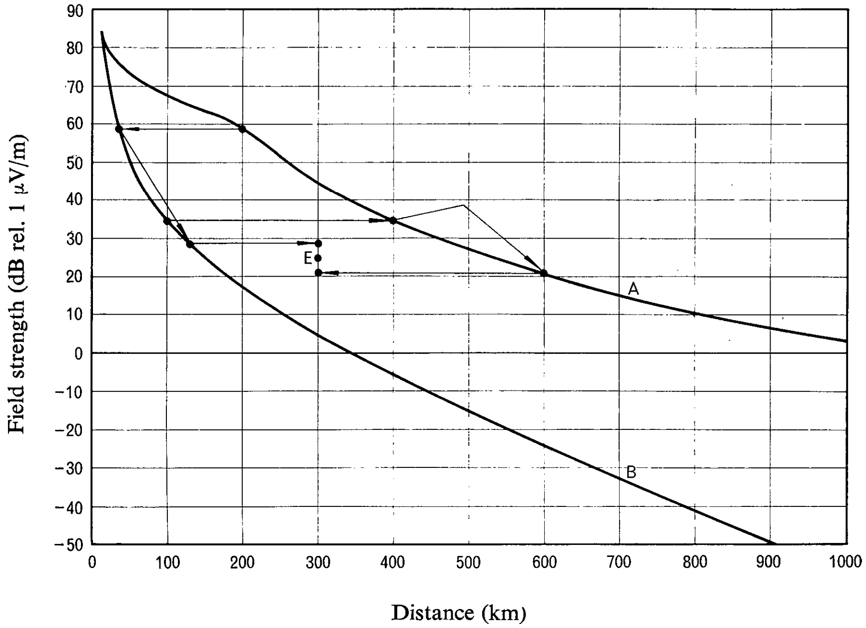


FIGURE 6

Method for estimating the field strength over a mixed land-sea path

Curve A: All-sea field strength/distance curve (1 %, time) $h = 300$ m.

Curve B: All-land field strength/distance curve (1 %, time) $h = 300$ m.

E = estimated field strength for the two-section path considered in example 1 of the text.

The arrows illustrate the steps in the method of estimating.

REPORT 241-1 *

PROPAGATION DATA REQUIRED FOR RADIO-RELAY SYSTEMS

Collection of data

(Study Programmes 5A/V and 5B/V)

(1959 - 1963 - 1966)

A large amount of data relevant to Study Programmes 5A/V and 5B/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 5A/V and 5B/V "), published by the International Telecommunication Union, Geneva, 1965.

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, height and gain of the antenna, 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 5A/V and 5B/V)

(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.

---

* This Report was adopted unanimously

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.

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 analysing 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:

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

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:

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

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 occurring in a short-term interval, lie between 0·2 t_m and 5 t_m. The arithmetic mean $\bar{t}$ 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 MHz, 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 MHz.

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, $\overline{f_s}$, is calculated:

$$\overline{f_s} = 1{\cdot}53\, f_{sm} \tag{9}$$

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:

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

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 $\overline{N/f_s}$ 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 0·04 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, $\overline{f_s}$, 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 II 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.

BIBLIOGRAPHY

1. RICE, S. O. Statistical properties of a sine-wave plus random noise. *B.S.T.J.*, Vol. 27, 109-157 (January, 1948).

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).

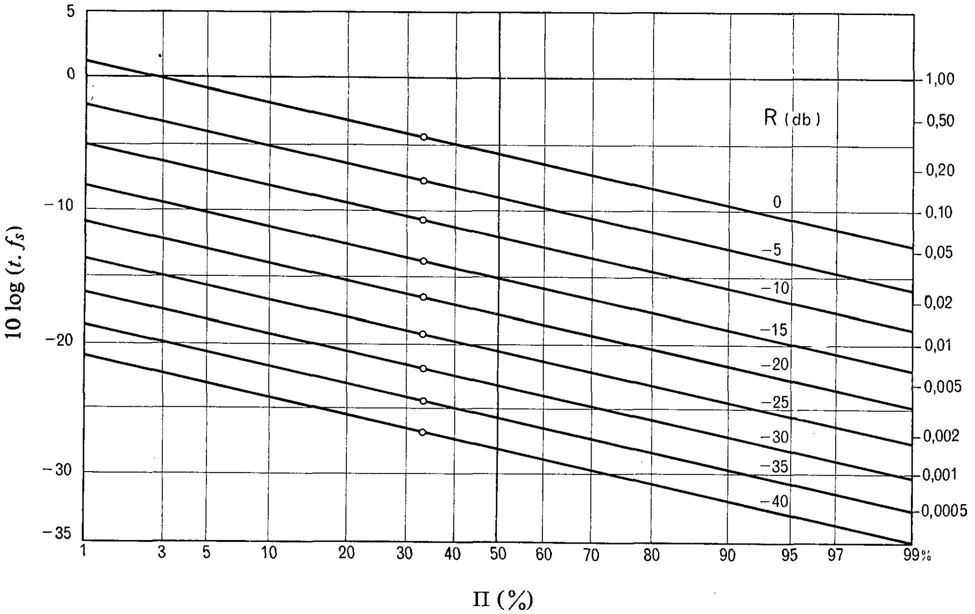


FIGURE 1

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

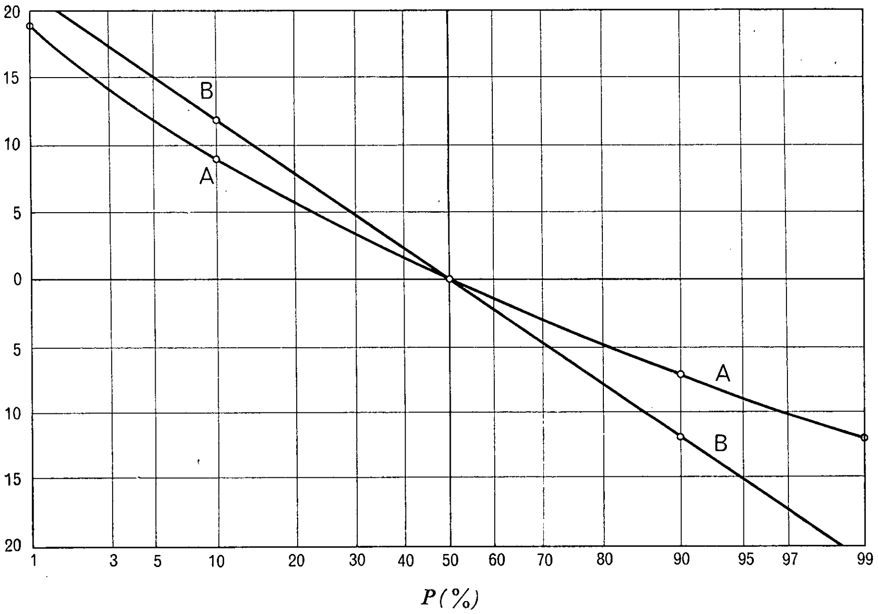


FIGURE 2

Long-term distributions of the scatter field-strength (dB)
(Resulting from long-term recordings on different paths:
up to 450 km long and at frequencies between 100 MHz and 2 GHz)
Curve A: hourly median values
Curve B: instantaneous values

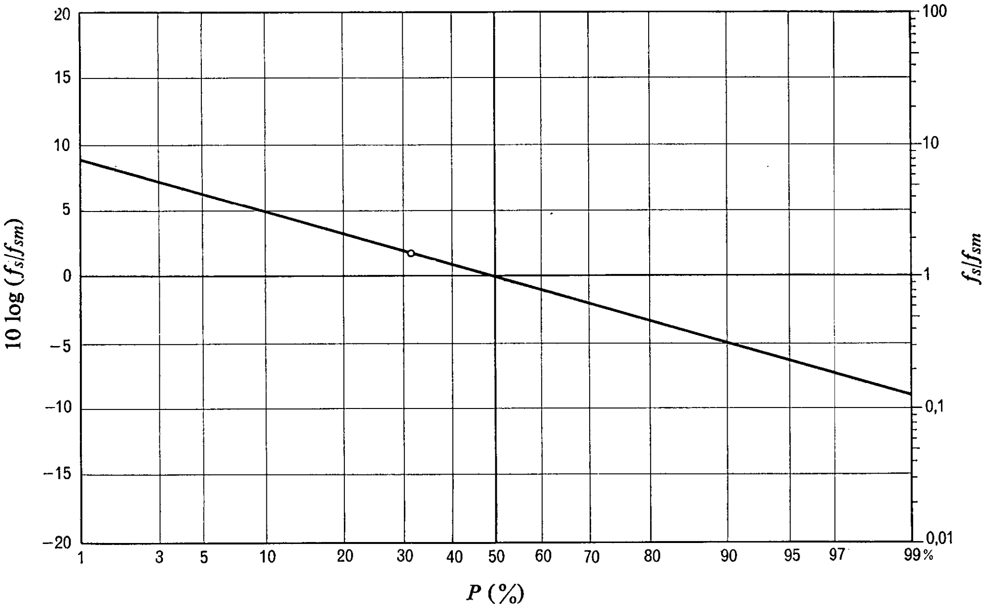


FIGURE 3

Long-term distribution of the mean fading-frequencies
(Wrotham-Krefeld, 100 MHz, 430 km, recorded during a few months of 1956)

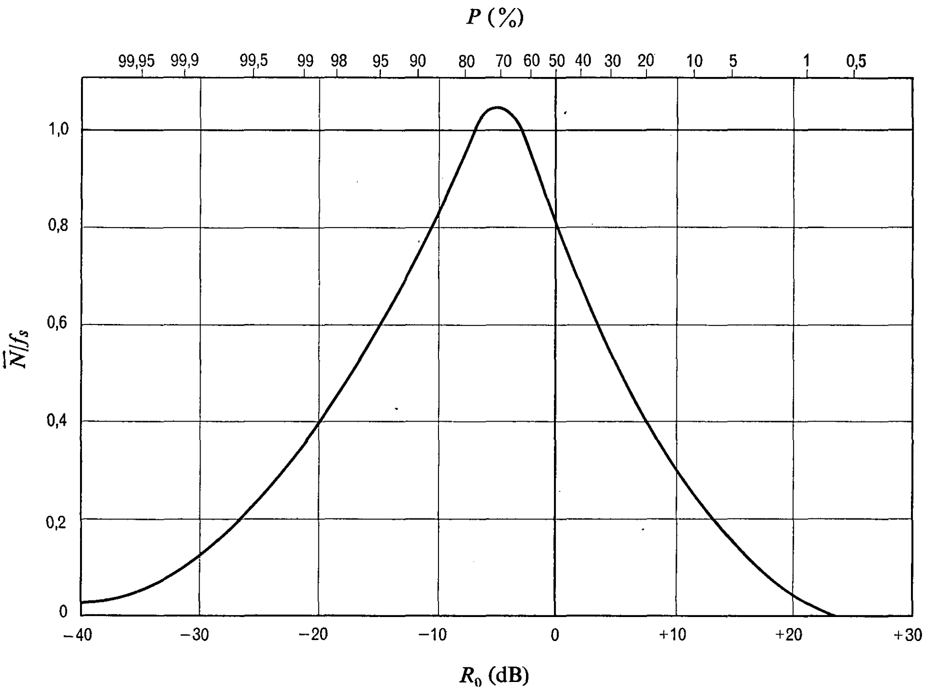


FIGURE 4

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

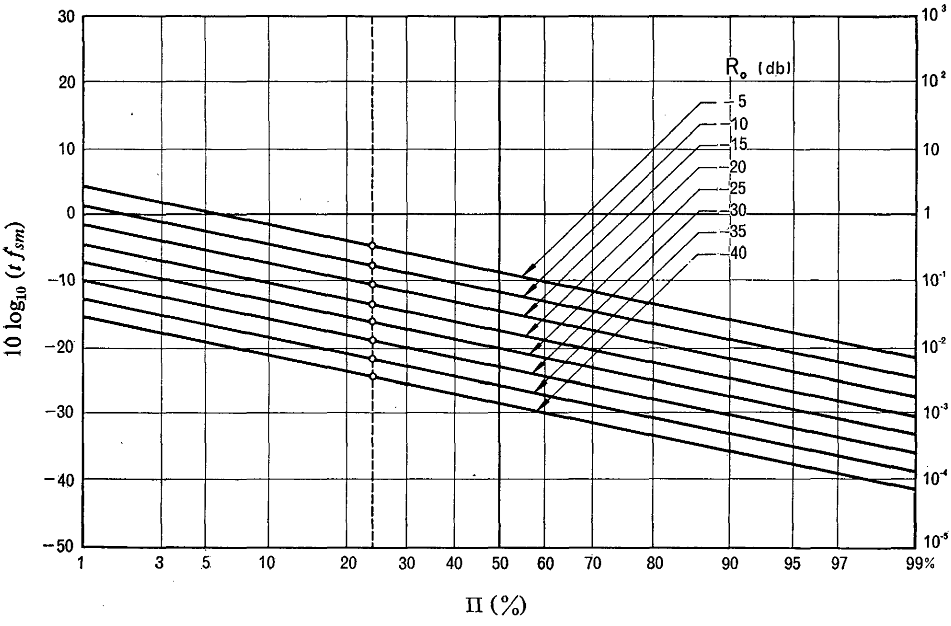


FIGURE 5

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 GHz

(Study Programmes 5A/V and 5B/V)

(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 GHz.

   Fig. 1 gives the transmission loss between isotropic antennae for the frequency 4 GHz, 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 GHz.

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 244–1.

---

* This Report was adopted unanimously.

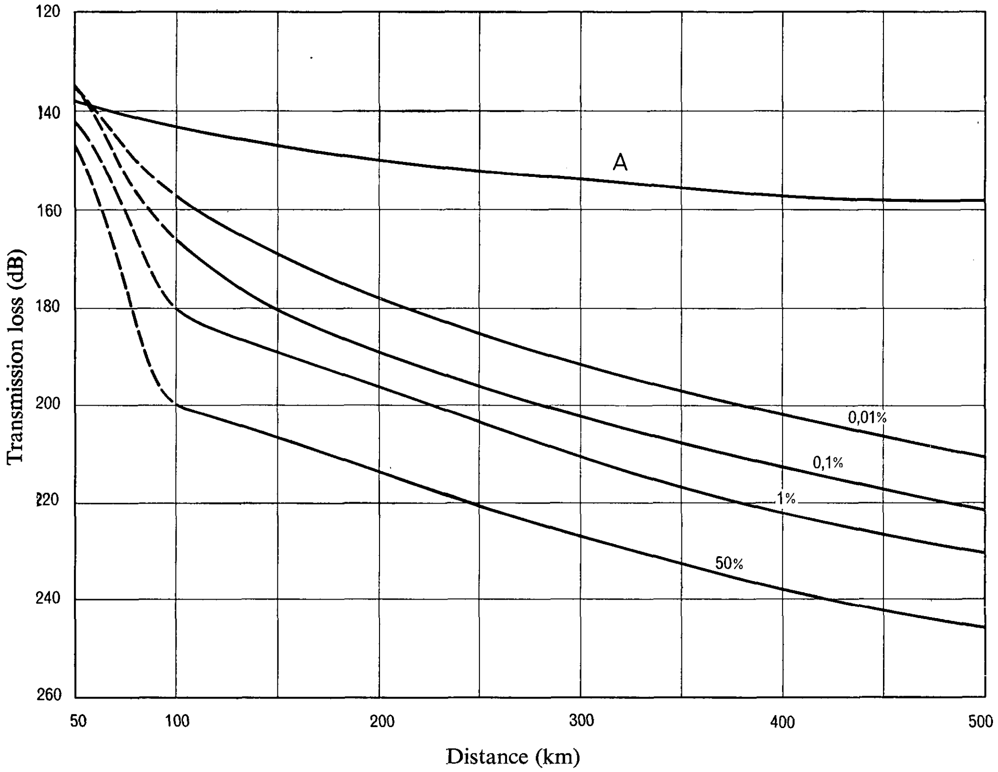


FIGURE 1

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 GHz)

Curve A: free-space propagation

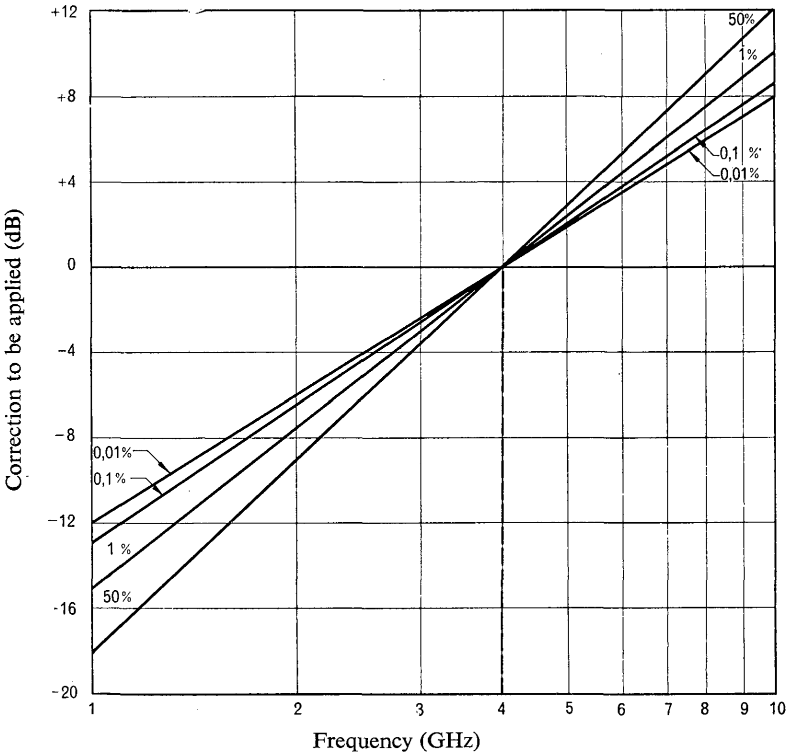


FIGURE 2

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 244-1 *

ESTIMATION OF TROPOSPHERIC-WAVE TRANSMISSION LOSS

(1963 - 1966)

1. Introduction

Study Programmes 5A/V, 5B/V and 5D/V state requirements for radio propagation data and their analysis, for frequencies from 40 MHz to at least 20 GHz, 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. Such data are being furnished in response to a request by the Director, C.C.I.R. in AC/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].

An International Working Group has been established to continue the work of collecting and analysing data in accordance with Resolution 2. This preliminary report summarizes data available at present in the frequency range 40 MHz to 10 GHz, 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.

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:

$$P = P_r - L \qquad (1a)$$

$$L_b = L + G_p \qquad (1b)$$

---

* This Report was adopted unanimously.

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

$$A = L_b - L_{bf}\,(\text{dB}), \tag{2}$$

$$L_{bf} = 32{\cdot}45 + 20 \log f_{MHz} + 20 \log r_{km} \tag{3}$$

Note. — Equations such as (3) may conveniently be expressed in the form of a nomogram (see Fig. 16).

where L_{bf} is the basic transmission loss in free space, and r is the straight-line distance between antennae. In this Report distances are in kilometres and angles are in radians.

For links between earth stations and spacecraft, it is important to know the attenuation relative to free space $A\,(q)$, between the earth station and space station as a function of time availability q, range r_o, frequency f, and the angle of elevation, θ_o; the example, shown in Fig. 1 was drawn for $\theta_o = 0{\cdot}3$ 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:

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

where G_t and G_r are free space transmitting and receiving antenna gains in decibels relative to the gain of an isotropic radiator.

2.2 *Line-of-sight propagation*

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 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. See Report 233-1.

For small grazing angles, ψ, and with antennae h_1 and h_2 (km) above the earth,

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

where h'_1 and h'_2 are the heights of the antennae 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

$$2h_1^2/d_0 - h_1 d_0/(2a) + d_0^3/(32a^2) = \lambda/6 \tag{8}$$

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 $h_1 \leqslant h_2$, $h_1 \leqslant 9a\psi^2/_2$, and that ψ is small. Then

$$\Delta r \approx 2\, h_1 \sin\psi \approx h_1 \sqrt{\theta_h^2 + 4h_1/3a} + \theta_h \tag{9}$$

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

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, $A(\nu)$ may be obtained, either for line-of-sight paths ($\nu<0$), or for trans-horizon paths ($\nu>0$).

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

$$A = G(\chi_0) - F(\chi_1) - F(\chi_2) - 20{\cdot}67 \text{ dB} \tag{10}$$

The functions $G(\chi_0)$ and $F(\chi_{1,2})$ and an auxiliary function $\Delta(\chi_{1,2})$ are plotted in Fig. 5.

$$\chi_0 = dB_0;\ \chi_1 = d_{Lt}B_0;\ \chi_2 = d_{Lr}B_o;\ B_o = 670\,(f/a^2)^{1/3} \tag{11}$$

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

$$\chi_0 - \chi_1\Delta(\chi_1) - \chi_2\,\Delta(\chi_2) > 320 \text{ (km)} \tag{12}$$

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, especially 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 transmission loss due to forward scatter is approximately:

$$L(50) = 30 \log f - 20 \log d + F(\theta d) - G_p - V(d_e) \text{ dB} \tag{13}$$

where $F(\theta d)$ is shown in Fig. 6 as a function of the product θd. The angular distance, θ, is the angle between radio horizon rays in the great circle plane containing the antennae and d is the distance between antennae. [1].

A semi-empirical estimate of G_p is provided by the formula

$$G_p = G_t + G_r - 0{\cdot}07 \exp\,[0{\cdot}055\,(G_t + G_r)] \text{ dB} \tag{14}$$

for values of G_t and G_r each less than 50 dB.

$V(d_e)$, shown in Fig. 7, is an adjustment for the following types of climate:

1. Equatorial (data from Congo and Ivory Coast).
2. Continental sub-tropical (Sudan).

3. Maritime sub-tropical (data from West Coast of Africa).
4. Desert (Sahara).
5. Mediterranean (no curves available).
6. Continental temperate (data from France, Federal Republic of Germany, and U.S.A.).

7a. Maritime temperate, overland (data from U.K.).

7b. Maritime temperate, oversea (data from U.K.).

8. Polar (no curves available).

This division is, of course, rather crude and local geographical conditions may require serious modifications. A brief description of these climates is given in Annex 1.

2.4 *Variability of transmission loss*

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 $P(q)$, the value of P exceeded for $q\%$ of the time, or $L(q)$, the value of L exceeded $(100-q)$ per cent 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 MHz.

Define θ_{sl} as the angular distance where diffraction and forward scatter transmission loss are approximately equal over a smooth earth of effective radius $a = 9000$ km, and define d_{sl} as 9000 θ_{sl}. Then:

$$d_{sl} = 65(100/f)^{1/3} \text{ km}. \qquad (15)$$

The path length, d, is compared with the sum of d_{sl} and the smooth-earth distances to the radio horizons:

$$d_L = 3\sqrt{2h_{te}} + 3\sqrt{2h_{re}} \text{ km}, \qquad (16)$$

where the effective antenna heights h_{te} and h_{re} are now expressed in metres.

It has been observed that the long-term variability of hourly median values (i.e. of transmission loss) is greatest on the average for values of d only slightly greater than the sum of d_{sl} and d_L; The effective distance d_e is arbitrarily defined as:

for $d \leqslant d_L + d_{sl}$, $$d_e = 130\, d/(d_L + d_{sl}) \text{ km} \tag{17a}$$

for $d > d_L + d_{sl}$ $$d_e = 130 + d - (d_L + d_{sl}) \text{ km} \tag{17b}$$

$P(q)$ and the corresponding transmission loss $L(q)$ are referred to long-term median values $P(50)$ and $L(50)$.

Thus:

$$P(q) = P(50) + Y(q) \text{ dBW} \tag{18a}$$

or

$$L(q) = L(50) - Y(q) \text{ dB} \tag{18b}$$

$$Y(q) = Y_0(q)\, g(f) \tag{19}$$

where empirical estimates of the factor $g(f)$ are shown in Fig. 8 and of $Y_0(q)$ in Figs. 9 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:

$$\sigma(q) = \sqrt{13 + 0{\cdot}12\, Y^2(q)} \text{ dB} \tag{20}$$

3. Summary of an alternative method [2]

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* [5]

This method involves the determination separately of the loss not exceeded for a high percentage of the time, for example 99%, of the worst month and of the loss not exceeded for a small percentage of the time, for example 1% of the entire year. The first loss is useful for the design of point-to-point links and the second for interference problems.

Having determined the equivalent distance (here defined as the angular distance, θ, times the effective radius of the earth), by a study of the profile of the path traced for an earth radius of 8500 km, reference is made to Figs. 17*a* and 17*b* prepared for a frequency of 1 GHz for different climates. The loss between isotropic antennae is thus obtained for the climate considered. The climates considered here are the same as those referred to in the Annex.

For any frequency between 200 and 4000 MHz the correction read on Fig. 18 is added to the preceding loss. In this way losses not exceeded for 99% of the worst month and for 1% of the year are obtained for the frequency and climate chosen.

If it is required to know this loss for another percentage of the worst month, the standard deviation is determined from Fig. 19 and a log-normal law is taken to represent the monthly distribution of slow variations. This method can also be used for determining transmission losses for small percentages of the entire year, other than 1%, but the accuracy obtained is poorer.

4. Further methods

A further method for the calculation of the statistical distribution of signal levels over line-of-sight paths is described in reference [3]. This method takes into account signal variations caused by variations in the vertical gradient of the refractive index and by reflections from layers in the troposphere: the effect of ground profile is also considered. Corresponding calculations for beyond-the-horizon paths are empirically based on experimental data [4]. Another method for beyond-the-horizon paths, which has been found useful in the United Kingdom is described in [6].

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 GHz;
- 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.

BIBLIOGRAPHY

1. National Bureau of Standards Technical Note 101, Revised (May 1, 1966).
2. Technical Note No. PR 3104, Centre National d'Etudes des télécommunications (1962).
3. KALININ, A. I. Calculation of radio-relay links, SVIAZ, (1964).
4. KALININ, A. I. Over-the-horizon propagation at VHF. Sovietskoye Radio (1965).
5. BOITHIAS, L. and BATTESTI, J. Les faisceaux hertziens transhorizon de haute qualité (High-quality radio-relay systems) *Annales des télécommunications*. (July-August, 1965).
6. C.C.I.R. Doc. V/87 (United Kingdom), 1963-1966.

ANNEX

The climates considered in this Report are described below.

1. **Equatorial**: corresponds to the region between latitudes 10°N and 10°S. The climate is characterized by a slightly varying high temperature and by monotonous heavy rains which sustain a permanent humidity. The annual mean value of N_s (refractivity at the surface of the earth = $(n-1)\ 10^6$ where n is the refractive index of the air) is about 360 N-units and the annual range of variation is 0 to 30 N-units.

2. **Continental sub-tropical**: corresponds to the regions between latitudes 10° and 20°. The climate is characterized by a dry winter and rainy summer. These are marked daily and annual variations of radio propagation conditions, with least attenuation in the rainy season. Where the land area is dry radio ducts may be present for a considerable part of the year. The annual mean value of N_s is about 320 N-units and the range of variation, throughout the year, of monthly mean values of N_s is 60 to 100 N-units.

3. **Maritime sub-tropical**: also corresponds to the regions between latitudes 10° and 20° and is usually found on lowlands near to the sea. It is strongly influenced by the monsoon. The summer monsoon, which blows from sea to land, brings high humidity into the lower layers of the atmosphere. Although the attenuation of radio waves is relatively low at both the beginning and end of the monsoon season, during the middle of the monsoon the atmosphere is uniformly humid to great heights and the radio attenuation increases considerably despite a very high value of N_s. There is an annual mean N_s of about 370 N-units with a range of variation over the year of 30 to 60 N-units.

4. **Desert**: corresponds to two land areas which are roughly situated between latitudes 20° and 30°. Throughout the year there are semi-arid conditions and extreme diurnal and seasonal variations of temperature. This climate is very unfavourable for forward-scatter propagation, particularly in summer. There is an annual mean value of N_s of about 280 N-units and throughout the year monthly mean values may vary over a range of 20 to 80 N-units.

5. **Mediterranean**: corresponds to regions in both hemispheres on the fringe of desert zones, close to the sea, and lying between latitudes of 30° and 40°. The climate is characterized by a fairly high temperature, which is reduced by the presence of the sea, and an almost complete absence of rain in the summer. Radio-wave propagation conditions vary considerably, particularly over the sea where radio ducts exist for a large percentage of the time in summer. Although considerable propagation data exist for this climatic region, no summarizing curves have been included in this Report.

6. **Continental temperate**: corresponds to regions between latitudes 30° and 60°. Such a climate in a large land mass shows extremes of temperature and pronounced diurnal and seasonal changes in propagation conditions may be expected to occur. The western parts of continents are influenced strongly by oceans, so that temperatures here vary more moderately and rain may fall at anytime during the year. In areas progressively towards the east, temperature variations increase and winter rain decreases. Propagation conditions are most favourable in the summer and there is a fairly high annual variation in these conditions. The annual mean value of N_s is about 320 N-units and monthly mean values may vary by 20 to 40 N-units throughout the year.

7a. **Maritime temperate, overland**: also corresponds to regions between latitudes of about 30° to 60° where prevailing winds, unobstructed by mountains, carry moist maritime air inland. Typical of such regions are the United Kingdom, the West coast of North America and of Europe and the northwestern coastal areas of Africa. There is an annual mean value of N_s of about 320 N-units, with a rather small variation of monthly mean values over the year of 20 to 30 N-units. Although the islands of Japan lie within this range of latitudes, the climate is somewhat different and shows a greater annual range of monthly mean values of N_s, about 60 N-units. The prevailing winds in Japan have traversed a large land mass and the terrain is rugged. Climate 6 is therefore probably more appropriate to Japan than climate 7, but duct propagation may be important in coastal and adjacent oversea areas for as much as 5% of the time.

7b. **Maritime temperate, oversea**: corresponds to coastal and oversea areas in regions similar to those for climate 7*a*. The distinction made is that a radio propagation path having both horizons on the sea is considered to be an oversea path (even though the teminals may be inland); otherwise climate 7*a* is considered to apply. Radio ducts are quite common in occurrence for a small fraction of the time between the United Kingdom and the European continent and along the west coasts of the United States of America and Mexico.

8. **Polar**: corresponds approximately to the regions between latitudes 60° and the poles. This climate is characterized by relatively low temperatures and relatively little precipitation. No radio-wave propagation curves are at present available for inclusion in this Report.

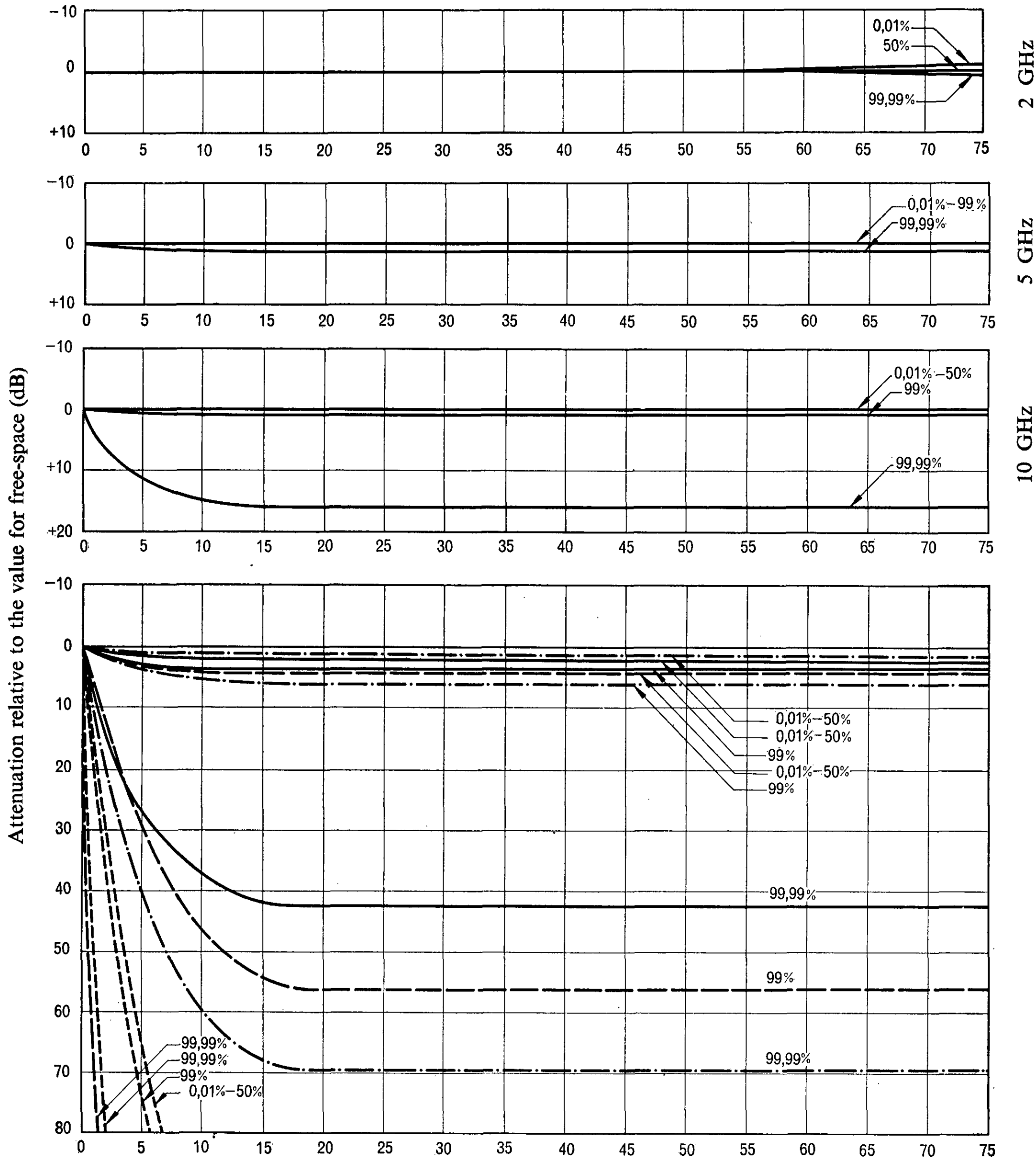
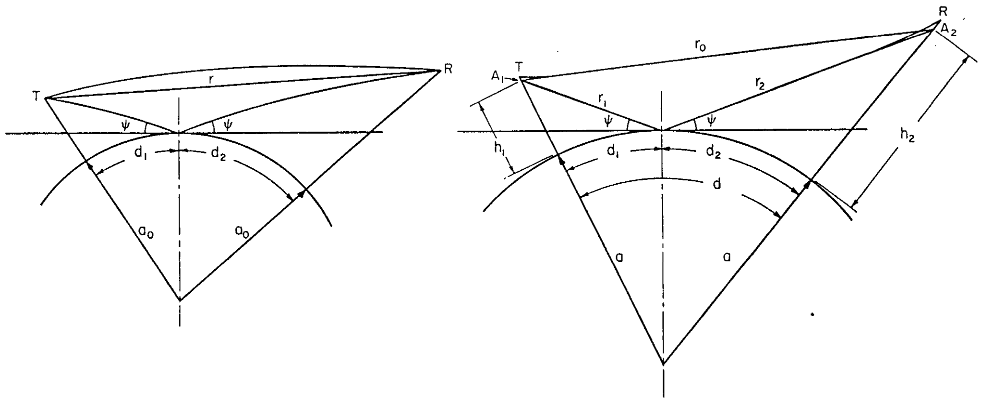


FIGURE 1

Standard propagation curves for links between earth-stations and spacecraft

(θ_0 = 0·3 rad., no allowance has been made for ground reflection)

——————— 2·2 GHz
—·—·—·— 32·5 GHz
- - - - - - - - - - - 6·0 GHz
— — — — — — 10·0 GHz



(a) (b)

FIGURE 2

Geometrical relationships for within-the-horizon paths

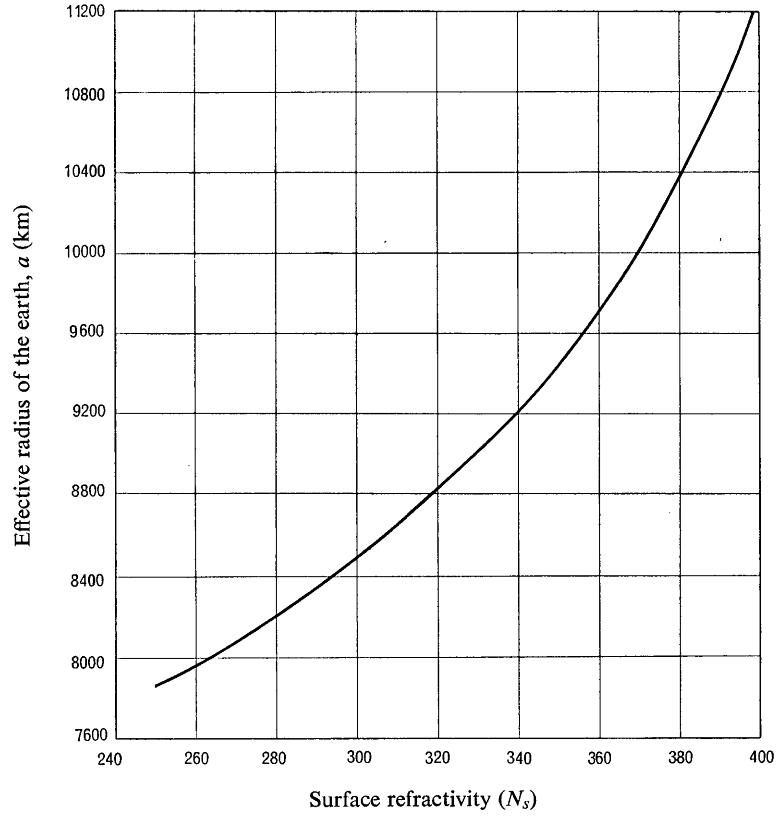


FIGURE 3

Variation of the radius of the earth, a, as a function of the surface refractivity, N_s

$$v = \sqrt{(2d/\lambda) . \tan \alpha_0 \tan \beta_0}$$

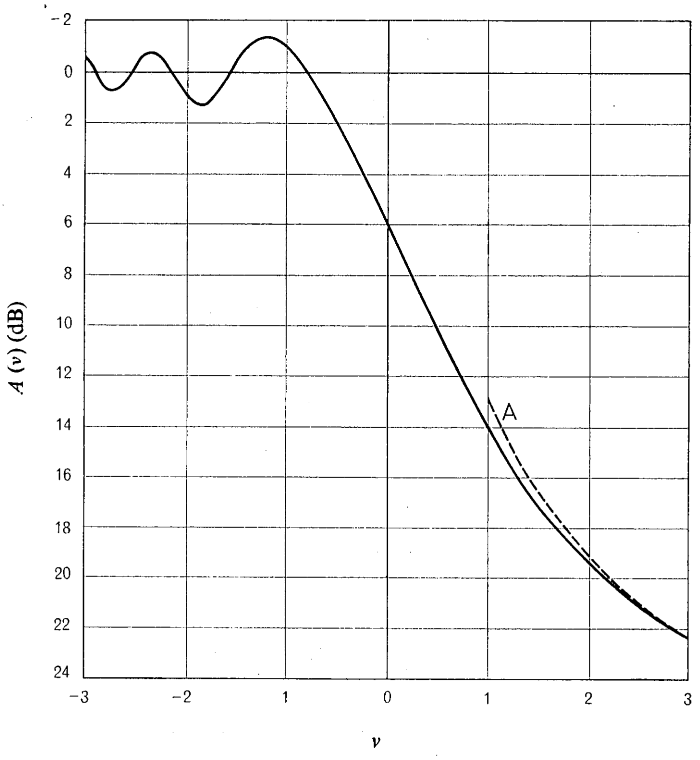


Figure 4

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

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

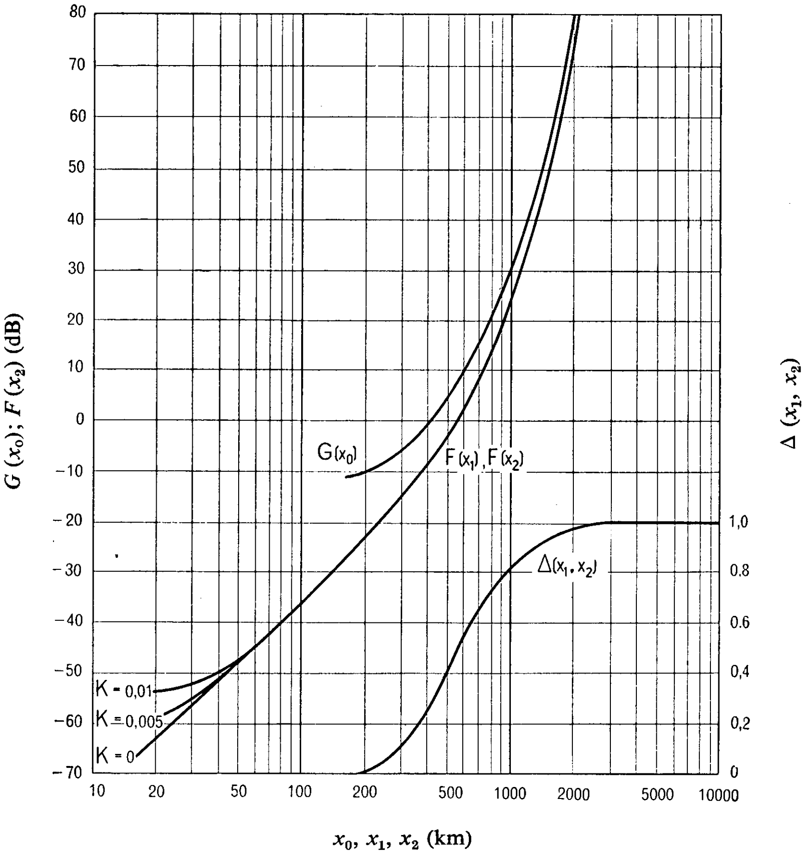


FIGURE 5

Note: For large values of x:

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

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

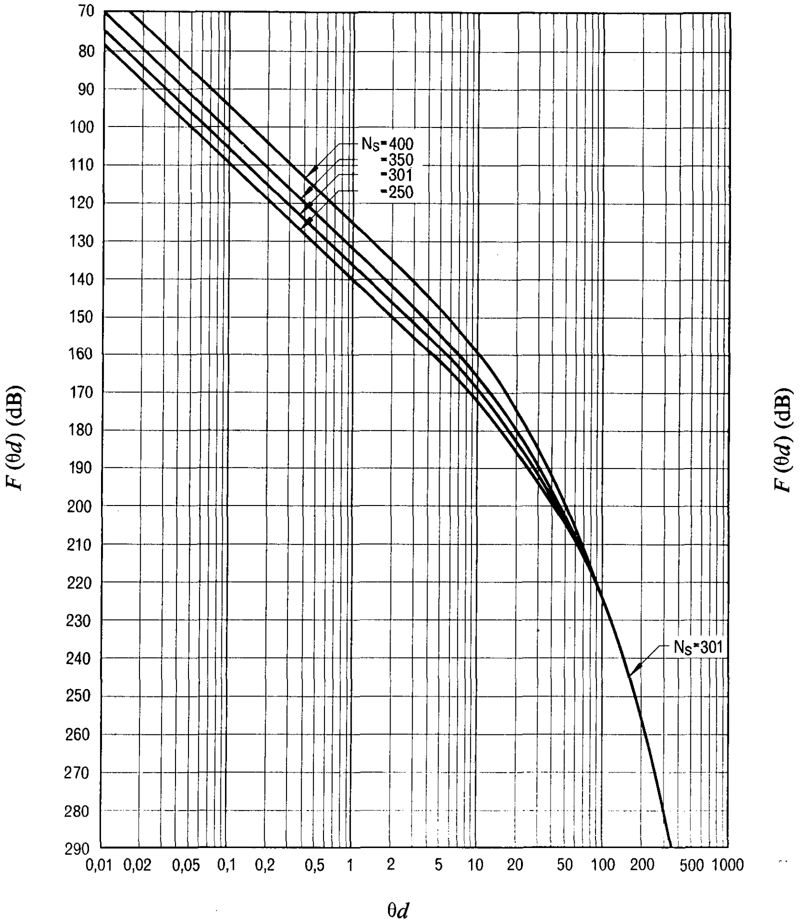


FIGURE 6

The attenuation function, F (θd), where d is in km and θ is in radians

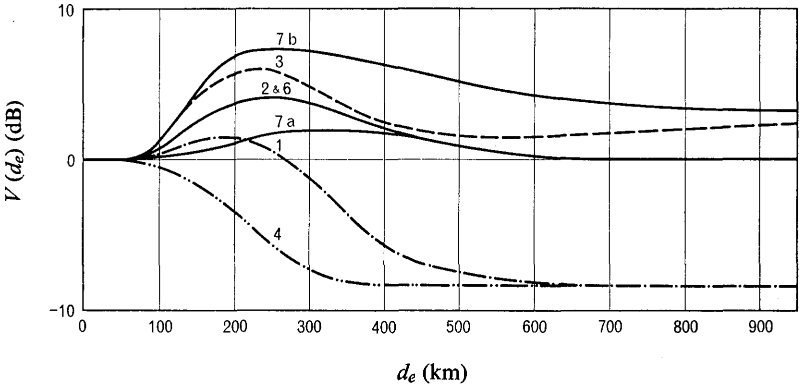
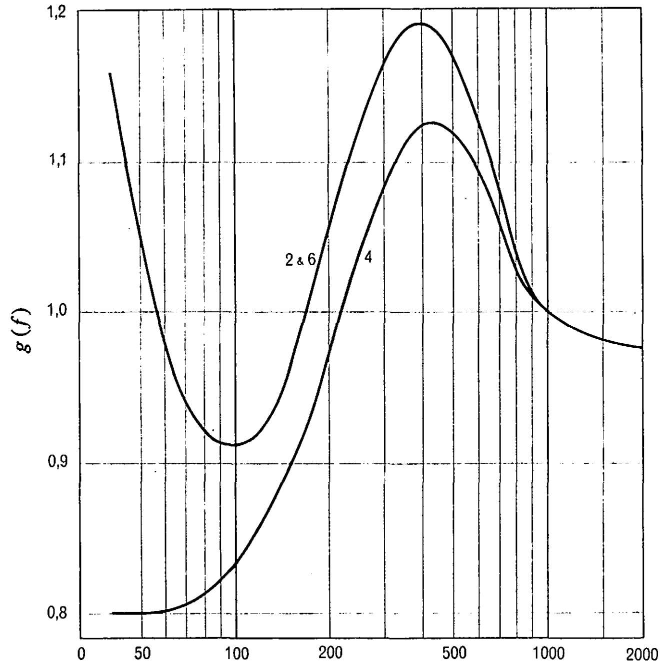


FIGURE 7

The function $V(d_e)$ for the types of climate indicated on the curves (see § 2.3)



Frequency (MHz)

FIGURE 8

The function g(f) for the types of climate indicated on the curves (see § 2.3)

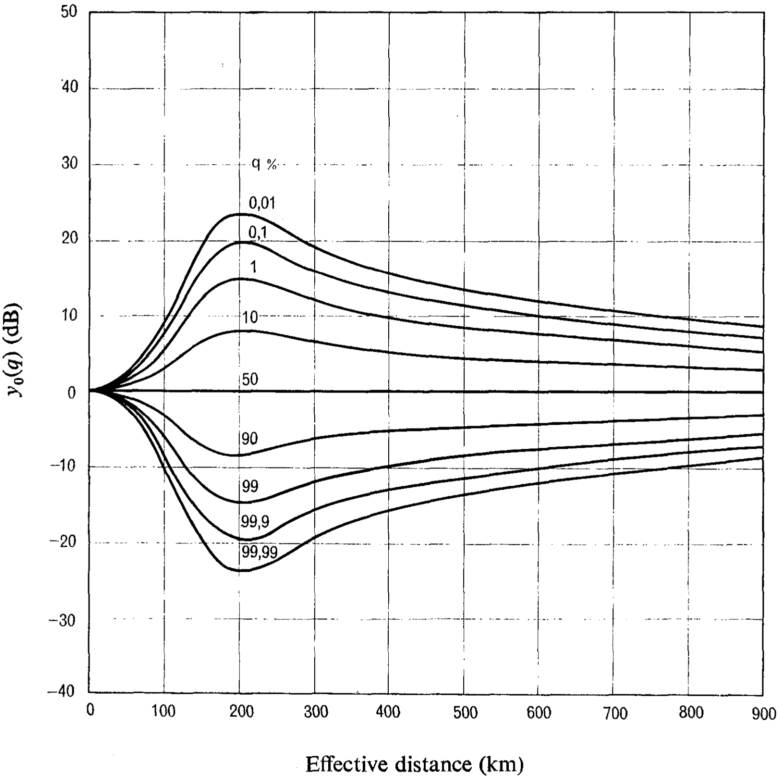


FIGURE 9

Variation of transmission loss with effective distance for an equatorial climate (Type 1)

(The values of q are indicated on the curves)

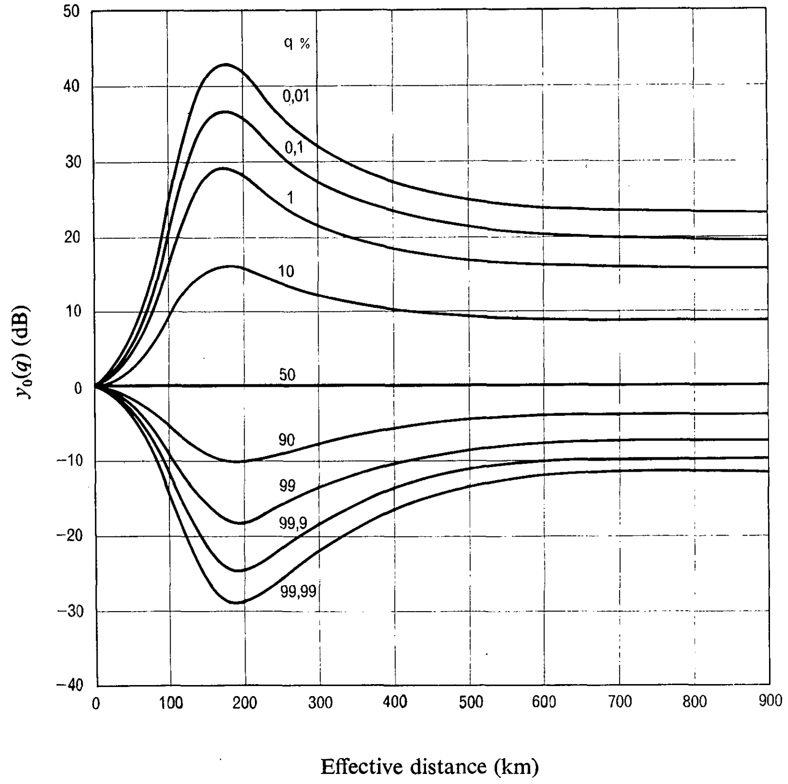


FIGURE 10

Variation of transmission loss with effective distance for a continental sub-tropical climate, Sudan (Type 2)

(The values of q are indicated on the curves)

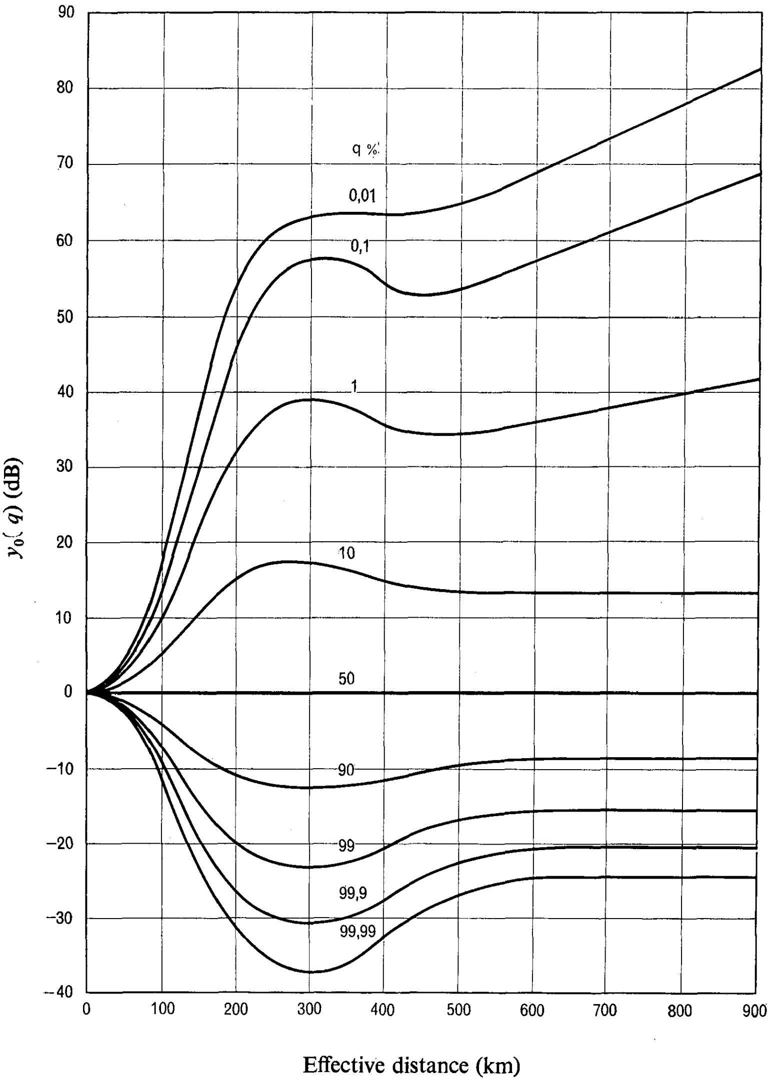


FIGURE 11

Variation of transmission loss with effective distance in a maritime sub-tropical climate (Type 3)

(The values of q are indicated on the curves)

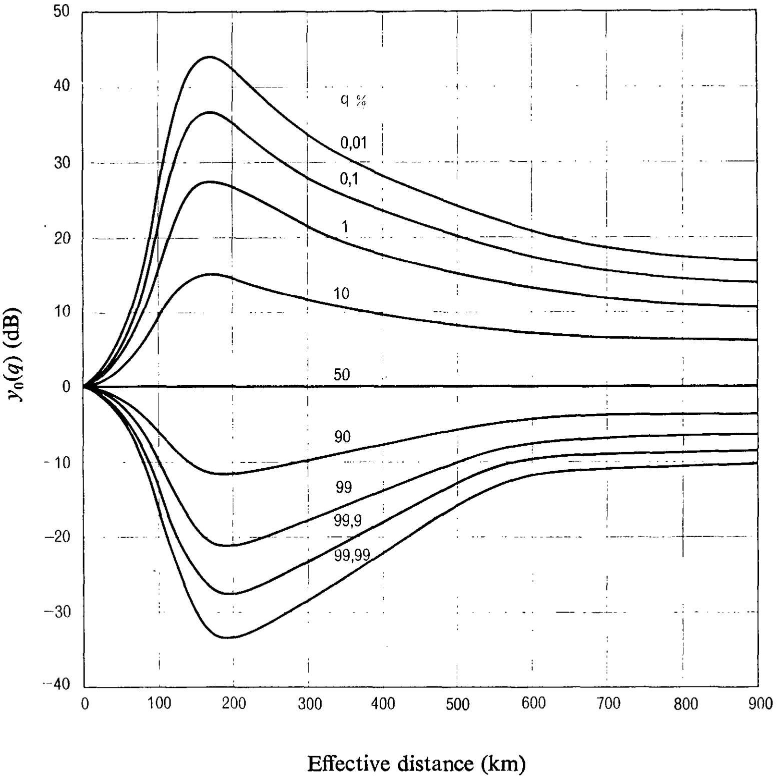


FIGURE 12

Variation of transmission loss with effective distance for a desert climate, Sahara (Type 4)

(The values of q are indicated on the curves)

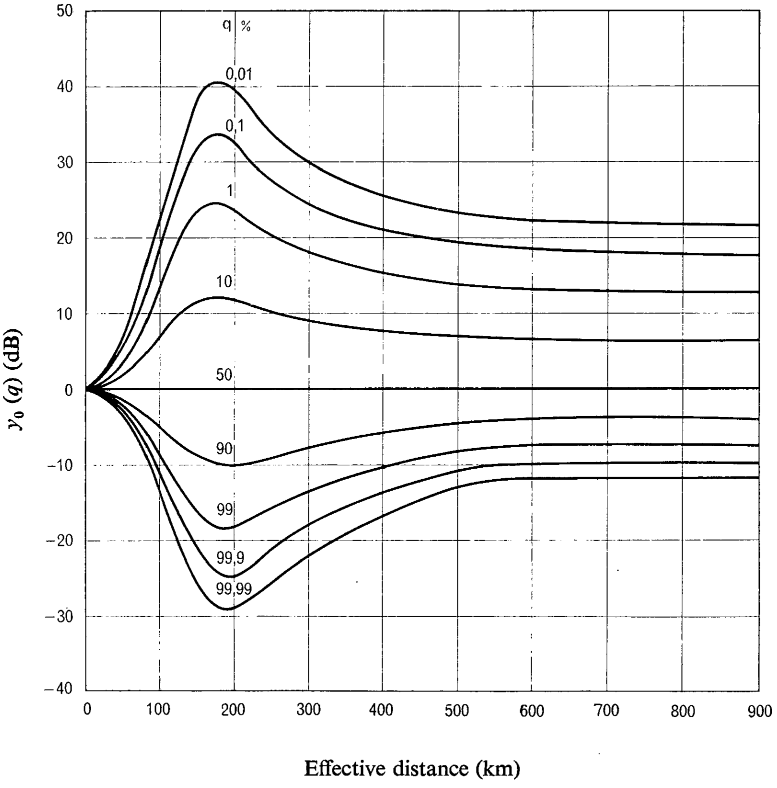


FIGURE 13

Variation of transmission loss with effective distance for a continental temperate climate (Type 6)

(The values of q are indicated on the curves)

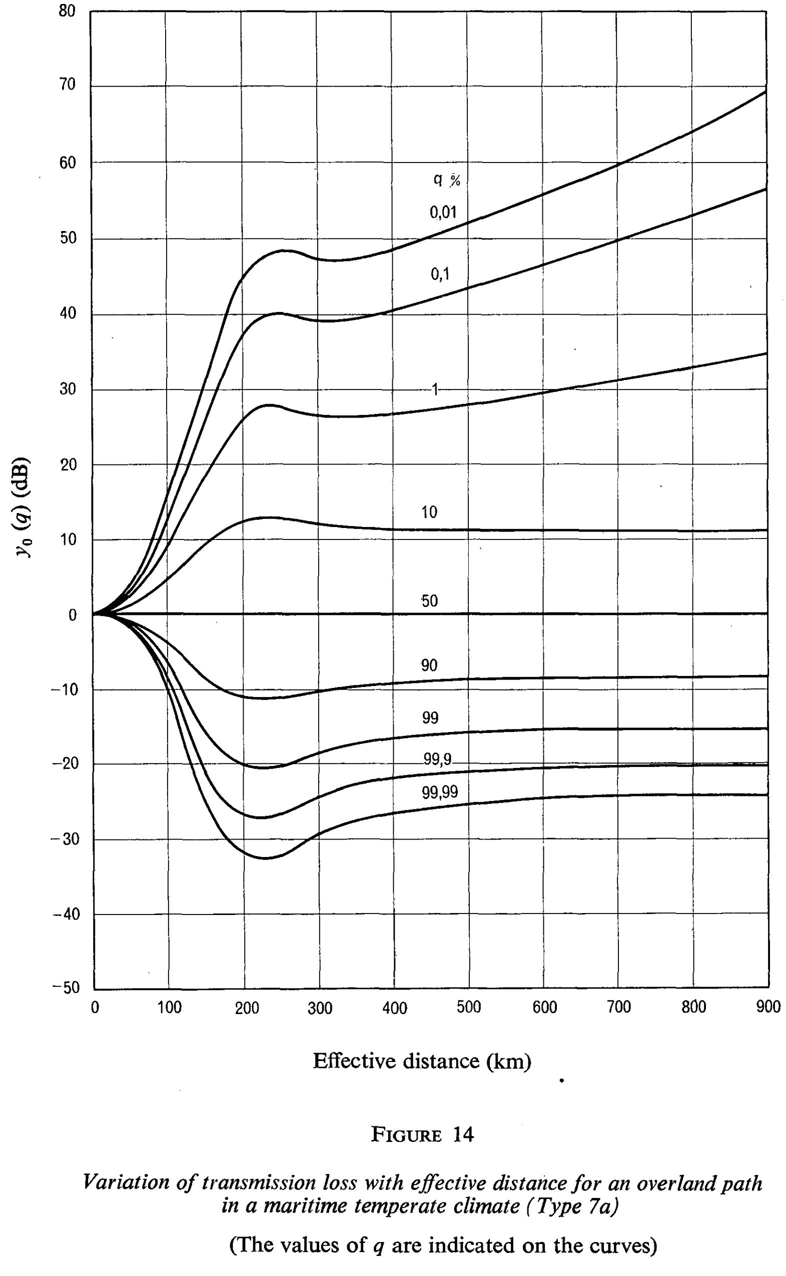


FIGURE 14

Variation of transmission loss with effective distance for an overland path in a maritime temperate climate (Type 7a)

(The values of q are indicated on the curves)

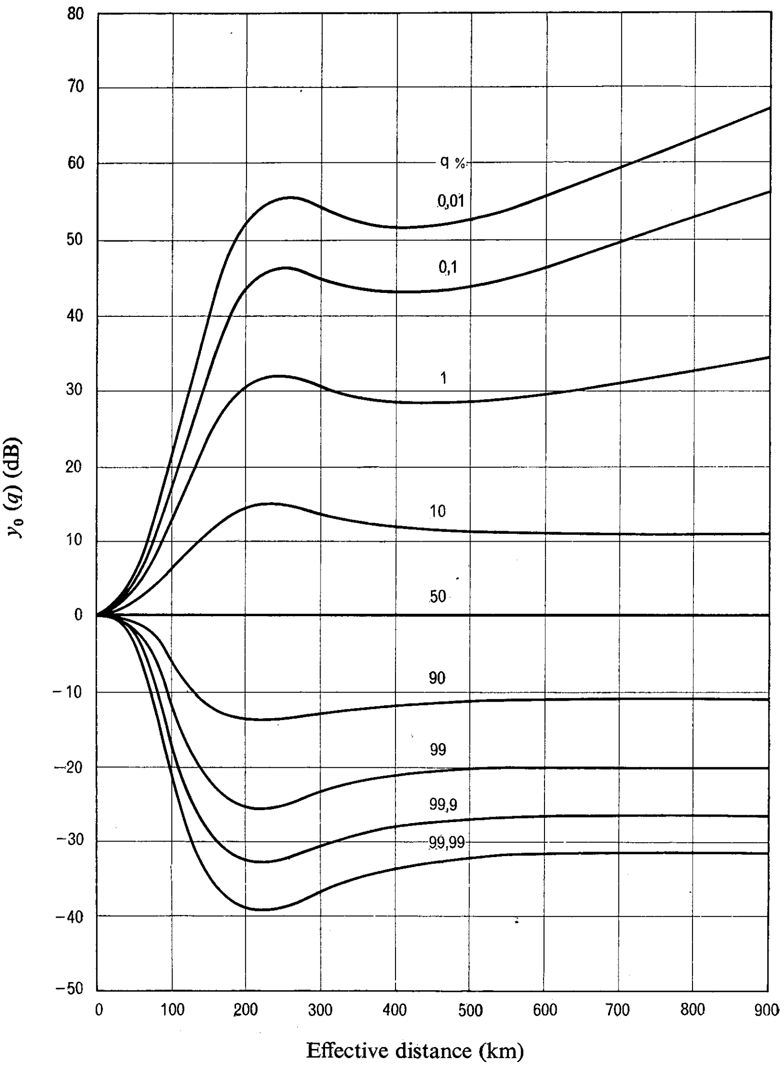


FIGURE 15

Variation of transmission loss with effective distance for an oversea path in a maritime temperate climate (Type 7b)

(The values of *q* are indicated on the curves)

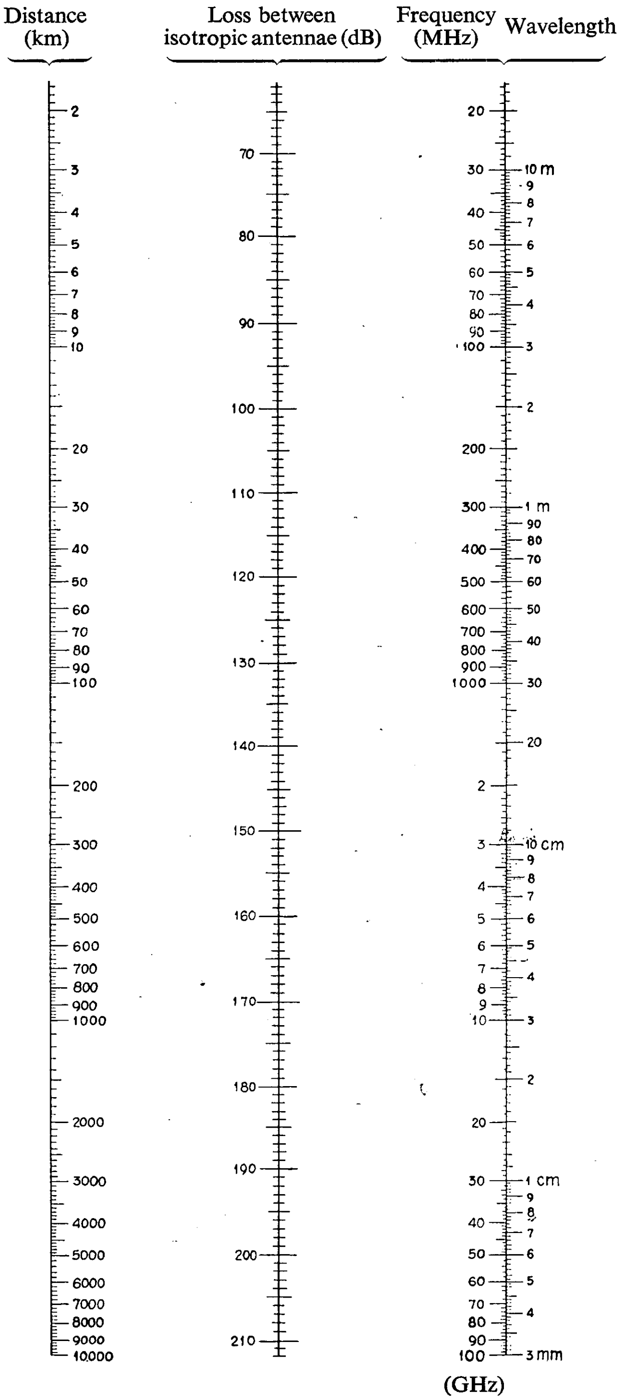


FIGURE 16

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

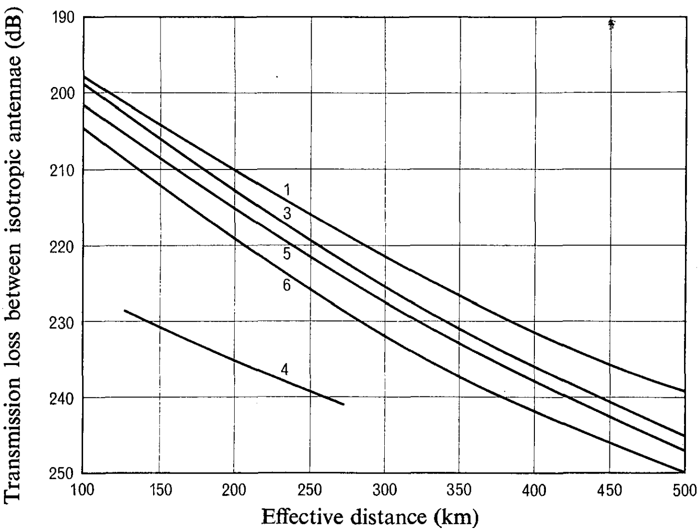


FIGURE 17*a*

Transmission loss not exceeded for 99% of the worst month for the types of climate indicated on the curves (see § 2.3)

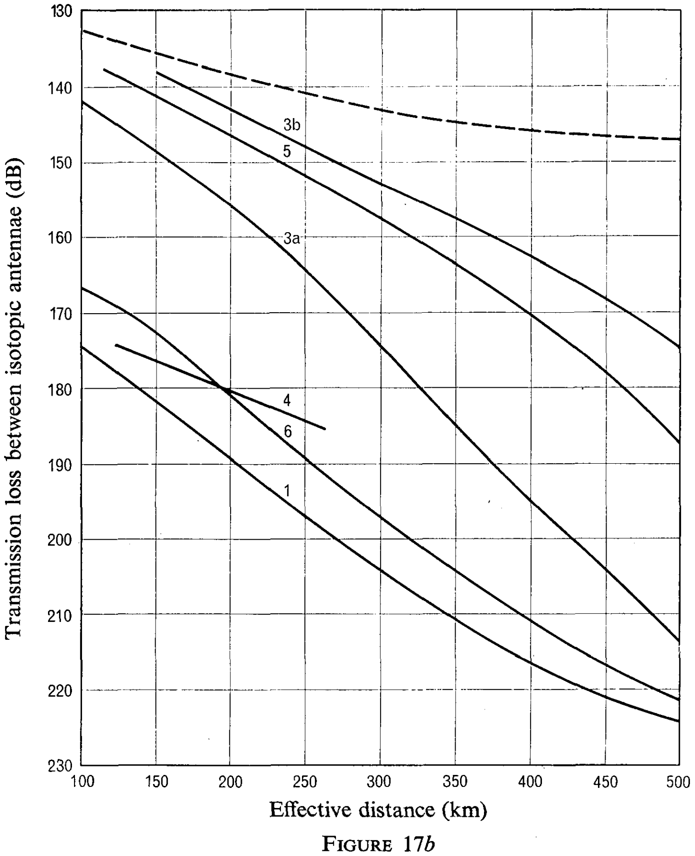


FIGURE 17*b*

Transmission loss not exceeded for 1% of the entire year for the types of climate indicated on the curves (see § 2.3)

Curves 1, 4 and 6: Land paths
Curves 3*a*, 3*b* and 5: Sea paths
— — — — — —: Free space

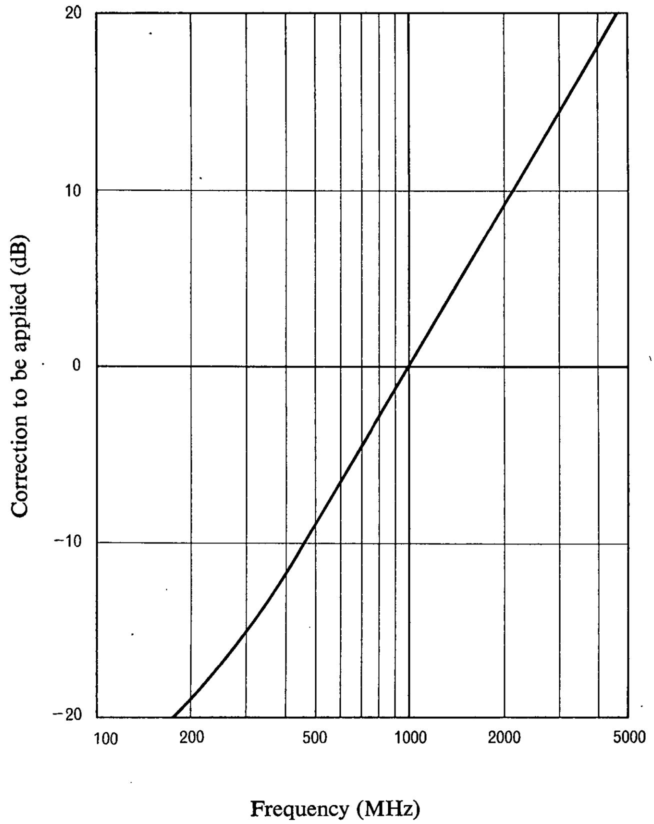
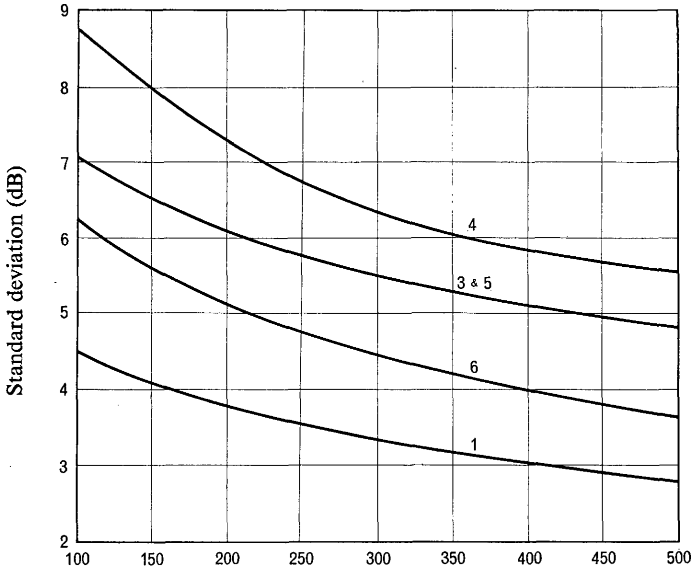


FIGURE 18

Correction (dB) to be applied to the values obtained from the curves of Fig. 17, for frequencies other than 1 GHz



Effective distance (km)

FIGURE 19

Standard deviation for the types of climate indicated on the curves (see § 2.3)

REPORT 336 *

FREQUENCY UTILIZATION ABOVE THE IONOSPHERE AND ON THE FAR SIDE OF THE MOON

(1966)

In Question 15/IV, § 2, which has been referred to Study Group V for consideration, the problem is raised of the geometrical shielding of the Moon as a function of frequency, angular distance from the limb of the Moon toward the centre of the far side, and distance above the surface of the Moon.

In the existing documents of Study Group V, reference is made to diffraction round large obstacles, but only in relation to propagation over the earth. The main point of § 2 in this Question is presumably the geometrical shielding factor due to diffraction round the Moon, regarded as a large spherical object.

Fortunately, as the radius of the Moon is very large compared with the longest wavelength that is likely to be implied in the Question, the classical theory of radio-wave propagation round a spherical earth is available for the solution of this problem, since it is expressible mathematically in terms of a radius a without any restriction on its value other than the condition that $2\pi a/\lambda \gg 1$, where λ is the wavelength, in the same units as a. (For the Moon, the condition that $2 \pi a/\lambda = 10$ corresponds approximately to a frequency of 300 Hz.)

This concept has been developed with reference to diffraction round spherical or cylindrical hills [1], where various quantities are given graphically as functions of a certain parameter which is itself a function of the frequency, the radius, and the electrical constants under consideration. These quantities are related to such factors as the attenuation in decibels per radian of angular distance round the sphere in the diffraction region and the parameters in terms of which the height-gain function is expressed.

Within the horizon, the geometric-optical treatment with reference to reflection at a convex surface may be used within its limitations, and for small distances, where the effect of surface roughness may be dominant, the methods of dealing with propagation over irregular terrain are already available as described in Report 236-1.

For heights or distances from the Moon comparable with, or large compared with, the radius of the Moon, but for which the terminals are so placed that there is not a line-of-sight propagation path, approximate methods exist for treating the problem as a combination of free-space inverse-distance attenuation along the tangents from the terminals to the sphere and the diffraction loss, over the angular distance of that portion of the sphere, that prohibits a line-of-sight path.

It thus appears that all the essential information needed for the solution of this problem is available in a form that is readily adaptable to the parameters considered to apply to the curved surface of the Moon. Some work has in fact already been done along these lines for certain assumed electrical constants of the Moon [2] (see also Report 244, Geneva, 1963).

BIBLIOGRAPHY

1. MILLINGTON, G. A note on diffraction round a sphere or cylinder. *Marconi Review*. Vol. 23 **139**, 170 (1960).
2. VOGLER, L. E. A study of lunar-surface radiocommunications. NBS Monograph No. 85 (1965).

---

* This Report was adopted unanimously.

REPORT 337 *

PROPAGATION FACTORS AFFECTING THE CALCULATION OF COORDINATION DISTANCE

(1966)

This Report is an interim reply to Question 14/IV relating to the calculation of coordination distance. Because of the short notice given for studying this Question and owing to the lack of data at present available, this Report must be regarded as provisional. Nevertheless, it is hoped that further studies will be possible within the next few months, which will lead to an improved Report being prepared at the time of the XIIth Plenary Assembly.

The following propagation factors may have to be taken into account in the calculation of coordination distance:

— the effects of terrain,
— the effects of vegetation and buildings,
— the effects of tropospheric inhomogeneities,
— scatter from precipitation,
— scatter from aircraft.

Report 244–1 contains information which can be used to estimate the effects of terrain and tropospheric inhomogeneities, but does not deal with the effects of vegetation, buildings, scatter from precipitation or from aircraft.

Report 339 discusses the basic factors involved in the calculation of the strength of signals scattered from rain and can be regarded as an interim reply to Question 14/IV.

The Annex gives a method for deriving site shielding factors and is in reply to Question 14/IV.

ANNEX

SITE-SHIELDING FACTOR

1. Introduction

Study Group V has studied the questions raised in Question 14/IV concerning the site shielding factor to be used in calculating coordination distance, and is of the opinion that the values of this factor proposed at the Extraordinary Administrative Radio Conference, Geneva, 1963, are in general rather conservative. Moreover, Study Group V feels that it is not possible to give one table of site-shielding factors, independent of path length, and suggests that the following method should be used to calculate site-shielding factors.

The approach of the Extraordinary Administrative Radio Conference, Geneva, 1963, is to assume that only the elevation and distance of the radio horizon around the earth-station is known. Under these conditions, the most conservative assumption that can be made concerning the terrain profile is that the radio horizon comprises a knife-edge, beyond which the terrain is smooth and at sea-level (see Fig. 1).

2. Diffraction losses

The difference between the path loss over this assumed terrain profile, and the path loss for the same distance over a smooth earth, is the site-shielding factor. In general, this

---

* This Report, which was adopted unanimously, should immediately be brought to the attention of Study Groups IV and IX, and the International Working Parties established under Resolutions 2 and 3.

will be positive, i.e. the obstacle will introduce additional attenuation. However, it will be seen from Fig. 1 that the angular distance between the obstacle and the assumed position of a radio-relay station is reduced, and it is possible that the consequent reduction in scatter loss may offset the increased loss due to diffraction over the knife-edge. In an extreme case, the knife-edge may be visible from both the earth-station and the radio-relay station, and the path loss might well be less than that over smooth earth and the site-shielding factor would be negative. This is the phenomenon known as " obstacle gain ".

The diffraction loss at the ridge may be calculated on the basis of the formula given in Report 244-1 and is only slightly dependent on the distance of the radio-relay station from the ridge, as long as this distance is at least twice the distance of the earth-station from the ridge. It may be assumed that the diffraction loss does not vary with time, since the effects of refraction in altering the angle of diffraction are negligibly small. However, natural mountain ridges depart considerably from perfect knife-edges and some allowance may be made for this fact. Methods are available for calculating the loss over rounded knife-edges, but their application is rather complex, and it is here proposed that an increase of 5 dB in the diffraction loss be made to allow for the imperfection of natural knife-edges [1].

The path loss, exceeded for 99·9% of the time, between the obstacle and the radio-relay station can be calculated by the method given in Report 244–1.

3. Additional losses due to tropospheric scatter

An alternative method for determining the additional loss due to the obstacle would be to assume that the only effect of the obstacle would be to increase the angular distance between the earth-station and the radio-relay station. This would be the case if the terrain beyond the obstacle were such as to preclude any reduction in the angular distance between the obstacle and the radio-relay station.

In this case, the increased loss can be determined by calculating the path loss by the method of Report 244–1, with the angular distance increased by the elevation angle of the obstacle as seen from the earth-station.

4. Method of calculation

As an example of the calculation of the site-screening factor by the methods outlined in §§ 2 and 3, consider the case of an obstacle 16 km the earth-station with an angle of elevation of 1° to 5°

4.1 *Diffraction formula*

The formula for diffraction loss relative to free-space, given in Fig. 4 of Report 244–1, can be written as:

$D = 20 \log_{10} \left[\sqrt{2}\, \pi \sqrt{\frac{2\,(d_A + d_B) \tan\alpha_0 \tan\beta_0}{\lambda}} \right]$ decibels where the symbols are defined in Fig. 1. When α_0 and β_0 are less than 10° and d_B is greater than $2\, d_A$ then the above formula can be approximated within 2 dB, by:

$$D = 20 \log_{10} \left[2\, \pi\, \theta \sqrt{\frac{d_A}{\lambda}} \right] \text{ decibels.}$$

The distance d_A is very nearly equal to *ES* the distance from *E* to the screen and the diffraction angle θ can be obtained from the formulae for curved earth geometry for given values of θ_s, the angle of elevation of the top of the screen above the horizontal place through *E*. The variation of this diffraction loss *D* with θ_s at 4 GHz and for *ES* equal to 16 km is shown in the following Table:

TABLE I

Diffraction loss, D, at 4 GHz

θ_S (degrees)	1	2	3	4	5
θ (degrees)	1·6	2·8	4·0	5·1	6·2
Diffraction loss (dB)	38	43	46	48	50

When the antenna of the radio-relay station *R* is within optical distance of the top of the screen, the diffraction angle θ may differ from the value corresponding to the point *H*, but this alters the diffraction loss by less than 2 dB as long as *R* is more than 30 km from the screen.

4.2 *Calculation of scatter path losses*

Fig. 2 gives a curve for the loss $L_{0\cdot1}$ between the earth-station and the radio-relay station in the absence of the obstacle. This curve was derived from Report 244–1, assuming antenna heights of 15 m and 50 m for the earth-station and radio-relay station respectively, and using the data appropriate to a continental temperate climate.

Other curves in Fig. 2 give the loss $l_{0\cdot1}$ between the obstacle and the radio-relay station, for those obstacles at heights corresponding to angles of elevation between 1° to 5°.

4.3 *Calculated site-shielding factors*

The site-shielding factor, due to the effect of diffraction over a knife-edge obstacle, can now be determined as $D + l_{0\cdot1} - L_{0\cdot1}$ decibels. This is plotted in Fig. 3 against total length of path, as the full-line curves. It will be observed that the curves show that the value of the site-shielding factor decreases to a minimum at a distance dependent on the angle of elevation and thereafter increases.

The dashed curves in Fig. 3 show the site-shielding factors determined by the method described in § 3. It will be seen that the site-shielding factors at first increase with distance and eventually reach a constant value.

Clearly, in the absence of any knowledge of the terrain profile beyond the obstacle, it is necessary to derive the site-shielding factor from the curves giving the lower value, after making the allowance of 5 dB for an imperfect knife-edge. It will be seen that it is not

TABLE II

Site-shielding factor (dB)
Continental temperate climate

Angle of elevation (degrees)	Distance (km)					
	100	150	200	300	400	500
1	20	15	11	8	8	8
2	(1)	21	18	17	17	17
3	(1)	(1)	23	23	23	23
4	(1)	(1)	(1)	28	28	28
5	(1)	(1)	(1)	33	33	33

(1) In these cases it is considered unwise to state a value of site-shielding factor, since it is likely to be very dependent on the actual shape of the obstacle.

possible to specify values of site-shielding factors that are independent of distance. However, it is possible to draw up the following Table giving site-shielding factors for various combinations of distance and angle of elevation.

The values given in Table II may be applied to obstacles between 5 and 16 km from the earth-station. Nearer obstacles are likely to be within the near-in field region of the antenna beam, where the calculation methods do not apply.

Although the procedure described above relates to overland transmission in a continental temperate climate, it can also be applied to the other climates referred to in Report 244-1.

5. Effect of precipitation scatter

On occasions, transmission via scatter due to precipitation may partly nullify the increased losses effected by obstacles. Information on this propagation mechanism is scarce and a knowledge of rainfall statistics is required.

Further information on this subject is given in Report 339.

BIBLIOGRAPHY

1. C.C.I.R. Doc. V/48, 1963 - 1966.

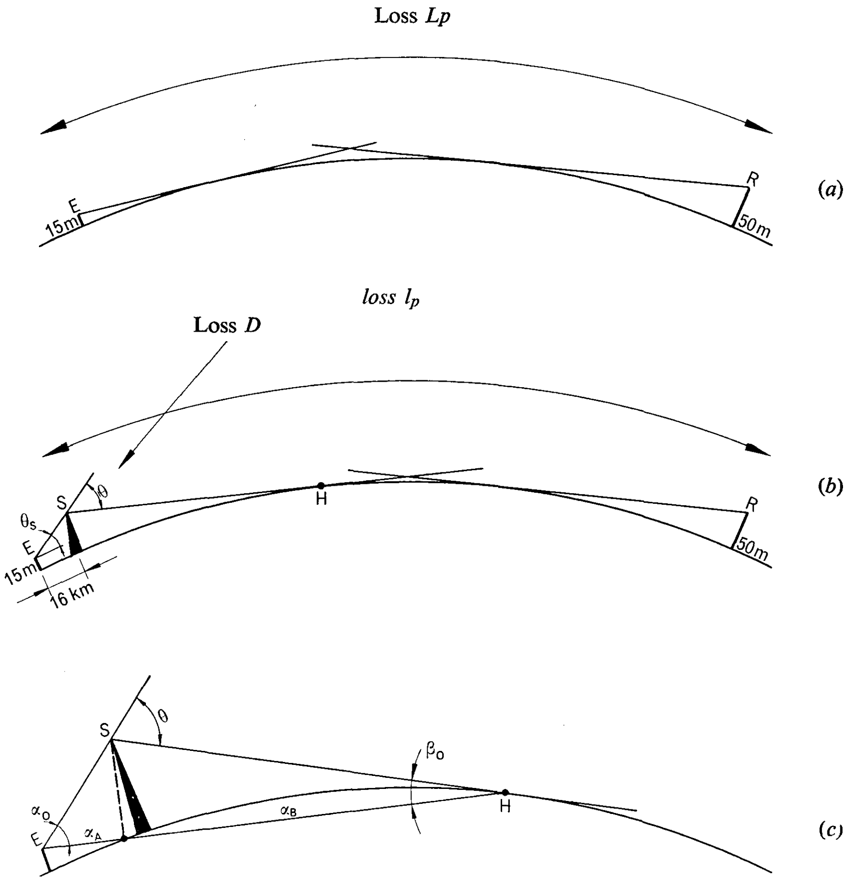


FIGURE 1

Practical method for calculating effective diffraction loss when a diffracting ridge is inserted in an otherwise non-optical path

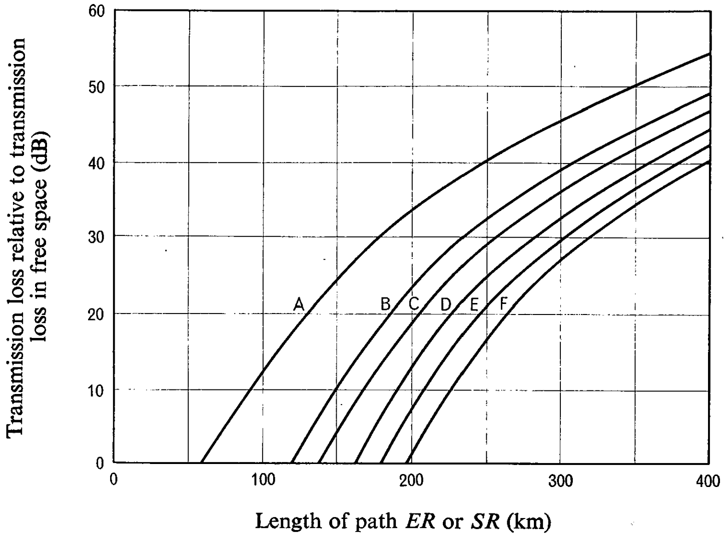


FIGURE 2

Transmission loss not exceeded for 0·1% of time at 4 GHz for continental temperate climate for conditions indicated in Figure 1

A: $l_{0\cdot 1}$ for path ER
B: $l_{0\cdot 1}$ for path SR ($\theta_s = 1^\circ$ screen $H_r = 311$ m)
C: $l_{0\cdot 1}$ for path SR ($\theta_s = 2^\circ$ screen $H_r = 590$ m)
D: $l_{0\cdot 1}$ for path SR ($\theta_s = 3^\circ$ screen $H_r = 870$ m)
E: $l_{0\cdot 1}$ for path SR ($\theta_s = 4^\circ$ screen $H_r = 1155$ m)
F: $l_{0\cdot 1}$ for path SR ($\theta_s = 5^\circ$ screen $H_r = 1425$ m)

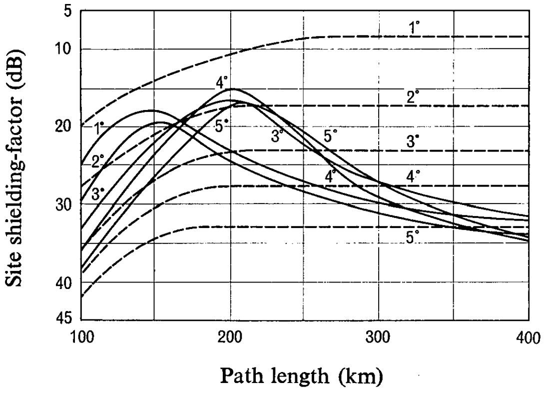


FIGURE 3

Site shielding-factor at 4 GHz for continental temperate climate

(For 0·1% of the time)

——— due to diffraction
– – – – due to tropospheric scatter

REPORT 338 *

PROPAGATION DATA REQUIRED FOR LINE-OF-SIGHT RADIO-RELAY SYSTEMS

(Study Programme 5A/V)

(1966)

1. Introduction

In addition to the large amount of data collected in response to Administrative Circular AC/63 (see Report 241) and the relevant information contained in Report 244–1, it is possible to give some additional general information on propagation for the guidance of designers of line-of-sight radio-relay systems. In particular, statistical analysis of many path-loss recordings has enabled the preparation of general propagation curves which are described later in this Report.

2. Frequencies below about 1 GHz

For line-of-sight links operating on frequencies below about 1 GHz, it is possible in many cases to compute the expected statistical distribution of the transmission loss from an examination of the path profile, and from information on the long-term variations in the effective radius of the earth. Wherever possible, however, these computations should be verified by direct measurements of the transmission loss.

3. Frequencies above about 1 GHz

3.1 *Terrain effects*

For line-of-sight links operating at frequencies above about 1 GHz, diffraction theory indicates that the direct path between the transmitter and the receiver needs a clearance above ground of at least 60% of the radius of the first Fresnel zone, to achieve free-space propagation conditions. It is, however, necessary to make an allowance for possible sub-refraction, and it is usual to do this by ensuring that the required clearance is maintained, even when the effective earth radius is reduced below its normal value. For example, radio-link designers in the United States of America and the United Kingdom often require that 60% of the first Fresnel zone radius shall be clear even when the effective radius of the earth is only 4500 km ($K = 0{\cdot}7$). However, an analysis of 300 000 hours of chart records obtained from 21 radio-relay sections in the United Kingdom [1], planned more or less in accordance with this clearance rule, has shown no instances of sub-refraction fading. It would therefore appear that the rule may be too conservative. Some Administrations require a ground clearance of a full Fresnel zone radius when the earth's effective radius has its normal value of 8500 km ($K = 1{\cdot}33$). This is generally a smaller clearance than that required in the United States of America and the United Kingdom.

---

* This Report was adopted unanimously.

When the statistics of sub-refractive conditions are known, it may be possible to replace this " rule of thumb " by a more accurate procedure which takes into account the actual expected sub-refraction occurring in various regions (see Report 237–1).

If the radio path traverses smooth terrain there is sometimes a possibility of reflections from the ground. This can result in phase interference and consequent fading. Under these conditions, it is desirable to avoid excessive path clearance which could exaggerate the effects of the terrain reflections.

To summarize, there is a large amount of evidence that a clearance of 60% of the first Fresnel zone, with an effective radius of the earth of 4500 km, is quite adequate to avoid fading due to sub-refraction. However, it is possible that a smaller clearance would be adequate and would occasionally be advantageous over potentially reflecting terrain. Unfortunately there is at present insufficient evidence to suggest by how much the clearance can be reduced with safety.

In addition to sub-refraction and reflection from the ground, experiments in the Federal Republic of Germany [2] have revealed that total reflection can occur in an atmospheric layer near the ground, this layer being connected mostly with mist or ground fog experienced over moist river valleys or moors. Some earlier work carried out in the United Kingdom [3] also shows correlation between fading and ground fog.

If the radio path crosses water, and the geometry of the path is such that the point of specular reflection falls on the water, very severe fading can occur, with minima occasionally deeper than predicted when using the two ray model. This behaviour may be represented by a model in which secondary waves, in addition to the two primary waves, are taken into account [7]. It is usual to avoid such paths. However, if such a path cannot be avoided, height or frequency diversity may be used to reduce the severity of the fading (see Report 237–1). Alternatively, it has been found that if the path can be so arranged that the geometrical point of reflection on the water is screened from one or other of the terminals by the terrain, even if the surface of the water is still visible from both terminals, the fading can be reduced considerably. However, experience on one over-water path 80 km long [4] has shown that it was very difficult to achieve transmission of complex signals, such as colour television, if the water was not completely invisible from at least one terminal.

3.2 *Fading statistics*

The analysis of the 21 paths in the United Kingdom, referred to above, has shown that to a first approximation, the fading depth, relative to the free-space signal level, exceeded for a small percentage of time, is a function of the path length. It also depends on the type of terrain traversed, but it is not very dependent on the frequency within the range 2 to 9 GHz.

However, work carried out in France [5], on paths over 100 km long, indicates that the fading depends only to a small extent on the nature of the terrain, and the frequency dependence is more marked.

The results of the United Kingdom and French tests have been found to be fairly compatible, bearing in mind that the lengths of paths concerned differed considerably. For the general guidance of designers of radio links in Europe, the provisional curves of Fig. 1 have been derived from the United Kingdom and French results. These curves give the distribution of fading depth during the worst month of a year, relative to free-space, for various path lengths, for average terrain, and for the climate of North-Western Europe. The frequency is 4 GHz. Under these conditions, the curves fit the original data with an r.m.s. error of about 4 dB. Great care should be exercised in applying these provisional curves to any other conditions of climate, terrain, or path clearance.

First order corrections for different frequencies are as follows: At 2 GHz, the fading depth exceeded for 1% of the time is less than that given in Fig. 1 by an amount varying from 0·5 dB for 50 km to 5 dB for 250 km. At 6 GHz, the fading depth exceeded for 1% of the time is greater than that given in Fig. 1, by an amount varying from about 1 dB for 50 km to 6 dB for 250 km.

For paths less than 100 km in length over fairly smooth terrain, the fading depth exceeded for 0·01% of the time is about 6 dB greater than shown in Fig. 1, and if the path crosses water, moist river valleys, or moors, the fading depth may be 12 dB greater than shown in Fig. 1. Observations on a 100 km path, using a frequency of 6 GHz, have shown that even on a rough path considerable fading may occur [8].

The method of calculation of the statistical distribution of the depth of fading, taking account of path length, contour of terrain, climate, height of antenna, and frequency used in the U.S.S.R., is given in [6].

3.3 *Diversity reception*

On short over-water paths, space-diversity effects can be represented by a two-ray model. On longer paths, diversity techniques may be required over both land and water, although the two-ray model is no longer applicable.

Studies carried out in the Federal Republic of Germany have shown that diversity, with the antennae spaced vertically by 50 wavelengths, reduces fading due to multipath propagation. Measurements across the English channel at 4 GHz show, that this spacing is inadequate when signal defocusing occurs, and vertical antennae spacings of 700 to 1400 wavelengths may then be required. In Italy, four paths have been examined and it has been found that for paths of length greater than 100 km, the space-diversity improvement obtainable is only that expected from uncorrected signals.

Frequency diversity measurements have been made at 2·5 GHz in the Federal Republic of Germany and at 2 GHz in Italy [2, 7], where it has been found that on paths of length 50 to 70 km, a frequency separation of 150 to 200 MHz is required for efficient diversity, but that on paths of length 120 km, the frequency separation may be reduced to 80 MHz.

4. Conclusions

The information given above gives some general guidance to designers of line-of-sight radio-relay links. Although a large amount of data has contributed to this information, it is not possible as yet to provide more precise guidance and the Report should be used with some caution. In particular, it is not possible to state precisely the effect of reducing the path clearance well below that required by the simple rules given in § 3.1. It is known that for paths very near grazing incidence, losses of the order of 30 dB above the free-space loss can be expected to occur for at least 10% of the time. However, no long-term propagation statistics are yet available for links where the path clearance is well clear of grazing incidence although still less than required by the rules given in § 3.1.

BIBLIOGRAPHY

1. C.C.I.R. Doc. V/11, 1963-1966.
2. C.C.I.R. Doc. V/23, 1963-1966.
3. Smith-Rose, R. L. and Stickland, A. C. An experimental study of the effect of meteorological conditions upon the propagation of centimetre radio waves. Meteorological Factors in Radio Wave Propagation, published by the Physical Society (1946).

4. Giugliarelli, G. On the influence of oversea propagation on the transmission of colour television signals. *E.B.U. Review*, 90-A, Technical (April 1965).
5. Battesti, J. and Boithias, L. Etude des sections longues dans les faisceaux hertziens en visibilité. (Study of long sections in radio-relay systems with direct visibility.) *Annales des télécommunications* (July-August 1964).
6. C.C.I.R. Doc. 196 (U.S.S.R.), Geneva 1963.
7. C.C.I.R. Doc. V/106 (Italy), 1963-1966.
8. C.C.I.R. Doc. V/111 (New Zealand), 1963-1966.

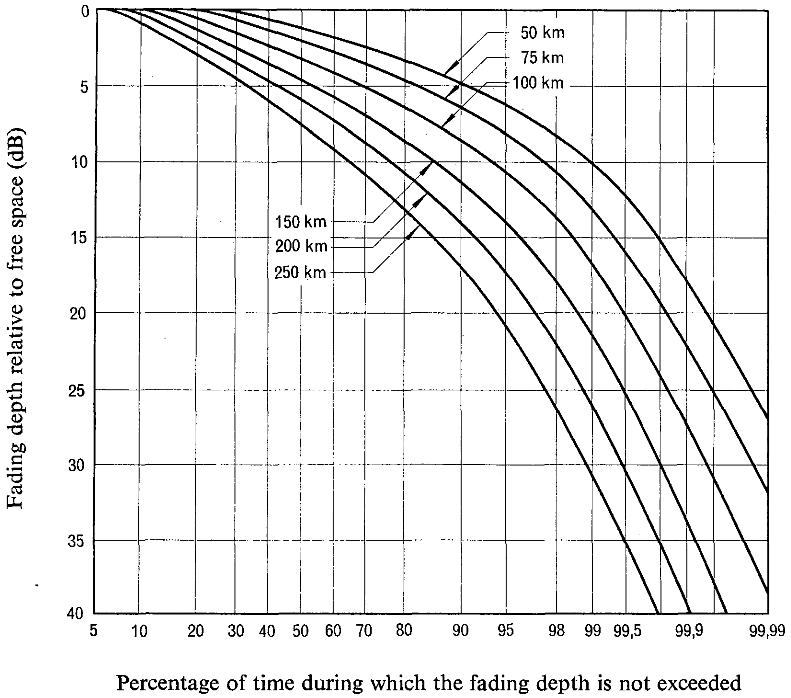


Figure 1

Provisional curves of fading depth not exceeded for a given percentage of the worst month of the year, 4 GHz, average rolling terrain. North-west Europe

REPORT 339 *

INFLUENCE OF SCATTERING FROM PRECIPITATION ON THE SITING OF EARTH STATIONS

(Study Programme 5D/V)

(1966)

1. Introduction

Recent work [1, 2] has shown that scattering from precipitation may be an important factor in determining the probability of interference between an earth station and a terrestrial radio-relay station operating on the same frequency. In view of the urgent need for estimates of coordination distance, this preliminary contribution has been prepared to provide some information one the time-distribution of the magnitude of scattering from rain, with special reference to those conditions in which this factor is likely to be the dominant one in determining the value of the interference field exceeded for small percentages of the time.

The interference effects appear to fall into two main categories. The first is long-range interference occuring at separations of hundreds of kilometres, when major portions of the two beams intersect in a high, strongly-scattering thunderstorm. The second may occur at separations of less than 100 km when heavy precipitation, at any altitude, is present in the side-lobes of the antennae patterns. Only the first mechanism is considered in this Report.

2. Basis of method

The method assumes that the transmission loss (equal to 10 log, P_t/P_r), associated with scattering from rain between two points on the surface of the earth, may be calculated from the general equation:

$$P_r/P_t = (G_A/4\pi d_A^2)\ (\eta\upsilon/4\pi d_B^2)\ (G_B\lambda^2/4\pi)$$

where P_r and P_t are the received and transmitted powers respectively,

G_A and G_B are the gains of the terrestrial-station and eart-station antennae respectively,

d_A and d_B are the respective distances from terrestrial and eart-stations to the scattering region,

υ is the scattering volume,

λ is the wavelength,

and η is the scattering cross-section per unit volume.

It is further assumed that the radio-relay station has an antenna about two metres in diameter with the beam directed close to the local horizon. The earth-station is assumed to have an antenna of 25 m or more in diameter, with the beam elevated at angles of 3° or more above the horizon. The results given in this Report have been obtained from calculations of the volume common to the two 3 dB beamwidths and from values of η obtained from radar studies. Isotropic scattering is assumed and no account has been taken of the effect of scattering from rain in the side-lobes of the antennae patterns.

---

* This Report was adopted unanimously.

With these assumptions it may be shown that [6]:

$$P_r/P_t = \frac{\sqrt{G_A}\,\lambda^2\,\eta}{4\,\pi^2\,d_A\,\sin\theta} \text{ (for rain filling the common volume)} \qquad (1)$$

where θ = angle between the antennae beams.

But $\eta \approx Z/3{\cdot}6 \times 10^{15}\,\lambda^4$, where Z is the reflectivity factor, in mm^6/m^3, and λ is in m.

$$\text{Therefore, } P_r/P_t = \frac{\sqrt{G_A}\,Z}{1{\cdot}4\,d_A\,\lambda^2\,\sin\theta \times 10^{17}} \text{ with } d_A \text{ and } \lambda \text{ in m.} \qquad (2)$$

Equations (1) and (2) assume antennae of high efficiency, with effective apertures approximately equal to the geometrical apertures. For the practical case being considered, with antennae of 60-70% efficiency, we may write:

$$P_r/P_t \approx \frac{\sqrt{G_A}\,Z}{3\,d_A\,\lambda^2\,\sin\theta \times 10^{17}} \qquad (3)$$

This equation is used for deriving the results in this Report and is valid for transmission in either direction.

3. Data on reflectivity factor

For a useful solution to this problem, even approximate, it is necessary to assume a distribution of precipitation reflectivity-factor based on uniform sampling in time and space (Doc. V/119, 1966). Although many interesting vertical profiles have been published, the only results based on regular, comprehensive sampling at several heights over an extended horizontal area are those from Montreal, Canada, for five summer months of 1963, including most of the year's thunderstorms [3, 4]. From these data it was determined, for example, that the reflectivity factor, Z, at any height, which was exceeded no more than 0·01% of the 5 months could be approximated by:

$$\begin{array}{lll} h & = -4{\cdot}15 \log Z + 22{\cdot}7, & 0 < h < 6\text{ km} \\ h & = -2{\cdot}14 \log Z + 14{\cdot}6, & 6\text{ km} < h < 21\text{ km} \\ Z & = 0, & 21\text{ km} < h \end{array}$$

Although these data were taken with a 3 cm radar, they have been suitably corrected for attenuation. From a study of the monthly variations, it is considered that the above representation is appropriate for 0·02% of the worst month, July.

The limited sample of data for only one geographical area precludes determination of the results to be expected for other years or other locations. Without further study, it is not possible to compare the Montreal climate used and others of interest in any conclusive manner, but it is similar to that of Milan in total annual rainfall and in maximum daily rainfall. Such extrapolations from surface observations must be made with caution, as it is known that there may sometimes be high reflectivity aloft without accompanying rain at the surface.

An estimate of the maximum interference likely to be encountered may be obtained from [5], which reports a slowly-moving hailstorm about 6 km in height and 6 km in diameter with a value of Z of 1×10^7, maintained for several hours. This represents an increase of about 15 dB over the values given by the curves of § 5.

In some locations, the worst month may be characterized by widespread precipitation at heights of no more than a few kilometres. In such locations, the interference is likely to be limited to situations in which the separation of transmitter and receiver is not more than 250-300 km.

4. Results

The probability of interference by an unwanted signal is the probability that the wanted-to-unwanted signal ratio is less than a minimum tolerable value for a given percentage of the time. Figs. 1, 2, and 3 indicate the worst cases for 6 GHz in the following manner. An earth station, *ES*, with an antenna 26 m in diameter pointed at fixed angles of elevation, E_E, of 3°, 7·5° and 30° respectively, is imagined to be at the origin aimed to the right as shown. A terrestrial station, with an antenna 1·8 m in diameter at an elevation, E_T, of 0°, is assumed to be located at points on the plane with azimuths such that the axis of the beam intersects the axis of the earth-station beam. Loci of terrestrial station positions producing constant values of the ratio P_t/P_r are plotted. If, for example, −115 dBW is the maximum permissible level of unwanted signal at the terrestrial input to the receiver and the power of the earth-station transmitter is 10 kW, 40 dBW, then the curve marked 155 dB (transmission loss) indicates the region outside of which a radio-relay antenna will not receive harmful interference for more than about 0·02% or 0·005% of the worst month. The above transmission loss is understood to include about 100 dB in antenna gains, corresponding to the antenna sizes given above.

For given station and storm locations, the ratio P_t/P_r may be assumed to vary directly as the third power of the wavelength and inversely with the diameter of the smaller antenna. It is relatively independent of the diameter of the large antenna (see Eq. (3)).

As the interference discussed here cannot usually be reduced by site-shielding and can require large separation distances, it is necessary to consider the probability of occurrence of the severity indicated on the figures. Regarding precipitation intensity, no more can now be said than at the end of § 3. Regarding the geometrical considerations, however, preliminary calculations have been made with the following results. If a terrestrial radio-relay station, with a beam at random azimuth and 0° elevation, is located at random on a circle about an earth station with a beam elevation near 3°, the probability of P_t/P_r being as small as 155 dB for as much as 0·02% of the time is 0·04 at 200 km and 0·015 at 300 km.

Some calculations using Eq. (3) have also been made using rainfall data from the United Kingdom [6] assuming a frequency of 4 GHz, an antenna gain, G_A = 46 dB at the terrestrial radio-relay station, and an angle of elevation of the earth-station beam of 5°. When the two beams intersect off the great-circle path between two stations 100-200 km apart, the value below which the transmission loss may fall for 1, 0·1 or 0·01% of the time (assuming scatter from rain in the common volume), is 33-50 dB less than that assuming isotropic antennae and tropospheric scatter via the great-circle path (see for example the data in Report 243).

5. Conclusions

The results in this Report indicate that interference caused by scattering from precipitation may be important when the beams of a terrestrial radio-relay system and an earth-station intersect. This interference cannot always be reduced by site-shielding. The probability of the beams intersecting is small and as yet there have been no reported occurrences of such interference in operational systems. However, much more work is necessary to evaluate more fully the effects of precipitation scatter in all types of climate, taking account of scattering via both the main beams and side-lobes in the antennae patterns.

Note. — The theoretical results presented in this Report are based on a number of assumptions and the data must therefore be used with caution. Administrations are requested to carry out the largest possible number of measurements to verify and expand the data in this Report.

BIBLIOGRAPHY

1. DOHERTY, L. H. and STONE, S. A. Forward scatter from rain. *Trans. IRE.* AP-8 (July 1960).
2. DENNIS, A. S. Precipitation scatter as an interference source in communication systems. IRE Convention Record, Part I, Antennas and Propagation, 145 (1962).
3. MARSHALL, J. S., HOLTZ, C. D. and WEISS, M. Parameters for airborne weather radar. McGill University Stormy Weather Group Scientific Report MW-48 (May 1965).
4. HAMILTON, P. M. Precipitation profiles for the total radar coverage. McGill University Stormy Weather Group Scientific Report MW-37 (September 1964).
5. BROWNING, K. A. and LUDLAM, F. H. Radar analysis of a hailstorm. Tech. Note No. 5, Imperial College of Science and Technology, London, Dept. of Meteorology, 69 (July 1960).
6. C.C.I.R. Doc. V/93, 1963-1966.

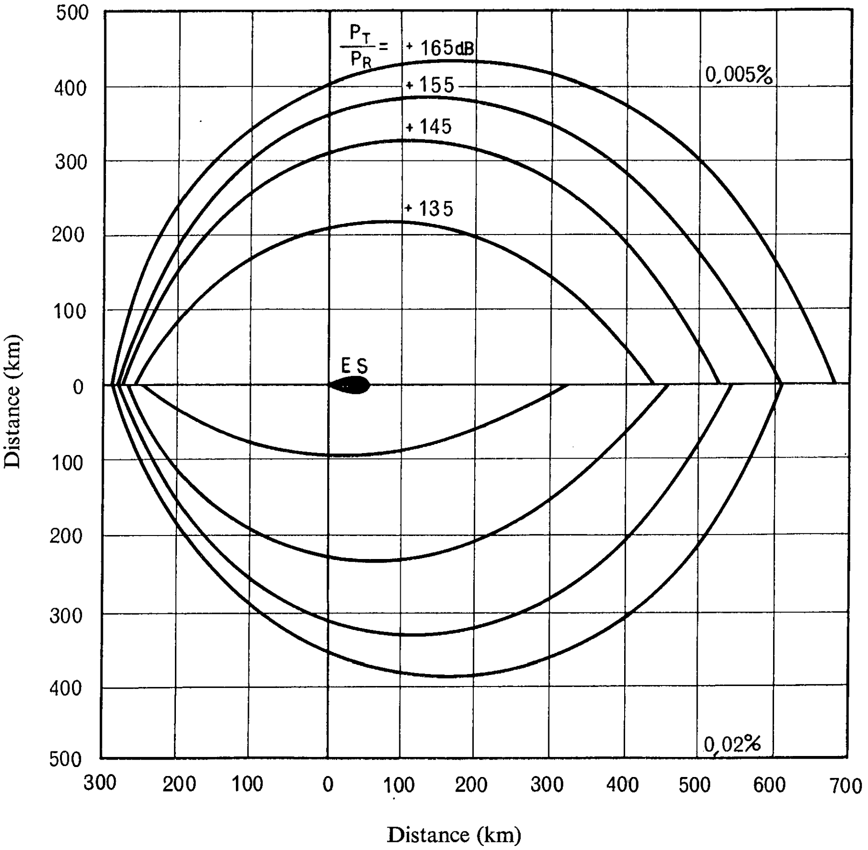


FIGURE 1

Contours of maximum values of the ratio P_T/P_R

$E_E = 3°$ $E_T = 0°$

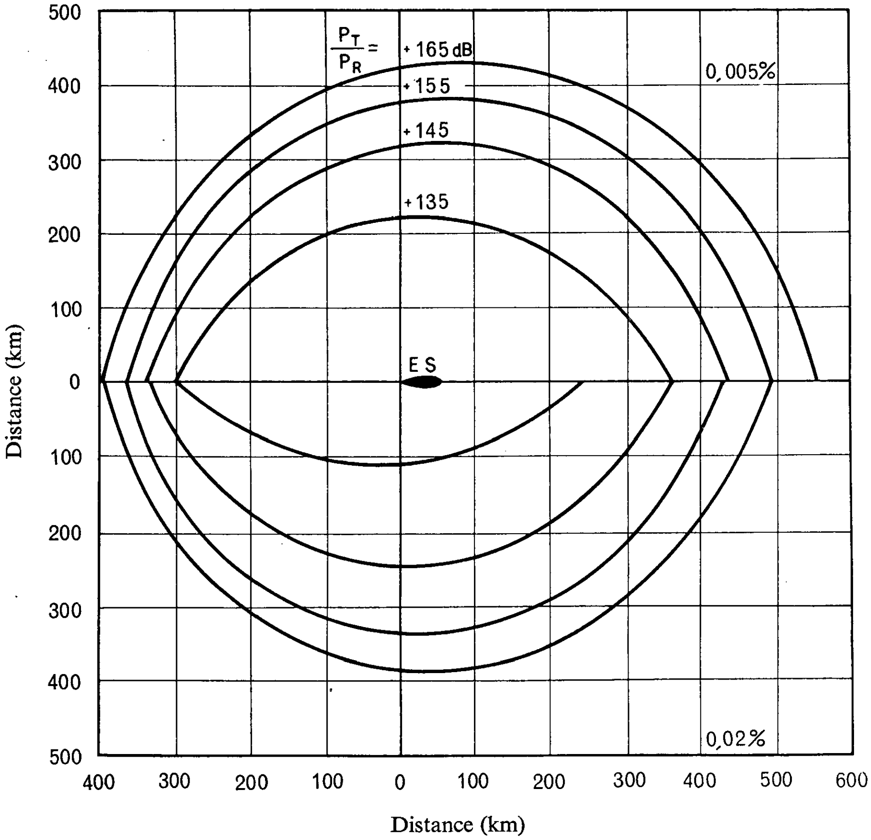


FIGURE 2

Contours of maximum values of the ratio P_t/P_r

$E_E = 7{\cdot}5°$ $E_T = 0°$

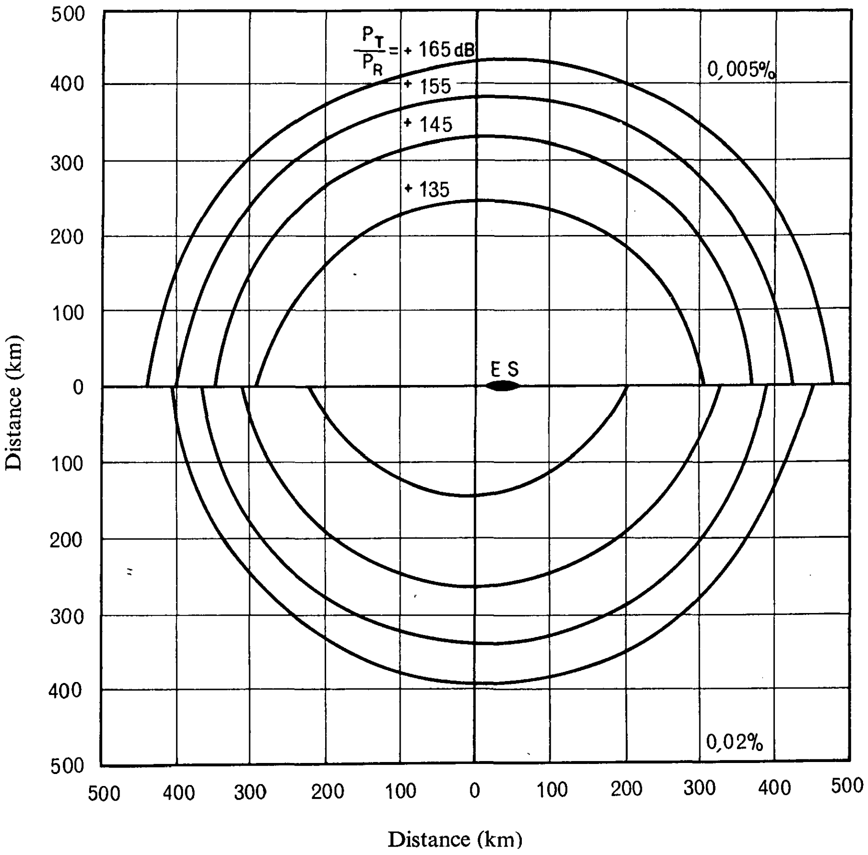


FIGURE 3

Contours of maximum values of the ratio P_t/P_r

$E_E = 30°$ $E_T = 0°$

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

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. Meetings

Two meetings of the Study Group were held between the Xth and XIth Plenary Assemblies of C.C.I.R. in Geneva, 1963 and in Oslo, 1966. The first of these was an Interim Meeting of Study Group V, Geneva, 1965, while the second took place in Oslo, 1966, immediately prior to the XIth Plenary Assembly. It was an advantage that the 1965 meeting was held after the corresponding Interim Meeting of Study Group IV, Monte Carlo, 1965, as a number of questions which has arisen in connection with the development of space communications were referred to Study Group V for consideration and report. These were discussed and rationalized in Oslo, during the meetings of both Study Groups.

2. Documentation and Working Parties

Following the issue in August 1965 of the booklet containing the conclusions of the Interim Meeting, nearly forty additional documents were distributed to the Study Group at Oslo. This whole documentation was divided among six Working Parties under the following headings:

— transmission loss;
— radio-meteorology;
— tropospheric propagation curves;
— propagation data required for radio-relay systems;
— propagation data of interest to Study Groups IV and V;
— definitions of terms relating to propagation in the troposphere.

During the various meetings of these Working Parties the programme of the Study Group was reviewed, and some rationalization of its subject matter was carried out. As a result there are now five basic Questions before the Group and an equal number of Study Programmes, the pursuit of which should eventually provide the technical answers to the problems which stimulated the Questions. The present position of the work achieved at the recent Plenary Assembly is summarized in the following sections.

3. Questions

3.1 There are two basic Questions referring to conditions in which the nature and properties of the terrain are the main, but not the exclusive, factors determining the propagation of radio waves. These are:

Question 1/V: Ground-wave propagation over inhomogeneous earth.

Question 3/V: Effect of tropospheric refraction at frequencies below 10 MHz.

3.2 Next, considering the general problem, in which the propagation of radio waves over a wide band of frequencies is determined by the properties of the atmosphere through which the waves travel, the following basic Question falls within the scope of radio-meteorology.

Question 2/V: Influence on the non-ionized regions of the atmosphere on wave propagation.

3.3 Turning to the practical application of radiocommunication systems using very high frequencies, two Questions have been formulated, designed to stimulate investigations, the results of which can help in the development of such systems.

Question 5/V: Propagation data required for terrestrial radio-relay systems and communication-satellite systems.

Question 4/V: Fading of multipath signals propagated by the troposphere.

4. Study Programmes

To seek answers to the above Questions, the following Study Programmes were adopted in Oslo:

Study Programme 5A/V: Propagation data required for line-of-sight radio-relay systems.

Study Programme 5F/V: Site shielding-factor to be used in calculating coordination distances.

Study Programme 5E/V: Influence of scattering from precipitation on the siting of earth stations.

Since it is envisaged that in the future, the expansion of communications may necessitate the sharing of bands of frequencies, the following Study Programme was adopted:

Study Programme 5D/V: Propagation factors affecting the sharing of the radio-frequency spectrum between space and terrestrial radio-relay systems.

Finally, with the specific object of assisting the broadcasting and mobile radio services, the following Study Programme was formulated:

Study Programme 7A/V: VHF and UHF propagation curves in the frequency range 30 MHz to 1 GHz.

5. Recommendations

Based upon the results of investigations conducted into these subjects in various parts of the world, a number of Recommendations were adopted at the XIth Plenary Assembly. These are designed to assist both the research scientist and the practical engineer in the advancement of radiocommunications at frequencies at which these are dependent on the properties of the troposphere.

First we have:

Recommendation 310-1: Definitions of terms relating to propagation in the troposphere,

with which may be associated:

Recommendation 369-1: Definition of a basic reference atmosphere.

5.1 Next there is the matter of describing, in a practically useful form, the nature of the radiation from the various types of antennae used in communication systems.

Recommendation 168-1 : Presentation of antenna radiation data.

5.2 Finally, there is the compilation of a set of reliable curves from which the practical engineer may estimate the field strength that will be obtained over a wide range of frequencies, for various distances of transmission over land, sea and mixed terrain. A comprehensive set of graphs, applicable to the VHF and UHF bands (30-250 and 450-1000 MHz respectively), is incorporated in the following document with advice as to their use in the practical planning of broadcasting and mobile services, as distinct from point-to-point communication links.

Recommendation 370-1 : VHF and UHF propagation curves for the frequency range from 30 MHz to 1 GHz.

6. Reports

The results of investigations conducted during the past three years in various parts of the world on the different problems presented by radio-wave propagation through the troposphere, are incorporated in twelve Reports printed in this volume (Reports 228-1, 231-1, 233-1, 234-1, 236-1, 237-1, 241-1, 244-1, 337, 338 and 339).

The subjects reported upon range from methods of measuring field strength under various conditions, to the problems of fading, scattering and the effect of irregular terrain over the path of transmission.

The extended scope of the Study Group of the investigation of propagation phenomena outside the earth's ionosphere is illustrated by Report 336, which deals with frequency utilization above the ionosphere and on the far side of the Moon. This may be an indication as to what the future holds in store for the continued work of Study Group V.

QUESTION 1/V *

GROUND-WAVE PROPAGATION OVER INHOMOGENEOUS EARTH

(1965 - 1966)

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:

— the prediction of the service areas of radio transmitters;

— the accuracy of navigational aids and direction-finding equipment;

— the effect of coastal refraction on the use of such aids and equipment;

(*b*) that the rigorous mathematical analysis so far refers mainly to idealized models including:

— one or more boundaries between regions of different electrical constants normal to the path, with possible discontinuities in height;

— horizontal stratification;

— spherical earth;

UNANIMOUSLY DECIDES that the following question should be studied:

1. the refinement of methods for measuring the values of the equivalent permittivity, ε, and conductivity σ for a path, for portions of a path, or for local areas for various frequencies;

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, to define more closely the limitation 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;

6. the effect, on waves propagated over the surface of the earth, of changes in such factors as the temperature, vegetation, climate or other causes.

---

* Formerly Question 310(V).

RESOLUTION 3

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

(1963)

The C.C.I.R.,

CONSIDERING

(a) that the data presented in Report 233–1 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 radio-meteorological studies (see Question 2/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 5C/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 233-1, 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 XIIth Plenary Assembly of the C.C.I.R.

QUESTION 2/V *

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

Radio-meteorology

(1966)

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;

---

* This Question replaces Study Programme 192.

(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:

DECIDES that the following question should be studied:

1. what are the most appropriate methods and instruments for studying the variations of those thermodynamic parameters of the atmosphere which affect wave propagation (see Annex, § 1);
2. what are the variations in space and time of the refractive index of the air and of its vertical gradient;
3. what is the influence on wave propagation of the various constituents of the atmosphere, such as water vapour, oxygen, cloud, rain, snow, fog, sand, etc., and in particular:
   - — what are their statistical and geographical distributions;
   - — what are the space and time correlation characteristics of each of the factors;
4. what are the radio-meteorological parameters, other than those mentioned above, which may be useful in radio wave propagation;
5. what is the correlation between the different radio-meteorological 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;

Note 1 — Administrations and private operating agencies should be asked to supply full data on the refractive index and the vertical gradient, to complete the work on world radio-climatology described in Report 233-1 (see Annex), and to make a large number of detailed and accurate measurements, to check the various theories put forward to explain propagation.

Note 2 — This Question 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 of the Annex.

Note 3 — This Question should be brought to the attention of the U.R.S.I. by the Director, C.C.I.R.

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 : ± 0·2° C,
   Humidity (mixing ratio) : ± 0·1 gm/kg,

   continuous measurement equipment should preferably be used.

2. The refractivity N should be used as defined by the formula:

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

   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.

QUESTION 3/V *

EFFECTS OF TROPOSPHERIC REFRACTION AT FREQUENCIES BELOW 10 MHz

(1951 – 1953 – 1956 – 1963 – 1966)

The C.C.I.R.,

CONSIDERING

(a) that the ground-wave propagation curves for frequencies below 10 MHz, 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 MHz, 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 kHz 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 231-1;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what further measurements of ground-wave field strengths, including those using pulse techniques, over a sufficiently long path of uniform conductivity, such as a sea path, are necessary to determine experimentally the modification of the ground-wave curves required to include the effects of tropospheric refraction at frequencies below 10 MHz;
2. how should the mathematical analysis relating to ground-wave propagation be interpreted, to include the effects of tropospheric refraction at frequencies below 10 MHz;
3. what is the influence of tropospheric refraction on the phase of the ground-wave?

---

* This Question replaces Study Programme 246A.

QUESTION 4/V

FADING OF MULTIPATH SIGNALS PROPAGATED BY THE TROPOSPHERE

(1966)

The C.C.I.R.,

CONSIDERING

(a) that the performance of tropospheric communication systems using line-of-sight, diffraction and tropospheric scatter, is determined by signal characteristics which may be degraded by multipath and fading phenomena;

(b) that diversity-reception-systems (e.g. time, space and frequency diversity) may be engineered, to take advantage of the propagation characteristics and to improve system performance;

UNANIMOUSLY DECIDES that the following question should be studied:

in the various frequency bands used in radiocommunication by means of the troposphere, what are:

1. the long-term and short-term time variabilities of transmission loss and bandwidth as a function of frequency, path geometry including distance and type of terrain, meteorological conditions, propagation mechanism, time of day, season of the year and geographical location;
2. the variabilities of transmission loss and of bandwidth with antenna location and pattern at a given instant as a function of the same parameters;
3. the variabilities of transmission loss and of bandwidth with frequency at a given time and location, also as a function of the same parameters;
4. the time and space distributions of fading (e.g. Rayleigh, normal and log-normal);
5. the real and complex power spectra and autocorrelation functions to specify the time variability of the fading characteristics;
6. the real and complex cross-correlation functions between signals received simultaneously on locally spaced antennae, to specify the variability in space of the fading characteristics;
7. the real and complex cross-correlation functions between signals received simultaneously on spaced-carrier frequencies, to specify any variability in frequency of the fading characteristics;
8. the relations, for the received signals, between the frequency- and space-correlation functions in order to specify the combined effects of frequency- and space-diversity;
9. the effects of fading on the performance of various types of radiocommunication systems including wide-band systems and systems employing diversity;

---

* This Question replaces Study Programmes 57 and 176 and should be studied in relation with Question 13/IX.

10. the causes of fading including the characteristics of the various possible sources of multipath such as reflections from the earth's surface, terrain and tropospheric irregularities;

11. the development of engineering methods necessary to improve the performance of tropospheric radiocommunication systems operating in the presence of fading?

QUESTION 5/V *

PROPAGATION DATA REQUIRED FOR TERRESTRIAL RADIO-RELAY SYSTEMS AND COMMUNICATION-SATELLITE SYSTEMS

(1953 - 1956 - 1959 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that the quality of communication by terrestrial radio-relay systems or by communication-satellite systems is determined by the propagation characteristics of the waves used, especially as regards the highest values of basic transmission loss that may occur;

(b) that interference between different systems may occur at very great distances, particularly when values of basic transmission loss are low;

UNANIMOUSLY DECIDES that the following question should be studied:

what are the propagation characteristics of paths over which radio-relay and communication-satellite systems, conforming with Recommendations of the C.C.I.R. regarding system performance and mutual interference are to be established?

STUDY PROGRAMME 5A/V **

PROPAGATION DATA REQUIRED FOR LINE-OF-SIGHT RADIO-RELAY SYSTEMS

(1963 - 1966)

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

---

* Formerly Question 311(V).

** Formerly, Study Programme 311A(V).

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 on the path from the interfering transmitter;

(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. the distribution with time of the instantaneous value of basic transmission loss in the VHF (metric), UHF (decimetric), and SHF (centimetric) bands for each month of the year (Note);

2. the signal levels for given percentages of time corresponding to the most unfavourable month, the most favourable month and those corresponding to the whole year;

3. the dependence of the distributions found on the path length, the climate, the nature of the terrain over which the path passes and the clearances of the antennae;

4. the extent to which the distributions found can be described by simple statistical laws;

5. the limitations imposed on transmission by the effects of multipath propagation and how may these be overcome;

6. the limitations on the use of the system 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 GHz with antennae representative of practical systems, over representative paths and at longer distances.

Study Group IX particularly requires:

- the value of basic transmission loss not exceeded for 99·998%, 99·99%, 99·9%, 99%, 80%, 50%, 20%, 1%, 0·1%, 0·01% and 0·002% of each month of the year;
- that the measurements be made in such a way that the distribution of the values of noise power (dependent on transmission loss) at the output of a system, averaged over 5 ms, 1 s, 1 min and 1 hr, can be derived.

It is recognized that, in practice, estimates of transmission loss, not exceeded for time percentages less than 1% and greater than 99%, will be much less reliable than those for time percentages between 1% and 99%.

STUDY PROGRAMME 5B/V *

PROPAGATION DATA REQUIRED FOR BEYOND-THE-HORIZON RADIO-RELAY SYSTEMS

(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 (other time constants may be used, should it appear desirable, but in all cases the time constant used should be specified) 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 (other periods of time may be used to define the median value, but these periods should be stated), 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, 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;

---

* Formerly Study Programme 311B(V).

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 efforts 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.

STUDY PROGRAMME 5C/V *

TROPOSPHERIC ABSORPTION AND REFRACTION IN RELATION TO SPACE TELECOMMUNICATION SYSTEMS

(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 GHz 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;

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.**

---

* The radio-meteorological aspects of this Study Programme, formerly Study Programme 311C(V), are considered in Question 2/V. The attention of the International Working Party, established under Resolution 2, is drawn to this Study Programme.

** The attention of the International Working Party on radio-meteorology, set up under Resolution 3, is drawn to those aspects of this Study Programme which concern radio-meteorology, and to Doc. V/75, Geneva, 1962, for their comments.

STUDY PROGRAMME 5D/V *

PROPAGATION FACTORS AFFECTING THE SHARING OF THE RADIO-FREQUENCY SPECTRUM BETWEEN SPACE AND TERRESTRIAL RADIO-RELAY SYSTEMS

(1963 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that it is desirable to require coordination between countries only when there is real danger of interference;

(b) that coordination distances should be as short as possible with some margin of safety;

(c) that in the calculation of coordination and interference between systems, all pertinent propagation mechanisms should be taken into account;

(d) that separate detailed consideration of the mechanisms of interest in configurations close to those in actual use will lead to improved accuracy and smaller required margins;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the most suitable method by which contributions of known tropospheric propagation mechanisms, including scatter from precipitation or aircraft, can be taken into account when considering the signal received over normal trans-horizon paths 50 to about 2000 km (500 km with SHF) in length, particularly with reference to the signal strengths exceeded for small percentages of time, such as 0·01 %, 0·1 % and 1 % of a year; in particular, it should be determined to what extent the use of angular distance automatically allows for the high transmission loss usually associated with a high angle of elevation for the radio horizon at either end of the path;
2. determination of the distributions of signal amplitude and fading duration due to tropospheric mechanisms such as ducting, precipitation scatter and aircraft scatter as indicated below:
   - — the amplitude distributions of greatest interest are the cumulative distributions of hourly medians exceeded 0·01, 0·1 and 1 % of the time, during periods of at least one year and also during the worst months, when the wanted signal is low or when the unwanted signal is high;
   - — path lengths of greatest interest are between 50 km and about 2000 km (500 km with SHF); over oceans in equatorial and tropical regions measurements could be useful up to much greater distances;
3. the possibility of dividing the world into broad zones, to show the relative importance of various propagation mechanisms, and the extent to which the field strength exceeded for small percentages of time depends on the dominant mechanism;
4. the experimental theoretical studies of the total losses over mixed paths, partly over obstacles and partly over smooth earth or sea;

---

* This Study Programme, formerly Study Programme 311E/V, has been drafted taking account of Question 14/IV.

5. the effect of using high-gain antennae, taking into account the various extreme cases of interest, such as the following, which arise in considering communication-satellite and radio-relay services at 4 GHz and 6 GHz:

5.1 the antenna at one end of the path may be assumed to have gain either close to unity, or about 40 dB, with the beam directed almost horizontally along the bearing of the other antenna;

5.2 the antenna at the other end of the path may have a gain of about 60 dB, with the beam directed either well above the horizon or towards the other antenna at an angle of elevation of about 3° above the horizontal. Radiation diagrams of large antennae at communication-satellite earth stations, for use in interference studies, are given in Report 391.

Note. — The results to be furnished under this Study Programme, particularly under § 5, are urgently required by Administrations and the I.F.R.B.

STUDY PROGRAMME 5E/V *

INFLUENCE OF SCATTERING FROM PRECIPITATION ON THE SITING OF EARTH STATIONS

(1966)

The C.C.I.R.,

CONSIDERING

(a) that rain, hail, snow, and certain inhomogeneities in the refractive-index structure of the atmosphere may scatter radio waves more strongly and over wider angles than occurs under normal atmospheric conditions (see Docs. IV/79 (Canada) and V/153, 1963 - 1966);

(b) that studies of these phenomena need to be undertaken, so that antenna sites may be selected to minimize the total probability of interference;

(c) that the integration of expected scatter from precipitation existing somewhere in a volume of space visible to two antenna locations requires, for each small scattering sub-volume, a knowledge of the statistical distribution of directive gains for both antennae and the effective scattering cross-section per unit volume;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the range of angles in which the integrated scattering from precipitation can be considered as isotropic and, in general, determination of the relation between this range of angles and the scattering angle, polarization and frequency, in the range 1 to 10 GHz;

2. determination of the average distribution in time and space of observed values of effective scattering cross-section for volumes of the order of one cubic kilometre, as a function of:

---

* This Study Programme, formerly Study Programme 311D(V), was drafted taking into account Question 14/IV. The attention of the International Working Party, set up under Resolution 3, is drawn to this Study Programme.

— height above ground,
— time of day,
— season,
— climatic region;

3. the possible existence of a simple dependence of scattering cross-section on the rate of precipitation (mm of water per hour) in the case of rain, and also for other forms of precipitation giving significant scattering.

Note. — To meet the needs of Study Groups IV and IX, priority should be give to measurements to establish the magnitude of interfering fields at 4 and 6 GHz, with antennae representative of practical systems and on representative paths.

STUDY PROGRAMME 5F/V *

SITE SHIELDING-FACTOR TO BE USED IN CALCULATING COORDINATION DISTANCES

(1965 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that, in accordance with Recommendation No. 1A of the Extraordinary Administrative Radio Conference, Geneva, 1963, a coordination distance should be calculated for earth stations in the frequency bands shared between the space service and the fixed and mobile services;

(b) that in some instances, calculation of the coordination distance may involve the use of a site shielding-factor or an obstacle-gain factor, to allow for the influence of ground relief in the vicinity of an earth station;

(c) that diffraction loss over an isolated ridge may provide less site shielding than that represented by the values of F_s on page 188 of the Final Acts of the Extraordinary Administrative Radio Conference Recommendation No. 1A, while multiple ridges or rounded obstacles may provide more shielding;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the circumstances in which allowance can be made for site shielding or obstacle gain in the calculation of coordination distances;

2. the safe working values of site shielding-factors which can be used in the calculation of coordination distances;

3. the influence of the shape of an obstacle and also multiple obstacles;

---

* This Study Programme, formerly Study Programme 311F(V), has been drafted taking account of Question 14/IV. The attention of Administrations is directed to this Study Programme and to Doc. IV/93 (Japan), 1963-1966, in the hope that as much information of this character as possible may be made available before the XIIth C.C.I.R. Plenary Assembly for the preparation of a Report.

4. the influence of path length, particularly when it is several hundred kilometres, on the value of the shielding factor or obstacle gain associated with a given obstacle in the vicinity of an earth station.

Note. — The results to be furnished under this Study Programme are urgently needed by Administrations and the I.F.R.B.

RESOLUTION 2 *

TROPOSPHERIC PROPAGATION DATA FOR BROADCASTING, SPACE AND POINT-TO-POINT COMMUNICATIONS

(1963)

The C.C.I.R.,

CONSIDERING

(a) that the curves for broadcasting and mobile services attached to Recommendation 370-1 should be kept under review, in the light of new experimental data;

(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 telecommunication 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 Party should be established, to continue the examination of all available data;
2. that the Working Party should propose revisions of Recommendation 370-1 as these appear desirable;
3. that the Working Party should study methods of determining, as accurately and concisely as possible, the transmission loss (see Report 244 which is a provisional answer to this problem) 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 Party 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 Party should be undertaken by the United Kingdom;
5. that the Working Party should work in close collaboration with the International Working Party established under Resolution 3;
6. that, as far as possible, the work of the Party should be conducted by correspondence;
7. that the Working Party should prepare a report prior to the XIIth Plenary Assembly of the C.C.I.R.

---

* This Resolution replaces Resolutions 23 and 41.

STUDY PROGRAMME 6A/V *

INFLUENCE OF IRREGULAR TERRAIN ON TROPOSPHERIC PROPAGATION

(1951 - 1953 - 1956 - 1959 - 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 a 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;
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.

---

* This Study Programme, formerly Study Programme 188(V), does not arise from any Question under study.

STUDY PROGRAMME 7A/V *

VHF AND UHF PROPAGATION CURVES IN THE FREQUENCY RANGE 30 MHz TO 1 GHz

Broadcasting and mobile service

(1963 - 1966)

The C.C.I.R.,

CONSIDERING

that the provisional propagation curves given in Recommendation 370–1 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 recordings of field strength or transmission loss at frequencies between 30 MHz and 1 GHz, 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 370–1, 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 transmitting antenna heights of between 9 m and 1200 m and receiving antenna heights between 2 m and 150 m above ground, while aeronautical mobile services may use antennae at heights of up to about 30 000 m above ground;

   Note. — Particular attention should be given to the immediate requirements of the aeronautical mobile service in the frequency band 100 to 140 MHz.
4. particular investigation of the problems of oversea paths and of mixed land and sea paths;
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 resuslt from the existence of an elevated or depressed horizon;
6. investigation 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 370–1.

---

* Formerly Study Programme 189(V)

** Many of these studies relate closely to Study Programme 5D/V.

LIST OF DOCUMENTS CONCERNING STUDY GROUP V

(Period 1963-1966)

Doc.	Origin	Title	Reference
V/1 and Corr. 1	France	Propagation data required for line-of-sight radio-relay systems — Influence of long links	S.P. 185A
V/2	United States of America	Relative effectiveness of indoor and roof-top television reception — New York City UHF-television project	S.P. 189
V/3	United States of America	Comparison of channel 31 measurements with C.C.I.R. propagation curves in the New York City UHF-television project	S.P. 189
V/4	United States of America	Height gain measurements for antennae 3·0 m and 9·1 m above ground	New York City UHF television project
V/5	Federal Socialist Republic of Yugoslavia	Influence of irregular terrain on tropospheric propagation	S.P. 188, §§ 2, 3, 6 and 7
V/6	Federal Socialist Republic of Yugoslavia	Effects of tropospheric refraction at frequencies below 10 MHz	S.P. 246A, § 2
V/7	Federal Socialist Republic of Yugoslavia	Ground-wave propagation over inhomogeneous earth	S.P. 246B, §§ 3 and 4
V/8	France	Propagation data required for line-of-sight radio-relay systems — Determination of the necessary antenna clearance	S.P. 185A and 192
V/9	United Kingdom	VHF and UHF propagation curves for the frequency range 40 MHz to 1000 MHz — Broadcasting and mobile services	S.P. 189 Rec. 370
V/10	United Kingdom	Influence of the non-ionized regions of the atmosphere on wave propagation	Rep. 234
V/11	United Kingdom	Propagation data required for line-of-sight radio-relay systems — Method for estimating the propagation fading on line-of-sight microwave links in the United Kingdom	Q. 185 S.P. 185A
V/12	United States of America	Draft Question — Tropospheric radio-relay systems diversity techniques	
V/13	United States of America	Draft revision of Recommendation 310 — Definitions of terms relating to propagation in the troposphere	Rec. 310

Doc.	Origin	Title	Reference
V/14	France	Proposed modifications to Question 185 (V) — Propagation data required for radio-relay systems	Q. 185 S.P. 185A, 185B, 190 and 191
V/15	France	Determination of reduction in antenna gain in beyond-the-horizon propagation	S.P. 139 and 185B
V/16	France	Limits on the use of the refractive index at the surface of the earth (for beyond-the-horizon circuits)	S.P. 192
V/17	United Kingdom	Coordination distance between space and terrestrial services in shared frequency bands	S.P. 190
V/18	United Kingdom	Influence of irregular terrain on tropospheric propagation — Screening effect of hills	S.P. 188
V/19	United Kingdom	Advantages to be gained by using orthogonal wave polarizations in the planning of broadcasting services in the VHF (metric) and UHF (decimetric) bands	Rep. 122
V/20	United Kingdom	VHF and UHF propagation curves in the frequency range from 40 MHz to 1000 MHz-Broadcasting and mobile services — A new method for estimating field strengths over mixed land/sea paths at UHF	Rep. 239
V/21	Federal Republic of Germany	Radio transmissions utilizing inhomogeneities in the troposphere (commonly termed " scattering ")	S.P. 139
V/22	Federal Republic of Germany	Fading of signals propagated by the troposphere	S.P. 176
V/23	Federal Republic of Germany	Propagation data required for line-of-sight radio-relay systems — Propagation on 40 to 140 km overland paths at frequencies between 400 MHz and 10 GHz	S.P. 185A
V/24	Federal Republic of Germany	VHF and UHF propagation curves in the frequency range 40 MHz to 1 GHz — Attenuation produced by the general roughness of the ground, generally termed " terrain factor "	S.P. 188 and 189
V/25	Federal Republic of Germany	Influence of the non-ionized regions of the atmosphere on wave propagation	S.P. 192
V/26	Federal Republic of Germany	Influence of the non-ionized regions of the atmosphere on wave propagation	S.P. 192
V/27	People's Republic of Poland	Radio-climatological data relative to the values of N_o for central Poland	S.P. 192
V/28	People's Republic of Poland	Empirical method of evaluation of the attenuation correction factor to VHF and UHF propagation curves for the frequency bands I to V	S.P. 189

Doc.	Origin	Title	Reference
V/29	Japan	Influence of irregular terrain on tropospheric propagation — Long-term properties of UHF path loss and multipath distortion on over-the-horizon radio links over a path with obstacle gain	S.P. 188 and 185B
V/30	C.C.I.R. Secretariat	Submission of Docs. IV/148; IV/115 (Rev.1); IV/122 (Rev. 1); IV/123; IV/125 (Rev. 3); IV/129; IV/142 (Rev. 1); IV/146.	
V/31	C.C.I.R. Secretariat	Note by the Director *a. i.* C.C.I.R.	Atlas of ground-wave propagation curves
V/32	Chairman, Study Group V	Propagation over the surface of the Earth and through the non-ionized regions of the atmosphere	
V/33	United Kingdom	Study of possibilities of interference occurring between earth stations and terrestrial stations sharing the same frequency-bands and located within the coordination distance — Presentation of data for calculating transmission loss over tropospheric paths	Rep. 244
V/34	People's Republic of Poland	Investigation of the influence of urban terrain on the attenuation of field strength in the VHF band	S.P. 188
V/35	People's Republic of Poland	Examination of the dependence of the field strength level on the receiving antenna height in the urban area in the VHF band	S.P. 188 and 189
V/36	Chairman, International Working Party V/2	Influence of the non-ionized regions of the atmosphere on the propagation of waves	Res. 3
V/37	O.I.R.T.	Correction factors for the field-strength curves F (50,50) as a function of terrain irregularities	S.P. 188 and 189
V/38	O.I.R.T.	Correction of electromagnetic waves propagation curves F (50,50) in bands IV to V over irregular terrain	S.P. 188 and 189
V/39	O.I.R.T.	The dependence of field-strength on height between 3 and 10 m in the country-side and in towns at 780 MHz	S.P. 188 and 189
V/40	Working Group V-C	Proposed retention of Reports 242 and 243	
V/41 (I/19) (II/29)	Study Groups, I, II and V	Summary record of the joint opening session	
V/42	Federal Republic of Germany	Influence of irregular terrain on tropospheric propagation	S.P. 188
V/43	Federal Republic of Germany	Influence of irregular terrain on tropospheric propagation — Third contribution	S.P. 188

Doc.	Origin	Title	Reference
V/44	Federal Republic of Germany	Investigation of multipath transmission through the troposphere. — Multipath transmission over line-of-sight paths with free first Fresnel zone	S.P. 57
V/45	U.S.S.R.	An engineering method of calculating the attenuation factor in long-distance tropospheric propagation of ultra-short waves	S.P. 185B Res. 2
V/46	U.S.S.R.	Determination of transmission loss of antennae	S.P. 139 and 185B
V/47	Italy	Propagation data required for line-of-sight radio-relay systems — Influence of oversea propagation on the transmission of colour television signals	S.P. 185A
V/48	C.C.I.R. Secretariat	Submission of Doc. IV/93 — Feasibility of frequency sharing between communication satellite systems and terrestrial radio services	S.P. 235A
V/49	C.C.I.R. Secretariat	Submission of Doc. IX/131 (Rev. 2) — Revision of Report 285 — Tropospheric- scatter radio-relay systems — Transmission, interference and interconnection	Q. 260 (IX)
V/50	C.C.I.R. Secretariat	List of documents issued (V/1 to V/50)	
V/51	Study Group V	Summary record of the first meeting	
V/52	France	Tropospheric propagation data for broadcasting, space and point-to-point communications	
V/53	Working Group V-B	Revision of Report 240	Rep. 240
V/54	Working Group V-C	Revision of Report 233 — Influence of the atmosphere on wave propagation	Rep. 233
V/55	Study Group V	Summary record of the second meeting	
V/56	International Working Party	Summary record of meeting held on 11 June, 1965	
V/57	Working Group V-B	Propagation curves for VHF/UHF broadcasting in the African continent	Rep. 240
V/58	Working Group V-C	Multipath and fading of signals propagated by the troposphere	Draft S.P.
V/59	Study Group V	Summary record of the third meeting	
V/60 and Corr. 1	Working Group V-B	Draft revision of Report 236 — Influence of irregular terrain on tropospheric propagation — Point-to-point propagation	Rep. 236

Doc.	Origin	Title	Reference
V/61	Working Group V-A	Proposed action on Doc. V/30	
V/62	Study Group V	Summary record of the fourth meeting	
V/63	Working Group V-B	Proposed action on Reports 227, 228, 229, 230, 235	
V/64	Working Group V-B	Ground-wave propagation curves for frequencies below 10 MHz	Rec. 368
V/65	Working Group V-B	Presentation of antenna radiation data	Rec. 168
V/66	Working Group V-B	Influence of irregular terrain on tropospheric propagation	S.P. 188
V/67	Working Group V-B	VHF and UHF propagation curves in the frequency range 40 MHz to 1 GHz	S.P. 189
V/68	Working Group V-B	Temporal variations of ground-wave field strength	Rep. 46
V/69	Working Group V-B	Effects of tropospheric refraction at frequencies below 10 MHz	S.P. 246A
V/70	Working Group V-B	Ground-wave propagation over inhomogeneous earth	S.P. 246B
V/71 and Add. 1	Working Group V-B	Draft Revision of Report 239 — Propagation statistics applied to broadcasting and mobile services	S.P. 189
V/72	Working Group V-B	Ground-wave propagation over inhomogeneous earth	S.P. 246B
V/73	Study Group V	Summary record of the fifth meeting	
V/74	Working Group V-A	Propagation factors affecting the calculation of coordination distance	Draft Rep.
V/75	Working Group V-C	Revision of Question 185(V) and the corresponding Study Programmes	
V/76	Working Group V-C	Fading of signals due to multipath transmission in the troposphere	Draft Rep.
V/77 and Add. 1	Working Group V-C	Draft Report — Propagation data required for line-of-sight radio-relay systems	S.P. 185A
V/78	Working Group V-A	Draft new Question in Doc. IV/123 (V/30) — Frequency utilization above the ionosphere and on the far side of the Moon	
V/79 and Corr. 1	Working Group V-B	Draft revision of Rec. 370 — VHF and UHF propagation curves for the frequency range from 30 MHz to 1000 MHz	Rec. 370
V/80	Working Group V-C	Action concerning texts	

Doc.	Origin	Title	Reference
V/81	Study Group V	Summary record of the sixth meeting	
V/82	Working Group on Terminology	Revised draft Recommendation 310	Rec. 310
V/83	Study Group V	Summary record of the seventh and last meeting	
V/84	C.C.I.R. Secretariat	List of participants	
V/85	C.C.I.R. Secretariat	List of documents issued (V/51 to V/85)	
V/86 (IV/168)	C.C.I.R. Secretariat	Comments by the Administration of the United Kingdom on Questions 285(IV) and 286(IV)	Q. 285 and 286 (IV)
V/87	United Kingdom	Tropospheric propagation factors affecting the sharing of the radio-frequency spectrum between radio-relay systems, including space and terrestrial telecommunication systems	S.P. 190
V/88	Federal Republic of Germany	Influence of the non-ionized regions of the atmosphere on wave propagation	S.P. 192, § 1
V/89	United Kingdom	Propagation factors affecting the sharing of the radio-frequency spectrum between space and terrestrial radio-relay systems — Attenuation and screening by vegetation and buildings	S.P. 311E
V/90	Australia	Propagation measurements on 1·9 GHz oversea paths	S.P. 311A
V/91	United Kingdom	VHF and UHF propagation curves for the frequency range from 30 MHz to 1 GHz	Draft Rec.
V/92	United Kingdom	Definitions of terms relating to propagation in the troposphere	Draft Rec.
V/93	United Kingdom	Propagation factors affecting the sharing of the radio-frequency spectrum between space and terrestrial radio-relay systems — Interference effects of rain scatter	S.P. 311E
V/94 (IX/213)	United Kingdom	Proposed modifications to Question 311(V), Study Programmes 311A and 311E(V) — Propagation data required for radio-relay systems including communication-satellite systems	Q. 311 S.P. 311A, 311E
V/95	United States of America	World charts of atmospheric radio refractive index	S.P. 192
V/96	United States of America	World charts of mean monthly ΔN	S.P. 192
V/97	United States of America	World charts of ground-based super-refractive layers	S.P. 192
V/98	United States of America	World charts of ground-based sub-refractive layers	S.P. 311A, 192

Doc.	Origin	Title	Reference
V/99	Italy	Results of propagation measurements in large cities	S.P. 188, § 8
V/100	C.C.I.R. Secretariat	List of documents issued (V/86 to V/100)	
V/101	Japan	Influence of the non-ionized regions of the atmosphere on wave propagation — Attenuation of radio waves due to precipitation	S.P. 192
V/102	Japan	Fading of multipath signals propagated by the troposphere — Space- and frequency-correlations of the received power on line-of-sight paths	Draft. Q.
V/103	Finland	Refractive index in Finland	S.P. 192
V/104 (IV/224) (VI/170)	France	Frequency utilization above the ionosphere and on the far side of the Moon	Q. 288 (IV)
V/105 (IV/225)	France	Propagation data necessary for radio systems and satellite telecommunication systems	Q. 285, 286, 287(IV) and 311
V/106 (II/59) (IX/210)	Italy	Propagation on line-of-sight paths	Q. 311 and 298(IX)
V/107 (IV/227) and Corr. 1	Canada	Effects on system performance due to water on radomes	Q. 284(IV) and 311
V/108	U.S.S.R.	Experimental determination of loss in antenna gain	S.P. 139, 185B, 311B
V/109 (IX/221)	New Zealand	Propagation data required for line-of-sight radio-relay systems — Rapid variations in path length of transmission at SHF due to multipath propagation	S.P. 311A
V/110 (XII/1)	New Zealand	Draft Question — Propagation data required for MF broadcasting systems	
V/111 (IX/222)	New Zealand	Propagation data required for line-of-sight radio-relay systems — Time distribution of path attenuation at 6 GHz	S.P. 311A
V/112	France	Limitation on the use of the index gradient near the earth's surface for the calculation of the equivalent radius of the earth	Draft Rep. S.P. 192
V/113	France	UHF propagation at distances well beyond the horizon	Draft Rep. Draft Rep. S.P. 311E
V/114	France	Variation in the frequency correlation coefficient with circuit length	Draft Q.
V/115 (IV/201) (IX/189)	United States of America	Proposed modifications to Draft Report L.2.g (IV) — Frequency sharing between communication-satellite systems and terrestrial services	Q. 235(IV) and 285(IV) S.P. 235B(IV) and 311E Draft Rep.
V/116	Chairman, Study Group V	Report by the Chairman — Propagation over the surface of the earth and through the non-ionized regions of the atmosphere	

Doc.	Origin	Title	Reference
V/117	O.I.R.T.	Field strength measurements at 1100 MHz at distances 125 - 280 km beyond the optical horizon	S.P. 311B
V/118 and Add. 1	E.B.U.	Planning and construction of VHF and UHF sound and television broadcasting stations	S.P. 188 and 189
V/119	United States of America	Scattering from precipitation as a factor in the siting of earth stations	Q. 285 (IV) and 286 (IV)
V/120	France	The use of certain radio-meteorological parameters	Rep. 233 Draft Rep.
V/121	Federal Republic of Germany	Influence of irregular terrain on tropospheric propagation — The influence of the plane of polarization (horizontal and vertical) on the quality of television reception in bands III and IV	S.P. 188, § 9
V/122	Italy	Draft amendment to Report 228 — Measurement of field strength for VHF (metric) and UHF (decimetric) broadcast services including television	Rep. 228
V/123	Sweden	Field strength measurements — Some test results from an over-the-horizon path in the Baltic Sea area	S.P. 189 and 192
V/124	Study Group V	Summary record of the first meeting	
V/125	Working Group V-B	Amendment of Recommendation 369 — Definition of a basic reference atmosphere	
V/126	Working Group V-C	Amendment of Report 229 — Determination of the electrical characteristics of the surface of the earth	
V/127	Working Group V-C	Amendment of Draft Report G.1.e(V) — Influence of irregular terrain on tropospheric propagation	
V/128	Working Group V-C	Amendment to Report 228 — Measurement of field strength for VHF (metric) and UHF (decimetric) broadcast services including television	
V/129	India	Results of some studies on extended range VHF propagation in northern and eastern part of India	S.P. 139, 189 and 192
V/130	Working Group V-C	Draft Report G.1.g (V) — Propagation statistics applied to broadcasting and mobile services on frequencies from 30 to 1000 MHz	S.P. 189
V/131	Working Group V-C	Draft revision of Recommendation 370 — VHF and UHF propagation curves for the frequency range from 30 MHz to 1000 MHz	Draft Rec.

Doc.	Origin	Title	Reference
V/132	Study Group V	Documents	
V/133	Working Group V-E	Revision of Study Programme 311E(V)	
V/134	Working Group V-E	Revision of Study Programme 311F(V)	
V/135	Working Group V-E	Revision of Study Programme 311E(V)	
V/136	Working Group V-B	Draft amendment to Draft Report G.1.d(V) — Influence of the non-ionized atmosphere on wave propagation — Ground-ground link	S.P. 192
V/137	Study Group V	Amendment of Draft Report G.1.f(V) — Fading of signals due to multipath transmission in the troposphere	
V/138	Study Group V	Amendment of Draft Report G.1.j(V) — Propagation data required for line-of-sight radio-relay systems	
V/139	Study Group V	Amendment to Question 311(V)	
V/140	Study Group V	Amendments to Draft Question G.1.m (V) — Fading of multipath signals propagated by the troposphere	
V/141	Study Group V	Amendments to Study Programme 311A(V) — Propagation data required for line-of-sight radio-relay systems	
V/142	Study Group V	Modification of Report 231 — Reference atmosphere	
V/143	Working Group V-A	Proposed modifications and corrigenda to Report 244 — Estimation of tropospheric-wave transmission loss	
V/144	Study Group V	Draft Question — Influence of the non-ionized regions of the atmosphere on wave propagation — Radiometeorology	
V/145	Study Group V	Report 230 — Ground-wave propagation over inhomogeneous earth	
V/146	Study Group V	Modification to Report 238	
V/147 and Add. 1	Study Group V	Draft Recommendation G.1.b (V) — Definitions of terms relating to propagation in the troposphere	
V/148	Study Group V	Summary record of the second meeting	
V/149	Study Group V	List of texts cancelled	
V/150	C.C.I.R. Secretariat	List of documents issued (V/101 to V/157)	
V/151	Study Group V	List of texts maintained unchanged	

Doc.	Origin	Title	Reference
V/152	Study Group V	Summary record of the third meeting	
V/153	Working Group V-E	Draft Report — Influence of scattering from precipitation on the siting of earth stations	S.P. 311E
V/154	Working Group V-B	Report 234 — Influence of the non-ionized regions of the atmosphere on the propagation of waves — Earth-space propagation	S.P. 191 and 192
V/155	Study Group V	Summary record of the fourth meeting	
V/156	Study Group V	Summary record of the fifth and last meeting	
V/157	Study Group V	Status of texts	

LIST OF DOCUMENTS OF THE XIth PLENARY ASSEMBLY ESTABLISHED BY STUDY GROUP V

Doc.	Title	Final text
V/1001	Propagation data required for radio-relay systems — Collection of data	Rep. 241–1
V/1002	Frequency utilization above the ionosphere and on the far side of the Moon	Rep. 336
V/1003	Presentation of antenna radiation data	Rec. 168–1
V/1004	Ground-wave propagation over inhomogeneous earth	Q. 1/V
V/1005	Effects of tropospheric refraction at frequencies below 10 MHz	Q. 3/V
V/1006	VHF and UHF propagation curves in the frequency range 30 MHz to 1 GHz — Broadcasting and mobile services	S.P. 7A/V
V/1007	Influence of irregular terrain on tropospheric propagation	Rep. 236–1
V/1008	Measurement of field strength for VHF (metric) and UHF (decimetric) broadcast services including television	Rep. 228–1
V/1009	Definition of a basic reference atmosphere	Rec. 369–1
V/1010	Propagation factors affecting the sharing of the radio-frequency spectrum between space and terrestrial radio-relay systems	S.P. 5D/V
V/1011	Influence of scattering from precipitation on the siting of earth stations	S.P. 5E/V
V/1012	Site shielding-factor to be used in calculating coordination distances	S.P. 5F/V
V/1013	Propagation data required for terrestrial radio-relay systems and communication-satellite systems	Q. 5/V
V/1014	Propagation factors affecting the calculation of coordination distance	Rep. 337
V/1015	Fading of multipath signals propagated by the troposphere	Q. 4/V
V/1016	Propagation data required for line-of-sight radio-relay systems	S.P. 5A/V
V/1017	Propagation data required for line-of-sight radio-relay systems	Rep. 338
V/1018	Definitions of terms relating to propagation in the troposphere	Rec. 310–1
V/1019	Influence of the non-ionized regions of the atmosphere on wave propagation — Radio-meteorology	Q. 2/V
V/1020	Influence of scattering from precipitation on the siting of earth stations	Rep. 339
V/1021	Reference atmosphere	Rep. 231–1
V/1022	Estimation of tropospheric-wave transmission loss	Rep. 244–1
V/1023	VHF and UHF propagation curves for the frequency range from 30 MHz to 1000 MHz — Broadcasting and mobile services	Rec. 370–1

Doc.	Title	Final text
V/1024	Fading of signals due to multipath transmission in the troposphere	Rep. 237–1
V/1025	Propagation statistics applied to broadcasting and mobile services on frequencies from 30 to 1000 MHz	Rep. 239–1
V/1026	Influence of the non-ionized atmosphere on wave propagation — Ground-ground propagation	Rep. 233–1
V/1027	Influence of the non-ionized regions of the atmosphere on the propagation of waves — Earth-space propagation	Rep. 234–1
V/1028	List of documents issued (V/1001 to V/1028)	

RECOMMENDATIONS OF SUB-SECTION G.2: IONOSPHERIC PROPAGATION

RECOMMENDATION 313-1

EXCHANGE OF INFORMATION FOR THE PREPARATION OF SHORT-TERM FORECASTS AND THE TRANSMISSION OF IONOSPHERIC DISTURBANCE WARNINGS

(1951 - 1959 - 1966)

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 through the International Ursigram and World Days Service (I.U.W.D.S.), between some Administrations, operating services and the organizations studying the characteristics of the ionosphere and preparing forecasts of ionospheric disturbance;

(g) that synoptic codes, available through the I.U.W.D.S., have proved their usefulness in the dissemination of information for the preparation of short-term forecasts;

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;

3. that, of the data thus assembled, those which are of use for forecasting within 48 hours should be disseminated, in accordance with the I.U.W.D.S. decisions, by suitable available communication channels;

4. that the other data, of the 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 I.U.W.D.S. 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 Administrations 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 I.U.W.D.S., these facilities should be maintained, and, if necessary, extended in the future.

RECOMMENDATION 371

CHOICE OF SOLAR INDICES FOR IONOSPHERIC PROPAGATION

(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_{F2} 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_{F2}, 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_{F2} 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_{F2}. 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-median 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

(1951 – 1953 – 1956 – 1959 – 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 (published separately) should be used until sufficient new data to justify further revision have been accumulated and made available.

RECOMMENDATION 373–1

DEFINITIONS OF MAXIMUM TRANSMISSION FREQUENCIES

(1959 – 1963 – 1966)

The C.C.I.R.,

CONSIDERING

(a) that the upper limiting frequency of transmission for a given propagation path is perhaps the single most extensively used propagation parameter in HF communications;

---

* This Recommendation, together with Resolution 8, replaces Recommendation 315.

(b) that the increasing use of HF sounding equipment requires specialized and unambiguous terminology;

(c) that the World-Wide Soundings Committee of the U.R.S.I. has recommended the use of the conventional transmission curve for rapid analysis of ionograms [1];

(d) that experience has shown that transmission is often possible above the maximum theoretical frequency, calculated for waves assumed to have been propagated solely by ionospheric refraction (i.e. without ionospheric and ground scatter);

(e) that some prediction services use empirical correction factors to take account of this experience when making predictions;

(f) that U.R.S.I. has recently recommended a set of terms (based on the findings of the Conference on Oblique Sounding, Lindau, 1963), to describe maximum transmission frequencies (see Notes below);

UNANIMOUSLY RECOMMENDS

1. that the term *operational MUF* should denote the highest frequency that permits acceptable operation between given points at a given time, and under specified working conditions; the word " operational " could well be dropped in common usage (Note 1);

2. that the term *classical MUF* should denote the highest frequency that can be propagated by a particular mode between specified terminals by ionospheric refraction alone; it can be experimentally determined as the frequency at which the high- and low-angle rays merge into a single ray (Note 2);

3. that the term *standard MUF* should denote an approximation to the classical MUF, that is obtained by application of the conventional transmission curve [1] to vertical-incidence ionograms, together with the use of a distance factor (Note 3);

4. that the term *maximum observed frequency (MOF)*, introduced by U.R.S.I., should denote the highest frequency that can be detected on an oblique-incidence ionogram (Note 4);

5. that the terms classical MUF and standard MUF are to be applied only to propagation involving the regular layers (Note 5);

6. that users of predictions should familiarise themselves with the new terminology, recommended by U.R.S.I., which is already in limited use, with the hope that it might ultimately replace the old terminology (Note 6).

Note 1. — This term, or an equivalent, has not been defined by U.R.S.I.

Note 2. — U.R.S.I. recommends the term *junction frequency* (JF) for the classical MUF. If either term is used without reference to a particular mode of propagation, the highest of the values for the individually possible modes is implied.

Note 3. — U.R.S.I. recommends the term *estimated junction frequency (EJF)* for the standard MUF, which is, however, widened to include other methods of estimation.

Note 4. — Whenever the term *maximum observed frequency (MOF)* is used, there is the clear implication that an oblique-incidence sounding is being described. With the advent of " communication sounding " in conjunction with operational systems, such a term is required. The term MOF should not be used to describe the highest frequency usable under particular circumstances on a communication circuit (see § 1).

Note 5. — By their nature, the terms *operational MUF* and *maximum observed frequency* are applicable even in circumstances when sporadic-E (E_s) propagation dominates.

Predictions of maximum transmission frequencies involving E_s propagation are as yet of only limited use owing to insufficient knowledge.

Note 6. — In several documents of the C.C.I.R. originating mainly in Study Group VI, the new terms are given in parentheses after the old.

Note 7. — This Recommendation should be brought to the attention of Study Group XIV.

BIBLIOGRAPHY

1. Piggott, W.R. and Rawer, K. *U.R.S.I. handbook on ionogram interpretation and reduction.* Elsevier, Amsterdam (1961).

RECOMMENDATION 434

C.C.I.R. ATLAS OF IONOSPHERIC CHARACTERISTICS

(1966)

The C.C.I.R.,

CONSIDERING

(a) that International Working Party VI/3 has defined specifications, both for the production of a first edition of the C.C.I.R. Atlas (to be regarded as provisional) and for the studies required before undertaking the production of a further improved edition;

(b) that International Working Party VI/3 has prepared a first edition of the C.C.I.R. Atlas (to be regarded as provisional) in alternative forms, either as a set of charts or as a set of punched cards containing a set of coefficients, for use in a computer;

(c) that the first edition of the Atlas, with accompanying explanation, has been prepared and made available for inspection by Study Group VI at the XIth Plenary Assembly;

(d) that a master set of cards containing the coefficients, together with programmes for computing the functions to which the coefficients apply, will be deposited with C.C.I.R. for purposes of reproduction and sale;

(e) that the cards and programmes can be kept up to date relatively cheaply, while a further edition of the chart form of the Atlas is expensive, so that the cards may include later information than the charts;

UNANIMOUSLY RECOMMENDS

1. that, until future revised editions of this Atlas are available, international organizations, such as the I.F.R.B., should use the punched-card form of the Atlas for the solution of ionospheric problems requiring the information in the Atlas;

2. that persons and organizations, having access to a computer and requiring the information in this Atlas, should use the punched-card form of the Atlas;

3. that in other cases the Atlas in chart form should be used.

Note. — The Director, C.C.I.R. is requested to arrange for the publication of the Atlas and to keep the cards and programmes available for distribution.

RECOMMENDATION 435

SKY-WAVE PROPAGATION CURVES BETWEEN 300 km AND 3500 km AT FREQUENCIES BETWEEN 150 kHz AND 1500 kHz IN THE EUROPEAN BROADCASTING AREA

(1966)

The C.C.I.R.,

CONSIDERING

(a) that there is a need to give guidance to engineers in the planning of broadcast services in the hectometric and kilometric wavebands;

(b) that it is important, for stations working in the same or adjacent frequency channels, to determine the minimum geographical distance of separation required to avoid interference due to long-distance ionospheric transmission;

(c) that the curves in Report 264–1 are based on the statistical analysis of a very large number of experimental data obtained in the European Broadcasting area;

UNANIMOUSLY RECOMMENDS

that formulae (1*a*) and (2*a*) and the curves in Figs. 1, 2, 3, 6 and 7 of Report 264–1, should be adopted for provisional use within the European Broadcasting area.

REPORTS OF SUB-SECTION G.2: IONOSPHERIC PROPAGATION

REPORT 245-1 *

PREDICTION OF SOLAR INDEX

(Study Programme 8A/VI)

(1963 - 1966)

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 19th Zürich cycle diverged 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. 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 [1].

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 [2]. This estimate is improved by adding to it a correction proportional to the departure or 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 1964 inclusive; the sunspot 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.

4. A current review of predictions of solar activity is given in a book by Vitinskii [3], including detailed description of the work at the Astronomical Observatory of Poulkovo, concerning predictions of the maximum for the next solar cycle.

5. In a study undertaken by the Secretariat of the C.C.I.R. [4], it was concluded that, in the several methods available for predicting the solar index, the error (r.m.s. value of the

---

* This Report was adopted unanimoulsy.

" predicted value minus the actual value ") generally exceeds 10, and that no new method would be acceptable unless it produced errors of considerably less than 10. Further, new investigations, carried out by the Secretariat of the C.C.I.R., into methods combining both linear and non-linear functions to produce a solar index prediction, failed to produce an improvement on the results of the methods currently employed. It was finally concluded that, in practice, perhaps it is not possible to improve on an error of approximately 10 in the prediction of the solar index. This document [4] provides a useful summary of several prediction methods. Only the statistical methods (comparison of cycles or autocorrelation) are considered useful, the methods based on harmonic analysis having never produced satisfactory results.

BIBLIOGRAPHY

1. Halley, P. and Gervaise, A.M. Essai d'une prévision à long terme de l'activité solaire (An attempt at long-term prediction of solar activity). *Annales des télécommunications, 18,* 94-105 (1963).
2. McNish, A.G. and Lincoln, J.V. Prediction of sunspot numbers. *Trans. American Geophys. Union,* **30**, 5, 673-685 (1949).
3. Vitinskii, J.I. Prediction of solar activity. (In Russian) Moscow (1963).
4. C.C.I.R. Doc. 254, Warsaw, 1956. Preliminary report on Recommendation 117, Prediction of solar index.

REPORT 246-1 *

CHOICE OF BASIC INDICES FOR IONOSPHERIC PROPAGATION

(1953 - 1956 - 1959 - 1963 - 1966)

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 and to present information on other possible indices. The term " ionospheric propagation ", which was used in Study Programme 150, 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;

---

* This Report was adopted unanimously.

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 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 :

$$R_{12} = \frac{1}{12}\left[\sum_{n-5}^{n+5} R_k + \frac{1}{2}(R_{n+6} + R_{n-6})\right]$$

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, 6], who have presented evidence which shows that the index I_{F2} 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_{F2} was based on measurements of foF2 at ten long-established ionospheric observatories from 1938 to 1963 and has been based on measurements at nine observatories since then. Monthly values of I_{F2} are available from 1938 onwards (see the Telecommunication Journal).

4.2 In view of the high correlation with foF2 and the long series of earlier values, I_{F2} appears to be the best index at present available for making predictions of foF2 up to about nine months ahead. To calculate I_{F2} for a given month, it is necessary to have the monthly median noon values of foF2 at the several observatories, together with statistical data relating to past measurements at the observatories. The statistical data have been made available to the C.C.I.R. (see Annexes I and II), 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 In Canada, an equipment identical to that known as "Ottawa" at the Algonquin Radio Observatory (ARO) at Lake Traverse, Ontario, was put into operation in June 1964 at the Dominion Radio Astrophysical Observatory (DRAO), Penticton, B.C., except that the frequency of operation is 2700 MHz instead of 2800 MHz. Japanese and other laboratories also make regular measurements of solar noise-flux at wavelengths of about 10 cm. Though it is possible, after allowing for small systematic differences, to convert measurements made at one place into the equivalent value at another, 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_{F2}, 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_{F2} with foF2, but it would slightly decrease the small statistical fluctuations which arise when a median value is determined from nine values only.

5.4 It has been suggested by Chaman Lal [7], that the monthly mean value of the diurnal average of foF2 varies as $\sqrt{R + 100Ci}$ throughout the solar cycle. R represents the monthly relative sunspot number and Ci the international character figure for geomagnetic activity. By this expression, the contributions due to both electromagnetic ultraviolet and corpuscular radiations from the Sun are taken into account in producing the ionization in the F2 region.

5.5 *A* long-term prediction of foF2 can also be made on the basis of the prediction of the solar cycle phase; Novysh-Bilinskaia [8] showed that the foF2 variations were very similar in the three high solar cycles 17 – 19.

5.6 Studies have been made independently in the U.S.A. and by Joachim [9] of the correlation between the indices R_{12}, I_{F2} and Φ. The regression between Φ and R_{12} is, with the exception of values of R_{12} between 0 and 50, practically linear, whereas, a curvilinear regression between Φ or R_{12} and I_{F2} was found.

Quite recently, Joachim [10] has studied an effect of ionospheric " hysteresis " of I_{F2} values, as a function of Φ or R_{12}. In fact, for a given value of solar parameters R_{12} or Φ, the ionospheric parameter I_{F2} does not have the same value on the descending part of the solar cycle as on the ascending one. This effect does not exist in the relationship between R_{12} and Φ.

5.7 Chaman Lal [11] has analysed the average-global pattern of F2 ionization over the period 1947 to 1961, and has found that the monthly averages of planetary F2-layer ionization, designated $(\Sigma\ \overline{\mathrm{foF2}})_p$, show marked biannual periodicity with maxima at the months of April and October every year. He has reported that a simple relation of the form

$$(\Sigma\overline{\mathrm{foF2}})_p^2 = K\,\Phi\,S$$

agrees very well with the secular variations of planetary F2-layer ionization.

In this expression K is a constant of proportionality, Φ is the solar flux at 2800 MHz as reported by Covington, and S stands for the seasonal enhancement factor, the monthly values of which are given in Annex III.

The above expression provides a close month-to-month correlation between solar activity and planetary F2-layer ionization. Further development of the above formula has been made [12].

BIBLIOGRAPHY

1. Kundu, M.R. J. Geophys. Res., **65**, 3903 (1960).
2. Minnis, C.M. and Bazzard, G.H. Nature, **181**, 1796 (1958).
3. Eyfrig, R. Nature, **196**, 758 (1962).
4. Medd, W.J. and Covington, A.E. Proc. IRE, **46**, 112 (1958).
5. Minnis, C.M. and Bazzard, G.H. J. Atmos. Terr. Phys., **14**, 213 (1959).
6. Minnis, C.M. Ionospheric indices (in *Advances in Radio Research, Vol. II)*, edited by J.A. Saxton (Academic Press, London and New York, 1964)).
7. Chaman Lal, M. Proc. IEEE, 1471-1474 (November, 1963).
8. Novysh-Bilinskaia, V. Article to appear in Geomagnetism and Aeronomy, (U.S.S.R.).
9. Joachim, M. Study of correlation of the three basic indices of ionospheric propagation: R_{12}, I_{F2} and Φ. Nature **210**, 289-290 (1966).
10. Joachim, M. Un effet d'hystéresis ionosphérique (An effect of ionospheric hysteresis). Comptes rendus des séances de l'Académie des Sciences (Paris), Série B, **263**, 92-94 (4 July, 1966).
11. Chaman Lal, M. Derivation of a formula for planetary F2-layer ionization. *I.T.U. Telecommunication Journal*, **32**, 401-403 (October, 1965).
12. Chaman Lal, M. The development of a formula for the seasonal and secular characteristics of F2-layer critical frequency (ΣfoF2). *I.T.U. Telecommunication Journal*, **33**, 257-262 (July, 1966).

ANNEX I

MONTHLY MEDIAN VALUES OF $100 \times$ fo$F2$ FOR $R_3 = 0$ AND 150

(fo$F2$ is in MHz)

Station	January		February		March		April		May		June		July		August		September		October		November		December	
	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
College	400	1044	424	1013	405	826	405	695	442	625	450	614	419	633	425	620	429	656	458	836	480	1032	445	999
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
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
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(1)	574	1298	584	1289	507	1260	488	1029	470	801	494	686	455	690	469	747	530	951	660	1200	678	1272	664	1225

(1) Also known as Fort Belvoir.

ANNEX II

1. The index I_{F2} is based on the monthly median noon values of foF2 at

Canberra
Churchill
College
Dehli
Godley Head
Huancayo
Slough
Tokyo
Washington *

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 I. 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_{F2} for a month is the median value of all the available values of R'_3.

ANNEX III

TABLE OF SEASONAL ENHANCEMENT FACTORS

January	1·19	July	1·00
February	1·30	August	1·16
March	1·47	September	1·43
April	1·50	October	1·59
May	1·25	November	1·47
June	1·06	December	1·28

REPORT 247-1 **

IDENTIFICATION OF PRECURSORS INDICATIVE OF SHORT-TERM VARIATIONS AND EVALUATION OF THE RELIABILITY OF SHORT-TERM FORECASTS OF IONOSPHERIC PROPAGATION CONDITIONS

(Study Programme 10A/VI)

(1959 - 1963 - 1966)

1. Identification of precursors indicative of short-term variations of ionospheric propagation conditions

Since the International Geophysical Year (I.G.Y.), there have been several advances towards more successful forecasting of sudden-commencement geomagnetic storms and

---

* Also known as Fort Belvoir.

** This Report was adopted unanimously.

associated disturbances of ionospheric propagation that are prevalent during periods of sunspot maximum. Some of these have occurred, or been recognized, since Report 247 [1] was prepared.

A commonly applied sun-earth relationship is, that a geomagnetic storm with associated radio propagation disturbance, is expected to begin within 1 to 2 days, or even sometimes 3 days, of the occurrence of a flare of importance 3 or 3+ (very great), regardless of its position on the Sun. The probability of disturbance is greater if the flare occurs in the sun's central zone. Bell [2] reported that nearly half of the major flares which were located within 30° of the central meridian (CM±30°), and that, over the past three sunspot cycles, 80% of the very great storms arose from within 20° of CM, and all but one of the remainder in the 20° to 39° zone. All but one of these arose from the northern hemisphere. During the past several sunspot cycles, the northern hemisphere of the Sun has been the main source of great magnetic storms. This is in accord with the characteristics of solar activity which have manifested themselves mainly in the northern hemisphere. The percentage of storms coming from the northern solar hemisphere increases with the intensity of the storm, ranging from 50% for the moderate storms, $160 \leqslant \overset{4}{\Sigma} ap \leqslant 299$, to 94% for the very great storms, $\overset{4}{\Sigma} ap \geqslant 1000$: $\overset{4}{\Sigma} ap$ is the sum of the greatest four consecutive 3-hour *ap* indices during the storm.

When a major solar radio noise outburst at frequencies $\leqslant 200$ MHz occurs with its first part in the pre-maximum phase of a solar flare, followed by a second part that is often more intense and of longer duration, geomagnetic disturbance may be expected to begin within 1 to 4 days. This relationship was first noted by Dodson and Hedeman [3], and was confirmed by Sinno [4] and by Warwick and Warwick (5]. The Warwicks approach was to use 18 MHz solar noise bursts which preceded maxima of sudden cosmic noise absorption (S.C.N.A). A special study has been made of Type-IV continuum radio bursts, which are usually followed by a geomagnetic storm. Stress was laid on the importance for forecasts of SHF radiation (observed in the 10 cm and 3 cm ranges), which is the initial phase of Type-IV bursts and which is less directive than VHF radiation characteristics of the following phase [6, 7]. In her study, Bell [2] reported that, of 30 major flares accompanied by full range ($\geqslant 2800$ MHz to $\leqslant 100$ MHz) Type-IV outbursts, 87% were followed by magnetic storm within an interval of 10 hours to 3 days. The probability falls off for Type-IV events of more limited frequency range. Bell also reported that the likelihood of a major flare, with a spectral Type-IV burst to produce a magnetic storm, is independent of the magnetic classification of the sunspot. On the other hand, a $\beta\gamma$ or γ sunspot is about 5 times more likely to produce a major flare with associated Type-IV events than is an α or β sunspot of comparable area.

All of the above solar-geomagnetic relationships are enhanced, if a polar-cap absorption (PCA) event is observed within about six hours following the H-alpha flare. These are the absorption events recognized by Bailey [8] and Reid and Collins [9] on VHF scatter circuits, and by Reid and Leinbach [10] on records from riometers at high latitudes (measurement of cosmic noise absorption through the ionosphere). Obayashi and Hakura [11], and numerous other authors, pointed out that a very close relationship exists between PCA events and spectral Type-IV outbursts. PCA events rarely occur that are not preceded by Type-IV outbursts, and prolonged severe PCA events appear to be always preceded by Type-IV outbursts. The probability of occurrence of PCA events is strongly enhanced if the Type-IV outburst has a particularly well-developed continuum and is of great duration at metric and decametric wavelengths [12]. A comparison between PCA events in the period July 1957 to September 1963 [13], with occurrence of magnetic storms, shows that magnetic storms followed the onset of PCA events within three days 92% of the time. The PCA event appears to be the most reliable precursor to magnetic (and ionospheric and radio-propagation) disturbance so far recognized. During PCA, the occurrence of a sudden commencement of geomagnetic storm could be a good precursor of the disturbance which tends to move southward with the main phase of the magnetic storm. An example of this has been shown by Jelly [14]. A valuable review and bibliography is given by Bailey [13].

If one is interested in the identification of the centres which produce outbursts of Type-IV, one should note that these centres have several characteristics:

— the solar flux density at 3 cm is clearly more enhanced than in general [6, 15];

— the spectral ratio of emission at 3 cm to emission at 10 cm is greater than the mean and is of the order of unity [16];

— a fairly rare configuration occurring in certain sunspot regions has been found to be very strongly related to the productivity of high energy protons in that region [17, 18, 19]. This configuration has been called " δ configuration ", defined as the occurrence of spots of opposite polarity within 2° of one another and in the same penumbra [20];

— Caroubalos has shown that " repetition centres " (that is to say centres associated with many Type-IV outbursts), are capable of producing several successive geomagnetic disturbances, which can be used for forecasting, especially since these centres are usually grouped in " privileged areas of the Sun " [7].

Techniques, other than optical, for the detection of solar flares have been developed. Mitra [21] employs the sudden enhancement of signal (SES) observed on continuous recordings of field strength on a distant long-wave transmission. Such sudden increases in signal correspond in occurrence to observations of solar flares.

In the VLF range there exists some kind of extraterrestrial noise known as " dawn chorus ", as first proposed by Tremellen, which is known to have its origin in the exosphere though the producing mechanism has not yet been fully understood. By a preliminary investigation into its correlation with ionospheric disturbances [22], Mattern has shown that the occurrence of " dawn chorus " could possibly be used as a precursor of such disturbances.

Some information on the occurrence of solar flares and the duration of the associated short-wave fadeouts (SWF) and sudden enhancement of atmospherics (SEA), during part of the 1954 – 1964 solar cycle is given by Brice and Evans [23]. Statistical characteristics of the relationships between optical observations of solar flares, solar radio noise bursts, magnetic crochets, and the various types of sudden ionospheric disturbance have been studied by Mitra *et al* [24] for the International Geophysical Year (1 July, 1957 – 31 December, 1958). Sudden phase anomalies (SPA), observed on very low-frequency transmissions, are a useful means of detecting the occurrence of flares [25], and may prove to be one of the most sensitive. An automatic flare-detection device has been developed using the VLF-SPA effect. Both the SES and the SPA are of the broader class of events known as sudden ionospheric disturbances (SID). SID's may occur on a radio path only when a sufficient portion of the path is in sunlight, therefore the average solar zenith angle for the path becomes a parameter in the evaluation of SES and SPA. In studies of X-ray and Lyman-α emission data obtained by means of satellites, Kreplin *et al* [26] have shown that X-rays, but not Lyman-α emission, are significant in the production of ionospheric effects concurrent with solar flares. Further, that the Sun does not normally emit X-rays in the spectral range 0–8Å, which fall within the limits of measurement, but that most of the time when such a flux is observed (exceeding the limit of measurement $0{\cdot}6 \times 10^{-3}$ erg.cm^{-2}.s^{-1} of 2×10^{6} °K radiation), one or more distinct solar events are visible on the Sun. When the 0–8Å flux exceeds 2×10^{-3} erg.cm^{-2}.s^{-1}, short-wave fadeouts and other SID effects are noticeable on Earth. Also, active prominence regions, bright limb surge regions and small limb flares produce X-ray events apparently of the same sort as those accompanying major disk-flares. Further study of solar-activity associated X-ray events, it is hoped, may prove their usefulness in the prediction and evaluation of geomagnetic storms.

Snyder *et al* [27] found a very close relationship (correlation coefficient, assuming zero time lag, of 0·73), between the velocity of the solar wind and the geomagnetic K_p indices. They used data obtained from Mariner II during the period 29 August 1962 through 3 January 1963. Little evidence of correlation was found between plasma velocity and cosmic-ray variations or solar activity indices.

The Cosmos, Elektron, Explorer, Mariner, and OGO experiments, among others, have done much to expand man's knowledge of the Earth and its atmosphere, of interplanetary space, and of solar radiation and particle fluxes. The IMP-1 Experiment (Explorer XVIII), launched on 27 November 1963, provided accurate measurements of interplanetary magnetic fields [28]. Other experiments, such as OSO, have been designed primarily for the study of the Sun and solar activity. That real-time reporting of observations made in space is becoming possible was amply demonstrated by lunar-probe Ranger VII.

Satellite measurements of energetic particles could be a very useful real-time input to a warning system. The detection of protons over the polar region would give more definite information about the onset of PCA than any other system. A polar-orbiting satellite could provide such information on every pass. Also, the precipitation of electrons over auroral latitudes has been shown to be clearly associated with auroral absorption [29].

In the U.S.S.R., effective short-term forecasts for the different zones (polar-cap, central, north-east, and south parts of the U.S.S.R.), have been based on synoptic charts of ΔfoF2, Δf_{min} and fEs >4 MHz [30, 31, 32, 33, 34, 35]. This system necessitates a rapid interchange of ionospheric information from a network of stations, especially ones 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.

In the U.S.A. at I.T.S.A., a programme is under development to produce world-wide synoptic maps of ΔfoF2 by means of computer techniques. This will provide the means for making synoptic maps for a given instant, provided ionospheric foF2 data are digitalised and transmitted to the computer on a real-time basis. Ionospheric data from measurements made by oblique soundings and by satellites are being investigated to augment data from vertical soundings. Also in progress is another programme to determine the spatial and time-lag dependence of ionospheric characteristics. This work will help determine the optimum feasible distribution of ionospheric stations to provide coverage sufficiently complete for the synoptic mapping and other programmes.

In the field of infra-sonics, travelling pressure waves during periods of geomagnetic activity have been recorded by Chrzanowski *et al* [36], at a microphone station located at Washington, D.C. Other microphone stations are operating at Boulder, Colorado and Boston, Massachussets and a fourth is being constructed in Israel. Recent evidence indicates periods of from 50 to 90 s, and pressure amplitudes, zero-to-peak, from 1 to 8 dynes/cm^2 for the geomagnetic activity related pressure waves. These phenomena seem to originate in, or near, the auroral zones, probably near local midnight, and probably from E-layer heights or above. Direction-finding techniques employed by each of the four microphone stations should establish the origin of the infra-sonic pressure waves.

The 27-day recurrence patterns of geomagnetic activity appear most strongly during the declining phase of the solar cycle. Ochs and Beckmann [37] found that disturbances tended to recur, even at sunspot maximum, although the recurrent period was not constant at 27 days, but varied from 27 to 31 days. 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. In these investigations the quality figure used by the Administration of the Federal Republic of Germany (see § 2.4) proved to be useful and, in some respects, even superior to other indices of short-term geomagnetic and ionospheric variations.

Considerable progress has been made in the detection and evaluation of precursors to geomagnetic storms and the related radio-propagation disturbances. The need is apparent for forecast purposes 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 through the auspices of the International Ursigram and World Days Service. There is an ever increasing need for certain kinds of information to be reported on a real-time, or near real-time, basis.

2. Usefulness and reliability of short-term forecasts

Progress in the improvement of short-term ionospheric disturbance forecast 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.

Several methods have been used [1] to evaluate the forecasts issued by the various Administrations. They are as follows:

2.1 $\mathrm{M} = (x\text{-}ky)/S$ (used by the United Kingdom)

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).

2.2 $R = A^2/S_1S_2$ (suggested by Japan)

where

A is the number of storm days correctly forecast,
S_1 is the number of storm days forecast,
S_2 is the number of actual storm days.

The index M is designed to measure the usefulness of a set of short-term predictions in a radiocommunications organization. On the other hand, the index R 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 [38].

2.3 At I.T.S.A. 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, is computed. Periods observed to have been quiet and disturbed are analysed separately. 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 worth than the correct forecasting of a continuance of an existing situation.

The C.R.P.L. technique is covered extensively in the CRPL-RWS descriptive literature available, on request, from C.R.P.L. Radio Warning Services in the U.S.A. (see Report 248-1). The CRPL-RWS literature also describes fully the forecast services available from I.T.S.A. (C.R.P.L.).

2.4 At the FTZ in the Federal Republic of Germany, a quality figure is in use which takes into account the highest and lowest observable frequency for a given path as well as the received field strength, and which relates the quality of a given day to the average conditions of one solar rotation [39]. This quality figure brings to evidence variations of propagation conditions not only during disturbed periods but also during quiet periods. It is used also for comparison with short-term forecasts and the study of their reliability [40].

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 [41]. 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.

Liakhova [42] found that, in the auroral zone during disturbance, when reflections from the F2 layer do exist, foF2 does not undergo strong fluctuations over periods of 15 to 30 minutes. This indicates that relatively stable communications may be possible in the high latitudes during the disturbed periods.

BIBLIOGRAPHY

1. C.C.I.R., Report 247. Identification of precursors indicative of short-term variations and evaluation of reliability of short-term forecasts of ionospheric propagation conditions. Documents of the Xth Plenary Assembly of the C.C.I.R., II, 251, Geneva (1963).
2. Bell, B. Type-IV solar radio bursts, geomagnetic storms, and polar cap absorption (PCA) events. Smithsonian Contributions to Astro-physics, **8**, 3, 119-131 (1963).
3. Dodson, H.W. and Hedeman, R.W. Geomagnetic disturbances associated with solar flares with major premaximum bursts at radio frequencies 200 Mc/s. *J. Geophys. Res.*, **63**, 77 (1958).
4. Sinno, K. Method of magnetic storm forecasting from the active flares accompanied by the solar noise outbursts. *J. Radio Research Laboratories*, **4**, 267 (1957).
5. Warwick, C.S. and Warwick, J.W. Flare associated bursts at 18 Mc/s. IAU/URSI Paris Symposium on Radio Astronomy, R.N.Bracewell, Ed.,Stanford (1959).
6. Pick, M. Evolution des émissions radioélectriques solaires de type IV et leur relation avec d'autres phénomènes solaires et géophysiques. (Evolution of solar radio emissions of Type-IV and their relation to other solar and geophysical phenomena). *Ann. Astrophys.* **24**, 3, 183 (1961).
7. Caroubalos, C. Contribution à l'étude de l'activité solaire en relation avec ses effets géophysiques (Contribution to the study of solar activity in relation to geophysical effects). *Ann. Astrophys.* 27, 5, 333 (1964).
8. Bailey, D.K.
   (a) Disturbances in the lower ionosphere observed at VHF following the solar flare of 23 February 1956, with particular reference to auroral-zone absorption. *J. Geophys. Res.*, **62**, (1957).

(b) Abnormal ionization in the lower ionosphere associated with cosmic-ray flux enhancements. *Proc. IRE*, **47**, 255 (1959).

9. Reid, G.C. and Collins, C. Observations of abnormal VHF radio wave absorption at medium and high latitudes. *J. Atmos. Terr. Phys.*, **14**, 63 (1959).
10. Reid, G.C. and Leinbach, H. Low energy cosmic-ray events associated with solar flares. *J. Geophys. Res.*, **64**, 1801 (1959).
11. Obayashi, T. and Hakura, Y. Enhanced ionization in the polar ionosphere caused by solar corpuscular emissions. *J. Radio Research Lab., Japan*, **7**, 27-65 (1960).
12. Thompson, A.R. and Maxwell, A. Solar radio bursts and low energy cosmic rays. *Nature*, **185**, 89 (1960).
13. Bailey, D.K. Polar-cap absorption. *Planet. Space Sci.*, **12**, 495-541 (1964).
14. Jelly, D.H. The effect of polar-cap absorption on LF oblique-incidence circuits. *J. Geophys. Res.*, **68**, 1705, (1963).
15. Boischot, A. Study of the slowly varying component at 9400 Mc/s as a function of solar activity. *N.A.S.A. Symposium on " Physics of the Solar Flares "* 203, (Greenbelt C, 28-30 October, 1963).
16. Tanaka, H. and Kakinuma, T. The relation between the spectrum of slowly varying components of solar radio emission and solar proton events. *Rep. of Ion. and Space Res. in Japan*, XVIII, 32 (1964).
17. Ellison, M.A., McKenna, S. and Reid, J.H. A description and discussion of the ten great solar flares which have generated cosmic noise at ground level. *Dunsink Obs. Publ.* I, 3 (1961).
18. Křivský, L. Y-shaped stage of cosmic ray flares development as phase conditioning ejection. *Bull. Astr. Inst. Czech.* **14**, 77 (1963).
19. Martres, M.J. and Pick, M. Caractères propres aux émissions chromosphériques associées aux émissions radioélectriques. (Characteristics of solar flares associated with radio flux emissions). *Ann. Astrophys.* **25**(5) (1962).
20. Züngel, H. Die Flare — Häufigkeit in Fleckengruppen unterschiedlicher Klasse und magnetischer Struktur. (The flare frequency in sunspot groups of different classes and magnetic structure). *Astron. Nach.* **285**, 271 (1960).
21. Mitra, S.N. A radio method of detecting solar flares. *J. Atmos. Terr. Phys.*, **26**, 375-398 (1964).
22. Mattern, G. Zusammenhänge zwischen dawn-chorus Beobachtungen und den Güteziffern des Funkverkehrs (Relations between the observations of dawn-chorus and the quality of propagation). *Zeitschrift für Geophysik*, **32** (1966).
23. Brice, P.J. and Evans, G.O. Performance of long-distance HF radio links terminating in the United Kingdom. *Proc. I.E.E.*, **110**, 1514 (1963).
24. Mitra, A.P., Subrahmanyan, C.V. and Mirjana Karabin Scientific Report No. 19, Radio Propagation Unit, National Physical Laboratory, Delhi, India.
25. Chilton, C.J., Steele, F.K. and Norton, R.B. Very low frequency phase observations of solar flare ionization in the D region of the ionosphere. *J. Geophys. Res.*, **68**, 5421-5435 (1963).
26. Kreplin, R.W., Chubb, T.A. and Friedman, H. X-ray and Lyman-Alpha emission from the sun as measured from the NRL SR-1 satellite. *J. Geophys. Res.*, **67**, 2231-2253 (1962).
27. Snyder, C.W., Neugebauer, M. and Rao, U.R. The solar wind velocity and its correlation with cosmic-ray variations and with solar and geomagnetic activity. *J. Geophys. Res.*, **68**, 6361-6370 (1963).
28. Ness, N.F., Scearce, C.S. and Seek, J.B. Initial results of the IMP-1 magnetic field experiment. *J. Geophys. Res.*, **69**, 3531-3569 (1964).
29. Jelly, D.H., McDiarmid, I.B., and Burrows, J.R. Correlation between intensities of auroral absorption and precipitated electrons. *Can. J. Phys.* **42**, 2411 (1964).
30. Liakhova, L.N. The procedure for forecasting ionospheric and magnetic disturbances and the short-range forecast service at Izmiran. *Trudy IZMIRAN*, **19** (29), 3-17 (1961).
31. Zevakina, R.A. The seasonal variation of ionospheric disturbances at high latitudes. *Geomagnetism and Aeronomy*, **1**, 83 (1964)
32. Lavrova, Ye. V. Geographic distribution of ionospheric disturbance in the F2-layer. *Geomagnetism and Aeronomy*, **3**, 606 (1964).
33. Goncharova, E.E. The sporadic E layer in the high latitudes in the periods of geomagnetic disturbances. *Geomagnetism and Aeronomy*, **1**, 67 (1964).
34. Besprozvannaya, A.C. and Gorbuchina, G.N. Maps of the distribution in space of the abnormal ionospheric absorption at high latitudes. *Geomagnetism and Aeronomy* (in Russian) **3**, 470 (1962).

35. Judevich, L.A. Space distribution of the anomalous ionisation in the F2-layer at high latitudes. *Geomagnetism and Aeronomy* (in Russian) **3**, 518 (1964).
36. Chrzanowski, P., Green, G., Lemmon, K.T. and Young, J.M. Travelling pressure waves associated with geomagnetic activity. *J. Geophys. Res.*, **66**, 3727 (1961).
37. Ochs, A. and Beckmann, B. On the 27 days recurrence tendency of radio propagation disturbances in the period of high solar activity, in *The effect of disturbances of solar origin on communications*. Edited by G.J. Gassmann, Pergamon Press, London (1963).
38. Minnis, C.M. Ionospheric storm forecasts; formulae for the assessment of their usefulness. *Electronic Technology*, **39**, 172 (1962).
39. Beckmann, B. Betrachtungen zur Güte des Funkwetters (Remarks on radio quality figures). *Fernmeldetechn. Zeitschrift*, **7**, 285 (1954).
40. Beckmann, B., and Ochs, A. Funkwetter im Internationalen Geophysikalischen Jahr (Propagation Conditions during the I.G.Y.), *Nachrichtentechn. Zeitschrift* (N.T.Z.) **13**, 414-418 (1960).
41. Annals of the Corpuscular Conference of the Academy of Science of the U.S.S.R., Moscow (1957).
42. Liakhova, L.N. Latitude-variation of the stability of the F2-layer critical frequencies at times of disturbance. *Trudy IZMIRAN*, **19** (29), 48-51 (1961).

REPORT 248-1 *

AVAILABILITY AND EXCHANGE OF BASIC DATA FOR RADIO PROPAGATION FORECASTS

(Study Programme 10A/VI, Recommendation 313-1)

(1951 - 1953 - 1956 - 1959 - 1963 - 1966)

1. Introduction

Propagation of radio signals in the range 3 to 30 MHz 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 (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 communication 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 re-routed, 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.

---

* This Report was adopted unanimously.

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 for interchange 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).

2.3 *Working documents for long-term predictions*

The following documents are sources of MUF (EJF), 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 ionosphere 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. Since 1962, through the International Ursigram and World Days Service (I.U.W.D.S.) (a Permanent Service of U.R.S.I. in association with I.A.U. and I.U.G.G. adhering to the Federation of Astronomical and Geophysical Services), these data are collected, coordinated and exchanged by rapid means through suitable interchange synoptic codes. 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, communication 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. The regional warning centres (RWC) in France, Federal Republic of Germany, Netherlands, Japan and U.S.S.R., plus associate regional centres in Australia, Czechoslovakia, India, Sweden and U.S.S.R. (Irkutsk), collect data in their regions and forward them by telegraph to the I.U.W.D.S. World Warning Agency (near Washington, D.C., U.S.A.), which has also collected data from its region. The I.U.W.D.S. World Warning Agency makes the final decisions, having advice available from the other centres, whether or not to declare a worldwide GEOPHYSICAL ALERT (issued shortly after an exceptional solar or geophysical event has occurred or started)—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. Code booklets are available from Dr. P. Simon, Secretary, I.U.W.D.S. Steering Committee, Observatoire de Paris, 92, Meudon (France) or Miss J. Virginia Lincoln, Deputy Secretary, I.U.W.D.S. Steering Committee, I.T.S.A., E.S.S.A., Boulder, Colorado, 80302, U.S.A. A manual containing essentially all the solar and geophysical codes in use anywhere since 1950 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 of the I.U.W.D.S. 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.	L.I.A.R.A., Av. Libertador No. 327 Vicente López República Argentina	×		3	
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	
Canada	D.O.T.	Telecommunication and Electronic Branch, Department of Transport, Ottawa	×			
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	I.T.S.A.	Institute for Telecommunication Sciences and Aeronomy, Environmental Science Services Administration, Boulder, Colorado 80302	×		6	×

Country	Organization	Address	A	RC	L	S
		Telecommunication and Space Disturbance Services Center Box 178, Fort Belvoir, Virginia 22060		×		×(1)
	R.C.A. Inc.	R.C.A. Incorporated, 66, Broad Street, New York, N. Y. 10004				×
France	C.N.E.T.	Centre National d'Etudes des télécommunications (a) Service des Ursigrammes Observatoire de Paris 92 Meudon	×	×		×(2)
		(b) Division des Prévisions ionosphériques Château de la Martinière 91 Saclay	×		6	
India	Council of Scientific and Industrial Research	The Secretary, Radio Research Committee, National Physical Laboratories, Hillside Road, New Delhi, 12	×	×	6	
	India Meteorological Dept.	Kodaikanal Observatory				×
	All India Radio	Research Department, All India Radio Indraprastha Estate, New Delhi-1	×		×	
Italy		Istituto Nazionale di Geofisica, Città Universitaria, Roma Tel. adress: Geofisica, Roma. (All messages should begin with the word " Ionosphere ")	×			
Japan	R.R.L.	Radio Research Laboratories, Ministry of Posts and Telecommunications, Kokubunji, Tokyo (WDC)	×	×	3	×(3)

---

(1) Warnings radiated from WWV.

(2) Warnings radiated from Pontoise.

(3) Warnings radiated from JJY.

Country	Organization	Address	A	RC	L	S
Mexico	S.C.T.	Dirección general de Telecommunicaciones, Estación de radiosondes ionosférico, Xola y Universidad, Mexico, (12) D.F.	×			
New Zealand		Carter Observatory (Wellington)				×
Netherlands	P.T.T.	Afdeling " Ionosfeer en Radio-astronomie ", St. Paulus St. 4, Leidschendam	×			
	P.T.T.	P.T.T. Receiver 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.S.R.S.	Director, Radio and Space Research Station Ditton Park Slough, Buckinghamshire Tel. address: Radsearch, Slough (WDC)	×		6	
Republic of South Africa	C.S.I.R.	Telecommunications Research Laboratory, Department of Electrical Engineering, University of Witwatersrand, Johannesburg	×		1	
Sweden		Board of Telecommunications, Radio Department, Fack, Farsta 1 Tel. address: Genradiotec, Stockholm	×	×		
Switzerland		Division Radio et Télévision, Direction Générale des P.T.T., Speichergasse, 6, Bern.	×			
Czechoslovak S.R.		Geophysical Institute, Academy of Sciences, Boční 2, Praha 4, Spořilov		×		

Country	Organization	Address	A	RC	L	S
U.S.S.R.	IZMIRAN	Scientific Research Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Moskovskaya Obl., P/O Akademgorodok	×	×	12 and 1	× (1)
	SIBIZMIR	Irkutsk	×	×		

(1) Warnings radiated from RDZ and RND.

REPORT 249-1 *

IONOSPHERE SOUNDING AT OBLIQUE INCIDENCE

(1959 - 1963 - 1966)

1. Introduction

During the past twenty years, considerable development of the technique of probing the ionosphere at oblique incidence has occurred [1]. Progress continues to be made both in equipment techniques and in application of the data to the understanding of ionospheric phenomena.

This Report concerns chiefly experiments in which pulse equipment is located at both ends of the propagation path. Equipment for operational use in this way is now offered by several manufacturers.

Single frequency pulse transmissions reveal more information about ionospheric modes than CW transmissions; however, the use of sweep-frequency or step-frequency transmissions provides much more information and easier interpretation of data. Circuit design and synchronization is eased by frequency stepping rather than by frequency sweeping and at the same time very little is lost in interpretation of data.

2. Sweep-frequency and step-frequency results at HF and VHF

2.1 The existing theories of propagation seem to be adequate for calculating standard MUF (EJF) for distances up to several hundred kilometres. Oblique-incidence pulse tests in Canada [2], France [3], Federal Republic of Germany [4] and in the U.S.A. [5, 6] indicate that the classical MUF (JF) is observed to be 3% to 10% higher than the standard MUF (EJF) for paths up to about 4000 km.

2.2 For high-latitude paths, the classical MUF(JF) for transmission distances in the 2000 - 3400 km range is normally controlled by the F1 layer especially in the summer [7]. For long paths, the one hop F2 (Pedersen ray) is the principal mode [8] under certain conditions

---

* This Report was adopted unanimously.

over a wide range of latitudes. For certain distances, the F1 layer may determine the highest classical MUF(JF), especially in summer daytime during periods of low solar activity.

Analysis of Es occurrence on oblique-sounding observation and comparison with vertical incidence observations reveal that frequently Es is observed vertically which is not important on oblique transmissions; however the blanketing type of Es does appear to be effective. The reflection coefficient of Es and the ionosonde equipment characteristics must be considered in estimating the usefulness of Es as a reflector at oblique incidence [9].

2.3 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 (JF's) for the ordinary and extraordinary modes as the path length increases. The separation at 2400 km is about 0·2 MHz [10].

2.4 A study of pulse amplitudes at frequencies near the classical MUF(JF) for a 2370 km east-west path in the U.S.A. indicates that "classical MUF(JF) focusing" amounts, on the average, to no more than about 6 dB [10].

2.5 Reciprocity measurements, using oblique-pulse methods have been made to record the signal strength and fading characteristics; high correlation between fading pulsed signals received simultaneously at each end of a path is observed when the signal contains only one magneto-ionic component. When both magneto-ionic waves were present of comparable strength, and using horizontal antennae for transmitting and receiving, the fading correlation was low [11, 12]. Theoretical studies have explained these observations and have indicated corrective procedure [13].

3. Measurements of angle of arrival

Tests carried out on the relative merits of high and low antennae have yielded useful statistics on vertical wave-arrival angles to be expected on long-distance HF circuits [15]. The values observed are greater than those anticipated by ray tracing calculations.

Work carried out in the United Kingdom over many years has associated the angles of arrival from a number of listed transmitters with the propagation modes. However, there are notable departures from the simple theoretical calculations [15].

4. Application to practical HF communication links

Results from frequency sounding studies have led a number of workers [2, 16, 17] to suggest that frequency sounding equipment could be used in parallel with a communications system to determine optimum, short-term operating frequencies. A number of studies have now been carried out [18, 19] and are being considered, which are designed to determine the improvements that can be achieved from the use of sounding information.

Improvement in radiocommunications during disturbed propagation conditions has been achieved, due to effective selection and use of available operating frequencies when predictions or pre-arranged operating frequency schedules are inaccurate.

It has been found that sounding information can be a valuable aid in assessing the performance of the communication system. With propagation removed as an unknown variable, any defects in, or limitation of, the communications system performance can be more readily discovered.

It was found during frequency sounding trials, that many frequencies assigned to stations in a particular system were not extensively used, although they could support reliable transmissions.

Inaccuracies in sounder prediction of propagation characteristics result from sounding over an ionospheric path separated from the ionospheric path used by the communication system. These differences are of particular importance, when sounding is used for quantitative prediction of signal levels on a communication path separated from the sounding path by several miles or more, and/or in opposite directions on a non-reciprocal HF path [13]. Preliminary studies [20] have shown that for separation of ionospheric paths by 16 km, these differences can be reduced to less than 10 dB by averaging sounding information over a number of short-term fading correlation periods.

BIBLIOGRAPHY

1. C.C.I.R. Report 249. Documents of the Xth Plenary Assembly, Geneva [1-15] (1963)
2. Hatton, W.L. Oblique-sounding and HF radio communication. *IRE Trans.*, **PGCS-9**, 275, (September, 1961).
3. Delobeau, F., Eyfrig, R. and Rawer, K. Résultats expérimentaux de transmission ionosphérique d'impulsions en incidence oblique (Experimental results of ionospheric pulse transmissions at oblique incidence). *Ann. Télécomm.* **10**, 55-64 (1955).
4. Möller, H.G. Ergebnisse der Impulsübertragung mit veränderlicher Frequenz auf der Strecke Sodankylä-Lindau (Results of variable frequency pulse transmissions over the path Sodankylä-Lindau) *Kleinheubacher Berichte* **7**, 115-123, edited by FTZ, Darmstadt (1960).
5. Agy, V. and Davies, K. Ionospheric investigations using the sweep-frequency pulse technique at oblique incidence. *Jour. of Res. NBS*, **63-D**, 151-174 (September-October, 1959).
6. Tveten, L.H. Long-distance one-hop F1 propagation through the auroral zone. *J. Geophys. Res.*, **66**, 1683-1684 (June, 1961).
7. Petrie, L.E. and Stevens, E.E. An F1 layer MUF prediction system for northern latitudes, *IEEE Trans. Ant. and Prop.* 547 (July, 1965).
8. Hagg, E.L. and Rolfe, W. A study of transatlantic radio propagation modes at 41·5 MHz. *Can. Journ. Phys.*, **41** 220 (1963).
9. C.C.I.R. Doc. VI/83 (Canada), 1963-1966.
10. Davies, K. Ionospheric radio propagation. *NBS Monograph 80*, U.S. Government Printing Office Washington 25, D.C. (1965).
11. Meadows, R.W. An experiment to test the reciprocal radio transmission conditions over an ionospheric path of 740 km. *Proc. I.E.E.*, **103B**, 224 (1956).
12. Jull, G.W. and Pettersen, G.W.E. Origin of non-reciprocity on high frequency ionospheric paths. *Nature* **201**, 483-484 (February, 1964).
13. Budden, K.G. and Jull, G.W. Reciprocity and non-reciprocity with magneto-ionic rays. *Can. Journ. Phys.* **42**, 113, (1964).
14. Low, A.T. and Harris, B.V. Vertical wave-arrival angle measurements of HF transmissions during the period December, 1960 to July, 1961. *Proc. Convention on HF Communications I.E.E.* (March, 1963).
15. C.C.I.R. Doc. VI/36, §§ 3, 4 (United Kingdom), 1963-1966.
16. 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 (1959).
17. Doyle, D.J., Ducharme, E.D., and Jull, G.W. The structure of HF signal revealed by an oblique incidence sweep frequency sounder. *IRE Trans. Antennae and Propagation* AP-8, 449 (1960).
18. Jull, G.W., Doyle, D.J., Irvine, G.W., and Murray, J.P. Frequency sounding techniques for HF communications over auroral zone paths. *Proc. IRE*, **50**, 1676 (1962).
19. Egan, R.D. and Pratt, D.S. Oblique sounding and HF communications. *Proc. Convention on HF Communications I.E.E.*, 47 (March, 1963).
20. Jull, G.W., Poaps, G.E. and Murray, J.P. Prediction of HF channel characteristics with frequency sounding information. Presentation at Globecom VII, *IEEE Communication Convention, University of Colorado* (June, 1965).

REPORT 250-1 *

LONG-DISTANCE IONOSPHERIC PROPAGATION WITHOUT INTERMEDIATE GROUND REFLECTION

(1959 - 1963 - 1966)

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 a single-hop out to 10 000 km.

   Modes of propagation which are now recognized include:

   — normal one-hop propagation including both direct and Pedersen rays;

   — ionospheric ducting between E- and F-regions;

   — those resulting from horizontal ionization gradients, such as the equatorial F-region ionization trough.

2. Both direct and Pedersen-ray propagation have been observed [1] to well beyond the classical geometrical limit of single hop (4000 km). The relative amounts of power transmitted by the Pedersen and direct rays have been considered [2]. The Pedersen ray has been observed on North American [3] and on trans-Atlantic paths [2, 3, 4]. The one-hop mode provides explanations for communication often observed at frequencies above the classical geometrical limit of single-hop propagation.

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 [5].

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 [6, 7, 8]. 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 refracted 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. It has been found [1] that, even if horizontal gradients are ignored, long-range trans-equatorial propagation can be explained on the basis of normal one-hop propagation.

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 [8, 9, 10, 11, 12].

6. Ionospheric soundings from a satellite [13, 14] have shown the existence of significant sheets of ionization irregularities above the height of a maximum electron density of the F-region. These sheets probably extend to heights below the height of maximum electron density,

---

* This Report was adopted unanimously.

where they may be responsible for long-distance propagation of frequencies above the standard MUF (EJF) [15] at high latitudes. At low latitudes, they are probably responsible for trans-equatorial scatter propagation [16].

7. It is hoped that future ionospheric sounding satellites may spend part of their time in the ionized regions to advance the study of the duct mode of propagation. Theoretical studies have been made of this mode of propagation [17, 18, 19].

BIBLIOGRAPHY

1. MULDREW, D.B. and MALIPHANT, R.G. Long distance one-hop ionospheric radio propagation. *J. Geophys. Res.*, **67**, 1805-1815 (1962).
2. WARREN, E.S. and MULDREW, D.B. Signal strength of radio waves signal. *IRE Trans.*, **PGAP-9**, No. 4 (1961).
3. AGY, V and DAVIES, K. Ionospheric investigations using the sweep-frequency pulse technique at oblique incidence. *Jour. of. Res. NBS*, **63-D**, 151-174 (1959)
4. WARREN, E. and HAGG, E.L. Single hop propagation of radio waves to a distance of 5300 km. *Nature*, **181**, 34 (1958).
5. ARGIROVIĆ, M. The effect of ionospheric electrical constants on some propagation modes (in Serbo-Croat). *Elektrotechnika*, **4**, 121 (1962).
6. STEIN, S. The role of ionospheric layer-tilts in long-range high-frequency radio propagation. *J. Geophys. Res.*, **63**, 217-241 (March, 1958).
7. SOUTHWORTH, M.P. Night-time equatorial propagation at 50 Mc/s. *J. Geophys. Res.*, **65**, 601-607 (February, 1960).
8. FENWICK, R.B. and VILLARD, O.G. Jr. A test of the importance of ionosphere—ionosphere reflections in long distance and around-the-world high-frequency propagation. *J. Geophys. Res.*, **68**, 5659-5666 (1963).
9. v. SCHMIDT, O. Neue Erklärung des Kurzwellen-Umlaufes um die Erde (New explanation of the HF-echoes around the Earth). *Zeitschrift für technische Physik*, **17**, 443-446 (1936).
10. HESS, H.A. Investigation of HF-echoes. *Proc. IRE*, **36**, 981-992 (1948).
11. de VOOGT, A.H. Les échos radioélectriques autour de la Terre (Radio echoes around the Earth). *Onde Electrique*, **30**, 433-437 (1950).
12. C.C.I.R. Doc. 301, Warsaw, 1956; Docs. 210 and 211, Los Angeles, 1959.
13. PETRIE, L. Topside spread echoes, *Can. Jour. Phys.*, **41**, 194 (1963).
14. LOCKWOOD, G. and PETRIE, L. Low-latitude field aligned ionization observed by the Alouette topside sounder. *Planetary and Space Science*, **11**, 327 (1963).
15. HAGG, E.L. and ROLFE, W. Study of transatlantic radio propagation modes at 41·5 Mc/s. *Can. Jour. Phys.*, **41**, 220 (1963).
16. DAVIES, K. and BARGHAUSEN, A.F. The effect of Spread-F on the propagation of radio waves near the Equator; to be published in proceedings of AGARD Conference on the influence of the Spread-F on Communications, held at Copenhagen (1965).
17. CHVOJKOVÁ, E. Analytic formulae for radio path in spherically stratified ionosphere. *Radio Science*, **69D**, 453-457 (1965).
18. CHVOJKOVÁ, E. Antipodal reception of satellite signals. *Bull. Astr. Czechoslovak*, **12**, 1-7 (1961).
19. CHVOJKOVÁ, E. Radio communications in astronautics. *Publ. Astronom. Inst. Czechoslovak*, **49**, 13-16 (1963).

REPORT 251-1 *

INTERMITTENT COMMUNICATION BY METEOR-BURST PROPAGATION

(Study Programme 15A/VI)

(1959 - 1963 - 1966)

1. Introduction

The subject of VHF propagation by reflections from columns of ionization produced by meteors (meteor trails), has been referred to in Report 259-1, 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.

2. Summary of available information

2.1 Complete information is not 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, the United States, Australia, New Zealand and Italy. The data available are probably adequate for prediction within 10 dB, but this possibility has not yet been demonstrated.

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 single-channel two-way telegraph circuits have been operated in the 30 to 40 MHz 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. Experimental results have indicated the possibility of useful transmission, in bandwidths up to 100 kHz, for time intervals of the order of one second and duty cycles of the order of 5%. However, it should be noted that the duty cycle decreases with increasing frequency.

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 During the burst interval, the system loss is significantly less than that associated 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.

---

* This Report was adopted unanimously.

2.6 Meteor-burst propagation is known to be subject to abnormal attenuation, as for example, during polar-cap absorption events and sudden ionospheric disturbances. As would be expected, the absorption effects are less at higher frequencies as shown by measurements on 104 MHz and 41 MHz. But note that attenuation as high as 30 dB at 100 MHz has been observed on rare occasions during polar-cap absorption events.

2.7 Few data are available at frequencies above 100 MHz.

BIBLIOGRAPHY

Some general references on the characteristics of meteors are:

1. Lovell, A.C.B. *Meteor Astronomy*, Oxford (1954).
2. McKinley, D.W.R. *Meteor Science and Engineering*, McGraw-Hill Book Co., Inc. (1961).

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).
4. Manning, L.A. and Eshelman, V.R. Meteors in the ionosphere. *Proc. IRE,* **47**, 186-199 (February, 1959).

These papers 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)).

More recent papers are:

5. Maynard, L.A. Propagation of meteor burst signals during the polar disturbance of November 12-16, 1960. *Canadian Jour. Phys.* **39**, 628 (1961).
6. Hornback, C.E. *et al.* The NBS meteor-burst propagation project, a progress report. *NBS Technical Note 86* (March, 1960).
7. Eyfrig, R.W., Hess, H.A. and Rawer, K. Über die Häufigkeit von Meteorechos (Concerning the frequency of occurrence of meteor echoes). *Archiv der elektrischen Übertragung,* **16**, 609 (1962).
8. Sugar, G.R. Radio propagation by reflection from meteor trails. *Proc. IEEE,* **52**, 116 (February, 1964).

REPORT 252–1 *

ESTIMATION OF SKY-WAVE FIELD STRENGTH AND TRANSMISSION LOSS BETWEEN THE APPROXIMATE LIMITS OF 1·5 AND 40 MHz

(Study Programme 11A/VI)

(1956 – 1959 – 1963 – 1966)

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 was established by Study Group VI, Warsaw, 1956, to examine the relative merits of existing methods. The initial task of this International Working Party was the evaluation of the method of RPU-9 [1], which was being used extensively in lieu of the methods of NBS Circular 462 [2]. This latter method forms the basis of I.F.R.B. technical examinations. However, several other methods of field-strength prediction have been produced, those of the U.S.S.R. [3, 4], the United Kingdom [5], France [6, 7, 8, 9, 10], the Federal Republic of Germany [9, 10, 11] and Japan [12]. In addition to these methods, India has developed a method for tropical areas [13]. The methods of RPU-9, U.S.S.R. (Kazantsev) and the Federal Republic of Germany (Rawer), have been adapted for evaluation by electronic computer.

Although the International Working Party had already concluded at an early stage that the method of RPU-9 was in general more satisfactory than that of NBS Circular 462, the fact that several other methods are now available makes it desirable to consider these also. Resolution 7–1 revises the task of the International Working Party to produce a preferred C.C.I.R. method, adapted for evaluation by electronic computers and continues a measurement programme to assist in its development.

2. Summary of major factors determining transmission loss

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 (JF) 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 was adopted unanimously.

2.2 For frequencies below the classical MUF (JF) 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, particularly when considering the longer paths. In addition, for the case of trans-equatorial paths, propagation may occur over long distances without intermediate ground reflections (by so called super-modes). Hence there are grounds for doubt that a calculation, based upon conventional great circle modes, is either warranted or necessary. Further investigation of the nature of very long-distance propagation is necessary before the best approach can be determined.

An important consideration in the practical calculation of transmission loss of field strength is the continuity of calculated values as a function of distance. If two different procedures are used, one for intermediate and the other for long ranges for the calculation of field strength, it may be preferable to make both calculations in the transition range, and thus provide an estimate of the extent of any discontinuity introduced by the two procedures. Ultimately, it may be desirable to adopt one procedure of calculation for both distance ranges, to preserve continuity throughout the transition region.

2.3 The variations of absorption with latitude, and the relative contributions of deviative and non-deviative absorption for oblique incidence propagation are not well understood. Enhanced absorption in tropical and auroral regions may be of importance, as also may absorption at night time. Night absorption has been investigated by Wakai [14]. During the winter months, an enhanced absorption occurs in sub-auroral latitudes. Periods of several consecutive days with excessive absorption are often observed to alternate with normal days, thus making the day-to-day spread of received field strength considerably greater than in summer.

2.4 Over the shorter distances, the one-hop sporadic-E mode and the laterally deviated 2-hop F2 mode with ground scatter sometimes give relatively low transmission-loss propagation. Of these, the sporadic-E mode seems to be the more important. The sporadic-E layer may also influence the signal strength of waves that are propagated via the F layer for frequencies below the classical MUF (JF). The presence of such a lower layer may serve to reflect back to ground some of the incident energy, thereby weakening the penetrating wave.

Meteors give occasional short-lived bursts of strong signal, and for frequencies just above the classical MUF (JF), continuous propagation of relatively low transmission loss may result from the combination of forward scattering by irregularities in the D and E regions, together with ordinary reflections from 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 (JF), but the transmission loss is high.

2.5 At distances well beyond 4000 km, relatively low transmission-loss propagation may be observed at frequencies above the standard MUF (EJF). Propagation may take place via:

— multi-hop classical modes laterally deviated via ground side-scatter into regions of higher electron densities and corresponding higher MUF;

— direct or side-scattered multi-hop sporadic-E modes;

— the combination of scatter in the D or E region, together with a classical F-region reflection;

— the extra-long Pedersen-ray hop.

Examples of this last have been reported [15].

3. Special features of the existing methods of field-strength prediction

3.1 NBS Circular 462 contains one procedure for distances up to about 4000 km and a second procedure for longer distances. The long-distance procedure is presented in a simple nomogram and both procedures have adjustments for the anomaly of increased absorption during winter.

3.2 The method of RPU-9 is continuous throughout the entire distance range and relatively simple nomograms permit a direct manual solution. Estimates of the height of the F2 region, as a function of time and location, permit the consideration of the vertical pattern of the transmitting and receiving antennae. The method has been used extensively for approximately one and one half solar cycles and has been recently revised [16], to give special consideration to auroral and polar circuits, to include the calculation of transmission loss and to be adapted for electronic computers.

3.3 The Kazantsev method permits a direct estimate of field strengths when foE is known and therefore no arbitrary index of D-region absorption is required. A computer calculation for this method has been worked out in the U.S.S.R. for the calculation of the lowest usable high frequency (LUF) and the field strength [17]. A comparison of the results of the computer and manual calculations showed a satisfactory correspondence.

3.4 The method of Piggott incorporates an allowance for the greater absorption experienced in tropical regions than would be expected assuming a direct dependence upon the zenith angle of the Sun. It makes use of vertical incidence absorption data obtained at a number of locations and allows for absorption in the early night hours by assuming a finite recombination time for the lower ionosphere. Expressions for spatial attenuation take account of horizon focusing near the limits of one-hop propagation.

3.5 The French method originally developed by Rawer at SPIM is applied to frequencies below the classical MUF (JF) and distances up to about 10 000 km. The modes of propagation (on the great circle) are considered individually taking account of deviative and non-deviative absorption and, in so far as F-layer echoes are concerned, of blanketing by E- and Es-layers. Curves of 30 and 90% probability are normally given (otherwise blanketing by Es could not be taken into account). Thus the prediction is essentially a statistical one. Rules are given as to how the angles of elevation for the different modes can be included for a given vertical antenna diagram.

The extension of the method developed by Harnischmacher (also originally developed at SPIM) is suitable for larger distances. It is a combined method of looking for the attenuation and the reflection conditions at the same time. Essentially, a ray with a given frequency, angle of elevation and azimuth is considered, and these parameters are then varied. It appears that for very large distances those frequencies are the most interesting ones which are reflected from the F-layer on the night-side and from the E (or Es) layer on the day-side. The method admits off-great circle propagation to a certain amount such that, for distances above 16 000 km the contributions from different azimuths are summed up. The attenuation is computed from the local absorption (given by a solar zenith angle law) on the day-side by averaging over the different E-layer reflections, taking account of the given angle of elevation. Whilst the influence of steep horizontal ionization gradients is considered in some way by admitting off-great circle propagation, the angle of elevation of the considered ray is supposed to be the same for all earth reflection points.

3.6 Beckmann's semi-empirical method applies mainly to distances beyond 4000 km. It does not attempt to give a full answer to the problem of field-strength calculation. Its main intention is to extrapolate the field strength from the LUF through the usable frequency range up to the operational MUF (MUF), the LUF being determined either by calculation using existing methods, provided that the LUF is sufficiently below the classical MUF (JF), or by observation. Scatter losses below and above the classical MUF (JF) are taken into account, together with deviative absorption, by introducing a second attenuation term proportional to $(f/\text{operational MUF})^2$ $[(f/\text{MUF})^2]$. The operational MUF (MUF), taken for a certain level of field strength, is determined by observation or by applying an empirical correction factor to the standard MUF (EJF). So the method yields a maximum of the estimated field strength near to the middle of the usable frequency range and a decrease for higher frequencies, as is confirmed by observations. The method can also be used for converting the field strength at any one frequency to that which is to be expected at another.

3.7 The Japanese method considers the calculation for propagation paths involving side-scatter the MUF of which is equal to the frequency used, or the least value above that frequency, when no F2 normal propagation can take place. By application of an experimental equation, the attenuation of the ground side-scatter mode is given as a simple function of the angle between the normal reflecting wave and the side-scattering wave. It is suggested that an allowance for the effects of ground side-scatter should be incorporated in all field-strength calculation methods.

3.8 The method of the Indian Administration uses an expression for non-deviative absorption, based upon a long series of vertical absorption measurements in India. An allowance of 2·5 dB, for losses due to deviative absorption by night, is incorporated and there is assumed to be a 3 dB polarization loss. Spatial attenuation is taken as including the effects of horizon focusing.

4. Comparisons between calculated and measured field strengths

4.1 The United Kingdom has made measurements of field strength from transmitters employed on long-distance operational circuits and has compared these measurements with calculations based on the method of RPU-9 [18]. In general, the measured values of field strength are considerably lower than the calculated ones, in particular, during night-time conditions, when the differences may 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.

4.2 The Japanese have compared observations extending over a long period of time with values calculated by the Japanese method. A good agreement was reported, but it must be emphasized that the number of comparisons made was rather limited [19].

4.3 Field-strength values calculated by means of Beckmann's method for a transatlantic circuit (15 and 20 MHz), using monthly predictions of the FTZ (F.R. of Germany), have been compared with measured values since 1958. The diurnal variations of 8 months' data (high solar activity) show clearly the dependence of the field strength on the operational MUF (MUF) [20]. The general trend of the annual mean values during 5 years of the declining phase of solar activity (slight increase at 15 MHz, rather steep decrease at 20 MHz), is well reproduced by the calculation.

4.4 It is reported by India that their method, developed for calculating sky-wave field strengths for the tropical broadcasting service, gives the closest agreement with measured field strengths when compared with other methods of prediction [21].

BIBLIOGRAPHY

1. LAITINEN, P.O. and HAYDON, G.W. Analysis and prediction of sky-wave field intensities in the high frequency band. *Technical Report 9, United States Army Signal Radio Propagation Agency*, Fort Monmouth, New Jersey, U.S.A. (1950). Available as catalogue Number PB103045 from the Office of Technical Services, Department of Commerce, Washington 25, D.C. U.S.A.
2. *NBS Circular 462.* Ionospheric radio propagation. National Bureau of Standards, Boulder, Colorado, U.S.A. (25 June, 1948).
3. KAZANTSEV, A.N. Developing a method of calculating the electrical field strength of short radio waves. *Trudy IRE (Transactions of the Institute of Radio Engineering and Electronics of the Academy of Sciences)*, U.S.S.R., **2**, 134 (1956).
4. C.C.I.R. Doc. 744 (U.S.S.R.), Warsaw, 1956.
5. PIGGOTT, W.R. The calculation of the median sky-wave field strength in tropical regions. *Special Report 127*, Department of Scientific and Industrial Research, Slough, England (1959).
6. RAWER, K. *Rev. Sci.* **85**, 361 (1947).
7. RAWER, K. *Arch. electr. Übertr.* **5**, 154 (1951).
8. RAWER, K. Calculation of sky-wave field strength. *Wireless Engineer*, **29**, 287 (1952).
9. HARNISCHMACHER, E. A calculation method of ionospheric propagation conditions for very high and antipode distance. *Electromagnetic wave propagation.* Academic Press, London, 527 (1960).
10. RAWER, K. Intercomparison on different calculation methods of the sky-wave field strength. *Electromagnetic wave propagation.* Academic Press (1960).
11. BECKMANN, B. Über Beziehungen der Feldstärke zu den Grenzen des Übertragungsfrequenzbereiches (LUF, MUF) (On the relation of the received field strength to the limits of the transmission frequency range). *Nachrichtentechn. Zeitsch.* **11**, 523 (1958). Bemerkungen zur Abhängigkeit der Empfangfeldstärke von den Grenzen des Übertragungsfrequenzbereiches (MUF, LUF). (Remarks on the dependence of received field strength on the limits of the transmission frequency range (MUF, LUF)). *Nachrichtentechn. Zeitsch.* **11**, 643 (1965).
12. KANAYA, S., YOKOI, H. and ISOMURA, E. A convenient method to estimate the signal strength for ground-scatter propagation mode at frequencies above the classical MUF in long distance beyond 4000 km. *P.G.R.P. Inst. Electr. Comms. Eng., Japan* (May, 1962).
13. C.C.I.R. Report 305, Documents of the Xth Plenary Assembly, Vol. V, 152 (Geneva 1963).
14. WAKAI, N. Non-deviative absorption at night. *J. Radio Res. Labs.* **8**, **37**, 213 (May, 1961).
15. MULDREW, D.B. and MALIPHANT, R.G. Long distance one-hop ionospheric radio wave propagation. *Journ. Geophys. Res.* **67** (May, 1962).
16. HAYDON, G. and LUCAS, D. Technical considerations in the selection of optimum frequencies for high frequency sky-wave communication services. *NBS Report 7249.* National Bureau of Standards, Boulder, Colorado.
17. C.C.I.R. Doc. VI/73 (U.S.S.R.), 1963-1966.
18. C.C.I.R. Report 252, Documents of the Xth Plenary Assembly, Vol. II, 267 (Geneva, 1963).
19. C.C.I.R. Docs. VI/57 (Japan) and VI/190 (Japan), 1963-1966.
20. BECKMANN, B. Ergebnisse zur näherungsweisen Berechnung der Raumwellenfeldstärke aus den Grenzen des Übertragungsfrequenzbereiches (Results of approximate calculations of the sky-wave field strength from the limits of the usable frequency range). *Nachrichtentechn. Zeitschrift (N.T.Z.)* **13**, 470 (1960).
21. C.C.I.R. Doc. 95 (India), Geneva, 1963.

REPORT 253-1 *

SYSTEMATIC MEASUREMENTS OF SKY-WAVE FIELD STRENGTH AND TRANSMISSION LOSS AT FREQUENCIES BETWEEN THE APPROXIMATE LIMITS OF 1·5 AND 40 MHz

(Study Programme 11A/VI)

(1963 - 1966)

1. Introduction

Field-strength measurements in the frequency band between 1·5 and 40 MHz are required to provide the International Working Party VI/1, 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 and § 5 of this Report.

Note. — In this Report, the term " field strength " is considered to include the term " transmission loss " where appropriate.

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 uncer-

---

* This Report was adopted unanimously.

tainty 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 doubtful as compared with those obtained on a standard set, may yet provide valuable information on diurnal variations of field strength that would be differently predicted according to the method used. Some of these difficulties might possibly be avoided by converting field strength to transmission loss, as discussed in Report 112.

3. Provision of transmissions

Resolution 7–1 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.

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 that 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 analyse 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 as 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 Circular 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 in the Table in Annex I. The actual method of measurement in each case should be stated.

It is realized that continuous recording may be impracticable and that measurements may only be made at certain times of day and on certain 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. Annex I gives details of a typical method of obtaining the required information from point-to-point telegraph and telephone transmissions.

5. Measurements of ionospheric absorption

Provided that distance and operating frequency are suitably chosen, significant values of the ionospheric absorption can be obtained by means of relative field-strength measurements. Widespread use of this rather simple method could result in a considerable increase of basic data, needed for the evaluation of a more accurate method for the estimation of sky-wave field strength and transmission loss. Annex II intends to give some guidance for planning and executing such measurements.

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 kHz might be used for a transmission consisting of two telegraph channels and a bandwidth of 8 kHz for a transmission consisting of two 3 kHz 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:

$$F_s = F_m - (P_t - L) - G_t - H \qquad (1)$$

where:

F_s = sky-wave field strength,
F_m = measured field strength, which is a resultant of the sky-wave and ground reflected waves, } (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.

---

* If an isotropic antenna is used as the reference, G_t would be increased by 4·8 dB.

TABLE I

MEASUREMENTS OF HF 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 .... (MHz) *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.

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 attached to individual readings.

ANNEX II

MEASUREMENT OF THE IONOSPHERIC ABSORPTION BY MEANS OF FIELD-STRENGTH RECORDINGS

1. Introduction

Systematic comparisons and several years of experience have shown that relative field-strength measurements are suitable for determining the ionospheric absorption around noon, provided that the parameters of the radio circuit meet certain requirements [1]. Rules for establishing such a circuit have been given in one of the I.Q.S.Y. Manuals [2], but the calibration method described there is rather complicated.

This Annex proposes a somewhat simplified method. In the terminology of the U.R.S.I. this method is called the A3 method, in contrast to the A1 method (measurement of absorption using vertical incidence pulse transmissions) and the A2 method (measurement of absorption of extraterrestrial noise). These names have no relation whatsoever to the terms used for characterizing the class of emission.

2. Choice of frequency and distance

Frequency and distance must be selected in such a way that the observed noon value of the field strength is essentially (to about 1 dB) given by one-hop E propagation, F propagation being prevented by blanketing and higher-order reflections being strongly absorbed. In mid-latitudes, frequencies of 2-3 MHz and distances of about 100-400 km give good results. In most countries suitable transmitters can be found in coast stations.

3. Choice of types of antenna

Since the absorption is smaller for the ordinary than for the extraordinary component, the antennae should be designed so as to select the ordinary component. If the extraordinary component were used, the measurement could be influenced by the stronger ordinary component, especially during high absorption conditions. Close attention must be given to the suppression of the ground wave, especially for the lower frequencies and shorter distances. For this reason, propagation paths over sea should not be used. In addition, the antennae can be used to minimize the effects of modes other than the 1 × E mode.

For instance, in mid-latitudes in the northern hemisphere the following antennae are recommended for a path running approximately in north-south direction: a horizontally polarized antenna at the northern terminal and a vertically polarized antenna at the southern terminal. With this combination the errors due to polarization effects can be expected to be less than 3 dB. The use of a polarimeter antenna at the receiving terminal would result in an even smaller error.

4. Receiving and recording equipment

The requirements as regards the receiver and recorder are essentially the same as for other field-strength measurements (see, e.g., Annex I, § 2). If a double-sideband transmission is recorded, a narrow receiver bandwidth selecting only the carrier frequency may be used and would result in a better signal-to-noise ratio.

5. Calibration

The simplicity of the method results mainly from the fact that only relative, not absolute, values of field strength are needed, nor do the antenna diagrams need to be known in detail. It is convenient to have an approximately logarithmic receiver response calibrated in terms of input voltage. Relative changes from day to day can be easily read out from these records.

To obtain absolute values of absorption, however, some more information is needed. As absorption is negligible in magnetically quiet nights, night-time measurements can be used for calibration, provided that the reflection occurs essentially at the same height as in day-time, i.e. via a blanketing Es layer (this case is not too rare on the rather low frequencies used for these measurements). Under these conditions, the geometry of the path is the same, day and night, and the difference of the logarithmic field-strength values for night and day, $F_n - F_d$, should directly give the absorption. However, in most latitudes the extraordinary component is strongly absorbed at noon but appears in the night. Therefore in this case, if the unwanted component is not suppressed by the antennae, the absorption is given by $F_n - F_d - 3$ dB. Likewise, if higher-order reflections are not negligible at night, F_n will be too great.

The best calibration conditions are therefore encountered when a blanketing E*s* layer occurs around sunset. In this case, the higher-order modes are still absorbed and the calibration is easily obtained by extrapolation of the daily field-strength variation until sunset (a similar procedure could be used at sunrise, however, Es is less probable at sunrise). The cases where propagation takes place via the Es layer around sunset are easily identified and can be deduced from the field-strength records themselves. Of course, ionograms taken from a nearby ionosonde may facilitate the identification of Es propagation.

It is recommended that records covering a period of about three months be used for the calibration, considering only those 10% of all days where the highest sunset values were obtained. The average of these few days should be taken for F_n. The accuracy can be expected to be better than about ± 3 dB. This is reasonable since the day-time absorption is of the order of 30 dB. If possible, however, the more thorough procedure described in [2] ought to be employed.

6. Presentation of results

Half-hourly or hourly values of day time absorption loss, L, should be given in monthly tables. The characteristic parameters of the measuring circuit (frequency, distance, path orientation, type of antennae) should be clearly indicated on the sheets, so that a reduction to vertical incidence data is possible.

BIBLIOGRAPHY

1. SCHWENTEK, H. Ein Vergleich von Impuls- und Dauerstrichbeobachtungen auf derselben Übertragungsstrecke bei 2,5 MHz (Comparison of pulse and CW observations over the same circuit on 2·5 MHz). *Forschungsbericht des Landes Nordrheinwestfalen Nr. 1443*, published by Westdeutscher Verlag, Köln and Opladen (1965).
2. *I.Q.S.Y. Instruction Manual No. 4, Ionosphere*, issued by I.Q.S.Y. Secretariat, 6 Cornwall Terrace, London N.W.1.

REPORT 254-1 *

MEASUREMENT OF ATMOSPHERIC RADIO-NOISE

(Study Programme 20A/VI)

(1959 - 1963 - 1966)

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 (1959); equipment for 19 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 of 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. A few measurements have continued using the older aural techniques.

The data obtained during the last few years have been used in the preparation of Report 322. It should be noted that the time blocks referred to in § 2 of Report 322 are defined in terms of local time.

Reports of recent measurements at high frequencies suggest that the data in Report 322 are too low during daytime in some tropical regions [3, 4, 5]. The discrepancies may be up to 10 dB or more in the lower part of the HF band, and these regions need particular examination when the Report is revised.

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. There are insufficient data for a full report to be made, but the results of some investigations have been published [6, 7,] and 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

---

* This Report was adopted unanimously.

counters of a type which has been adopted by C.I.G.R.E. (Comité International des Grands Réseaux Electriques) and which has been used extensively, can be correlated with data from the C.C.I.R. counters provided that appropriate sensitivities have been used. Experiments with another counter, operating on the high-frequency energy from atmospherics have led to similar conclusions, regarding the incidence of discharges, as those from the C.C.I.R. counter.

Experiments in the United Kingdom [7] and others, reported in a C.C.I.R. document from Sweden [8], 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 [9] 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 kHz, where n is the number of discharges counted per hour with the C.C.I.R. counter and is not less than 30. Similar empirical relationships can be found for higher frequencies, but there is evidence that some measured noise-power values at medium frequencies are much too low in the daytime when local storms occur [10].

Although a large volume of data from atmospherics direction-finding networks exists, 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.

Some recent works bearing on results obtained by direction-finding on atmospherics is contained in [11].

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 [12, 13, 14]. The spectrum has been used, in conjunction with lightning-flash counters and propagation data, to give estimates of integrated noise at certain locations [9]. 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.

BIBLIOGRAPHY

1. Crichlow, W.Q., Disney, R.T. and Jenkins, M.A. Quarterly radio noise data. *NBS Tech. Notes, Nos. 18 and 18-2 to 18-11.* NBS, Boulder, Colo., U.S.A. (1959-1966).
2. U.R.S.I. Measurements of characteristics of terrestrial radio noise. *Special Report*, 7, Elsevier (1962).
3. C.C.I.R. Doc. VI/79, Geneva, 1963-1966.
4. C.C.I.R. Doc. VI/201, Geneva, 1963-1966.
5. C.C.I.R. Doc. VI/202, Geneva, 1963-1966.
6. Kronjäger, W. and Vogt, K. Über das Aussengeräusch kommerzieller Antennanlagen (On the external noise of commercial antenna installations). *NTZ* **12**, 371 (1959).
7. Bradley, P.A. and Clarke, C. Atmospheric radio noise and signals received on directional aerials at high frequencies. *Proc. I.E.E.*, **111**, 1534 (1964).
8. Horner, F. The design and use of instruments for counting local lightning flashes. *Proc. I.E.E.*, **107B**, 321 (1960).
9. C.C.I.R. Doc. 183 (Sweden) Geneva, 1963. Practical experience with the C.C.I.R. lightning counter.
10. Horner, F. The lightning flash counter and its application to radio noise studies. (To be published in Electronics Letters.)
11. C.C.I.R. Doc. VI/67 (Rev. 1) (F.R. of Germany), 1963-1966. Measurement of atmospheric radio noise.
12. Taylor, W.L. and Jean, A.G. Very low frequency radiation spectra of lightning discharges. *Jour. Res. NBS*, **63D**, 119 (1959).
13. Watt, A.D. and Maxwell, E.L. Characteristics of atmospheric noise from 1 to 100 kc/s. *Proc. IRE*, **45**, 787 (1957).
14. Horner, F. and Bradley, P.A. The spectra of atmospherics from near lightning discharges. *Jour. Atmos. and Terr. Phys.* **26**, 1155 (1964).

REPORT 255-1 *

BASIC PREDICTION INFORMATION FOR IONOSPHERIC PROPAGATION

(1959 - 1963 - 1966)

1. Prediction of the oblique-incidence standard MUF (EJF) from vertical-incidence data

Many Administrations have methods of prediction in which charts of ionospheric characteristics, e.g. F2 zero MUF and F2 4000 MUF based on data from vertical ionosondes are presented [1]. The C.C.I.R. is now developing an Atlas of selected ionospheric characteristics based on vertical ionosonde data. The ionospheric characteristics have usually been presented in graphical charts [2], showing the world-wide distribution of the ionospheric parameters, but the representation is now frequently in the form of mathematical expressions which may be readily manipulated by electronic computers. Both the graphical represent-

---

* This Report was adopted unanimously.

ation and the mathematical expression involve extrapolation into areas of the world where ionosonde data is lacking and are dependent upon a correlation with a solar activity index for prediction purposes. Several potential sources of errors are inherent in the prediction of radiocommunication frequencies from vertical incidence data, these potential error sources include:

1.1 Errors in the graphical charts or mathematical expressions due to the lack of data in certain geographic areas.

1.2 Failure of the ionospheric characteristics to correlate with solar activity index, e.g. in the rising and descending phase of the solar cycle as well as between cycles.

1.3 Inability to predict the solar activity index.

1.4 Difficulty in the translation of vertical ionosonde data to propagation predictions for operational communication circuits, i.e. the difference between the standard MUF (EJF) and the operational MUF (MUF).

Differences in the graphical mapping by the various Administrations have been studied by the C.C.I.R. Secretariat [1]. The failure of ionospheric characteristics to correlate with the sunspot number index and the inability to predict sunspot numbers has promoted a search for a better prediction index, e.g. the cyclic nature of solar noise or of the ionospheric characteristics.

The difficulty of translating the vertical data to oblique incidence is small on most 1-hop paths and the difference between the classical MUF (JF) and the operational MUF (MUF) is often negligible. However, when steep horizontal gradients and inhomogeneities in ionization occur in the transmission path, the difference can be large. Examples of this are given [3, 4], where exceptionally high values of the ratio of the standard MUF (EJF) to the classical MUF (JF) are attributed to non-symmetrical paths.

2. The ratio of operational MUF (MUF) and standard MUF (EJF)

Information has been collected by several countries and is tabulated in [1]. Some tendencies were indicated, which are repeated since more recent information has not been received.

The ratio of operational MUF (MUF) to standard MUF (EJF) tended to be higher for night-time than for daytime conditions. For middle latitudes, the corresponding ratio in summer, for both day and night, seemed to be lower than for night conditions in winter. The highest values of this ratio, for middle and high latitudes, usually occurred in winter at the time of lowest standard MUF (EJF). The ratio tended to increase for circuits passing near the auroral zones. The differences between operational MUF (MUF) and standard MUF (EJF) can be explained, on the one hand, by the theoretical formula and ray-tracing methods applied and, on the other hand, by various ionospheric phenomena, such as scattering in the E and F regions, off great-circle propagation, and propagation by unusual modes when ionization " ridges ", " troughs " and isolated " clouds " exist in the E or F regions [5, 6, 7, 8, 9, 10, 11, 12, 13].

3. The effect of the F1 layer on radiocommunications

It is now recognized that F1-layer MUFs cannot be determined by an extension of E-layer nomograms, at least at high latitudes. Ray-tracing computations and sounding results show that for distances greater than 3400 km the earth intercepts the F1-layer low angle ray propagation and the F2 layer usually determines the overall MUF. An F1-layer prediction system for latitudes greater than 40°N has been developed in which it is assumed that F1 layer controls the overall MUF for transmission distances in the range 2000-3400 km [14]. Monthly contour maps have been constructed and improved distance factors using ray-tracing methods, have been developed. The prediction compares well with propagation observations.

4. The effect of E-region ionization

Little difficulty is encountered in introducing the effect of the regular E layer into prediction systems. The world-wide occurrence of sporadic-E has been predicted on a statistical basis and published for many years [15]. However, for radiocommunication purposes its effects are not well understood.

A system of prediction has recently been developed which takes into account the probability of Es reflection of a given frequency, the frequency reflected with a given probability and the frequency at which the Es ionization acts as a screen against reflection from higher layers [16, 17, 18, 19, 20].

Analysis of oblique sounding observations over several years indicates that Es was a useful propagation medium on a transatlantic path (Ottawa - The Hague) less than 1% of the time and on a trans-auroral path (Winnipeg-Resolute) only 7% of the time [9]. It has been proposed, that for application of Es to predictions, a tabulation of fbEs would be useful, since it has been found to be the most important as a propagating medium.

A method which incorporates the tropical Es layer has been described [21].

5. Introduction of propagation modes and horizontal ionization gradients

Certain methods of MUF prediction take modes of propagation into account explicitly. These methods can be expected to give results which are more accurate, however, until the introduction of computer prediction methods, the calculations involved prevented their general usage. It is now evident that individual mode predictions should replace the former two-control point method.

Methods of prediction, taking account of the horizontal ionization gradient, where the angle of arrival may differ from the angle of departure, are not yet available. Ray trajectories for such situations have been computed [22, 23, 24].

Angles of arrival were measured on the commercial circuit Osaka-Hamburg (8913 km), by comparing antenna voltages of two different rhombic antennae on a statistical basis. At 13·8 MHz, a range of 3° - 10° (maximum 6°) was found, at 19·2 MHz, 3° - 8° (maximum 6°). In these cases the used frequency was near the operational MUF, therefore a $3 \times F$ mode is supposed. Steeper angles (maximum 11°), prevailing during periods of higher MUF may be explained by a combination of $3 \times F$ and $4 \times F$ modes. Similar results were found elsewhere (Report 249-1, § 2) [25].

6. Ray tracing techniques

In recent years, ray-tracing techniques have been developed for use in improvement of the accuracy of predictions based on vertical incidence observations [26]. Chvojkova [27, 28, 29, 30] derived analytical formulae for real radio paths and for their group paths. These results can be used to identify the modes of propagation on sweep-frequency records. A complete summary of the formulae is presented. Long-distance one-hop propagation has been successfully studied and frequency ranges and angles of propagation have been detailed [31].

7. Effect of working conditions

The ratio of operational MUF (MUF) to standard MUF (EJF) 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. Generally, the most exacting type of service is associated with its lowest values. Measurements on commercial multiplex circuits (192 bauds) have shown, that the degree of signal distortion depends essentially on the receiver input voltage. In most cases the multiplex circuits ceased to be commercial for input voltages below 10–20 μV [32]. This suggests that more detailed physical considerations must be taken into account for predictions on complex services.

8. Off great-circle propagation

Several observing programmes show reception of long-distance emissions consistently from azimuths significantly different from the great-circle direction [33].

In 1961 and 1962, measurements of azimuthal angles of arrival of transmissions from WWV, WSL, MSF and JJY were made at Moscow by means of a direction-finder [34]. As a result of measurements of WWV and WSL transmission in autumn and winter from 1800 to 0500 hours (UT), it has been established that the deviations from the great circle:

— in 14% of the cases, do not exceed ±5°;

— in 33% of the cases, vary between +6° and +25°;

— in 53% of the cases, exceed −6°, sometimes reaching −100°.

Off great-circle scatter echoes have been observed at 41·5 MHz on a transatlantic (London - Ottawa) circuit [9]. Ground side-scatter signals were received at Ottawa from a region of the Atlantic Ocean about 35° South of the great-circle path. The bearing agreed very closely with that corresponding to the predicted intersection of the one-hop skip zones illuminated from London and Ottawa.

Ionospheric side-scatter from irregularities in E-and F-region ionization in the auroral zone was also observed. These echoes had an angle of arrival of about 7° North of the great-circle path. They were detected only during periods when the great-circle modes were greatly defocused and when ground side-scatter signals were absent.

BIBLIOGRAPHY

1. C.C.I.R. Report 255. Documents of Xth Plenary Assembly, Geneva, 1963.
2. Environmental Science Services Administration I.T.S.A, *Ionospheric Prediction*, 1963.
3. Williams, H.P. Increase in MUF due to horizontal gradients. *Nature* **196**, 256 (1962).
4. Moller, H.G. Ergebnisse der Impulsübertragung mit veränderlicher Frequenz auf der Strecke Sodankylä - Lindau (Results of variable frequency pulse transmissions over the path Sodankylä - Lindau). *Kleinheubacher Berichte*, **7**, 115-123. Edited by FTZ, Darmstadt (1960).
5. Bailey, D.K. The role of ionospheric forward scattering in oblique incidence MUF. *Abstracts for U.R.S.I. - IRE Spring meeting, Washington, D.C.* (May 2, 3, 4, 5, 1955).
6. Kovalevskaya, E.
   (a) The propagation at the frequencies above the MUF-F2 in the presence of scattering in the E layer. (In Russian). *Trudy IZMIRAN* **19** (29) 85-95 (1961).
   (b) *Trudy IZMIRAN* **19** (29) 71-84 (1961).
7. Beckmann, B., Menzel, W. and Vilbig, F. Einige Bemerkungen zur Frage der Grenzwellen (Some observations concerning MUF). *Telegraph-, Fernsprech-, Funk- und Fernseh-Technik* **28**, 223-225 (1939).
8. Fulton, B.J. and Petrie, L.E. The analysis of transient modes of propagation across the auroral zone. *Jour. Geophys. Res.* **66** (August, 1961).
9. Hagg, E.L. and Rolfe, W. A study of transatlantic radio propagation modes at 41·5 Mc/s. *Can. Jour. Phys.* **41** (1963).
10. Ochs, A. Erhöhung der MUF durch ionosphärische Streuung (Increase of the MUF caused by ionospheric scattering). *Kleinheubacher Berichte* **4**, 69-74, edited by Fernmeldetechnisches Zentralamt, Darmstadt (1956).
11. Ochs, A. Über MUF-Beobachtungen im Funkverkehr (On MUF observations on radio circuits). *Kleinheubacher Berichte* **5**, 165-166, edited by Fernmeldetechnisches Zentralamt, Darmstadt (1958).

12. Langer, O.M. Schrägwinkel — Impulsübertragung im Vergleich mit Feldstärkemessungen auf Transatlantikstrecken (Oblique-incidence pulse transmission compared with field-strength measurements on transatlantic paths). *Nachrichtentechnische Zeitschrift* **19** (1966).

13. Muldrew, D.B. F-layer ionization troughs deduced from Alouette data. *Jour. Geophys. Res.* **70**, 2635-2650 (June, 1965).

14. Petrie, L.E. and Stevens, E.E. An F1 layer MUF prediction system for northern latitudes. *IEEE Trans. Ant. and Prop.* (July, 1965).

15. U.S. National Bureau of Standards, CRPL D series (1942-1962).

16. Kerblai, T.S. Instruktsia po raschyotu chastot korotkovolnovoy radiosvyazi, otrazhayushchikhsya ot sloya Es. (Instruction on calculation of HF communications reflected from the Es-layer). *Nauka M* (1964).

17. Kerblai, T.S. O zavisimosti predelnykh chastot Es ot kharakteristik apparatury. (Relation between critical Es frequencies and characteristics of apparatus). sb. *Issledovanya ionosfery*, **5**, 50-63 (1960).

18. Kerblai, T.S. Ob izmenchivosti kharakteristik Es (Variability of Es characteristics). sb. *Issledovanya ionosfery*, **10**, 48-57 (1962).

19. Kerblai, T.S. Predelnye chastoty pri naklonnom padenii dlya dvukh tipov Es (Critical frequencies at oblique incidence for two types of Es.) *Geomag. i Aeronom.* 2, **3**, 489-494 (1962).

20. Kerblai, T.S. Nekotorye resultaty statistiki razlichnykh tipov sloya Es (Some statistical data on various types of Es-layer.) *Geomag. i Aeronom.* 2, **3**, 495-501 (1962).

21. Kift, F. The propagation of high frequency radio waves to long distances. *Proc. I.E.E.*, 107**B**, **32**, 127.

22. Kerblai, T.S. and Voloshinova Estimation of the tilts of the isosurfaces of NF2 on the basis of Nh profiles. *Geomag. i Aeronom*, **1**, 61 (1964).

23. Kerblai, T.S. and Kovalevskaya, E. Estimation of the ship distance in the horizontal inhomogeneous ionosphere. *Geomag. i Aeronom*, **5**, 962 (1964).

24. Bibl, K. The detection of an important anomaly in the F-region ionization above Central Europe. *Annales de Géophysique*, **20**, 447-453 ((1964).

25. Werle, H. Die Bestimmung von Einfallswinkeln im Kurzwellenbereich aus systematischen Antennenvergleichsmessungen (Determination of the angles of incidence in the HF band from systematic comparison measurements of different antennae). Communications of the overseas receiving station Lüchow, Report 1/64.

26. Muldrew, D.B. An ionospheric ray tracing technique and its application to a problem in long distance radio propagation. *IRE Trans. Ant. and Prop. AP*-**7**, 393 (October, 1959).

27. Chvojková, E. Analytical formulae of ray paths in spherically stratified ionosphere. *Radio Science*, **690**, 453-457 (1965).

28. Chvojková, E. Antipodal reception of satellite signals. *Bull. astron. Czechosl.* **12**, 1-7 (1961).

29. Chvojková, E. Radio communication in astronautics from the Geometrical astronautics point of view. *Publ. astron. Inst. Czechosl.* **49**, 14-17 (1963).

30. Chvojková, E. Some characteristics of ray paths. Submitted to *Radio Science* for publication (1966).

31. Muldrew, D.B. and Maliphant, R.G. Long distance one hop ionospheric radio wave propagation. *Jour. Geophys. Res.* **67**, 1805-1815 (May, 1962).

32. Kühn, J. and Werle, H. Untersuchungen über minimal brauchbare Empfängereingangsspannungen bei Funklinien mit MUX-Betrieb (Minimum acceptable receiver input signals for radio circuits using MUX-transmission). Communications of the overseas receiving station Lüchow, Report 3/64.

33. C.C.I.R. Report 249, References 22-30. Documents of the Xth Plenary Assembly, Geneva, 1963.

34. C.C.I.R. Doc. VI/80 (U.S.S.R.), 1963-1966.

REPORT 256–1 *

MAXIMUM TRANSMISSION FREQUENCIES

(Recommendation 373–1)

(1959 – 1963 – 1966)

1. The *operational MUF (or simply the MUF)* is the highest frequency that permits acceptable operation between given points at a given time and under specified working conditions. When referring to the operational MUF, all pertinent details of the actual system should be given, including antennae, power output, class of emission, information rate and the required signal-to-noise ratio.

The operational MUF refers to propagation in the actual 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.

2. The *classical MUF or the junction frequency (JF)* is the highest frequency that can propagate by a particular mode between specified terminals by ionospheric refraction. The classical MUF is independent of power, and is calculable in principle by ray optics in the presence of the Earth's magnetic field.

It is also measurable by oblique-incidence pulse transmission, and refers to the frequency at which the upper and lower traces are seen to merge on the ionogram. However, no account is taken of the nose extension observed in some ionograms.

In cases where scatter, interference, or most of all poor definition prevents a clear junction from being recognised, extrapolation of the low-and high-angle traces may be used with caution to approximate to the junction frequency.

Effects due to partial reflections and to scattering are not considered in the determination of the junction frequency. However, large-scale irregularities or " layer tilts " and the anisotropy caused by magneto-ionic double refraction, are included. This means that the ray path may not follow a great circle.

3. The *standard MUF or estimated junction frequency (EJF)* is an analytical approximation to the classical MUF or junction frequency (JF). It is found by combining data obtained from vertical soundings with a simplified analytical solution of the oblique-incidence refraction problem. The basic ionospheric parameters generally used for the F2 layer are:

— foF2 and M3000F2 for the conventional transmission curve method;

— foF2, h_c, and q_c for the parabolic layer method (h_c and q_c were formerly known as h_m and $y_m/2$, respectively.

The first method applies a 3000 km transmission curve to a conventional vertical-incidence ionogram and then applies distance factors to determine the standard MUF (EJF) for other path lengths. Both procedures are based on assumptions concerning the vertical profile of electron density.

---

* This Report was adopted unanimously.

The main sources of error in the conventional transmission curve method are that:

- the propagation is adequately described by ray optics and, as a consequence, scattering is omitted;
- the effect of the magnetic field is approximated by a partial theory;
- the deviation of a ray by underlying layers of the ionosphere is frequently ignored;
- the curvature of the ionosphere introduces difficulties that are as yet incompletely resolved;
- the nature and effects of horizontal ionization gradients are incompletely understood, and their consideration is often omitted.

4. The *maximum observed frequency (MOF)* is the highest frequency that can be detected on an oblique-incidence ionogram. With the advent of " radiocommunication sounding " used in conjunction with operational systems, such a term is required. In general, MOF is defined on a per mode basis, that is, defined in conjunction with other parameters that identify the mode. When stated without qualification, MOF should imply the highest of all propagation frequencies in a given path. The MOF is actually the operational MUF of the oblique-incidence sounder, but not in general that of any associated telecommunication system.

REPORT 257-1 *

QUESTIONS SUBMITTED BY THE I.F.R.B.

(1953 – 1956 – 1959 – 1963 – 1966)

From the nature of the last two questions contained in the Annex below it is clear that full answers to these questions cannot yet be given. Nevertheless, the International Working Parties now operating under Resolutions 7–1, 10–1, 12–1 and 13–1, are actively engaged in work which will provide general answers from which specific answers to questions such as those posed by the I.F.R.B. can be derived.

ANNEX

QUESTIONS SUBMITTED BY THE I.F.R.B.

Ionospheric propagation

Question (a)

Question *(a)* has been satisfied by the adoption of the " C.C.I.R. Atlas of Ionospheric Characteristics ", Report 340.

---

* This Report was adopted unanimously.

Question (b)

What is the best method of calculating the field strength produced by a transmitter working at frequencies above 1500 kHz 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:

- as a function of magnetic latitude;
- as a function of season;
- 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 21A/IV)

(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 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 analysed 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.

---

* This Report was adopted unanimously.

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 MHz. The normalized values of F_{am} (expressed in dB above thermal noise at 288°K; see Report 322) 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 259-1 *

VHF PROPAGATION BY WAY OF SPORADIC E AND OTHER ANOMALOUS IONIZATION

(Study Programme 17A/VI)

(1951 - 1953 - 1956 - 1959 - 1963 - 1966)

1. Review of propagation by regular ionization

1.1 *E-layer*

A study of routine vertical-incidence measurements indicates, that it is unlikely that transmission of waves above 30 MHz 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 above 30 MHz 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 values would, under the same conditions, exceed these for the Fl layer, this fact is of little importance. The Fl-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 transmissions by way of

---

* This Report was adopted unanimously.

the regular F2-layer ionization can occur for a significant fraction of the time in temperate latitudes on waves of up to about 50 MHz. In the low latitudes (between geomagnetic latitudes, 20°N and 20°S), however, such transmission can occur on waves of up to 60 MHz, with almost regular transmission on waves of 30 to 40 MHz.

It is clear that, for several years around the solar maximum, intolerable long-range interference may be expected in temperate latitudes, at frequencies up to about 50 MHz 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 MHz. The lowest frequency at which such interference becomes so infrequent as to be negligible is about 60 MHz, for stations in temperate latitudes, and about 70 MHz 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% of the time are found in Report 260-1.

World-wide predictions of F2-layer MUF are given in monthly charts published by the I.T.S.A. in the U.S.A., by the former D.S.I.R. in the United Kingdom, by C.N.E.T. in France and by other authorities.

2. Propagation by sporadic-E ionization [1, 2, 3]

The most familiar form of sporadic-E appears as an intensification in ionization in the form of a horizontal sheet with a thickness of about 1 km and a horizontal dimension of the order of 100 km. The majority of the cases of interest will occur in the height range 100 to 120 km. These sheets appear in a random manner, but do show distinct preference for certain times of day and months of the year. Some sheets have been observed to travel hundreds of kilometres, others show no apparent movement. The importance of sporadic-E decreases rapidly with frequency and Es propagation becomes a negligible factor above 90 MHz for normal radiocommunication systems although examples of sporadic-E propagation at higher frequencies have been reported [4].

2.1 *Path length*

Propagation by sporadic-E above 30 MHz rarely occurs at distances less than 500 km. Geometrical considerations limit the propagation by means of a single sheet to about 2000 km. When two sheets are separated by a distance of less than 2000 km from each other, two-hop propagation via sporadic-E becomes possible. Alternatively, if a single sheet achieves a dimension of more than 500 km it can support two reflections. Thus the primary distance range for VHF sporadic-E transmission is 500 to 2000 km. A secondary range out to 4000 km is occasionally possible through two hops.

2.2 *Geographical and temporal variations*

There are three major sporadic-E zones: equatorial, temperate, and auroral. The equatorial zone is a belt centred on the magnetic equator and extending 6° in magnetic dip on either side of it. A highly transparent form of sporadic-E (q-type) is a regular occurrence on the day side of the belt and can be shown to be associated with the equatorial electrojet. Propagation of VHF signals via q-type Es is by scattering.

The temperate zones cover most of the earth and extend from the equatorial zone to a geomagnetic latitude of about 60° (actually to the line at which the occurrence of aurora is 15% of its maximum). The most dominant feature in the temperate zone is the summer maximum in occurrence of intense sporadic-E, which becomes more distinct as one moves to higher latitudes until it is sharply altered by auroral zone influences. Sporadic-E rarely occurs between the hours of midnight and 0600 local time. It normally peaks around 1000 local time and in some areas exhibits a second peak in the evening. The sporadic-E layer is often very dense in the daytime. There are considerable longitude as well as latitude variations in the occurrence of sporadic-E in the temperate zones. A mechanism associated with wind shear appears most promising as an explanation for intense sporadic-E at temperate latitudes.

In the auroral zones, the dominant feature is the night-time peak in the occurrence of sporadic-E. The summer peak observed at temperate latitudes disappears entirely at the zone of maximum visible aurora. The auroral zones, like the equatorial zone, are regions of heavy current flow in the lower ionosphere. In addition, they are regions where ionized layers can be formed through the precipitation of charged particles. It appears that both of these phenomena may be responsible for the production of sporadic-E.

2.3 *Charts of sporadic-E occurrence*

The predicted world distribution of sporadic-E has been indicated in world charts published by C.R.P.L. (now I.T.S.A.) in the U.S.A., C.N.E.T. in France and by other authorities. A very different system of mapping, introduced by IZMIRAN in the U.S.S.R., is based on the hypothesis that probability distribution functions of Es versus the frequency are uniform in large geographic zones; the probability of foEs and fbEs exceeding a given frequency value is presented in world maps [5, 6].

2.4 *Estimating Es signal strength from vertical-incidence data*

The only comprehensive and continuing source of sporadic-E data is the world-wide network of ionosonde stations. It is important therefore to develop quantitative methods for estimating the oblique-incidence transmission characteristics from the vertical-incidence data.

A recent study of this problem in Japan [7] shows particular promise. Sporadic-E is first classified by its reflection coefficient as observed on VHF oblique-incidence circuits. A parameter Γ is defined as the attenuation observed in the signal relative to that expected if the ionosphere were a perfect reflector. The study suggests that if $\Gamma \leqslant 45$ dB, then the sporadic-E reflections are specular in nature, while if $45 \text{ dB} < \Gamma < 70$ dB, a scattering mechanism is involved. Curves are available for calculating Γ in terms of the ratio f/foEs, where f is the transmission frequency in question and foEs is the vertical-incidence critical frequency of the ordinary wave for sporadic-E taken from ionosonde observations. Estimates are available for both single-hop (0 to 2100 km) and two-hop (2400 to 4000 km) sporadic-E. An important feature of the method is the inclusion of antenna-to-medium coupling loss.

2.5 *Occurrence of oblique sporadic-E propagation*

Oblique-incidence pulse soundings between Greece and the Federal Republic of Germany (1700 km) showed that the MOF was often determined by Es reflections from May through September, the average daytime probability (0600 to 1800 hours UT) being about 10% at 22 MHz decreasing to almost zero at 30 MHz [8]. An examination of the oblique-incidence data obtained on the Ottawa-The Hague (5500 km) and Winnipeg-Resolute Bay (2800 km) circuits indicates that the sporadic-E mode at times controls the operational MUF, but sporadic-E layer propagation seldom occurs at frequencies greater than 30 MHz (Doc. VI/83, 1963-1966).

Since 1961, the E.B.U. has recorded data on many paths (20 paths in 1965), varying in length between 900 and 2500 km and which are situated in different locations in Western Europe. Daily measurements were taken at five frequencies between 41 and 59 MHz between 0800 and 2300 hours UT from May through October of each year. The results can be summarized as follows (Doc. VI/194, 1963-1966):

- considerable year-to-year variation exists;
- the month of the maximum occurrence of sporadic-E varied between May and August and was not necessarily the same on all paths for a given year;
- as expected, the lower frequencies showed a higher field intensity and occurrence than the higher ones.

3. Propagation by other anomalous ionization

3.1 *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 251-1 gives a bibliography on this subject. The matter of meteor-burst communication is dealt with separately in Study Programme 15A/VI.

3.2 *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 MHz for paths of the order of 4000-9000 km; paths between South America-North America, Africa-Europe, and Japan-Australia have been noted [9, 10, 11].

3.3 *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 irregularities may occasionally give rise to reflections of waves in the 30 to 300 MHz range, the principal case being that of reflection from the edges or sides of magnetic-field aligned irregularities which occur within or near the auroral zone [12, 13, 14]. Such reflections may constitute a source of interference to stations working on waves in the 30 to 300 MHz 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 [15], in South America and in Africa and appear to be a phenomenon of high sunspot years. The equinoctial months appear to be favoured [16].

4. Main causes of interference to stations working at frequencies between 30 to 300 MHz

Cause of interference	Latitude zone	Period of severe interference	Approximate highest frequency with severe interference (MHz)	Approximate frequency above which interference is negligible (MHz)	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	500-4000
	Temperate	Day and evening Summer	60	90	
	Equatorial	Day	60	90	
Sporadic-E scatter	Low	Evening up to 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

BIBLIOGRAPHY

1. Smith, E.K. and Matsushita, S. *Ionospheric sporadic-E.* Pergamon Press (1962).
2. Kerblai, T.S. The characteristics of the sporadic-E layer and their use in radio prediction (in Russian) *Academy of Sciences, IZMIRAN,* **19**, (1961).
3. Halley, P., Duboc, J., and Thuillier, J. Etudes des limites supérieures des fréquences susceptibles d'être réfléchies par l'ionosphère en Europe (Study of the upper limits of frequency which can be reflected by the ionosphere in Europe). *Ann. des télécomm.* **16**, 5-6 (May-June, 1961).
4. Marique, J. Sur quelques cas de brouillage observés en ondes métriques. (On some cases of interference observed at VHF). *La Revue H.F.* Vol. 1, **1**, 1-9 (1964).
5. Kerblai, T.S. Instruction on calculation of HF communications reflected from the Es-layer. (In Russian), *Nauka*, Moscow (1964).
6. Kerblai, T.S. Some statistical data on various types of Es-layer. (In Russian) *Geomag. i Aeronom.*, Vol. 2, 3, 495-501 (1962).

7. Miya, K. and Sasaki, T. Characteristics of ionospheric Es propagation and calculation of Es signal strength. *Radio Science*, Vol. 1 (new series), **1**, 99-108 (January, 1966).

8. Reinisch, B. Die Bedeutung von Echos an der sporadischen E-Schicht bei Impulsfernübertragung über 1700 km (Athen-Breisach) (The influence of sporadic-E echos using pulse transmission for a distance of 1700 km (Athens-Breisach)). *AEÜ* **19**, 361-366 (1965).

9. Southworth, M.P. Night-time equatorial propagation and 50 Mc/s. First results from IGY amateur observing programme, *J. Geophys. Res.* **65**, 601 (1960).

10. Stein, S. The role of ionospheric layer tilts in long-range high-frequency radio propagation, *J. Geophys. Res.*, **63**, 217 (1958).

11. Dieminger, W., Rose, G. and Widdel, H.U. On the probability of co-channel interference in VHF bands I, II, and III in Africa, caused by scatter and reflection from the E and F layers. *Telecommunication Journal.*, Vol. 30, **8** (1963).

12. Kaiser, T.R. Radio investigations of auroral and related phenomena. *The Airglow and Aurorae*, Pergamon Press (1959).

13. Collins, C. and Forsythe, P.A. A bi-static radio investigation of auroral ionization. *J. Atm. and Terr. Phys.*, **13**, 315-345 (1959).

14. Lange-Hesse, G.
    (a) Fernausbreitung ultrakurzer Wellen im mitteleuropäischen Raum durch Rückstrahlung am Polarlicht (VHF long-distance propagation in Central Europe by aurora-backscatter). *Archiv der elektrischen Übertragung, (AEÜ)*, **16**, 251-261 (1962).
    (b) Fernausbreitung Ultrakurzer Wellen in mittleren Breiten durch Rückstrahlung am Polarlicht (VHF long-distance propagation in central latitudes by aurora-backscatter. *Archiv der elektrischen Übertragung (AEÜ)* **18**, 430-438 (1964).

15. Bateman, R. et al. IGY observations of F-layer scatter in the Far East. *J. Geophys. Res.*, **64**, 403 (1959).

16. Bailey, D.K. *Ionospheric forward-scattering* — Monograph on ionospheric radio. Ed. W.J.G. Beynon, Elsevier, 189-199 (1962).

REPORT 260–1 *

IONOSPHERIC-SCATTER PROPAGATION

(1956 – 1959 – 1963 – 1966)

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 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). The newer operational links have, in accordance with earlier mid-latitude height measurements, been designed, and at least operated initially, to use midpoint scattering from a height of 85 km.

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

---

* This Report was adopted unanimously.

the problem of reliability. Experience with ionospheric-scatter propagation, derived both from experimental studies and practical communication systems, has clarified a number of features of the observed propagation such as the important advantages that may be obtained practically by realization of the contribution from aspect-sensitive meteor ionization and magnetic field-aligned ionization structures. The implications of these contributions from the view-point of interference are negligible compared with the occasional occurrence of propagation by the sporadic-E mode. Report 259–1 gives information regarding propagation by sporadic-E at the appropriate frequencies. Report 109–1 may be consulted in connection with this Report for a more detailed discussion of system aspects of ionospheric-scatter propagation. 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 irregularity are aligned with the direction of the Earth's magnetic field. Indeed in the region of the minimum just described, communication systems employing antennae directed to take advantage of scattering from field-aligned ionization have exhibited greatly improved performance in comparison with otherwise substantially identical facilities with antennae directed towards the path midpoint.

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. 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 are almost independent of 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. At low latitudes, propagation by means of the intense field-aligned ionization existing near the magnetic equator has been found to increase in intensity with decreasing sunspot number, as might be expected from the negative correlation between the intensity of the equatorial electrojet and sunspot number. 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 MHz 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. At low latitudes, very little correlation exists between the signal intensity resulting from the normally random scattering process and magnetic activity. However, the propagation by way of the intense field-aligned ionization at the magnetic equator shows a remarkably close correlation during daytime with even small variations in the local horizontal magnetic intensity such as magnetic bays. The dependence on magnetic activity of the field-aligned propagation, that is of particular operational significance at locations removed 20° to 30° from the magnetic equator, remains to be determined.

5. Equatorial ionospheric-scatter

It has been suggested that the strong signal intensities associated with equatorial ionospheric-scatter propagation are related to the equatorial or *q*-type sporadic-E. Because of the very close correlation between variations of the intensity of scatter signals and variations of local magnetic intensity during the daytime that are associated with the equatorial electrojet, an association with the electrojet seems also indicated. These associations are strengthened by observations which show that the scattering sources responsible for the strong signals lie between the heights of 100 and 110 km, within which the electrojet occurs. Oblique scatter signal intensities, however, have been observed at night without *q*-type sporadic-E, that are of nearly equal intensity to daylight signal intensities when *q*-type sporadic-E is present.

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. No serious difficulties in the operation of ionospheric-scatter links have resulted from the simultaneous presence of F-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 MHz 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 of 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 MHz range, at times of high solar activity, if extreme reliability of operation is sought.

The upper limit of frequency is fixed by mainly economic considerations. Since, as a rough guide, the signal intensities may be taken as varying inversely as the 7½ power of the frequency, for scaled antennae with equal input power, while the cosmic noise intensities vary inversely as about the 2½ power of the frequency, the signal-to-noise ratio varies inversely as approximately the 5th power of the frequency. With this frequency dependence of the signal-to-noise ratio and using scaled antennae, 15 dB more transmitter power is required at 60 MHz than at 30 MHz to give the same signal-to-noise ratio.

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 MHz)*

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 multipath 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 2500 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 MHz*

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 MHz.

8.3 *Two-frequency circuits*

Particular interest is being taken in two frequency operations, using one frequency in the 30 to 45 MHz range and the other between 45 and 60 MHz. 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 100 words per minute are now in 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.

11. Antenna orientation

While it is 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 midpoint of the path, the importance of scattering from aspect-sensitive ionization, which is usually most effective in azimuths somewhat different 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, meteor activity, and with path position, length and orientation. By using antennae which take advantage of scattering from field-aligned ionization in regions of the ionosphere other than above the midpoint of the path, the signal-to-noise ratios obtained can, at certain times, be significantly increased. Such increases may be of particular importance in improving the usability of a circuit at certain seasons, times of day and geographical locations, particularly where very low signal-to-noise ratios for scattering from the midpoint region occur for much of the time.

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.

BIBLIOGRAPHY

1. Bailey, D.K. *et al.* A new kind of radio propagation at very high frequencies observable over long distances. *Phys. Rev.*, **86**, 141-145 (1952).
2. Bailey, D.K., Bateman, R. and Kirby, R.C. Radio transmission at VHF by scattering and other processes in the lower ionosphere. *Proc. IRE*, **43**, 1181-1230 (1955).
3. Abel, W.G. et al. Investigations of scattering and multipath properties of ionospheric propagation at radio frequencies exceeding the MUF. *Proc. IRE*, **43**, 1255-1268 (1955).
4. Bray, W.J. et al. VHF propagation by ionospheric scattering and its application to long-distance communications. *Proc. I.E.E.*, **103**, Part B, 236-260 (1956).
5. Bailey, D.K. Ionospheric " forward " scattering. General survey to the XIIIth General Assembly, of U.R.S.I. (London, September, 1960) in Monograph on ionospheric radio. Elsevier, 189-199 (1962).
6. Rose, J. et al. The Pacific scatter communication system. *Convention Record, 5th National Symposium on Global Communication*, 110-113 (May, 1961).
7. Halley, P., Duboc, J. and Thuillier, J. Etude des limites supérieures des fréquences susceptibles d'être réfléchies par l'ionosphère en Europe (Study of the upper limits of frequency that can be reflected by the ionosphere in Europe). *Ann. des télécomm.*, **16**, 5-6 (May-June, 1961).
8. Blair, J.C., Davis, R.M. and Kirby, R.C. Frequency dependence of D-region scattering at VHF. *J. Res. National Bureau of Standards*, **65D**, 417-425 (1961).
9. Sasaki, I. and Isomura, E. On space diversity effect in ionospheric-scatter propagation at VHF. *P.G.R.P. Inst. Electr. Comms. Engs., Japan* (January, 1962).
10. Bain, W.F. Solar-induced effects on VHF ionospheric propagation at low magnetic latitudes, in AGARDograph 59. The effect of disturbances of solar origin on communications. 185-192, Pergamon (1963).

In addition to the above, attention is drawn to substantial parts of issues of journals as follows:

11. *Proc. IRE*, **43** (October, 1955).
12. *IRE Transactions on Communications Systems*, Vol. CS-4 (March, 1956).
13. *Proc.* I.E.E., **105**, Part B (May, 1968), containing, under Session 1, the papers and discussion of a symposium on " Ionospheric forward scatter propagation ".
14. *Proc. IRE*, **48**, 7-31 (January, 1960). Report of JTAC on " Radio transmission by ionospheric and tropospheric scatter ".

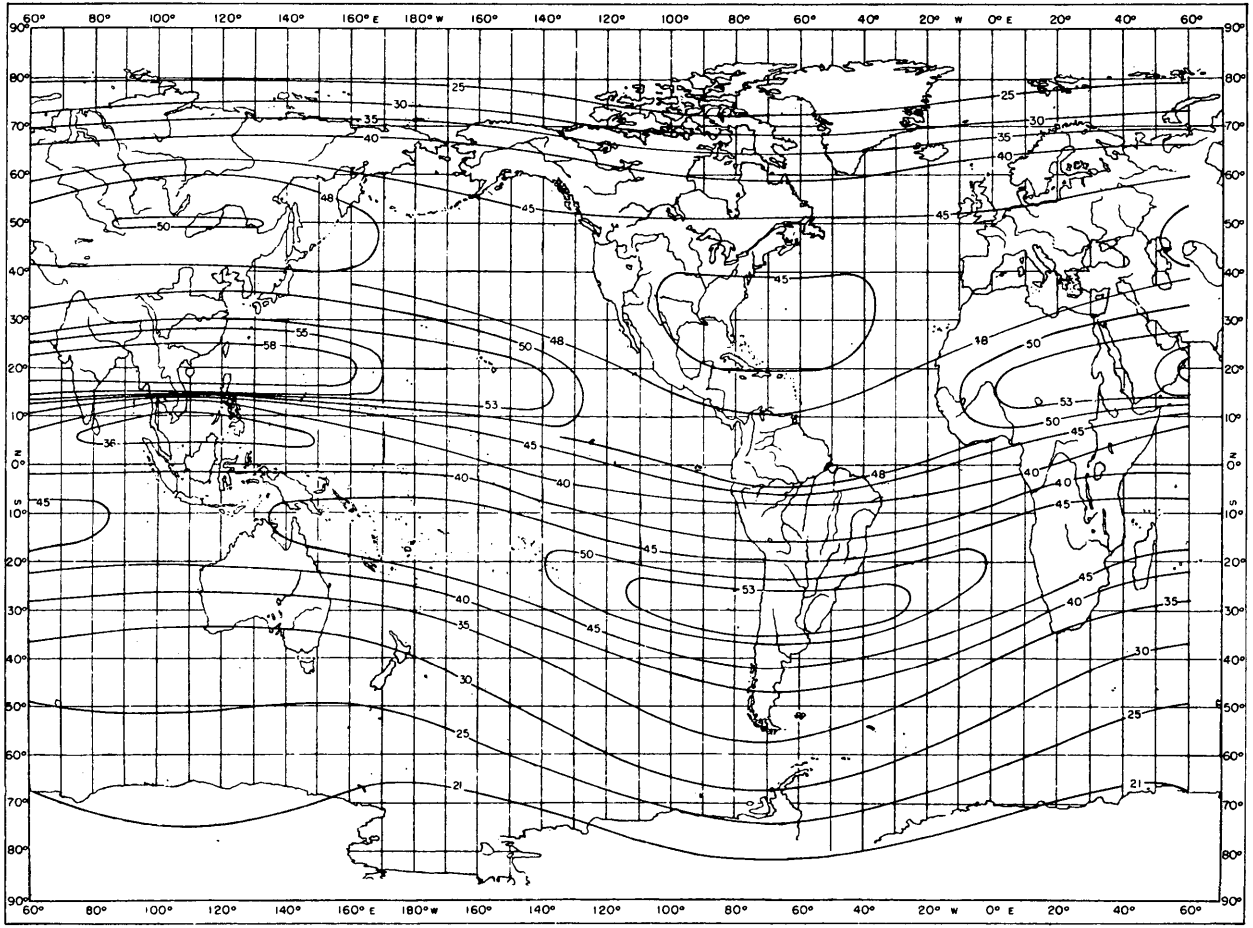


Figure 1

F2 4000 MUF exceeded during 1% of hours — December solstice; sunspot maximum

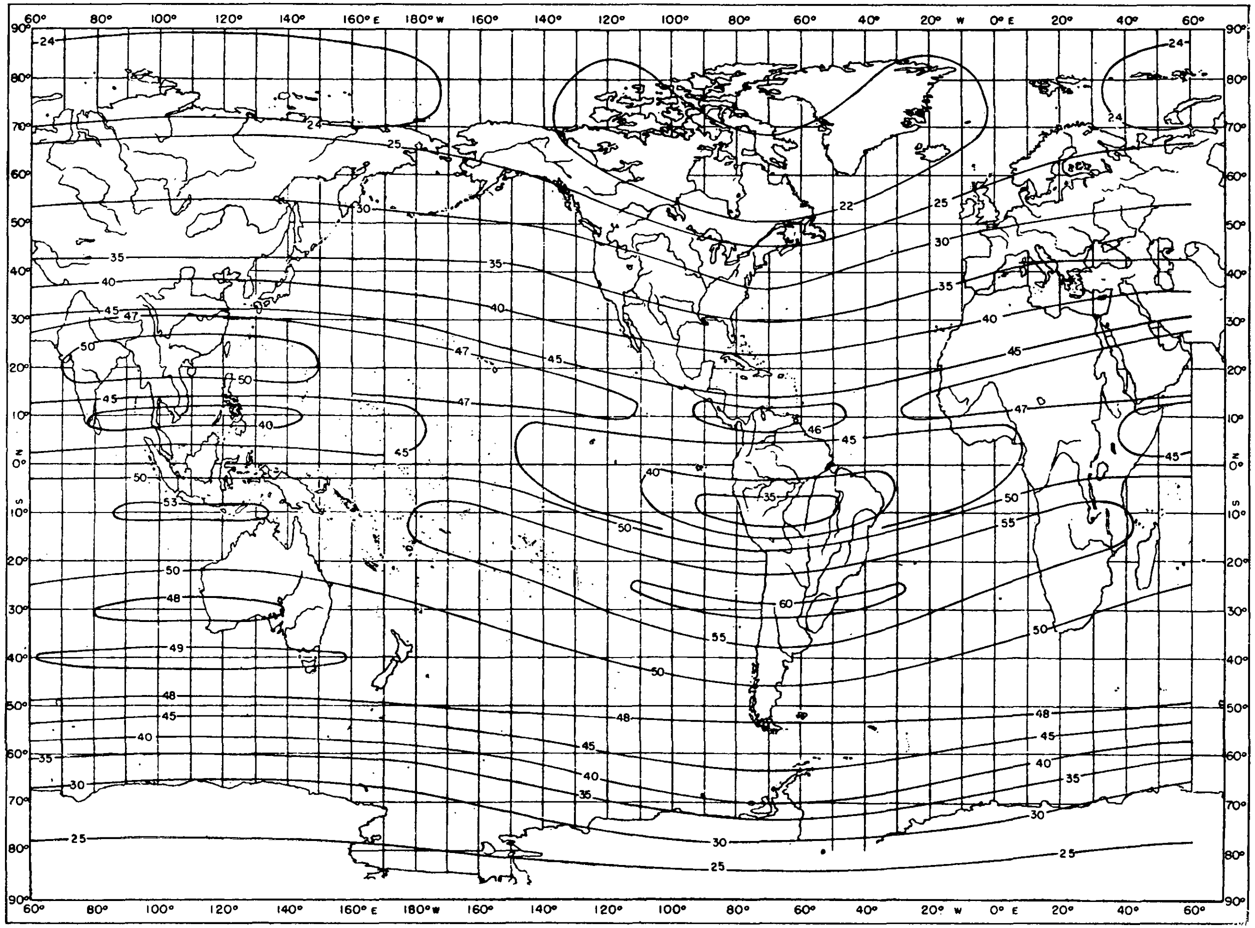


FIGURE 2

F2 4000 MUF exceeded during 1% of hours — June solstice; sunspot maximum

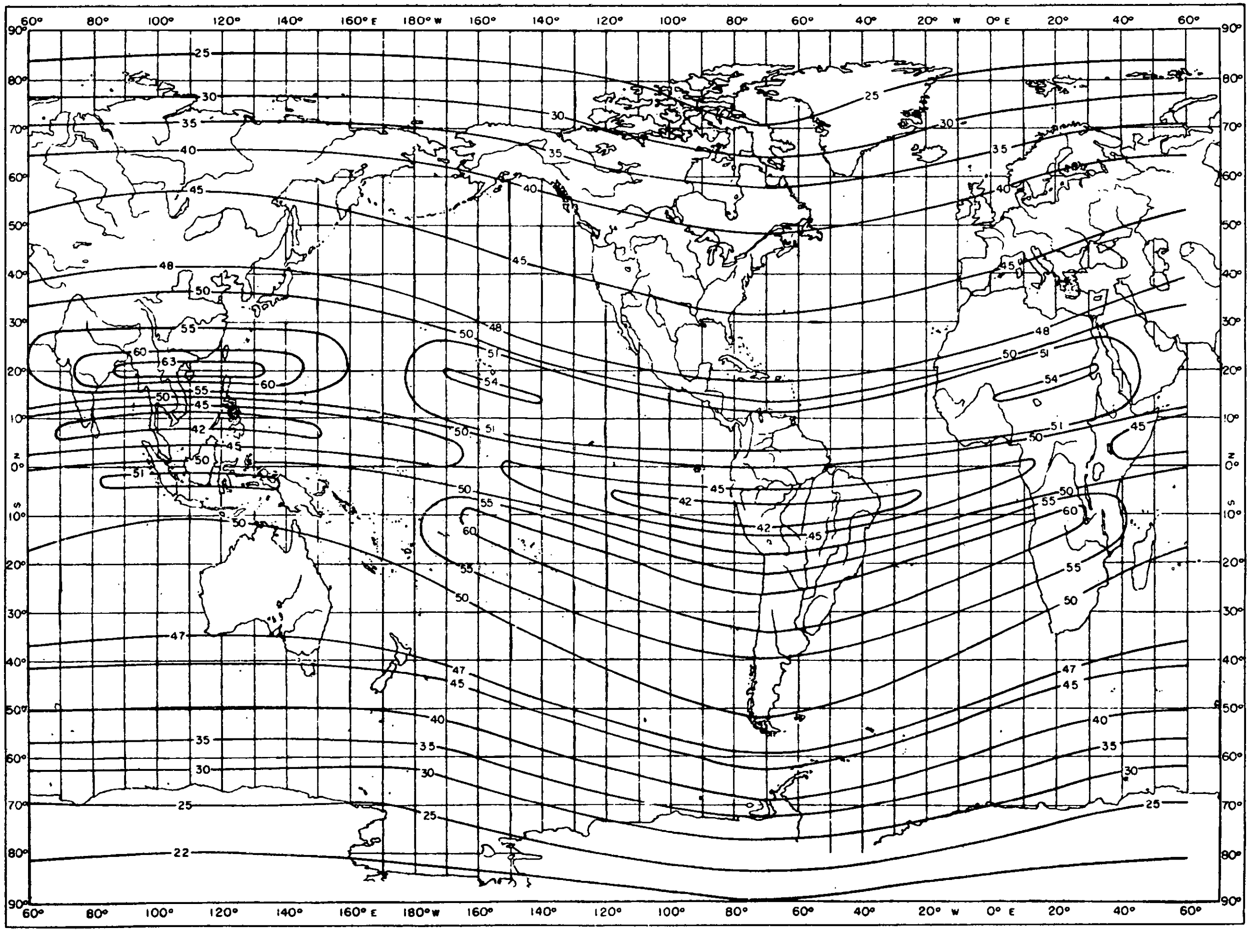


FIGURE 3

F2 4000 MUF exceeded during 1% of hours — Equinox; sunspot maximum

REPORT 261-1 *

BACK-SCATTERING

(Study Programme 14A/VI)

(1963 - 1966)

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. Scattering coefficients of the earth's surface may be quite variable depending upon the nature of the surface and the elevation angle [1]. Some of the scattered energy is returned over the same propagation path to the vicinity of the transmitter [2 to 7] 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 [8, 9]. 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 [10]. 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 [11, 12]. 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 sources of back-scatter

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. However, because of ionospheric tilts, the possible errors in azimuthal information become progressively greater with the number of hops involved.

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 [13].

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 [14]. Another method of identifying Es modes is the use of the azimuth-sweeping back-scatter sounder:

---

* This Report was adopted unanimously.

motion of isolated Es patches can be traced with surprising ease, and a general westward drift has been noted around 40° north latitude [15 to 20].

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 [21]. In addition, when sufficiently short pulses are used for back-scatter sounding, irregularities in signal amplitude which may change range with time are seen. These signal enhancements appear to be caused by moving irregularities in the ionosphere which cause signal focusing [21, 22] or by certain special conditions [23].

A lack of correlation was often observed between the transmission loss in a given radiocommunication link and the total loss in the back-scatter soundings performed along the same path as the radio link. This is due to the fact that the intensity of the back-scatter echoes strongly depends upon the presence of focusing F2-region irregularities, which have no detectable influence on the transmission loss in a radiocommunication link. It is also observed that this focusing effect is stronger when the back-scatter sounding in temperate latitudes is performed in the direction of the Earth's magnetic field [27].

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 [12, 24, 25].

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 [26].

Back-scatter techniques have been used to observe the effects of solar flares [28].

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 250-1). They are generally attributed to layer tilts and have been the subject of considerable study [29, 30].

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 [31].

Other work at 40·3 MHz has shown echoes with delay up to 50 times greater than those for E reflections [32]; 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.

Observations have been reported of anomalous back-scatter returns observed at the time the satellite passes through an area accessible to the sounder or through the region in the opposite hemisphere magnetically conjugate [33].

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 [34]. 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. A survey of work prior to 1955 is contained in [35, 36, 37, 38]. These echoes are closely related to the 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 [36]. These echoes appear to come from height regions about 10 km in thickness [39] but of great lateral extent.

Systematic studies of auroral back-scattering have now been carried out on scaled systems operating in one experiment at four frequencies between 42 and 104 MHz inclusive [40, 41], and in another at two frequencies near 500 and 1000 MHz [42]. These studies indicate that critical reflection may occur at frequencies as high as 100 MHz during auroral disturbances supporting the use of a theroetical model which includes both weak scattering and critical reflection [43], to explain echoes at these frequencies. At higher frequencies, the evidence suggests that auroral back-scatter echoes arise only by weak-scattering from non-isotropic, field-aligned, irregularities, although present theories appear somewhat inadequate in explaining all of the results. Multiple scattering may also be significant.

Direct back-scatter from irregularities in the F-region at heights of 250-400 km apparently unrelated to visual aurora have been obtained [44], with winter daytime echoes appearing more " patchy " than those seen at night [45].

Even at latitudes far from the auroral zone, HF ground back-scatter equipment has observed distant echoes from auroral ionization, with the aid of ionospheric bending and possibly an additional reflection from the ground [46].

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 [47]. A 200 MHz 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 [48].

5.4 *Equatorial field-aligned ionization*

In the special case of the magnetic-dip equator, where the magnetic field is parrallel 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, actually consists of field-aligned horizontal irregularities which principally give echoes in the east-west plane through the vertical containing the station [49] and exhibit characteristic drift patterns [50].

5.5 *Artificial satellites*

Spread-F echoes have been observed by means of the " Alouette " topside-sounder satellite. Spread echoes occur largely at high latitudes and appear to arise from back-scatter from local irregularities in the turbulent ionosphere and also at times from clouds of ionization within the auroral zone [51]. Equatorial spread-F has also been observed [52, 53]. This spreading has been explained on the basis of north-south propagation along sheets of ionization aligned with the magnetic field, in which trapping by the field-aligned sheets occurs at levels near the normal height of F-layer reflection.

BIBLIOGRAPHY

1. Steel, J.G. The effect of the ground back-scatter coefficient on observations of sporadic-E over sea, land and mountains. *J. Atmos. Terr. Phys.*, **26**, 2, 323-324 (1964).
2. Villard, O.G. and Peterson, A.M. Scatter-sounding: a technique for study of the ionosphere at a distance. *Trans. IRE, PGAP*, **3**, 186-201 (1952).
3. Shearman, E.D.R. A study of ionospheric propagation by means of ground back scatter. *Proc. I.E.E., Paper 1914 R* (1955).
4. Silberstein, R. Sweep-frequency back-scatter — Some observations and deductions. *Trans. IRE, AP-2*, 56 (1954).
5. Peterson, A. M. Ionospheric back-scatter. *Annals of the IGY III*, Part IV, 361-381, Pergamon Press (1957).
6. Kono, T. Experimental study on scattered echoes (II). *Report of Ionospheric Research in Japan*, **4**, 189-199 (1950).
7. Dieminger, W. The scattering of radio waves. *Proc. Phys. Soc.*, **64-B**, 142-158 (1951).
8. Kosikov, K.M. Oblique return sounding and problems of radio communication and broadcasting over long distances. *Electrosvyaz*, **7**, 699 (1959).
9. Bibl, K. Aktive Hochfrequenzspektrometer für die ionosphärische Echolotung I: Direktregistrierung ionosphärischer Charakteristiken (The active high frequency spectrometers for ionospheric sounding I. Direct recording of ionospheric characteristics). *Arch. elektr. Übertr.*, **14**, 341-347 (1960).
10. Peterson, A.M., Egan, R.D. and Pratt, D.S. The IGY three-frequency back-scatter sounder. *Proc. IRE*, **47**, 300-314 (1959).
11. Peterson, A.M. The mechanism of F-layer propagated back-scatter echoes. *J. Geophys. Res.*, **56**, 221 (1951).
12. Beckman, B. and Vogt, K. Back-scatter Beobachtungen an Telegraphie-Signalen (Observations of back-scattering on telegraph signals). *Electromagnetic Wave Propagation*, edited by M. Desirant and J.L. Michiels, 157-166, (Academic Press, 1960).
13. Ranzi, I. Back-scatter echo pattern and vertical radiation diagram. Centro radioelettrico sperimentale G. Marconi (Rome), Note **8** (1961).
14. Bibl, K. Experimental proof of focusing at the skip distance by back-scatter records. *Proc. IRE*, **48**, 956-957 (1960).
15. Villard, O.G. and Peterson, A.M. A method for studying sporadic-E clouds at a distance. *Proc. IRE*, **40**, 992-994 (1952).

16. CLARK, C. Motion of sporadic-E patches determined from high-frequency back-scatter records. *Nature*, **178**, 486-487 (1956).

17. HARWOOD, J. Some observations of the occurrence and movement of sporadic-E ionization. *J. Atmos. Terr. Phys.*, **20**, 4, 243-262 (1961).

18. EGAN, R.D. and PETERSON, A.M. Back-scatter observations of sporadic-E, 89-109, *Ionospheric sporadic E*, edited by Smith, E.K. and Matsushita, S., Pergamon Press (1962).

19. BIBL, K. Neuartige Back-scatter-Registrierungen und Ergebnisse (A new method of recording back-scatter and presenting the results) from the reports of the meeting on ionospheric physics and wave propagation (*FTZ* Darmstadt) Kleinheubach (1961).

20. SHEARMAN, E.D.R. and HARWOOD, J. Sporadic-E as observed by back-scatter techniques in the United Kingdom. *JATP*, **18**, 29 (1960).

21. TVETEN, L.H. Ionospheric motions observed with high-frequency back-scatter sounders. *J. Res. NBS*, **65**-*D*, 115-127 (1961).

22. SHEARMAN, E.D.R. The amplitude and spectrum of ground back-scatter echoes. *Proceedings of the International Conference on the Ionosphere 1962*, edited by A.C. Strickland, 293-300 (Bartholomew Press 1963).

23. DUENO, B. Interpretation of some sweep-frequency back-scatter echoes. *J. Geophys. Res.* **68**, 3603-3610 (1963).

24. SHEARMAN, E.D.R. An investigation of the usefulness of back-scatter sounding in the operation of high frequency broadcasting services, *Proc. I.E.E.*, **108** *B*, 361 (1961).

25. BECKMANN, B. and VOGT, K. Über Beobachtungen der Rückstreuung (back-scatter) im Kurzwellengebiet an kommerziellen Telegraphie Signalen (Observations on back-scattering of commercial telegraph signals in the HF band). *Fernmeldetechnische Zeitschrift.*, **8**, 473-481 (1955).

26. MITRA, S.N. and IYENGAR, V.C. *Ind. Jour. Phys.*, **28**, 147 (1954).

27. C.C.I.R. Doc. VI/56, 1963-1966.

28. BARRY, G.H. and WIDESS, P.R. The effect of a solar flare on the frequency of HF ground back-scatter. *J. Geophys. Res.* **67**, 2707-2714 (1962).

29. STEIN, S. The role of ionospheric layer-tilts in long-range high-frequency radio propagation. *J. Geophys. Res.*, **63**, 217-241 (1958).

30. SOUTHWORTH, M.P. Night-time equatorial propagation at 50 MHz: First results from an IGY amateur observing program. *J. Geophys. Res.*, **65**, 601-607 (1960).

31. GALLET, R.M. and UTLAUT, W.F. Evidence on the laminar nature of the exosphere obtained by means of guided high-frequency wave propagation. *Phys. Rev. Letters*, **6**, 591-594 (1961).

32. MAYNARD, L.A. Propagation of meteor-burst signals during the polar disturbance of November 12-16, 1960. *Can. J. Phys.*, **39**, 628 (1961).

33. TIURI, M.E. and KRAUS, J.D. Ionospheric disturbances associated with Echo I as studied with 19 MHz radar. *J. Geophys. Res.* **68**, 5371-5386 (1963).

34. BOOKER, H.G. Turbulence in the ionosphere with application to meteor-trails, radio-star scintillation, auroral radar echoes and other phenomena. *J. Geophys. Res.*, **61**, 673-705 (1956).

35. LITTLE, C.G., RAYTON, W.M. and ROOF, H.B. Review of ionospheric effects at VHF and UHF. *Proc. IRE*, **44**, 992-1018 (1956).

36. PRESNELL, R.I. ET AL. VHF and UHF radar observations of the aurora at College, Alaska. *J. Geophys. Res.*, **64**, 1179-1190 (1959).

37. FRICKER, S.J., INGALLIS, R.P., STONE, M.L. and WANG, S.C. UHF auroral observations. *J. Geophys. Res.*, **62**, 527-546 (1957).

38. BATES, H.F. The slant-Es echo — A high-frequency auroral-echo. *J. Geophys. Res.*, **66**, 447-454 (1961).

39. UNWIN, R.S. The geometry of auroral ionization, *J. Geophys. Res.*, **63**, 501-506 (1958).

40. LYON, G.F. and FORSYTH, P.A. Radio-auroral reflection mechanisms. *Can. J. Phys.*, **40**, 749-760 (1962).

41. LYON, G.F. The effect of absorption and multiple scattering on radio-auroral observations. *Can. J. Phys.* **40**, 739-748 (1962).

42. BLEVIS, B.C., DAY, J.W.B. and ROSCOE, O.S. The occurrence and characteristics of radar auroral echoes at 488 and 944 Mc/s. *Can. J. Phys.*, **41**, 1359-1380 (1963).

43. MOORCROFT, D.R. Models of auroral ionization *Can. J. Phys.*, **39**, 677-715 (1961).

44. Bates, H.F. The height of irregularities in the arctic atmosphere. *J. Geophys. Res.* **64**, 1257-1265 (1959).

45. Bates, H.F. Direct HF back-scatter from the F-region. *J. Geophys. Res.* **65**, 1993-2002 (1960).

46. Peterson, A.M. and Leadabrand, R.L. Long-range radio-echoes from auroral ionization. *J. Geophys. Res.*, **59**, 306-309 (1954).

47. Peterson, A.M. et al. Regularly-observable aspect-sensitive radio reflection from ionization aligned with the earth's magnetic field and located within the ionospheric layers at middle latitude. *J. Geophys. Res.*, **64**, 497-512 (1955).

48. Heritage, J.L., Weisbrod, S. and Fay, W.J. Evidence for 200 Mc/s ionospheric forward-scatter mode associated with the earth's magnetic field. *J. Geophys. Res.*, **64**, 1235-1241 (1959).

49. Cohen, R. and Bowles, K.L. On the nature of equatorial spread-F. *J. Geophys. Res.*, **66**, 1081-1106 (1961).

50. Clemesha, B.R. An investigation of the irregularities in the F-region associated with equatorial type spread-F. *J. Atmos. Terr. Phys.* **26**, 91-112 (1964).

51. Petrie, L.E. Top-side spread echoes. *Can. J. Phys.*, **41**, 194-195 (1963).

52. Muldrew, D.B. Radio propagation along magnetic field-aligned sheets of ionization observed by the Alouette top-side sounder. *J. Geophys. Res.*, **68**, 5355-5370 (1963).

53. Lockwood, G.E.K. and Petrie. L.E. Low latitude field strength aligned ionization observed by the Alouette topside sounder. *Planetary and Space Science*, **11**, 327 (1963).

REPORT 262–1 *

VLF PROPAGATION IN AND THROUGH THE IONOSPHERE

(1963 - 1966)

1. Historical

It has been known for many years that very low frequencies can be propagated through the ionosphere by a mode which for historical reasons has been called the " whistler mode ". In the original studies, the signals originated in lightning flashes and the frequencies observed were within the audio range and were termed " musical atmospherics " [1, 2]. These frequencies were, moreover, subject to a dispersion in time, the velocity of propagation decreasing with frequency so that the received signals had a characteristic whistle of decreasing frequency over a period of a second or more. They also consisted of a series of well-separated echoes with increasing frequency dispersions. These remarkable properties were explained theoretically in terms of propagation, by an extraordinary mode of low velocity and small attenuation, along a path closely confined around a line of the Earth's magnetic field, the signals travelling to and fro between conjugate points on the surface of the Earth [3, 4 and 5]. This mode is known as the " whistler mode ". A comprehensive survey of the history and present state of whistler research has been recently published [6].

2. Use of VLF transmitters

More recently, this mode of propagation has been studied by using high-power VLF transmitters. With the increasing interest being shown in the problem of transmission on various

---

* This Report was adopted unanimously.

frequencies for terminal points on the surface of the Earth and in or above the ionosphere, it is now preferable to think of VLF propagation in general and to restrict the term " whistler " to transmissions covering a frequency spectrum such as is originated by a lightning flash for which the frequency dispersion characteristic of whistlers can be observed.

It is interesting to note, that the times when relatively strong signals have been obtained between conjugate points with VLF transmitters have shown only poor correlation with the times when whistlers were prevalent. Thus, although experiments using natural sources are of great scientific interest in unravelling some of the complexities of VLF propagation through the ionosphere, they must be supplemented with experiments directly related to propagation on given frequencies from chosen transmitting points.

3. Frequency limits and intensity considerations

It has been found that when both terminals are on the surface of the Earth, the whistler mode is effective at frequencies as low as 400 Hz and as high as 35 kHz. It has been observed at most locations between geomagnetic latitudes 20° and 80°, and there is a well-defined cut-off frequency which is approximately 0·6 of the minimum gyro-frequency along the path. Observations at middle latitudes show that, at night, signals by a single traverse between conjugate points can be obtained by the whistler mode for more than half the time and can approach in strength on occasion to within 10 dB of the conventional waveguide signal between the Earth and the ionosphere. Little is known about the intensity of daytime whistler-mode signals, but it appears that they are severely attenuated 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,
- multipath 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.

4. Propagation analysis

A general computer programme has been developed, for studying with a full-wave treatment, the fields in a horizontally stratified ionosphere for waves incident from above or below for a wide range of the relevant parameters [7]. A new reciprocity relation has been established between the transmission coefficient and the limiting polarization, for a whistler-wave incident on the ionosphere from above and the corresponding parameters for a wave incident from below. The analysis has been applied to a large amount of LF and VLF data available from south-east England and to various models including one based on wave interaction experiments at Oslo, from which the distributions of electron density and collisional frequency with height have been determined with some accuracy up to about 85 km [8, 9]. For any given model, it is necessary to extrapolate these distributions upwards through the E layer, in a manner consistent with the observed frequency dependence of reflection height and absorption at HF [10, 11].

A survey has been made of the whistler-mode characteristics for day and night. In some of the models used the effect of sporadic-E layers has been included [12]. Near 14 kHz, the transmission coefficient varies only slowly with angle of incidence between ±85°, whereas near 100 kHz, efficient transmission is possible only at angles within a limited cone with its axis along the direction of the magnetic field. Both by day and night, the transmission coefficient is mainly determined by losses in the ionosphere, provided that steep gradients of electron density, similar to those in a sporadic-E layer, are absent. When sporadic-E is present, the transmission coefficient falls. Both by day and night, sporadic-E can give very high internal reflection coefficients for waves reflected from above. This is important when one end of the field line is in daylight, since very efficient long whistler propagation may then be possible.

5. Satellite observations

The study of VLF propagation in and through the ionosphere has been considerably advanced by using satellites, whereby it has become possible to make measurements within the ionosphere itself, as well as below and above it. For a terminal point within the ionosphere, consideration must be given to the effect of a highly anisotropic medium on the antenna characteristics and thus on the transmission loss. In this connection, an interesting series of experiments has been undertaken in the LOFTI satellite programme. This programme was designed to study both theoretically and experimentally the degree and extent of VLF radio-wave penetration of the ionosphere. One aspect of the LOFTI programme includes an experiment to measure the impedance of dipoles and loops embedded in the ionosphere. To date, two space vehicles have been launched under the LOFTI programme. LOFTI I indicated that useful amounts of VLF radio energy can penetrate the atmosphere/ionosphere interface and, in particular, that 18 kHz signals from ground-based transmitters were detected as far as 10 000 miles away in the ionosphere with substantially less attenuation at night than by day, as expected. The observed time delays ranged from 10 to 200 ms, indicating that the VLF propagation velocity in the ionosphere is much lower than in free space [13]. In the LOFTI II experiment, in addition to signal strength, measurements were made of dipole impedance in the ionosphere. The measured impedance was found to be radically different from that in free space. Theoretical analyses have been made by various groups. These also indicate that the dipole impedance in a magneto-ionic medium is radically different from that in free space.

Alouette I contains a VLF receiver covering the frequency range 0·4 to 10 kHz using an electric dipole. While the observations do not yield amplitude information, the VLF signals received at the satellite are very strong indeed. The satellite moves in a nearly circular orbit, at an inclination of 80° to the equator and at a height of about 1000 km. Short fractional hop (SFH) whistlers, i.e. those which have been propagated from a lightning flash only once through the ionosphere, are strongly received and often overload the receiver. Transmissions are received from high-power ground-based transmitters and even from low-power transmitters (100 W) at 10 kHz, but no study has yet been made of these signals.

Concerning the propagation of very low frequencies, these observations emphasize two special points not hitherto considered in any detail:

- the importance of propagation within the ionosphere transverse to the direction of the Earth's magnetic field, no clear evidence of which has been obtained with ground-based equipment;
- the importance of ions on the propagation of the lowest frequencies.

With reference to the first, it is noted in the Alouette I satellite that long fractional hop (LFH) whistlers, i.e. those thought to be propagating down the line of force from the opposite hemisphere, can often be observed having the same dispersion characteristics during a full ten-minute telemeter recording. This implies that a particular duct is active throughout this period in propagating the whistlers which, after leaving the duct, can travel some thousands of kilometres transversely to reach the satellite receiver. Besides this fact, not previously noted in the literature, horizontal propagation of SHF whistlers can lead to reflection of these signals near the height of the satellite [14, 15, 16]. Moreover, a VLF plasma resonance (the lower hybrid resonance for the transverse mode of propagation), is evident in Alouette I VLF data as a cut-off frequency for a VLF noise band [17], and its identification is providing a source of information on the mean ionic mass at the height of the satellite [18].

The evidence for the importance of ions at the lowest frequencies is concerned with the identification of ion cyclotron whistlers [19], which are also being investigated as a means of studying the ions at the height of the satellite [20, 21].

6. The exosphere

The fact that propagation paths for the whistler mode can extend far from the Earth to distances of several earth-radii shows that a measure of ionization must exist out to these distances. As mentioned above, satellite experiments are revealing the part played by electrons and ions in the Earth's magnetic field as a major factor in VLF propagation, and the whole subject of the movement of charged particles in the exosphere is of interest in this connection. It has been shown that, not only the forces due to the movement of the particles in the Earth's magnetic field, but also those due to gravity, are of importance in determining the limits between which the particles spiral round the field lines. In addition to the " magnetic mirror ", where the particles are reflected back along the field lines at a point where the radius of the spiral path is a minimum, there is, in general, an upper reflecting level where the path has a maximum radius and the gravity field controls and prevents any further movement along the field line. The particle is thus trapped between these two levels and, in some conditions, the distance apart of these levels is small, so that for a certain critical condition the particle can be " frozen " at a fixed level along the field line. Such considerations explain why the density of electrons and ions, as deduced from investigations of the whistler mode of propagation, often differ from the value expected from simpler assumptions of the movement of charged particles in the exosphere [22].

7. Conclusions

In conclusion, it may be pointed out that there may be a close connection between very low-frequency propagation by the whistler mode and high-frequency propagation by ionospheric irregularities aligned along the lines of the Earth's magnetic field referred to in Report 341. It may well be that the study of the one mode will throw light on the nature of the other.

BIBLIOGRAPHY

1. Eckersley, T.L. A note on musical atmospheric disturbances. *Phil. Mag.*, **49**, 1250-1260 (1925).
2. Barkhausen, H. Zwei mit Hilfe der neuen Verstärker entdeckte Erscheinungen. (Two phenomena discovered with the use of new amplifiers). *Phys. Z.*, **20**, 401-403 (1919).
3. Helliwell, R.A. and Morgan, M.G. Atmospheric whistlers. *Proc. IRE*, **47**, 200-208 (1959).
4. Morgan, M.G., Dinger, H.E. and Allcock, G. McK. Observations of whistling atmospherics at geo-magnetically conjugate points. *Nature*, **177**, 29-31 (1956).

5. Storey, L.R.O. An investigation of whistling atmospherics. *Phil. Trans. Roy. Soc.*, A, **246**, 113-141 (1963).
6. Helliwell, R.A *Whistlers and related ionospheric phenomena.* Stanford University Press (1965).
7. Pitteway, M.L.V. The numerical calculation of wave fields, reflection coefficients and polarizations for long waves in the lower ionosphere. Part I, *Phil. Trans. Roy. Soc.* A., **257**, 219-242 (1965).
8. Piggott, W.R., Pitteway, M.L.V. and Thrane, E.V. Ditto, Part II, *Phil. Trans. Roy. Soc.*, A, **257**, 243-271 (1965).
9. Deeks, D.G. D-region electron distributions in middle latitudes deduced from the reflection of very long waves. *Proc. Roy. Soc.*, A, **291**, 413-437 (1966).
10. Piggott, W.R. and Thrane, E.V. *Electron density distribution in the ionosphere.* Ed. E.V. Thrane, 13-14, North Holland (1964).
11. Thrane, E.V. The electron densities in the E and D regions above Kjeller. *J.A.T.P.*, **28**, 467-479 (1966).
12. Pitteway, M.L.V. and Jesperson, J.L. A numerical study of the excitation, internal reflection and limiting polarization of whistler waves in the lower ionosphere. *J.A.T.P.*, **28**, 17-43 (1966).
13. Leiphart, J.P., Zeek, R.W., Bearce, L.S. and Toth, E. Penetration of the ionosphere by very low frequency radio signals. Interim results of the LOFTI I experiment. *Proc. IRE*, **50**, 6-17 (1962).
14. Barrington, R.E. and Belrose, J.S. Preliminary results from the very low frequency receiver aboard Canada's Alouette satellite. *Nature*, **198**, 651 (1963).
15. Carpenter, D.L., Dunckel, N. and Walkup, J.F. A new very low frequency phenomenon — whistlers trapped below the protonsphere. *J. Geophys. Res.*, **69**, 5009 (1964).
16. Smith, R.L. An explanation of sub-protonospheric whistlers. *J. Geophys. Res.* **69**, 5019 (1964).
17. Brice, N.M. and Smith, R.L. Recordings from Satellite Alouette I — a very low frequency plasma resonance. *Nature*, **203**, 926 (1964).
18. Barrington, R.E., Belrose, J.S. and Nelms, G.L. Ion composition and temperature at 1000 km as deduced from simultaneous observations of a VHF plasma resonance and topside sounding data from the Alouette I satellite. *J. Geophys. Res.*, **70**, 1647-1664 (1965).
19. Smith, R.L., Brice, N.M., Katsufrakis, J., Gurnett, D.A., Shawan, S.D., Belrose, J.S., and Barrington, R.E. An ion gyrofrequency phenomenon observed in satellites. *Nature*, **204**, 274 (1964).
20. Gurnett, D.A., Shawan, S.D., Smith, R.L. and Brice, N.M. Ion cyclotron whistlers. *J. Geophys. Res.*, **70**, 1665-1688 (1965).
21. Barrington, R.E., Belrose, J.S. and Nelms, G.L. Ion composition and temperature at 1000 km as deduced from VLF plasma resonances and topside ionograms. Proc. NATO Advanced Study Institute, Finse, Norway, April 1965 (to be published in the book " Electron Density Distributions in the Ionosphere and Exosphere " edited by J. Frihagen, North Holland Publishing Co., Amsterdam, 1965).
22. Chvojková, E. Geometry of spiralling particle-paths of high speeds affected by gravitation. *Bulletin of the Astronomical Institutes of Czechoslovakia*, BAC, *16*, **2**, 63-69 (1965) (C.C.I.R. Doc. VI/71, 1963-1966).

REPORT 263-1 *

IONOSPHERIC EFFECTS UPON EARTH-SPACE RADIO PROPAGATION

(Study Programme 19A/VI)

(1963 - 1966)

1. Introduction

The purpose of this Report is to treat the effects of the ionosphere upon radio waves of frequency greater than the vertical incidence ionosphere penetration frequency, i.e. frequencies which would conventionally be used to communicate to spacecraft. The ionos-

---

* This Report was adopted unanimously.

phere may affect any or all of the five basic parameters defining the propagation of radio waves. That is, the amplitude of the radio wave may be affected by absorption, or large-scale focusing effects, or by small-scale diffraction effects; the angle of arrival may be changed by refraction or diffraction; the instantaneous frequency of the radio wave may be affected by fluctuations in the received phase; the polarization of the radio wave may be changed by the magneto-ionic splitting and subsequent differential absorption refraction, and phase changes. The time and space variations of these various parameters may be affected by ionospheric irregularities of various sizes for a moving source even for the quiet non-varying ionosphere, but especially at times of disturbance (e.g. auroral disturbances).

In §§ 2 to 6, a brief mention will be made in turn of each of the various effects and § 8 gives an order of magnitude and the frequency dependence of the effects. Much of the material summarized in this Report comes from a paper [1], which describes the main American and British work, but similar work has been done elsewhere (e.g. in Canada, the Federal Republic of Germany [2], the U.S.S.R., and elsewhere). The bibliography is by no means complete.

2. Amplitude

Ionospheric absorption does occur, but it diminishes rapidly as the radio-wave frequency is increased and hence is unimportant for the frequencies above 100 MHz which would normally be used for space communication. Rather, absorption at the lower frequencies is an important tool for studying the low-lying levels of the ionosphere and the interaction of these levels with incoming radiation and charged particles.

The divergence effect which, in certain cases, may exceed absorption effects, is also unimportant for practical space communication.

The irregular structure of the ionosphere is responsible, through the interaction of the diffracted waves which it produces, for amplitude-scintillation effects. Amplitude scintillations can become extremely severe and thus they may represent a practical limitation for certain types of communication. They are most severe at night and at high latitudes, although a particularly violent form of scintillation is also found near the geomagnetic equator.

The refractive effects of the larger irregularities in the ionosphere might be expected to cause focusing of the radio waves. This phenomenon has been observed to occur at radio frequencies below 70 MHz.

In addition to its direct amplitude effects, the irregular structure of the ionosphere may operate in more subtle ways to produce the appearance of amplitude changes on a particular receiving system. For example, the irregularities may so enlarge the apparent size of a small source, or so destroy the correlation of the radio waves over the aperture of a large antenna, that the source seems to disappear. Also, the ordinary and extraordinary rays, travelling along slightly different paths, may be subject to uncorrelated phase fluctuation. The polarization of the resultant wave will vary rapidly and, if a linearly polarized antenna is used, the signal will undergo severe amplitude fluctuations, attributable to the " polarization flutter ".

A series of experiments have been conducted which show the effect of auroral disturbances on UHF propagation through the ionosphere [3, 4,]. Observations were made of the amplitude and polarization of signals at 440 MHz reflected from the Moon. Whilst the received signal level remained constant to within the accuracy of measurement (± 2 dB) during the course of the disturbance, 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, concerns the plane of polarization, which was subject to rapid fluctuations of one radian and more within times of a few minutes. Effects due to this rotation of the plane of polarization may be reduced by using circularly polarized antennae.

3. Angle of arrival

The steady, spherically stratified component of the ionospheric electron-density distribution increases the apparent elevation angle of an external radio source. This effect is proportional to the square of the radio wavelength. The magnitude of this systematic refraction is commonly overshadowed by both the regular and irregular components of refraction. The long-term average component of refraction at high elevation angles is to some extent predictable from the expected horizontal gradients in the ionosphere. Irregular refraction, which typically varies from one ten-minute period to the next, commonly dominates other types of ionospheric refraction, and is not predictable.

The same irregularities which produce amplitude scintillations also produce angular scintillations. These short-period fluctuations can result in variations in the angle of arrival, and may be so severe as to cause the source to " disappear " under certain conditions [5].

4. Frequency

The effects of the ionosphere upon the apparent frequency of a radio signal from a satellite produces only a second-order effect, and its influence upon a communications circuit is generally unimportant. On the other hand, the dispersive Doppler effect and the related phase-modulation techniques are of considerable interest as a tool for measuring the electron content of the ionosphere and exosphere [6, 7].

A work [8], done in the Federal Republic of Germany, reports on systematic observations of the Doppler effects at 48°N at 20 and 40 MHz respectively. Important ionospheric effects are found. 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 closest approach.

5. Radar range

The effects of the ionosphere upon the accuracy of the determination of distance appear to be small at 100 MHz (see lines 1 and 5, Table II).

6. Polarization

Earth-space communication stations require particular attention to ionospheric Faraday rotation. This phenomenon seriously affects any VHF space communication system which uses linear polarization and provides the basis for an accurate and sensitive technique to measure the total electron content of the ionosphere.

The paper [8] also reports on systematic observations of Faraday effects at 48°N at 20 and 40 MHz respectively. Important ionospheric effects are found, but ionospheric scintillation perturbed the regular sequence of Faraday fading in about 50% of all cases, and the Faraday fading was completely absent in 20% of all cases.

7. Trajectory and group path

Formulae for real radio paths and their group paths, presented in [9] and [10], can be used for paths penetrating through the ionosphere, as well as for connections between two satellites via reflection from the ionosphere.

8. Order of magnitude of ionospheric effects upon earth-space communications

Ionospheric effects upon earth-space communication are summarized in Table I, which shows the frequency dependence of the various ionospheric propagation effects at VHF and higher frequencies. The expressions are based on approximations to the Appleton-Hartree equations and may not be valid in the quasi-transverse case.

Table II is designed to give some feeling for the magnitude of the ionospheric effects at a frequency of 100 MHz. Most of the values are based on the total ionospheric contribution for zenithal quasi-longitudinal propagation through an ionosphere $\int_0^s N\mathrm{d}h$ is $10^{17}/\mathrm{m}^2$ column, and $\omega_L = 5 \times 10^6$ radians/s. The refraction is based upon a transverse gradient in $\int_0^s N\mathrm{d}h$ of 10^{11} electrons/m^2 column per metre, i.e., 1% per 10 km; the value of Δf is based upon a satellite observed near the horizon in a typical orbit just above the ionosphere. The value of $\int_0^s N\mathrm{d}h$ of $10^{17}/\mathrm{m}^2$ column is believed to be typical of an average ionosphere, and could vary by at least a factor of ten in each direction, i.e., from 10^{16} to $10^{18}/\mathrm{m}^2$, depending upon the time of day, the season, the position of the sunspot cycle, and the geographical location.

As an example, measurements made in India [11] have shown the following deviations from the normal diurnal and seasonal variations of the electron content (Is):

— while there is considerable scatter in the midday values, the scatter in the night-time values is very small. The value of Is remains practically steady from 0000 up to about 0600 hrs;

— during the period of low solar activity, the electron content values, as well as foF2, do not show any winter anomaly which is normally observed during high solar activity condition;

— the electron content values seem to be more or less independent of solar activity until the solar 10 cm flux exceeds about 80 units; there is an indication of a positive correlation for 10 cm solar flux exceeding about 80 units;

— the electron content seems to be positively correlated with magnetic activity during daytime, while night-time values do not show any dependence on magnetic activity;

— the electron content values show a dependence on the solar zenith angle. The exponent of the cosine of the solar zenith angle for the forenoon and afternoon have been calculated for different seasons;

— the thickness parameter shows variations that are correlated with both solar flux and hmF2 variations;

— it is seen that the percentage of occurrence of scintillations is maximum around 0200-0400 h IST. There are also two secondary maxima of scintillation occurrence, one around 2100-2200 h and the other around 1100-1200 h IST;

— on some days the electron content reached abnormally high values, correspondingly the foF2 values are also found to be unusually high. However, no significant solar or geomagnetic activity is reported for these days.

For ionospheric conditions other than those used in Table II, the proportional changes in $\int_0^s N\mathrm{d}l$ and ω_L should be used to estimate the ionospheric effects at 100 MHz; for VHF and UHF frequencies other than 100 MHz, the frequency dependence of Table I should then be used.

The absorption values are order-of-magnitude estimates of the one-way absorption, at vertical incidence, of a 100 MHz radio wave during the night, during the day, and during a strong daytime polar-cap absorption event.

TABLE I

Frequency dependence of ionospheric propagation effects

	Varies as
1. Phase-path length change (negative) (Δl)	$1/\omega^2$
2. Refraction (τ)	$1/\omega^2$
3. Phase change (negative) (δ)	$1/\omega$
4. Frequency change (negative) (Δf)	$1/\omega$
5. Group-path delay (ΔT)	$1/\omega^2$
6. Differential phase-path length (1) ($\Delta l_+ - \Delta l_-$)	$1/\omega^3$
7. Polarization rotation (Ω)	$1/\omega^2$
8. Absorption (dB) (A)	$1/\omega^2$
9. Differential (1) absorption (dB) ($A_- - A_+$)	$1/\omega^3$

(1) Subscript (−) indicates the extraordinary ray and (+) the ordinary ray.

TABLE II

Order of magnitude of ionospheric propagation effects at 100 MHz

1. Phase-path length change (Δl)		=	− 400 m
2. Refraction (τ)		=	4×10^{-4} radians
3. Phase change (δ)		=	− 840 radians
4. Frequency change (Δf)		=	− 6 Hz
5. Group-path delay (ΔT)		=	1·3 × 10^{-8} s
6. Differential phase-path length (1) ($\Delta l_+ - \Delta l_-$)		=	6·4 m
7. Polarization rotation		=	6·6 radians
8. Absorption (A)	night	=	0·005 dB
	day	=	0·05 dB
	daytime PCA (2)	=	1 dB
9. Differential (1) absorption ($A_- - A_+$)	night	=	5×10^{-5} dB
	day	=	5×10^{-4} dB
	daytime PCA (2)	=	1×10^{-2} dB

(1) Subscript (−) indicates the extraordinary ray and (+) the ordinary ray.
(2) Polar-cap absorption event.

BIBLIOGRAPHY

1. LAWRENCE, R.S., LITTLE, C.G. and CHIVERS, H.J.A. A survey of ionospheric effects upon earth-space radio propagation. *Proc. IEEE*, **52**, 1-27 (January, 1964),
2. RAWER, K. Propagation problems with space communications. *J. Res. Nat. Bur. Stand.*, **66D**, 375-393 (1962).
3. JAMES, J.C., BIRD, L.E., INGALLS, R.P., STONE, M.L., DAY, J.W.B., LOCKWOOD, G.E.K. and PRESNELL, R.I. Observed characteristics of an ultra-high-frequency signal traversing an auroral disturbance. *Nature*, **185**, 510 (1960).

4. Ingalls, R.P., James, J.C., and Stone M.L. A study of UHF space communications through an aurora using the moon as a reflector. *Planet. Sp. Sci.*, **7**, 272-285 (1961).
5. Little, C.G., Reid, G.C., Stiltner, E. and Merritt, K.P. An experimental investigation of the scintillations of radio stars observed at frequencies of 223 Mc/s and 456 Mc/s from close to the auroral zone. *J. Geophys. Res.*, **67**, 1763-1784, (1962).
6. Alpert, J.L. An investigation of the upper atmosphere in the basis of measurements of Doppler-effect in satellite signals at coherent frequencies (In Russian). *Geomagn. and Aeronomie*, **3** (1963).
7. Rawer, K. Erforschung der Ionosphäre mit Radiowellen von Satelliten und Raketen Phasenverfahren. (Investigation of the ionosphere with radio waves from satellites and rockets; phase methods). *Space Science Review*, **3**, 380-432 (1964).
8. Aarons, J. et al. (Joint Satellite Study Group). Atmospheric phenomena noted in the simultaneous observations of 1958 Delta 2 (Sputnik III).*Planet. Sp. Sci.*, Vol. 5, **3**, 169-184, 1961; A synoptic study of scintillations of ionospheric origin in satellite signals, *ibid.*, **13**, 51-62 (1965).
9. Chvojková, E. Analytical formulae of ray path determination. *Radio Science* (March, 1965).
10. Chvojková, E. Summary of formulae will appear in *Radio Science* later on.
11. Somayajulu, Y. V. and Tuhi Ram Tyagi. Some results on electron content measurements at Delhi using Faraday fading and satellite beacon transmissions Part 1. Radio Propagation Unit, National Physical Laboratory, Delhi, India. Paper presented at the VIIth International Space Science Symposium, Vienna (May, 1966).

REPORT 264-1 *

PREDICTIONS OF IONOSPHERIC FIELD STRENGTH AND PROPAGATION LOSS FOR THE FREQUENCY RANGE BETWEEN 150 AND 1500 kHz

(Study Programme 17A/VI)

(1959 - 1963 - 1966)

1. Introduction

Study Programme 17A/VI calls for the continuation of measurements of field strength at frequencies below 1500 kHz 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 kHz to 1500 kHz, since it has been found desirable to consider frequencies below 150 kHz separately, as is done in Report 265-1.

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. It therefore begins with a detailed description of the curves and the method of use. 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 Broadcasting 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.

---

* This Report was adopted unanimously.

2. European Broadcasting Area

2.1 *Introduction*

The nocturnal field strength at low frequencies (band 5) and medium frequencies (band 6) has been the subject of a measurement campaign organized by the European Broadcasting Union since 1952 and by the International Broadcasting and Television Organization (O.I.R.T.) since 1958. These measurement campaigns were undertaken independently of one another; the number of hours recorded were greater in the case of the E.B.U. than that of the O.I.R.T., but the O.I.R.T. measurement campaign covers more frequencies.

This Report is based on the field-strength recordings made by the two organizations in the European Broadcasting Area up to 1962; the total number of hours recorded exceeds 67 000. 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 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 detail in [1] and [2].

Note 1. — As these predictions are based on data obtained only in the European Broadcasting Area, they do not necessarily apply to other areas.

Note 2. — Administrations are encouraged to examine the methods in the light of information at their disposal, with a view to extending them to other areas.

2.2 *Annual median value of field strength*

The field strength can be represented by the following general expression:

$$F_1 = F_o + \Delta_A \qquad (1)$$

where

F_1 is the annual median value of the field strength (dB rel. 1 μV/m), for a power of 1 kW radiated by the transmitting antenna, reception being by a small loop antenna.

F_o is the annual median value of the field strength (dB rel. 1 μV/m), for a reference transmitting antenna giving, over perfectly conducting ground, a field strength of 3×10^5 μV/m, in all directions above the horizon, reception being by a small loop antenna.

Δ_A is a correction factor (dB) for the transmitting antenna to account for the radiation pattern; if this antenna radiates a power of 1 kW, the factor Δ_A is equal to the ratio (dB) between the field strength for a given angle of departure in the vertical plane at a distance of 1 km and a field strength of 3×10^5 μV/m.

The correction factor Δ_A may be deduced from the horizontal and vertical radiation patterns of the transmitting antenna assumed to be placed on a perfectly conducting earth. Fig. 2 gives values of Δ_A as a function of the distance between the transmitting and receiving points in the theoretical case of:

- — a lossless unloaded vertical antenna of height (h),
- — a reflection at a vertical height of 100 km above a spherical earth. (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 kHz, for the later hours and for the shorter distances.)

The discontinuity of the curves at 2200 km corresponds to the distance beyond which there are at least two hops.

The value of F_0 is given by:

$$F_0 = 80{\cdot}2 - 10 \log D - 0{\cdot}0018 f^{0{\cdot}26} D \qquad (1a)$$

where

D = the distance (km);

f = the frequency (kHz).

The values of F_1 and F_0 are valid for the following conditions:

— the frequency range is from 150 to 1500 kHz;

— the magnetic dip at the mid-point of the path is 61°;

— the sunspot number (Wolf number) $S = 0$;
(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 § 2.4 of this Report.)

— the local time at the mid-point of the propagation path is midnight;

— the distances D are between 300 and 3500 km.

Fig. 1 shows a family of propagation curves for F_0, computed from equation (1*a*), for frequencies of 150, 200, 300, 500, 700, 1000 and 1500 kHz, i.e. for the same frequencies as those used in Recommendation 368 (Ground-wave propagation).

The following equation should be used to obtain the annual median values for more general conditions:

$$F_H(50) = F_1 + P + \Delta_I + \Delta_H(50) - 0{\cdot}02S \qquad (2a)$$

The symbols in this formula have the following significance:

$F_H(50)$ is the annual median value of the vertical electric field strength (dB rel. 1 μV/m) at H hours local time at the mid-point of the propagation path, for:

— a transmitting antenna characterized by Δ_A;

— a sunspot number, S;

— a magnetic dip, I, at the mid-point of the propagation path.

F_1 is the value given by equation (1).

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 maps shown in Figs. 4 and 5.

$\Delta_H(50)$ 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. 6.

Note: — If the concept of propagation loss is used (see Recommendation 341 and Report 112), formulae (1*a*) and (2*a*) become respectively:

$$L_{po} = 10 \log D + 20 \log f + 0{\cdot}0018 f^{0{\cdot}26} D - \Delta_A - 7{\cdot}75 \qquad (1b)$$

$$L_{pH}(50) = L_{po} - \Delta_I - \Delta_H (50) + 0{\cdot}02\, S \qquad (2b)$$

L_{po} denoting the annual median value of propagation loss between the transmitting antenna and a small loop receiving antenna, and $L_{pH}(50)$ denoting the annual median value of propagation loss at a local time H at the mid-point of the propagation path; the symbols in the two formulae and the conditions in which the formulae are used are the same as for formulae ($1a$) and ($2a$) respectively. For reception with other types of receiving antenna, equation ($1b$) may still be used, if an additional term of the type Δ_A 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.

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. 7 give the order of magnitude of the statistical variations of the hourly medians (it is shown in reference [1] that the long-term distribution of half-hourly medians is very nearly the same as that 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:

$$F_H(T) = F_H(50) + \delta_H(T) \tag{3a}$$

$$L_{pH}(T) = L_{pH}(50) - \delta_H(T) \tag{3b}$$

Note. — Fig. 7 shows the values $\delta_H(T) = \Delta_H(\mathrm{T}) - \Delta_H(50)$, where $\Delta_H(T)$ are the values given in [1].

2.3.2 *Distribution within an hour*

In Report 266-1 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 medium frequencies (band 6) and between 4·5 dB and 2 dB for low frequencies (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 medium frequencies and around 2 dB for low frequencies.

2.4 *Formula for estimating the wanted-to-interfering signal ratio R*

At a particular receiving location, at a distance D_u from the wanted transmitter of power P_u and at a distance D_n from the interfering transmitter of power P_n, and considering an interval of one hour, the mid-point of which corresponds to the local times H_u and H_n of the mid-points of the path of the wanted and unwanted transmissions; the ratio $R(T)$ dB between the wanted hourly median signal level and the interfering hourly median signal level, exceeded for a percentage T greater than 50% of the hours of the year when the value R is exceeded, can be calculated for a non-directional receiving antenna from the following formula:

$$R(T) = P_u - P_n + F_{Hu}(50) - F_{Hn}(50) -$$
$$\sqrt{\delta^2_{Hu}(T) + \delta_{Hn}^2(100 - T) + 2\rho\delta_{Hu}(T)\delta_{Hn}(100 - T)} \qquad (4)$$

where ρ represents the correlation between the changes in hourly median values for the wanted and interfering signal 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 (4).

It should be noted that δ_{Hn} and δ_{Hu} always have opposite signs and that the minus sign before the radical in (4) is associated with the practical situation normally encountered, where the time availability T of satisfactory service is greater than 50%.

Strictly speaking, equation (4) 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.

2.5 *Combined influence of the hour and the season on the distribution of hourly medians*

Fig. 6 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. 7 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 kHz 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 lengths of which vary between 700 and 2200 km. This made it possible to establish the family of curves in Fig. 8, 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 Broadcasting Area at least, a similar effect occurs throughout the medium-frequency broadcasting band and that the family of curves in Fig. 8 is also valid for the high end of the medium-frequency band. However, the completion of this study must be awaited to know whether the same results will be found at lower frequencies, including the low-frequency band, and to determine the effect of the geographical position of the path.

The slight field-strength maximum in the second half of the night, to be seen on Fig. 6 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 kHz), and its position in the course of the night seems to be sensibly independent of the times of sunset.

The final objective of this study is to replace Fig. 6 by several families of curves similar to those giving the values $\Delta_H(50)$, $\Delta_H(90)$ and $\Delta_H(10)$ and valid for the whole medium-frequency band in the European Broadcasting Area. In certain applications, these families of curves might replace all those in Figs. 6 and 7.

A provisional method for giving a correction $\Delta'_{H},(50)$ in place of $\Delta_H(50,)$ so as to obtain median values for the actual time of year rather than the yearly median value, has been proposed, based on an analysis of measurements. It takes account of the changes in the times of sunrise and sunset during the year and the decreasing attenuation during the night, arising from the decay of D-region ionization.

$$\Delta'_H(50) = 9\,[f(\chi) - 1] + 0{\cdot}47\,t \qquad (5)$$

where

t is the time in hours relative to midnight,

χ is the negative angle of elevation of the sun (beneath the horizon) and

$$f(\chi) = \sin 2\chi \text{ when } \chi \leqslant 45^\circ$$
$$= 1 \quad \text{when } \chi \geqslant 45^\circ.$$

The validity of this correction is restricted to the period from three hours before midnight ($t = -3$) to three hours after midnight ($t = 3$), as most measurements were made in this period. Charts are available for obtaining χ as a function of latitude and time of year [3].

2.6 *Influence of finite ground conductivity on the vertical polar diagram of the antenna*

Finite ground conductivity near a transmitting or receiving antenna modifies the vertical polar diagram, as compared with the diagrams for perfectly conducting ground. The measurements used for deriving the propagation curves were not adjusted for this, and F_o therefore includes the effect of ground of average conductivity at both sending and receiving ends of the path. Correction for other cases depends on the angle of the path, and, to a lesser extent, on the type of antenna. As a rough guide for paths exceeding 1000 km, good conductivity at the transmitter (10^{-2} mho/m) gives a greater sky-wave field strength by about 1·5 to 2 dB, while poor conductivity (10^{-3} mho/m) gives a reduction of the same order. An extreme case is a transmitter sited next to the sea, with very good conductivity maintained for many wavelengths in the direction of the receiving point. An increase of about 6 dB is expected for this case, and a similar correction would also apply for sky-wave signals received at sea. In all cases, the correction for ground conductivity becomes less as the path length is reduced below 1000 km (see Report 401).

2.7 *Diurnal propagation of the sky-wave*

Within the framework of studies carried out by the E.B.U. on medium-wave propagation, the Norddeutscher Rundfunk's receiving and measuring station at Wittsmoor near Hamburg has made daytime measurements.

The transmitters used for these measurements were Strasbourg (1160 kHz, 150 kW) at a distance of 610 km and Mainflingen (1538 kHz, 270/300 kW), at a distance of 405 km. The recording period was from November, 1963, to November, 1964, and the recordings were made between 0500 GMT (beginning of transmission) and 2200 GMT (close-down). 107 recordings are available of the transmissions from Strasbourg and 128 from Mainflingen [4].

From the results obtained from these recordings it may be concluded that, for the frequencies and the propagation paths concerned, the annual mean value of the sky-wave field strength at noon, at the midpoint of the path, is about 45 dB lower than the corresponding value at midnight.

3. Australia

3.1 *Prediction curves*

A study of medium-frequency sky-wave characteristics has been conducted by the Australian Broadcasting Control Board since March, 1953. Measurements made during this study have been the subject of publications [5, 6] and contributions to the work of the C.C.I.R. [7, 8]. The field-strength curves of Figs. 9, 10, 11 and 12 are derived from the latter document which contains the results of two major measurement campaigns conducted in 1958-1959 and 1963-1965. These figures show the hourly median field strength exceeded on 50% and 10% of the nights of a year for an unattenuated field strength of 3×10^5 μV/m at 1 km in the direction of propagation and at the angle of departure appropriate to one-hop E propagation.

Figs. 9 and 10 refer to the field strength at the second hour after sunset for paths which are predominantly north-south, Fig. 9 being for the period of high sunspot activity and Fig. 10 for low sunspot activity. Fig. 12 also applies to the second hour after sunset and the period of low sunspot activity, but relates to long paths which are predominantly east-west. Fig. 11 relates to the field strength at 2330 hours during the period of low sunspot activity, for paths which are predominantly north-south.

Corrections given in Fig. 2 should be applied to field strength predictions from Figs. 9, 10, 11 and 12, to compensate for the transmitting antenna vertical radiation pattern and to enable the predictions to be made on the basis of a radiated power of 1 kW. The inverse of this correction was applied to measured field strengths from which the basic prediction values were derived. Corrections given in Fig. 2 are considered to be sufficiently accurate, except where the transmitting antenna environment departs significantly from that of the transmitting stations used in the sky-wave measurement campaigns. Most of these transmitting sites have a ground conductivity between 5×10^{-3} and 10^{-2} mho m.

3.2 *Interpretation of predictions*

3.2.1 When applied to individual cases, these predictions may be in error for the following reasons:

3.2.1.1 The random variation from night to night which produces a standard deviation of 2 dB over a period of one month for measurements made at a particular time of night.

3.2.1.2 The variation which occurs from hour to hour throughout the night.

3.2.1.3 The seasonal variation which produces a standard deviation of 2·5 dB for measurements made at the second hour after sunset.

3.2.1.4 The variation which occurs from site to site in the one locality. For reception in an urban area, this variation can be negligible at one frequency and up to ± 6 dB at another frequency. Predictions in Figs 10 and 11 were developed from measurements processed in such a way that this variation was eliminated. Figs. 10 and 11 therefore refer to the field strength exceeded at 50% of locations. An additional increase in field strength of the order of 6 dB may occur, where the receiving antenna is in very close proximity to domestic electric wiring. The predictions are not applicable to reception sites with sea water in the foreground.

3.2.1.5 The variation between sunspot minimum and sunspot maximum.

3.2.1.6 All other variations. These produce a standard deviation in annual median values of 1 dB.

3.2.2 The type of variation mentioned in §§ 3.2.1.2 and 3.2.1.3 can be seen in Fig. 13, which shows the hourly median field-strength exceeded at 50% of locations on 50% of the nights of a month, in dB relative to the hourly median field-strength at 50% of locations on 50% of the nights of a year (April 1964 - March 1965) at the second hour after sunset. Fig. 13 may be used in conjunction with the predictions given in Fig. 10 to determine the field strength at any time of night and in any month during the period of low sunspot activity, for a transmission frequency of 1000 kHz. When Figs. 10 and 13 are used in this manner, the predictions will be more accurate for a distance of 700 km than for a distance of 1600 km.

3.3 *A new transmission system*

A new transmission system is now being studied, which depends upon achieving heavy absorption of the radiated power as it passes through the ionosphere even at night. It has been named orthogonal transmission, since in the present studies transmitting antennae are mounted at right angles and phased appropriately to produce, instead of a vertically polarized wave, an elliptically-polarized wave that will excite only the extraordinary mode in the ionosphere. The ordinary mode, with its relatively small night-time attenuation at medium frequencies, is thereby excluded. Thus, the system provides a method of reducing the amplitude of interfering sky-wave signals and, while preserving the daytime performance of a conventional vertically-polarized antenna, may give a considerable increase in the night-time service area [9].

Propagation tests conducted with the system in Australia during August, 1965, gave sky-wave field strengths 16 dB less than those received from a vertically-polarized transmission for the same daytime ground-wave field strength. Whether reductions of this order or greater can be obtained in regular service will depend upon numerous factors yet to be investigated, the most important of which is probably the depelopment of suitable transmitting antennae.

4. India

The field strength of a number of transmitters, at frequencies between 550 and 760 kHz 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. [10]. A yearly mean value of the field strength is given for one path (670 kHz, 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 F.C.C. standard broadcast curves of yearly median field strength [11], 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 F.C.C. curves upon geographic latitude is translated into terms of geomagnetic latitude.

6. Africa

A joint measurement campaign was organized in Africa by the three broadcasting organizations—the O.I.R.T., the E.B.U. and the U.R.T.N.A.—for the African LF/MF Broadcasting Conference. The campaign lasted in all for about one year, from June, 1963 to July, 1964—but many paths were studied for less than one year. Unfortunately, it was too short for sufficiently reliable propagation curves to be prepared. However, 760 measurement sheets (one per path and per evening) were collected, representing a total of 2700 measurement hours distributed over 23 paths, and the results apparently correlate fairly well on the whole with what could have been gathered from the curves for the European Broadcasting Area, except for a relatively large spread which could not be accounted for. The results, together with additional data on sea-paths provided by a member of E.B.U., are shown in Fig. 14, together with a curve of field strength against distance for a frequency of 1 MHz at 2200 hours local time at the mid-point of the path, as deduced from the curves in Fig. 1. The plotted points are the median values of the field-strength measured for the various paths in Africa, corrections of the type valid in Europe having been applied to convert them to 1 MHz at 2200 hours. (This reference time was chosen because it corresponded closely to most observations, thereby minimizing errors due to uncertainty about the time correction for Africa.) It appears that, in the absence of other data, the curves of the European Broadcasting Area could be used temporarily for African planning requirements, but with some caution. For instance, near the magnetic equator, the measurement results seem to confirm that propagation loss is greater along east-west as compared with north-south paths, as might be predicted from theoretical considerations of wave polarization [12]. Also, the variation of the hourly median value of the field strength during the night may differ from that found in Europe and may depend considerably upon the magnetic dip. A new measurement campaign, which the three organizations referred to suggest organizing in 1965-1966 may, it is hoped, clear up the various points.

7. Measurements made at distances below 300 km and above 3500 km

7.1 *Pulse measurements at vertical and near-vertical incidence.*

For the study of short-distance sky-wave propagation, it will be recalled that a knowledge of the possible values of the ionospheric reflection coefficients at vertical and oblique incidence (see Study Programme 17A/VI), can be very helpful in giving a complete understanding of the physical phenomena underlying medium-frequency modes of propagation. The work done in South West Africa [13] can be mentioned in this connection. Measurements have been made at a number of frequencies between 350 and 5600 kHz. Values of the mean night-time attenuation ranging from 6 dB at 1070 kHz to 17 dB at 365 kHz were found. Daytime values are much higher and at one hour before sunset and one hour after sunrise they may be several times higher than the night-time values. However, the relationship between the vertical-incidence measurements and the propagation of medium-frequency waves arriving in the ionosphere at oblique incidence is not very clear. Vertical-incidence reflections may occur at a height of approximately 100 km (at which height obliquely arriving waves are generally reflected) and at around 250 km (F layer) and even at intermediate heights (150 km) or even at several heights simultaneously.

Recent observations at the same station in South-West Africa have also shown daytime reflections in the D region between 70 and 100 km. In general, maximum absorption at vertical incidence was found in the region of 500 kHz, apparently associated with a change of reflection level. Thus, the lower frequencies were reflected in the D region where, due to the small gradient of ionization, the deviative absorption increases with frequency. Reflections from the E region appear at about 500 kHz; here the ionization gradient is steeper, especially when sporadic E is present, and at higher frequencies only non-deviative absorption is important. In the evening after sunset, for vertical-incidence reflection at frequencies below about 500 kHz, the ordinary component is more highly attenuated than the extraordinary component, while at higher frequencies the reverse is true [14].

Ionograms made by the NBS at Boulder [15] actually show that the " 100 km stratum " has a very irregular structure and, since the origin of this " stratum " is unknown, its irregularity and its partial transparency to vertically-incident medium-frequency waves complicate extrapolation to obliquely-incident waves. The " 150 km stratum " seems, in actual fact, to be the real nocturnal E layer [15]. This fact is of interest for the physics of the nocturnal ionosphere, but probably this layer has no effect on the propagation of obliquely-incident medium-frequency waves.

7.2 *Field-strength recordings for distances below 300 km*

There are much less experimental data for distances below 300 km than for greater distances. One reason is the difficulty of obtaining the sky-wave field strength from broadcast transmitters because, in general, the total field strength includes contributions from both the ground wave and the sky wave. Where the ground-wave propagation is poor, the sky-wave may be isolated by means of a frame antenna. Results for a ground range of 38 km have been obtained [16] by this method and give an average reflection loss of about 12 dB at 827 kHz for the period from two hours after sunset to 2200 hours. There is, however, an important seasonal variation with stronger reflection in summer.

A method of analysis of total-field recordings has been developed [17], which enables the sky-wave term to be derived from the amplitude distribution. With the use of more than one receiving point at different ranges (e.g. from 100 to 300 km), the sky-wave field strengths can be compared and, taking into account the radiation polar diagram of the transmitting antenna, the presence of reflection from E or F regions can be distinguished.

7.3 *Field-strength recordings for distances above 3500 km*

Recent recordings have drawn attention to some cases of very high field strengths obtained at very great distances, over paths such as Cairo-Reunion Island, Monte Carlo-Djibouti, Monte Carlo-Brazzaville, Bonaire (Netherlands Antilles)-Limours (near Paris), Bonaire-Jurbise (near Brussels); the results for frequencies ranging from 620 to 1466 kHz over distances from 4500 to 7500 km show that the hourly median measured field strengths vary with distance approximately from 25 to 45 dB above the curve extrapolated mathematically for distances of from 300 to 3500 km in the European Broadcasting Area.

8. Future work

Future work should deal with several aspects of the question, namely:

8.1 to widen the geographical area in which propagation curves similar to those prepared for the European Broadcasting Area could be available and to associate such curves with one another, in accordance with various values of some parameters of geographical situation. In theory, plans for assigning and sharing medium-frequency channels over very wide areas, such as Europe or Australia or the United States of America, can be dealt with independently of one another, but there are bound to be problems in adjoining regions in the case of areas such as Europe, Africa and Asia; also, comparisons between measurements made at different parts of the world might give very useful information about geographical factors affecting field-strength curves. After the first measurement campaign mentioned in § 6, the O.I.R.T., the E.B.U. and the U.R.T.N.A. have jointly undertaken a new measurement campaign lasting for about one year in 1965-1966;

8.2 to expand the range of propagation-path lengths for which most measurements have so far been made, both for short distances (below 300 km) and for very long distances (above 3500 km). One problem with short distances is the difficulty of separating ground-wave effects from sky-wave effects, and the curves prepared so far have been based, not on direct measurements of the sky-wave field, but on the theoretical deductions from knowledge of the coefficient of ionospheric reflection at vertical incidence. However, most reflection data coefficients are derived from measurements of vertically-incident waves at a relatively small number of stations, and since little work has been done up to now on the critical frequency of the E layer at night, it is highly conjectural to extrapolate the vertical-incidence data to cover obliquely-incident waves and therefore the short-distance calculation of sky-waves. There is therefore a need to develop studies on the critical frequency of the E layer at night and on the reflection coefficient of the E and F layers for various incidences of medium-frequency and low-frequency waves and, if possible, direct short-distance measurements of sky-waves.

As regards long-distance measurements, they should help towards determining *inter alia* the influence of sunspot activity, and there are appreciable differences between over-sea paths and over-land paths.

8.3 There is a lack of detailed data on daytime ionospheric propagation between 150 and 1500 kHz; this form of propagation may be considerable, particularly in winter months;

8.4 still further statistical studies, based on known data or, even better, on new results, are required to reduce the area of uncertainty of predictions based on the curves available at present or to reduce the area of uncertainty by better knowledge, either of parameters affecting the field or of the correlation between the field and other parameters. Some Administrations or authorities are at present undertaking studies of this kind.

BIBLIOGRAPHY

1. EBERT, W. Ionospheric propagation on long and medium waves. *E.B.U. Review*, Part A, Technical, **71**, **72** and **73**; also Technical Monograph No. Techn. 3081, E.B.U., Technical Centre, 32, Avenue A. Lancaster, Brussels 18, Belgium.
2. C.C.I.R. Doc. 209 (O.I.R.T.), Geneva, 1963.
3. MÜLLER, K. and TÄUMER, F. Eine Methode zur Vorausbestimmung der nächtlichen Raumwellenfeldstärke im Frequenzbereich von 150-1500 kHz für Entfernungen zwischen 300 und 3000 km (A method of predicting nocturnal sky-wave field strength in the frequency range from 150 to 1500 kHz for distances between 300 and 3000 km.) *Technische Mitteilungen RFZ* **9**, 85-89 (1965).
4. C.C.I.R. Doc. VI/252 (E.B.U.), 1963-1966.
5. DIXON, J.M. Some medium frequency sky-wave measurements. *Proc. IRE*, Australia, **21** (June, 1960).
6. DIXON, J.M. Attenuation of medium frequency sky-wave signals in Australia following the Mid-Pacific high altitude nuclear explosions in August, 1958. *J. Geophys. Res.* (January, 1962).
7. C.C.I.R. Doc. VI/88 (Australia), Geneva, 1962.
8. C.C.I.R. Doc. VI/205 (Australia), Geneva, 1963-1966.
9. DIXON, J.M. The absorption of medium frequency sky-waves by close coupling to the extraordinary mode. *Proceedings I.R.E.E.* Australia, 369-380 (December, 1965).
10. C.C.I.R. Doc. X/14 (India), Bad Kreuznach, 1962.
11. Federal Communications Commission Rules of Practice and Procedure, Part III, U.S. Superintendent of Documents, Washington 25, D.C.
12. PHILLIPS, G.J. and KNIGHT, P. Effects of polarization on a medium-frequency sky-wave service, including the case of multihop paths. *Proc. I.E.E.*, Vol. 112, **1**, 31 (January, 1965).
13. ELLING, W. Scheinbare Reflexionshöhen und Reflexionsvermögen der Ionosphäre über Tsumeb, Südwest-Afrika, ermittelt mit Impulsen im Frequenzband von 350 bis 5600 kHz (Pulse measurements of virtual heights and reflection coefficients of the ionosphere over Tsumeb, South West Africa, in the frequency range from 350 to 5600 kHz). *A.E.Ü.*, **15**, 115-124 (1961).
14. C.C.I.R. Doc. VI/191 (F.R. of Germany), 1963-1966.
15. BELROSE, J.S. The low ionosphere regions in physics of the Earth's upper atmosphere (Ed. C.O. Hines et al.), 66-67, Prentice Hall Inc. (1965).
16. C.C.I.R. Doc. VI/208 (P.R. of Bulgaria), 1963-1966.
17. MÜLLER, K. Determination of the sky-wave field strength at short and medium distances from recordings of the total field on long- and medium-wave transmitters. *Technische Mitteilungen RFZ* **9**, 89-95 (1965)

ANNEX I

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 h
Wolf number:	S = 100
Frequency:	f = 800 kHz
Antenna height:	h = 150 m, non-loaded antenna
Radiated power	p = 100 kW

The successive stages of the calculation are as follows:

Stage	Parameters	Figures	Term calculated	Value	
				(dB)	(μV/m)
1	f = 800 kHz D = 1500 km	1	$F_o =$	33	
2	p = 100 kW		$P = 10 \log 100 =$	20	
3	S = 100		$-0{\cdot}02\ S =$	−2	
4	h = 150 m f = 800 kHz } $h/\lambda = 0{\cdot}4$	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.

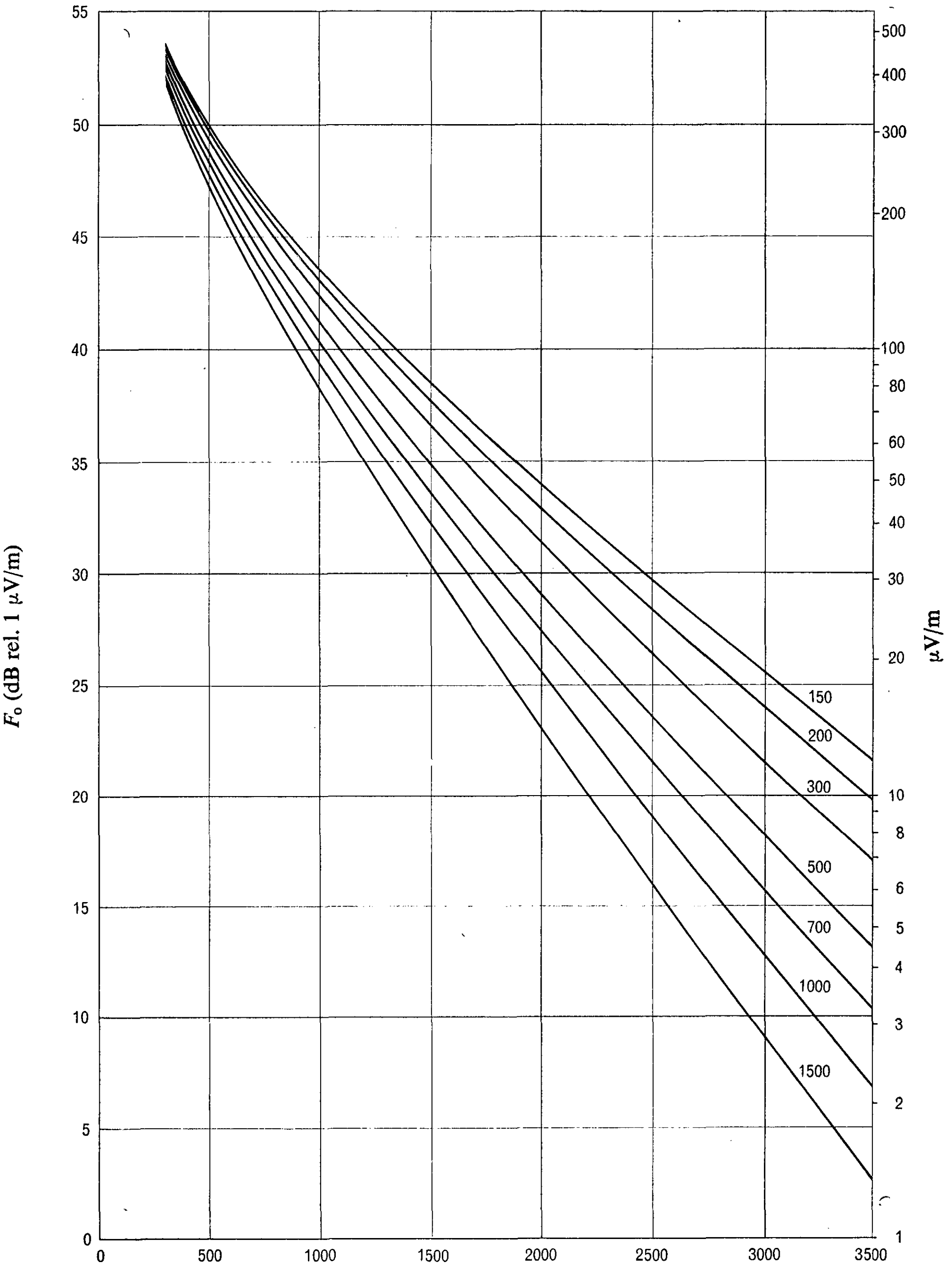


FIGURE 1

Family of basic curves of F_0 to be used to determine the annual median value of the field strength for the frequencies (kHz), indicated on the curves

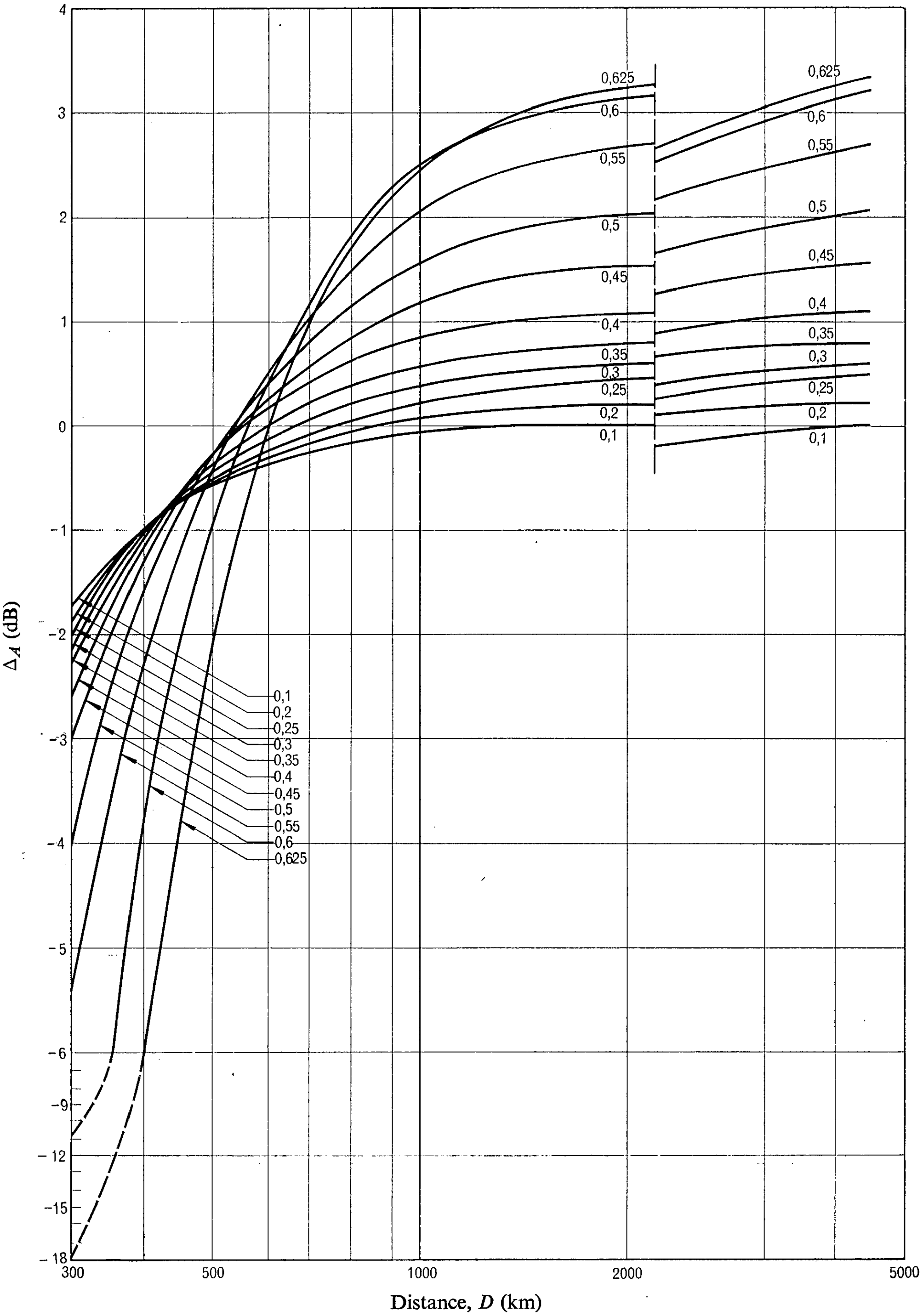


FIGURE 2

Gain Δ_A of vertical transmitting antennae of various lengths as a function of the distance from the point of reception

(The figures on the curves represent values of the parameter h/λ)

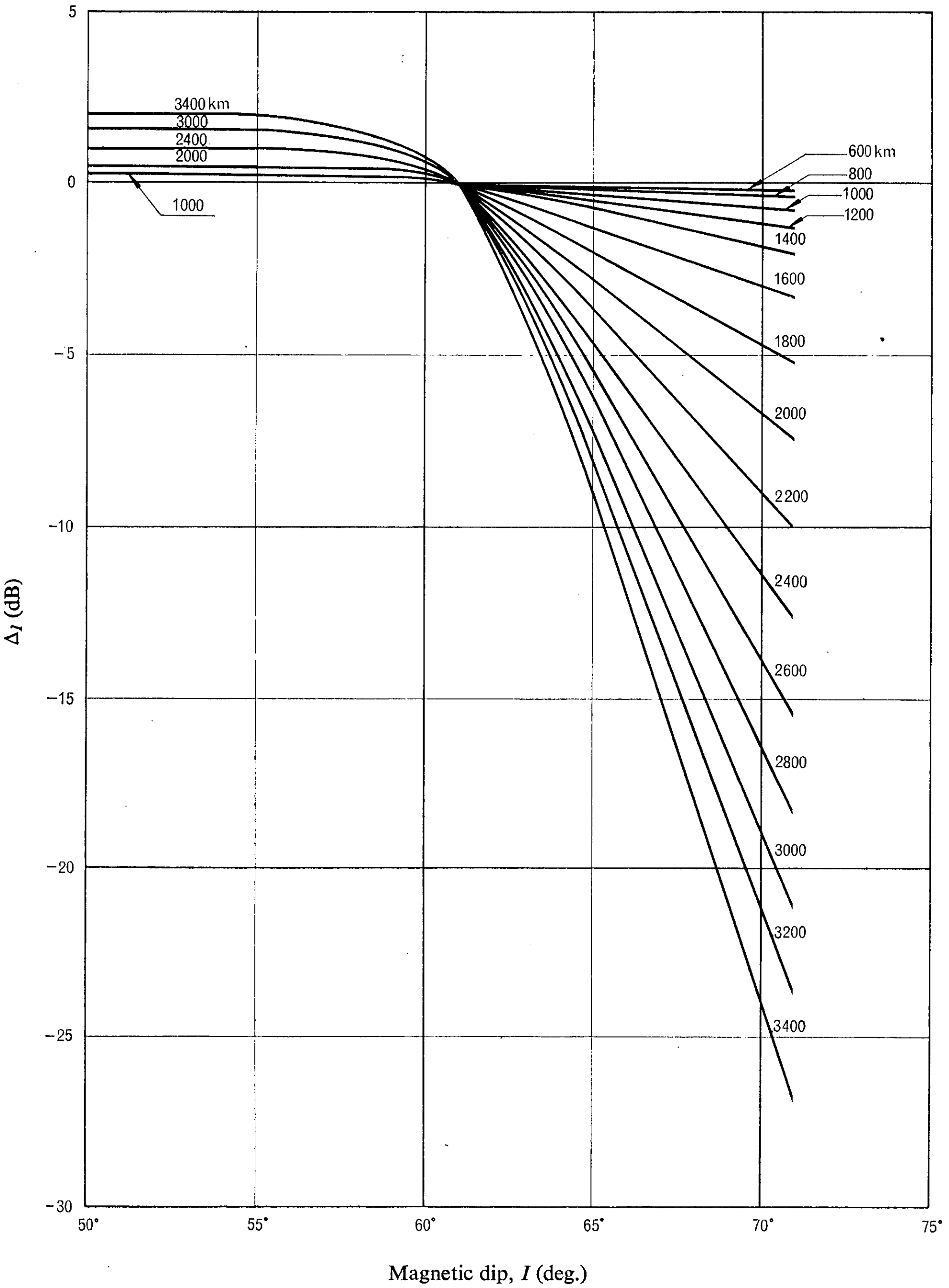


FIGURE 3

Correction (Δ_I) to be applied to take account of the magnetic dip.

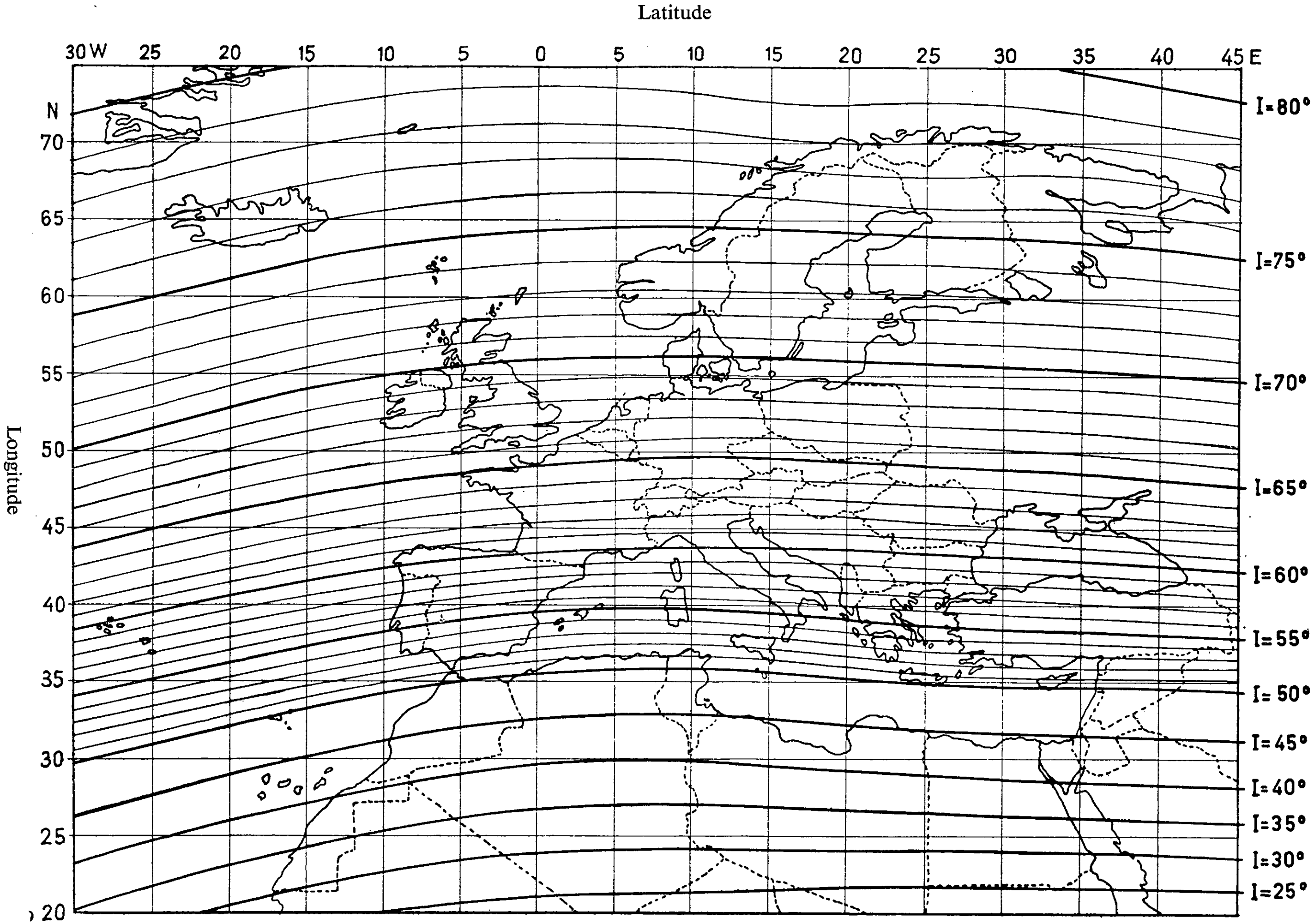


FIGURE 4

Map of Europe on a system of rectilinear co-ordinates having equally-spaced lines of geographic latitude and longitude. The curves are lines of equal magnetic dip, I.

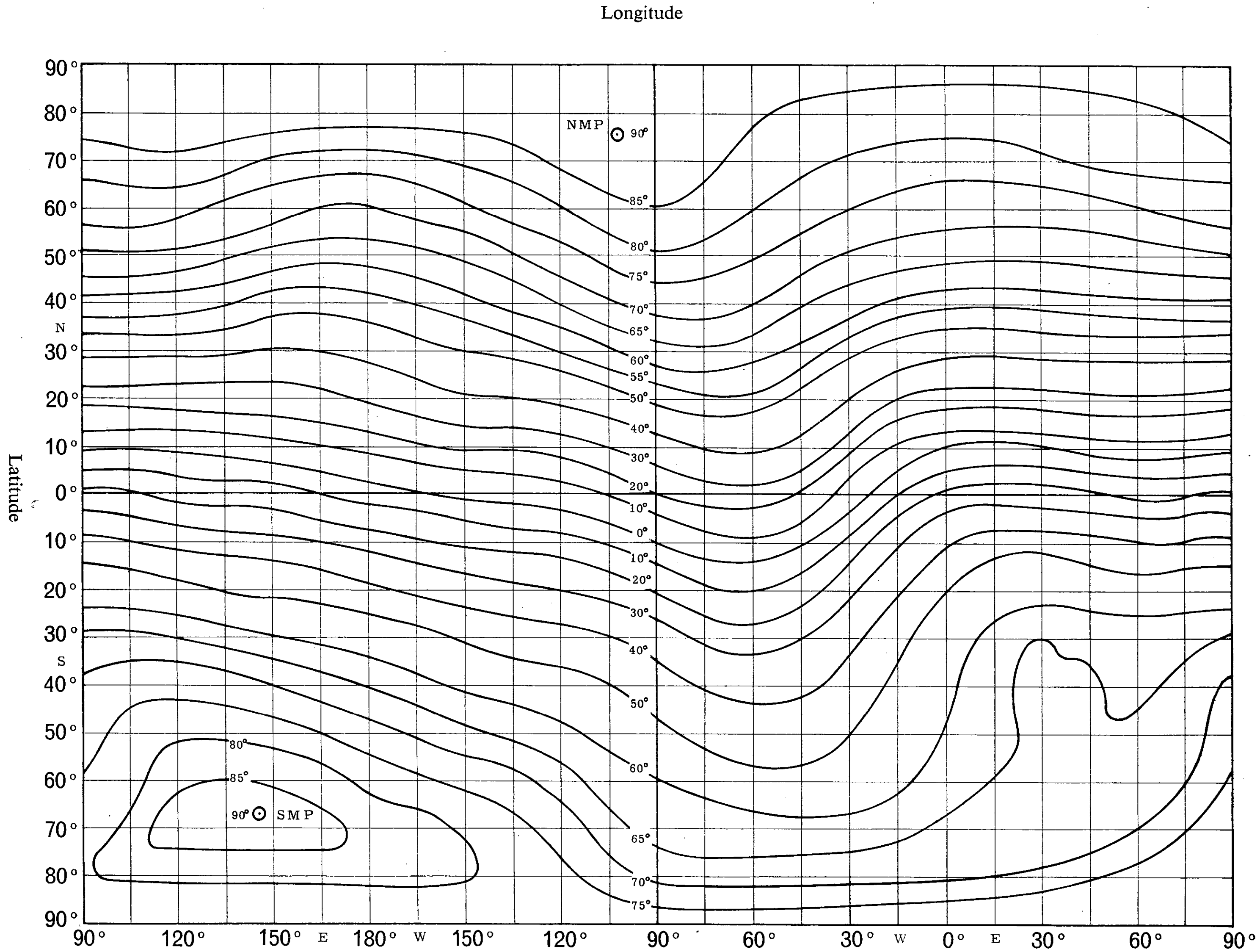
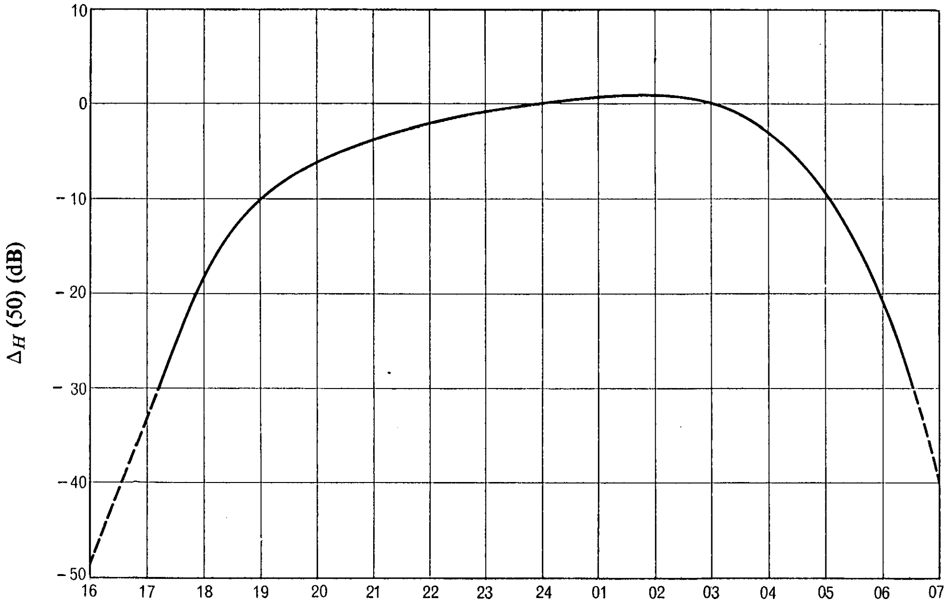


FIGURE 5

System of rectilinear coordinates of geographic latitude and for the whole world. The curves are lines of equal magnetic dip; those below the 0° curve correspond to negative dip, i.e. a dip downwards towards magnetic south.

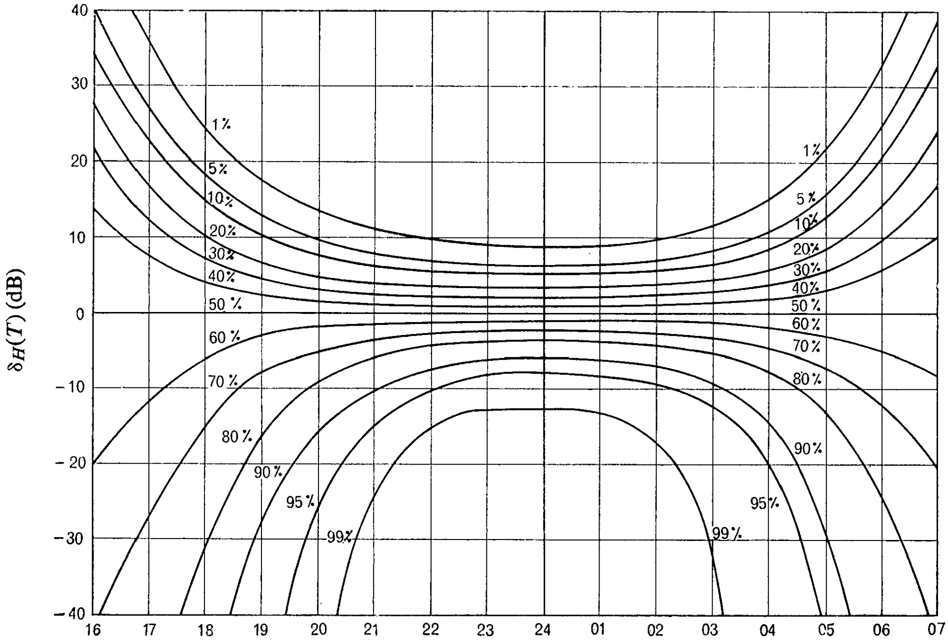
N: North magnetic pole,
S: South magnetic pole.



Time at the mid-point of the path (H)

FIGURE 6

Correction Δ_H (50) to be applied to take account of the time at the mid-point of the path



Time at the mid-point of the path (H)

FIGURE 7

Correction $\delta_H(T)$ to be applied to take account of the percentage of the nights of a year

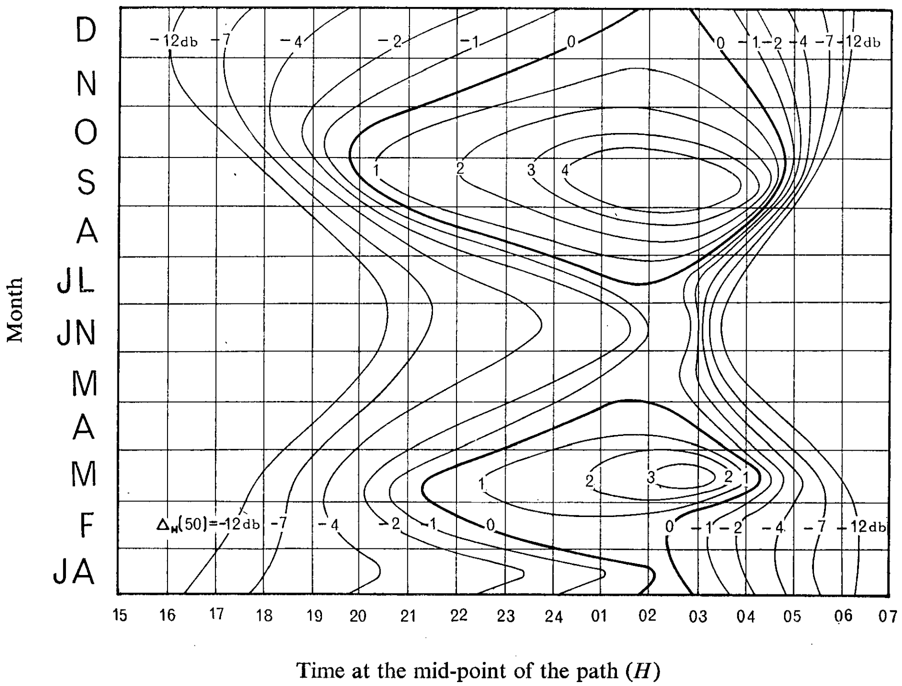


FIGURE 8

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 kHz)

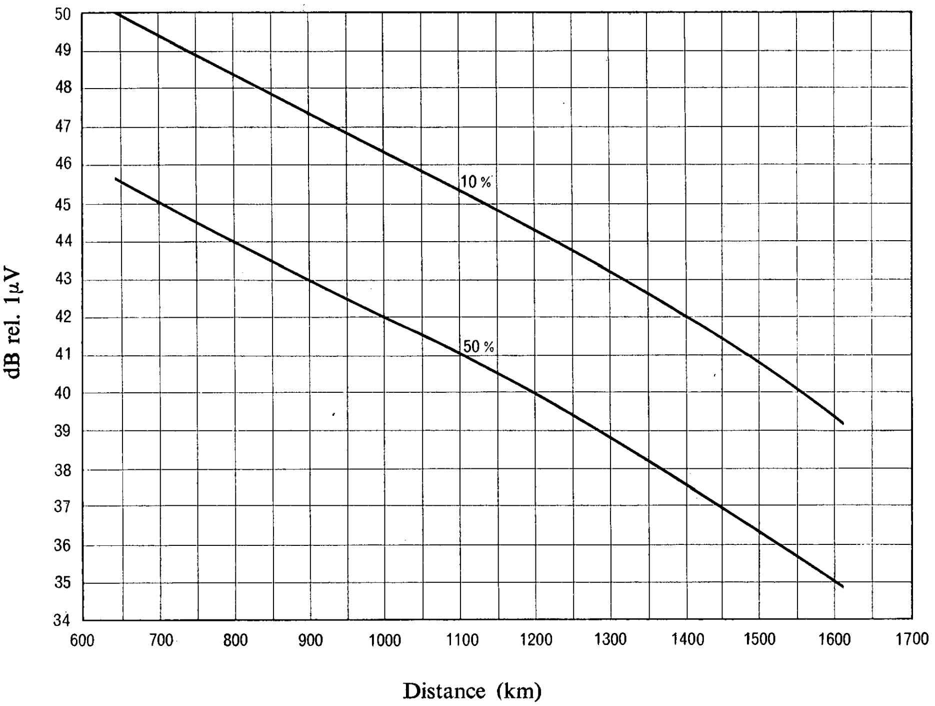


FIGURE 9

Hourly median values of the field strength exceeded on 50% and 10% of the nights of a year at the second hour after sunset.

(North-south paths; annual mean Zurich sunspot number 180.)

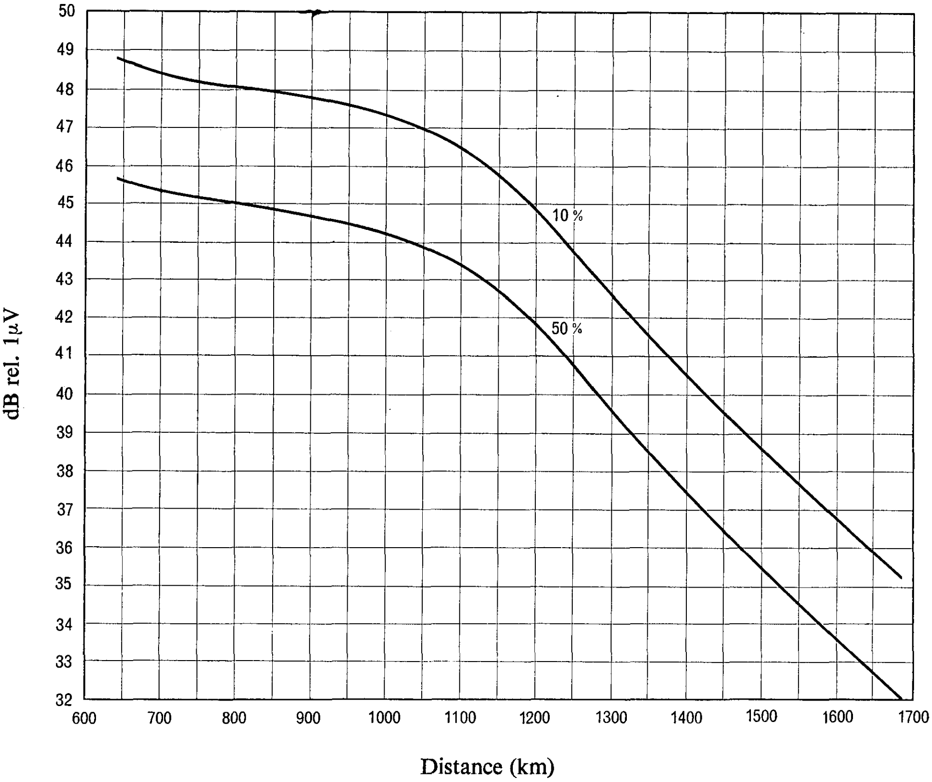


FIGURE 10

Hourly median values of the field strength exceeded at 50% of locations on 50% and 10% of the nights of a year at the second hour after sunset.

(North-south paths; annual mean Zurich sunspot number 10.)

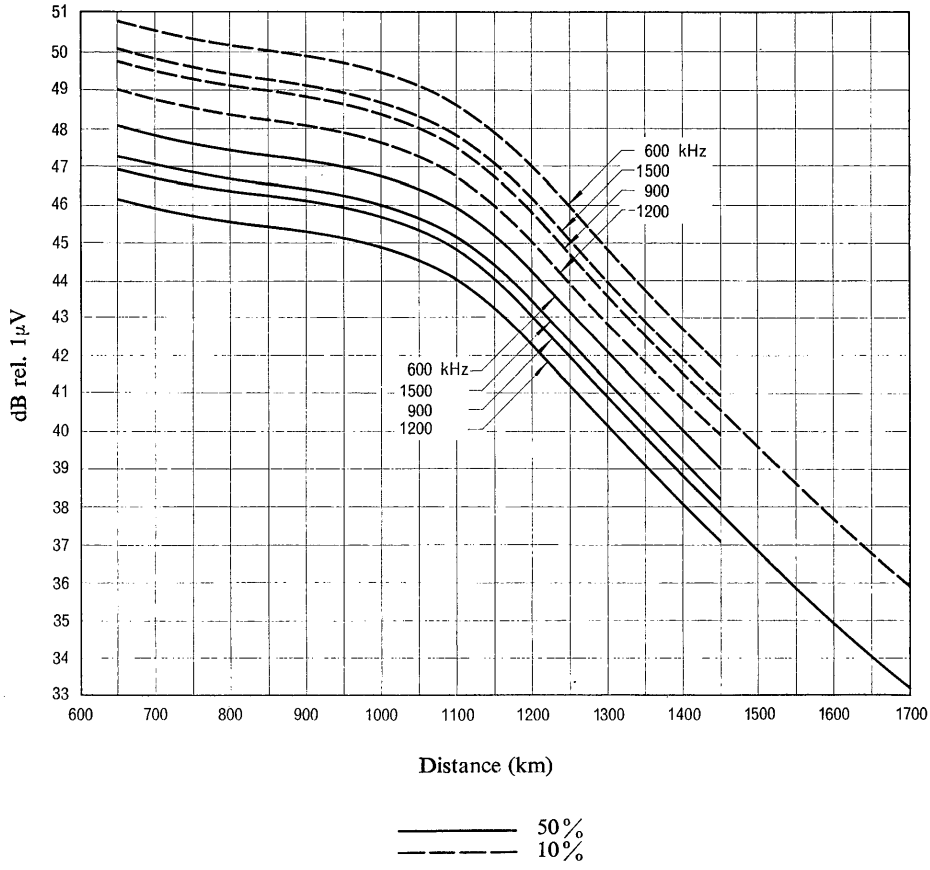


FIGURE 11

Hourly median values of the field strength exceeded at 50% of locations on 50% and 10% of the nights of a year at 2330 hrs.

(North-south paths; annual mean Zurich sunspot number 10.)

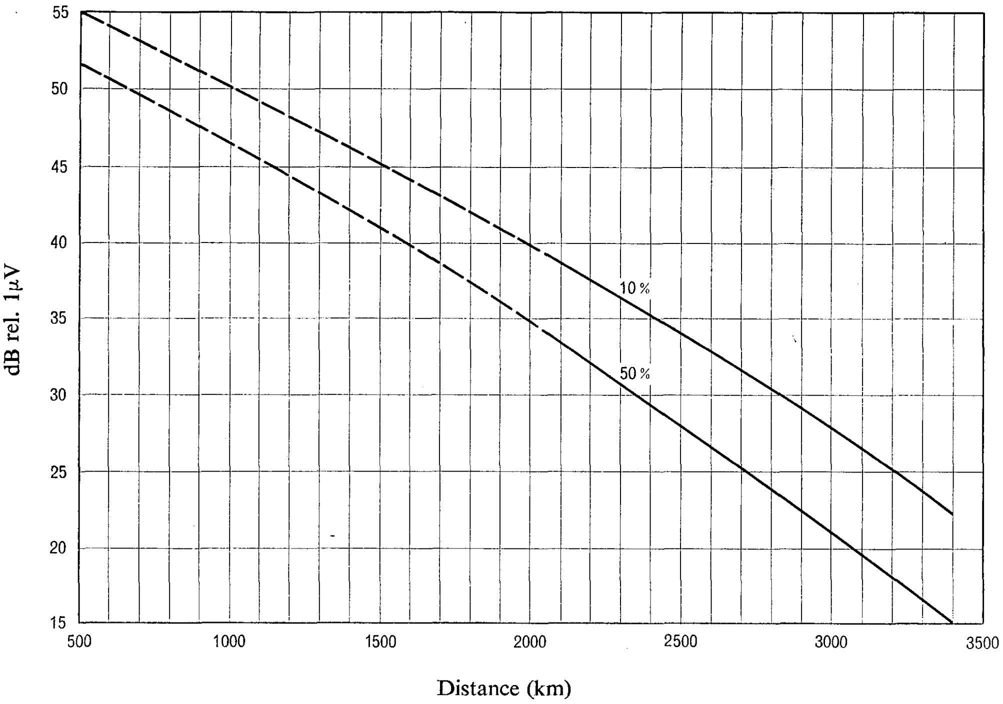


FIGURE 12

Hourly median values of the field strength exceeded on 50% and 10% of the nights of a year at the second hour after sunset for 50% of the locations. The number of the paths investigated was not sufficient to obtain an accurate prediction over the dashed section.

(East-west paths; annual mean Zurich sunspot number 20.)

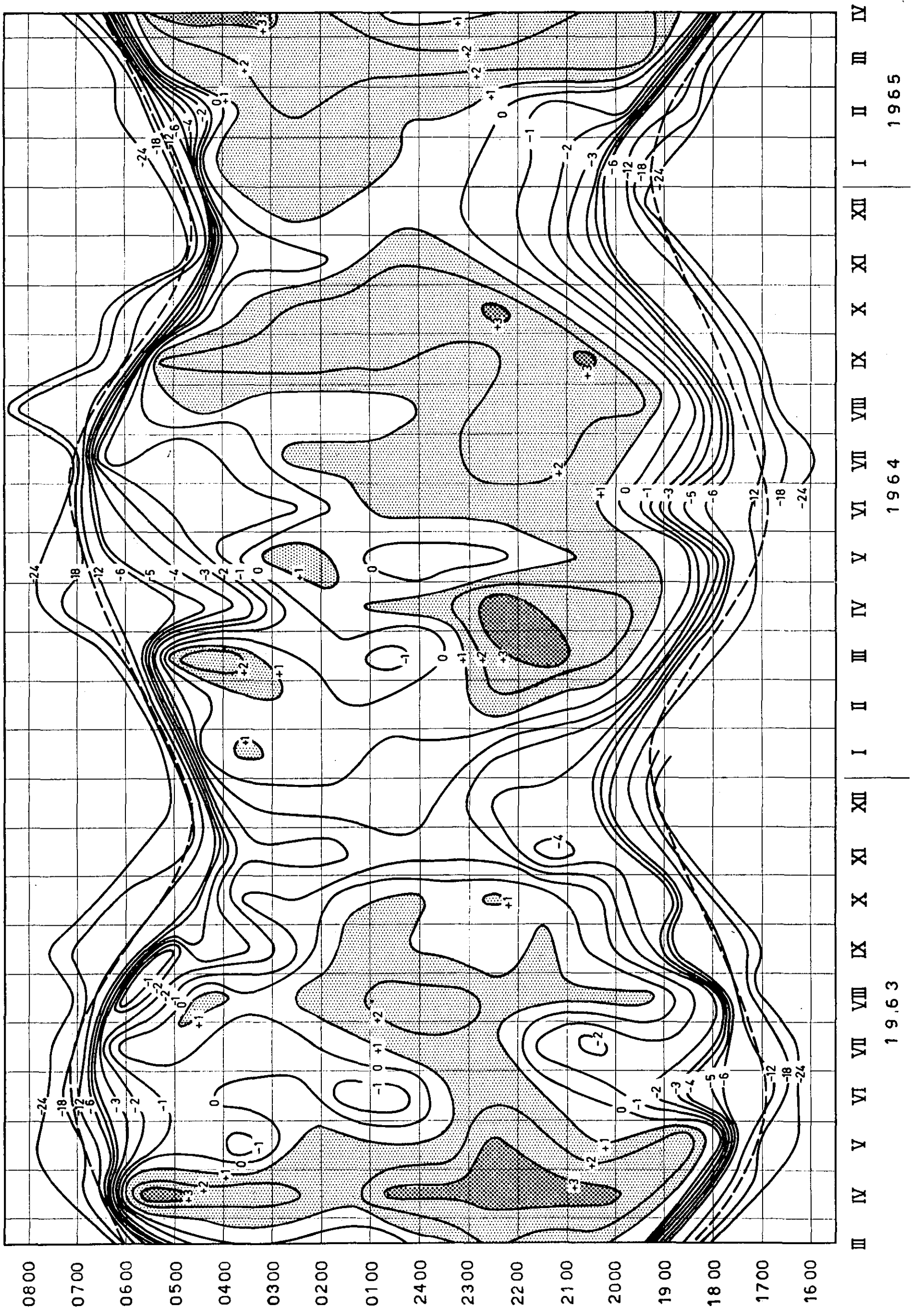


FIGURE 13

Field-strength variation with time of night and month of the year.

Contours show the hourly median values of the field strength exceeded at 50% of locations on 50% of the nights of a month, in decibels above the hourly median value of the field strength exceeded at 50% of locations on 50% of the nights of a year (April 1964 - March 1965) at the second hour after sunset. The values shown are accurate for quasi-longitudinal transmission on a path of 700 km for transmission frequencies in the range 900 kHz to 1100 kHz. Dashed lines show the times of sunset and sunrise.

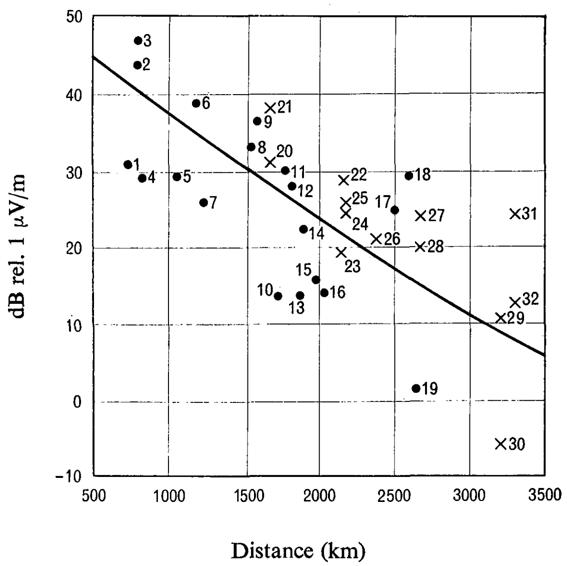


FIGURE 14

Medium-frequency measurements in Africa (median field strength corrected for 1 MHz, time 2200 hours and a transmitting antenna giving, over perfectly conducting ground, 3 × 10^5 μV/m at 1 km in all directions above the horizon).

—— : $F_o' = 80{\cdot}2-10 \log D - 0{\cdot}0018\, D f^{0{\cdot}26} + \Delta_{2200}$ (50)
● : paths over land,
× : paths over sea from shore-sited transmitter.
Key: (f = frequency (kHz), I = magnetic dip at mid-point,
Φ_m = approximate magnetic bearing of transmitter from mid-point).

No.	f (kHz)	I (deg.)	Φm (deg.)	No.	f (kHz)	I (deg.)	Φm (deg.)
1	1200	8	245	17	818	25	325
2	620	38	335	18	818	20	335
3	818	38	335	19	940	9	105
4	809	−64	205	20	1300	−16	215
5	940	− 4	70	21	555		
6	728	−15	210	22	1300	−19	240
7	665	−63	235	23	555		
8	995	−63	0	24	1300	−21	245
9	1484	39	300	25	555		
10	940	7	105	26	555	− 7	195
11	791	−15	190	27	1300	−20	250
12	1484	−20	145	28	555		
13	940	−17	340	29	1300	−19	245
14	1200	1	295	30	555		
15	935	28	10	31	1300	−34	275
16	935	29	35	32	555		

REPORT 265-1 *

SKY-WAVE PROPAGATION AT FREQUENCIES BELOW 150 kHz

(Study Programme 17A/VI)

(1959 - 1963 - 1966)

1. Introduction

Practical radiocommunication began at low frequencies, and if it were not for the limited bandwidth available, as well as for certain practical limitations, which are further discussed below, more extensive use would be made today of frequencies below 150 kHz. In this frequency range, at distances beyond the distance at which the ground wave becomes too weak to be useful (a distance which depends on frequency, time of day, season, and earth surface conditions and may lie between 500 to 1500 km), 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 field strength is obtained with decreasing frequency, down to 10 kHz or so, and the diurnal, seasonal and solar-cycle variations become smaller.

Because of the stability of propagation, frequencies in this range are useful not only for communications, but more especially for standard frequency and time broadcasts, as well as for navigational systems employing pulse or CW phase comparison or direction finding techniques. In particular, it has been found that the stability of the transmission permits frequency comparison to within a few parts in 10^{12}, which is some four orders of magnitude better than is possible at high frequencies, thus making possible long-range radio navigation utilizing phase comparison between spaced atomic-controlled or phase-locked transmissions. At frequencies above about 100 kHz, where it becomes practicable to isolate, in some circumstances, the ground- and sky-wave by pulse techniques, highly accurate time systems can be devised [1]. Marine communication makes considerable use of low and very low frequencies, which are also useful for point-to-point communications at times of severe ionospheric disturbances to HF circuits, since frequencies below 150 kHz are not adversely affected [2, 3]. Communications to points under the sea or below the ground can be achieved on these frequencies.

The propagation is essentially by way of vertical polarization which at long distances is well preserved, and an important limitation, which is partly economic, is the need for large transmitting antenna installations and high-power transmitters. Another limiting factor is the increasing level of atmospheric noise with decreasing frequency (ionospheric noise can also become important at the lowest frequencies especially at high latitudes) and thus, apart from the small total bandwidth available in this frequency range, services generally use a fairly narrow bandwidth and hence a low communication rate.

---

* This Report was adopted unanimously.

2. Research concerning LF propagation

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 [4], covering both the theoretical and experimental aspects. A useful survey of the conditions in the lower ionosphere governing the propagation of long waves has been published [5]. Propagation curves for the VLF range prepared by Wait and other workers [6, 7, 8, 9], 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 [10, 11].

Low-frequency pulse transmissions provide a means of measuring signals propagated with only a single ionospheric reflection [12]. The pulse measurements may be used to predict CW propagation conditions, but the converse is not practicable. Short duration variations of the pulse phase, which are not coincident with short duration variations of the pulse amplitude, may be indicative of the type of ionospheric conditions which produce the fading of higher frequencies. It is sometimes desirable to regard low-frequency propagation in terms of waveguide modes especially suitable for describing VLF propagation, but sometimes it is more appropriate to use the alternative and equivalent representation in terms of multi-hop reflections between the Earth and the ionosphere, mainly used to describe MF and HF propagation.

3. The problem of producing propagation curves

There are many aspects of the propagation which need study before curves can be prepared extending C.C.I.R. curves to cover long-distance propagation below 150 kHz, in particular, the non-reciprocal effects at VLF (the importance of which has not been established at LF) produced by the earth's magnetic field; the problems introduced by changes in the conductivity of the earth's surface along the path; and the lack of available data for high and low latitudes. Propagation over very high latitude paths is especially difficult to treat quantitatively, since, not only is the ionosphere different at these latitudes, but the ground conductivity can be very low (the conductivity of arctic tundra is 0·5 millimhos/m, and the conductivity of the ice of Greenland and Antarctica is probably less by more than an order of magnitude). The theory concerning the propagation of LF is now becoming fairly well understood [6, 13, 14, 15, 16, 17], but the mathematical complexity is considerable; and the results of the various methods have not been intercompared to any great extent. Much of the theoretical work has been based on idealized models of the ionosphere. There is a need for the intercomparison between LF field-strength measurements and theoretical calculations based on lower ionosphere properties measured at the same time.

An informal Working Party (International Working Party VI/5) was established to consider the feasibility of producing long-distance sky-wave propagation curves for frequencies below about 150 kHz, which predict median values of field strength and phase, as well as standard deviations about the median, as a function of distance for a variety of path conditions; direction of propagation, earth's surface, time of day, season, epoch of the solar cycle, and latitude. The recommendations of the Working Party were that propagation curves could be produced, althouth the task is by no means a simple one, since, due to limitations in both quality and quantity of LF field strength and phase data (e.g. as previously mentioned little data are available for propagation over high or low latitude paths), it was thought necessary to take account of all available sources from which LF propagation results could be derived. Accordingly, a threefold attack on the problem was proposed:

- the production of propagation curves based on LF propagation data alone (this is the most obvious method);

- the production of propagation curves based on theoretical computation using available ionospheric data obtained independently from ground based measurements at higher frequencies and also from *in situ* rocket measurements;
- the production of propagation curves based on a mathematical model which best explains the available LF propagation data.

4. Conclusions

In conclusion, there is much information available which could be summarized and more conveniently organized to be practically useful in computing long-wave fields (field strengths and phase) over arbitrary transmission paths. There is a particular need for field-strength measurements over low and high latitude paths; and for detailed comparison between measured and computed field-strengths for reflection from appropriate ionospheric models.

Resolution 13–1 proposes the continuance of the International Working Party of experts to study the problems of producing long-distance sky-wave propagation curves (field strength and phase).

BIBLIOGRAPHY

1. DOHERTY, R.H., HEFLEY, G. and LINFIELD, R.F. Timing potentials of Loran-C. *Proc. IRE*, **49**, 1659-1673 (1961).
2. BELROSE, J.S. and ROSS, D.B. Observations of unusual LF propagation made during polar cap disturbance (PCD) events. *J. of Phys. Soc. of Japan*, **17**, Supplement A-II (Int. Conf. on Cosmic Rays and the Earth Storm), 126-130 (1962).
3. BELROSE, J.S. LF propagation changes, associated with the auroral absorption of HF radio waves for a transmission path, which traverses the auroral zone. *Can. J. Phys.* (in press) (1965).
4. WAIT, J.R. A survey and bibliography of recent research in the propagation of VLF radio waves. Radio noise of terrestrial origin, edited by F. Horner, published by Elsevier, Amsterdam (1962).
5. BELROSE, J.S. Present knowledge of the lowest ionosphere, AGARDograph 74: Propagation of radio waves at frequencies below 300 kc/s. Ed. Blackband, Pergamon Press (1963).
6. WAIT, J.R. and SPIES, K.P. Characteristics of the earth ionosphere wave guide for VLF radio waves. *NBS Tech.* Note No. 300 (1964).
7. WATT, A.D. Comparison of observed VLF attenuation rates and excitation factors with theory. *Radio Science, J. of Res. NBS/USNC-URSI*, **68D**, 1-9 (1964).
8. ALPERT, Y.L. The propagation of electromagnetic waves of low frequency over the surface of the ground. (in Russian), U.S.S.R. Academy of Science, Moscow (1955).
9. VOLLAND, H. Bemerkungen zur Austinschen Formel. (Remarks on Austin's formula), *NTZ*, **12**, 641-652 (1964).
10. BELROSE, J.S., HATTON, W.L., MCKERROW, C.A. and THAIN, R.S. The engineering of communication systems for low radio frequencies. *Proc. IRE*, **47**, 661 (1959).
11. BELROSE, J.S. The oblique reflection of long radio waves from the ionosphere. Part 1, propagation over distances less than 1 500 km in Europe. Defense Research Board, Canada, DRTE Pub., No. 1154 (in press: Autumn 1965).
12. DOHERTY, R.H. Oblique incidence pulse measurements at 100 kc/s, AGARDograph 74; Propagation of radio waves at frequencies below 300 kc/s. Ed. Blackband. Pergamon Press (1963).
13. BERRY, L.A. Wave hop theory of long distance propagation of low frequency radio waves. *Radio Science, J. of Res. NBS/USNC-URSI*, **68D**, 1275-1284 (1964).
14. BUDDEN, K.G. Radio waves in the ionosphere. Cambridge University Press, 458-501 (1961).
15. JOHLER, J.R. Propagation of low frequency radio signal. *Proc. IRE*, **50**, 404-427 (1962).
16. PITTEWAY, M.L.V. The numerical calculation of wave fields, reflexion coefficients and polarizations for long radio waves in the lower ionosphere. Part I, *Phil. Trans. Roy. Soc. A.*, **257**, 219-241 (1965).
17. KRASNUSHKIN, P.Y. and YABLOCHKIN, N.A. The propagation theory of ultra-long waves (in Russian). Mathematical Institute, Academy of Sciences, Moscow (1963).

REPORT 266-1 *

FADING OF SIGNALS PROPAGATED BY THE IONOSPHERE

(Study Programme 16A/VI)

(1953 - 1956 - 1959 - 1963 - 1966)

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, space and frequency which occur as random short-period variations, irregular long-period variations and more or less regular variations, collectively described as fading, also have to be taken into consideration. Fading has a decisive influence on the performance of radiocommunication systems and on the type of modulation that may be used effectively. It is essential to know the severity and rapidity of fading to be able to specify the power required for transmitters, the necessary protection ratio to guard against interference and, with additional knowledge of the correlation of signals at separate antennae or frequencies, the most efficient and economical diversity or error-correction coding systems.

2. Causes of fading

Ionospheric fading of received signals is caused by the following effects and in systems it is usually important to distinguish between them:

- variations of absorption,
- movement of ionospheric irregularities producing focusing and defocusing,
- changes of path length among component signals propagated via multiple paths or multiple modes, and
- changes of polarization involving multiple paths consisting of the ordinary and extraordinary waves for each mode.

The relationship between multipath transmission and selective fading characteristics of radio circuits has been graphically demonstrated by several investigators [1, 2, 3, 4]. As evidenced by the techniques used in these studies, experimental separation of these effects requires special instrumentation and observation. Such work has led to the following conclusions.

Motion of non-uniformly ionized regions of the ionosphere, as well as motion of regular layers, produces effective changes of path length and Doppler shifts of frequency on each of the individual contributory signal components. The vector addition of these changing signal components gives rise to fluctuations of the composite received signal amplitude, observed at an antenna, which are functions of space, frequency, and time. Short-period fluctuations can arise from interference between components of a single mode and polarization following

---

* This Report was adopted unanimously.

closely separated paths but, at HF, they are more generally produced by interference between separate modes and between the ordinary and extraordinary components of each mode.

Long-period variations of field strength are found to depend upon variations of electron density and absorption over extensive ionospheric regions. Such changes exhibit regular variations (diurnal, seasonal, etc.) which are modified by superimposed random variations.

Continuing selective and multi-parameter experimental and theoretical studies of both long- and short-period fading of radio circuits will contribute to a better understanding of both temporal and geographic variations. The data obtained from such studies may then be employed as the basis for radio system design and performance analyses.

3. Sampling periods

For the purpose of communication system analyses, it is not always essential to identify the individual contributory effects; instead, it is possible to observe the resulting time series and characterize the fluctuations of signal levels in time as a random or stochastic process [5]. Characterization of the time series requires, first, the selection of an observation period T, long enough to include a sufficiently large number of fluctuations of the signal level. If this condition is fulfilled it may be found that, in successive periods, the parameters describing the random process will have changed, i.e. that the process is not " stationary ". Some compromise in the choice of T may be necessary in order that the process may be regarded as statistically stationary with each sample. The use of an averaging procedure may be helpful in enabling a more satisfactory choice of T to be made. This applies particularly to analysis of the amplitude distribution discussed in § 4.1. Thus the long-period fluctuations may be represented by a mean-value function $m(t)$, and for analysing short-period fluctuations, this function may be subtracted from the variable being analysed [6, 7, 8]. Subtraction on a logarithmic basis may be advantageous.

Although the selection of the sampling period T is arbitrary, it has been found to be expedient for several applications to carry out the analysis of fading data with samples of T equal to one hour on MF and HF paths. Somewhat shorter periods, between three minutes and one hour, may be suitable for HF paths [9, 10] and for ionospheric scatter paths.

The general features of diurnal, seasonal, and sunspot variations of the mean value function $m(t)$ are characterized over longer periods of time by more or less regular changes upon which are superimposed random variations. The variations of the mean value function may be treated as a statistical variable and analysed in a manner similar to the short-period fading phenomena discussed above. The choice of the sampling period T for these long-period statistical analyses is again arbitrary, but is generally made to suit the objective of an analysis. Thus, sampling periods of a month have been used, to estimate the random variations of each hourly period in a day and the systematic and random variations which occur during the course of the day. Longer sampling periods are needed to examine seasonal, annual, or sunspot cycle variations.

4. Severity and rapidity of short-period fading

The terms " severity " and " rapidity " as used here refer to the characteristics of the variations of the received signal amplitude. Severity or depth of fading is measured by the amplitude distribution or probability density function. Rapidity describes the second order properties of the variations, i.e. the rate of change, and may be expressed in terms of a correlation function or power spectrum. Alternatively, simpler measurements, such as the number of maxima per second, may often suffice.

4.1 *Severity of fading*

The *signal amplitude distribution function* $P(v_0)$ conventionally employed gives the probability of finding the signal amplitude v greater than v_0. It is related to the *probability density function* $p(v)$ by:

$$P(v_0) = \int_{v_0}^{\infty} p(v)\mathrm{d}v \tag{1}$$

Here $p(v)\mathrm{d}v$ is the fraction of time during the period T, for which the amplitude lies between v and $v + \mathrm{d}v$, while $P\,(v_0)$ is the fraction of time for which v exceeds v_0.

Note. — The signal amplitude distribution function $P(v_0)$ is a cumulative type of function, but differs from the cumulative function $\mathrm{E}(v_0)$ used in statistics. The relation between the two is given by:

$$E(v_0) = 1 - P(v_0)$$

It is desirable to examine measured distribution data for similarity to one of the distribution laws discussed below. This may provide a convenient method of describing the distribution, and may give evidence concerning the mechanism of fading applicable to the sample.

Techniques have been developed for checking whether an observed distribution corresponds to a certain model [11] and for measuring the departure of one distribution with respect to another [12, 13].

An alternative method of describing the characteristic fluctuations of signal level is by the distribution of fade lengths [14]. This type of data presentation is of some interest for engineering application, but does not lend itself readily to a transformation to other and more conventional representations [15].

Probability density functions, obtained analytically to describe the envelope of a fading signal, differ because of the assumptions made with respect to the structure of the contributory signals. Among the most frequently used models is the one which assumes that the received signal before detection is composed of a steady sinusoidal component and a random Rayleigh component (see equation (3)) with a uniform phase probability density. This leads to the Nakagami-Rice probability density function [16, 17, 18]:

$$p(v)\,\mathrm{d}v = (2\,v/v^2_{rms})\exp - [(v_1^2 + v^2)/v^2_{rms}]\,\mathrm{I}_0\,(2\,v_1\,v/v_{rms})\,\mathrm{d}v \tag{2}$$

where:

$\mathrm{I}_0(x)$ = modified Bessel function of zero order,
v = received signal envelope voltage,
v_1 = voltage amplitude of steady sinusoidal component,
v_{rms} = r.m.s. value of random voltage component.

Fig. 1 gives the corresponding signal amplitude distribution function $P(v_0)$.

If $v_1 \lessdot v_{rms}$, (2) reduces to the Rayleigh density

$$p(v)\,\mathrm{d}v = (2\,v/v^2_{rms})\exp - (v^2/v^2_{rms})\,\mathrm{d}v \tag{3}$$

If there is no random component but instead there are two sinusoidal components with random relative phase and amplitudes v_1 and v_2, then the probability density function becomes:

$$p(v)\,\mathrm{d}v = \frac{2}{\pi}\, v\,\mathrm{d}v \Big/ [(2v_1 v_2)^2 - (v^2 - v_1^2 - v_2^2)^2]^{1/2} \qquad (|\,v_1 - v_2\,| < v < |\,v_1 + v_2\,|) \qquad (4)$$

$$= 0 \text{ for all other values of } v.$$

In addition to the above probability densities, which are bound to certain theoretical assumptions (stationary processes, random motion of secondary radiators), there are other probability density functions worth considering, because they contain several arbitrary parameters to which values may be assigned to fit the measured data.

In this connection, mention may be made of the *m*-distribution [19], which is similar to the χ^2 and gamma distribution often used in statistics.

Finally, the normal and log-normal probability density functions are worthy of special mention. These can be expressed through one formula, as follows:

$$p\,(x)\,\mathrm{d}x = (1 \,/\, \sqrt{2\pi}\,\sigma_x)\,\exp - (x^2/2\sigma_x^2)\,\mathrm{d}x \qquad (5)$$

For the normal distribution, x is to be interpreted as $-m$, while for the log-normal distribution, x is to be interpreted as $20 \log (v/v_m)$, where v_m is the median value of v.

A comparison between probability density laws and measured statistical data is usually made in terms of the distribution function already defined (see equation (1)). The simplest method of characterizing empirical distributions is by the order statistics of the signal distribution which give an indication of the incidence of specified levels. A distribution can, for instance, be characterized by stating the levels exceeded for 50%, 99%, 90%, 10% and 1% of the time.

The following Table gives these levels for the theoretical distributions discussed earlier [20].

Distribution	Level relative to median exceeded for the following percentages of time (dB)			
	1%	10%	90%	99%
Rayleigh	8·22	5·21	—8·18	—18·39
Nakagami-Rice				
$v_1 = v_{\text{rms}}$	7·02	4·48	—7·53	—17·55
$v_1 = 3{\cdot}16\, v_{\text{rms}}$	3·54	2·12	—2·80	— 5·98
Log-normal	2·326 σ_x	1·282 σ_x	—1·282 σ_x	— 2·326 σ_x

Having discussed some of the mathematical formulae that may be used to describe fading, we pass on to some measured results. With short analysis intervals (3 to 7 minutes), distribution functions close to the Rayleigh distribution seem to predominate. On the other hand, during longer analysis intervals (30 to 60 minutes), the distribution seems to follow the log-normal law rather than Rayleigh. The fading range is often defined as the difference (in dB) between the signal levels exceeded for 10% and 90% of the time, and values of 13 ± 3·2 dB [21] and 16 ± 3·2 dB [22] have been given for long-distance HF paths. The value not appear to vary greatly with path length in the range 1500-6000 km, with time of day or with season [22]. It is of interest to note that, although the form of the measured distributions may differ from the Rayleigh, the observed fading range is of the same order as the value of 13·4 dB expected for the Rayleigh distribution. However, at high signal levels the fading range has been observed to fall below the Rayleigh value, possibly due to a strong constant term arising from a specular reflection, and distributions of the Nakagami-Rice type will apply under these conditions.

A topic of some interest is the relation between fading on reciprocal paths with identical antennae. In general, non-reciprocal propagation may occur in a medium containing a permanent magnetic field. In the case of the ionosphere, correlation between the fading of signals is high if one magneto-ionic wave (e.g. ordinary ray) is present, but may be low or negative if both waves are present, giving " polarization " fading [23, 24]. In theory polarization fading is expected to be well correlated, i.e., reciprocal, only for certain geometrical configuration [25]. The results of HF tests have not conclusively shown any systematic differences in long-term averaged path loss in two directions, although differences in short-term averaged path loss of up to 10 dB have been observed on U.K. — U.S.A. and U.K. Australia circuits [26].

4.2 *Rapidity of fading*

The rapidity of fading can be characterized in different ways [17, 27, 28, 29]. 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:

$$R(\tau) = \lim_{T \to \infty} (1/2T) \int_{-T}^{T} U(t).\ U(t+\tau)\, \mathrm{d}t \tag{6}$$

where $U(t)$ is used here to denote the signal amplitude.

From the above, the power spectrum of the fading process may be calculated by:

$$G(f) = 4 \int_{0}^{\infty} R(\tau).\ \cos(2\pi f t)\, \mathrm{d}t \tag{7}$$

The relation between $G(f)$ and the Fourier spectrum $F_T(f)$ is given by:

$$G(f) = \lim_{T \to \infty} (1/T)\, F_T(f).\ F_T^*(f) \tag{8}$$

where

$$F_T(f) = \int_{-T}^{T} U(t).\ \exp(\mathrm{j}\ 2\pi f t)\, \mathrm{d}t \tag{9}$$

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 (normal distribution of the components of the velocities of the secondary radiators), a normal curve is to be expected for the auto-correlation function:

$$R(\tau) = R(0) \exp - \left(\tau^2/2\tau_0^2\right) \tag{10}$$

However, it is questionable whether the assumption for the velocity distribution of the secondary radiators is always justified. Therefore, a possibility of other velocity distribution functions should also be taken into consideration. These other velocity distributions would presumably lead to other forms of the auto-correlation function.

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 characterising 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 (2), the fading rate through the level v is given by:

$$N(v) = \left(\sqrt{4\pi} f_s . v/v_{rms}\right). \exp - \left[\left(v_1^2 + v^2\right)/v_{rms}^2\right] I_0 \left(2\, v_1 v/v_{rms}^2\right) \tag{11}$$

where

f_s = r.m.s. frequency of fading (defined below).

In the special case of the Rayleigh distribution, we can introduce the median value v_m obtaining:

$$N(v) = 2{\cdot}95\, f_s\, (v/v_m) \exp - (0{\cdot}693\; v^2/v_m^2) \tag{12}$$

where,

if $v = v_m$, it follows that $N(v_m) = 1{\cdot}47\, f_s$.

This proportionality is also valid, at least approximately, for other amplitude distributions.

The r.m.s. fading frequency f_s, which is used in (11) and (12), can also be determined from the auto-correlation function. The square of the r.m.s. value of the fading frequency is given by:

$$f_s^2 = f^2 = \int_0^\infty f^2\, G(f)\, \mathrm{d}f \Big/ \int_0^\infty G(f)\, \mathrm{d}f = \left[1/4\, \pi^2 R(0)\right] \left(\mathrm{d}^2\, R(\tau)/\mathrm{d}\tau^2\right) \Big|_{\tau = 0} \tag{13}$$

The number of maxima, Z, of the received signal envelope amplitude per unit time, may also be used as a measure of the fading rapidity. The relationship between Z 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.

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:

$$S = (1/v) \left|\overline{\frac{\mathrm{d}v}{\mathrm{d}t}}\right| \tag{14}$$

Studies with the help of auto-correlation functions, have been carried out in the United States at HF and at 50 MHz (ionospheric scatter) [28], and in the United Kingdom at MF and HF [17]. Values of τ_0 measured in the United Kingdom, on the assumption that the auto-correlation function satisfied (10), were between 0·5 and 2·5 s at HF [17, 43]. Some auto-correlograms obtained in India show clear quasi-periodic components [30].

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 MHz).. 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.

HF paths in the tropics may show much more rapid fading than paths confined to higher latitudes on a certain proportion of days [30, 31, 32, 33, 34]. This phenomenon is associated with equatorial F-scattering (see Report 343) and usually occurs, starting about 2000 hours local time, for some two to four hours. It is likely to affect transmission paths with a reflection point in the F region between magnetic latitudes ± 15°. Seasonal and sunspot-cycle variations occur but may differ in nature with the path orientation. Long-distance paths appear to be affected more at the equinoxes and at sunspot maximum [35]. Besides increased fading rates, brief frequency changes of 20 to 30 Hz have been reported and the possibility of a lower frequency being affected but not a higher frequency [36]. More data is needed before a more exact account of the various fading characteristics can be given.

5. Long-period variations

In the case of long-period variations, the random component is analysed by using hourly median values of the starting point, and evaluating the amplitude distribution over a long period. For simplicity a log-normal distribution of the long-period variations is usually assumed, and often gives a good approximation to the actual distribution. A very full analysis, carried out in the Federal Republic of Germany [21, 37, 38] on long-period variations, showed that distribution curves for a sun-rotation period were closely log-normal for 50% of the 28 rotation periods examined; 25% could be split into two log-normal distributions, each valid over a different range of field strengths. The remainder could only be described in terms of the log-normal distribution if split up into more than two ranges.

Results for the spread of long-term variations have been analysed in a number of countries. Expressed in terms of the standard deviation σ_x of the log-normal distribution (equation (5)), the analyses mentioned above gave an average result of 8 dB, with some indication of greater values at night than in the daytime. U.S.S.R. experiments at HF over paths of 1500, 3000 and 6000 km, for all seasons and times of day, have given values within the range 5 to 10 dB [22]. Any systematic change with season or between day and night appears relatively small. Results obtained in the United Kingdom for Accra-U.K., Bombay-U.K. and Colombo-U.K. paths showed values in the range 5·5 to 7 dB. In certain regions higher values may be obtained, e.g. a value of 10 dB may be found for paths crossing polar areas with high absorption.

6. Correlation of signals in space, time, frequency and polarization

The study of correlation between two received signals as a function of their separation in position, time, frequency or polarization can provide useful information for the design of a communication system in the presence of fading. There are two major system parameters which are affected by differential fading (as lack of perfect correlation is sometimes called).

One is diversity reception, which ameliorates the effects of severe fading by combining the outputs of several receivers, and the other is distortion, which is caused by selective fading across the frequency band used for the transmission of information.

6.1 *Space diversity reception*

The basic principles of diversity are so well established [39] that no description of them is required here. Early investigations of space, polarization and frequency diversity have been carried out both in the United States and the United Kingdom prior to 1940. However, the mathematical techniques for the investigation of the theoretical and empirical aspects of diversity reception have largely been developed since 1947 [27, 40, 41, 42]. This was accompanied by the accumulation of substantial experimental data beginning in the early 1950's in the United Kingdom and the United States [43, 44, 45].

Based upon a simple, though not completely satisfactory, model of scattering from an inhomogeneous and time-varying ionosphere, a spatial correlation function $\rho\ (d)$, normalized to unity at $d = 0$, may be derived to show the dependence of signals at two antennae spaced at a distance, d, viz. [43, 46, 47]:

$$\rho(d) = \exp\left[-\, d^2/2\,\chi^2\right] \tag{15}$$

The parameter χ is a function of the structure size of the ionospheric inhomogeneities, of the path length, and the frequency. At a separation $d = \chi$, the correlation is 0·61 and at $d = \chi\sqrt{2}$, it is 0·37. At even the shorter of these distances, experience and theory have shown that, for all practical purposes, substantially all the benefits of diversity have already been obtained. For example, with two independently fading signals ($\rho = 0$), the diversity improvement was 14 to 15 dB at the 99·9% reliability level. For $\rho = 0{\cdot}61$, the diversity improvement was 13 dB. For this reason, it appears justifiable to identify the distance $d = \chi\sqrt{2}$ as the " diversity separation distance " or " correlation distance ".

In the United Kingdom, tests made in the frequency range 6 to 18 MHz over distances of 2000 to 17 000 km indicated that the structure size, χ, was between 150 and 400 m, implying diversity separation distances of 210 to 560 m (10 to 25 λ). These findings were confirmed by recordings of WWV (15 MHz) made in the Federal Republic of Germany. In addition, it was shown that the separation distances required, when specular reflection at the ionosphere is predominant, are much greater than when a substantial random component is present. Quite frequently, cases were observed where the recordings suggested a pure random component, but an examination of the spatial correlation suggested a mixture of weak specular reflection and random variations.

At HF, the evidence seems to be that the direction of the antenna separation relative to the propagation path has no significant effect on the effectiveness of diversity reception [48, 49, 50], although one paper [51] indicates a shorter diversity separation distance ($\chi = 10\ \lambda$) when the antennae are separated along the propagation path, as compared with the case when the separation is perpendicular to the path ($\chi = 15\ \lambda$). Some recent work in the United States [45, 52] has demonstrated that, at frequencies above 10 MHz and for path lengths from 1000 to 6000 km, two components (such as the upper and lower magneto-ionic rays or reflections from different ionospheric regions) may predominate. The amplitude variations over the ground then tend towards a " striped " pattern with maxima and minima along parallel lines. This will produce marked differences of correlation distance along two mutually perpendicular base lines and will be accompanied by quasi-sinusoidal fading as the relative path lengths change. Under these conditions the minimum correlation distance was found to be about 400 m. In general, for most high frequencies over long paths, and when random fading predominates, a separation distance of 200 m appears sufficient for diversity [48].

In other United States measurements below HF, the average correlation distance at 540 kHz was 29·4 $\lambda \pm 17{\cdot}1\ \lambda$ [53], while at 85 kHz [54], two distinct fading periods were observed, one of 7 min and one of 1·5 min. The correlation distance was determined to be 5 km for 7 min fading and 1 km for the 1·5 min fading.

6.2 *Polarization diversity*

Polarization diversity in the frequency range 6 to 18 MHz was studied in the United States and the United Kingdom. The antennae were at the same location but arranged to respond to waves with mutually perpendicular polarization. The result was that the diversity action was the same as that obtained with an equivalent space separation of 240 to 480 m [43]. Polarization diversity is, therefore, an effective means for improving HF reception under fading conditions and is particularly useful where space considerations prohibit setting up antenna systems suitable for space diversity.

6.3 *Frequency correlation*

The effects of fading on signal components separated in frequency and time have only had rather preliminary exploration to date [1, 2, 3]. However, much remains to be done to establish for frequency correlation, or for correlation in both frequency and time variables, the detailed knowledge that exists for space and polarization diversity. Some description of work to date in this area may serve to illustrate the type of data needed and the techniques which may be employed to obtain them.

Three techniques can be used to study frequency (or time) correlation of signals propagated over ionospheric paths:

— examination of the correlation of sinusoidal signals transmitted simultaneously at two or more frequencies [1],

— examination of a wide-band signal on a tapped delay line by means of multiple correlation detectors [3],

— examination of a frequency swept pulse over the band of interest, it being clearly understood that the sweep period is to be short compared to the time required for changes to take place on the path under study [2].

Studies made using the first two methods described above showed, not too surprisingly, several distinctive characteristics of ionospheric propagation. In one case, two distinct paths were observed with a time separation of 1·4 ms; in another case, a continuum of paths was observed spanning about 2 ms.

In the sweep-frequency technique, a single sweep provides information about the transfer function of the circuit at an instant of time. However, no extensive data of this type have been published for ionospheric paths.

7. Characterization of channels for modulated signals

The design of signals or choice of modulation to convey information on radio channels is necessarily related to the limitations imposed by fading in time, space, and frequency. A complete statistical description of a transmission circuit by the methods described is essential to an appreciation of the distortions or errors which may occur, and the methods (modulation systems, signal processing, diversity, etc.) of minimizing them.

Measuring techniques described above for a single (non-diversity) channel, it may be noted, are interrelated, although each emphasizes a different aspect of the same transmission path or medium. The choice of a technique for the investigation and characterization of a channel will, to a large degree, be dictated by the need to relate the properties of the channel to the characteristics of the equipment or system under study.

In recent years there has been a rigorous mathematical development of system theory which encompasses the characterization of channels as time-varying filters [55]. Such an empirical development for characterization of radio channels requires a more complete identification of the total radio-frequency environment than has been possible with the limitations in the design of propagation experiments carried out to date. Although much of the theoretical background has been developed by a number of investigators [56, 57, 58], who have obtained specific but limited results, much remains to be done to complete the statistical description of channels within the framework of the models representing the known physical processes which take place in the ionosphere and which have been described above.

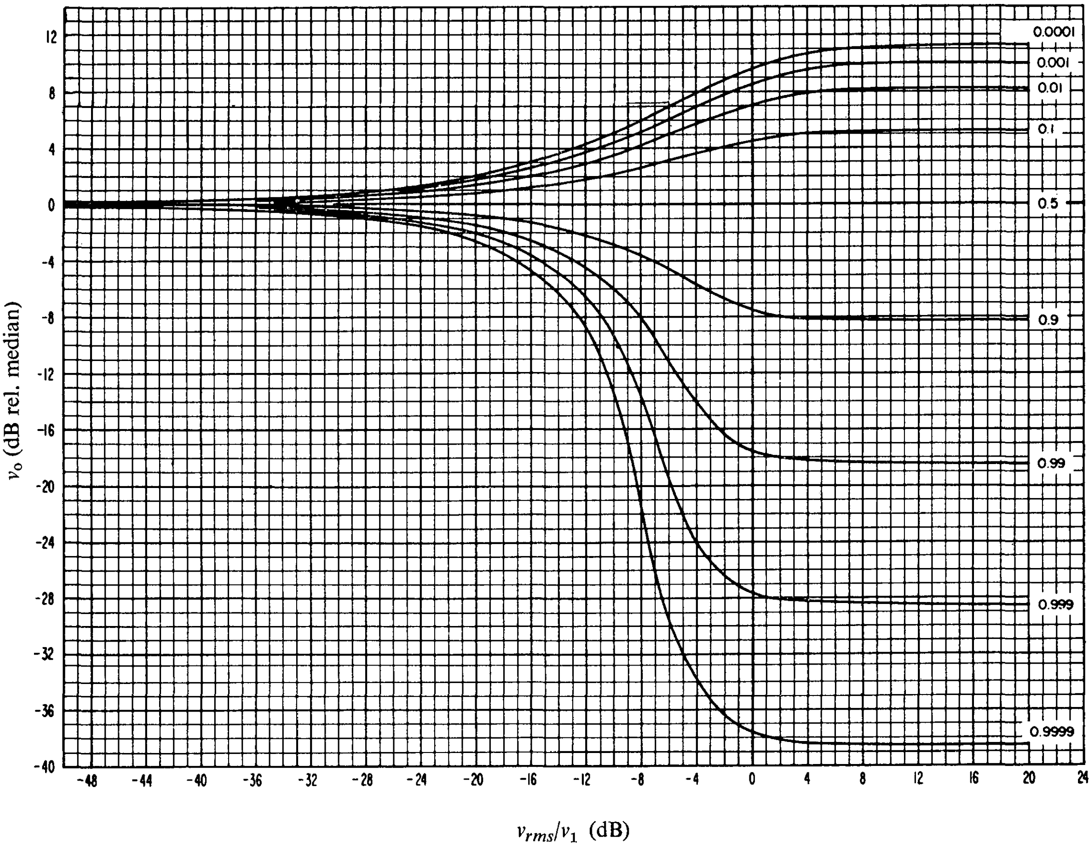


FIGURE 1

Distribution function $P(v_0)$ for the Nakagami-Rice distribution

(The values of $P(v_0)$ are shown on the curves)

BIBLIOGRAPHY

1. POTTER, R.K. Transmission characteristerics of a short-wave telephone circuit. *Proc. IRE* **18**, 581-648 (April, 1930).
2. BRIGGS, B.H. Investigation of certain properties of the ionosphere by means of a rapid frequency-change experiment. *Proc. Phys. Soc.* **B63**, 255 (1951).
3. PRICE, R. and GREEN, P.E., Jr. A communication technique for multipath channels. *Proc. IRE* **46**, 555-570 (March, 1958).
4. AMES, J. The correlation between frequency-selective fading and multipath propagation over an ionospheric path. *J. Geophys. Res.* **68**, 759-768 (February, 1963).
5. BRENNAN, D.G. Probability theory in communication system engineering (Chapter 2); Analysis of long-term variability (Chapter 20), in *Lectures in Communication System Theory* (ed. E. Baghdady), McGraw-Hill (1961).
6. PARZEN, E. An approach to empirical time series analysis. *J. Res. NBS* **68D**, 937-951 (September, 1964).
7. BENDAT, J.S. and THRALL, G.P. A summary of methods of analyzing non-stationary data. Jet Propulsion Lab., Calif. Inst. of Technology, TR32-744 (1 September, 1965).
8. PARZEN, E. Stochastic processes. Holden Day, Inc., San Francisco (1962).
9. MITRA, S.N. and SRIVASTAVA, R.B.L. Fading and random motion of ionospheric irregularities, *Indian J. Phys.*, **31**, 20-42 (1957).
10. AGGARWAL, K.K. Statistical analysis of fading on short-wave transmission. *J. Inst. Telecom. Engr.* (India), **5**, 230-237 (September, 1959).
11. SIDDIQUI, M.M. Some statistical theory for the analysis of radio propagation data. *J. Res. NBS* **66D**, 571-580 (September-October, 1962).
12. ROSENBERG, V.Ya. The estimate of similarities between distribution laws. *Radio Engineering and Electronic Physics* **10**, 521-524 (April, 1965).
13. ROSENBERG, V.Ya. and GUSINSKIY, I.S. Estimation of similarity between some distribution laws. *Radio Engineering and Electronic Physics* **10**, 524-638 (April, 1965).
14. BOWHILL, S.A. The distributionary fade lengths of a randomly fading radio signal. *Statistical Methods in Radio Wave Propagation*, W.C. Hoffman, ed., 220-226, Pergamon Press (1960).
15. BAGHDADY, E.J. Lectures on communication system theory, Chapters 5 and 6. McGraw-Hill (1961).
16. NAKAGAMI, M. Statistical character of short-wave fading. *J. Inst. Elec. Comm. Eng.* (Japan), **27**, 145 (February, 1943).
17. MCNICHOL, R.W.E. The fading of radio waves of medium and high frequencies. *Proc. I.E.E.*, Part III, **96**, 517-524 (1949).
18. RICE, S.O. Mathematical analysis of random noise. *Bell System Techn. J.* **24**, 46 (1945).
19. NAKAGAMI, M. The *m*-distribution: a general formula of intensity distribution of rapid fading. *Statistical Methods in Radio Wave Propagation*, W.C. Hoffman, ed., 3-36, Pergamon Press (1960).
20. NORTON, K.A., VOGLER, L.E., MANSFIELD, W.V. and SHORT, P.J. The probability distribution of the amplitude of a constant vector plus a Rayleigh distributed vector. *Proc. IRE* **43**, 1354-1361 (October, 1955).
21. GROSSKOPF, J. Statistical studies of short-wave transmission paths. *FTZ*, **6**, 373 (1953).
22. KONOPLEVA, E.N. Reliability of communications and necessary signal/noise ratio in short-wave radio channels. Elektrosviaz **5** (1964).
23. MEADOWS, R.W. An experiment to test the reciprocal radio transmission conditions over an ionospheric path of 740 km. *Proc. I.E.E.*, **103B**, 224 (1956).
24. JULL, C.W. and PETTERSEN, G.W.B. Origin of non-reciprocity on high-frequency ionospheric paths. *Nature*, **201**, 483 (1964).
25. BUDDEN, K.G. and JULL, C.W. Reciprocity and non-reciprocity with magneto-ionic rays. *Can. J. Phys.* **42**, 113 (1964).
26. LAVER, F.J.M. and STANESBY, H. An experimental test of reciprocal transmissions over two long-distance high-frequency radio circuits. *Proc. I.E.E.*, **103B**, 227 (1956).
27. RATCLIFFE, J.A. Some aspects of diffraction theory and their application to the ionosphere. *Reports on Progress in Physics*, **19**, 188, Physical Society, London (1956).
28. PRICE, R. The autocorrelogram of a complete carrier wave received over the ionosphere at oblique incidence. *Proc. IRE* **45** (1957).

29. Rice, S.O. Distribution of the duration of fades in radio transmission: Gaussian noise model. *Bell System Tech. J.* **37**, 581 (1958).
30. Chaman Lal. Flutter fading of short-wave radio signals in equatorial regions and its connection with spread echoes, magnetic storms and the radiation belt. *J. Inst. Telecom. Engr. (India)*, **6**, 223-230 (1960).
31. Osborne, B.W. Note on ionospheric conditions which may affect tropical broadcasting after sunset. *J. Brit. I.R.E.* **12**, 110 (1952).
32. Yeh, K.C. and Villard, O.G. A new type of fading observable on high-frequency radio transmission propagated over paths crossing the magnetic equator. *Proc. IRE* **46**, 1968-1970 (December, 1958).
33. Bennington, T.W. Equatorial ionospheric effects. *Wireless World*, **66**, 501 (1960).
34. Koster, J.R. Some measurements on the sunset fading effect. *J. Geophys. Res.*, **68**, 2571-2578 (1963).
35. Humby, A.M. Equatorial sunset effect. *Wireless World*, **65**, 342 (August, 1959).
36. Davies, K. and Barghausen, A.F. The effect of spread F on the propagation of radio waves near the equator. *AGARD Ninth Meeting of the Ionospheric Research Committee*, Copenhagen, (August, 1964).
37. Grosskopf, J. Feldstärkemessungen im Kurzwellenbereich, I Teil. (Field strength measurements in the short-wave band, Part I.) *FTZ*, **8**, 114 (1955).
38. Grosskopf, J. Feldstärkemessungen im Kurzwellenbereich, II Teil. (Field strength measurements in the short-wave band, Part II). *FTZ*, **8**, 146 (1955).
39. Beverage, H.H. and Peterson, H.O. Diversity receiving system of RCA Communications, Inc., for radiotelegraphy. *Proc. IRE* **19**, 531-584 (April, 1931).
40. Briggs, B.H., Phillips, G.J. and Shinn, D.H. The analysis of observations on spaced receivers of the fading of radio signals. *Proc. Phys. Soc. B.*, **63**, 106-121 (1950).
41. Booker, H.G., Ratcliffe, J.A. and Shinn, D.H. Diffractions from an irregular screen with applications to ionospheric problems. *Phil. Trans. Roy. Soc. (London)* Series A, **242**, 579 (September, 1950).
42. Glazer, J. and Faber, L. Evaluation of polarization diversity performance. *Proc. IRE* **41**, 1774-1778 (December, 1953).
43. Grisdale, G.L., Morris, J.G. and Palmer, D.S. Fading of long distance radio signals and a comparison of space- and polarization-diversity in the 6-18 Mc/s range. *Proc. I.E.E.*, **104B**, **13**, 39 (1957).
44. Brennan, D.G. The extrapolation and interpolation of spatial correlation functions. Statistical methods in radio wave propagation. W.C. Hoffman, ed., 296-305, Pergamon Press (1960).
45. Ames, J.W. Spatial properties of amplitude fading of continuous 17 Mc/s radio waves. *Radio Science*, Vol. 68D, **12**, 1309-1318 (December, 1964).
46. Bramley, E.N. Diversity effects in spaced-aerial reception of ionospheric waves. *Proc. I.E.E.* **98**, Part III, 19 (1951).
47. Khmelnitzky, E.A. Diversity reception and assessment of its effectiveness. Moscow, *Sviazizdat* (1960).
48. Van Wambeck, S.H. and Ross, A.H. Diversity reception systems. *Proc. IRE* **39**, 256 (1951).
49. Heidester, R. and Henze, E. Empfangsverbesserung durch Diversity-Betrieb. (Improvement of reception by means of diversity operation). *A.E.Ü.* **10** (1956).
50. Aisenberg, G.S. Short-wave antennae. Moscow, *Sviazizdat* (1962).
51. Grosskopf, J., Scholz, M. and Vogt, K. Korrelationsmessungen im Kurzwellenbereich. (Correlation measurements in HF band). *NTZ*, **11**, 2, 911 (1958).
52. Hayden, E.C. Propagation studies using direction-finding techniques. *J. of Res. of NBS, D. Radio Propagation*, Vol. 65D, **3**, 197-212 (May-June, 1961).
53. Brennan, D.G. and Phillips, M.L. Phase and amplitude variability in medium frequency ionospheric transmission. Lincoln Lab., M.I.T., TR-93 (1957).
54. Bowhill, S.A. Ionospheric irregularities causing random fading of very low frequencies. *J. Atmos. Terres. Phys.* **11**, 91-101 (1957).
55. Zadeh, L.A. and Desoer, C.A. Linear system theory. McGraw-Hill, New York (1963).
56. Bello, P.A. Measurement of the complex time-frequency channel correlation function. *J. Res. NBS* Vol. 68D, 1161-1165 (October, 1964).
57. Bello, P.A. Characterisation of randomly time-variant linear channels. *Trans. IEEE* Vol. CS-11, 360-393 (December, 1963).
58. Green, P.E., Jr. Time-varying channels with delay spread. Monograph on Radio Waves and Circuits, (ed. S. Silver), Elsevier, London (1963).

REPORT 322

REVISION OF ATMOSPHERIC RADIO-NOISE DATA

(1963)

This Report, which replaces Report 65, was adopted by correspondence and has been published separately.

REPORT 340

C.C.I.R. ATLAS OF IONOSPHERIC CHARACTERISTICS

(1966)

This Report, which was adopted unanimously, has been published separately.

REPORT 341 *

HF PROPAGATION BY DUCTING ABOVE THE MAXIMUM OF THE F-REGION

(Question 5/VI)

(1966)

1. Existence of HF propagation by ducting along field-aligned ionization

High-frequency propagation along ionization irregularities aligned with the earth's magnetic field was suggested by Obayashi [1] in 1959. This phenomenon has been observed experimentally both from the ground and with satellite observations.

In the case of ground observations, an explanation of long-delay echoes in HF radar was sought in guided propagation with reflection at the magnetic conjugate point [2, 3]. However, these results left some doubt as to whether the propagation was really by ducting or whether it was ionospheric propagation round the Earth. More recent results have been obtained by the measurement of HF propagation time between conjugate areas of France and South Africa [4], which seem to confirm the existence of propagation by ducting.

---

* This Report was adopted unanimously.

Rocket observations were likewise interpreted in terms of propagation by ducting [5], before satellite observations brought more extensive confirmation. References [6, 7] in fact explain some long-delay echoes observed by the satellite ALOUETTE 1 (1962 Alpha-Beta 1) as being due to guided propagation, while Calvert [8] was able to do the same for certain abnormal traces observed by the satellite EXPLORER 20 (1964-51 A.) Initial studies of the spatial and temporal occurrence of this mode of propagation were presented in [9 and 10] for ALOUETTE 1 and in [8] for EXPLORER 20.

The theory of HF guidance by field-aligned ionization irregularities was developed by several authors [6, 11, 12, 13]. The requisite conditions for such guidance depend upon the size of the irregularity, the gradient of the electron density in the irregularity and upon the curvature of the line of force.

2. Importance of HF propagation by ducting

According to the results obtained so far, field-aligned irregularities exist a fair percentage of the time at least at medium and low latitudes, with a few per cent increase in electron density over the background density and with a half thickness of a few kilometres.

Presently, it is not possible to determine the effect of such structures, but this mode of propagation could play a part in limiting the reliability of conventional communication. Based on the analyses of the ALOUETTE 1 data, it appears that HF propagation along field-aligned ionization is limited to frequencies usually less than 4 MHz.

Such prospects are sufficient justification for further studies to increase the information on this phenomenon. It would be interesting to study this phenomenon using a sweep-frequency oblique incidence experiment with terminals located at magnetic conjugate points.

BIBLIOGRAPHY

1. OBAYASHI, T. A possibility of long distance HF propagation along exospheric field-aligned ionization. *Rept. Iono, Sp. Res.* Japan, **13**, 177-186 (1959).
2. GALLET, R. and UTLAUT, W.F. Evidence of the laminar nature of the exosphere obtained by means of guided HF wave propagation. *Phys. Rev. Letters*, **6**, 591-594 (1961).
3. du CASTEL, F. Experimental research on geomagnetic HF guidance. *Ann. Telec.*, **18** (9-10), 177-184 (1963).
4. du CASTEL, F. Experimental evidence of geomagnetic HF guidance. *C.R. Ac. Sc. Paris,* **261** (10), 1057-1060 (1965).
5. CALVERT W., KNECHT, R.W., van ZANDT, T.E. and GOE, G.B. Evidence for field-aligned ionization irregularities between 400 and 1000 km above the earth surface. 324-329 in: The ionosphere, Ratcliffe ed., Inst. Phys. and Phys. Soc. London, (1962).
6. MULDREW, D.B. Radio propagation along magnetic field-aligned sheets of ionization observed by the Alouette topside sounder. *J. Geophys. Res.*, **68**, 5355-5370 (1963).
7. du CASTEL, F. Concerning certain guided echoes recorded by satellite ionospheric soundings. 216-228 in: Space Research V, P. Muller ed., North Holl. Pub. (1965).
8. CALVERT, W. Early results from the fixed frequency topside sounder satellite. Due to appear in: Electron density distribution in the ionosphere and exosphere. Proc. Nato Adv. Stud. Inst., Finse, Norway (April, 1965).
9. KING, J.W., SMITH, P.A., ECCLES, D., FOOKS, G.F. and HELM, H. Preliminary investigation of the structure of the upper ionosphere by the topside sounder satellite Alouette. *Proc. Roy. Soc.*, **A 281**, 464-487 (1964).
10. CALVERT, W. and SCHMID, C.W. Spread-F observations by the Alouette topside sounder satellite. *J. Geophys. Res.*, **69** (4), 1839-1852 (1964).

11. Voge, J. Guided propagation along an atmospheric or exospheric sheet. *Ann. Telec.*, **16**, (11-12), 288-295 (1961) and **17** (1-2), 34-43 (1962).

12. Booker, J. Guidance of radio and hydromagnetic waves in the magnetosphere. *J. Geophys. Res.*, **67** (11), 4135-4162 (1962).

13. du Castel, F. Project for the observation by satellite of field-aligned ionization irregularities in the magnetosphere. *Plan. Sp. Sci.*, **13**, 1255-1271 (1965).

REPORT 342 *

RADIO NOISE WITHIN AND ABOVE THE IONOSPHERE

(Question 7/VI)

(1966)

1. Introduction

The noise levels observable at a high-altitude satellite depend upon the variation of radiation resistance and the effective angular aperture of the antennae, due to the ionosphere surrounding the satellite, as well as upon the variation of noise-power over the sky. The effects of the ionosphere must be considered in estimating the true noise level.

2. Cosmic noise

The first successful observations of cosmic noise from an earth satellite were obtained with a 3·8 MHz receiver in " Transit 2A " (1960 Eta 1) [1] at an altitude of near 1000 km. For the observation period, 25-27 June 1960, there was no significant variation in cosmic noise from night to day or with latitude in the northern hemisphere. Equivalent linearly polarized free-space average noise levels were of the order of 0·7 μV/m, for a noise bandwidth of 40 kHz. Noise levels observed over Woomera, Australia, were abnormally high and as yet are unexplained.

Cosmic noise has been recorded regularly from the Alouette 1 satellite (1962 Beta-Alpha 1) since October 1962 at near 1000 km altitude in a range from near 1 MHz to 11 MHz. It has been found that all regions of the galaxy indicate a curve of apparent brightness temperature versus frequency with slopes —1·3 at 1·5 MHz, —1·7 at 2·3 MHz and 2·2 at 5 MHz [2]. It should be noted that Alouette 1 was not specially designed for these measurements. In particular, the response of the antenna matching arrangement necessary for ionospheric probes depends very much on the frequency. The influence of these circuits could not be eliminated above 5 MHz. The level of natural noise has been measured by rocket experiments carried out by Walsh and others (3] in 1963, at frequencies 0·75 MHz, 1·22 MHz and 2·2 MHz up to an altitude of 1690 km, later by Huguenin and others [4] at 0·7 MHz and 2 MHz with a rocket which reached an altitude of 11 600 km in the neighbourhood of the earth's equator, and by Alexander and Stone [5] between 1·9 MHz and 4·7 MHz.

Measurements were carried out by Smith and Hugill [6] between 1 and 4 MHz on satellite Ariel 2 (1964-15A) and the methods of data reduction have been discussed by Harvey [7].

---

* This Report was adopted unanimously.

Other measurements have been made by Benediktov and others [8] between 0·7 and 2·3 MHz on satellite ELEKTRON 2 (1964-6B) and ELEKTRON 4 (1964-38B) whose apogee is at 70 000 km, in addition by Slish [9] at 210 kHz and 2200 kHz on the space probe SONDE 2 (1964-78C), up to a distance of 8 earth radii.

The results obtained from these different measurements are summarized in Fig. 1.

3. Solar noise

The analysis of solar radiation shows that the emissions accompanying the eruptions and long duration noise storms can reach a level of more than 10^{-18} W m^{-2} Hz^{-1} in the frequency band from 1 to 10 MHz and correspond to emanations from sources at distances varying from 15 to 2 solar radii respectively [10].

4. Noise of terrestrial origin

Interference from terrestrial HF transmitters is received at the satellite, due to breakthrough of radio-waves at frequencies above the ionospheric critical frequency. The critical frequency can sometimes be lower than 3·8 MHz according to observations in satellite transit 2 A [11]. Since the interference is a function of the critical frequency, it is observed more often at night and at high latitudes [12]. However, it is also closely related to the distribution and operation of HF transmitters around the Earth. Information is being accumulated from observations in ALOUETTE 1, on the relative interference over various parts of the Earth.

Huguenin [13] has launched several receivers on frequencies close to the maximum critical frequency of the F2 layer, on board a satellites revolving between 300 and 500 km. He was able to note how terrestrial emissions passed through the ionosphere in many cases. More recently, Horner [14] studied the level produced by terrestrial storms above ionosphere, and Rawer [15] has proposed values for terrestrial noise of different origins, as a function of frequency and the region under consideration.

5. Ionospheric noise

A VLF receiver is included in the ALOUETTE 1 satellite, which is providing regular data in the range 400 Hz to 40 kHz. Besides noise bands which do not vary, or vary sporadically with the position of the spacecraft [16], noise bands are received, on occasion, which show a systematic variation with position of the spacecraft in the geomagnetic field [17]. These observations indicate that these noise bands are generated in the vicinity of the satellite. The lower edge of the noise band varies from near 3 kHz to 12 kHz and is being investigated as a source of information on mean ionic mass at the height of the satellite [18].

Most of the experiments carried out with rockets and satellites have consisted in the measurement of noise levels that are considered to be abnormal, the explanation of which is still vague. It seems possible to divide these cases into two categories:

- when the antenna is plunged into the ionospheric plasma and operates at frequencies such that infinite indices of refraction exist for certain propagation directions, its operation can no longer be dealt with theoretically. A very high noise e.m.f. is then recorded, antenna impedance being likewise very disturbed [3, 4, 5, 7];
- even when the antenna can be considered to be operating " normally " in the medium, sporadic emission on frequencies distant from the ionosphere resonance frequencies is observed. This seems to be the case for the measurements by Huguenin and others on 0·7 MHz [4], but especially for those by Benediktov and others [8]. These last-mentioned authors have observed levels 10 to 20 dB higher than galactic noise, with large variations in time and space, at altitudes at which the medium could not appreciably interfere with antenna operation. Some of these variations show the same symmetry as the geomagnetic field and seem to be correlated with the flux of particles possessing an energy of more than 100 eV.

Bibliography

1. Molozzi, A.R., Franklin, C.A. and Tyas, J.P.I. Cosmic noise measurements from Satellite 1960 η1 at 3·8 Mc/s. *Nature*, **190**, 616-617 (1961).

2. Hartz, T.R. Observations of the galactic radio emission between 1·5 and 10 Mc/s from the Alouette satellite. *Annales d'Astrophysique* **27**, 823 (1964).

3. Walsh, D., Haddock, F.T., and Shulte, H.F. Cosmic radio intensities at 1·225 and 2·0 Mc/s measured up to an altitude of 1700 km. *Space Research IV* (Ed. P. Muller, North Holland Publishing Co., 935-959 1964).

4. Huguenin, G.R., Lilley, A.E., McDonough, W.H., and Papagiannis, M.O. Measurements of radio noise at 0·7 and 2·0 Mc/s from a high altitude rocket probe. *Plan. Space Sc.* **12**, 1157-1167 (1964).

5. Alexander, J.K. and Stone, R.G. Rocket measurements of cosmic noise intensities below 5 Mc/s NASA Goddard Space Flight Center Documents No. X 615-65-185-1965.

6. Smith, F.G. and Hugill, J. Cosmic radio noise measurements from satellite Ariel II. Part 1 Receiving system and preliminary results. M.N. 131, 137, 143 (1965) Part II. Analysis of observed sky brightness, M.N. 131, 145, 153 (1965).

7. Harvey, C.C. Results from the U.K. II Satellite. *Ann. d'Astr.* **28**, (1965) and I.A.U. Symposium No.23 (Liège, 1964) on Astronomical Observation from space vehicles (Ed. J.L. Steinberg, C.N.R.S. Paris, 1965).

8. Benediktov, E.A., Gemantsev, G.G., Mitkakov, N.A., Rapoport, V.O.W., Sazonov, J.A., and Tarasov, A.F. Intensity measurements of radiation at frequencies 725 and 1525 kHz by means of receivers on the satellite Electron 2. Communication to 6th COSPAR Symposium on Space Sciences (Buenos Aires, 1965), due to appear in *Space Research VI.* See also the complete article by the same authors in *Cosmic Space Research* (Federal Conference on the Physics of Cosmic Space, Moscow) (10-16 June 1965) (in Russian).

9. Slish, V.E. The measurement of cosmic radiation on frequencies 210 and 2200 kHz at heights to 8 earth radii on Sonde 2 (in Russian). *J. of Cosmic Research* (U.S.S.R.) **3**, 760-767 (1965).

10. Hartz, T.R. Solar noise observations from the Alouette Satellite. *Annales d'Astrophysique*, **27**, 831 (1964).

11. Atkins, E.A., and Chapman, J.H. Satellite measurements of radio break-through, *Can. J. Phys.* **41**, 1388 (1963).

12. Nelms, G.L., Ionospheric results from the topside sounder satellite in Alouette, in *Space Research IV* (ed. P. Muller), 437, North Holland Pub. Co., Amsterdam (1964).

13. Huguenin, G.R., Long wavelength radioastronomy in space (Thesis) Harvard College Observatory, Cambridge (Mass.) U.S.A.

14. Horner, F. Radio noise in space originating in natural terrestrial sources. *Plan. and Space Science*, **13**, 1137-1150 (1965).

15. Rawer, K. Noise produced by terrestrial sources in the near—Earth space. 10th Symposium of the Agard Ionospheric Research Committee (Rome, Sept. 1965), due to appear in: Propagation factors in space communications, Agardograph, Ed. W.T. Blackband.

16. Barrington, R.E. and Belrose, J.S. Preliminary results from the very low frequency receiver aboard Canada's Alouette Satellite. *Nature*, **198**, 651-656 (1963).

17. Barrington, R.E., Belrose, J.S. and Keeley, D.A. Very low frequency noise bands observed by Alouette 1 Satellite. *J. Geophys. Res.*, **68**, 6539-6541 (1964).

18. Barrington, R.E., Belrose, J.S. and Nelms, G.L. Ion composition and temperatures at 1000 km as deduced from simultaneous observations of a VLF plasma resonance and topside sounding data from the Alouette 1 Satellite. *J. Geophys. Res.*, **70**, 1647-1664 (1965).

19. Smith, F.G. Low-frequency radioastronomical observations from rockets and satellites. *Ann. d'Astr.* **27**, 819 (1964) and I.A.U. Symposium No. 23, Liège (August, 1964) on Astronomical observations from space vehicles (Ed. J.L. Steinberg, C.N.R.S., Paris, 1965).

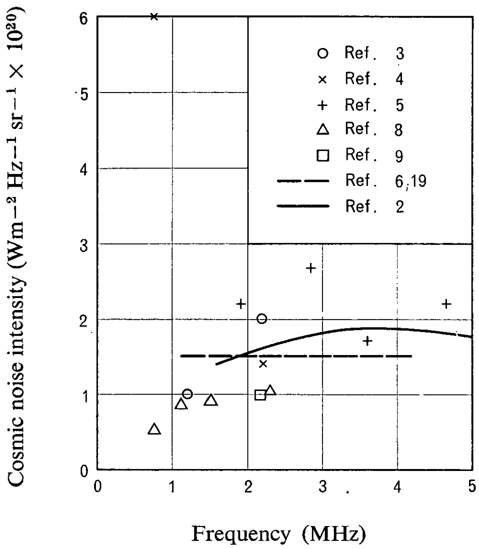

Cosmic noise intensity (Wm^{-2} Hz^{-1} sr^{-1} × 10^{20})
0
1
2
3
4
5
6
0
1
2
3
4
5
Frequency (MHz)
○ Ref. 3
× Ref. 4
+ Ref. 5
△ Ref. 8
□ Ref. 9
— — Ref. 6,19
—— Ref. 2

Figure 1

REPORT 343

SPECIAL PROBLEMS OF HF RADIOCOMMUNICATION ASSOCIATED WITH THE EQUATORIAL IONOSPHERE

(Question 6/VI)

(1966)

1. Introduction

The equatorial ionosphere differs from that at temperate latitudes in three respects:

— the daytime F region is very thick; its peak density may be at a height of 400-500 km; it has a very great electron density with a minimum at the magnetic equator and two maxima, one on each side.

— the night-time F region often gives " spread type " echoes due to an irregular structure;

— a particular type of Es layer, known as the " *q* type ", appears almost regularly during the day.

Each of these phenomena causes propagation features peculiar to equatorial HF propagation.

It should be noted that all the above-mentioned phenomena are controlled by the magnetic dip such that they are not " low-latitude " but " low-dip " phenomena. Though the well-known (ionized) layers and rather regular diurnal variations are found, the dip equator thus appears as a singularity for HF propagation. Therefore, propagation conditions along and transverse to the magnetic dip equator can be largely different. This phenomenon is confined to the equatorial area and it has a major influence on the normal diurnal propagation features [1].

The characteristic differences in absorption, reflection heights and critical frequencies observed between equatorial and temperate latitudes have been studied by Piggott [2]. Some typical propagation problems are discussed in the following.

2. Regular F-layer reflections

The daytime equatorial anomaly is characterized by a shift during the day of the locations of the two maxima of the critical frequency to latitudes corresponding approximately to magnetic dip values of ± 30°, with a minimum between them near to the magnetic dip equator. Also, the height of the F-region increases by at least 100 km in a rather narrow belt round the dip equator, say a distance of 10° in latitude. Therefore, steep horizontal gradients of ionization exist such that the form of the reflected rays is often asymmetric and deviations from great-circle propagation appear systematically for certain hours and directions. By the combined influence of the northern and southern gradient, two-hop propagation paths without intermediate ground reflection seems to be possible. Villard *et al* [3] observed echoes on backscatter recordings with a range of 7000 to 10 000 km, which were interpreted in this way.

The high electron density and the great height of the ionization peak makes the propagation conditions very variable, dependent on the site of stations with respect to the dip equator and on the direction. Fulton *et al* [4] and Muldrew and Maliphant [5] have shown that one-hop propagation paths in excess of 10 000 km may appear in equatorial regions.

A comparison of the observed classical MUF (JF) and predicted standard MUF (EJF) indicates considerable discrepancies. For transmission paths normal to the magnetic dip equator, the mean ratio of predicted MUF/classical MUF (EJF/JF) is approximately 0·85. For propagation paths parallel to the magnetic dip equator, this mean ratio is approximately 1·04. Oblique soundings show that greater extensions above the observed classical MUF (JF) are present on north-south paths than on east-west paths during daylight hours.

Bottomside contours of electron density near the equator have been given by Wright [6] on the basis of observations by A.C.I. stations. Vila [7] has published in the form of a latitude/local time diagram, maximum density contours of the F layer above the African equatorial region, for two equinox and solstice periods during a low sunspot period, based on airborne sounder observations. Topside contours have been plotted by Lockwood and Nelms [8] using the data obtained with topside sounder ALOUETTE. King [9], also using the Alouette's topside soundings, could show that the anomaly consists mainly in the upper ionosphere, in an arc of heavier ionization along a certain magnetic field-line which is transferred to higher field-lines in the afternoon.

Various interpretations of the F-region equatorial anomaly have been proposed [7, 10, 11, 12, 13, 14].

3. Equatorial F-scattering

In the latitudes affected by the equatorial anomaly, the behaviour of the F region becomes irregular in the evening, this being reflected in oblique propagation.

This phenomenon, which is generally known as "equatorial spread-F", occurs mainly in a belt of ± 15° around the magnetic dip equator. It was originally reported by Booker and Wells [15], and was subsequently studied by Osborne [16], Bibl [17], Lyon *et al* [18] by means of vertical soundings, and from HF scatter broadcast transmissions [19], by Yeh and Villard [20] on a trans-equatorial path, by Humby [21] and Bennington [1] on very long-distance links crossing the equatorial region, by Chaman Lal [22] on paths in India, by Davies and Barghausen [23] using oblique soundings, by Kent and Koster [24] who observed signal flutter from satellites. A survey of the methods of observing this phenomenon and of the experimental results was recently made by Clemesha and Wright [25].

There are various ways of studying the effects of equatorial F-scattering:

- examination of the amplitude variations of signals transmitted simultaneously on two frequencies;
- spectral frequency studies of the Doppler frequency changes induced by ionospheric irregularities;
- oblique soundings;
- vertical soundings;
- topside soundings from satellite.

The behaviour of the scattering phenomena is described as follows:

- — the phenomenon is more pronounced on magnetically quiet days than on disturbed days Lyon *et al* [18]; Davies and Barghausen [23];
- — at the minimum of the sunspot cycle it has pronounced maxima in occurrence and severity during the equinox periods (60% of the days) and a minimum during the solstice periods (10%) [23];
- — the height change of the F-layer seems to be correlated with the duration of the scattering phenomena;
- — the scattering phenomena mostly affect propagation at the lower frequencies;
- — the mean commencement time is 20 hours (LMT) and the mean duration is 3 hours;
- — the scattering phenomena occur less frequently during the minimum sunspot periods.

Evening scatter offers advantages and disadvantages for radiocommunication. Communications are possible at frequencies above the predicted standard MUF (EJF). On the other hand, scatter may be a source of interference. Long-term observations (one or more years) show higher transmission losses during the equinox periods for paths parallel to the magnetic dip equator and greater variability in the hourly median values when compared to similar paths in middle latitudes.

The equatorial flutter fading associated with F-layer scatter is due to the presence and movement of ionospheric irregularities. The phenomenon has been studied by Booker and Wells [15] and by Pittaway and Cohen [26]. The structure of these irregularities has been studied by means of sounder satellite observations (Calvert [27], Lockwood and Petrie [28]) and on the basis of incoherent scatter soundings (Cohen and Bowles [29]). The irregularities are thought to be aligned in relatively long thin columns, parallel to the earth's magnetic field, which move from west to east.

During the scattering conditions particular fading characteristics occur for HF transmissions [1, 17, 19, 23, 30, 31, 32]. The fading rate of the amplitude variations of the detected carrier envelope on frequencies near 10·1 and 20·2 MHz is approximately 0·7 Hz and 0·1 Hz respectively [23]. Consistently, the lower carrier frequency exhibited a fading rate five to seven times above that simultaneously observed on the higher frequency.

Spectral frequency analysis [31] of the Doppler shifts induced by ionospheric irregularities exhibit frequency changes of the order of 20 to 30 Hz for carrier frequencies of 10·1 and 20·2 MHz. The average value of the frequency spreading is of the order of 5 to 10 Hz. The frequency disturbance is first exhibited on the lower carrier by as much as one half to one hour prior to the higher carrier frequency. On magnetically disturbed days little evidence of frequency spreading exists. Paths parallel to the magnetic dip equator show less frequency spreading than those paths across or perpendicular to it [19].

4. Equatorial (q-type) sporadic-E

In a narrow zone around the magnetic dip equator a special type of sporadic-E appears regularly during daylight hours [33]. The width of this zone is about ± 6° in dip or ± 3° in latitude, thus very narrow compared with the F-region anomaly. While the q-type ionization is observed at almost all daytime hours, it disappears during the night. Type-2 sporadic-E is highly transparent and reaches high top-frequencies; values regularly around 10 MHz are observed at places near to the dip equator.

The structural characteristics of equatorial sporadic-E have been described by Bowles *et al* [34] on the basis of observations by the incoherent-scatter sounder of Jicamarca (Peru). The ionization of this type of sporadic-E has irregular structure aligned with the magnetic field.

It would appear that the origin of these irregularities is associated with the equatorial electrojet [35]. A theory about plasma instability phenomena, which could account for the formation of the equatorial sporadic-E layer, has been proposed by Farley [36] and by Waldteufel [37].

Propagation in the equatorial belt is highly influenced by q-type sporadic-E. The reflection properties of the q-type depend on the direction of propagation. Side-scatter may also appear. Moreover, it seems that a true classical MUF (JF) is not likely to be found for the q-type, the reflection coefficient may be expected to decrease with increasing frequency until the operational MUF is reached.

Further studies relating to the problems of HF-communications in the equatorial zone are highly desirable.

BIBLIOGRAPHY

1. Bennington, T.W. Equatorial ionospheric effects. *Wireless World*, **66**, 501 (1960).
2. Piggott, W.R. The calculation of the median sky wave field strength in tropical regions. Department of Scientific and Industrial Research, Special Report No. 27, Her Majesty's Stationery Office, London (1959).
3. Villard, O.G. Jr., Stein, S. and Yeh, R.C. Studies of transequatorial ionospheric propagation by the scatter-sounder method, *J. Geophys. Res.*, **62**, 413 (1957).
4. Fulton, B., Sandoz, O. and Warren, E. The lower frequency limits for F-layer radio propagation. *J. Geophys. Res.*, **65**, 177 (1960).
5. Muldrew, D.B. and Maliphant, R.G. Long-distance one-hop ionospheric radio-wave propagation. *J. Geophys. Res.*, **67**, 1805-1815 (1962).
6. Wright, J.W. A model of the F-region above $h_{max}F2$. *J. Geophys. Res.*, **65**, 185-191 (1960).
7. Vila, P. Experimental study of the equatorial ionospheric anomaly in Africa at sunspot minimum. Due to appear in *Annales de Géophysique* (1966).
8. Lockwood, G.E.K. and Nelms, G.L. Topside sounder observation of the equatorial anomaly at 75°W longitude. *J. Atmos. Terr. Phys.*, **26**, 569-580 (1964).
9. King, J.W., Smith, P.A., Eccles, D., Fooks, G.F. and Helm, H. Preliminary investigation of the structure of the upper ionosphere as observed by the top side sounder satellite Alouette. *Proc. Roy. Soc.*, **A 281**, 464-487 (1964).
10. Duncan, R.A. The equatorial F-region of the ionosphere. *J. Atmos. Terr. Phys.*, **18**, 89 (1960)
11. Rishbeth, H., Lyon, A.J. and Peart, M. Diffusion in the equatorial F-layer. *J. Geophys. Res.*, **68**, 2559-2569 (1963).
12. Bramley, E.N. and Peart, M. Diffusion and electromagnetic drift in the equatorial F_2-region. *J. Geophys. Res.*, **69**, 4609 (1964).
13. Chandra, S. and Goldberg, R.A. Geomagnetic control of diffusion in the upper atmosphere. *J. Geophys. Res.*, **69**, 3187-3197 (1964).
14. King, J.W. and Kohl, H. Upper atmospheric winds and ionospheric drifts caused by neutral air pressure gradients. *Nature*, London, **206** (4985), 699-701 (1965).
15. Booker, H.G. and Wells, H.W. Scattering of radio waves by the F region of the ionosphere. *Terrest. Magnetism and Atmospheric Elec.*, **43**, 249-256 (1938).
16. Osborne, B.W. Ionospheric behaviour in the F2-region at Singapore. *J. Atmos. Terr. Phys.* **2**, 66-78 (1951).

17. Bibl, K. Equatorial F-layer ionization movements, seasonal dependence of movements and turbulence phenomena. Agard — 9th meeting of the Ionospheric Research Committee, Copenhagen (August, 1964).

18. Lyon, A.J., Skinner, N.J. and Wright, R.W. Equatorial spread-F at Ibadan, Nigeria. *J. Atmos. Terr. Phys.*, **21**, 100-119 (1961).

19. Osborne, B.W. Note on ionospheric condition which may affect tropical broadcasting after sunset. *J. British IRE*, **12**, 110 (1952).

20. Yeh, G.C. and Villard, O.G. A new type of fading observable on high-frequency radio transmission propagated over paths crossing the magnetic equator. *Proc. IRE*, **46**, 1968-1970 (1958).

21. Humby, A.M. Equatorial sunset effect. *Wireless World*, **65**, 342 (1959).

22. Chaman Lal. Flutter fading of short-wave radio signals in equatorial regions and its connection with spread echoes, magnetic storms and the radiation belt. *J. Inst. Telecomm. Eng.* **6** (5), 223-231 (1960).

23. Davies, K. and Barghausen, A.F. The effect of spread-F on the propagation of radio waves near the equator. Agard — 9th meeting of the Ionospheric Research Committee, Copenhagen (August, 1964).

24. Kent, G.S. and Koster, J.R. Some studies of night-time F-layer irregularities at the equator using very high frequency signals radiated from earth satellites. Agard — 9th meeting of the Ionospheric Research Committee, Copenhagen (August, 1964).

25. Clemesha, B.R. and Wright, R.H.W. A survey of equatorial spead F. Agard — 9th meeting of the Ionospheric Research Committee, Copenhagen (August, 1964).

26. Pittaway, M.L. and Cohen, R. A wave guide interpretation of temperate-latitude spread F on equatorial ionograms. *J. Geophys. Res.*, **66** (10), 3141-3156 (1961).

27. Calvert, W. Instability of the equatorial F layer after sunset. *J. Geophys. Res.*, **68**, 2591-2593 (1963).

28. Lockwood, G. and Petrie, L. Low latitude field aligned ionization observed by the Alouette topside sounder. *Planetary and Space Science* **11**, 327 (1963).

29. Cohen, R. and Bowles, K.L. On the nature of equatorial spread F. *J. Geophys. Res.*, **66**, 1081-1106 (1961).

30. Koster, J.R. Some measurements on the sunset fading effect. *J. Geophys. Res.*, **68**, 2571-2578 (1963).

31. Barghausen, A.F., Jacobs, G. and Lillie, D.A. HF propagation characteristics in equatorial latitudes. 1963 PTGAP International Symposium on Space Telecommunications, Boulder, Colorado, 37-41 (July, 1963).

32. Lawrence, R.S., Little, C.G. and Chivers, H.J.A. A survey of ionospheric effects upon earth-space radio propagation. *Proc. IRE*, **52** (1), 4-27 (1964).

33. Matsushita, S., Knecht, R.W. and McDuffie, R.E. Ionospheric sporadic E. Smith E.K., ed., Oxford (Pergamon) 194-218 (1962).

34. Bowles, K.L., Balsley, B.B. and Cohen, R. Field aligned E region irregularities identified with acoustic plasma waves. *J. Geophys. Res.*, **68** (9), 2485-2502 (1963).

35. Mayaud, P.N. Morphological analysis of the day-to-day variability in the " regular " daily variation S_R of the earth's magnetic field. *Ann. Geophys.*, **21** (3), 369-401 (1965).

36. Farley, D.T. A plasma instability resulting in field-aligned irregularities in the ionosphere. *J. Geophys. Res.* **68**, 6083 (1963).

37. Waldteufel, P. Study of the instability associated with the equatorial sporadic E layer. *Ann. Geophys.* **21** (4), 579-604 (1965).

REPORT 344 *

PREDICTION OF SPORADIC-E IN TEMPERATE LATITUDES

(Study Programme 4A/VI)

(1966)

1. Physical understanding of sporadic-E

Understanding the physical processes in the ionosphere, which give rise to temperate latitude sporadic-E, is an important first step in the prediction of sporadic-E.

1.1 *Structure of sporadic-E* [1]

Many direct measurements by means of rockets are now available which show sporadic-E to exist in the form of thin layers with a thickness around 1 km and an electron density many times that of the ambient E-region value.

Ground-based VHF measurements indicate that both specular and scatter propagation can take place from the E_s layer. Miya [2], for example, has categorized sporadic-E reflections observed on VHF oblique incidence circuits in the Far East in terms of a parameter Γ, effectively the reflection coefficient (apparent loss in decibels) of the layer, as follows:

$\Gamma \leqslant 45$ dB: specular reflections from sporadic-E (appears like a layer reflection);

45 dB $< \Gamma <$ 70 dB: scattered reflections from E_s;

$\Gamma >$ 70 dB: sporadic-E masked by normal D-scatter.

1.2 *The cause of sporadic-E* [1]

An attractive explanation for the formation of sporadic-E at temperate latitudes is found in the wind-shear theory. According to this theory, an intensification in ionization over a very narrow height range can be achieved under appropriate conditions. Many attempts have been made to measure the wind vector, as a function of height, simultaneously with measurements of the vertical structure of the sporadic-E layer. Agreement of the observations with the predictions of the simple wind-shear theory have so far been only fair.

2. Forecasts of sporadic-E occurrence

No method currently exists which will forecast the occurrence of a sheet of sporadic-E. There are attractive prospects: for example, if a good connection between upper atmosphere winds and the occurrence and movement of sporadic-E can be found, then it may be possible to predict the occurrence of E_s from meteorological observations.

BIBLIOGRAPHY

1. Sporadic-E ionization. Special issue of *Radio Science*, S.A. Bowhill Ed., **1**, No. 2 (February, 1966).
2. MIYA, K., SASAKI, T. and ISHIKAWA, M. Observations of F-layer and sporadic-E scatter at VHF in the Far East. *J. Res. NBS*, **65D**, 93-99 (January-February, 1961).

---

* This Report was adopted unanimously.

STUDY GROUP VI

(Ionospheric propagation)

Terms of reference:

To study all matters relating to the propagation of radio waves (including noise) 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 concerns of the Study Group

Study Group VI is concerned with the acquisition and application of knowledge of ionospheric radio-wave propagation to telecommunication problems. Since the Study Group is not directly concerned with telecommunication systems, its main efforts are to codify experience and knowledge of the properties of the ionosphere and of background radio noise in forms that are as widely applicable as possible with respect to geographical position, season, time of day, and solar-terrestrial conditions. In addition, the Study Group takes active account of special features of ionospherically propagated radio waves. Finally, the Study Group proposes actions intended to foster the gathering of essential ionospheric and solar-terrestrial data in order that the basis for the needed predictions associated with ionospheric propagation can be maintained and improved.

2. Problems " already settled "

The topics indicated under this heading are not finally settled, but codified Reports have been prepared with practical users in mind. The information contained in these Reports represents the best information upon which the C.C.I.R. can agree at present, but revisions will clearly be required from time to time.

2.1 *C.C.I.R. Atlas of ionospheric characteristics*

The first edition of this monumental atlas, which makes it possible to predict EJF's (standard MUF's), is contained in Report 340, to be published separately. It represents the culmination of several years of work by an International Working Party of the Study Group, under the chairmanship of Dr. W.G. Baker (Australia). The Atlas is also available in the form of punched-cards, suited to user organisations having continuing and extensive needs of the information in the Atlas, and having access to modern computers. The Atlas charts may, however, be used by anyone and are especially suited to the needs of new and developing countries. Recommendation 434 endorses the use of the Atlas.

2.2 *Atmospheric radio noise*

Report 322, adopted by correspondence after the Xth Plenary Assembly, and published separately, makes it possible to estimate the limitations imposed on radiocommunications by the naturally occurring atmospheric radio noise. These limitations are particularly severe in many tropical regions, and are therefore of particular concern to a number of the new and developing countries. This Report and Recommendation 372, endorsing it for provisional use, have been maintained. However, a revision of Report 322 will probably be required within a few years, to take detailed account of such matters as:

- more recent observational material,
- directional characteristics of receiving antennae,
- variation with the solar cycle, especially insofar as long-distance propagation of atmospherics is concerned.

2.3 *Predictions of ionospheric field strength and propagation loss for the frequency range between 150 and 1500 kHz*

Under the Chairmanship of Mr. G. Millington (United Kingdom), a sub-group has prepared a revision of Report 264. The revised Report 264–1 represents the combination of the efforts of both the E.B.U. and the O.I.R.T. As such it is endorsed for provisional use within the European Broadcasting Area by Recommendation 435.

2.4 *Predictions of the LF and MF sky-wave field strengths for short distances in Africa*

As a special service for the African Broadcasting Conference, an International Working Party of the Study Group, under the Chairmanship of Mr. J.M. Dixon (Australia), prepared a report giving provisional predictions of short-distance sky-wave field strengths at LF and MF for equatorial Africa. This report was made available to the conference between the Xth and the XIth Plenary Assemblies of the C.C.I.R., and that action has now been endorsed by the XIth Plenary Assembly in Resolution 31, to which the report is attached as an Annex.

2.5 *Solar and ionospheric indices for use in connection with ionospheric propagation predictions*

There is now general agreement in the C.C.I.R., embodied in Recommendation 371, that three indices—two solar, R_{12} and Φ, and one ionospheric, I_{F2}, have the greatest relevance to ionospheric propagation predictions. Resolution 4–1 requests the Director, C.C.I.R., to collect the observational data necessary to determine the indices, and to calculate and publish them. The Resolution also calls upon organizations making the basic observations to continue to do so and to forward them to the Director, C.C.I.R. The matter of extrapolating the time series represented by the series of values of the indices is usually left to user organizations, although the C.C.I.R. Secretariat has made, and will probably continue to make, valuable studies of this aspect of prediction.

3. **Problems under " further study "**

It will be evident that the problems "already settled", described above, are not really so finally settled as to be incapable of further, and quite possibly significant improvement. The problems thus remain under continued review.

The Study Group has five International Working Parties that are now continued by Resolutions 7–1, 8–1, 10–1, 12–1 and 13–1 respectively. I.W.P. VI/2 will undertake a revision of Report 322 on atmospheric radio noise, as discussed earlier. I.W.P. VI/3 will eventually produce a revised edition of the C.C.I.R. Atlas of ionospheric characteristics, in the first instance probably only as replacement punched cards. Later, it is hoped, IWP VI/3 will take into account, in a practical manner, the fluctuations about the median values on the characteristics, and make some practical provision for Es and F1-layer predictions.

IWP VI/1, IWP VI/4, and IWP VI/5 still have much to do in the way of further study. Their respective terms of reference may be stated as follows:

— to produce a C.C.I.R. method for predicting HF sky-wave field strength or transmission loss, for any path, any time, for specified antennae, etc.,

— to produce a C.C.I.R. replacement for the Cairo curves of 1938 for LF and MF broadcasting that can be used anywhere in the world. As discussed above, partial results are available for the European Broadcasting Area, and for short distances in equatorial Africa,

— to produce C.C.I.R. propagation curves for frequencies below 150 kHz for world-wide use.

4. Problems of interest to new and developing countries

Certain problems under study, in addition to the topics already discussed, are of potential interest to new and developing countries.

4.1 *Propagation by way of sporadic-E and other anomalous ionization*

Question 4/VI has given rise to two Study Programmes on the subject of sporadic-E propagation. The outcome of such studies should be watched carefully by new and developing countries situated in low magnetic latitudes, where certain regular features of the sporadic-E region may offer useful possibilities for radiocommunication at both HF and VHF. Report 259-1 should also be noted relative to this problem.

4.2 *Special problems of HF radiocommunication associated with the equatorial ionosphere*

Question 6/VI and Report 343, with the above title, raise additional special problems associated with the equatorial ionosphere. Further developments in this subject should be watched by new and developing countries.

4.3 *Improvement in the world-wide ionospheric observing programme for numerical mapping purposes*

The problems raised by Study Programme 2A/VI, § 1, have special relevance to the territories of some new and developing countries, and deserve consideration by these countries. At the same time, note should be made of Opinion 22, which deals with routine ionospheric sounding, and Opinion 23, which is concerned with the continuance in operation of certain ionospheric and solar observing programmes, which have already been maintained continuously for many years, but which are still required, since the data they provide are used in connection with the solar and ionospheric indices adopted by the C.C.I.R.

OPINION 23

OBSERVATIONS NEEDED TO PROVIDE BASIC INDICES FOR IONOSPHERIC PROPAGATION

(1966)

The C.C.I.R.,

CONSIDERING

(a) that the ionospheric index I_{F2} is recommended as the index to be used for predicting monthly median values of foF2 for dates, certainly up to 6 months, and perhaps up to 12 months ahead of the date of the last observed value of I_{F2};

(b) that the monthly mean value of solar radio-noise flux at wavelengths near 10 cm Φ is recommended as the index to be used for predicting monthly median values of foE and foF1, for dates, certainly up to 6 months, and perhaps up to 12 months ahead of the date of the last observed value of Φ;

IS UNANIMOUSLY OF THE OPINION

1. that the following nine long-established ionospheric observing stations be encouraged to continue in operation for the production of the index I_{F2}:

Canberra
Churchill
College
Delhi
Godley Head
Huancayo
Slough
Tokyo
Washington *

2. that the National Research Council, Ottawa, Canada, should be encouraged to continue the 10·7 cm solar radio-noise flux-measurements necessary for determination of the index Φ.

---

* Also known as Fort Belvoir.

RESOLUTION 4–1

DISSEMINATION OF BASIC INDICES FOR IONOSPHERIC PROPAGATION

(1963 – 1966)

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};

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 and organizations which have had special experience in the prediction of ionospheric parameters or solar activity;

3. 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.

RESOLUTION 30

USE OF THE ELECTRONIC COMPUTER IN PREDICTING BASIC INDICES FOR IONOSPHERIC PROPAGATION

(1966)

The C.C.I.R.,

CONSIDERING

that the use of electronic computers in determining the correlation between the basic indices for ionospheric propagation, and to check ionospheric predictions, might improve the accuracy of the predictions;

UNANIMOUSLY DECIDES

that the C.C.I.R. Secretariat should be encouraged to use the I.T.U. electronic computer for the calculations required:

— to determine the correlations between basic indices for ionospheric propagation;
— to predict basic indices;
— to check ionospheric predictions in general.

QUESTION 1/VI *

CHOICE OF BASIC INDICES FOR IONOSPHERIC PROPAGATION

(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?

QUESTION 2/VI **

GEOGRAPHIC DISTRIBUTION AND PROGRAMME OF REGULAR IONOSPHERIC OBSERVATIONS

(1966)

The C.C.I.R.,

CONSIDERING

(a) that the earth is imperfectly covered with ground-based ionosondes from the viewpoint of numerical mapping and short-term synoptic studies, which are required for making better ionospheric propagation predictions;

---

* Formerly Question 247(VI).

** Formerly Question 313(VI).

(b) that topside sounders can be used to overcome some aspects of the present deficiencies;

(c) that the regular use of oblique-incidence sounders is increasing;

UNANIMOUSLY DECIDES that the following question should be studied:

what are the best world-wide ionospheric observing programmes for:

- long-term predictions,
- short-term synoptic studies?

STUDY PROGRAMME 2A/VI *

IMPROVEMENT IN THE WORLD-WIDE IONOSPHERIC OBSERVING PROGRAMME FOR NUMERICAL MAPPING PURPOSES

(1966)

The C.C.I.R.,

CONSIDERING

(a) that the present world-wide network of ground-based ionosondes, operating regularly and participating in the world-wide interchange of data, is far from ideal from the viewpoint of ionospheric propagation prediction;

(b) that it is possible that topside soundings and regular oblique-incidence ionospheric observations could be used in ionospheric numerical mapping;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the identification of geographical areas within which, for both long- and short-term predictions:
   - the installation of new fixed ionosondes would provide significant improvement;
   - the actual density of fixed ionosondes working on a routine basis appears to be satisfactory;
2. the practicability of incorporating in the work of numerical mapping ionospheric observations from:
   - topside sounders;
   - oblique-incidence sounders;

   when made on a regular basis.

Note. — The Director, C.C.I.R., is requested to transmit this text to the U.R.S.I., the C.I.G. and the I.Q.S.Y. Committees for comment.

---

* Formerly Study Programme 313A(VI).

QUESTION 3/VI *

SIDE-SCATTER DUE TO IONOSPHERIC IRREGULARITIES

(1965 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that large azimuthal deviations from the great-circle path have frequently been observed in radiocommunication;

(b) that these deviations appear to be due to lateral refraction and scattering from ionospheric irregularities, for example from field-aligned irregularities, or from strong lateral gradients of ionization in one or other of the ionospheric layers;

(c) that such phenomena may possibly be of use in extending the hours available for communication on certain circuits, provided that the antenna system is suitably designed, and may possibly affect the operational MUF (MUF);

UNANIMOUSLY DECIDES that the following question should be studied:

1. what is the frequency of occurrence of large deviations from the great-circle path in radiocommunications, in various regions of the world;
2. what are the underlying factors controlling such occurrences;
3. whether it is practicable to make use of such phenomena to extend periods available for communication, or to increase the operational MUF (MUF);
4. what considerations control the form of polar diagram of antennae intended to take advantage of this mode of communication?

QUESTION 4/VI **

PROPAGATION BY WAY OF SPORADIC-E AND OTHER ANOMALOUS IONIZATION

(1966)

The C.C.I.R.,

CONSIDERING

(a) that sporadic-E propagation may play an important role in HF and VHF radiocommunications;

---

* Formerly Question 314(VI).

** Formerly Question 315(VI).

(b) that other anomalous ionization in the E and F regions of the ionosphere may also be important to radiocommunications as, for example, phenomena associated with auroras and field-aligned irregularities of ionization;

(c) that propagation by way of sporadic-E or other anomalous ionization may also be a source of interference;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the properties of sporadic-E and other anomalous ionization in the ionosphere which affect propagation in ways that are important to radiocommunications;

1.1 can the long-term diurnal, seasonal, and annual variations of these properties be determined;

1.2 can short-term forecasts of these properties be made?

STUDY PROGRAMME 4A/VI *

PREDICTION OF SPORADIC-E

(1966)

The C.C.I.R.,

CONSIDERING

(a) that a major factor in the prediction of ionospheric propagation conditions is the occurrence of sporadic-E;

(b) that the routine scaling and statistical analysis of ionosonde observations of sporadic-E, while extensive and useful from certain viewpoints, have not led to the development of techniques for reliable prediction of sporadic-E, particularly in temperate latitudes;

(c) that fruitful approaches to the short-term prediction of sporadic-E are likely to come through improved understanding of the physical mechanism or mechanisms responsible for temperate latitude sporadic-E, such as:

— the role of wind-shear perhaps influenced by gravity waves;

— the role of plasma instabilities in the E-region;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the physical processes in the ionosphere, which give rise to sporadic-E and which may be of importance in predicting its occurrence;

2. methods of predicting the occurrence of sporadic-E in a manner likely to be of assistance to radiocommunicators.

Note. — The Director, C.C.I.R., is requested to transmit this text to the U.R.S.I. and the I.U.G.G. for comment.

---

* Formerly Study Programme 315A(VI).

STUDY PROGRAMME 4B/VI *

PROPAGATION BY WAY OF SPORADIC-E AND OTHER ANOMALOUS IONIZATION

(1959 - 1963 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that data on propagation by sporadic-E and other abnormal ionization obtained from continuous-wave recordings, and fixed frequency pulse measurements at oblique incidence, provide statistical data of the type needed by engineers;

(b) 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;

(c) that the path configuration plays an important part in those modes of propagation in which reflections from field-aligned ionization seem to occur, as for example, auroral-type phenomena;

(d) that world-wide charts of expected sporadic-E transmission loss at oblique incidence are not yet available;

(e) that the conversion of vertical incidence Es data, obtained from ionosondes to oblique incidence field-strengths, is difficult to accomplish at present;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. dependence of the field strength or transmission loss of signals propagated by anomalous modes in the ionosphere upon:
   - the different modes of propagation;
   - the length of the propagation path, transmission frequency, time of day, season and solar activity;
   - the geographic region;
   - ionization aligned along the earth's magnetic field;
   - characteristics of the terminal equipment, such as antenna gains and directivities, receiver characteristics and transmitter power;
2. determination of the elevation and azimuthal angles of arrival of the signals propagated by the various anomalous modes;
3. comparison, where possible, of the results so obtained with data from ionosondes (for example, foEs);
4. 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.

---

* This Study Programme replaces Study Programme 195.

QUESTION 5/VI *

PROPAGATION BY DUCTING ABOVE THE IONIZATION MAXIMUM OF THE F REGION

(1966)

The C.C.I.R.,

CONSIDERING

(a) that observations by Alouette satellite indicate that ducting, by field-aligned irregularities, is most likely to be observed at low magnetic latitudes (less than 30°);

(b) that similar phenomena may influence the propagation of MF, HF, and VHF waves through the ionosphere;

(c) that such propagation may also be capable of causing interference, in particular for satellite communications;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the forms of the ducts and what is their importance as a function of magnetic field, time of day, season, and solar and magnetic activity;

2. what is the influence of these ducts on the propagation of both wanted and unwanted MF, HF or VHF signals in or through the ionosphere;

3. what is, if any, the effect of field-aligned propagation through the ionosphere on communication between two points on the earth?

Note. — The Director, C.C.I.R. is invited to draw the attention of the U.R.S.I. to this Question.

QUESTION 6/VI **

SPECIAL PROBLEMS OF HF RADIOCOMMUNICATION ASSOCIATED WITH THE EQUATORIAL IONOSPHERE

(1963 - 1966)

The C.C.I.R.,

CONSIDERING

that HF communications are known to encounter special propagation conditions in the equatorial ionosphere,

---

* Formerly Question 316(VI).

** This Question replaces Question 248.

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the physical 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:
   - — frequency,
   - — time of day and season,
   - — level of solar and magnetic activity,
   - — geographic location, orientation and length of propagation path,
   - — antennae characteristics,
   - — class of emission?

Note. — The Director, C.C.I.R., is requested to transmit this text to the U.R.S.I. for comment, drawing particular attention to § 1.

QUESTION 7/VI *

RADIO NOISE WITHIN AND ABOVE THE IONOSPHERE

(1966)

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 within and above the ionosphere;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what are the characteristics of radio noise received in a spacecraft, within or above the ionosphere;
2. what are the methods of prediction of this noise level?

Note 1. — The following sources of noise should be considered:

- — galactic and extragalactic noise (cosmic noise),
- — solar noise,
- — planetary and interplanetary space noise,
- — ionospheric noise (noise generated within the ionosphere and magnetosphere),
- — noise of terrestrial origin (atmospheric noise and man-made noise).

Note 2. — The Director, C.C.I.R. is invited to draw the attention of the U.R.S.I. to this Question.

---

* Formerly Question 312 (VI).

STUDY PROGRAMME 8A/VI *

PREDICTION OF SOLAR INDEX

(1956 - 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.

RESOLUTION 10–1

BASIC LONG-TERM IONOSPHERIC PREDICTIONS

(Study Programme 9A/VI)

(1965 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that the International Working Party VI/3, set up by Resolution 10, has now produced a provisional C.C.I.R. atlas (see Recommendation 434, " C.C.I.R. Atlas of Ionospheric Characteristics "), representing world-wide ionospheric characteristics, to assist users of sky-wave propagation at frequencies above 1·5 MHz;

---

* This Study Programme, formerly Study Programme 193(VI), does not arise from any Question under study.

(b) that the detailed content of this atlas can be improved with the acquisition of further ionospheric observations;

(c) that further studies are required for future editions;

(d) that improvements in the techniques for applying the material in the atlas can be anticipated;

(e) that useful additional material can be added to the atlas;

UNANIMOUSLY DECIDES

1. that the existing International Working Party VI/3 should continue to function;
2. that the International Working Party should determine, with a view to later editions of the C.C.I.R. atlas, and whenever possible in consultation with users, how the atlas may be improved;
3. that the International Working Party should devise a practical method for including the statistical fluctuations about medians in the monthly predictions;
4. that the International Working Party should develop methods for taking into account in predictions the effects of sporadic-E and F1 layers.

STUDY PROGRAMME 9A/VI *

BASIC PREDICTION INFORMATION FOR IONOSPHERIC PROPAGATION

(1953 - 1959 - 1963 - 1966)

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 predictions are extensively used by radio propagation services and Administrations;

(c) that certain significant discrepancies are observed between the predictions and the operational results;

UNANIMOUSLY DECIDES that the following studies should be carried out :

1. a statistical determination in terms of season, solar cycle, and location of the day to day variation of both the operational MUF (MUF) and the standard MUF (EJF), so that correction factors may be introduced in the monthly prediction;
2. analysis of variations of the differences between operational MUF (MUF) and standard MUF (EJF), from hour to hour and from day to day;
3. the deficiencies of the present methods for predicting oblique-incidence standard MUF (EJF) from vertical-incidence data;
4. the importance of the various ionospheric layers and of modes of propagation for radiocommunications;
5. the improvements that can be achieved by application of ray tracing techniques and the development of new conversion nomograms.

---

* This Study Programme, which replaces Study Programme 200, does not arise from any Question under study.

STUDY PROGRAMME 10A/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

(1953 - 1956 - 1963 - 1966)

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;

(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 communication 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 facilitates 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, dawn chorus, 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 ionsopheric 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;

---

* This Study Programme, which replaces Study Programme 194, does not arise from any Question under study.

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 some objective scale of the importance of sudden ionospheric disturbances; various methods are known, such as:
   - riometer (cosmic-noise absorption) measurements,
   - sudden phase changes (on VLF),
   - changes of the average field strength of atmospherics (for example, in the frequency band 20 to 40 kHz).

RESOLUTION 7–1

SKY-WAVE FIELD STRENGTH AND TRANSMISSION LOSS AT FREQUENCIES BETWEEN THE APPROXIMATE LIMITS OF 1·5 AND 40 MHz

(Study Programme 11A/VI)

(1956 - 1959 - 1963 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that the International Working Party VI/1 is planning to produce initially only a provisional method of estimating sky-wave field strengths adapted for use by computers of limited capacity;

(b) that systematic high-frequency field-strength measurements are now becoming available;

(c) that a more accurate method of estimating sky-wave field strengths is desirable;

UNANIMOUSLY DECIDES

1. that the International Working Party VI/1 should continue to function;
2. that the International Working Party, in addition to a provisional method, should develop a more accurate method of estimating sky-wave field strengths and transmission loss;
3. that the International Working Party should continue to cooperate with Administrations and International Organizations by:
   - providing field strength and absorption measurements through the Director, C.C.I.R., e.g. in accordance with Report 253–1,
   - assisting in making predictions of field strengths for circuits under study by the methods of the C.C.I.R. or any other method;
4. that the task of the International Working Party should be conducted by correspondence as well as by meetings;
5. that the C.C.I.R. Secretariat should continue to assist the International Working Party, for example, by collecting and collating material submitted by Administrations and organizations and preparing summaries for the International Working Party.

STUDY PROGRAMME 11A/VI *

ESTIMATION OF SKY-WAVE FIELD STRENGTH AND TRANSMISSION LOSS FOR FREQUENCIES BETWEEN THE APPROXIMATE LIMITS OF 1·5 AND 40 MHz

(1951 - 1953 - 1956 - 1959 - 1963 - 1966)

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. improvement 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 and from suitable field-strength measurements of CW transmitters;
7. application of the temporal variations of the absorption of extraterrestrial noise and of field strength of signals received from spacecraft.

Note. — In making these studies, reference should be made to Study Programmes 4B/VI, 12A/VI, 14A/VI and 16A/VI.

---

* This Study Programme, which replaces Study Programme 198, does not arise from any Question under study.

OPINION 22

ROUTINE IONOSPHERIC SOUNDING

(1966)

The C.C.I.R.,

CONSIDERING

(a) that the routine hourly observations, from the existing ground-based network of vertical incidence ionospheric sounding stations, make possible continuous improvements in the basic data for long-term ionospheric predictions;

(b) that the efficiency of this network has been considerably improved by the guidance given by international scientific committees since 1956, which is likely to be discontinued at the end of the I.Q.S.Y.;

(c) that routine observations from topside sounders can also be expected to contribute to the improvements of long-term ionospheric predictions;

(d) that the existing ground-based network of ionospheric sounding stations represents a very important international effort and, together with the topside sounders, it provides synoptic information that will be indispensable in the ultimate development of techniques for producing short-term predictions;

(e) that the increasing importance of space research and earth-space communications, will require continued collection of the information derived as a matter of routine, together with possible increases and changes;

IS UNANIMOUSLY OF THE OPINION that Administrations should make every effort:

1. to continue the operation of the existing ionosonde network, and interchange basic data through the World Data Centres;
2. to establish new ionosondes at places recommended by the C.C.I.R. in fulfilment of Question 2/VI;
3. to support any suitable arrangements which may be made, by an appropriate international organization, for providing scientific guidance needed anywhere in the network;
4. to use the topside soundings now available at the World Data Centres for ionospheric predictions.

Note. — The Director, C.C.I.R. is invited to draw the attention of the U.R.S.I., I.U.G.G., I.C.S.U. and C.O.S.P.A.R. to this Opinion.

STUDY PROGRAMME 12A/VI *

IONOSPHERIC SOUNDING AT OBLIQUE INCIDENCE

(1965 – 1966)

The C.C.I.R.,

CONSIDERING

(a) that both fixed-frequency and variable-frequency test transmissions have been made, with both experimental and commercial equipment;

(b) that the use of oblique-incidence transmissions as, for example, with oblique-incidence sounders, would be of great assistance in the study of many problems 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 field strength, 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:

— standard MUF (EJF) calculations for the respective modes;

— operational MUF (MUF) on circuits operating simultaneously on the same path,

taking care of any differences in antenna patterns, particularly in vertical patterns;

2. loss compared to free space, or transmission loss of various modes, with a view to explaining observed loss on operating circuits;

3. off-great circle modes of propagation by measurements of direction of arrival of the individual modes;

4. 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 reflection, F-region spread echoes and abnormal absorption on oblique soundings, in polar, temperate and equatorial latitudes;

6. the relation of oblique soundings to vertical-incidence soundings, at appropriate points along the transmission path;

---

* This Study Programme, which replaces Study Programme 209, does not arise from any Question under study.

7. other factors which are appropriate to oblique soundings including:
   - — the nature of fading,
   - — focusing,
   - — non-reciprocity,
   - — magneto-ionic double refraction,
   - — vertical angle of arrival,
   - — field-aligned ionization,
   - — steep horizontal ionization gradients,
   - — polarization,
   - — the influence of azimuth on paths near the magnetic equator;
8. methods for anticipating frequency changes by forward extrapolation in time of the results of oblique sounding.

STUDY PROGRAMME 13A/VI *

IONOSPHERIC-SCATTER PROPAGATION

(1951 - 1953 - 1956 - 1959 - 1963 - 1966)

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;
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;

---

* This Study Programme, which replaces Study Programme 202, does not arise from any Question under study.

4. the use of diversity methods to reduce the short-term variations of received signal intensity;

5. 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 F-layer reflections, and from the occurrence of reflections from sporadic-E layers, with special reference to interference both to and from other transmissions.

STUDY PROGRAMME 14A/VI *

BACK-SCATTERING

(1951 - 1953 - 1956 - 1959 - 1963 - 1966)

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 (MUF) may exceed the classical MUF (EJF);

(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;

(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;

(j) that back-scatter observations made at a site containing both transmitter and receiver, can be of value in the detection of ionospheric irregularities and measurements of their motions over large areas of the ionosphere;

---

* This Study Programme, which replaces Study Programme 203, does not arise from any Question under study.

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 of actual propagation conditions from back-scatter measurements;

7. determination of appropriate antenna characteristics for:
   - — back-scatter measurements,
   - — communication circuits, on the basis of back-scatter measurements;

8. investigation, by back-scatter measurements, of unusual types of propagation, such as 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 ionospheric irregularities, including their relationship to acoustic and gravity waves in the ionosphere and their influence on the measurements referred to in §§ 3 and 4.

STUDY PROGRAMME 15A/VI *

INTERMITTENT COMMUNICATION BY METEOR-BURST PROPAGATION

(1959 - 1963 - 1966)

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, while experimental systems using this mode of propagation provide propagation data, the data thus obtained are not always capable of general application;

---

* This Study Programme, which replaces Study Programme 196, does not arise from any Question under study.

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 the occurrence of Es reflections and of F-layer reflections, with special reference to interference both to and from other transmissions.

STUDY PROGRAMME 16A/VI *

FADING OF SIGNALS PROPAGATED BY THE IONOSPHERE

(1966)

The C.C.I.R.,

CONSIDERING

(a) that the practical requirements of radiocommunication necessitate information, not only on the median value of the received signal-strength, taken as the available voltage from the antenna, but also on:

- — the amplitude distribution,
- — the rapidity of variations,
- — the differential fading with spaced antennae,
- — the differential fading with antennae responding to different polarizations,
- — the differential amplitude and phase fluctuations at different frequencies within the bandwidth of typical transmissions at more widely separated frequencies;

(b) that such information, particularly on the amplitude distribution, is essential to Study Groups II, III, IV, X and XII, in assessing the allowances for fading and is also important in determining the effects of fading on the quality of reception taking into account the system of modulation, the equipment time constants and possible methods of diversity transmission or reception:

(c) that temporal variations of signal-strength may, as a first approximation, be divided into three types:

- — regular and irregular short-period variations assumed in general to result from scattering, interference, focusing and changes of polarization, with an apparent period of occasionally as much as several minutes;

---

* This Study Programme, which replaces Study Programme 148, does not arise from any Question under study.

- irregular variations of periodicity which are large compared with the case above (i.e. hour-to-hour or day-to-day variations), which may be due to fluctuating absorption or to prolonged large-scale focusing, or which may result from variations of arrival angle;
- regular variations with time of day, season and solar activity, to which are added the two preceding variations,

(d) that the presence of various modes and paths, which provide the component signals at the receiving antenna, significantly affects the time characteristics (pulse response), as well as the space and frequency characteristics;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the distributions of signal-strength values for short-period variations, i.e. the distributions within a period of one hour or less;
2. the rapidity of fading expressed, for example, as the time correlation function for the signal-strength, the equivalent power spectrum or the number of crossings of a given level per unit time;
3. the distribution of the duration of fades, i.e. of the time intervals during which the signal-strength remains below a given level relative to the hourly median;
4. the day-to-day variations of hourly median signal-strengths;
5. the correlation of signal-strength variations;
   - at two similar antennae, spaced along or perpendicular to the direction of the transmitter, as a function of frequency separation,
   - at near-coincident antennae responding to different polarizations, e.g., vertical and horizontal,
   - at pairs of frequencies, as a function of frequency separation;
6. the extent to which the above statistical results are dependent on such factors as:
   - path length,
   - the presence of several modes, identified by different time delays and, in general, by different vertical or horizontal angles of arrival,
   - possible Doppler shifts for each mode,
   - frequency or its ratio to the standard MUF (EJF) of the path,
   - time of day,
   - season,
   - solar activity,
   - the relation of the propagation path to the direction of the earth's magnetic field,
   - geographical region, particularly auroral zones, middle latitudes and tropical regions,

   bearing in mind that, in some cases, one factor may have an important control over the effect of another factor, e.g., the effects of season and of solar activity will probably require separate examination for each of the main geographical regions;
7. the nature and relative importance of the mechanisms which produce signal-strength variations.

Note. — The Director, C.C.I.R. is requested to transmit this text to the U.R.S.I. for comment, drawing particular attention to § 7.

RESOLUTION 12–1

SKY-WAVE PROPAGATION AT FREQUENCIES BETWEEN 150 kHz AND 1500 kHz

(Study Programme 17A/VI)

(1963 – 1966)

The C.C.I.R.,

CONSIDERING

(a) that considerable interest exists (see Report 257–1) regarding the use of low- and medium-frequency field-strength curves for the various areas of the world;

(b) that, as the results of the work done in the European Broadcasting Area (see Report 264–1), in response to Study Programme 17A/VI, do not necessarily apply to low latitudes or to middle latitudes in the southern hemisphere or even in other parts of the northern hemisphere;

(c) that, for the determination of the interference zone between the sky-wave and the ground-wave it is desirable to have sky-wave propagation curves for distances less than 300 km;

(d) that there is a serious lack of systematic observations of the critical frequency of the nocturnal E layer;

UNANIMOUSLY DECIDES

1. that the International Working Party set up by Resolution 12 should continue to function and should invite assistance from other Administrations and organizations who are able to undertake measurements in the areas referred to in § *(b)*, and to cooperate in tests made over great distances;

2. that the International 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 calculated 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 kHz and 1500 kHz for these areas;
- the results of studies on LF and MF propagation in various geographical areas, including the field strength of signals propagated over paths less than 300 km and paths greater than 3500 km;
- the usefulness and limitations of presently available propagation data as to suitability for the production of propagation curves in the frequency range 150 kHz to 1500 kHz;
- the nocturnal values of foE as a function of geographical location, time and season;
- the effects of polarization coupling loss, as well as absorption loss, with particular emphasis on the equatorial region, including multi-hop transmissions.

RESOLUTION 13–1

SKY-WAVE PROPAGATION AT FREQUENCIES BELOW 150 kHz

(Study Programme 17A/VI)

(1963 - 1966)

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 kHz and 1500 kHz (see Resolution 12–1 and Reports 257–1 and 264–1), there is a need for such curves for frequencies below 150 kHz 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, in view of the Report submitted by the International Working Party VI/5 set up under Resolution 13 (the findings of which are abstracted in Report 265–1), the International Working Party should continue this study with increased participation;

2. that those countries which have been working in this field (e.g. Canada, United States of America, Federal Republic of Germany, U.S.S.R. and the United Kingdom) and other interested Administrations and organizations, should be invited to submit the names of their experts as soon as possible to the Chairman, Study Group VI, through the Director, C.C.I.R.;

3. that the Chairman of the present International Working Party VI/5 should continue to act as Chairman of the expanded International Working Party and will organize the work by correspondence;

4. that the International Working Party should invite assistance from other Administrations or organizations favourably placed geographically, to extend the available coverage of field strength data; e.g., most of the available long radio-wave propagation data have been obtained at middle latitudes, and few data are available for equatorial and high latitudes;

5. that the International Working Party should seek to implement the proposals made in the Report of the Chairman of the International Working Party VI/5 and abstracted in Report 265–1, with regard to the preparation of propagation curves for frequencies below 150 kHz.

STUDY PROGRAMME 17A/VI *

SKY-WAVE PROPAGATION AT FREQUENCIES BELOW 1500 kHz

(1951 - 1953 - 1959 - 1963 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that new night-time propagation curves and formulae for the European Broadcasting Area are given in Report 264–1;

(b) that, nevertheless, it is not yet possible to supply Administrations and the I.F.R.B. with complete answers regarding night-time propagation at frequencies below 1500 kHz, applicable to all areas and in particular at low and high latitudes;

(c) that there is an urgent need for guidance to be given to engineers in the planning of medium-frequency broadcasting systems in the tropical zone (as defined in Nos. 135 and 136 of the Radio Regulations, Geneva, 1959);

(d) that information is needed for daytime propagation at frequencies below 1500 kHz for various areas of the world and in particular at low and high latitudes;

(e) that it is known that there are differences in propagation over north-south and east-west paths in the medium frequency range in the tropical zone, in particular in areas within 30° of the magnetic equator;

(f) that it is difficult to integrate with the curves of Report 264–1, the measurements made at nearly vertical incidence and the particularly high fields being found on certain very long paths;

(g) 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;

(h) that while progress is being made in understanding the characteristics of the ionosphere relevant to sky-wave propagation at frequencies below 1500 kHz, the mathematical analysis has been confined largely to ideal cases that are not sufficiently representative of practical conditions;

(j) that an MF transmitter providing a ground-wave service, with an antenna adapted to give sky-wave radiation with elliptical polarization of a suitable form (orthogonal transmission), may, through attenuation of the sky-wave, give a substantial reduction of sky-wave interference to other stations and extend its own night-time ground-wave service area;

(k) that a medium-frequency transmitter, providing a sky-wave service with a vertically polarized antenna may, particularly at low latitudes, give a poor service in certain directions, because of polarization effects;

UNANIMOUSLY DECIDES that the following studies should be carried out:

---

* This Study Programme, which replaces Study Programme 206, does not arise from any Question under study. It should be brought to the attention of Study Group X.

1. the continuation of measurements at vertical and oblique incidence at frequencies below 1500 kHz, 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 occurring simultaneously at more than one height;
3. the dependence of field strength and phase as a function of frequency and distance on a variety of path conditions:
    - geographical location, with particular attention to transpolar and equatorial paths and antipodal regions;
    - path orientation, including the influence of the earth's magnetic field, with special reference to differences between north-south and east-west propagation and the characteristic polarization of the ordinary and extraordinary waves in the ionosphere;
    - earth conductivity;
    - time of day;
    - season;
    - orientation of the path with respect to the day-night line;
    - epoch of the solar cycle;
    - disturbance changes, with particular reference to S.I.D.'s, polar cap disturbances, and changes associated with geomagnetic and auroral variations and magnetic storms;
4. the development of the mathematical analysis, to apply more closely to 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 264–1 as further measurements become available, especially for other areas in low and high latitudes and for distances less than 300 km and greater than 3500 km;
7. the possibility of establishing curves and formulae for daytime propagation.

STUDY PROGRAMME 18A/VI *

VLF PROPAGATION IN AND THROUGH THE IONOSPHERE

(1959 - 1963 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that reasonably efficient VLF propagation can frequently be obtained 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;

---

* This Study Programme, which replaces Study Programme 201, does not arise from any Question under study.

(b) that such propagation depends upon the existence of electrons and ions along the path and their behaviour in the earth's magnetic field;

(c) that the characteristics of an antenna are considerably modified when it is embedded in a magneto-ionic medium such as the ionosphere, which can be highly overdense at very low frequencies;

(d) that such propagation can, under certain conditions, provide a means of communication, but can also produce interference;

(e) that understanding of such VLF propagation is still very imperfect;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the potential usefulness of VLF propagation as a means of communication in and through the ionosphere;
2. the interference potentialities of VLF signals propagated in and through the ionosphere;
3. the calculation of field-strength or transmission loss for VLF waves 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. the impedance and power pattern of various antenna structures (e.g. dipoles and loops) in the ionosphere;
5. the further development of the mathematical analysis.

STUDY PROGRAMME 19A/VI *

CHARACTERISTICS OF THE IONOSPHERE AFFECTING SPACE-COMMUNICATION SYSTEMS

(1963 - 1966)

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;

(c) that uncoordinated frequency sharing, between frequency allocations for sub-ionospheric communication services and frequency allocations for spacecraft-to-spacecraft communication services, cannot yet be accepted, owing to the lack of necessary data on the minimum isolation afforded by ionospheric phenomena;

---

* This Study Programme, which replaces Study Programme 208, does not arise from any Question under study.

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. development of methods for measuring and predicting between two given points, as functions of frequency and ionospheric and geomagnetic parameters;

1.1 the attenuation, refraction and scintillation of radio waves passing through the ionosphere;

1.2 the relative influences of Doppler and Faraday effects;

1.3 the degree of isolation provided by the ionosphere for frequencies below foF2;

2. the usefulness of a modified antenna diagram, taking account of the effects of refraction and attenuation through the whole atmosphere; such a diagram would include the effects of both the ionosphere and the troposphere on the passage of the waves from an earth station through the atmosphere;

3. the usefulness of the new ionospheric parameter f_d, characterizing the effect of refraction by the ionosphere on the waves emitted horizontally from an earth station (f_d is defined as the " standard MUF " (EJF) obtained from a vertical-incidence ionogram, not for a given distance, but for zero angle of elevation). The propagation conditions are particularly complex for frequencies below f_d, for which multiple paths with intermediate ionospheric reflections can occur.

RESOLUTION 8–1

REVISION OF ATMOSPHERIC RADIO NOISE DATA

(1951 - 1956 - 1959 - 1963 - 1966)

The C.C.I.R.,

CONSIDERING

(a) that the information in Report 322 (published separately) requires continual revision;

(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 co-ordination of these data;

(d) that the new data should make possible further extension of the scope and improvement in the accuracy of Report 322;

(e) that man-made radio noise is important in the application of the world charts of atmospheric radio noise;

(f) that observations obtained from lightning-flash counters are valuable in the revision of the world charts of atmospheric radio noise;

UNANIMOUSLY DECIDES

1. that the International Working Party VI/2 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 International Working Party 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 the relative noise-intensities at different locations suggest that the noise contours should be amended;

2.2 the relative noise-intensities at different frequencies suggest that the frequency curves should be amended;

2.3 the ratios of the upper and lower decile values to the median value should be amended;

2.4 the curves of probability distribution of the measured amplitudes approximate closely to one of the relevant family of idealized curves presented in Report 322;

3. that the International Working Party should keep the data under continual review and should formulate proposals for a further revision of Report 322 when it appears opportune.

4. that the terms of reference of the International Working Party on atmospheric radio noise be extended to include studies of man-made radio noise outlined in Study Programme 21A/VI;

5. that the International Working Party on atmospheric radio noise should study and make recommendations on the items contained in the Annex to this Resolution.

ANNEX

1. The object of lightning-flash counter observations, in so far as they are required for radio-noise studies, is to determine the number of lightning discharges occurring per unit time over unit area of the earth's surface, in different places and at different times. These requirements differ from those for some non-radio applications in which only the ground discharge is significant.

Differing experiences in the use of the C.C.I.R. counter have been reported, caused either by differences in the counter characteristics, or in the physical layout of the installation, or in the nature of the meteorological environment. There is some disagreement as to the best performance specification of a counter for the required purpose, and the best instrumental design for achieving this performance. Also, a uniform method of reporting the results for radio-noise purposes is required.

2. As a guide to the programme to be followed by the International Working Party VI/2, the following suggestions are offered:

2.1 study the causes of differences in the performance of C.C.I.R. counters in different places and under different weather conditions and recommend means for eliminating such differences;

2.2 study methods of using data from the counters to improve radio-noise predictions;

2.3 study the question whether the C.C.I.R.-type counter, with or without modifications, is the best for synoptic radio-noise studies, and if not, make recommendations for a new design;

2.4 recommend a standard method of reporting the results of synoptic observations;

2.5 keep the W.M.O. informed of the results of these studies, communicate to them any changes in the necessary criteria for making satisfactory observations, and encourage their continued participation in the observing programme.

STUDY PROGRAMME 20A/VI *

MEASUREMENT OF ATMOSPHERIC RADIO NOISE

(1951 - 1953 - 1956 - 1959 - 1963)

The C.C.I.R.,

CONSIDERING

(a) that the atmospheric noise data in Report 322 (published separately) are available for provisional use;

(b) that this Report now contains information on the short-term amplitude probability distribution 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;
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.

---

* This Study Programme, formerly Study Programme 199(VI), does not arise from any Question under study.

STUDY PROGRAMME 21A/VI *

MEASUREMENT OF MAN-MADE RADIO NOISE

(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.

---

* This Study Programme, formerly Study Programme 153(VI), does not arise from any Question under study.

RESOLUTION 31

PREDICTIONS OF THE LF AND MF SKY-WAVE FIELD STRENGTHS FOR SHORT DISTANCES IN AFRICA

(1966)

The C.C.I.R.,

CONSIDERING

(a) Resolution No. 1 of the Preparatory Meeting of Experts for the African LF/MF Broadcasting Conference (Geneva, 1964);

(b) Doc. 7 of the African Broadcasting Conference (Geneva, 1964);

UNANIMOUSLY DECIDES

1. that the action taken by the Director, *ad interim*, C.C.I.R. and the Chairman, Study Group VI, explained on page 1 of Doc. 7, in presenting to the African Broadcasting Conference the Report contained in the Annex, which was prepared by International Working Party VI/4, under the chairmanship of Mr. Dixon (Australia), should be endorsed;

2. that the attention of Administrations should be drawn to the Annex, which may be of use, for the time being, in predicting LF and MF sky-wave field strengths for short distances in Africa.

ANNEX

PREDICTIONS OF THE LF AND MF SKY-WAVE FIELD STRENGTH FOR AFRICA

In response to an invitation contained in the Report by the Preparatory Meeting of Experts, African LF/MF Broadcasting Conference, Geneva, February, 1964, International Working Party VI/4 has prepared the following predictions for the short-distance sky-wave field strength for Africa.

Figs. 1 and 2 show the predicted median values of the sky-wave field strength at ground level (dB above 1 μV/m), for an unattenuated field strength of 3×10^5 μV/m at a distance of 1 km from a vertically polarized transmitting antenna, along the appropriate ray for one-hop transmission. Fig. 1 refers to the value predicted two hours after sunset (ground level at the path mid point), and Fig. 2 refers to the value at midnight. To correct for the vertical radiation pattern of the antenna, the factor ΔA(dB), which is plotted in Fig. 4 (one-hop F) and Fig. 3 (one-hop E), as a function of the distance for antennae at various heights, should be added to the value obtained from Fig. 1 or Fig. 2. Predictions will then be based on a radiated power of 1 kW from the antenna employed, and may be applied in all regions of Central Africa except in the vicinity of the equator of magnetic dip, where eastward and westward transmissions, at or near the gyro frequency (1 MHz), are attenuated appreciably below the values indicated in Figs. 1 and 2. The order of attenuation, below the level predicted for north-south propagation at 900 km, is as follows:

Magnetic bearing of path on or near the equator of magnetic dip	Additional attenuation at or near the gyro frequency (dB)
90° ± 12° 270° ± 12°	$\geqslant$ 17
90° ± 33° 270° ± 33°	$\geqslant$ 11
90° ± 45° 270° ± 45°	$\geqslant$ 4

This influence is also expected to be evident at distances shorter than 300 km. A change of frequency, within the range 800 kHz to 1200 kHz, should produce no appreciable reduction in the additional attenuation shown above. It should be emphasised that these attenuation values are tentative but, nevertheless, they should be used as corrections to Figs. 1 and 2, when considering transmission paths in the vicinity of the equator of magnetic dip.

Figs. 1 and 2 deal only with the vertical component of the resultant electric field-strength and may be used to calculate the induced voltage in vertical rod antennae, without a further correction for the polar diagram of the receiving antenna. When loop antennae are used, the correction given in Fig. 5 should be added to the calculated ratio of ground-wave to sky-wave voltage at the receiver input, derived from ground-wave curves and the predictions from Figs. 1 to 4. This situation is created by the relatively small electric field-strength and relatively large magnetic field-strength at ground level at small angles of incidence. The influence of ground reflection on the predicted field strength has been calculated for a ground conductivity of 3 mmho/m and a dielectric constant of 10.

Several sources of data were used to produce the propagation curves of Figs. 1 and 2. Tests at vertical incidence conducted at Tsumeb (latitude 19° 14′ S) in South West Africa, provide a measure of the effective reflection coefficients for the ionosphere, which are assumed to apply out to 80 km for one-hop E transmission. (Mean hourly values of all measurements made at specified test frequencies and specified times relative to sunset and sunrise.) These reflection coefficients display fairly wide variations from night to night, but in general, the median value for any single night is not likely to be more than ±10 dB from the mean hourly value used. Towards the upper limit of distance considered, one-hop E predictions are based on the assumption that, at 400 km, the annual mean value of the hourly medians is independent of frequency throughout the LF/MF bands, and has a value which is the mean of that predicted at 1000 kHz for the northern hemisphere (E.B.U.), and for the southern hemisphere (Australia). Between 80 km and 300 km, these reflection coefficients (in dB) are changed linearly to converge on the assumed value at 400 km. When the results of oblique-incidence measurements in Africa become available, it may be necessary to correct the predictions, in accordance with a field strength slightly different from that assumed at 400 km. Table I has been included in this Report to facilitate such an adjustment. For one-hop F transmission, effective reflection coefficients at vertical incidence are considered to apply out to 240 km and to a first approximation out to 300 km. The lower frequency limit (f_{min}) of vertical incidence echoes from the F layer exceeds the E-layer critical frequency and is probably due to the critical frequency of an intermediate layer between the E and F regions. One-hop F propagation curves drawn with long dashes, indicate that this lower frequency limit is usually above the frequency associated with each curve.

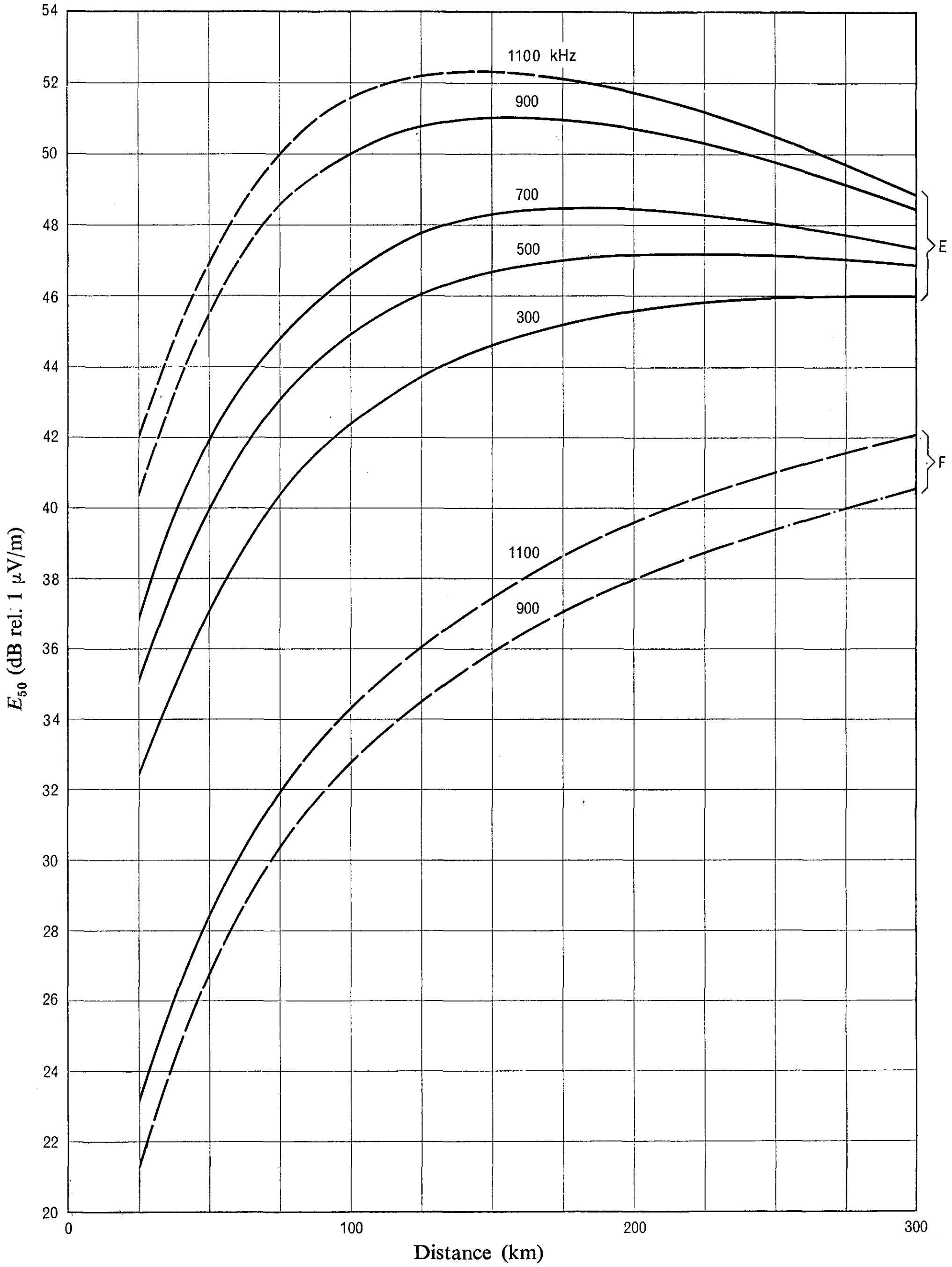


FIGURE 1

Family of propagation curves giving the predicted hourly mean value of the sky-wave field strength for one-hop E and one-hop F modes at the second hour after sunset during sunspot maximum, for the indicated frequencies. (Second hour after sunset, mean sunspot number 180).

– – – – – – Transmission frequency usually exceeds the E-layer critical frequency.

—— —— —— Transmission frequency is usually less than the minimum frequency for F-layer propagation.

——·——·—— One-hop F mode cut-off by the E-layer.

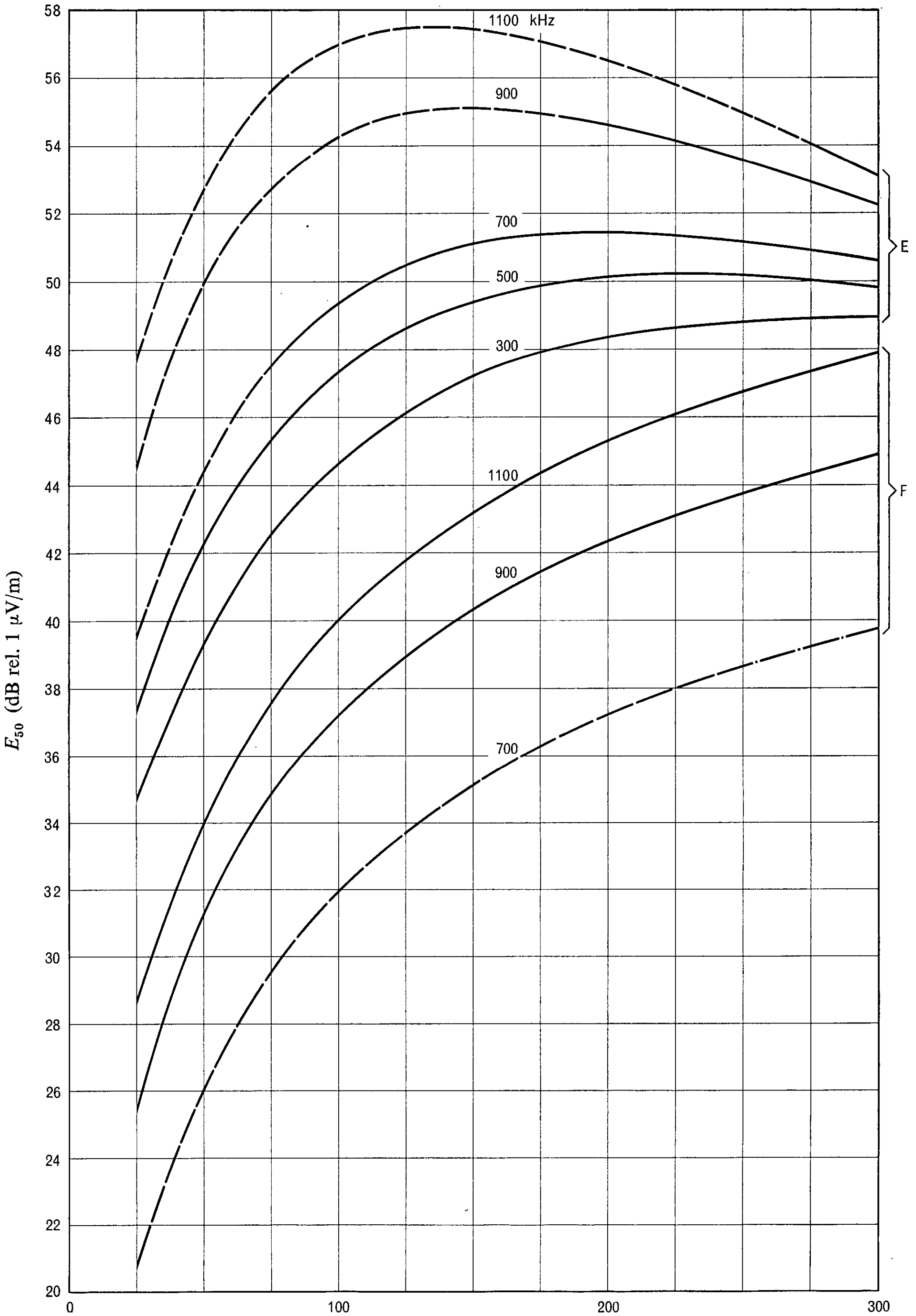


FIGURE 2

Family of propagation curves giving the predicted hourly mean values of the sky-wave field strength for one-hop E and one-hop F modes at midnight during sunspot maximum, for the indicated frequencies. (Midnight, mean sunspot number 180)

– – – – – – – Transmission frequency usually exceeds the E-layer critical frequency.

—— —— —— Transmission frequency is usually less than the minimum frequency for F-layer propagation.

——·——·—— One-hop F mode cut-off by the E-layer.

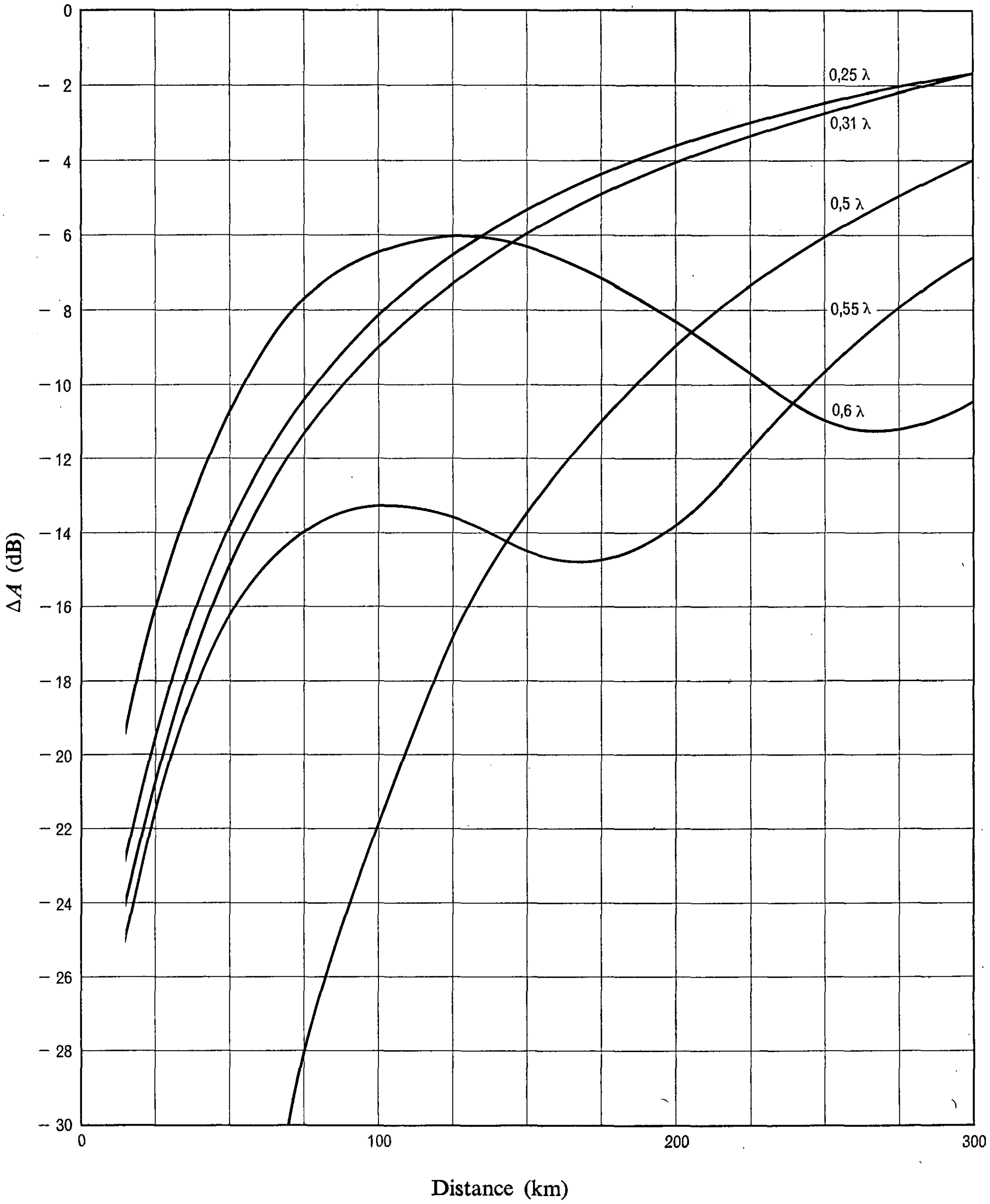


FIGURE 3

Correction factor ΔA, as a function of distance, to convert one-hop E predictions (Figs. 1 and 2) to those for a radiated power of 1 kW from base-fed vertical antennae of various indicated lengths, over a perfectly conducting plane earth. Calculations are based on a reflecting layer at a height of 100 km.

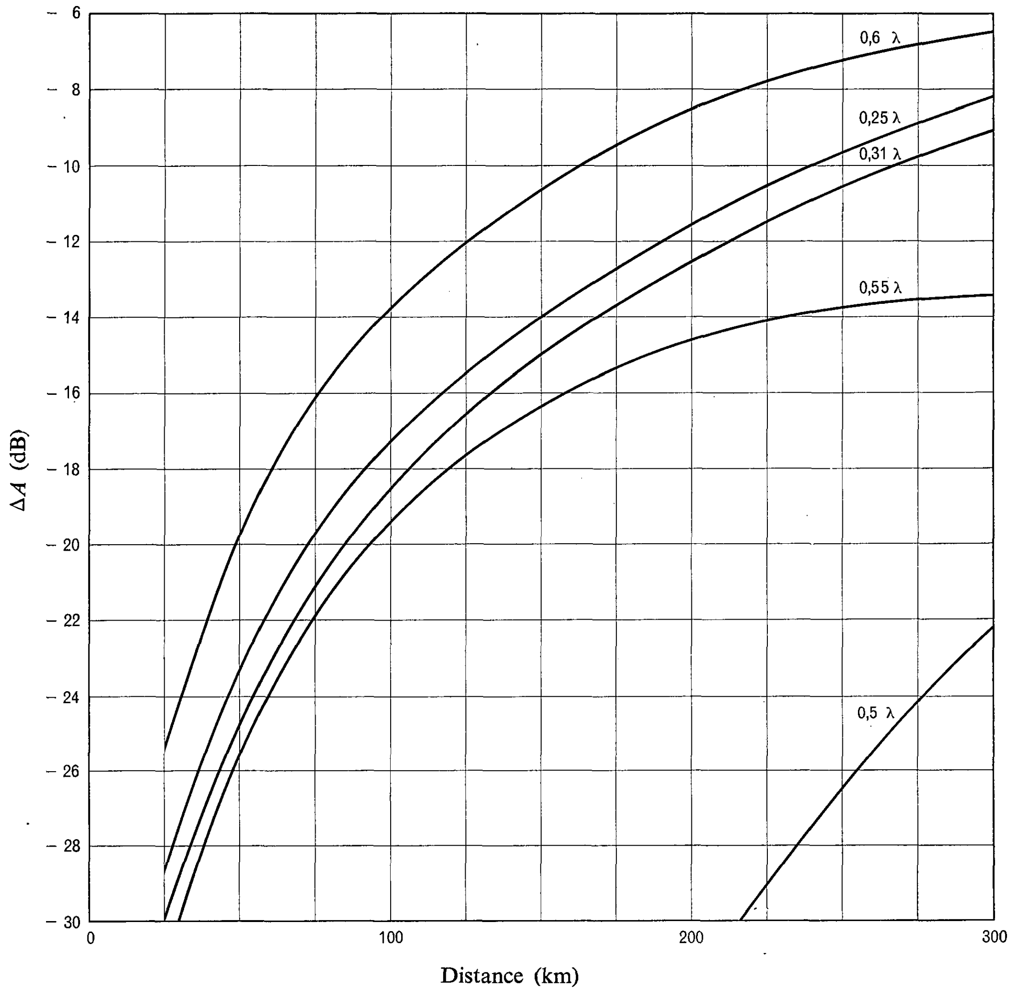


Figure 4

Correction factor ΔA, as a function of distance, to convert one-hop F predictions (Figs. 1 and 2) to those for a radiated power of 1 kW from base-fed vertical antennae of various indicated lengths, over a perfectly conducting plane earth. Calculations are based on a reflecting layer at a height of 300 km.

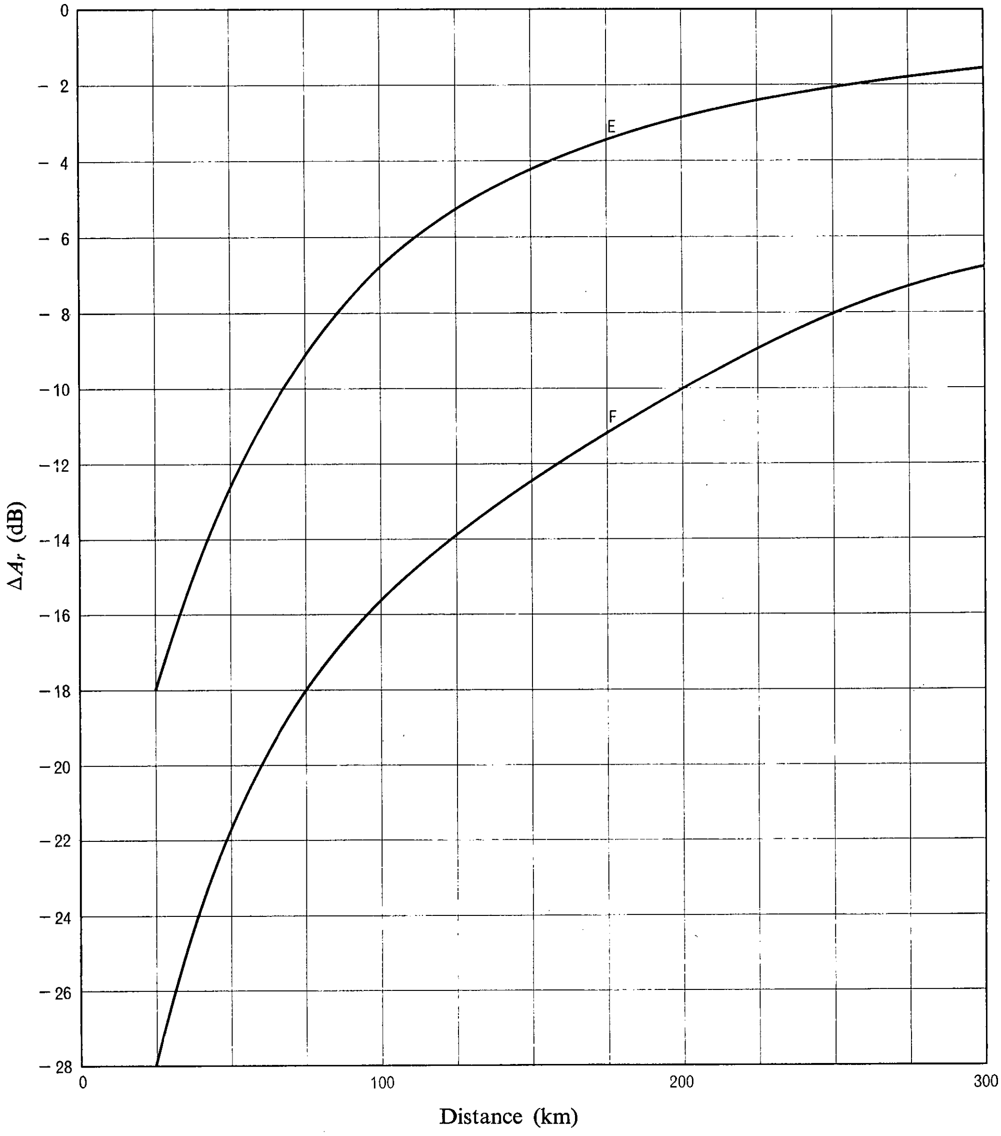


FIGURE 5

Correction factor ΔA_r, which should be added to the calculated ratio of ground-wave to mean sky-wave induced voltages in loop receiving antennae for one-hop E and one-hop F modes.

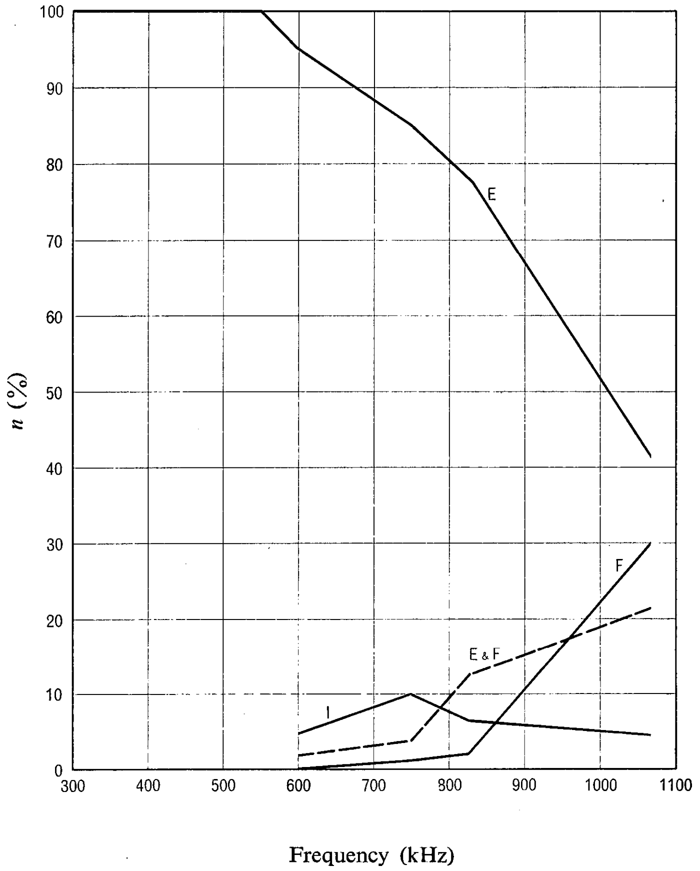


FIGURE 6

Percentage of E, F, (E,F) and I vertical-incidence echoes as a function of the test frequency.

These predictions should be interpreted on the basis of sporadic-E propagation. The following foE values are applicable:

	Second hour after sunset (kHz)	Midnight (kHz)
Sunspot maximum	830	660
Sunspot minimum	620	550

The short dash curves in Figs. 1 and 2 are intended to indicate that transmission via the E-region occurs above the mean critical frequency, as shown in Fig. 6. Furthermore, vertical-incidence data are available only in a form which does not differentiate between E- reflections, F- reflections, or reflections from an intermediate region between the two, referred to as I-reflections. All that can be said in this respect is, that for frequencies below the indicated E-region critical frequency, transmission usually occurs by way of the E-region, whereas for frequencies above the E-region critical frequency, transmission may occur by way of all three regions.

Predictions in Figs. 1 and 2 relate to an average sunspot number of 180. During the sunspot minimum period, approximately 1 dB should be added to the one-hop E values at 300 km, but vertical-incidence reflection coefficients for the ionosphere during this period are not known.

TABLE I

Predicted annual median value of the hourly median field strength at 400 km during sunspot maximum

	Second hour after sunset (dB rel. 1 μV/m)	Midnight (dB rel. 1 μV/m)
E.B.U. (1000 kHz)	42·5	46·5
Australia (1000 kHz)	49	52
Value assumed for Africa	45·7	49·2

BIBLIOGRAPHY

1. C.C.I.R. Doc. VI/83 (Federal Republic of Germany), 1958: Radio propagation at frequencies below 1500 kc/s.
2. C.C.I.R. Doc. VI/6 (Federal Republic of Germany), 1961: Radio propagation at frequencies below 1500 kc/s.
3. ELLING, W. Scheinbare Reflexionshöhen und Reflexionsvermögen der Ionosphäre über Tsumeb, Südwest-Africa, ermittelt mit Impulsen im Frequenzband von 350 bis 5600 kHz. (Apparent height of reflection and reflection capacity of the ionosphere above Tsumeb, South-West Africa, obtained by impulses in the frequency-band 350 to 5600 kHz). Archiv der Elektrischen Übertragung. Band 15, Heft 3 (1961).
4. C.C.I.R. Report 264–1: Predictions of ionospheric field strength or propagation loss for the frequency range between 150 kHz and 1500 kHz.
5. PAGE, H. and MONTEATH, G.D. The vertical radiation patterns of medium-wave broadcasting aerials. *Proc. I.E.E.*, 279-297 (May, 1955).

6. Davies, K. The importance of wave polarization on the propagation of medium frequencies in low latitudes (United States of America). A contribution to the work of C.C.I.R. Working Party VI/4.

7. Barghausen, A.F. Some characteristics of medium frequency propagation in equatorial latitudes (United States of America). A contribution to the work of C.C.I.R. Working Party VI/4.

8. Eckersley, T.L. and Millington, G. The limiting polarization of medium waves reflected from the ionosphere. *Proc. Phys. Soc.* **51**, Part 1 (1939).

9. Phillips, G.J. and Knight, P. Effects of polarization on a medium-frequency service, including the case of multihop paths. *Proc. I.E.E.*, **112**, 31 (January, 1965).

PAGE INTENTIONALLY LEFT BLANK

PAGE LAISSEE EN BLANC INTENTIONNELLEMENT

LIST OF DOCUMENTS CONCERNING STUDY GROUP VI

(Period 1963-1966)

Doc.	Origin	Title	Reference
VI/1 (III/1)	United Kingdom	Operational ionosphere sounding at oblique incidence	S.P. 197
VI/2	E.B.U.-O.I.R.T.	Ionospheric propagation in the frequency range between 150 and 1500 kHz in the European Broadcasting Area	Rep. 264
VI/3	C.C.I.R. Secretariat	LF and MF sky-wave field strength predictions for Africa Report by W.P. VI/4	
VI/4	Canada	Solar noise observations at 2800 Mc/s (Ottawa-ARO) and 2700 Mc/s (Penticton-DRAO)	Res. 4
VI/5	Canada	Adjustments to observations of 10·7 cm solar noise to take account of variations in the distance between the earth and the sun	Res. 4
VI/6	E.B.U.	Propagation by way of sporadic-E and other anomalous ionization in the E- and F-regions of the ionosphere	S.P. 195
VI/7	Canada	Back-scattering	Rep. 261 S.P. 203
VI/8 Add. 1 Corr. 1 and 2	Canada	Cosmic noise observed in satellites	S.P. 205
VI/9	Canada	Radio measurements of the electronic density of the equatorial ionosphere	Q. 248
VI/10	Canada	Reciprocity and non-reciprocity on high frequency ionospheric paths	Rep. 249,266 S.P. 197
VI/11	Chairman, Working Party VI/3	Basic long-term ionospheric predictions	Res. 10
VI/12	F.S.R. of Yugoslavia	Propagation by way of sporadic-E and other anomalous ionization in the E- and F-regions of the ionosphere	S.P. 195, §3
VI/13	United Kingdom	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

Doc.	Origin	Title	Reference
VI/14	United Kingdom	Study of fading	S.P. 148
VI/15	United States of America	Ionospheric effects upon earth-space radio propagation	Rep. 263 S.P. 204, 205
VI/16	United States of America	Characteristics of the ionosphere affecting space telecommunication systems	S.P. 204
VI/17	United States of America	Measurement of atmospheric radio-noise	Rep. 254 S.P. 199
VI/18	United States of America	Measurement of man-made radio-noise	Rep. 258 S.P. 153
VI/19	United States of America	Lightning flash counters	Rep. 254 S.P. 199
VI/20	United States of America	High-frequency propagation by ducting above the F2-region peak	Op. 8
VI/21	United States of America	Special problems of HF radio-communication associated with the equatorial ionosphere	Draft Rep.
VI/22	United States of America	Whistler mode of propagation	S.P. 201
VI/23	United States of America	Whistler mode of propagation	Rep. 262
VI/24	United States of America	Prediction of solar index	Rep. 245
VI/25	United States of America	Choice of basic indices for ionospheric propagation	Rep. 246
VI/26	United States of America	Identification of precursors indicative of short-term variations and evaluation of reliability of short-term forecasts of ionospheric propagation conditions	Rep. 247
VI/27	United States of America	Availability and exchange of basic data for radio propagation forecasts	Rep. 248
VI/28	United States of America	Exchange of information for the preparation of short-term forecasts and the transmission of ionospheric disturbance warnings	Rec. 313
VI/29	United States of America	Pulse transmission tests at oblique incidence	S.P. 197
VI/30	United States of America	Basic prediction information for ionospheric propagation	S.P. 200
VI/31	United States of America	Back-scattering	S.P. 203
VI/32	United States of America	Pulse-transmission tests at oblique incidence	Rep. 249
VI/33	United States of America	Long-distance ionospheric propagation without intermediate ground reflection	Rep. 250
VI/34	United States of America	Back-scattering	Rep. 261

Doc.	Origin	Title	Reference
VI/35	Canada	An F1 layer MUF prediction system for northern latitudes	Rep. 255 S.P. 200
VI/26	United Kingdom	Pulse transmission tests at oblique incidence	S.P. 197
VI/37	United Kingdom	Long-distance sky-wave propagation at frequencies below 1500 kHz. Effects of polarization on a medium-frequency sky-wave service including the case of multi-hop paths	Res. 12 S.P. 206
VI/38	United States of America	The meaning of MUF, MOF, JF and EJF	Rep. 256
VI/39	United States of America	Maximum transmission frequencies MUF, MOF, JF and EJF	Rec. 373
VI/40	United States of America	Sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 MHz	Res. 7 S.P. 198
VI/41	United States of America	Proposed modifications to Report 252 — Estimation of sky-wave field strength and transmission loss between the approximate limits of 1·5 and 40 MHz	Rep. 252
VI/42	United States of America	Reconstitution of International Working Party on lightning flash counters	Rep. 254 S.P. 199
VI/43	United States of America	Routine ionospheric sounding	Res. 5, 6
VI/44	United States of America	Basic long-term ionospheric predictions	Res. 10
VI/45	United States of America	Geographical disposition of regular ionospheric observations	Draft Q.
VI/46	United States of America	Improvement in the world-wide ionospheric observing programme	Draft S.P.
VI/47	United States of America	C.C.I.R. Atlas of ionospheric characteristics	Res. 10
VI/48	United States of America	Intermittent communication by meteor-burst propagation	Rep. 251
VI/49	United States of America	Prediction of sporadic-E	Draft Op.
VI/50	C.C.I.R. Secretariat	List of documents issued (VI/1 to VI/50)	
VI/51	United States of America	Proposed modification to Report 264. Predictions of ionospheric field strength or propagation loss for the frequency range between 150 and 1500 kHz	Rep. 264
VI/52	United States of America	Draft Study Programme — Fading of signals propagated by the ionosphere	S.P. 148
VI/53	United States of America	Draft Opinion — Fading of signals propagated by the ionosphere	Op. 10

Doc.	Origin	Title	Reference
VI/54	United States of America	Draft Report — Fading of signals propagated by the ionosphere	Rep. 266
VI/55	United States of America	Proposed modifications to Resolution 12. Sky-wave propagation for frequencies between 150 kc/s and 1500 kc/s	Res. 12
VI/56	Italy	A limiting factor in the technique of back-scatter sounding	Rep. 261 S.P. 203
VI/57	Japan	Sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 MHz. Measurement of HF field strength made at Hiraiso	Res. 7 S.P. 198
VI/58	International Working Party VI/4	Report by the Chairman — The accuracy of predictions for LF/MF sky-wave field strength	Res. 12
VI/59	India	Proposed modification to S.P. 197(VI) — Pulse transmission tests at oblique incidence	Rep. 249 S.P. 197
VI/60	C.C.I.R. Secretariat	Submission of Docs. IV/115(Rev. 1), IV/123 and IV/146	
VI/61	International Working Party VI/2	Report by the Chairman — Revision of world distribution and characteristics of atmospheric radio noise	Res. 8 Rep. 322
VI/62 and Add. 1	International Working Party VI/1	Report by the Chairman — Sky-wave field strength and transmission loss of frequencies between the approximate limits of 1·5 and 40 MHz	Res. 7
VI/63	Chairman Study Group VI	Interim Report — Ionospheric propagation	
VI/64 and Rev. 1	Federal Republic of Germany	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, §§ 1, 2
VI/65	Federal Republic of Germany	Propagation by way of sporadic-E and other anomalous ionization in the E- and F-regions of the ionosphere	S.P. 195, § 1
VI/66	Federal Republic of Germany	Estimation of sky-wave field strength and transmission loss for frequencies between the approximate limits of 1·5 and 40 MHz	S.P. 198, §§ 5, 6
VI/67	Federal Republic of Germany	Measurement of atmospheric radio-noise	S.P. 199, § 4
VI/68	Federal Republic of Germany	Basic prediction information for ionospheric propagation	S.P. 200, §§ 2, 3, 5

Doc.	Origin	Title	Reference
VI/69	Federal Republic of Germany	Long-distance sky-wave propagation at frequencies below 1500 kHz	S.P. 206, § 1
VI/70	Czechoslovak S.R.	Analytical formulae for radio path determination	S.P. 197
VI/71	Czechoslovak S.R.	Velocity and density of charged particles in the exosphere	S.P. 201
VI/72	U.S.S.R.	Cyclical curves of critical frequencies of the F2 ionospheric layer as a basis for foF2 prediction for all phases of a solar cycle	Q. 247, §§ 1, 2 Rep. 246
VI/73	U.S.S.R.	Computer calculation of operating frequency range (MUF and LUF) and field-strength (E) of short-wave radiocommunication	Res. 7, § 5.1 Rep. 252, § 3.2
VI/74	U.S.S.R.	Calculations of radio frequencies reflected from the Es-layer	S.P. 195
VI/75	E.B.U.-O.I.R.T.-U.R.T.N.A.	Medium wave ionospheric propagation in Africa	S.P. 206
VI/76	International Working Party VI/5	Report by the Chairman — Long-distance sky-wave propagation at frequencies below 150 kHz	Res. 13
VI/77	Canada	Operational oblique incidence ionospheric sounding	S.P. 197
VI/78	India	Solar corpuscular activity and ionization density in the F2 layer of the ionosphere	Q. 247 Rep. 246 Rec. 371
VI/79	India	Characteristics of atmospheric radio-noise	Rec. 372 S.P. 199 Rep. 322 Res. 8
VI/80	U.S.S.R.	Angle of arrival with azimuthal deviation from curvature of great circle	S.P. 195, 200
VI/81	U.S.S.R.	Ionospheric signal fading	S.P. 148
VI/82	France	Identification of precursors indicative of short-term variations and evaluation of the reliability of short-term forecasts of ionospheric propagation conditions	Rep. 247 S.P. 194
VI/83	Canada	The significance of sporadic-E as a propagating medium for transmission distances exceeding 2000 km at higher latitudes	S.P. 195, 197 Doc. VI/49 1963-1966
VI/84	Sub-Group VI-E	Ionospheric sounding stations after the international geophysical year (IGY)	
VI/85	Sub-Group VI-A	Revision of Recommendation 313 — Exchange of information for the preparation of short-term forecasts and the transmission of ionospheric disturbance warnings	

Doc.	Origin	Title	Reference
VI/86	Sub-Group VI-A	Draft revision of Resolution 4 — Dissemination of basic indices for ionospheric propagation	
VI/87	Sub-Group VI-A	Revision of Study Programme 194(VI)	
VI/88	Sub-Group VI-B	Revision of Study Programme 203(VI) — Back-scattering	
VI/89	Study Group VI	Summary record of the first meeting	
VI/90	Sub-Group VI-A	Prediction of indices of solar activity	Op. 7
VI/91 and Rev. 1	Sub-Group VI-A	Revision of Report 245 — Prediction of solar index	
VI/92 and Rev. 1	Sub-Group VI-A	Revision of Report 246 — Choice of basic indices for ionospheric propagation	
VI/93	Sub-Group VI-S	Effects of the ionosphere on radio waves used for telecommunication with and between spacecraft beyond the lower atmosphere	Op. 9
VI/94	Sub-Group VI-A	Choice of basic indices for ionospheric propagation	Q. 247
VI/95	Sub-Group VI-C	Draft Resolution — Sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 MHz	
VI/96	Sub-Group VI-C	Estimation of sky-wave field strength and transmission loss for frequencies between the approximate limits of 1·5 and 40 MHz	S.P. 198
VI/97	Sub-Group VI-F	Draft revision of Question 248(VI) — Special problems of radiocommunication associated with the equatorial ionosphere	
VI/98	Study Group VI	Summary record of the second meeting	
VI/99	Sub-Group VI-A	Study Programme 193(VI)	
VI/100	C.C.I.R. Secretariat	List of documents issued (VI/51 to VI/100)	
VI/101	Sub-Group VI-A	Opinion 6	
VI/102	Sub-Group VI-A	Recommendation 371	
VI/103	Sub-Group VI-A	Proposed revision of Report 247 — Identification of precursors indicative of short-term variations and evaluation of the reliability of short-term forecasts of ionospheric propagation conditions	

Doc.	Origin	Title	Reference
VI/104	Sub-Group VI-A	Revision of Report 248 — Availability and exchange of basic data for radio propagation forecasts	
VI/105	Sub-Group VI-B	Revision of Report 261 — Back-scattering	
VI/106	Sub-Group VI-H	Draft Study Programme — Fading of signals propagated by the ionosphere at frequencies below 30 MHz	
VI/107	Sub-Group VI-H	Opinion 10 — Fading of signals propagated by the ionosphere	
VI/108	Sub-Group VI-D	Recommendation of the Sub-Group	S.P. 153, 199 Rep. 258, 322 Rec. 372 Res. 9
VI/109	Sub-Group VI-S	Draft Question — Radio noise within and above the ionosphere	
VI/110	Sub-Group VI-S	Revision of Study Programme 204(VI) — Characteristics of the ionosphere affecting space telecommunication systems	
VI/111	Sub-Group VI-G	Draft Report — Long distance sky-wave propagation at frequencies below 150 kHz	
VI/112	Sub-Group VI-S	Consideration of Doc. VI/60 and attachments (Docs. IV/115, IV/123, IV/146)	
VI/113	Sub-Group VI-F	Proposed revision of Study Programme 196 (VI) — Intermittent communication by meteor-burst propagation	
VI/114 and Rev. 1	Sub-Group VI-F	Proposed revision of Study Programme 202 (VI) — Ionospheric-scatter propagation	
VI/115	Sub-Group VI-F	Revision of Report 251 — Intermittent communication by meteor-burst propagation	
VI/116	Sub-Group VI-E	Draft Recommendation — C.C.I.R. Atlas of ionospheric characteristics	
VI/117 and Rev. 1	Sub-Group VI-E	Draft Report — The meaning of MUF, JF, EJF and MOF	
VI/118 and Corr. 1	Sub-Group VI-B	Proposed revision of Report 255 — Basic prediction information for ionospheric propagation	
VI/119	Sub-Group VI-G	Draft Study Programme — Very low frequency propagation in and through the ionosphere	
VI/120	Sub-Group VI-E	Draft Question — Geographic distribution and programme of regular ionospheric observations	
VI/121	Sub-Group VI-B	Draft Question — Side scatter due to ionospheric irregularities	

Doc.	Origin	Title	Reference
VI/122	Joint Sub-Group VI-B/VI-E	Draft Recommendation — Maximum transmission frequencies MUF, MOF, JF and EJF	
VI/123	Sub-Group VI-E	Draft Study Programme — Improvement in the world-wide ionospheric observing programme for numerical mapping purposes	
VI/124 and Rev. 1	Sub-Group VI-E	Draft Opinion — Routine ionospheric sounding	
VI/125	Sub-Group VI-E	Draft Resolution — Basic long-term ionospheric predictions	S.P. 200
VI/126	Sub-Group VI-D	Draft revision of Resolution 8 — Revision of atmospheric radio-noise data	
VI/127	Sub-Group VI-D	Draft revision of Report 254 — Measurement of atmospheric radio-noise	
VI/128	Sub-Group VI-D	Comments by Sub-Group VI-D on Report 322 to be transmitted to the Chairman of International Working Group VI/2 on atmospheric radio-noise	
VI/129	Sub-Group VI-F	Proposed modifications to Report 260 — Ionospheric-scatter propagation	
VI/130	Sub-Group VI-E	Proposed action on Resolution 11 — Basic prediction information for ionospheric propagation	
VI/131	Sub-Group VI-G	Draft Report — VLF propagation in and through the ionosphere	
VI/132	Sub-Group VI-C	Revision of Report 253 — Systematic measurements of sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 MHz	
VI/133	Sub-Group VI-C	Revision of Report 252 — Estimation of sky-wave field strength and transmission loss between the approximate limits of 1·5 and 40 MHz	S.P. 198
VI/134	Sub-Group VI-H	Draft revision of Report 266 — Fading of signals propagated by the ionosphere	
VI/135	Sub-Grouo VI-F	Draft Question — Propagation by way of sporadic-E and other anomalous ionization	
VI/136	Sub-Group VI-F	Draft Study Programme — Propagation by way of sporadic-E and other anomalous ionization	
VI/137	Sub-Group VI-F	Draft Study Programme — Prediction of sporadic-E	

Doc.	Origin	Title	Reference
VI/138	Sub-Group VI-F	Draft revision of Opinion 8 — Draft Question — Propagation by ducting in the topside ionosphere	—
VI/139	Sub-Group VI-F	Draft Report — High frequency propagation by ducting above the F2 region peak	Op. 8
VI/140	Study Group VI	Summary record of the third meeting	
VI/141	Sub-Group VI-S	Draft Report — Ionospheric effects upon earth-space radio propagation	S.P. 204, 205
VI/142	Sub-Group VI-S	Draft Report — Radio noise within and above the ionosphere	
VI/143	Sub-Group VI-G	Draft Resolution — Sky-wave propagation at frequencies below 150 kHz	S.P. 206
VI/144	Sub-Group VI-G	Proposed revisions to Resolution 12 — Long-distance sky-wave propagation for frequencies between 150 and 1500 kHz	S.P. 206
VI/145	Sub-Group VI-B	Draft revision of Study Programme 200(VI) — Basic prediction information for ionospheric propagation	
VI/146	Sub-Group VI-B	Proposed revision of Report 250 — Long-distance ionospheric propagation without intermediate ground reflection	
VI/147	Sub-Group VI-B	Revision of Study Programme 197(VI) — Ionospheric sounding at oblique incidence	
VI/148	Sub-Group VI-B	Revision of Report 249 — Ionospheric sounding at oblique incidence	
VI/149	Sub-Group VI-G	Draft revision of Report 264 — Predictions of ionospheric field strength and propagation loss for the frequency range between 150 and 1500 kHz	S.P. 206
VI/150	C.C.I.R. Secretariat	List of documents issued (VI/101 to VI/150)	
VI/151	Sub-Groups VI-B, VI-C, VI-G	Draft Report — Questions submitted by the I.F.R.B.	
VI/152	Sub-Group VI-G	Proposed modifications to Study Programme 206(VI) — Long-distance sky-wave propagation at frequencies below 1500 kHz	
VI/153	Sub-Group VI-F	Draft Report — Special problems of HF radiocommunication associated with the equatorial ionosphere	
VI/154	Sub-Group VI-F	Proposed action on Opinion 8 — High frequency propagation by ducting above the F2 region peak	

Doc.	Origin	Title	Reference
VI/155	Study Group VI	Summary record of the fourth meeting	
VI/156	Sub-Group VI-E	Proposed deletion of Resolutions 5 and 6	
VI/157	Sub-Group VI-S	Proposed deletion of Study Programme 205(VI)	
VI/158	Sub-Group VI-F	Draft revision of Report 259	
VI/159	Sub-Group VI-G	Draft Recommendation — Broadcasting on hectometric and kilometric waves in the European Broadcasting Area	
VI/160	Study Group VI	Summary record of the fifth meeting	
VI/161	Study Group VI	Summary record of the sixth meeting	
VI/162	Study Group VI	Summary record of the seventh and last meeting	
VI/163	C.C.I.R. Secretariat	List of participants	
VI/164	C.C.I.R. Secretariat	List of documents issued (VI/151 to VI/164)	
VI/165	Australia	Draft Study Programme (VI) — The absorption of medium frequency sky-waves by close coupling to the extraordinary mode	Draft S.P.
VI/166	Australia	The absorption of medium frequency sky-waves by close coupling to the extraordinary mode	Draft S.P.
VI/167 and Corr. 1	Working Party VI/3	Report by the Chairman of Working Party VI/3 — Basic long-term ionospheric predictions	Res. 10
VI/168	United Kingdom	VLF propagation in and through the ionosphere	Draft Rep. G.2.u
VI/169 and Corr. 1	Japan	Estimation of sporadic-E signal strength	Draft S.P. G.2.ae
VI/170 (IV/224) (V/104)	France	Proposed revision of Question 288(IV) — Frequency utilization above the ionosphere and on the far side of the Moon	Q. 288(IV)
VI/171	France	Proposed additions to Draft Report G.2.aa (VI) — Radio noise within and above the ionosphere	Draft Rep. G.2.aa
VI/172	France	Draft amendment to Draft Report G.2.h(VI) — Availability and exchange of basic data for radio propagation forecasts	Draft Rep. G.2.h
VI/173	Canada	Proposed revision of Draft Report G.2.j(VI) — Long-distance ionospheric propagation without intermediate ground reflection	Draft Rep. G.2.j

Doc.	Origin	Title	Reference
VI/174	O.I.R.T.	Replacement of the Cairo (1938) curves by more accurate curves based on further study of ionospheric propagation of MW and LW	Draft Rep. G.2.w Draft S.P. G.2.al Draft Res. G.2.as
VI/175	India	A formula for planetary F2 layer ionization	Q. 247 Draft Rep. G.2.f Rec. 371
VI/176	United States of America	Proposed modifications to Draft Report G.2.g(VI) — Identification of precursors indicative of short-term variations and evaluation of the reliability of short-term forecasts of ionospheric propagation conditions	Draft Rep. G.2.g
VI/177	United States of America	Proposed modifications to Draft Report G.2.o(VI) — Basic prediction information for ionospheric propagation	Draft Rep. G.2.o
VI/178	United States of America	Proposed modifications to Draft Opinion G.2.an(VI) — Routine ionospheric sounding	Draft Op. G.2.an
VI/179	United States of America	Proposed modifications to Draft Report G.2.x(VI) — Sky-wave propagation at frequencies below 150 kHz	Draft Rep. G.2.x
VI/180	United States of America	Proposed modifications to Draft Study Programme G.2.am(VI) — Fading of signals propagated by the ionosphere	Draft S.P. G.2.am
VI/181	United States of America	Proposed modifications to Draft Report G.2.y(VI) — Fading of signals propagated by the ionosphere	Draft Rep. G.2.y
VI/182	C.C.I.R. Secretariat	Study of the correlation between the basic solar indices for ionospheric propagation	Draft Rep. G.2.f
VI/183 and Add. 1	Working Party VI/3	Report by the Chairman, Working Party VI/3 — C.C.I.R. Atlas of ionospheric characteristics	Res. 10
VI/184	Chairman, Study Group VI	Report by the Chairman, Study Group VI — Ionospheric propagation	
VI/185	United States of America	Proposed modification to Draft Report G.2.ab(VI) — High-frequency propagation by ducting above the F2-region peak	Draft Rep. G.2.ab Q. 316
VI/186	O.I.R.T.	Determination of the sky-wave field strength at short and medium distances (less than 300 km) from recordings of the total field of LW and MW transmitters	Draft Rep. G.2.w Draft S.P. G.2.al
VI/187	O.I.R.T.	Method for prediction of nocturnal sky-wave field strength for the frequency range between 150 and 1500 kHz and distances between 300 and 3000 km	Draft S.P. G.2.al

Doc.	Origin	Title	Reference
VI/188 (X/145)	O.I.R.T.	Computation of protection field strength and interference of sky-waves in the 150-1500 kHz frequency range at distances from 300 to 3000 km	Draft Rec. G.2.c Draft Rep. G.2.w Q. 262(X), 263(X)
VI/189 (I/51) (XIII/112)	Director a.i., C.C.I.R.	Note by the Director a.i. — Radio noise in ships	
VI/190	Japan	Sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 MHz — Measurement of HF field strengths made at Hiraiso	Res. 7 S.P. 198
VI/191	Federal Republic of Germany	Long-distance sky-wave propagation at frequencies below 1500 kHz	S.P. 206, § 1 Rep. 265
VI/192	Czechoslovak S.R.	Some characteristics of ray paths	S.P. 200
VI/193	India	Determination of atmospheric radio noise levels at Trivandrum (8 °29′N, 76° 57′E)	Draft Res. G.2.aq Rep. 322 Rec. 372 S.P. 199
VI/194	E.B.U.	Propagation in the VHF band by way of sporadic-E ionization	S.P. 195
VI/195	France	Draft revision of Draft Report G.2.ab(VI) — Propagation by ducting above the ionosphere	Draft Rep. G.2.ab
VI/196	France	Draft revision of Draft Report G.2.z(VI) — Special problems of HF radiocommunication associated with the equatorial ionosphere	Draft Rep. G.2.z
VI/197	India	Development of a formula for the seasonal and secular characteristics of F2 layer critical frequency (Σ foF2)	S.P. 200
VI/198	India	Statistical characteristics of sudden ionospheric disturbances	S.P. 194 Rep. 247 Op. 6
VI/199	India	Some results of electron content measurements at Delhi using Faraday fading of satellite beacon transmissions	S.P. 204 Rep. 263
VI/200	C.C.I.R. Secretariat	List of documents issued (VI/165 to VI/200)	
VI/201	India	World distribution and characteristics of atmospheric radio noise	Rec. 372 S.P. 199 Rep.322 Res. 8
VI/202	India	World distribution and characteristics of atmospheric radio noise	Rec. 372 S.P. 199 Rep. 322 Res. 8
VI/203	India	Proposed modification to Draft Study Programme 209(VI) — Ionospheric sounding at oblique incidence	S.P. 197, 209

Doc.	Origin	Title	Reference
VI/204	France	Identification of precursors indicative of short-term variations and evaluation of the reliability of short-term forecasts of ionospheric propagation conditions	Draft S.P. G.2.ad
VI/205	Australia	Medium frequency sky-wave field strength predictions for Australia	Draft S.P. G.2.al
VI/206	International Working Party VI/3	Draft Report on the Meeting of International Working Party VI/3	
VI/207	India	Proposed modification to Report 248 — Availability and exchange of basic data for radio propagation forecasts	Rep. 248
VI/208	P.R. of Bulgaria	Field strength of the sky-wave on frequency 827 kHz at quasivertical incidence in medium latitudes	Draft Rep. G.2.w Draft S.P. G.2.al
VI/209	Study Group VI	Summary record of the first meeting	
VI/210	Study Group VI	Revision of Draft Opinion G.2.an(VI) — Routine ionospheric sounding	
VI/211	Study Group VI	Revision of Draft Resolution G.2.ar(VI) — Basic long-term ionospheric predictions	
VI/212	Study Group VI	Revision of Draft Recommendation G.2.d (VI) — C.C.I.R. Atlas of ionospheric characteristics	
VI/213	Study Group VI	Revision of Study Programme 209(VI) — Ionospheric sounding at oblique incidence	
VI/214	Study Group VI	Revision of Study Programme G.2.ak(VI) — Back-scattering	
VI/215	Working Group VI-D	Radio noise in ships	
VI/216	Study Group VI	Revision of Study Programme 199 — Measurement of atmospheric radio noise	S.P. 199
VI/217	Study Group VI	Revision of Draft Study Programme G.2.ag (VI) — Estimation of sky-wave field strength and transmission loss for frequencies between the approximative limits of 1·5 and 40 MHz	Draft S.P. G.2.ag
VI/218	Study Group VI	Revision of Draft Resolution G.2.ap(VI) — Sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 MHz	Draft Res. G.2.ap
VI/219	Study Group VI	Revision of Draft Report G.2.m(VI) — Systematic measurements of sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 MHz	Draft Rep. G.2.m

Doc.	Origin	Title	Reference
VI/220	Study Group VI	Deletion of Study Programme 205(VI)	S.P. 205 Op. 9
VI/221	Study Group VI	Radio-noise within and above the ionosphere	Q. 312
VI/222	Study Group VI	Recommendations of Sub-Group VI-A	
VI/223	Study Group VI	Draft Recommendation G.2.a(VI) — Exchange of information for the preparation of short-term forecasts and the transmission of ionospheric disturbance warnings	
VI/224	Study Group VI	Revision of Draft Report G.2.e(VI) — Prediction of solar index	
VI/225	Study Group VI	Revision of Draft Resolution G.2.ao(VI) — Dissemination of basic indices for ionospheric propagation	
VI/226	Study Group VI	Draft Study Programme G.2.ad(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	
VI/227	Study Group VI	Draft Resolution G.2.at(VI) — Sky-wave propagation at frequencies below 150 kHz	
VI/228	Study Group VI	Draft Study Programme G.2.ai(VI) — Very low frequency propagation in and through the ionosphere	
VI/229 and Rev. 1	Study Group VI	Draft Resolution — Observations needed for basic indices for ionospheric propagation	
VI/230 and Rev. 1	Study Group VI	Draft amendments to Draft Report G.2.h(VI) — Availability and exchange of basic data for radio propagation forecasts	
VI/231 and Rev. 1	Study Group VI	Draft amendments to Draft Report G.2.g (VI) — Identification of precursors indicative of short-term variations and evaluation of the reliability of short-term forecasts of ionospheric propagation conditions	
VI/232	Study Group VI	Draft addition to Draft Report G.2.f(VI) — Choice of basic indices for ionospheric propagation	
VI/233	Study Group VI	Actions of Sub-Group VI-F involving no or negligible change to Interim Meeting documents	
VI/234	Study Group VI-D	Radio-noise documents of Geneva, 1963	

Doc.	Origin	Title	Reference
VI/235	Study Group VI	Revision of Study Programme 199(VI) — Measurement of atmospheric radio noise	
VI/236	Study Group VI	Revision of Draft Resolution G.2.aq(VI) — Revision of atmospheric radio noise data	
VI/237	Study Group VI	Revision of Draft Study Programme G.2.am (VI) — Fading of signals propagated by the ionosphere	
VI/238	Study Group VI	Deletion of Opinion 10 — Fading of signals propagated by the ionosphere	
VI/239	Study Group VI	Question 313(VI) — Geographic distribution and programme of regular ionospheric observations	
VI/240	Study Group VI	Study Programme 313A(VI) — Improvement in the world-wide ionospheric observing programme for numerical mapping purposes	
VI/241	Study Group VI	Deletion of obsolete texts	
VI/242	Study Group VI	Revision of Draft Report G.2.j(VI) — Long-distance ionospheric propagation without intermediate ground reflection	
VI/243	Study Group VI	Revision of Draft Report G.2.t(VI) — Back-scattering	
VI/244	Study Group VI	Revision of Question 314(VI)	
VI/245	Study Group VI	Revision of Draft Report G.2.i(VI) — Ionosphere sounding at oblique incidence	
VI/246	Study Group VI	Summary record of the second meeting	
VI/247	Study Group VI	Draft Resolution — Use of the electronic computer in predicting basic indices for ionospheric propagation	
VI/248	Study Group VI	Revision of Draft Report G.2.v(VI)	
VI/249	Study Group VI	Study Programme 208(VI)	
VI/250	C.C.I.R. Secretariat	List of documents issued (VI/201 to VI/250)	
VI/251	Study Group VI	Revision of Draft Report G.2.aa(VI)	
VI/252	E.B.U.	Attenuation of the diurnal sky-wave	S.P. 206
VI/253	C.C.I.R. Secretariat	Submission of Doc. V/110(XII/1) — Propagation data required for MF broadcasting systems	

Doc.	Origin	Title	Reference
VI/254	Study Group VI	Propagation by way of sporadic-E and other anomalous ionization in the E- and F-regions of the ionosphere	Draft S.P. G.2.ae
VI/255	Study Group VI	Approval of Draft Question G.2.ac(VI) and Question 316(VI)	
VI/256	Study Group VI	Draft Report — Ionospheric scatter propagation	
VI/257	Study Group VI	Propagation by way of sporadic-E and other anomalous ionization	
VI/258	Study Group VI	Draft Recommendation G.2.c(VI) — Sky-wave propagation curves between 300 km and 3500 km, between 150 kHz and 1500 kHz in the European Broadcasting Area	
VI/259 and Rev. 1	Study Group VI	Revision of Draft Report G.2.o(VI) — Basic prediction information for ionospheric propagation	
VI/260	Study Group VI	Draft Revision of Draft Report G.2.ab(VI) — High frequency propagation by ducting above the maximum of the F region	
VI/261	Study Group VI	Revision of Draft Report G.2.z(VI) — Special problems of HF radiocommunication associated with the equatorial ionosphere	
VI/262	Study Group VI	Draft Report G.2.x(VI) — Long distance sky-wave propagation at frequencies below 150 kHz	
VI/263	Study Group VI	Draft Resolution G.2.as(VI) — Sky-wave propagation for frequencies between 150 kHz and 1500 kHz	
VI/264	Study Group VI	Draft Study Programme G.2.ah(VI) — Basic prediction information for ionospheric propagation	
VI/265	Study Group VI	Summary record of the third meeting	
VI/266	Study Group VI	Retention of Recommendation 372 and Report 322 — Use of atmospheric radio-noise data	
VI/267	Study Group VI	Future revision of Report 322 — World distribution of atmospheric radio noise	
VI/268	Study Group VI	Report by the Chairman, Working Party VI/4 — Draft Report on studies of LF and MF sky-wave propagation in various geographical areas	
VI/269	Study Group VI	Draft revision of Report G.2.n(VI)	

Doc.	Origin	Title	Reference
VI/270	Study Group VI	Revision of Draft Report G.2.l(VI) — Estimation of sky-wave field strength and transmission loss between the approximate limits of 1·5 and 40 MHz	
VI/271	Study Group VI	Draft Recommendation G.2.b(VI) — Definitions of maximum transmission frequencies	
VI/272	Study Group VI	Approval of Draft Study Programme G.2.al(VI)	
VI/273	Study Group VI	Revision of Draft Report G.2.y(VI) — Fading of signals propagated by the ionosphere	
VI/274	Study Group VI	Draft Report G.2.u(VI) — VLF propagation in and through the ionosphere	
VI/275	Working Group VI-F	Draft Report G.2.r(VI) — Propagation by way of sporadic-E and other anomalous ionization	S.P. 195
VI/276	Study Group VI	Summary record of the fourth meeting	
VI/277	Study Group VI	Draft Report G.2.q.(VI) — Questions submitted by the I.F.R.B.	
VI/278 and Add. 1	Study Group VI	Draft Report G.2.w(VI) — Predictions of ionospheric field strength and propagation loss for the frequency range between 150 kHz and 1500 kHz	
VI/279	Study Group VI	Opinion 8 — High-frequency propagation by ducting above the F2-region peak	
VI/280	Study Group VI	Study Programme 315A(VI) — Prediction of sporadic-E	
VI/281	Study Group VI	Draft New Report — Prediction of sporadic-E at temperate latitudes	S.P. 315A
VI/282	Study Group VI	Revision of Draft Report G.2.p(VI) — Maximum transmission frequencies	Draft Rec. G.2.b
VI/283	Study Group VI	Summary record of the fifth meeting	
VI/284	Study Group VI	Report by the Chairman, International Working Party VI/1 — Sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 MHz	
VI/285	Study Group VI	Draft Resolution — Predictions of the LF and MF sky-wave field strength for short distances in Africa	

Doc.	Origin	Title	Reference
VI/286	Study Group VI	Summary record of the sixth meeting	
VI/287	Study Group VI	Summary record of the seventh and last meeting	
VI/288	Study Group VI	Status of texts	
VI/289	C.C.I.R. Secretariat	List of documents issued (VI/251 to VI/289)	

LIST OF DOCUMENTS
OF THE XIth PLENARY ASSEMBLY ESTABLISHED BY STUDY GROUP VI

Doc.	Title	Final Text
VI/1001	Routine ionospheric sounding	Op. 22
VI/1002	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. 10A/VI
VI/1003	Estimation of sky-wave field strength and transmission loss for frequencies between the approximate limits of 1·5 and 40 MHz	S.P. 11A/VI
VI/1004	Sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 MHz	Res. 7-1
VI/1005	Radio noise within and above the ionosphere	Q. 7/VI
VI/1006	Sky-wave propagation at frequencies below 150 kHz	Res. 13-1
VI/1007	Dissemination of basic indices for ionospheric propagation	Res. 4-1
VI/1008	Basic long-term ionospheric predictions	Res. 10-1
VI/1009	C.C.I.R. Atlas of ionospheric characteristics	Rec. 434
VI/1010	Ionospheric sounding at oblique incidence	S.P. 12A/VI
VI/1011	Exchange of information for the preparation of short-term forecasts and the transmission of ionospheric disturbance warnings	Rec. 313-1
VI/1012	Back-scattering	S.P.14A/VI
VI/1013	Intermittent communication by meteor-burst propagation	S.P. 15A/VI
VI/1014	Fading of signals propagated by the ionosphere	S.P. 16A/VI
VI/1015	Geographic distribution and programme of regular ionospheric observations	Q. 2/VI
VI/1016 and Rev. 1	Improvement in the world-wide ionospheric observing programme for numerical mapping purposes	S.P. 2A/VI
VI/1017 and Rev. 1	Use of the electronic computer in predicting basic indices for ionospheric propagation	Res. 30
VI/1018	Very low frequency propagation in and through the ionosphere	S.P. 18A/VI
VI/1019	Observations needed to provide basic indices for ionospheric propagation	Op. 23
VI/1020	Ionospheric-scatter propagation	S.P. 13A/VI
VI/1021	Revision of atmospheric radio noise data	Res. 8-1
VI/1022	Side scatter due to ionospheric irregularities	Q. 3/VI
VI/1023	Special problems of HF radiocommunication associated with the equatorial ionosphere	Q. 6/VI

Doc.	Title	Final Text
VI/1024	Propagation by way of sporadic-E and other anomalous ionization	S.P. 4B/VI
VI/1025	Propagation by ducting above the ionization maximum of the F region	Q. 5/VI
VI/1026	Propagation by way of sporadic-E and other anomalous ionization	Q. 4/VI
VI/1027	Basic prediction information for ionospheric propagation	S.P. 9A/VI
VI/1028	Characteristics of the ionosphere affecting space telecommunication systems	S.P. 19A/VI
VI/1029	Sky-wave propagation for frequencies between 150 kHz and 1500 kHz	Res. 12-1
VI/1030	Definitions of maximum transmission frequencies	Rec. 373-1
VI/1031	Sky-wave propagation curves between 300 km and 3500 km, between 150 kHz and 1500 kHz in the European Broadcasting Area	Rec. 435
VI/1032	Sky-wave propagation at frequencies below 1500 kHz	S.P. 17A/VI
VI/1033	Prediction of sporadic-E	S.P. 4A/VI
VI/1034	C.C.I.R. Atlas of ionospheric characteristics	Rep. 340
VI/1035	Maximum transmission frequencies	Rep. 256-1
VI/1036	High frequency propagation by ducting above the maximum of the F region	Rep. 341
VI/1037	Fading of signals propagated by the ionosphere	Rep. 266-1
VI/1038	VHF propagation by way of sporadic-E and other anomalous ionization	Rep. 259-1
VI/1039	Sky-wave propagation at frequencies below 150 kHz	Rep. 265-1
VI/1040	Choice of basic indices for ionospheric propagation	Rep. 246-1
VI/1041	Identification of precursors indicative of short-term variations and evaluation of the reliability of short-term forecasts of ionospheric propagation conditions	Rep. 247-1
VI/1042	Question submitted by the I.F.R.B.	Rep. 257-1
VI/1043	Measurement of atmospheric radio-noise	Rep. 254-1
VI/1044	Estimation of sky-wave field strength and transmission loss between the approximate limits of 1·5 and 40 MHz	Rep. 252-1
VI/1045	Radio noise within and above the ionosphere	Rep. 342
VI/1046	Ionospheric effects upon earth-space radio propagation	Rep. 263-1
VI/1047	Prediction of solar index	Rep. 245-1
VI/1048	Availability and exchange of basic data for radio propagation forecasts	Rep. 248-1
VI/1049	Intermittent communication by meteor-burst propagation	Rep. 251-1
VI/1050	List of documents issued (VI/1001 to VI/1061)	
VI/1051	Ionosphere sounding at oblique incidence	Rep. 249-1

Doc.	Title	Final Text
VI/1052	Prediction of sporadic-E at temperate latitudes	Rep. 344
VI/1053	Basic prediction information for ionospheric propagation	Rep. 255-1
VI/1054	VLF propagation in and through the ionosphere	Rep. 262-1
VI/1055	Predictions of ionospheric field-strength and propagation loss for the frequency range between 150 and 1500 kHz	Rep. 264-1
VI/1056	Predictions of the LF and MF sky-wave field strengths for short distances in Africa	Res. 31
VI/1057	Ionospheric-scatter propagation	Rep. 260-1
VI/1058	Systematic measurements of sky-wave field strength and transmission loss at frequencies between the approximate limits of 1·5 and 40 MHz	Rep. 253-1
VI/1059	Special problems of HF radiocommunication associated with the equatorial ionosphere	Rep. 343
VI/1060	Long-distance ionospheric propagation without intermediate ground reflection	Rep. 250-1
VI/1061	Back-scattering	Rep. 261-1

PRINTED IN SWITZERLAND