INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

C.C.I.R.

XIIth PLENARY ASSEMBLY

NEW DELHI, 1970

VOLUME II

PART 1

PROPAGATION IN NON-IONIZED MEDIA
(STUDY GROUP 5)

Published by the

INTERNATIONAL TELECOMMUNICATION UNION

GENEVA, 1970

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PROPAGATION

IN

NON-IONIZED

MEDIA

RECOMMENDATIONS AND REPORTS

5A Propagation predictions and curves, and interference problems

5B Radio meteorology

5C Terrain effects

5D Ground-wave propagation

QUESTIONS AND STUDY PROGRAMMES
RESOLUTIONS AND OPINIONS

(Study Group 5)

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DISTRIBUTION OF TEXTS OF THE XIIth PLENARY ASSEMBLY OF THE C.C.I.R. IN VOLUMES I TO VII

Volumes I to VII, XIIth Plenary Assembly, contain all the valid texts of the C.C.I.R.

1. Recommendations, Reports, Resolutions, Opinions

1.1 *Numbering of these texts*

Recommendations, Reports, Resolutions and Opinions are numbered according to the system in force since the Xth Plenary Assembly.

When one of these texts is modified, it retains its number to which is added a dash and a figure indicating how many revisions have been made. For example: Recommendation 253 indicates the original text is still current; Recommendation 253-1 indicates that the current text has been once modified from the original, Recommendation 253-2 indicates that there have been two successive modifications of the original text, and so on.

The Tables which follow show only the original numbering of the current texts, without any indication of successive modifications that may have occurred. For further information about this numbering scheme, please refer to Volume VII of the C.C.I.R.

1.2 *Recommendations*

Number	Volume	Number	Volume	Number	Volume
45	VI	265, 266	V	374-376	III
48, 49	V	268	IV	377-379	I
77	VI	270	IV	380-393	IV
80	V	275, 276	IV	395-406	IV
100	I	279	IV	407-421	V
106	III	283	IV	422, 423	VI
139, 140	V	289, 290	IV	427-429	VI
162	III	302	IV	430, 431	III
166	I	304-306	IV	432, 433	I
182	I	310, 311	II	434, 435	II
205	V	313	II	436	III
214-216	V	314	IV	439-441	VI
218, 219	VI	325-334	I	442, 443	I
224	VI	335-340	III	444-446	IV
237	I	341	I	447-451	V
239	I	342-349	III	452, 453	II
240	III	352-359	IV	454-461	III
246	III	361	VI	462-466	IV
257, 258	VI	362-367	IV	467-474	V
262	V	368-373	II	475-478	VI

1.3 *Reports*

Number	Volume	Number	Volume	Number	Volume
19	III	226	IV	341-344	II
32	V	227-231	II	345-357	III
42	III	233-236	II	358, 359	VI
79	V	238, 239	II	361	VI
93	VI	241	II	362-364	III
106, 107	III	244-251	II	366	III
109	III	252	(1)	367-373	I
111	III	253-256	II	374-393	IV
112	I	258-266	II	394	VI
122	V	267	III	395-397	IV
130-137	IV	269-271	III	398-401	V
176-194	I	272, 273	I	403-407	V
195	III	275-282	I	409-412	V
196	I	283-290	IV	413-415	(1)
197, 198	III	292-294	V	416-423	I
200, 201	III	297-308	V	424-432	II
202	I	311-316	V	433-439	III
203	III	318-320	VI	440	(1)
204-214	IV	321	III	441	III
215	V	322	(1)	442-456	IV
216	VI	324-334	I	457-498	V
218, 219	IV	335	III	499-515	VI
222-224	IV	336-339	II	516	V
		340	(1)		

(1) Published separately.

1.4 *Resolutions*

Number	Volume	Number	Volume	Number	Volume
2-4	II	21-23	III	39, 40	VII
7, 8	II	24	VII	41-44	I
10	II	26, 27	VII	45-51	II
12, 13	II	30	II	52-54	III
14	III	33	VII	55, 56	IV
15, 16	I	36, 37	VII	57, 58	V
20	VI	38	V VII		

1.5 *Opinions*

Number	Volume	Number	Volume	Number	Volume
2	I	22, 23	II	32-35	I
11	I	24	VI	36, 37	III
13, 14	IV	26-28	III	38-41	V
15, 16	V	29, 30	I	42, 43	VI

2. Questions and Study Programmes

2.1 *Text numbering*

2.1.1 *Questions*

Questions are numbered in a different series for each Study Group; where applicable a dash and a figure added after the number of the Question indicate successive modifications. The number of a Question is completed by an *Arabic figure indicating the relevant Study Group.* For example:

— Question 1/10 would indicate a Question of Study Group 10 with its text in the original state;

— Question 1-1/10 would indicate a Question of Study Group 10, whose text has been once modified from the original; Question 1-2/10 would be a Question of Study Group 10, whose text has had two successive modifications.

2.1.2 *Study Programmes*

Study Programmes are numbered to indicate the Question from which they are derived if any, the number being completed by a capital letter which is used to distinguish several Study Programmes which derive from the same Question. For example:

— Study Programme 1A/10, which would indicate that the current text is the original version of the text of the first Study Programme deriving from Question 1/10;

— Study Programme 1C/10, which would indicate that the current text is the original version of the text of the third Study Programme deriving from Question 1/10;

— Study Programme 1A-1/10 would indicate that the current text has been once modified from the original, and that it is the first Study Programme of those deriving from Question 1/10;

— Study Programme 3-1A/10 would indicate that the current text is the original and that this Study Programme is the first deriving from Question 3-1/10, which has itself been once modified from the original;

— Study Programme 3-1B-1/10 would indicate that the current text has been once modified from the original, and that this Study Programme is the second of the group deriving from Question 3-1/10, which has itself been once modified from the original.

It should be noted that a Study Programme may be adopted without it having been derived from a Question; in such a case it is simply given a sequential number analogous to those of other Study Programmes of the Study Group, except that on reference to the list of relevant Questions it will be found that no Question exists corresponding to that number.

Also, the up-to-date number of the Question concerned is used in assembling the number of a Study Programme; this is to facilitate reference to the Volumes, but does not exclude the possibility of the Study Programme having been evolved before the latest version of the Question.

2.2 *Arrangement of Questions and Study Programmes*

The plan shown on page 8 indicates the Volume in which the texts of each Study Group are to be found, and so reference to this information will enable the text of any desired Question or Study Programme to be located.

PLAN OF VOLUMES I TO VII
XIIth PLENARY ASSEMBLY OF THE C.C.I.R.

(New Delhi, 1970)

VOLUME I	Spectrum utilization and monitoring (Study Group 1).
VOLUME II (Part 1)	Propagation in non-ionized media (Study Group 5).
VOLUME II (Part 2)	Ionospheric propagation (Study Group 6).
VOLUME III	Fixed service at frequencies below about 30 MHz (Study Group 3). Standard frequencies and time signals (Study Group 7). Vocabulary (CIV).
VOLUME IV (Part 1)	Fixed service using radio-relay systems (Study Group 9). Coordination and frequency sharing between communication-satellite systems and terrestrial radio-relay systems (subjects common to Study Groups 4 and 9).
VOLUME IV (Part 2)	Fixed service using communication satellites (Study Group 4). Space research and radioastronomy (Study Group 2).
VOLUME V (Part 1)	Broadcasting service (Sound) (Study Group 10). Problems common to sound broadcasting and television (subjects common to Study Groups 10 and 11).
VOLUME V (Part 2)	Broadcasting service (Television) (Study Group 11). Transmission of sound broadcasting and television signals over long distances (CMTT).
VOLUME VI	Mobile services (Study Group 8).
VOLUME VII	Information concerning the XIIth Plenary Assembly. Structure of the C.C.I.R. Complete list of C.C.I.R. texts.

Note. — To facilitate reference, page numbering is identical in all three versions of each Volume, that is, in English, French and Spanish.

VOLUME II

PART 1

INDEX *

PROPAGATION IN NON-IONIZED MEDIA

(Study Group 5)

* In this Volume, Recommendations and Reports dealing with the same subject are collected together. These texts are numbered in such a manner that they cannot be presented in numerical order and at the same time, in numerical sequence of pages. Consequently, this index, in numerical order of texts, does not follow the numerical sequence of pages.

QUESTIONS AND STUDY PROGRAMMES

RESOLUTIONS

OPINIONS

There are no Opinions concerning the work of this Study Group.

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PROPAGATION IN NON-IONIZED MEDIA

STUDY GROUP 5

Terms of reference :

To study the propagation of radio waves (including radio noise)
— at the surface of the earth,
— through the non-ionized regions of the earth's atmosphere,
— in space where the effect of ionization is negligible,
with the object of improving communication.

Chairman : J. A. Saxton (United Kingdom)
Vice-Chairman : A. Kalinin (U.S.S.R.)

INTRODUCTION BY THE CHAIRMAN, STUDY GROUP 5

Study Group 5 of the C.C.I.R. is the successor to former Study Group V, the change in nomenclature resulting from the rearrangement of the Study Groups that was approved at the XIIth Plenary Assembly in New Delhi in 1970. In fact the rearrangement did not affect Study Group V in any large degree, and it will be found that all relevant Study Group V texts from New Delhi are now attributed to Study Group 5.

Study Group V held two meetings between the XIth Plenary Assembly, Oslo, 1966 and the XIIth Plenary Assembly, New Delhi, 1970. These were an Interim Meeting at Boulder, Colorado, in 1968 and a Final Meeting at Geneva in 1969.

Dr. R. L. Smith-Rose (United Kingdom) retired from the Chairmanship of the Study Group at the Plenary Assembly in New Delhi after leading its work since the creation of the Group in 1948. The comprehensive nature of the activities of the Study Group owes much to his influence.

1. Scope of the Study Group's work

While the Study Group continues to have contributions to make to the further understanding of ground wave propagation, including some studies at frequencies below 30 MHz, the emphasis is now mainly on the investigation of tropospheric and terrain effects at frequencies above 30 MHz. These investigations are of fundamental importance to the further development of both terrestrial and space telecommunication services themselves and are essential to the determination of the criteria governing the sharing of frequencies between these services. The Recommendations and Reports of the Study Group approved at the Plenary Assembly in New Delhi will therefore contribute significantly to the basic information required for the World Administrative Radio Conference for Space Telecommunications of 1971.

The full scope of the studies being pursued and the results which have been derived from investigations already made are presented in detail in the texts which follow these introductory remarks.

2. Some problems of particular interest

While some of the studies proposed are particularly relevant to terrestrial services and others are primarily concerned with space services, many of them in fact have significance for both services, especially in so far as the coexistence of the two services is involved.

Recommendations exist for broadcasting and land mobile services for which improvements are possible in the light of new data: more work is required for aeronautical mobile services for which however a Report providing useful guidance has been drawn up.

Extensive studies have been made of transmission loss over point-to-point terrestrial paths. No Recommendations concerning a single preferred method have yet been possible but Report 244-2 mentions alternative methods having applications in different circumstances.

Important areas requiring further study concern:

- propagation over mixed paths;
- shielding effects of obstacles and scattering by them;
- transmission loss at frequencies greater than 3 GHz (terrestrial);
- transmission loss variability in Earth-space paths;
- interference probabilities between space and terrestrial services e.g. effects of precipitation scatter;
- frequency allocations have been made up to 40 GHz, and further information about propagation factors such as absorption and scattering to this limit and indeed beyond is needed;
- radio-meteorological considerations in relation to all of the above.

While the manner in which the Study Group is tackling the above problems is described in detail in the full texts of the Questions and associated Study Programmes included in this Volume, the following points in relation to three particular topics are worthy of special mention.

2.1 *Radio-meteorology*

The manner in which meteorological conditions affect propagation at frequencies above 30 MHz is the dominant factor in such propagation and it is vitally important that data should be obtained for as wide a variation of climatic conditions as possible. An Interim Working Party of experts (see Resolution 3-1) is charged with continuing studies in this field. The matter is of particular importance in tropical and semi-tropical areas. Since many of the new or developing countries are situated in these areas it is clear that such countries can make a major contribution to progress by carrying out propagation measurements and presenting their results to the Study Group for consideration and incorporation in its Reports and Recommendations. Points of particular importance are given in Questions 2-1/5 and 8/5 and the appropriate parts of Study Programmes 5-1B-1/5, 5-1C-1/5, 5-1D-1/5, 5-1E-1/5.

2.2 *Sharing of frequencies*

With the further expansion of space and terrestrial systems operating at frequencies above about 1 GHz it is obvious that the efficient use of the spectrum will demand the maximum degree of frequency sharing which is economically feasible. Efforts towards achieving this objective are therefore of the utmost urgency. Relevant studies are included in Question 5-1/5 and the associated Study Programmes 5-1A-1/5, 5-1B-1/5, 5-1D-1/5, 5-1F-1/5. This work is one of the important responsibilities of a further Interim Working Party. (See Resolution 2-1.)

It should be borne in mind that, in view of the absence of reliable propagation data for many tropical areas (see above), the actual sharing of frequencies between different services in such areas could lead to difficulties which cannot be foreseen at the present time.

Here again, though problems of frequency sharing may not appear to be so immediately urgent in some countries, these problems should nevertheless be considered by all Administrations in the early planning stages of new systems.

2.3 *Application of computer techniques*

While the application of computer techniques to the determination of transmission loss for point-to-point paths is well established, up to the present, broadcast coverage estimations have largely been based on empirical curves derived from observations at a number of locations in the service areas of typical operational transmitters. It is true that computing techniques have for some time been applied to the problem of the siting of co-channel transmitters to avoid interference, but it is only now that these techniques are being seriously used in the determination of broadcast coverage areas, based on a statistical evaluation of many point-to-point paths within an appropriate area. Considerable progress is to be expected from these developments.

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SECTION 5A: PROPAGATION PREDICTIONS AND CURVES, AND INTERFERENCE PROBLEMS

RECOMMENDATIONS AND REPORTS

Recommendations

RECOMMENDATION 311-1

PRESENTATION OF DATA IN STUDIES OF TROPOSPHERIC-WAVE PROPAGATION

Broadcasting and television

(1953 - 1956 - 1959 - 1970)

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 and television services in the frequency band 30 MHz — 18 GHz;

(b) that it is important to determine how the field strength 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-strength 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. 1 μV/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, wherever 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.

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

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

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

An amplitude Gaussian distribution for a field strength, F, measured in dB (log-normal distribution) is given by:

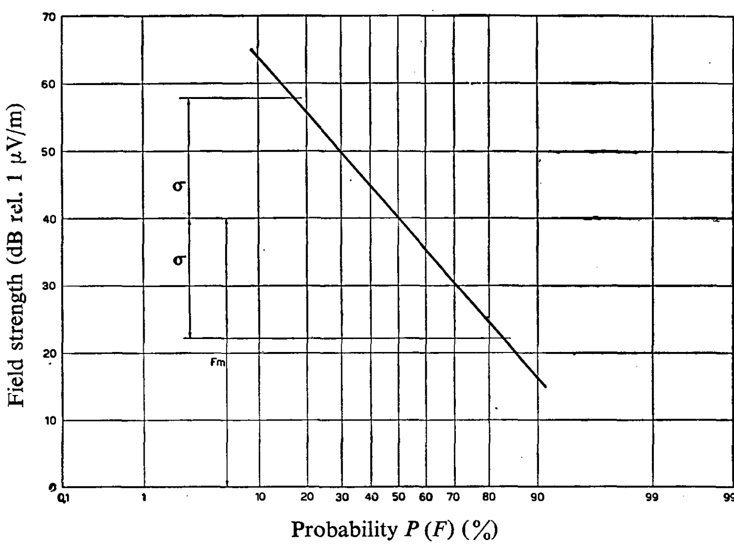
$$P(F) = \frac{1}{\sigma\sqrt{2\pi}} \int_{F}^{\infty} \exp\left(-(f - F_m)^2/2\sigma^2\right) df$$

$P(F)$ 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 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;

(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 239-2);

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 239-2, § 4.2.

1.6 A method for determining field strengths over mixed land and sea paths is described in Report 239-2.

* 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.

** It must be emphasised 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.

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.

   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 239-2.

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 239-2.

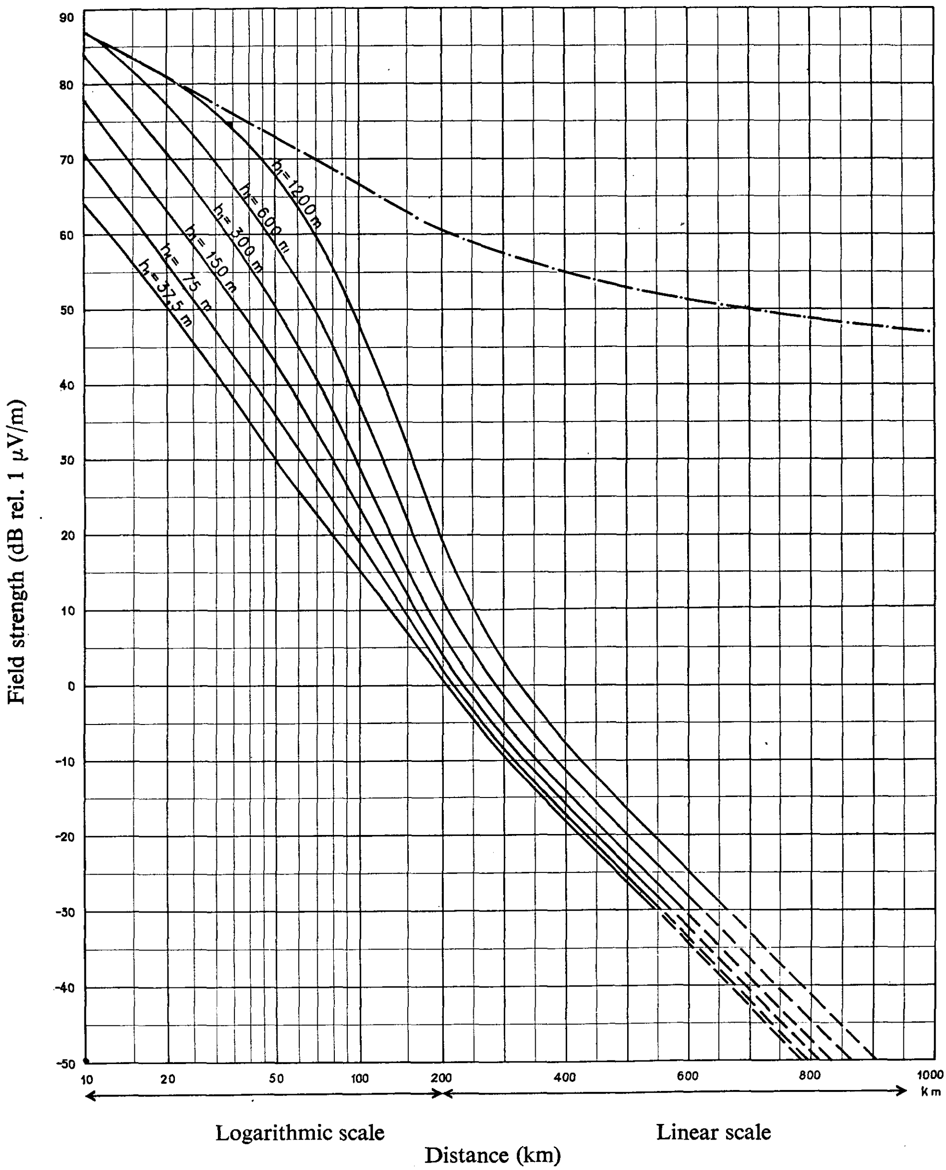


FIGURE 1

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 region; 50% of the time; 50% of the locations; h_2 = 10 m.

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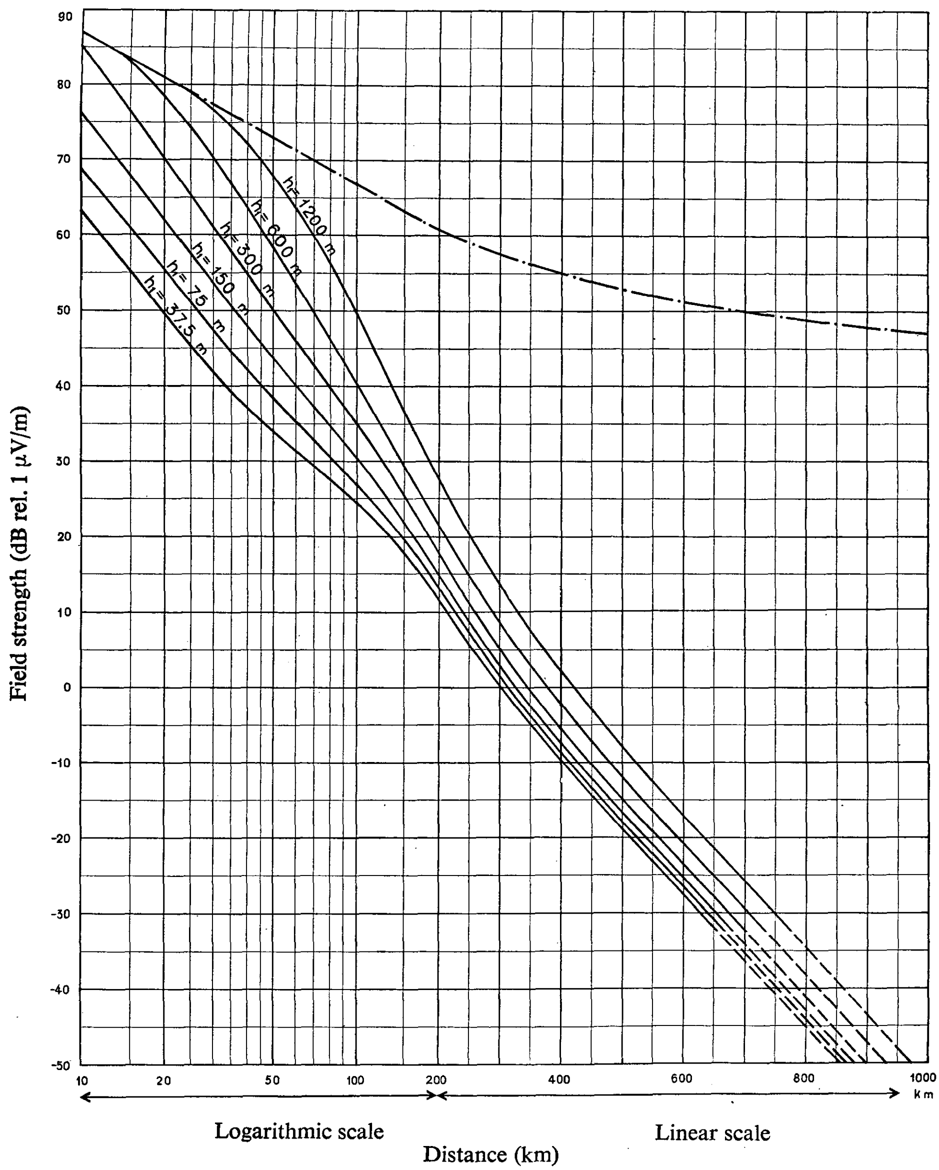

FIGURE 2

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

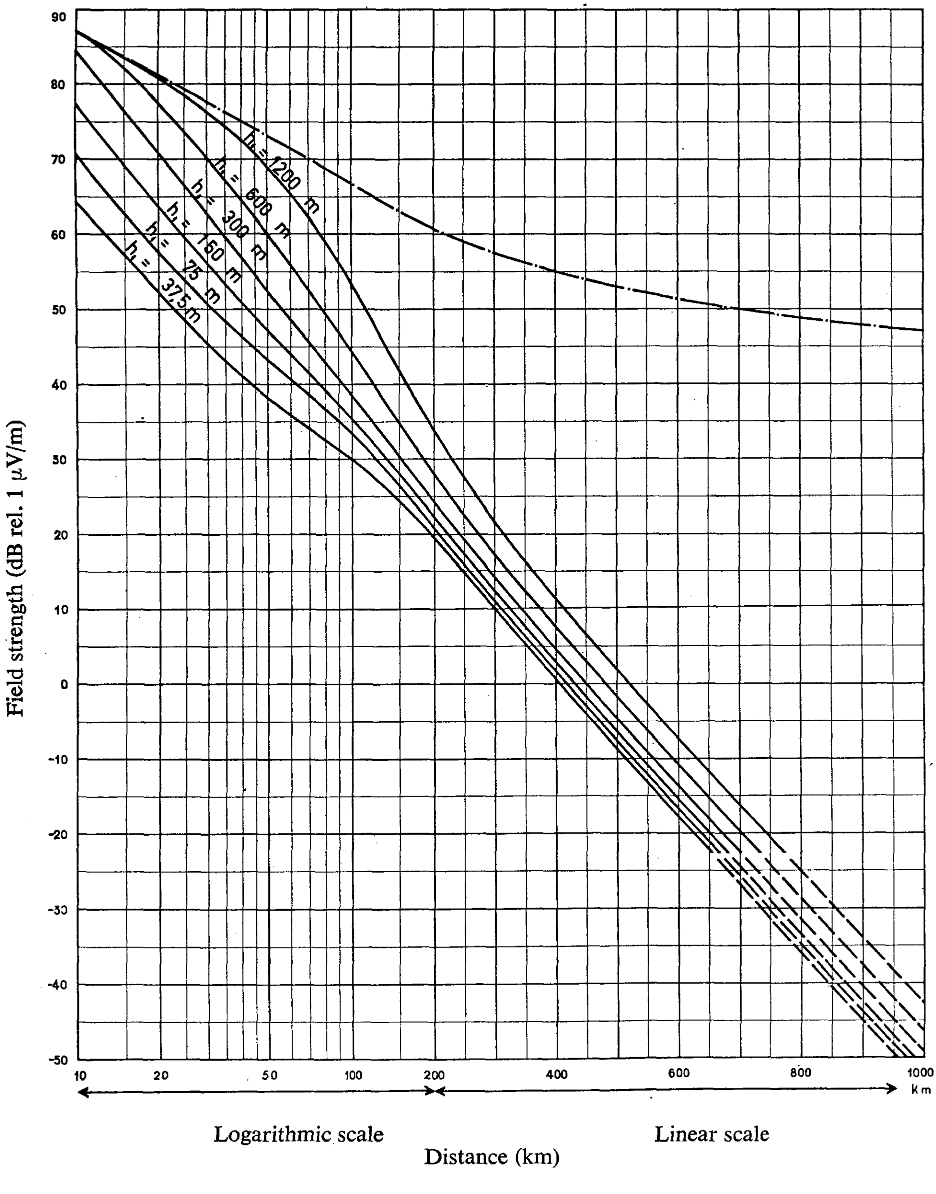

FIGURE 3

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.

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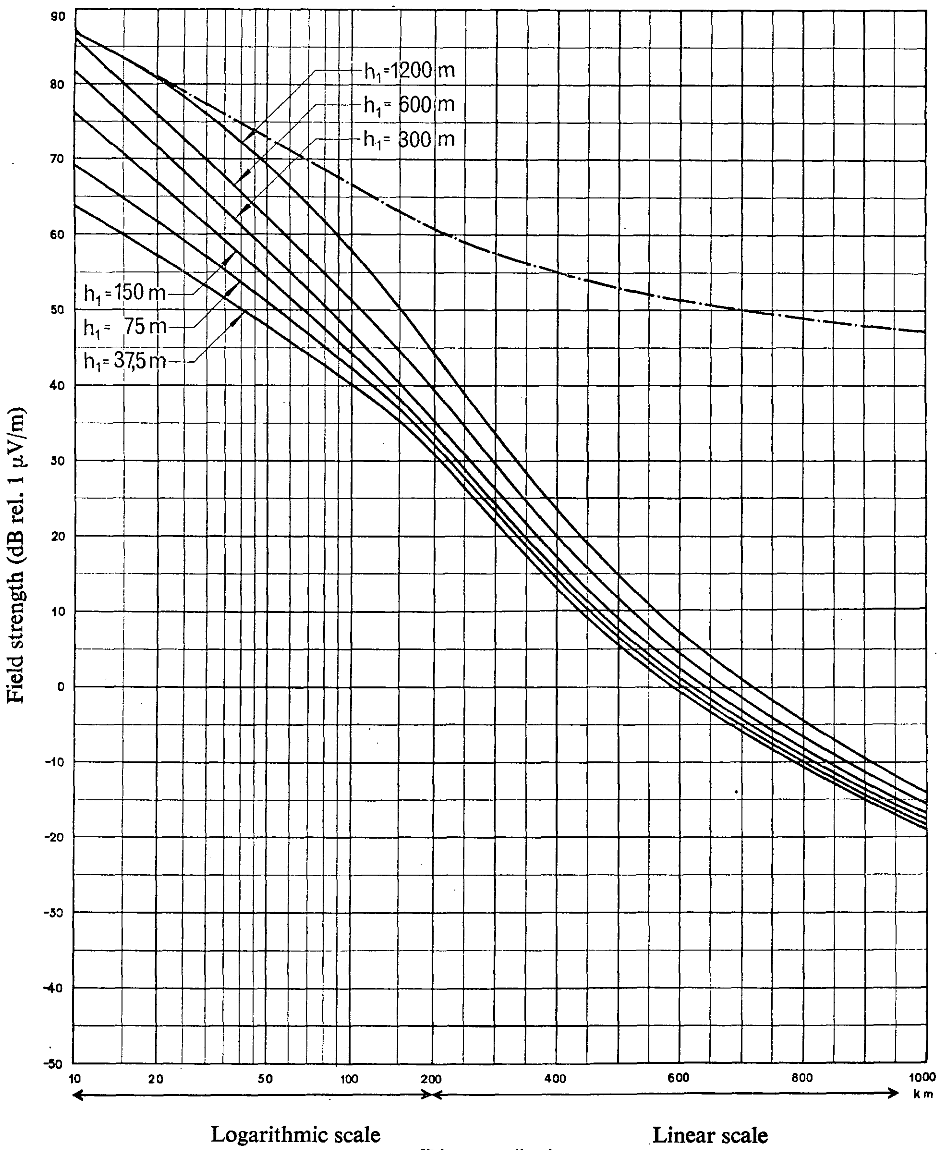

FIGURE 4

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.

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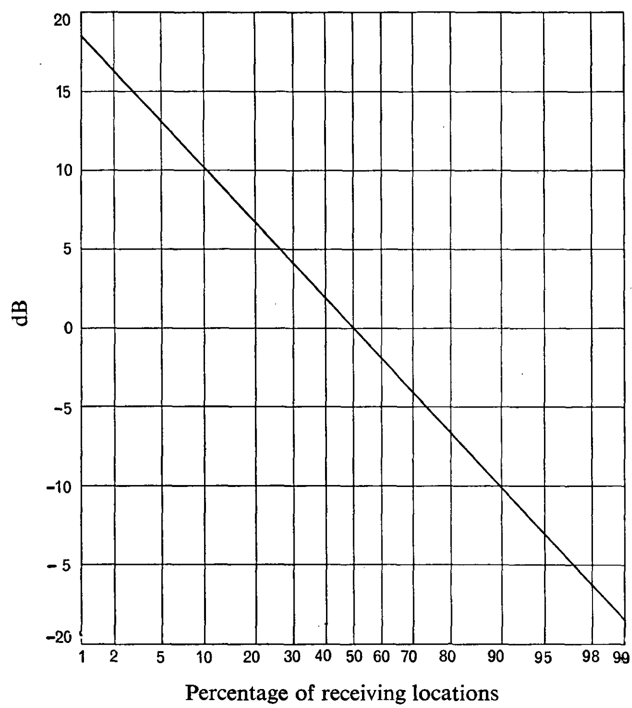

FIGURE 5

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)

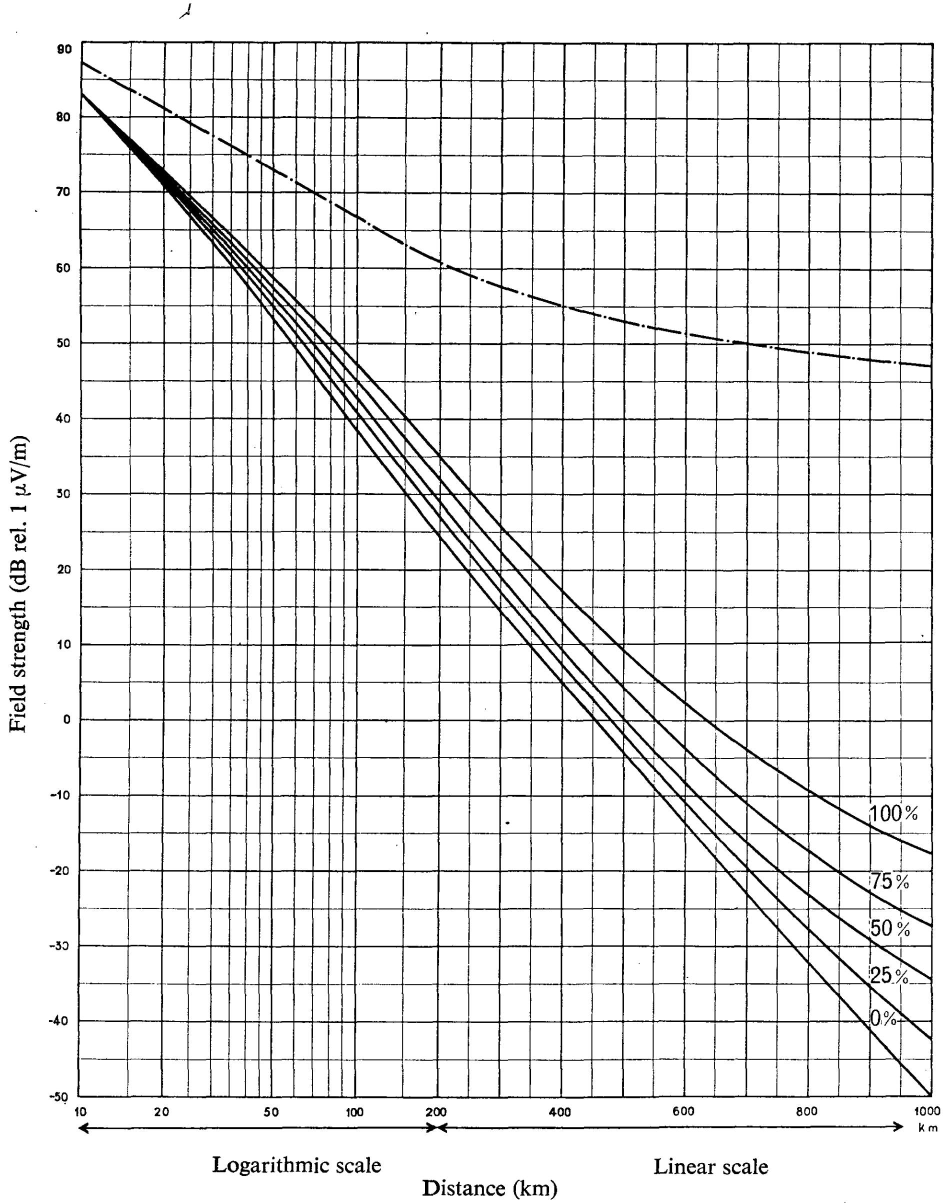

FIGURE 6

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).

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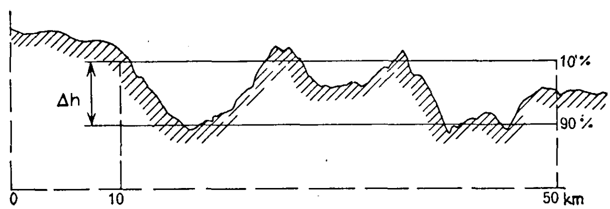

Transmitter

FIGURE 7

Definition of the parameter Δh

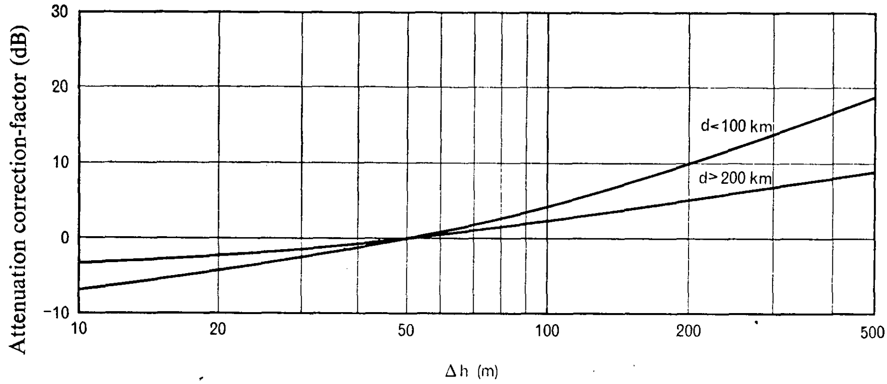

FIGURE 8*a*

Attenuation correction-factor as a function of Δh *for frequencies 150–250 MHz (Band III)*
(Parameter d represents the distance from transmitter)

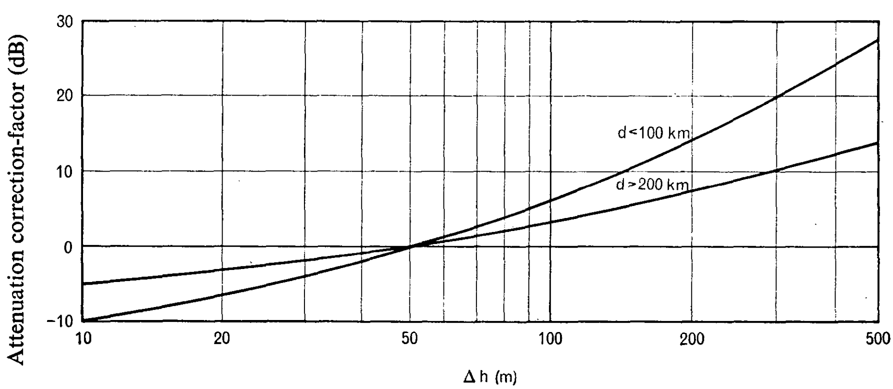

FIGURE 8*b*

Attenuation correction-factor as a function of Δh *for frequencies 450–1000 MHz (Bands IV and V)*
(Parameter d represents the distance from transmitter)

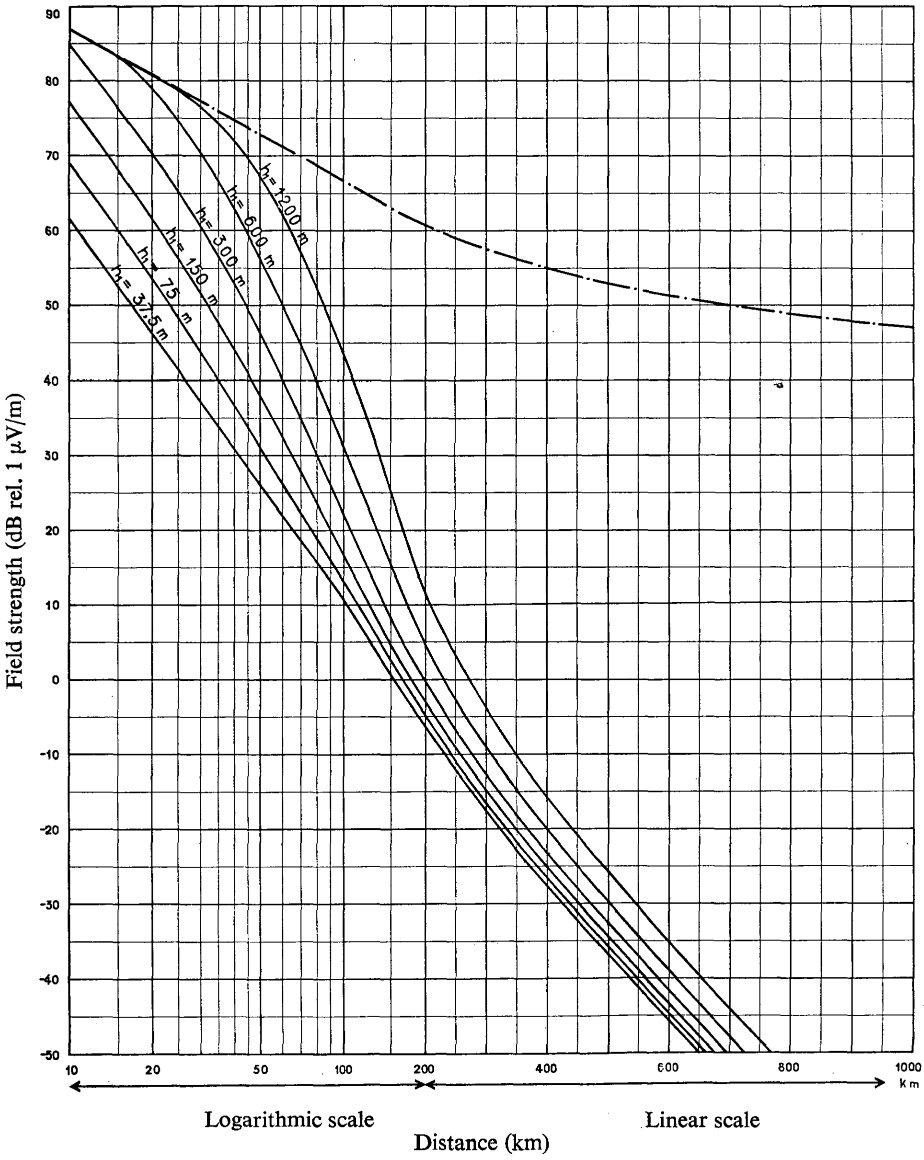

FIGURE 9

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.

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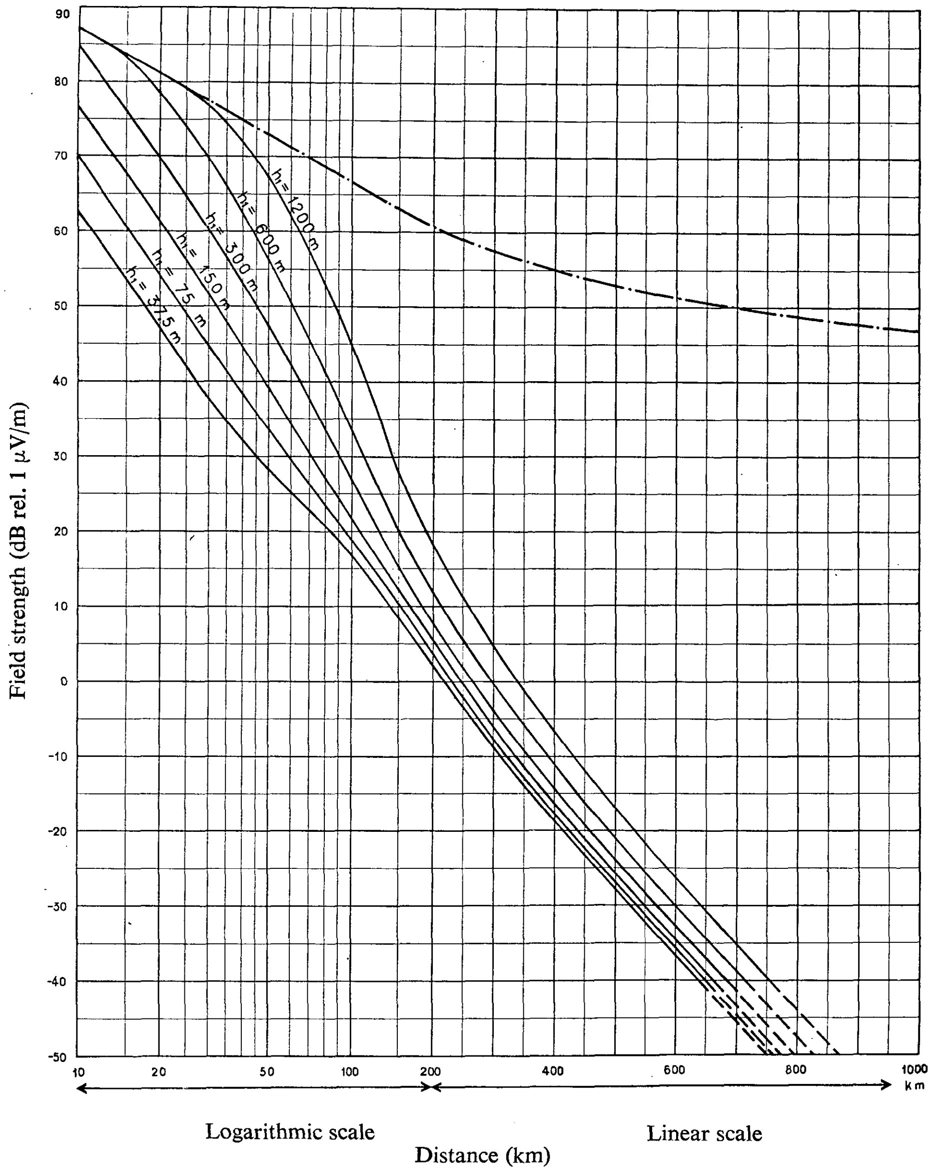

FIGURE 10

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.

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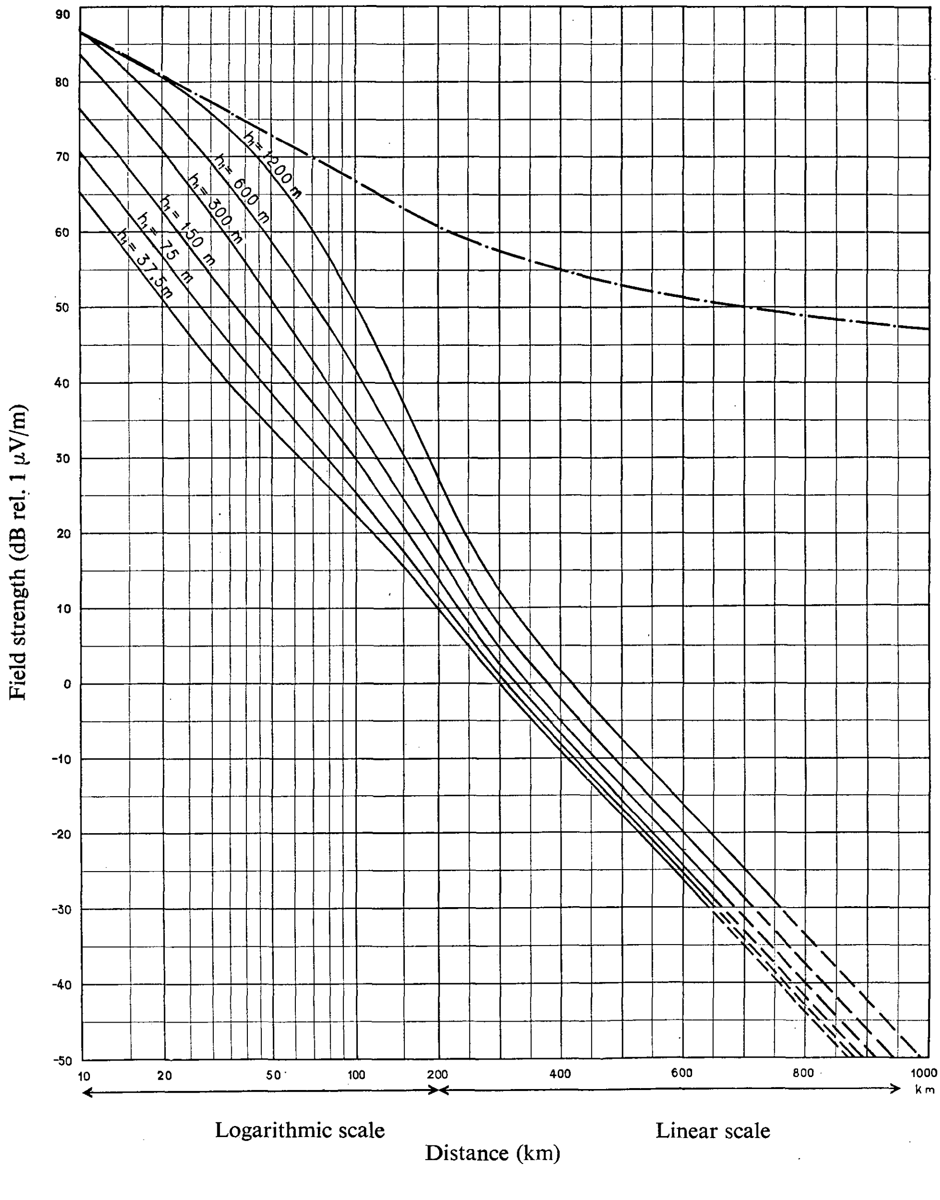

FIGURE 11

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.

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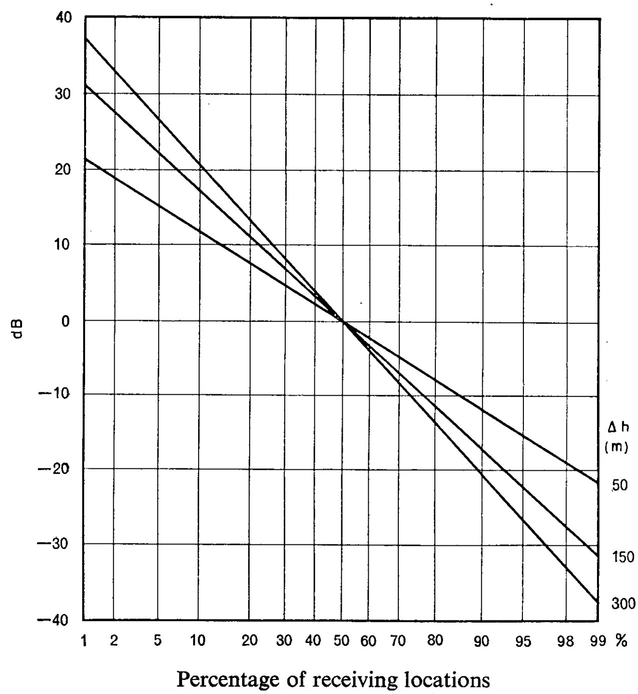

FIGURE 12

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)

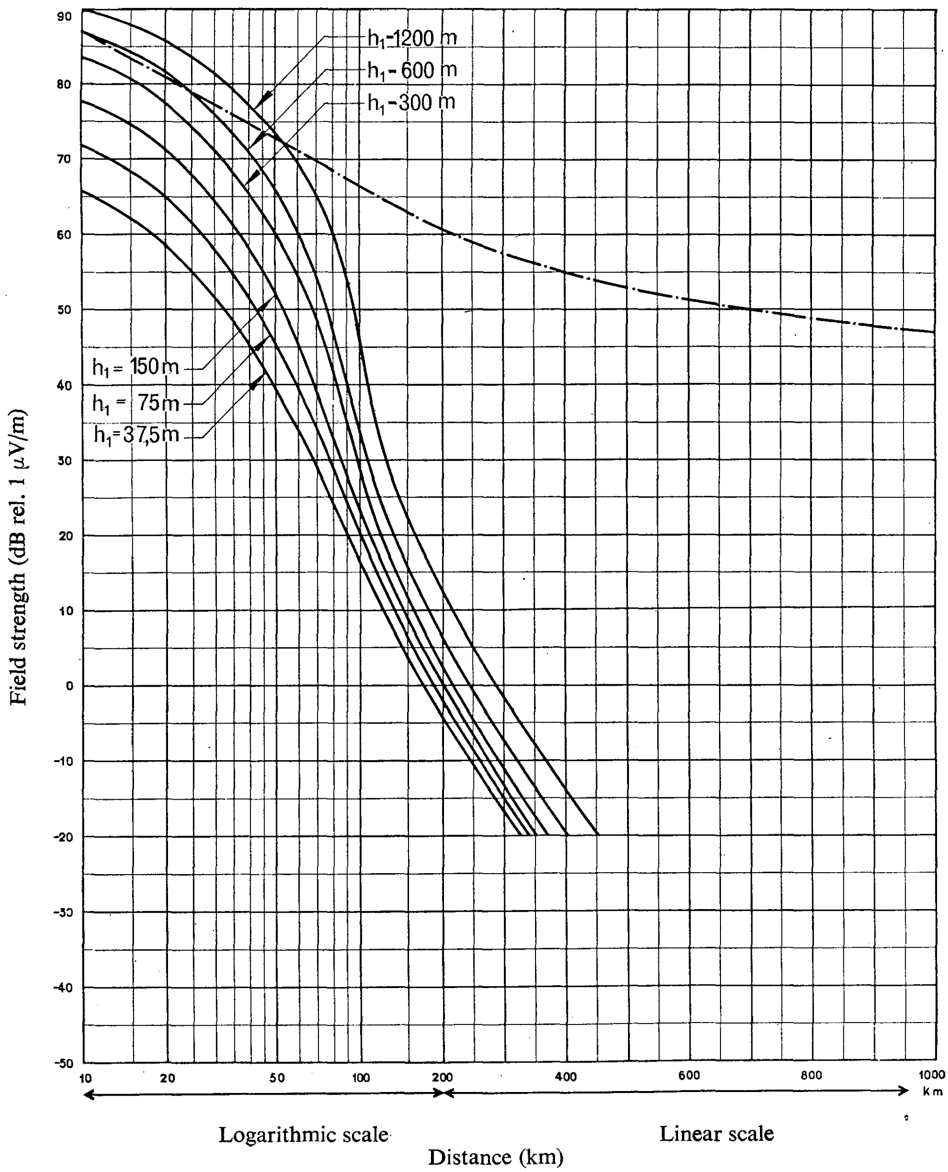

FIGURE 13

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; $\Delta h = 50$ m.

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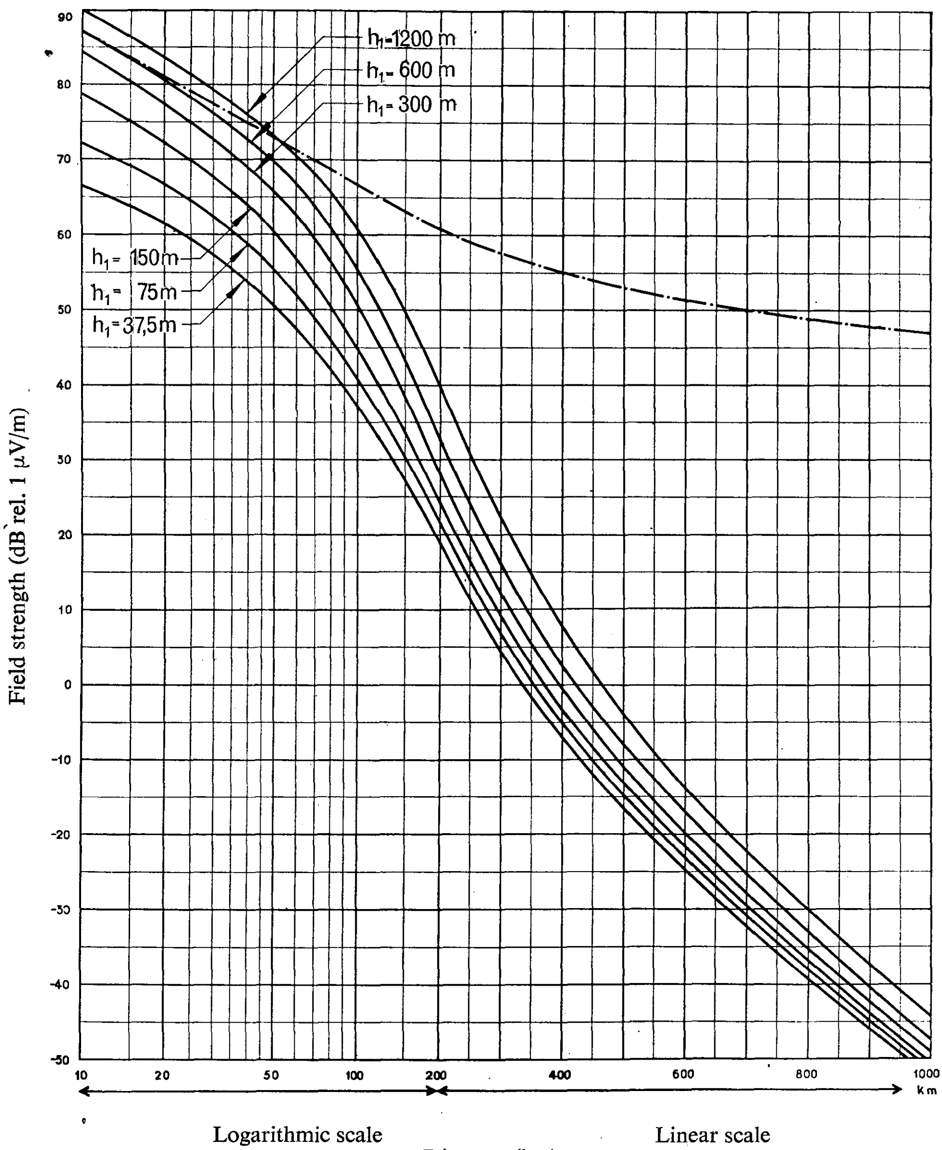

FIGURE 14

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.

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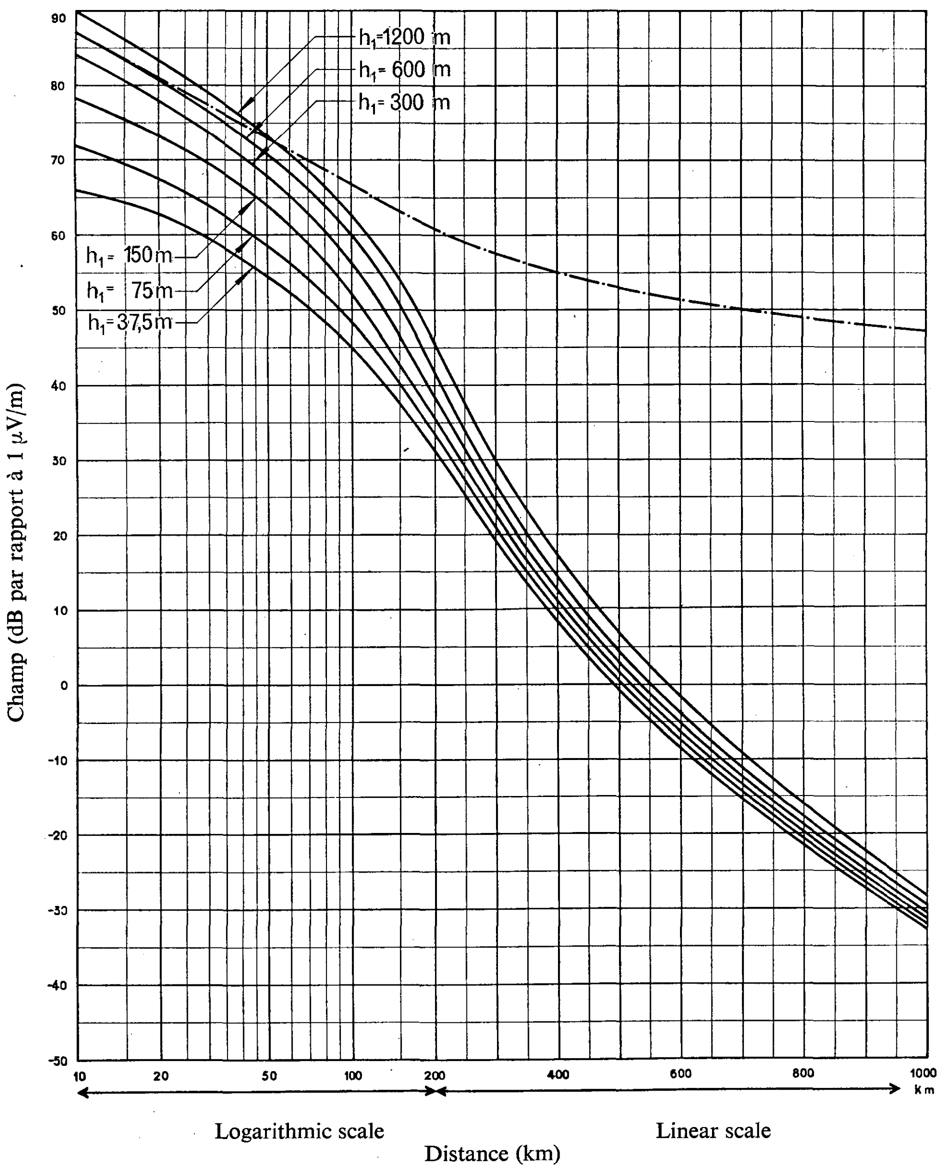

FIGURE 15

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.

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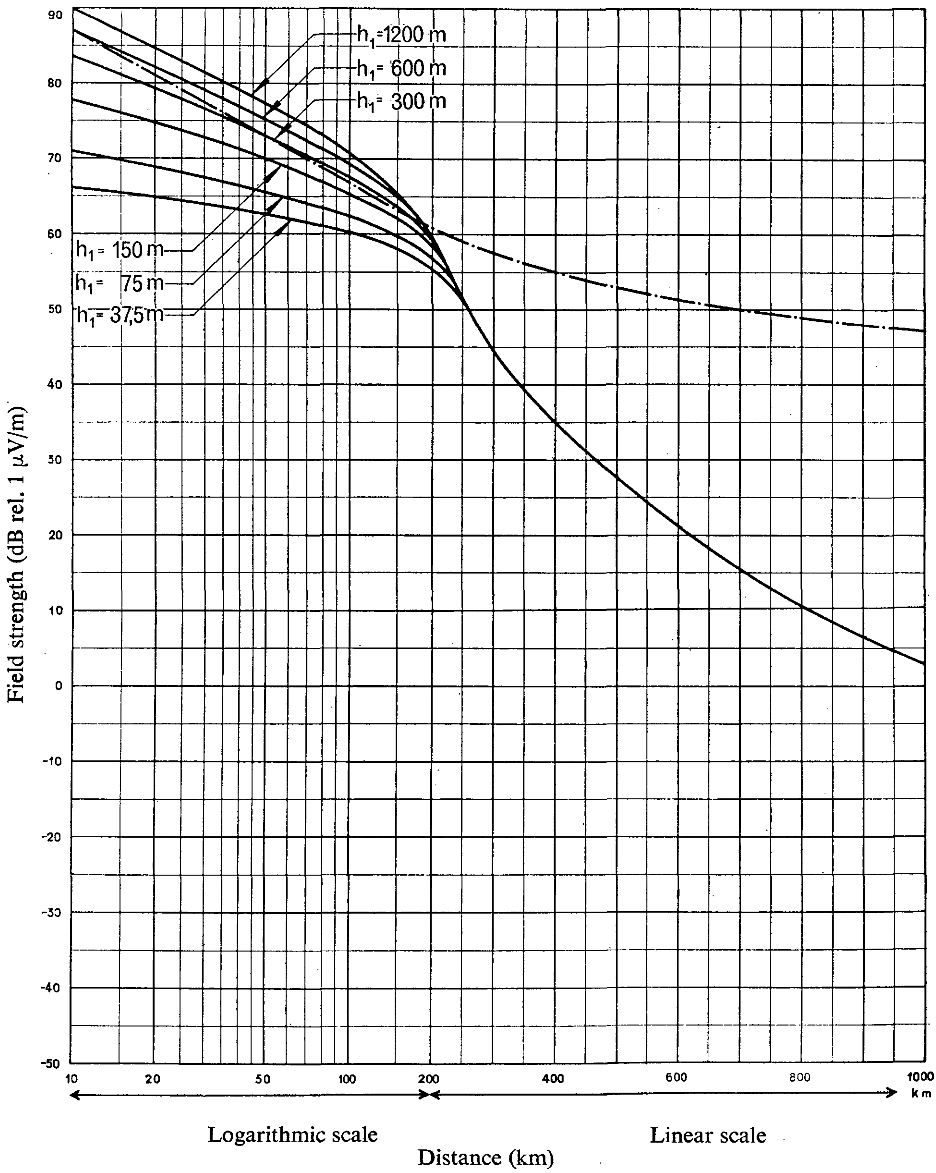

FIGURE 16

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.

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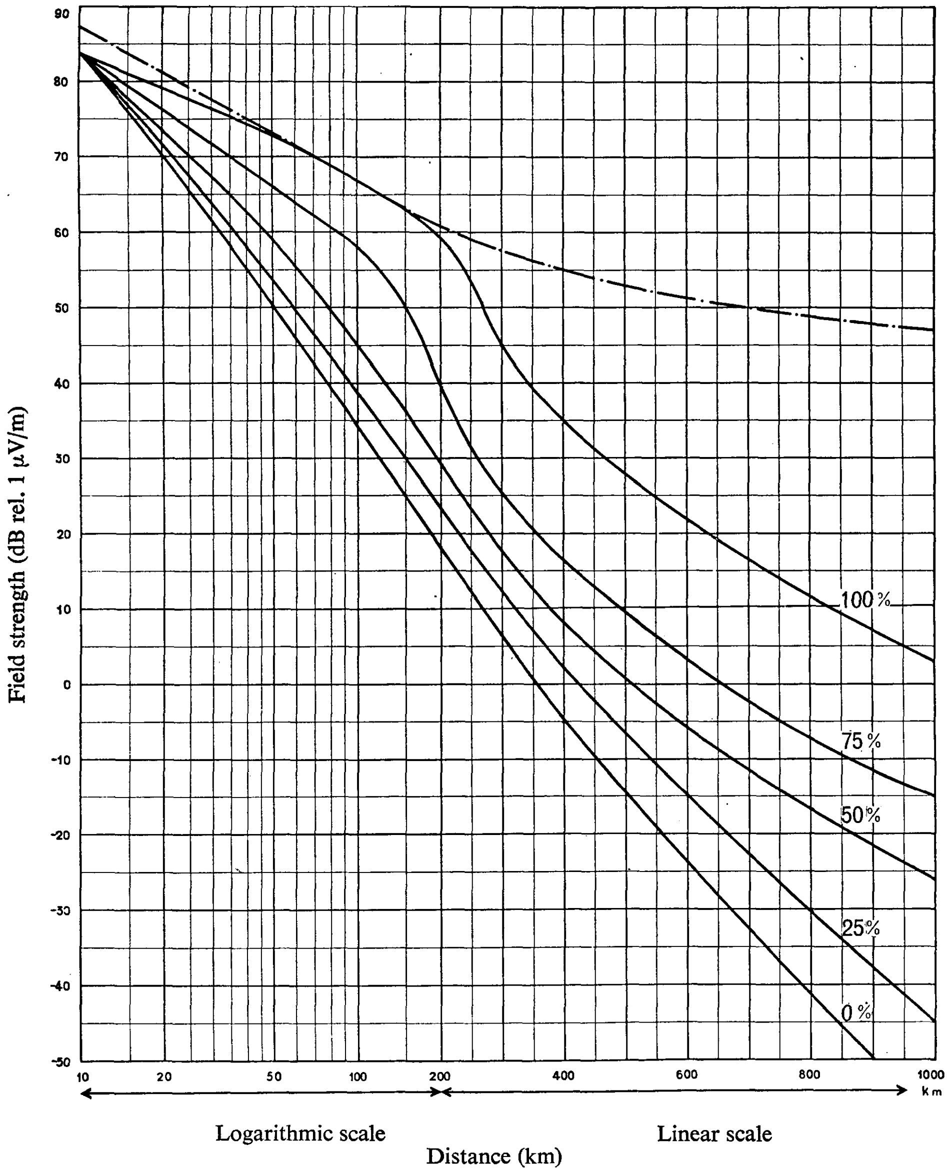

FIGURE 17*a*

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)

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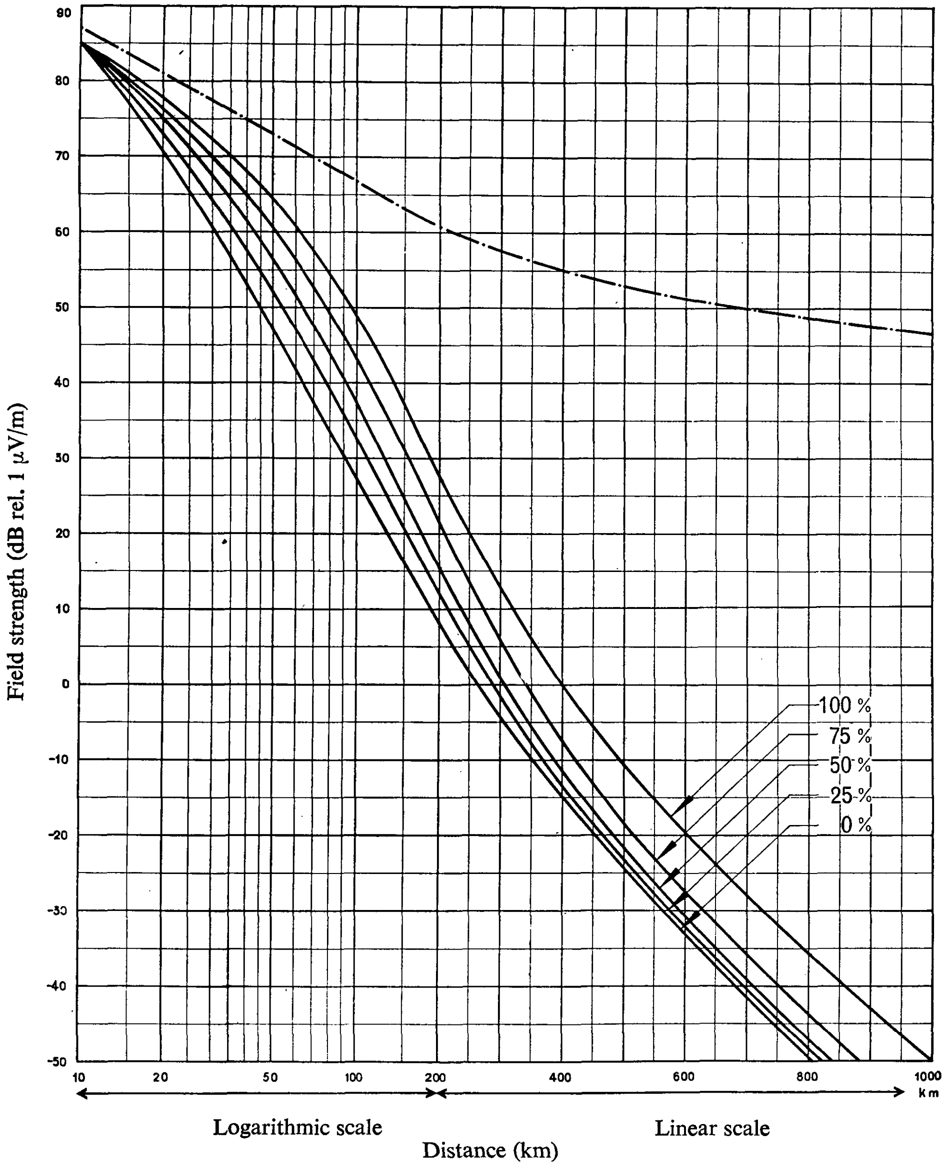

FIGURE 17*b*

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)

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RECOMMENDATION 452

PROPAGATION CONSIDERATIONS FOR ASSESSING CO-CHANNEL INTERFERENCE BETWEEN SPACE AND TERRESTRIAL SERVICES

(1970)

The C.C.I.R.,

CONSIDERING

(a) that, in order to assess co-channel interference between space and terrestrial services, it is necessary to calculate transmission losses over various types of path;

(b) that, in Question 5-1/5, Study Group 5 has been asked to provide propagation information required for this purpose, by Study Groups 4 and 9 for communication-satellite systems and terrestrial radio-relay systems respectively;

UNANIMOUSLY RECOMMENDS

that Administrations make use of the methods for calculating transmission loss that are discussed in Reports 239-2, 244-2 and 425; that they determine which of these methods they consider to be the most appropriate in given circumstances and inform the Director, C.C.I.R., of the method used and the results obtained in each case.

5A: *Reports*

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 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

* This Report was adopted unanimously.

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

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 polarized antennae, the fields will remain substantially the same until a certain height is reached, and then there will be cyclic variations. The height range of a 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 strength 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 $2{\cdot}7 \times 10^{-15}{}_{5}$ 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 II in § 13.3 for standard bandwidths.

13.3 *Quasi-peak measurement*

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

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

TABLE II

Frequency range (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:

$$f = \frac{e^2}{z} \qquad (1)$$

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:

$$a_e = \frac{\lambda^2 g_r r_f}{4 \pi r} \qquad (2)$$

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:

$$p'_a = \frac{e^2 \lambda^2 g_r r_f}{4 \pi z r} = \frac{v^2}{4r} \qquad (3)$$

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:

$$v = e \sqrt{\lambda^2 g_r r_f / \pi z} = el \qquad (4)$$

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).

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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

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* This Report was adopted unanimously.

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 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. 1 μV/m for VHF and UHF respectively. Towns, where the median field strength is outside these ranges, can be considered to be either inadequately served or to have good coverage, so that in these cases small errors in measurement of field strength are less important. Fig. 3

shows the number of independent sample measurements required to give 95% probability that the probable error ε in a median value will be less than 2 dB or 4 dB. In practice, the acceptable sampling error ε should not be greater than 2 dB in the critical zone, but may be increased to 4 dB where accuracy is less important. The relationship between the necessary number of samples and the "variation factor", V, defined as the ratio (in decibels) of the field strengths exceeded at 50% and 90% respectively of the locations within the town or other compact area under consideration, is given in Fig. 3, which is derived from the assumption that the distribution of field strength is log-normal.

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

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

To assess the extent of service, the measurement procedure may be considered a sampling process in which the cumulative distribution of the sample represents an estimate of the variations within a given area of the actual fields. The choice of sampling locations should be free of bias and should as nearly as possible represent typical operating installations. An important factor affecting the choice of sampling 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. The refore, 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.

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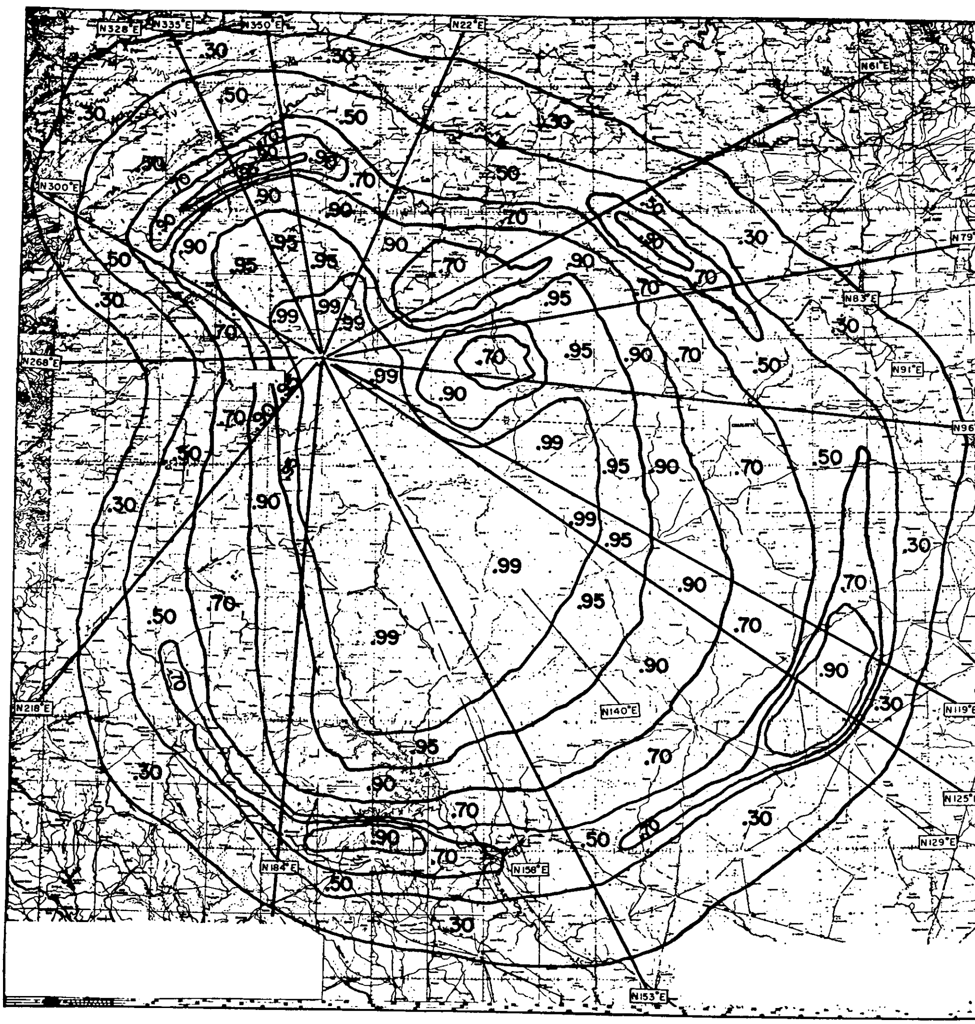

FIGURE 1

The concept of service probability

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

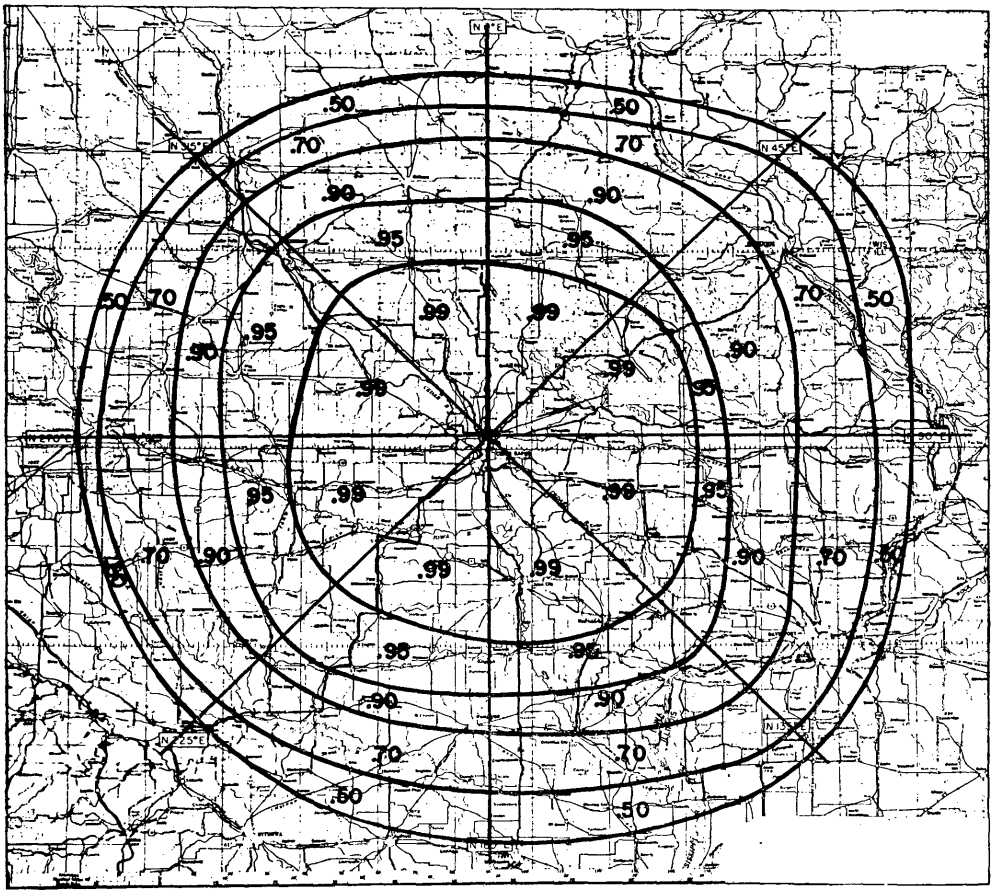

FIGURE 2

The concept of service probability

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

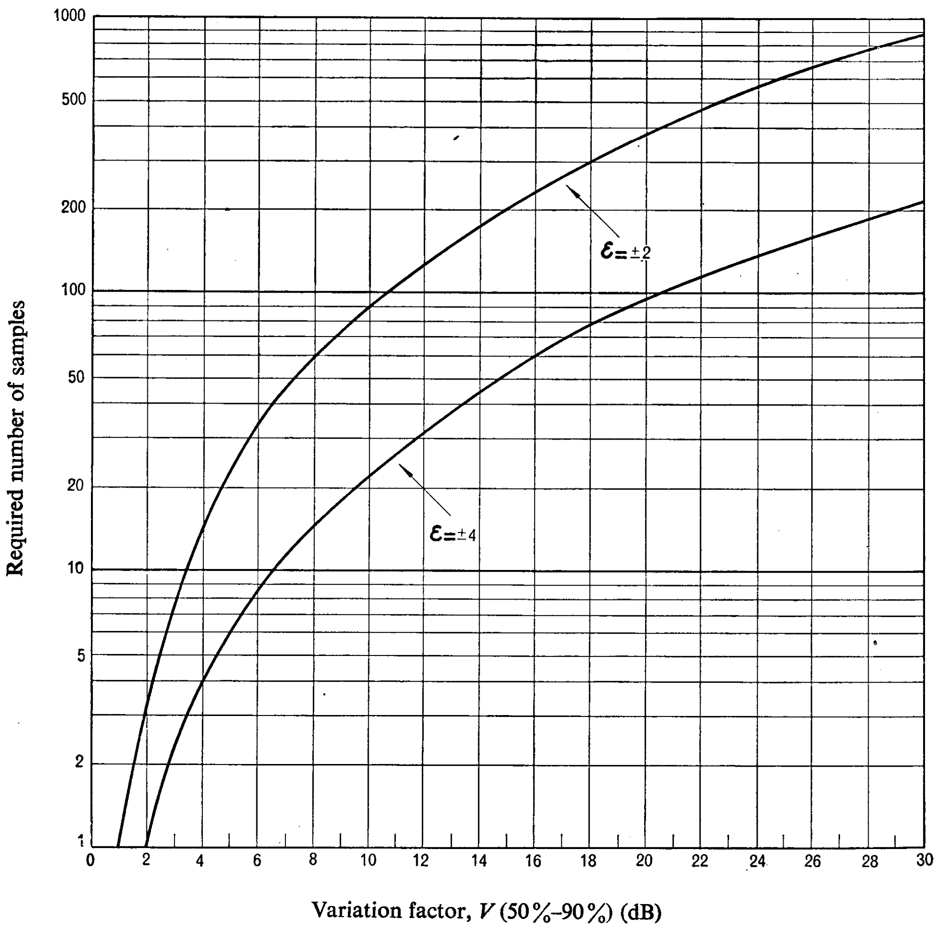

FIGURE 3

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

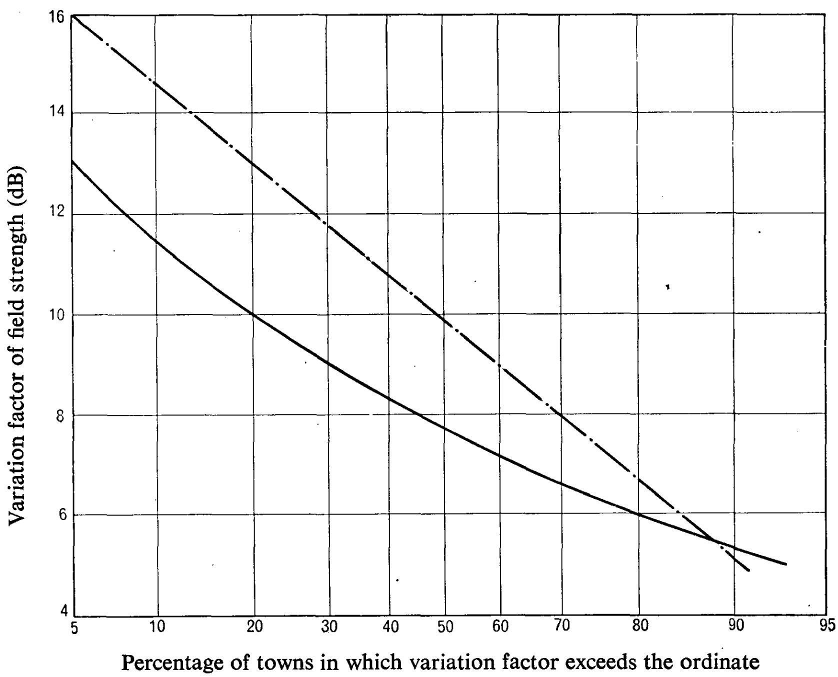

FIGURE 4

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

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

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

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

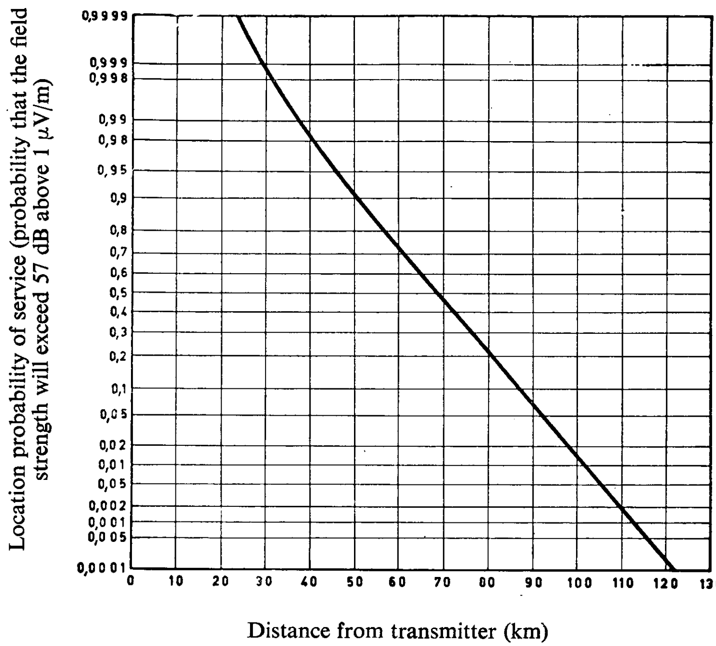

FIGURE 5

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

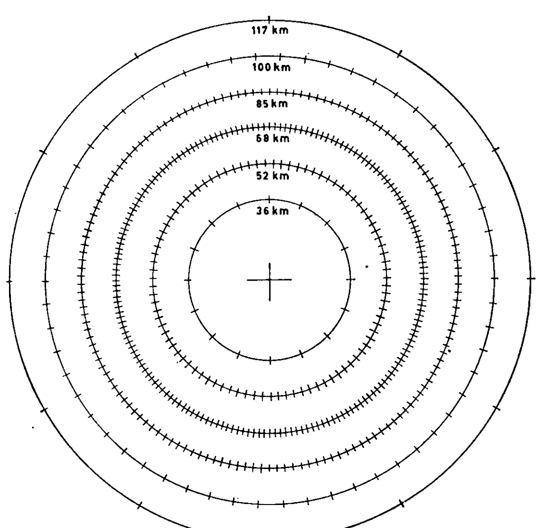

FIGURE 6

Possible arrangement of measurement sites for a 100 kW station over average terrain

(The transmitter is located at the centre of the diagram).

REPORT 238-1 *

PROPAGATION DATA REQUIRED FOR TRANS-HORIZON RADIO-RELAY SYSTEMS

(Study Programme 5-1B-1/5)

(1959 - 1963 - 1970)

1. General

It is well known that under conditions of standard refraction the transmission loss at frequencies above 30 MHz increases rapidly beyond the horizon in accordance with the theory of 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 to great distances. At these distances, fading is severe; however, the 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, so that 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. Such signals cannot serve as a basis for a permanent link but they may give rise to harmful interference.

Both slow and rapid variations of field strength are observed. Slow fadings are ascribed to overall changes in refractive conditions in the atmosphere. The hourly median values below the long-term median are distributed approximately log-normally with a standard deviation which generally lies between 4 and 8 decibels, depending on the climate. 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 fades 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 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 noted when a frontal disturbance passes over a link. Reflections from aircraft can give pronounced rapid fading.

Report 244-2 shows that the long-term median transmission loss relative to free space increases as the first power of the frequency f. However, measurements made in Sweden [8] at 1 and 3 GHz indicate that, as the hourly median value of the transmission loss increases, the frequency dependence of the transmission loss, relative to free space, varies continuously from f^2 to $f^{-1/3}$.

* This Report was adopted unanimously.

2. Effect of climate

In temperate climates, monthly median transmission losses tend to be higher in winter than in summer, but the difference diminishes as the distance increases. Measurements made in the European parts of the U.S.S.R. on a 920 km path at 800 MHz show a difference of only 2 dB between summer and winter medians [9]. For medium-distance links the difference is about 15 dB. Oversea paths are more likely to be affected by super-refraction and elevated layers than land paths and so give greater variation. Diurnal variations also occur. Transmission loss is generally at a maximum in the afternoon [10].

In dry, hot, desert climates attenuation reaches a maximum in the summer. The annual variations of the monthly medians for medium-distance paths exceed 20 decibels, while the diurnal variations are very large.

In equatorial climates, the annual and diurnal variations are generally small.

In monsoon climates where measurements have been carried out (Senegal, Barbados), attenuation is minimum during the transition periods between the dry and wet seasons.

3. Diversity reception

The deep fading occurring with scatter propagation severely reduces the performance of systems using this propagation mode. The effect of fading can be reduced by diversity reception, using two or more signals which fade more or less independently, owing to differences in path, frequency, or time interval. The effect of space diversity has been studied in the Federal Republic of Germany [6] by measuring the space correlation function and its scale length L, using simultaneous recording of the transmission loss at several horizontally and vertically spaced antennae (usually three).

Adequate spacing of two receiving antennae in a space diversity system depends on the scale length L (m) as defined by the space correlation function and on the antenna diameter D (m) of the receiving antennae. Because of the statistical character of L, its value exceeded in 1% of time, denoted by L_y in the horizontal and L_z in the vertical direction should be used. Adequate diversity spacings Δ_y (m) and Δ_z (m) are then given for frequencies greater than 1000 MHz by the relations

$$\Delta_y = 0{\cdot}36\,(D^2 + 4\,L^2_y)^{1/2}$$
$$\Delta_z = 0{\cdot}36\,(D^2 + L^2_z)^{1/2}$$

Measurements yielded the values:

$$L_y \simeq 20 \text{ m},\ L_z \simeq 15 \text{ m}.$$

It is also possible to use frequency diversity. An adequate frequency separation Δf (MHz) has been found [6] to be

$$\Delta f = (1{\cdot}44\, f/\delta d)\,(D^2 + L^2_z)^{1/2},$$

where f (MHz) is the carrier frequency, δ (mrad) the angle of scattering in the centre of the common volume, and d (km) the distance between transmitter and receiver. Some caution is needed using these formulae with frequencies well below 1000 MHz. The variation in the frequency correlation coefficient with path length has been studied in France [2].

It is also possible to have angle diversity using multiple feeds and a common reflector. A simple system of this kind, employed at the receiver end, may provide a performance capability comparable to and considerably more economical than that of space diversity, particularly as one approaches the SHF range [11].

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.

4. Path antenna gain

The combined gain of transmitting and receiving antennae may be less than the sum of their plane-wave gains. This apparent drop in gain is termed "gain degradation" or "antenna-to-medium coupling loss". 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. Theoretical analysis [3] states that the amount of loss is dependent on the antenna gain and the path length.

The path antenna gain or total effective antenna gain over a tropospheric scatter circuit has been observed experimentally to be practically independent of distance between about 150 and 500 km [7]. 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, and that the gains of the two antennae are not too different.

If antennae of very high gain are used, the total effective antenna gain (path antenna gain) increases by only a quarter of the increase given by the sum of the two free space gains. For distances longer than 500 km, [12] indicates that the antennae-to-medium coupling loss appears to decrease and become very small at about 1000 km.

For purposes of computing interference fields, the antenna-to-medium coupling loss does not apply since fields much stronger than the median are usually coherent and do not experience this loss.

5. Fading frequency

The rapidity of fading is important particularly in communicating digital signals. It has been studied in the Federal Republic of Germany [4, 5, 13] in terms of the time auto-correlation function, which provides a "mean fading frequency". This mean fading frequency is a measure of fading rapidity (or fading rate). It varies in a statistical manner between 0·0444 (99% of time) and 4·3 (1% of time) times its median value. The median value f_{sm} itself increases nearly proportionally to distance and carrier frequency and reaches approximately 4 Hz with a carrier frequency of 10 GHz. Besides it decreases slightly as the antenna diameter increases [6].

6. Transmissible bandwidth

Differential delays between components of the scattered signal result in signal distortion 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 fact it has been found that links much longer than 500 km may not provide more than 24 satisfactory voice channels.

7. Effect of the siting of stations

The siting of terminals of trans-horizon links requires some care. The antennae beams must not be obstructed by nearby objects and the basic 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.

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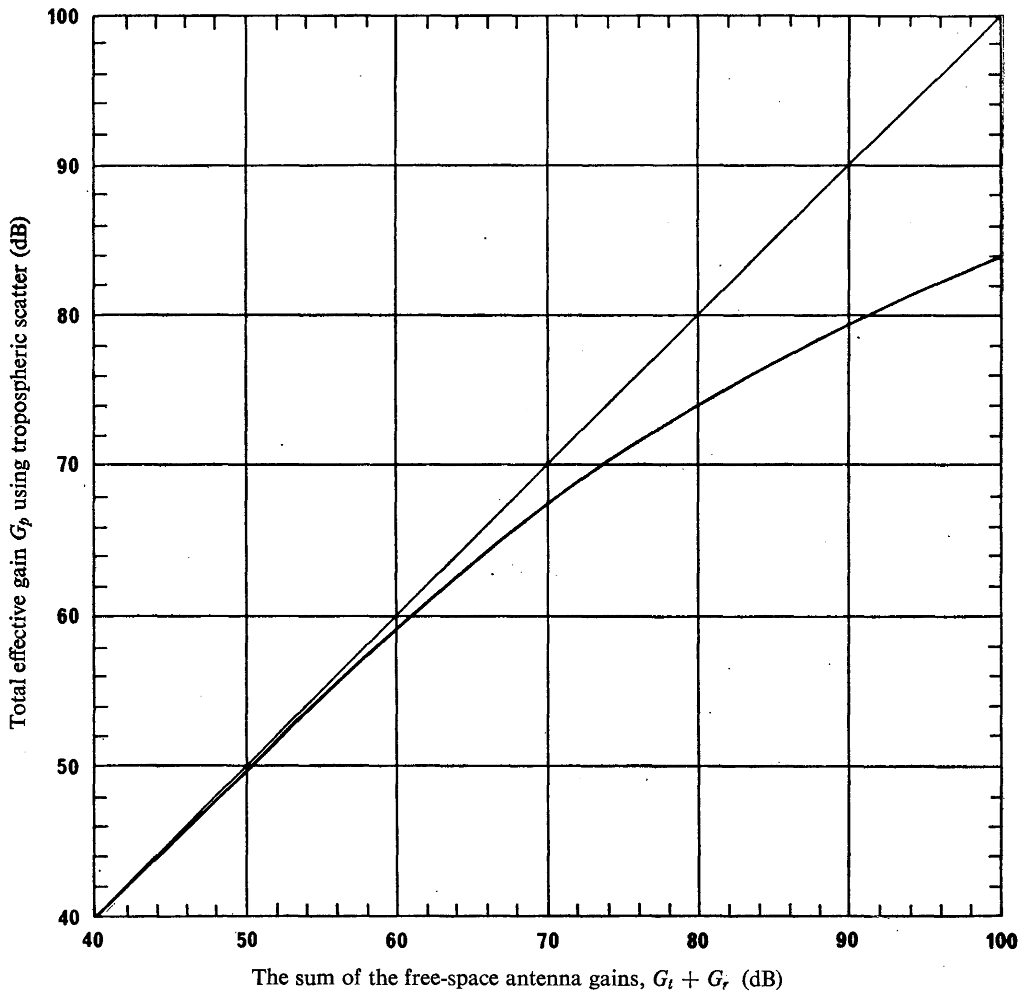

100
90
80
70
60
50
40
40
50
60
70
80
90
100
Total effective gain G_p using tropospheric scatter (dB)
The sum of the free-space antenna gains, $G_t + G_r$ (dB)

FIGURE 1

REPORT 239-2 *

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

(Study Programme 7A/5)

(1959 – 1963 – 1966 – 1970)

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 urban areas and of vegetation on propagation. The last section suggests an improved method for computing field strength over mixed land-sea paths.

Report 240, Geneva, 1963, 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.**

Report 236-2 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 Party 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.

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* 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.

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 first 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 244-2. 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 described 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 field strengths in the Mediterranean area show that median values tend to be higher than those observed in the North Sea area, and field strengths exceeded for small percentages of the time are appreciably greater [45].

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].

Measurements in Sweden of field strength over periods ranging from 3 months to 4 years on transmissions over 3 VHF paths and 2 UHF paths in the Baltic Sea area [39] are in good agreement with values shown in Recommendation 370-1 for the North Sea area. The month-to-month variation of field strength is, however, found to be large, and for the worst month the field strengths measured during 1% and 10% of the month exceed the predicted field strengths by 30 to 40 dB.

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 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 defraction, 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 122-1 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.

The nature of the receiving site also has other important influences on wave polarization phenomena. For example, VHF observations in the Federal Republic of Germany [46] have shown that, in shadow regions, whereas reflections have little effect on horizontally polarized signals, their effects on vertically polarized signals are often great enough to distort FM reception seriously.

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 Socialist Republic 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 Federal Republic of Germany [4] in which the mean slope of the terrain plays an important rôle in the derivation of the factor, as does the r.m.s. value of Δh.

4.1.2 A method developed in the People's Republic 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. A similar method has also been developed in Japan for the prediction of field strengths [41].

4.1.4 A method developed in Japan [40] introduces a parameter Γ which represents the effects of environmental clutter in the vicinity of a receiving site. This is in addition to the correction for terrain irregularities and gives corrections for urban effects.

4.1.5 The various prediction methods described above are all based either on modifications of the field strength derived for propagation over a smooth spherical earth or on the assumption of well-defined diffracting obstacles along the transmission path. However, in a further method, recently developed in Japan [41], the free-space field strength is taken as the initial standard of reference for propagation over any kind of terrain.

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

4.2.1 *Medium 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 and 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 and 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).

Measurements in Japan [40] give values of receiving antenna height gain as a function of a parameter Γ to take into account the environmental clutter.

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 and 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 People's Republic 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 south-east 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 distances in excess of 100 km the above factors should be reduced by 50%, with linear interpolation for intermediate distances.

Measurements in Japan have shown that the height-gain factor at 1·5 to 3 m is 3 dB in urban areas for the UHF band [41]. This value can be used to estimate the median field strength at receiving antennae at a height of 1·5 m for bands IV and V in urban areas by adding to the correction factor shown in Table I.

Field-strength measurements carried out in rural areas in the People's Republic of Poland [47] at frequencies between 34 MHz and 306 MHz are in good agreement with Recommendation 370-1 modified where necessary for terrain effects as indicated in this Report. Measurements in the same frequency range in urban areas show that the dispersion of the field strength seems to be practically independent of frequency [48].

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.

In the United Kingdom, measurements made at UHF (600 MHz) inside 2-storey suburban houses, on the ground floor and in the lofts, show a mean attenuation of 19 dB and 10 dB respectively, compared with measurements at 10 m in the street outside the house [42].

4.3 *Depolarization phenomena*

The depolarization factor is defined as the ratio of the amplitude of the orthogonally polarized component, produced by some propagation mechanism, to the amplitude of the original plane polarized wave. For communication systems, it is sometimes more convenient to consider the polarization discrimination obtained using an antenna in a given environment. These factors are normally expressed in decibels and, in practice, are of opposite sign but numerically equal, provided that the depolarization factor is not too small.

4.3.1 *Broadcast services*

Where the transmitter itself is at a clear site, the polarization discrimination achieved at roof top level in built-up areas by the use of orthogonal polarization may have a median value of 18 dB with corresponding values exceeded at 90% and 10% of receiving sites, 9 dB and 29 dB respectively (see Report 122-1). The discrimination is better in open country and worse at cluttered receiving sites or where reception is poor.

Measurements made in the Federal Republic of Germany at 520 and 700 MHz [16], have indicated 1 to 2 dB more depolarization for vertically as compared with horizontally polarized waves. Also, studies in the United Kingdom at 570 MHz [15] have shown that the discrimination, obtained with a vertically polarized antenna directed 180° away from an incident horizontally polarized wave, exceeds the front-to-back ratio (16 dB) of the antenna by 6 dB.

Studies have been made in the Czechoslovak Socialist Republic [25, 27] and by other Administrations, on the effect of the type of terrain in the vicinity of the receiving site. Measurements have been made at a frequency of 570 MHz within the service area and show that depolarization increases in a similar manner to diffraction loss, with increase in roughness of terrain at the receiving site. Results are summarized in Table II.

TABLE II

Type of terrain	Median path loss relative to free space (dB)	Polarization discrimination exceeded at 90% of sites (dB)
Suburban, optical to transmitter	7	18
Suburban, in slight diffraction zone	26	13
Suburban, in moderate diffraction zone	31	10
Suburban, in deep diffraction zone	40	4
Thickly wooded area (in leaf) with no obstruction due to terrain	27	2

The last item in Table II shows that a wooded environment causes a much greater depolarization than that found in other areas having a similar path loss.

Measurements made in the Federal Republic of Germany at 520 and 700 MHz near Heidelberg, indicated the effects of frequency and building density to be negligible. The effect of variation in the parameter Δh is shown in Table III.

TABLE III

Type of terrain	Δh (m)	Polarization discrimination exceeded at 90% of sites (dB)	Polarization discrimination exceeded at 50% of sites (dB)
Flat	10	20	30
Hilly	50	14	27
Mountainous	200	0	16

4.3.2 *Mobile services*

Measurements in Sweden of the depolarization effect in terrain with both antennae at a low height (less than 10 m) have shown that the depolarization factor increases with increasing frequency from about —18 dB at 35 MHz to about —7 dB at 950 MHz [43].

The depolarization factor is log-normally distributed with a standard deviation somewhat dependent on the frequency. The average value of the difference between the 10% and 90% values (in the frequency range 30 to 1000 MHz) is about 15 dB. Whether the original polarization is vertical or horizontal has been observed to make only a slight difference in this respect.

Two types of time variation of the depolarization effect have been found. The first is a slow variation resulting from the changing electrical properties of the ground with weather conditions. This effect is most pronounced at lower frequencies. The second is due to the motion of trees which gives a depolarization fading phenomenon amounting to several decibels in amplitude at quite moderate wind velocities.

4.4 *Attenuation due to vegetation and buildings*

A 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.

Further work in Japan [40] gives values of attenuation behind buildings as a function of frequency, height and depth of building and angle of arrival. The results show good agreement with measurements at 100, 200 and 700 MHz.

Measurements in the United Kingdom [42] give values of attenuation behind various types of buildings at UHF (600 MHz) of as much as 30 dB. Measurements [42] made behind deciduous woods in summer and winter indicate that although the attenuation due to foliage is not negligible at UHF, it is significantly less than that due to bare trees.

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.

Measurements made in the Federal Republic of Germany [31] have shown that, at 190 MHz, the field strength over line-of-sight paths is 3 dB lower with vertical as compared with horizontal polarization and for shadowed regions, the difference increases to 4·5 dB. Other measurements [46] in shadowed regions at 97 MHz have shown this difference to be 5 dB with a deviation of $\pm$ 5·2 dB. At 500 MHz the propagation differences between polarizations are much less marked and the corresponding values are 0 dB and 1·5 dB. The subjective quality of television pictures was found to correlate with these measurements.

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 the 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:

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

which is the required field strength.

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

While the above proposals are at present the best available for the calculation of the field strength over a mixed land-sea path, further work in the United Kingdom [44] has shown that, although good agreement is obtained, provided the land path is small in proportion to the sea path, for greater proportions of land paths the agreement is poor, the measured value being substantially less than the calculated values.

It may be that the discrepancy is due to the differing temporal characteristics of abnormal propagation over land and sea paths. Further work is urgently needed to assess the validity of this explanation and before any alternative proposals for mixed land and sea path calculations can be submitted to the C.C.I.R.

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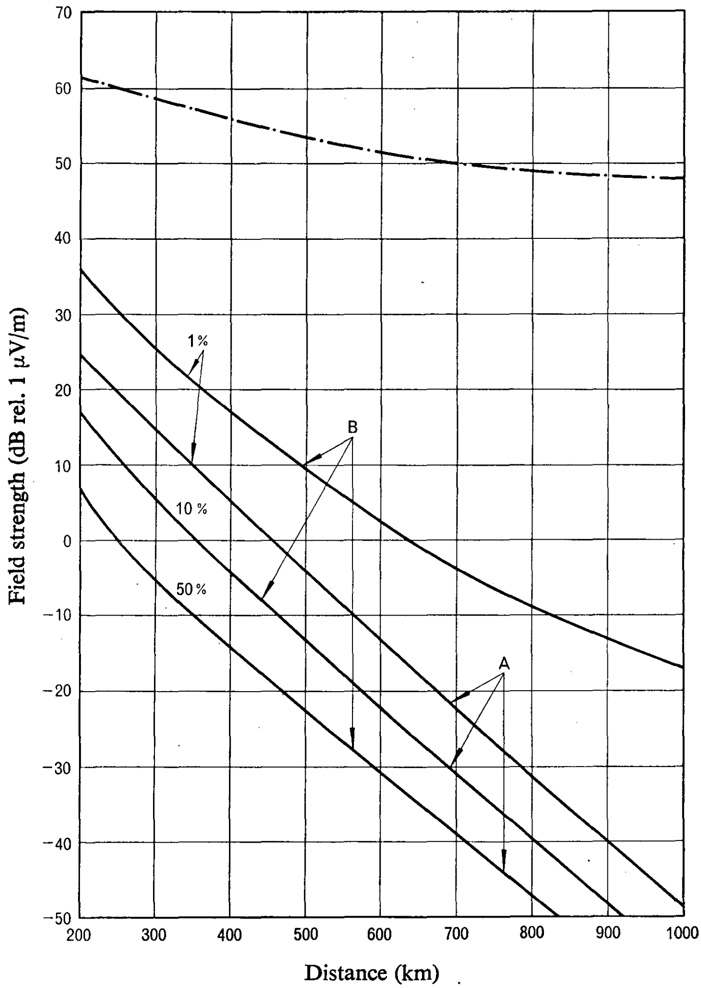

FIGURE 1

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

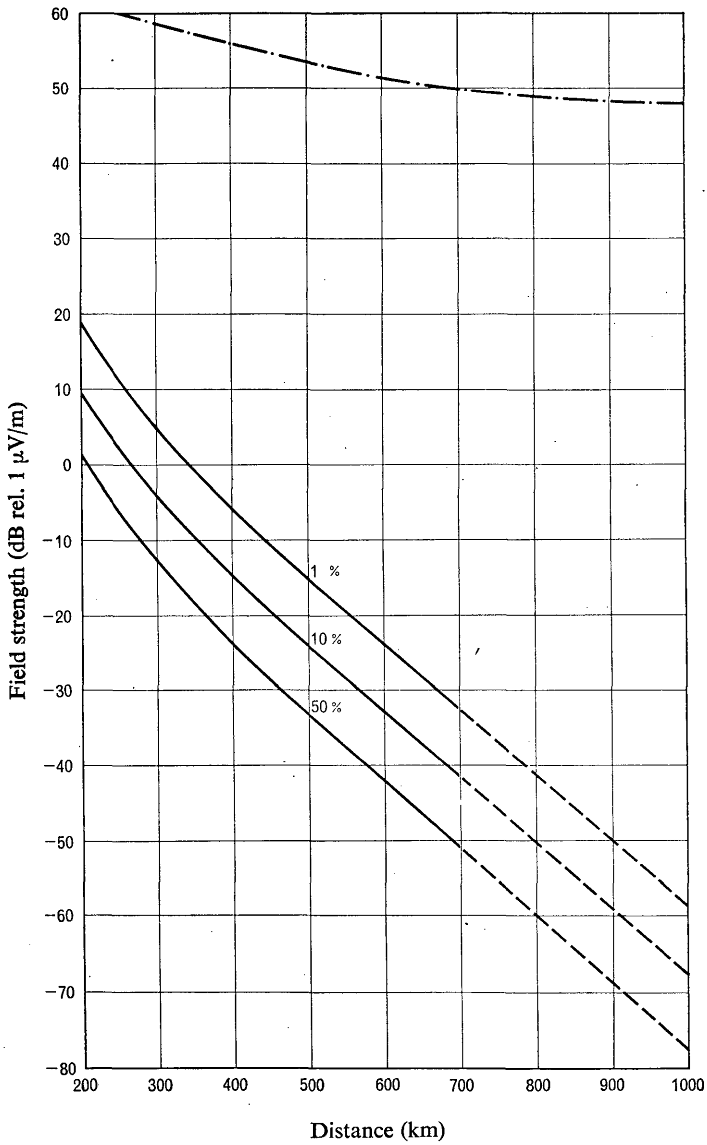

FIGURE 2

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

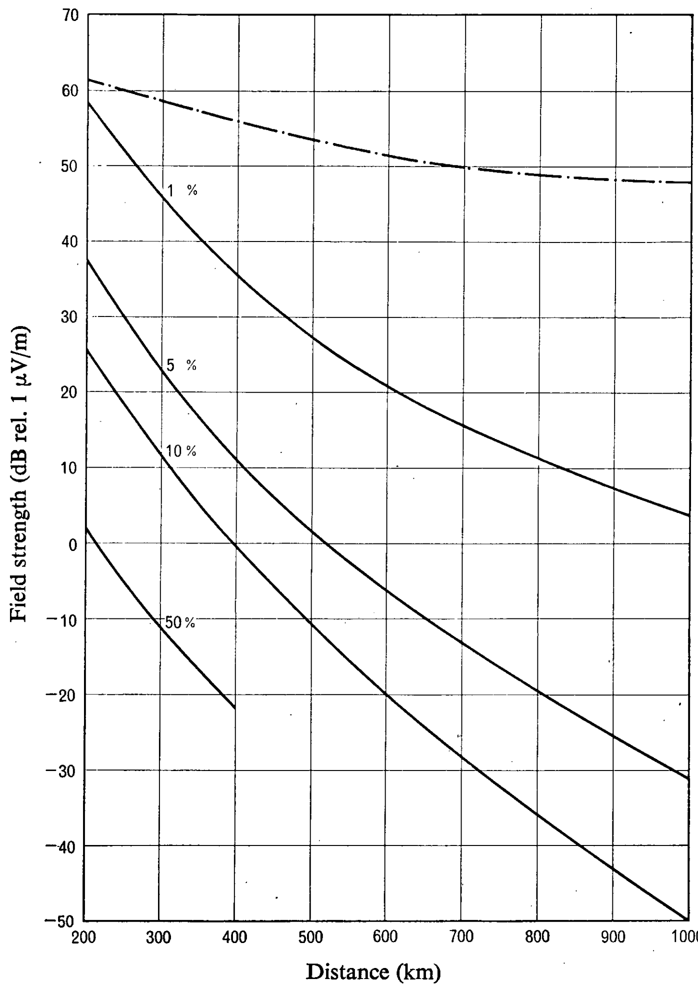

FIGURE 3

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

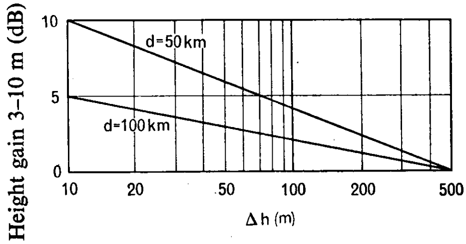

FIGURE 4

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

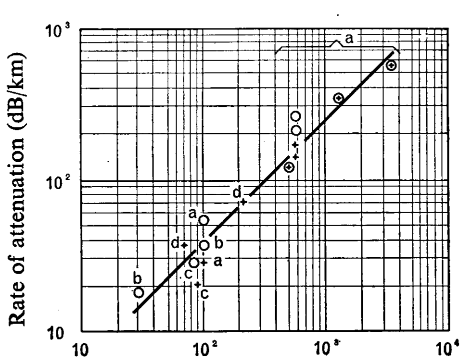

FIGURE 5

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	

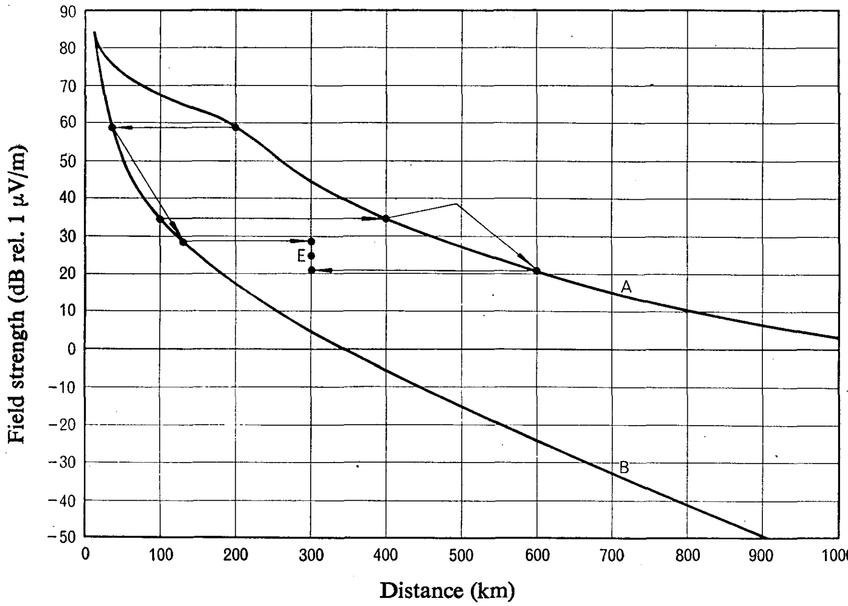

FIGURE 6

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 5-1A-1/5 and 5-1B-1/5)

(1959 – 1963 – 1966)

A large amount of data relevant to Study Programmes 5-1A-1/5 and 5-1B-1/5 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 244-2 *

ESTIMATION OF TROPOSPHERIC-WAVE TRANSMISSION LOSS

(1963 – 1966 – 1970)

1. Introduction

Study Programmes 5-1A-1/5, 5-1B-1/5 and 5-1D-1/5 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].

* This Report was adopted unanimously.

An Interim Working Party has been established to continue the work of collecting and analysing data in accordance with Resolution 2-1. 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 upon 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 Interim Working Party 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 Interim Working Party 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 should 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. Transmission loss calculations

2.1 *Free-space propagation*

Recommendation 341-1 and Report 112 relate the available power, P, from the receiving antenna, the total radiated power, P_r, the transmission loss, L, the basic transmission loss L_b, and the path antenna gain, G_p, as follows:

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

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

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

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

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

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.

Note. — Equations such as (3) may conveniently be expressed in the form of a nomogram (see Fig. 15).

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_0, frequency f, and the angle of elevation, θ_0, taking into consideration the attenuation due to precipitation and atmospheric gases [1]; this matter is discussed further in Report 234-2.

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

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

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. 1. An effective earth radius, a, rather than the real radius, was used to allow for average refraction of radio rays in Fig. 1. Fig. 2 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 233-2.

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 $h_1 \leq h_2$, $h_1 \leq (9a\psi^2)/2$, and that ψ is small. Then

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

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

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. 3, from which the diffraction attenuation relative to free space, $A(v)$ may be obtained, either for line-of-sight paths ($v < 0$), or for trans-horizon paths ($v > 0$).

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

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

The functions $G(\chi_0)$ and $F(\chi_{1,2})$ and an auxiliary function $\Delta(\chi_{1,2})$ are plotted in Fig. 4.

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

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. 5 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. 6, 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 United States).

7*a*. Maritime temperate, overland (data from United Kingdom).

7*b*. Maritime temperate, oversea (data from United Kingdom).

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 the Annex.

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 multi-path 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 $9000\,\theta_{sl}$. Then:

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

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

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

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:

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

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

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

Thus:

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

or

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

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

where empirical estimates of the factor $g(f)$ are shown in Fig. 7 and of $Y_0(q)$ in Figs. 8 to 14 for the various climates.

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

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

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. 15.

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. 16*a* and 16*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. 17 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. 18 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.

3.2 *Calculation of attenuation in the scatter zone from radio-meteorological parameters*

3.2.1 Studies by the French Administration have shown that the attenuation between isotropic antennae could be represented by a formula which appears to be valid for all climates:

$$L_b = 110{\cdot}5 + 30 \log d + 30 \log f - T \qquad (21)$$

L_b is the attenuation between isotropic antennae (basic transmission loss in decibels)

d is the distance in kilometres

f is the frequency in MHz

T is a parameter equal to

$$T = -\frac{3}{8} G_e - \frac{5}{4} G_c \qquad (22)$$

G_e is the equivalent gradient between the ground and the common volume (which can often be replaced by the difference between the value of N one kilometre above the ground surface and at the surface).

G_c is the difference between the value of N at a point situated one kilometre above the base of the common volume and the value at that base.

The time percentage to which the value of L_b relates depends on the times of the meteorological soundings used, as explained in [7].

Note. — Descriptions of N and of the equivalent gradient are given in Report 233-2.

3.2.2 The Administration of the United States of America compared formula (21) with all of the data upon which the method described in § 2.3 is based, and it found that the computed values and the measured values agree well. However, this Administration considers that the method of computation could be further improved if the following amendments were introduced:

— *Replace* the terms $30 \log d + 30 \log f$ in formula (21) by:

$$20 \log (fd) + 10 \log (fD_s)$$

where D_s is the distance in kilometres between radio horizons for median atmospheric conditions.

— *Replace* the constant 110·5 dB by:

$$K_1 (D_s) - K_2 (D_s\theta)$$

where θ is the angular distance in radians for median atmospheric conditions. The functions $K_1 (D_s)$ and $K_2 (D_s\theta)$ are shown in Figs. 19*a* and 19*b*.

3.2.3 If data are not available to determine G_e and G_c, various maps given in [8] may be used and the approximate value of the equivalent gradient G_e may be taken to be a gradient G_0 that is ten times the difference between the value of N one hundred metres above the Earth's surface and its value at the surface. World maps are available [8] for February, May, August, and November, showing the values of G_0 exceeded 2% and 10% of each month. These gradients correspond to field strengths exceeded 90% and 98% of each month.

By mixing these distributions and using the methods of [8] to find the median values of G_0 and the surface refractivity, N_s, it is possible to estimate G_0 and N_s for any percentage of a year, and then to approximate the common volume gradient G_c by means of the following semi-empirical formula:

$$G_c \begin{cases} \dfrac{1}{3}[200 - N_s - \dfrac{2}{3} G_0] & \text{for } 1 \text{ km} < D_s\theta < 2{\cdot}7 \text{ km} \\ \dfrac{3}{7}[200 - N_s - \dfrac{2}{3} G_0] & \text{for } D_s\theta \geqslant 2{\cdot}7 \text{ km.} \end{cases} \qquad (23)$$

For $D_s\theta < 1$ km or $D_s < 50$ km, the dominant propagation mechanism is expected to be diffraction, rather than forward scatter.

Typically, values of N_s exceeded 90% and 99% of the time are about 10 and 20 N-units, respectively, below the long-term median values given by the methods of Report 233-2 or [8].

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 Interim Working Party 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.

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7. Battesti, J., Boithias, L. and Misme, P. Calcul des affaiblissements en propagation transhorizon à partir des paramètres radiométéorologiques. (Calculations of attenuations in trans-horizon propagation from radio-meteorological parameters. *Annales des télécommunications* (May-June, 1968).
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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. There 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.

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 any time 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 terminals 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.

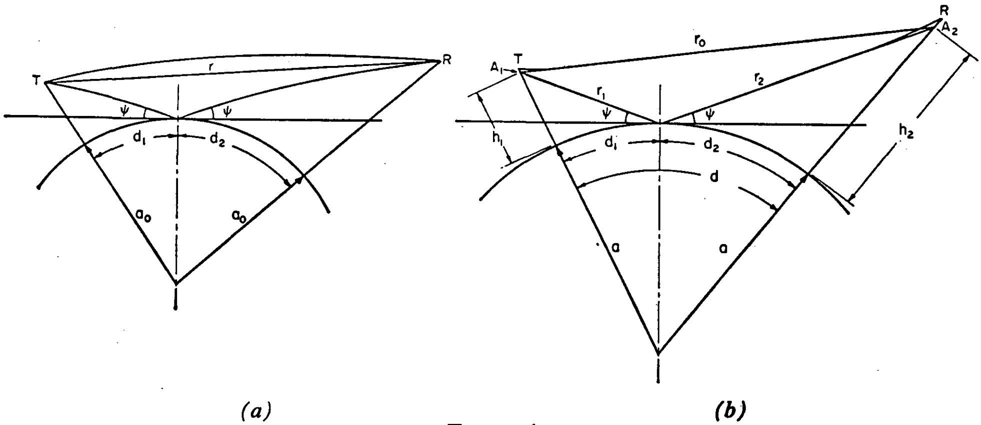

FIGURE 1

Geometrical relationships for within-the-horizon paths

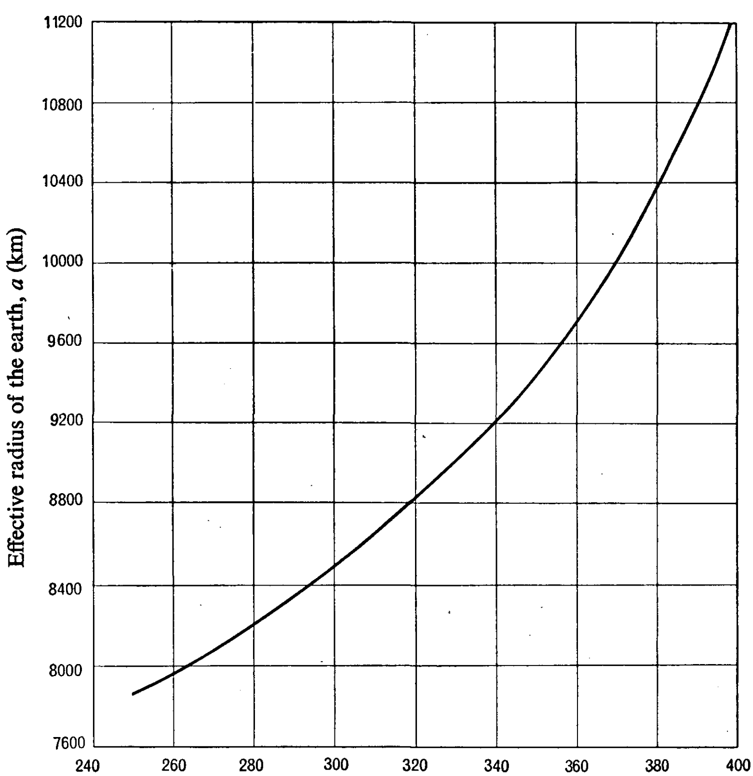

FIGURE 2

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

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

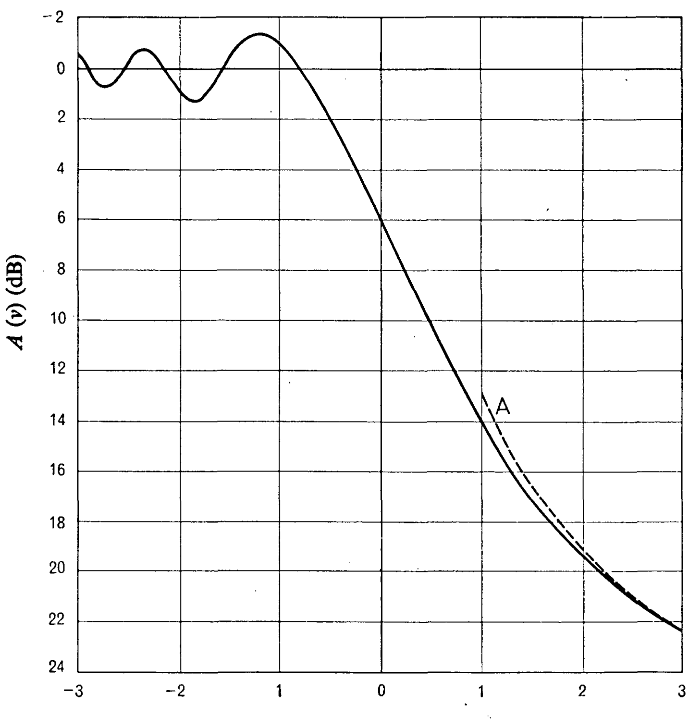

FIGURE 3

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

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

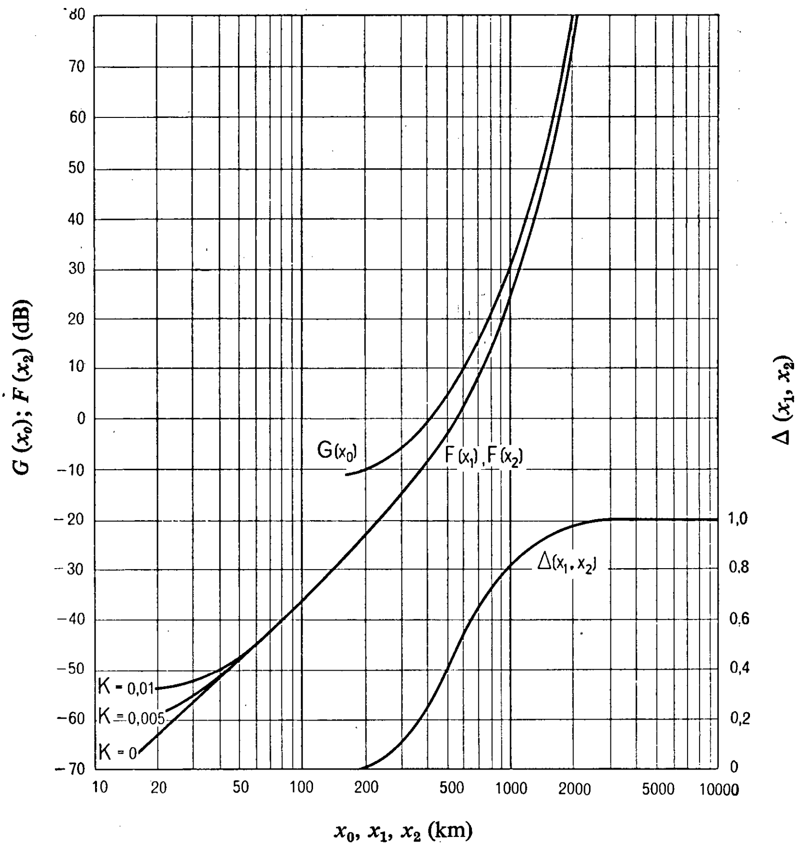

FIGURE 4

Note : — For large values of x :

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

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

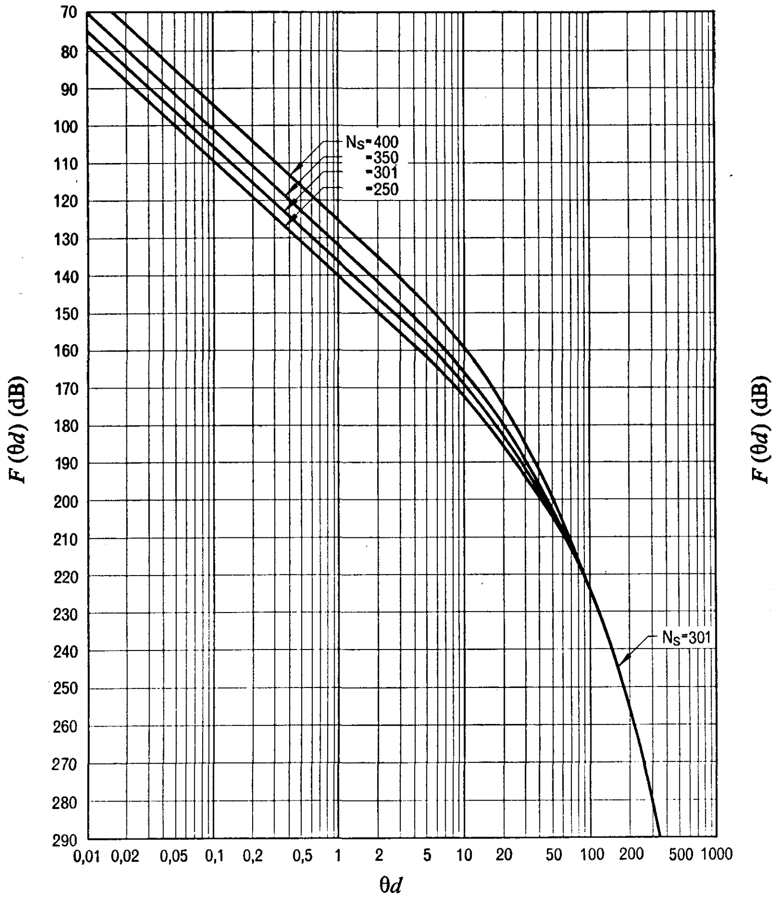

FIGURE 5

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

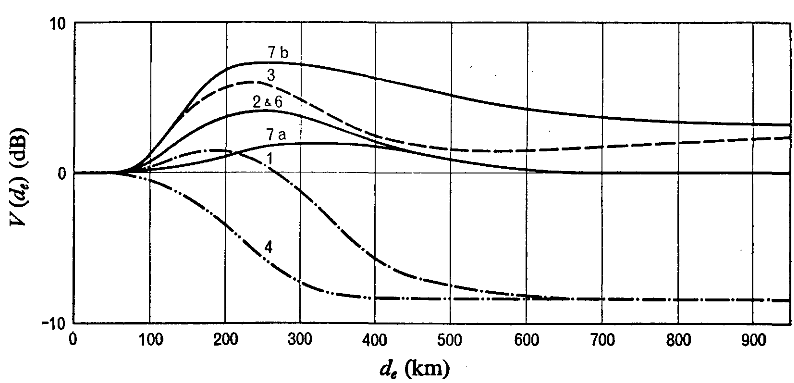

FIGURE 6

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

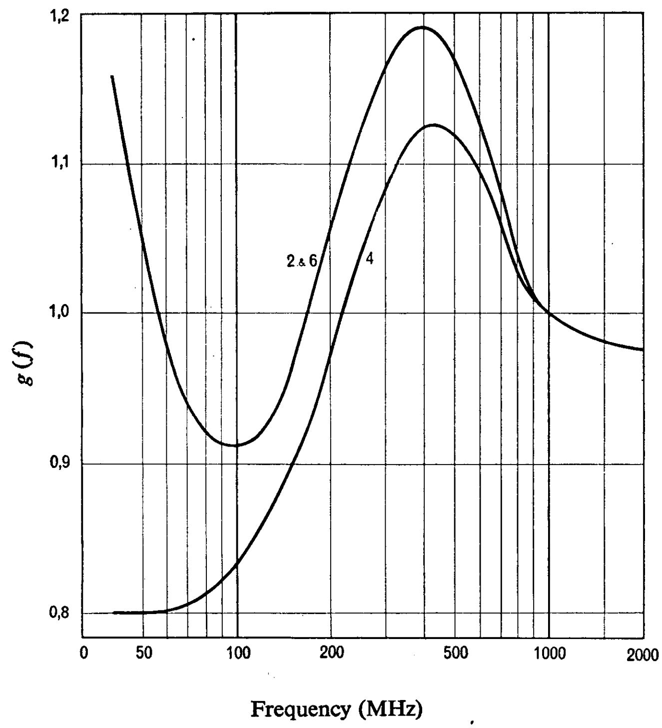

FIGURE 7

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

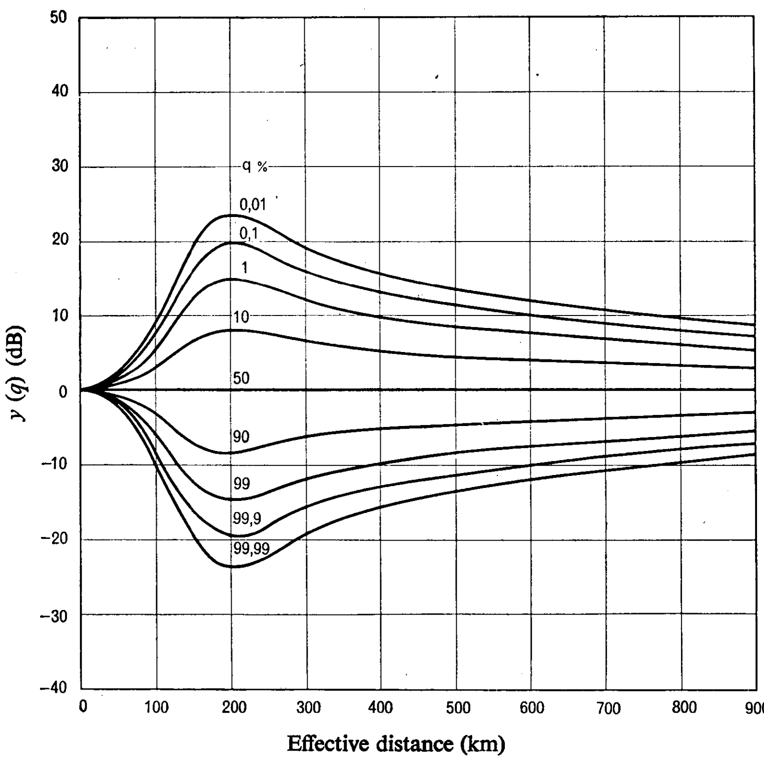

FIGURE 8

Variation of transmission loss with effective distance for an equatorial climate (Type 1)
(The values of q are indicated on the curves)

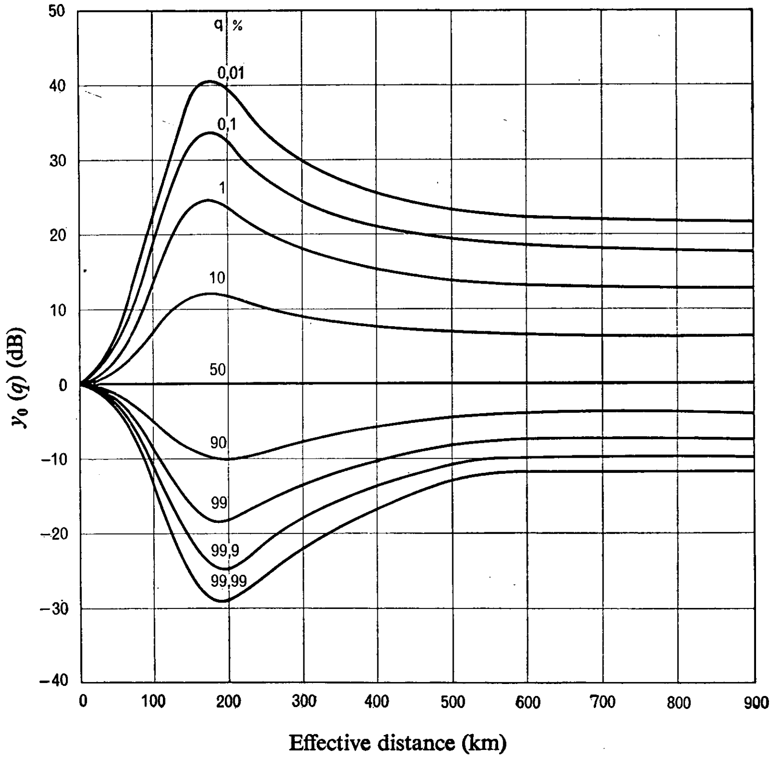

FIGURE 9

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)

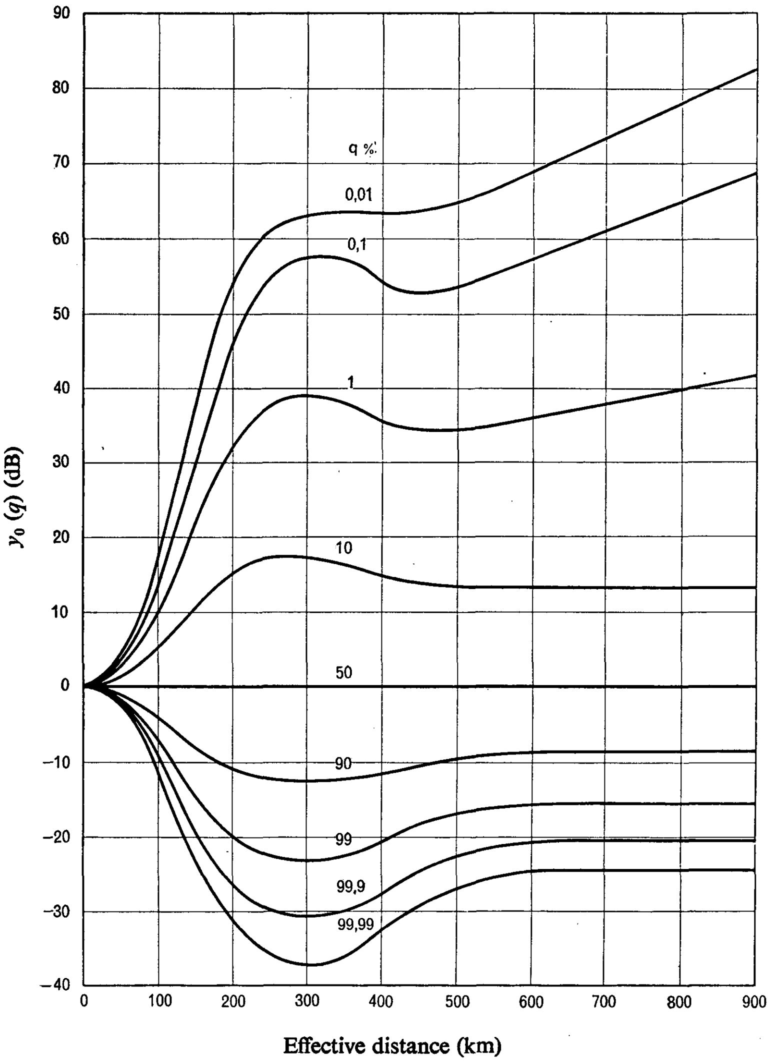

FIGURE 10

Variation of transmission loss with effective distance in a maritime sub-tropical climate (Type 3)
(The values of q are indicated on the curves)

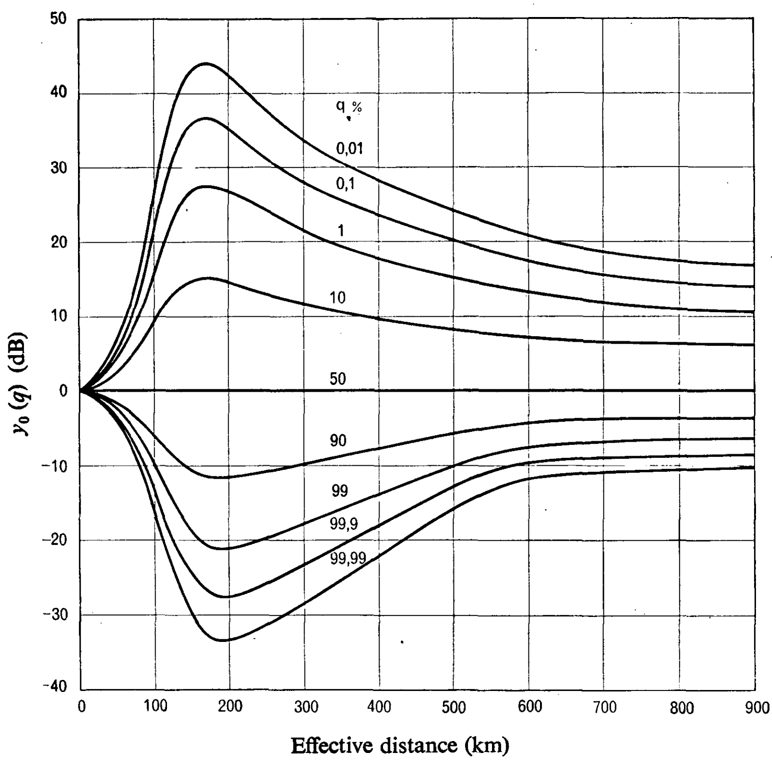

FIGURE 11

Variation of transmission loss with effective distance for a desert climate, Sahara (Type 4)
(The values of q are indicated on the curves)

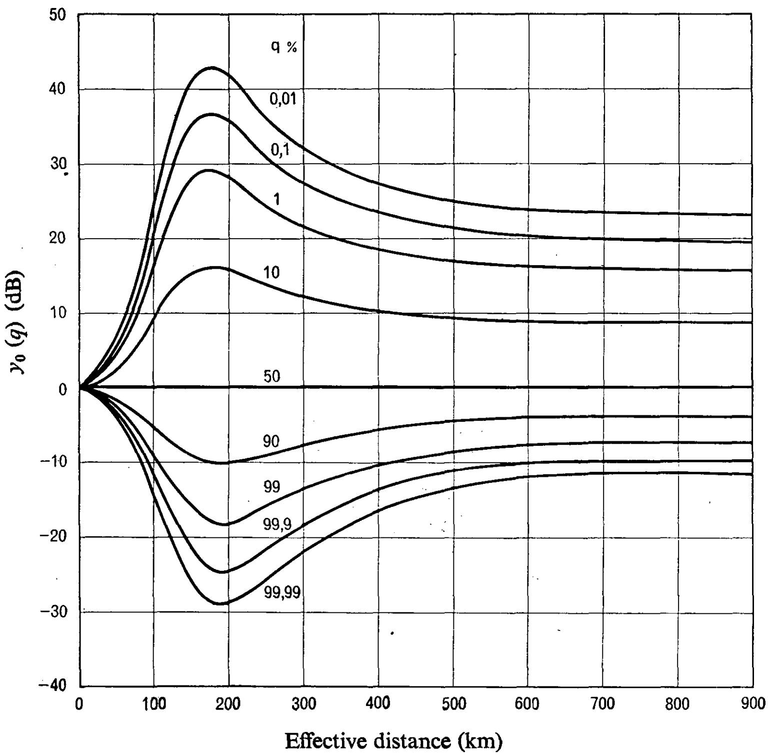

FIGURE 12

Variation of transmission loss with effective distance for a continental temperate climate (Type 6)
(The values of q are indicated on the curves)

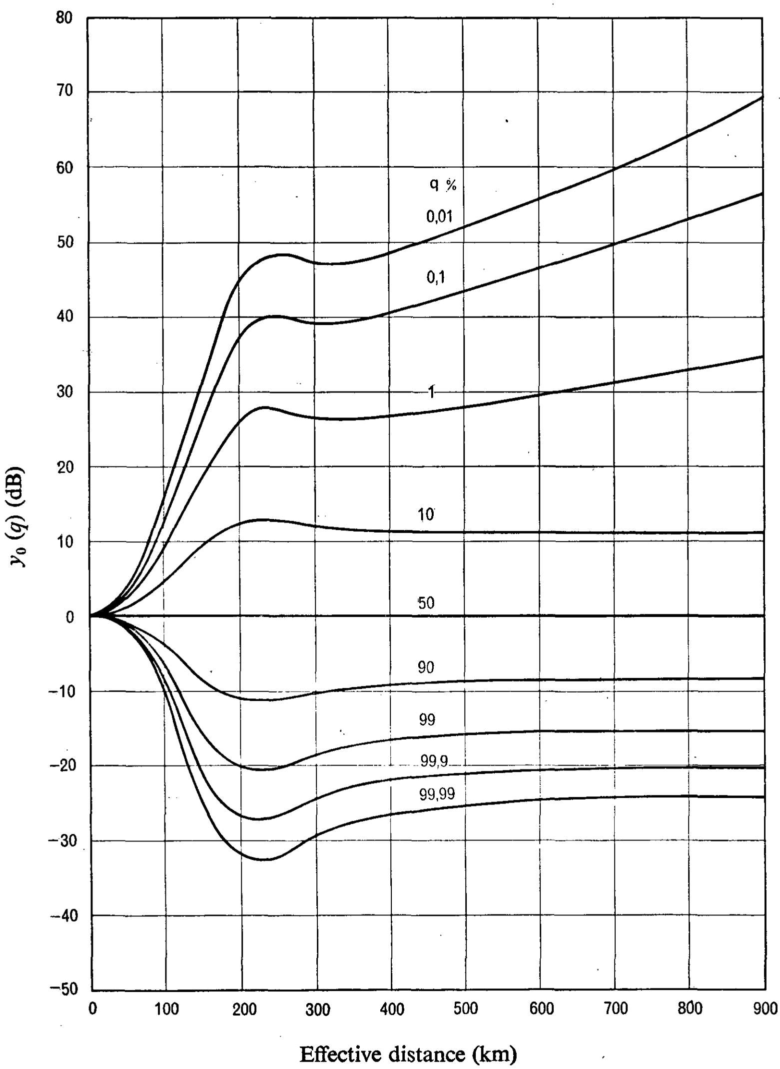

FIGURE 13

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)

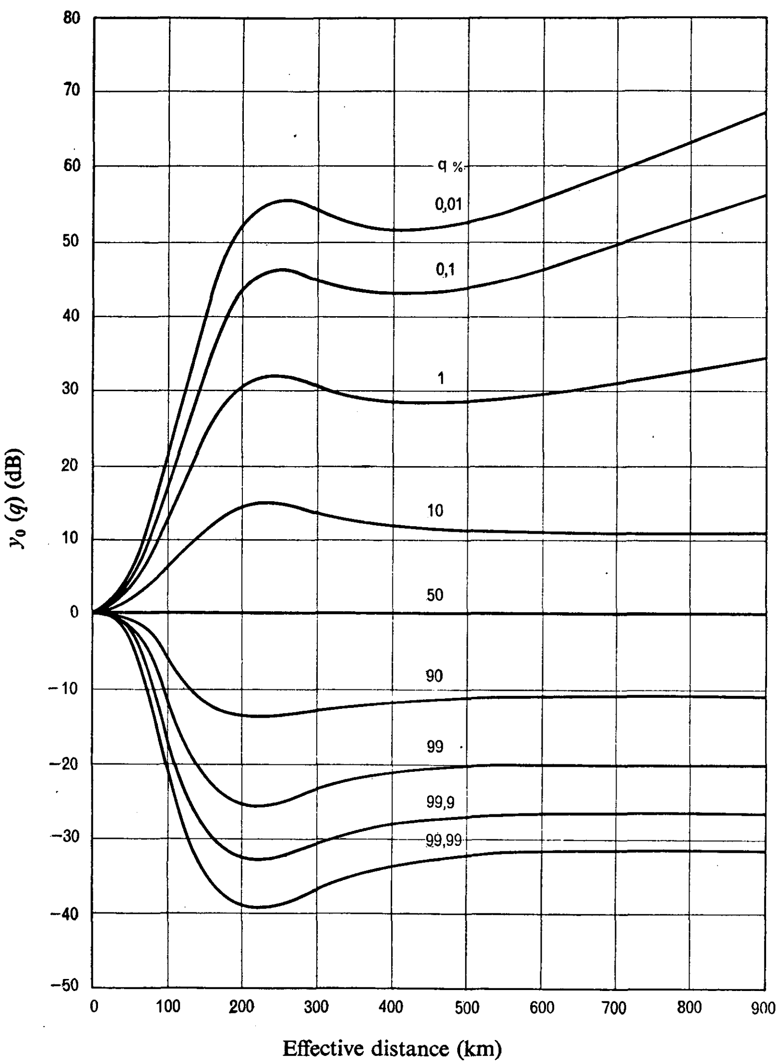

FIGURE 14

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)

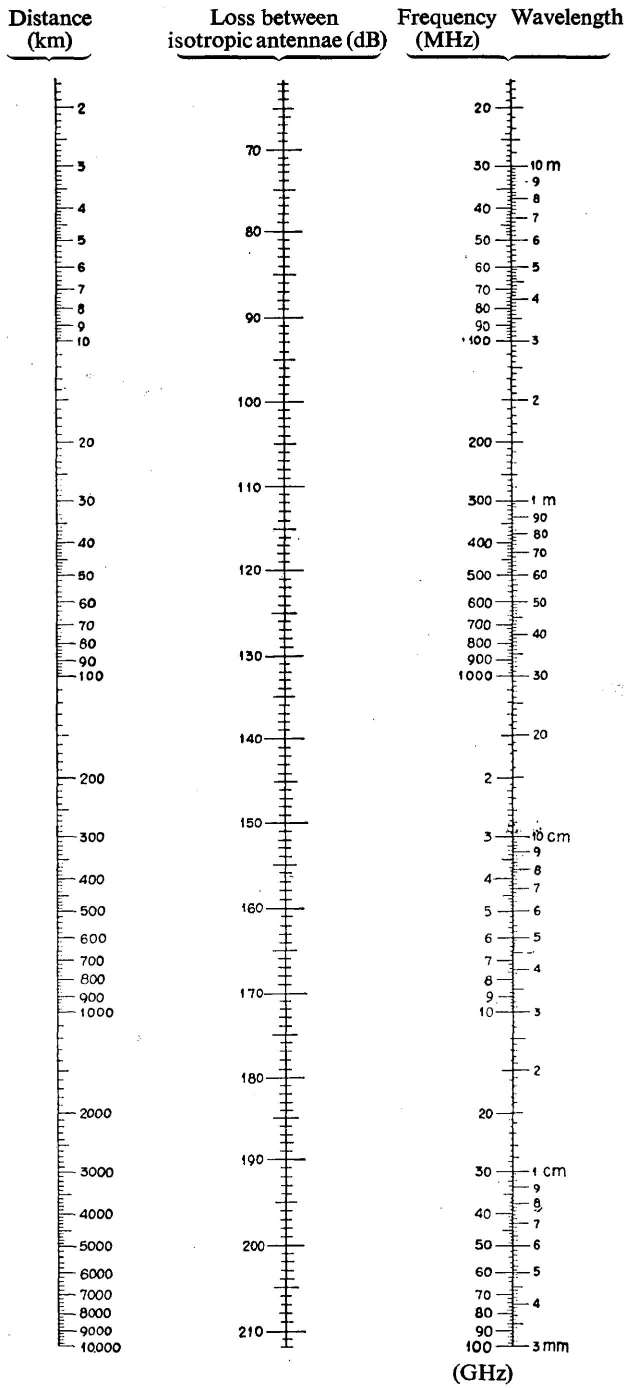

FIGURE 15

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

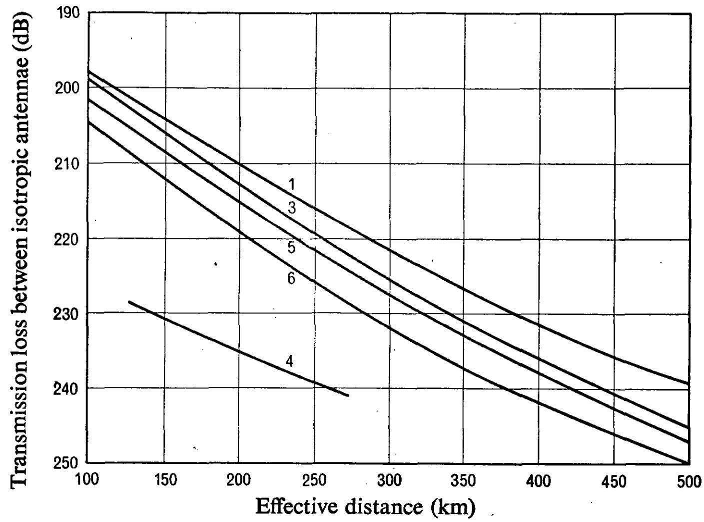

FIGURE 16*a*

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

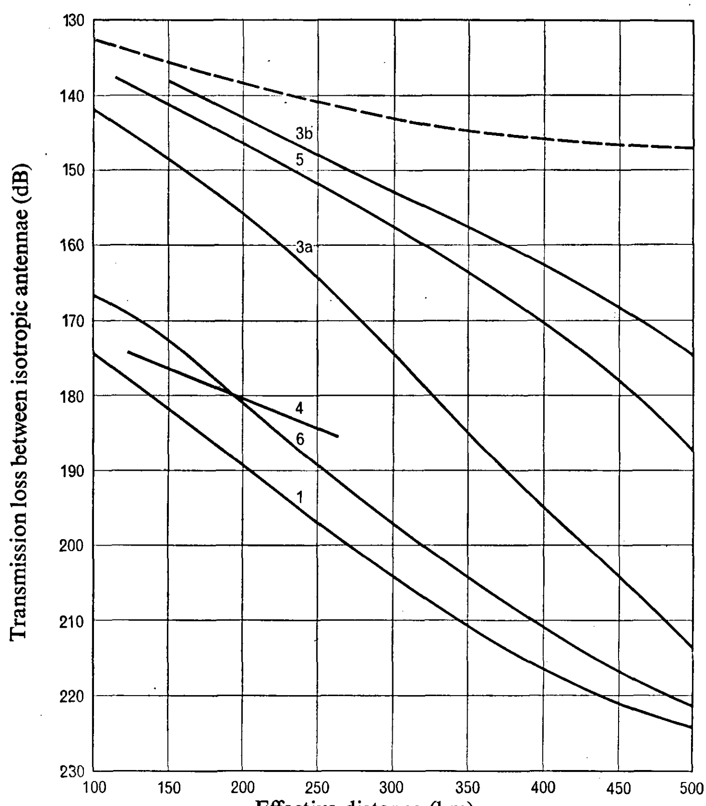

FIGURE 16*b*

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

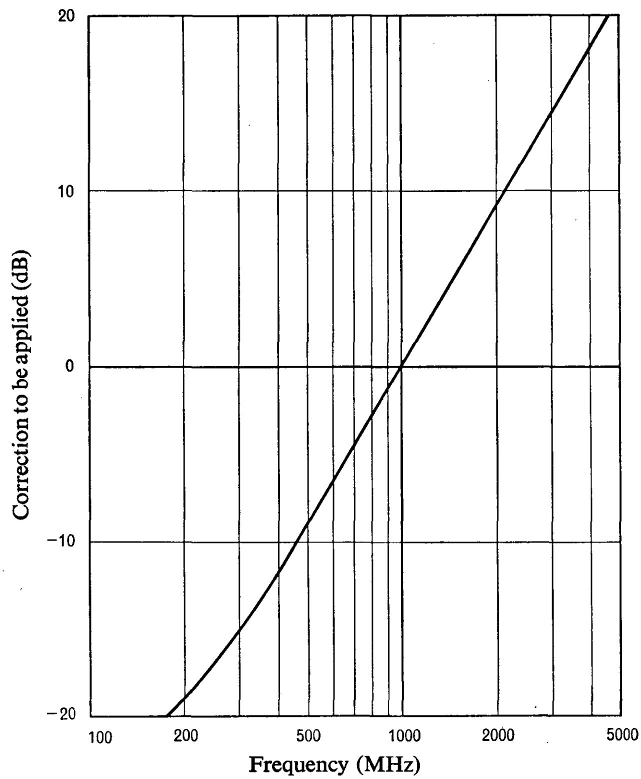

FIGURE 17

Correction (dB) to be applied to the values obtained from the curves of Fig. 16, for frequencies other than 1 GHz

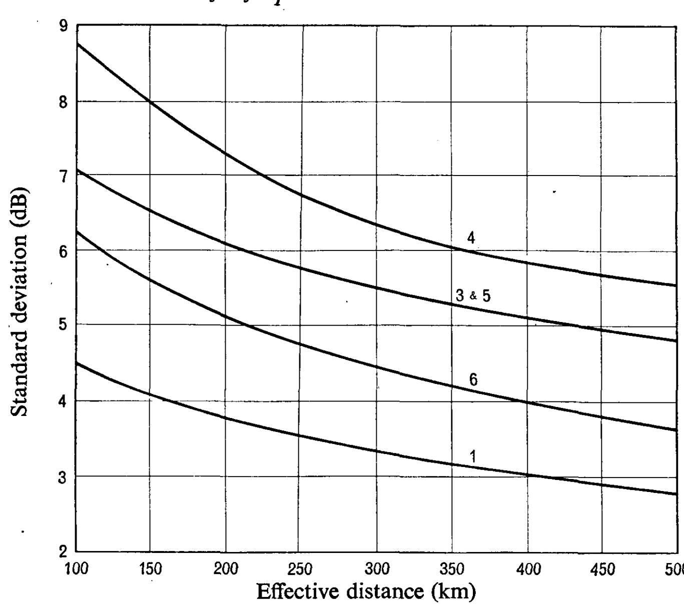

FIGURE 18

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

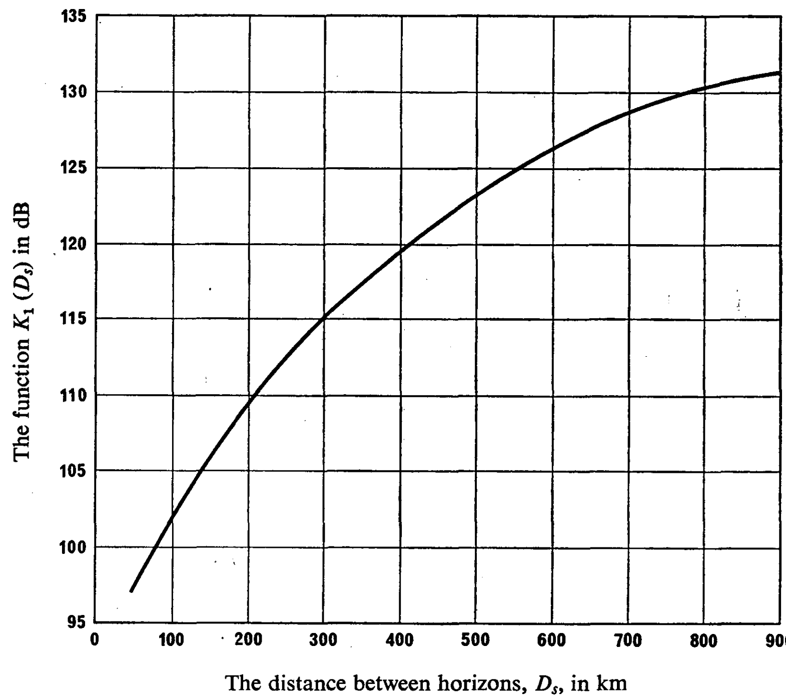

FIGURE 19*a*

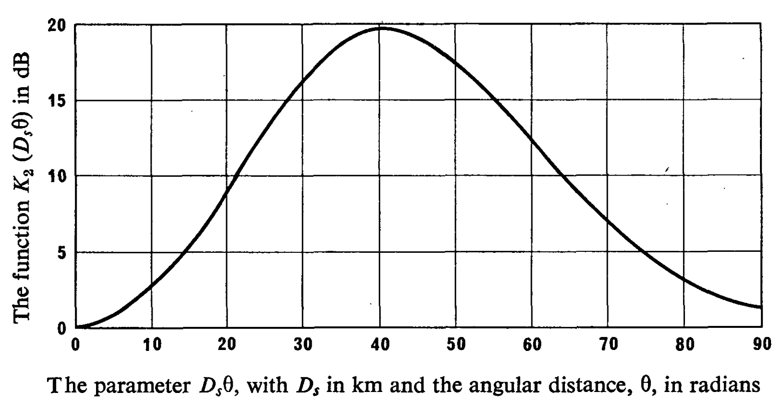

FIGURE 19*b*

REPORT 336 *

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

(1966)

In Question 8/2, § 2, which has been referred to Study Group 5 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 5, 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 $2\pi a/\lambda >> 1$, 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 236-2.

For heights or distances on 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 244-2).

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 337-1 *

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

(1970)

In considering aspects of sharing between space and terrestrial systems, the following propagation factors may have to be taken into account:

— effects of terrain,
— effects of vegetation and buildings,
— effects of tropospheric inhomogeneities,
— effect of tropospheric ducts or layers,
— scatter from hydrometeors,
— scatter from aircraft,
— tropospheric refraction.

Report 244-2 contains information which can be used to estimate the effects of terrain and characteristics of the troposphere, but does not deal with the effects of vegetation, buildings and scatter from precipitation or aircraft.

Report 339-1 discusses the basic factors involved in the calculation of signal strength due to scatter from hydrometeors and can be regarded as a partial reply to Question 14-1/4.

Report 427 gives a method for obtaining site-shielding factors and is another reply to Question 14-1/4.

REPORT 338-1 **

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

(Study Programme 5-1A-1/5)

(1966 – 1970)

1. Introduction

In addition to the large amount of data collected in response to Administrative Circular AC/63 (see Report 241-1) and the relevant information contained in Report 244-2, some additional general information on propagation for the guidance of designers of line-of-sight radio-relay systems is given in this Report, in particular, statistical analysis of many path-loss recordings which enable the preparation of general propagation curves.

* This Report, with Report 427, replaces Report 337 and was adopted unanimously.

** This Report was adopted unanimously.

Although there exist certain links operating at frequencies below 1 GHz the C.C.I.R. does not yet have sufficient data available on the propagation characteristics of these systems. Therefore at this time typical curves cannot be presented. Some information is available in the bibliography [8, 32, 50]. For this reason the present Report deals mainly with frequencies above 1 GHz.

2. Refraction effects

Changes in atmospheric refraction sometimes cause severe fading on line-of-sight microwave radio links. 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 discontinuities. Refraction can also cause fading when extreme conditions cause the ray to arrive at an angle off the main axis of the receiving antenna.

Measurements of the vertical refractive-index gradient in the lower layers of the atmosphere show that the range of values is extremely large.

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 was exceeded during 0·05% of the time, and −370 N/km, which was exceeded during 99·9% of the time, which correspond to k values of 0·4 and −0·7 respectively (concave earth) [48].

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 [2].

Measurements conducted in Japan [3] and in the United Kingdom [4] show that the variation of the gradient is greatly dependent on the layer thickness. In these two countries the results of measurements were very similar and showed that, for the first 100 m, values of about 70 N/km and −200 N/km were exceeded respectively for 0·1% and 99·9% of the time. A method of predicting the variation of gradient from radiosonde data has been developed [3] and confirmed experimentally.

Measurements in the U.S.S.R. [5] have shown that the statistical distribution of the vertical gradient of the refractive 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.

2.1 *Effect on path clearance*

When the atmosphere is sufficiently sub-refractive (large positive values of the gradient of refractive modulus), 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.

For line-of-sight links 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 [6], planned more or less in accordance with this clearance rule, has shown no instances of sub-refractive 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.

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.

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.

It must be pointed out, however, that so far as wave propagation is concerned, extreme values of the index gradient measured at a point, are usually 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.

In Japan [7] simultaneous observations of the incident angle on a 30-km path and the refractive-index gradient in a 75 m layer at the mid-point of the path showed fairly good agreement through a period of one month.

Measurements of angle-of-arrival over a 70-km line-of-sight path in the Federal Republic of Germany [8] carried out at 515 MHz, indicate that, averaged over such a path, the effective k does not exhibit such a wide range of values as would be expected from meteorological observations made at a single point in the path.

Measurements of refraction over a 55-km line-of-sight path in the United Kingdom [9] show that the effective k value exceeds $0{\cdot}9$ for $99{\cdot}9$% of the time.

Measurements made in Italy [10] on a very long (240 km) link over the sea, at 900 MHz and 2164 MHz, show that no value of k less than 1 was measured during the 10-month period of measurement (which included the worst month).

It has been shown [11] that a minimum effective value of k can be derived as a function of path length, as shown in Fig. 1, for a continental temperate climate.

2.2 *Effect on variation in angle of arrival*

Variation of atmospheric refraction can cause changes in the apparent angle of arrival of the line-of-sight ray, particularly in the vertical plane, and can therefore in principle cause a reduction in gain in the antennae used at the ends of the radio path.

Measurements made in England [9] at a frequency of 11 GHz on a path 55 km in length, indicated no variations greater than $\pm$ 7 minutes of arc, during a period of one year.

Measurements made in the Federal Republic of Germany [8], at a frequency of 515 MHz on a path of 70 km, show approximately the same order of variation.

Measurements made in the United States of America, however, on a short path of 28 km, at frequencies of 4 and 24 GHz [12, 13], show that the angle of arrival can change rapidly, by as much as 0·75° above and below the normal line-of-sight. The variation in the horizontal plane is usually much less, being of the order of 0·1°.

Measured variations in the angle of arrival for various radio paths in Japan show fairly good agreement with those predicted by the radio-meteorological statistics of ΔN and $\sigma_{\Delta N}$ in the first 1-km layer, and the layer thickness of ΔH over which the radio waves are propagated [7].

2.3 *Effect on multipath*

Multipath effects occur in two forms: reflection from the ground or water surfaces, and refraction or reflection by inhomogeneities in the atmosphere.

Under some circumstances, the direct ray will be interfered with by the ground-reflected ray or other multipath rays. The most severe fading occurs when there are two effective components of the same order of magnitude. Measurements made in the United States [12] show that as many as six components may exist at one time.

Measurements of multipath propagation carried out in Japan [31] show that most of the deep fades are caused by destructive interference between two dominant rays and that the path-length difference between these rays varies to a considerable extent with propagation path conditions. Maximum path-length differences of 2 m and 20 cm were observed on an oversea path and an overland path respectively. The relative amplitude ratio of multiple rays showed a rapid variation over a wide extent, resulting in an almost uniformly distributed probability density. A method for estimating the multipath characteristic has been developed using the fading probability and has been verified experimentally.

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 twoprimary waves, are taken into account [14]. If such a path cannot be avoided, height or frequency diversity may be used to reduce the severity of the fading. 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 the 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 [15] showed 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.

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 [16]. However, when the atmosphere is super-refractive and the earth appears concave, the reflected wave is enhanced by the convergence of the associated rays.

In addition, experiments in the Federal Republic of Germany [19] 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 [18] also shows correlation between fading and ground fog.

Multipath fading caused by layering in the atmosphere exhibits a frequency and duration of fading which are related to the variation of the structure of refractive index with time;

i.e. the worst propagation conditions occur during periods of extreme stratification of the atmosphere. On overland paths and in temperate climates, these conditions normally occur during the night and early morning hours of summer days.

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 [19].

3. Fading statistics

The analysis of 27 paths in the United Kingdom, [6], all involving path lengths of less than 100 km, has shown that relative to a free space signal, the fading depth exceeded for a small percentage of time is a function, to a first approximation, of the path length. It also depends on the type of terrain traversed but is not very dependent on the frequency within the range 2-6 GHz.

However, work carried out in France [27] 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. 2 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. 2 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. 2, 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. 2, and if the path crosses water, moist river valleys, or moors, the fading depth may be 12 dB greater than shown in Fig. 2. Observations on a 100 km path, using a frequency of 6 GHz, have shown that even on a rough path considerable fading may occur.

In the U.S.S.R. a method has been developed for the calculation of the statistical distribution of the depth of fading, taking into account the path length, terrain contour, climate, height of antenna and frequency [46].

Measurements made in an area near Dresden on a path 56 km in length [37] demonstrated that in the examined area there was little difference in the fading at 8 and 11 GHz. The fading depth at 11 GHz between 50-99·9% attained a yearly average of 24 dB. This value was about 21 dB at 8 GHz. Frequency diversity operation at 11 GHz with frequencies displaced by 240 MHz resulted only in an improvement of 5 dB for 99·9% of the time. The daily and seasonal variations of the fading are similar to those at lower frequencies. The maximum fading caused by summer storm-showers occurred mostly in the late afternoon. The analysis of rainfall intensity at two stations situated at a distance of 50 km measuring the precipitation showed very similar distributions.

Of considerable interest to system designers is the extent to which increases in hourly mean noise due to fading on one path coincide with increases on another path of the same system. Measurements in the United Kingdom [20] indicate there is little justification for estimating the mean hourly noise performance of microwave systems on the assumption that the worst hours occur simultaneously on all paths.

For designing radio-relay systems conforming to C.C.I.R. Recommendations, it is necessary to predict the probability of deep fades for very small percentages of the time (e.g. about 0·0002% for an average hop of about 50 km). To overcome the difficulty which may be encountered in predicting fading depth for such a small percentage of the time, a method of utilizing the occurrence probability of Rayleigh fading has been developed in Japan [35]. The analysis of a large number of links in Japan has shown that the Rayleigh fading probability P_R is given by the following empirical formula for clear line-of-sight paths with negligible earth reflection:

$$
\begin{aligned}
P_R &= (K \times Q)(f/4)^{1\cdot 2} \times d^{3\cdot 5} \\
K &= 5{\cdot}1 \times 10^{-9} \\
Q &= 0{\cdot}4 \text{ (over mountain)} \\
&= 1{\cdot}0 \text{ (over plain)} \\
&= 72/(\bar{h})^{1/2},\ \bar{h} = (h_1 + h_2)/2 \text{ (over sea or coast)} \\
f &= \text{frequency (GHz)}, \\
d &= \text{path length (km)}
\end{aligned}
$$

The probability of the circuit noise burst exceeding a value of N due to deep fades can be evaluated by:

$$P_R\,(N_0/N),$$

where N_0 is the thermal noise in free space conditions [36].

4. Diversity reception

The most severe multipath fading occurs when there are two effective components equal in magnitude. Multipath fading may be alleviated by the use of diversity systems such as frequency, or space diversity. Radio links with diversity equipment to combat this type of fading have operated quite satisfactorily [23, 24, 25].

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. Methods have been developed for determining the antenna or frequency separation necessary to provide diversity protection against deep fades. Methods [25, 1] 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 applicable to multipath propagation through the atmosphere has been developed and experimentally verified in Japan [26].

Studies carried out in the Federal Republic of Germany have shown that space diversity reception with antennae spaced vertically by 50 wavelengths reduced fading due to multipath propagation although studies in France [7] and in Italy [10] indicate that a spacing of 150 wavelengths is desirable. Measurements across the English Channel at 4 GHz show that these spacings are 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 practically that expected from uncorrelated signals.

Measurements have been carried out in Italy [10] on a long-distance oversea path to investigate the efficiency of space diversity related to the quality of the transmitted signal. Such measurements have shown that a switching space diversity controlled by the received field can be efficient enough to improve reception mostly during deep fading.

Frequency diversity measurements have been made at 2·5 GHz in the Federal Republic of Germany and at 2 GHz in Italy [17, 14], 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.

Measurements made by the Administration of France on a path length of 106 km in the Federal Republic of Cameroon at a frequency of 6 GHz have shown that it is possible to reduce the correlation between received signals on two antennae arranged such that one antenna was pointed slightly upwards from the direct path, creating in effect an angle diversity system.

As a result of numerous experimental measurements carried out by several Administrations [27, 28, 29], it was possible to plot the curves shown in Fig. 3 [11] indicating the improvement obtained with space or frequency diversity. These curves are valid for the least favourable month on links seriously affected by fading, for frequencies between about 2 and 10 GHz. The improvement would probably be slightly better for lower frequencies. With space diversity, it is assumed that the vertical spacing between the antennae is greater than about 150 wavelengths.

Measurements in the United States [33, 34] have compared the efficacy of frequency diversity and space diversity. These measurements bring out the fact that current design procedures applicable to over-water and regular terrain are not in general suitable for paths over irregular terrain.

5. Intermodulation noise due to multipath propagation

Multipath transmission through the atmosphere contributes to both the thermal noise and the intermodulation noise arising in a frequency modulated system. Long-term measurements in the United Kingdom on a 55-km long path at 4 GHz [30] and on a 58-km long path at 11 GHz [20] of the amplitude and delay of multipath signals, indicate that the resulting intermodulation noise in a telephony system of less than 600 channels would not be significant. This may not necessarily be true for other paths and in climates differing from that experienced in the United Kingdom.

Theoretical and experimental studies carried out in Japan [31] have shown that ground reflections can give a distribution of total noise more unfavourable than that for thermal noise alone, even on propagation paths having relatively weak reflections.

A statistical method for estimating the distortion due to interference between two rays has been developed in Japan and confirmed by noise loading experiments on the propagation path. According to these experiments the effect of distortion due to atmospheric multipath only was not very serious for a radio-relay system with a capacity of 2700 telephone channels and with a frequency deviation of 100 kHz/channel.

A method for calculating the distortion when several or a large number of wave components are present simultaneously in the received signal, with phases of equal probability ($0 - 2\pi$), has been developed in Sweden [47].

In France, measurements carried out on a path of 95 km, with a radio-relay system of 1800 channels at 6 GHz, have shown that the intermodulation noise due to propagation effects was of little importance [49].

6. Additional information on frequencies above 10 GHz *

Microwave radio propagation through the atmosphere is attenuated by rain, hail, snow and water vapour. The attenuation effects of rain, while small in the lower microwave region, become more important at frequencies above 10 GHz. In Japan [38], for example, at 15·4 GHz, a uniform rain falling at the rate of 100 mm/hr has been observed to produce an excess attenuation of about 7 dB/km. An attenuation of 49 dB, due to rain falling at the rate of 72 mm/hr, was observed over a path of 15 km in length. In the United States [39] a uniform rain, falling at the rate of 100 mm/hr, has been observed to produce an excess attenuation greater than 22 dB/km at 18 GHz. Under these conditions, it is obviously impossible to maintain transmission over paths longer than a few kilometres. However, recent measurements have shown that the temporal and spatial distributions of such severe rain storms are highly restricted. Nevertheless, radio-relay systems operating at these frequencies will have to employ short hops if they are to have a high degree of reliability [40, 41]. While the excess attenuation caused by rainfall is the controlling factor the attenuation effects of water vapour and fog must also be taken into account.

Measurements on six paths in the United Kingdom at 11 GHz [20, 9] show that, although more fading is experienced than at 4 and 6 GHz, neither on an annual nor a monthly basis is the fading at 11 GHz due to precipitation a major factor. This may not necessarily be true for countries in other climates. Studies made in Japan [21] indicate that in rainy districts the attenuation due to rain is a dominant factor for frequencies higher than about 10 GHz. Here and in other countries methods have been derived for calculating rain attenuation from data observed at weather stations and these indicate a need to allow for the non-uniform spatial distribution of precipitation. Measurements at 15 GHz on a 16-km path in Canada [22] indicate that intense rain results in considerable additional fading. In addition, the possibility of fading due to wet snow is emphasized [20].

Comparative measurements [45] in Southern England on the effects of precipitation in causing fading over a 24-km path at three frequencies, 11, 18 and 36 GHz are shown in Table I.

Calculations based on work in the United States [44] show that, in the United Kingdom [42, 43], at a frequency of 100 GHz on a pulse code modulation link 2 km long, 20 microwatts would be adequate, except for rain heavier than 25 mm/hr, which occurs for 0·008% of the time. For a link 6 km long, however, a reliability of 99·99% would require a transmitter power of about 5 watts assuming the same receiver characteristics.

* See also Report 234-2 which also contains information of interest in the design of line-of-sight radio-relay systems.

Although these results should be regarded as provisional pending more detailed information on the characteristics of high-intensity rainfall, they give an indication of the feasibility of practical systems.

For scintillation fading, with paraboloidal antennae of up to a few metres in diameter, it is estimated that the order of magnitude of the peak-to-peak fluctuations occasionally experienced on terrestrial links with terminal heights of 10 or 20 m will be as follows:

At 100 GHz: ±1 dB at 2 km; ±5 dB at 10 km.
At 35 GHz: ±3 dB at 10 km; ±8 dB at 50 km.

In some problems (e.g. the evaluation of gain degradation in large antennae) it is often necessary to estimate the phase differences which can occur across the wavefront. These can also be calculated from theoretical work assuming models of refractive-index structure. For a 6 m spacing it is estimated that, for small percentages of the time, the r.m.s. value of phase difference in the wavefront on terrestrial links may reach the following values:

At 100 GHz: 30° at 2 km; 70° at 10 km.
At 35 GHz: 25° at 10 km; 55° at 50 km.

Although the results given are largely based on theory, they are in reasonable agreement with the limited experimental data available. However, they should be used with caution pending more comprehensive experimental and theoretical work.

7. 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 yet possible to state precisely the effect of reducing the path clearance well below that required by the simple rules given in § 2.1.

TABLE I

Depth of fading (dB) exceeded for indicated percentage of time

GHz	Whole year				Worst Month			
	0·001	0·01	0·1	1·0	0·001	0·01	0·1	1·0
11	15	8	2	0	24	14	1	0
18	34	18	7	2	>50	26	7	0
36	>50	>50	38	9	>50	>50	>50	31

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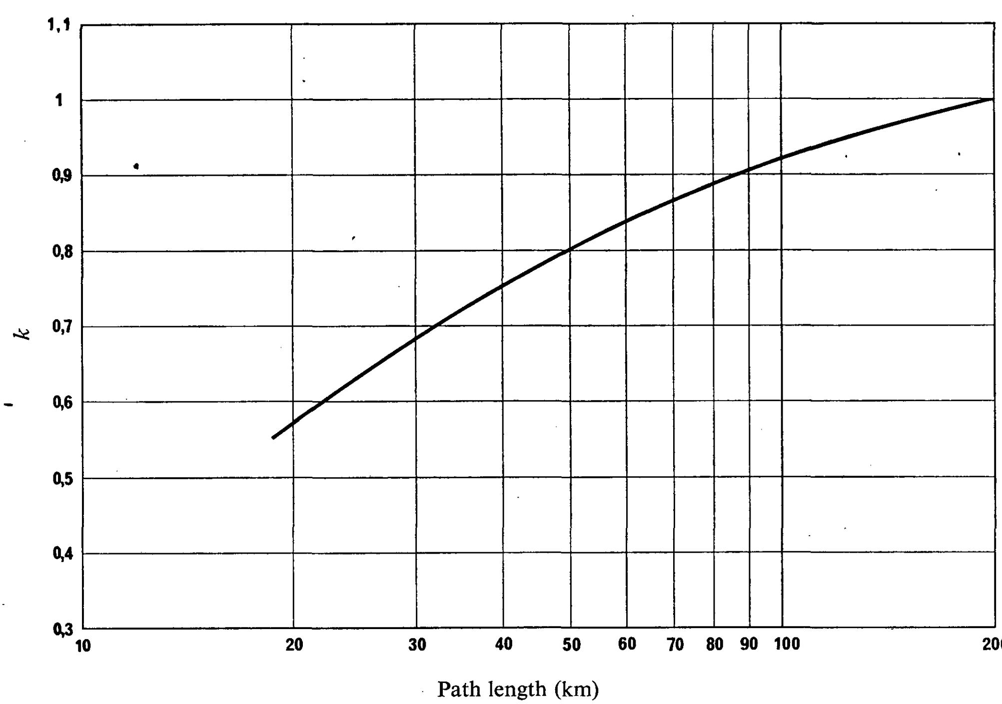

FIGURE 1

Minimum effective value of k (exceeded for approximately 99·9% of the time)
(Continental temperate climate)

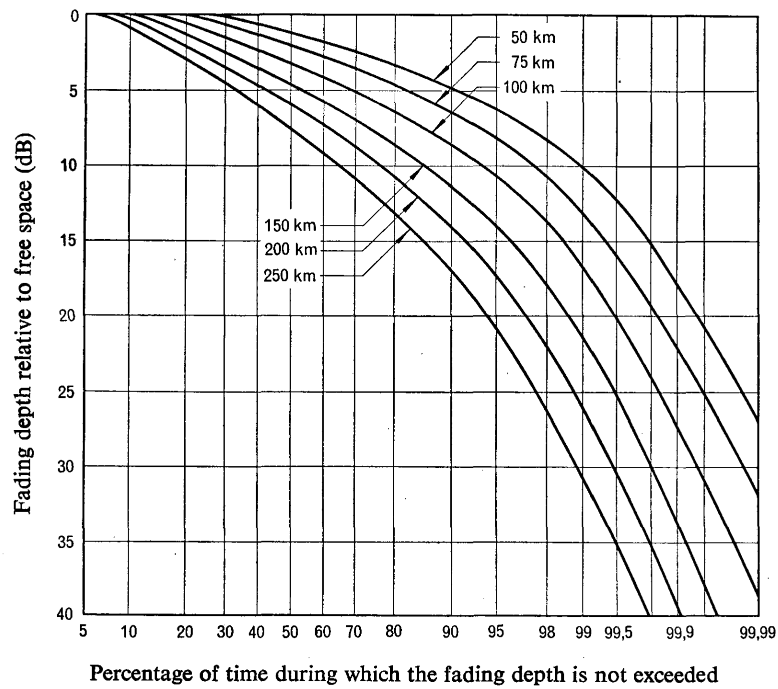

FIGURE 2

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

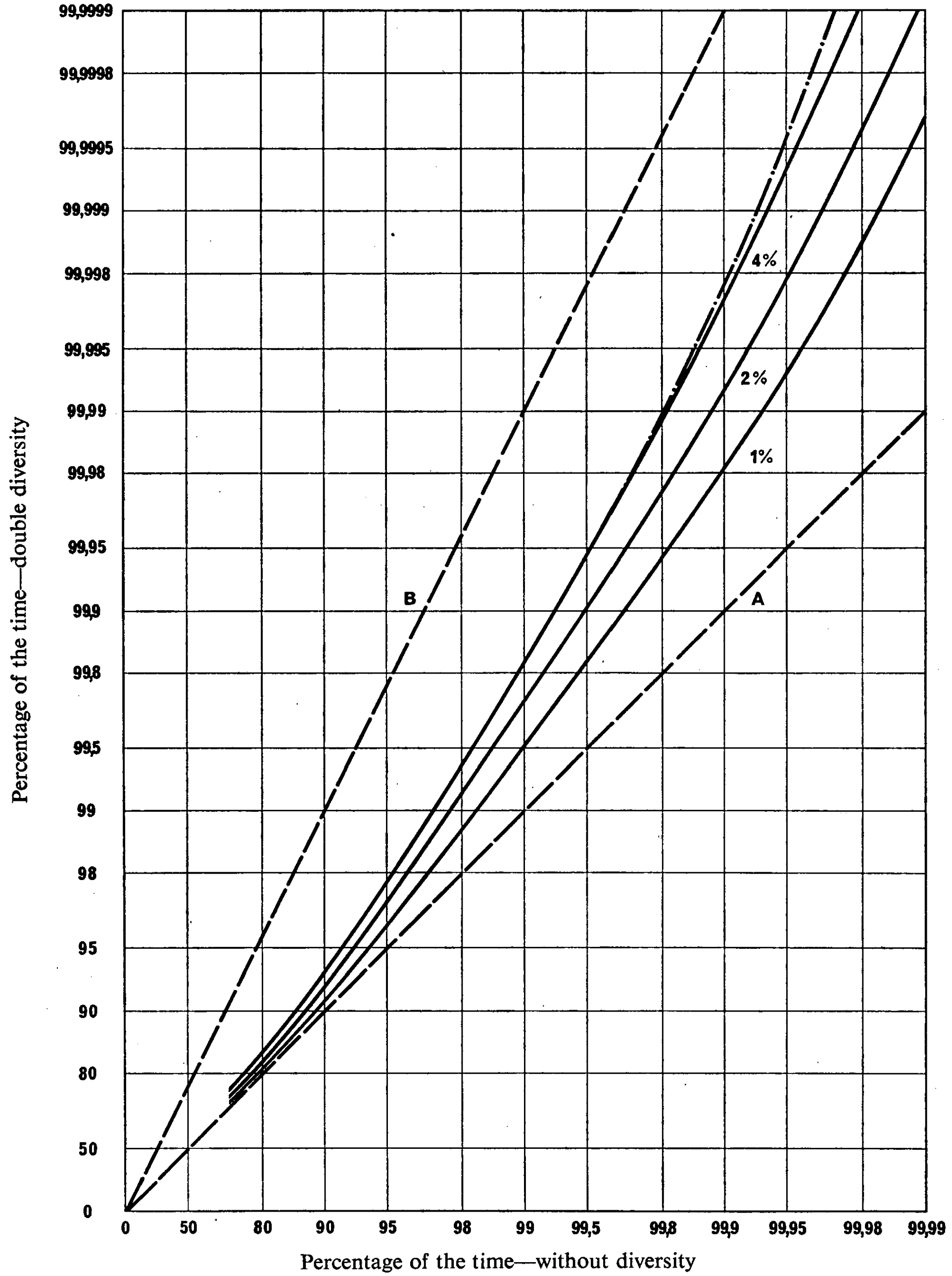

FIGURE 3

Curve A: Limiting curve without diversity
Curve B: Limiting curve with double switched diversity

———— Frequency diversity with $\Delta F/F = 1\%$, 2% and 4%
—·—·— Space diversity

REPORT 424 *

VHF, UHF AND SHF PROPAGATION CURVES FOR THE AERONAUTICAL MOBILE SERVICE

(Study Programme 7A/5)

(1970)

1. Introduction

The rapid and increased growth of aviation has suggested that the C.C.I.R. provide guidance to engineers in the planning of aeronautical communications in the various frequency bands allocated to this service. Since greater antenna heights and higher frequencies are involved, the existing propagation curves of Recommendation 370-1 are not convenient for use by the aeronautical mobile service. This Report illustrates new curves specifically developed for this service and suggests that Administrations apply the curves and evaluate their practicability in determining wanted-to-unwanted signal ratios in interference studies. Interference to either ground or aircraft stations operating on co-channel or adjacent channel assignments may be effectively avoided by the judicious separation of aeronautical ground stations. This may readily be accomplished by the use of these curves. Administrations, having studied these curves, may wish to prepare a Recommendation on this subject at a future assembly.

2. Development of the curves

The curves summarize an analysis of thousands of mobile recordings plus many long-term median transmission loss values. Methods given in [1] were used to calculate long-term median values of the basic transmission loss. In performing these calculations, a smooth earth with an effective earth-radius factor of 4/3 was used. The long-term power fading statistics used correspond to a continental temperate climate (see Report 244-2).

With the exception of a region "near" the radio horizon, values of the transmission loss for "within-the-horizon" paths were obtained by adding the attenuation due to atmospheric absorption (in decibels) to the transmission loss corresponding to free-space conditions. Within the region "near" the radio horizon, values of the transmission loss were calculated using geometric optics, to account for interference between the direct ray and a ray reflected from the surface of the earth. Segments of curves resulting from these two methods were joined to form a curve that shows transmission loss as increasing monotonically with distance.

Values of transmission loss read from the curves that are less than those associated with free-space transmission should be disregarded. The two-ray interference model was not used exclusively for within-the-horizon calculations, because the lobing structure obtained from it for short paths is highly dependent on surface characteristics (roughness as well as electrical constants), atmospheric conditions (the effective earth radius is variable in time), and antenna characteristics (polarization, orientation and gain pattern). Such curves would often be more misleading than useful; i.e., the detailed structure of the lobing is highly dependent on parameters that are difficult to determine with sufficient precision.

* This Report was adopted unanimously.

3. Description of the curves

The aeronautical curves are contained in Figs. 1 to 5. The following points are to be noted:

3.1 Figs. 1 to 5 show median values of the basic transmission loss, L_b for the frequencies 125, 300, 1600, 5100 and 15 500 MHz.

3.2 The curves average the difference between horizontal and vertical polarization for both average ground and sea water. The difference is distinguishable only at 125 MHz for the 15 m (50′), 15 m (50′) antenna height combination, and does not exceed ± 2 dB.

3.3 Because of the widespread use of the nautical mile for the expression of distances for aviation, the abscissa is presented in this unit, with an auxiliary scale in kilometres. Similarly, antenna heights are given basically in feet with their equivalents in metres.

3.4 Antenna heights (shown at the top of the graphs) vary from 15 to 18 300 m (50 to 60 000 feet), covering both ground station and aircraft altitudes. Report 239-2, § 2, shows how to interpolate between the given antenna heights.

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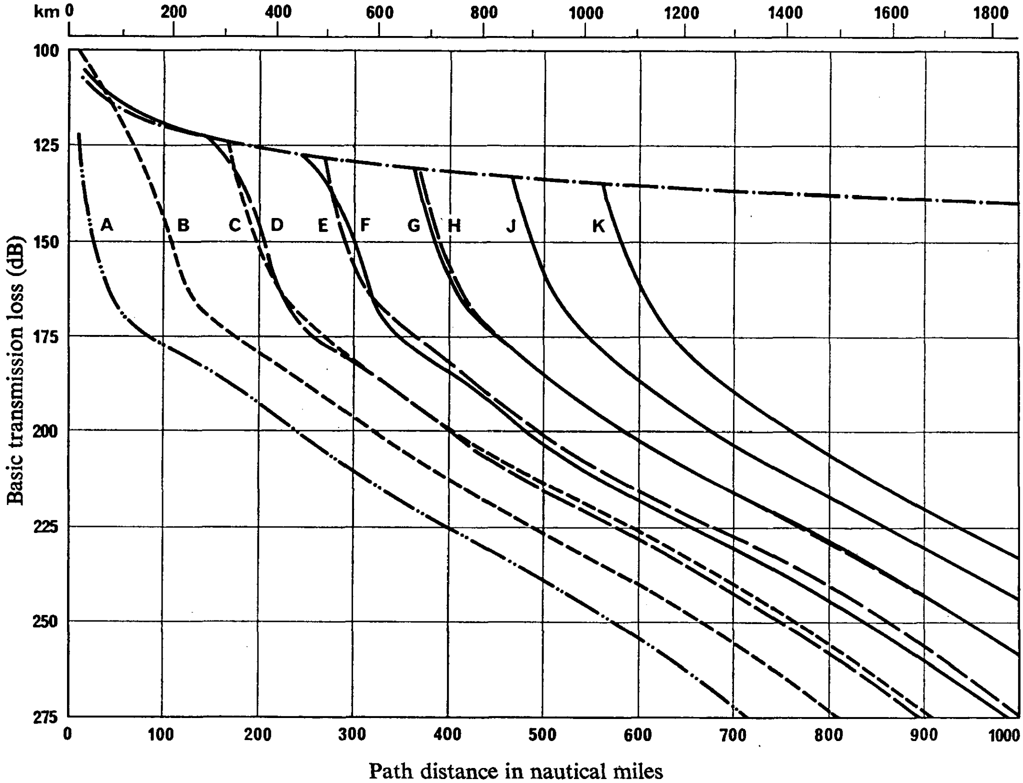

FIGURE 1

Long-term median values of the basic transmission loss, continental temperate

$N_s = 301$ (Four-thirds Earth), $\Delta h = 0$, isotropic antennae, heights H_1 and H_2 at either terminal, as indicated

Frequency 125 MHz

H_1					
	m	feet		m	feet
A	15·2	50	F	15·2	50
B	15·2	50	G	1 524	5 000
C	1524	5000	H	7 620	25 000
D	15·2	50	J	7 620	25 000
E	1524	5000	K	18 300	60 000

H_2

———	18 300 m	60 000 feet	
—— —	7 620 m	25 000 feet	
- - - - -	1 524 m	5 000 feet	
·—··—	15·2 m	50 feet	
—·—	Free space		

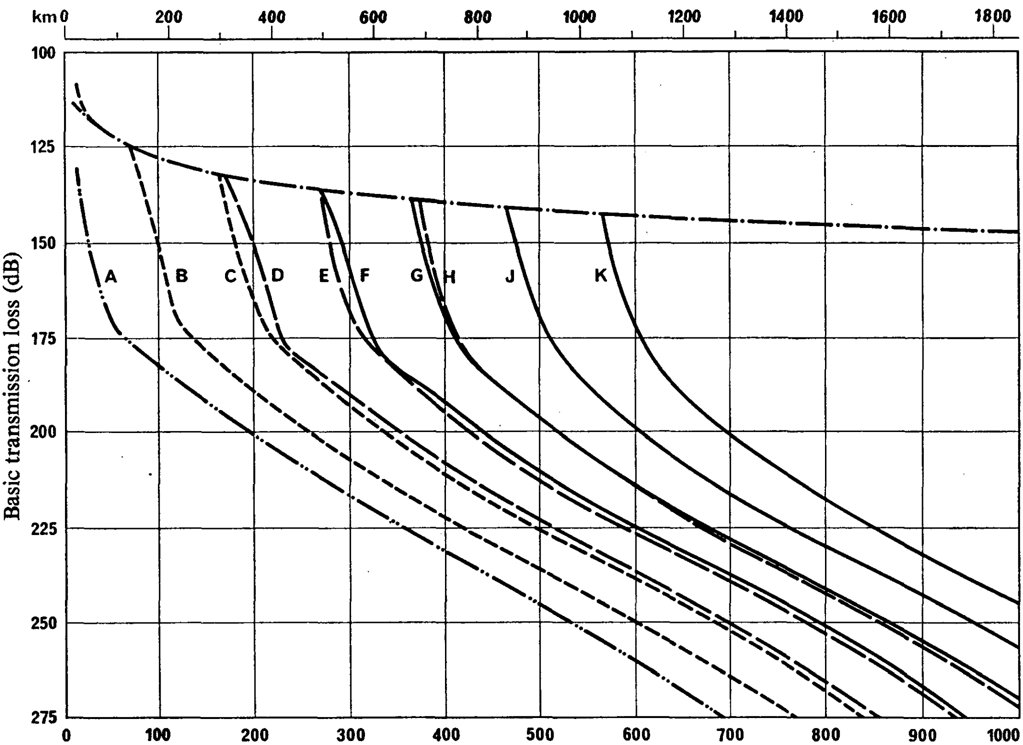

FIGURE 2

Long-term median values of the basic transmission loss, continental temperate

$N_s = 301$ (Four-thirds Earth), $\Delta h = 0$, isotropic antennae, heights H_1 and H_2 at either terminal, as indicated

Frequency: 300 MHz

	H_1				
	m	feet		m	feet
A	15·2	50	F	15·2	50
B	15·2	50	G	1 524	5 000
C	1524	5000	H	7 620	25 000
D	15·2	50	J	7 620	25 000
E	1524	5000	K	18 300	60 000

H_2

————	18 300 m	60 000 feet
— — — —	7 620 m	25 000 feet
- - - - - -	1 524 m	5 000 feet
—··—··—	15·2 m	50 feet
—·—·—	Free space	

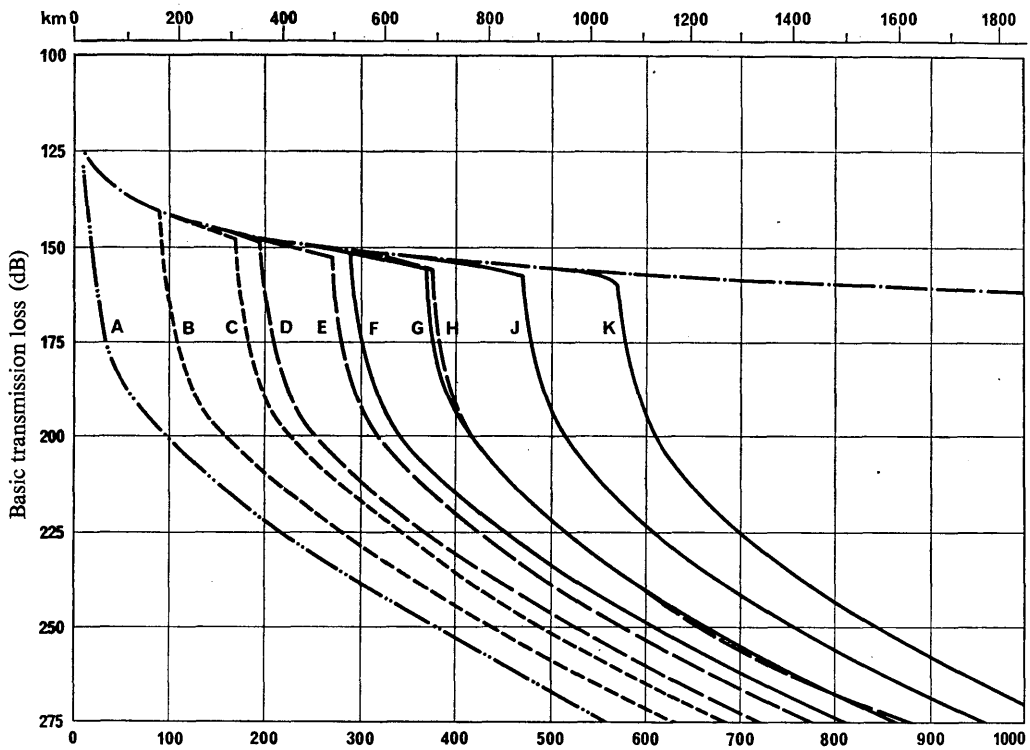

FIGURE 3

Long-term median values of the basic transmission loss, continental temperate

$N_s = 301$ (Four-thirds Earth), $\Delta h = 0$, isotropic antennae, heights H_1 and H_2 at either terminal, as indicated

Frequency: 1600 MHz

H_1					
	m	feet		m	feet
A	15·2	50	F	15·2	50
B	15·2	50	G	1 524	5 000
C	1524	5000	H	7 620	25 000
D	15·2	50	J	7 620	25 000
E	1524	5000	K	18 300	60 000

H_2

———————	18 300 m	60 000 feet
——— ———	7 620 m	25 000 feet
— — — — —	1 524 m	5 000 feet
··——··——	15·2 m	50 feet

—·— Free space

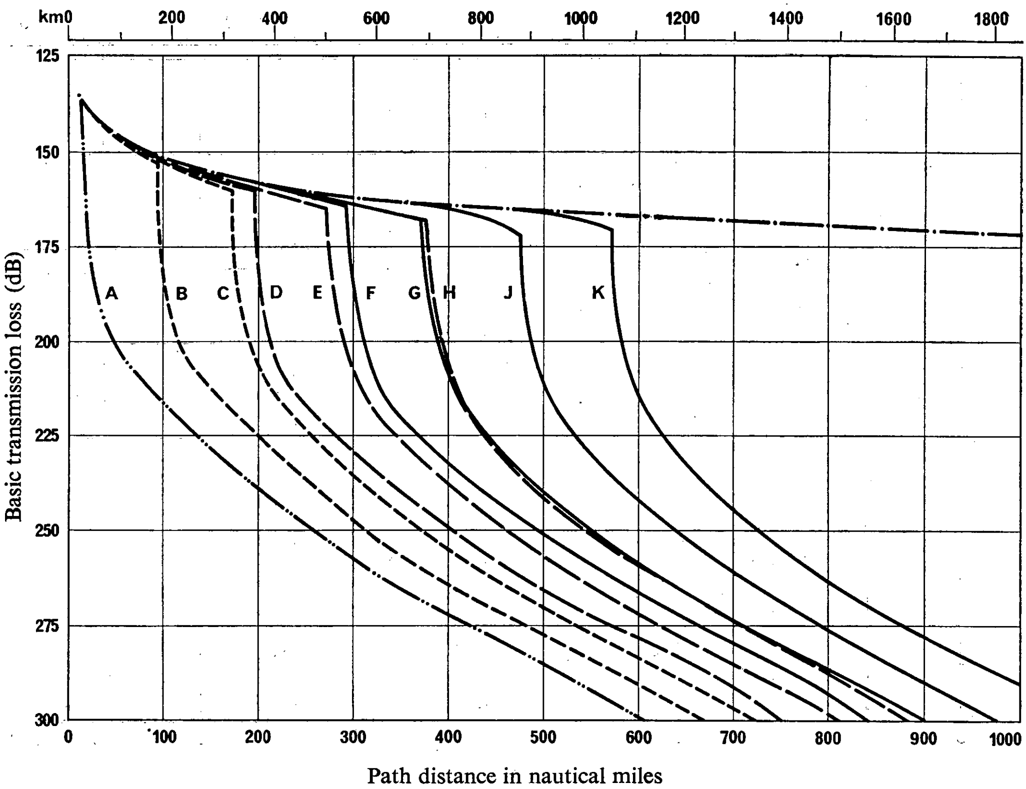

FIGURE 4

Long-term median values of the basic transmission loss, continental temperate

$N_s = 301$ (Four-thirds Earth), $\Delta h = 0$, isotropic antennae, heights H_1 and H_2 at either terminal, as indicated

Frequency: 5100 MHz

H_1					
	m	feet		m	feet
A	15·2	50	F	15·2	50
B	15·2	50	G	1 524	5 000
C	1524	5000	H	7 620	25 000
D	15·2	50	J	7 620	25 000
E	1524	5000	K	18 300	60 000

H_2

————	18 300 m	60 000 feet
—— ——	7 620 m	25 000 feet
— — — —	1 524 m	5 000 feet
··——··——	15·2 m	50 feet

—·— Free space

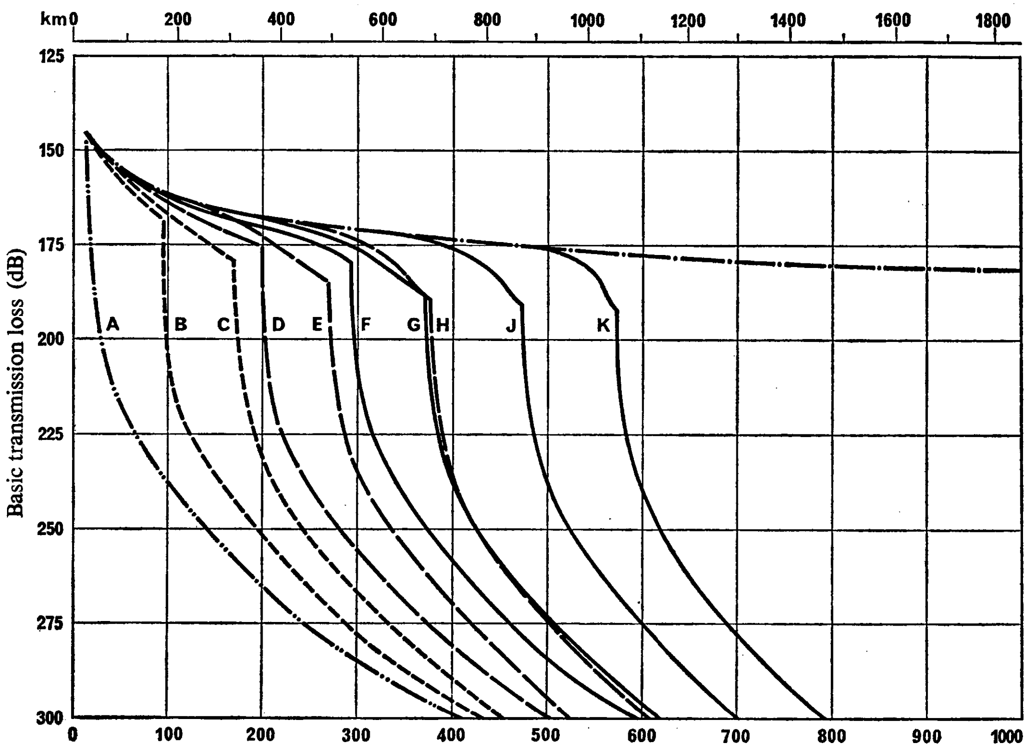

FIGURE 5

Long-term median values of the basic transmission loss, continental temperate

$N_s = 301$ (Four-thirds Earth), $\Delta h = 0$, isotropic antennae, heights H_1 and H_2 at either terminal, as indicated

Frequency: 15 500 MHz

	H_1				
	m	feet		m	feet
A	15·2	50	F	15·2	50
B	15·2	50	G	1 524	5 000
C	1524	5000	H	7 620	25 000
D	15·2	50	J	7 620	25 000
E	1524	5000	K	18 300	60 000

H_2

——— (solid)	18 300 m	60 000 feet
— — — (long dash)	7 620 m	25 000 feet
- - - - (short dash)	1 524 m	5 000 feet
··—··— (dash-dot-dot)	15·2 m	50 feet

—·—·— Free space

REPORT 425 *

ESTIMATION OF TROPOSPHERIC-WAVE TRANSMISSION LOSS

Availability of computer methods and preparation of propagation curves for broadcast and mobile services

(1970)

1. This document refers to two computer methods for estimating tropospheric radio transmission loss over irregular terrain. Method A [1, 4] is at present used only for broadcasting in band 9 (UHF) and method B [2] is intended to have a much wider application. Either method is more accurate and much faster for extensive studies in its field of application than are available propagation curves such as those in Recommendation 370-1 or the graphical methods of Report 244-2. Figs. 1 and 2 compare the scatter of the decibel ratios of predicted to observed values of field strength for band 9 (UHF) broadcast recordings in the United Kingdom for the "Stockholm Method" (nearly the same as Recommendation 370-1) and for computer method A. It must be emphasized that the computer method A [1, 4] is primarily used for evaluating the field strength for 1 % and 5 % of the time in order to give a value of the interference from co-channel stations.

A summary of both methods is given below with sufficient information for a manual calculation to be made by method A, although for rapid calculation a computer is normally used.

2. Method A

The heights of the antennae at the two terminals, h_1 and h_2, are the heights above mean sea level and the analysis given here is applicable only to the type of rolling terrain encountered in Northern Europe. The sum of the distance to the horizon (sea level) from the transmitting antenna and the distance to the horizon (sea level) from the receiver is called the combined horizon distance and is given by $d_h = 4{\cdot}12\,(\sqrt{h_1} + \sqrt{h_2})$. ($d$ is in kilometres, h is in metres and standard refraction is assumed).

To determine the field strength E_T for T equal to 50 %, 5 % or 1 % of the time, the appropriate curve in Figs. 3, 4, 5 and 6 is used for the particular value of d_h. Figs. 3, 4 and 5 are for complete land paths and Fig. 6 is for a complete sea path. If the path is a mixture of land and sea it is necessary to know the proportion of sea, and to interpolate between the land value and sea values. The interpolation factor A is linear within the horizon distance but for the 1 % and 5 % time values beyond the horizon the interpolation factor is determined from Fig. 7. To determine the field strength over the mixed path, it is necessary to evaluate the difference between the field strength for an all-sea path and field strength for an all-land path, this is

* This Report was adopted unanimously.

then multiplied by the interpolation factor and is added to the all-land value. This gives the required mixed land/sea path field strength:

$$E_T = E_{L,T} + A(E_{S,T} - E_{L,T})$$

The value E_T is, of course, for paths where there is no intervening high ground between transmitter and receiver. To allow for the losses due to the intervening "obstacles" within 16 km of each terminal, a terrain correction factor must be applied to the values E_T in order to determine the field strength received over the particular path. To do this, the angle subtended at each aerial and measured between the horizontal and the line which clears all obstacles within 16 km of the aerials in the direction of the transmission path, must be evaluated. These clearance angles are shown in Fig. 8 as θ_1 and θ_2 and have to be measured from topographical maps.

For path lengths less than d_h the angle needed is that which determines whether or not the path is "optical". This angle has been called the "redefined angle" and is the clearance angle to the line joining the transmitting and receiving antennae *not* to the horizontal. Thus θ_1 and θ_2 are replaced by α_1 and α_2 which can be calculated from a knowledge of h_1, h_2 and d and Fig. 10. In using Fig. 10, it must be remembered that h_1 is always the height at the end at which the redefined angle is required and *(a)*, *(b)* etc. represent scales in order of use.

Having values for the clearance angles, the terrain correction (dB) is obtained from Fig. 9 for each end of the path and added to the value E_T obtained for smooth earth. This gives the field strength for the required percentage of time.

A correction factor of 10 dB is deducted if the receiving site is within a built-up area and this applies to all domestic television receiving installations in such areas.

3. Method B

Computer Method B [2], on the other hand, may be used for different classes of service simply by restricting consideration of the governing parameters to the ranges normally associated with these services. The method may be used either with detailed terrain profiles for actual paths, or where these are unknown or inappropriate (as with a broadcast or mobile operation), with profiles that are representative of median terrain and atmospheric characteristics in a given area.

Fig. 11 compares propagation curves prepared by methods A and B for the special case of 700 MHz and $d_{Ls} = 40$ and 80 km, where this parameter is the sum of smooth-earth horizon distances for effective antenna heights h_{e1} and h_{e2}, expressed in metres:

$$d_{Ls} = 4{\cdot}1\,(\sqrt{h_{e1}} + \sqrt{h_{e2}})\ \text{km} \qquad (1)$$

Note 1. — The methods described in this Report are particularly useful in the line-of-sight and diffraction regions but should not be used for point-to-point services in the scatter region.

Note 2. — This Report does not take into consideration all the meteorological parameters discussed in Report 233-2.

The two values chosen for d_{Ls} in Fig. 11 correspond approximately to effective antenna height combinations of 10 m, 37·5 m and 10 m, 300 m. In this example the urban factor for computer method A has been omitted to facilitate comparison between the two methods.

When detailed profile information is available for a specific path, a "calculated reference attenuation," A_{cr}, expressed in decibels below the free space field strength or transmission loss may be predicted on the basis of the following parameters:

— the propagation path distance, d, in kilometres. See Fig. 12;

— the radio frequency, f, in MHz;

— effective antenna heights, h_{e1}, and h_{e2}. These are defined in the references [1] and [2]. For an antenna radiating centre near the ground (0·5 to 20 metres), h_e is typically equal to the height above ground, h_g. Otherwise, heights above sea level, heights above average terrain, or heights above a dominant reflecting plane are commonly used to define effective heights;

— effective conductivity σ and dielectric constant ε of the surface, land or water;

— refractivity of the atmosphere near the surface, N_s (see Report 233-2);

— effective earth's radius, a, or $a(N_s)$, a function of N_s [2];

— electric polarization, horizontal or vertical;

— actual horizon distances, d_{L1} and d_{L2}. See Fig. 12;

— the sum, θ_e, of antenna horizon elevation angles θ_{e1} and θ_{e2} above the horizontal at each antenna, Fig. 12. These angles can be positive or negative;

— a parameter Δh to allow for terrain irregularity in a particular type of terrain, or a parameter $\Delta h(d)$ to allow for terrain irregularity over the entire length, d, of a propagation path. The parameter defined here allows for *irregularity*, mainly the likelihood of large diffraction or scatter angles, as well as *roughness*, which is allowed for by the parameter Δh presently defined in Recommendation 370-1. The new parameter, $\Delta h(d)$ is the interdecile range of terrain heights in metres above and below the average slope of the terrain for a particular profile of length d kilometres. The interdecile range is the difference between (a) elevations exceeded by ten per cent of the hills, and (b) depths exceeded by ten per cent of the valleys. With one or both antennae moving, or if a typical transmission loss value for antennae located in a given area is desired, the input to the computer or the propagation curves produced by it is the median value $\Delta h_m(d)$ for a randomly selected set of paths in the area, all of length d. A study of many hundreds of terrain profiles in different types of terrain has shown that, with increasing distance $\Delta h_m(d)$ reaches a maximum value Δh:

$$\Delta h = \Delta h_m(d)/[1 - 0{\cdot}8 \exp(-0{\cdot}02\, d)] \text{ metres} \tag{2}$$

When the distances approach and exceed 150 km, (2) shows that $\Delta h_m(d)$ reaches the constant value Δh which is used in method B to characterize terrain. Values $\Delta h = 50$, 100, 200, and 500 metres correspond, respectively, to smooth, fairly smooth, very hilly, and extremely rugged terrain.

The input to the computer may consist of the first four or all of the following parameters: d, f, h_{g1}, h_{g2}, h_{e1}, h_{e2}, σ, ε, N_s, a, d_{L1}, d_{L2}, θ_e, $\Delta h(d)$, Δh and polarization. If only the first four parameters are supplied, it is important in some cases to specify the polarization and whether a path or set of paths is over land or over water. In any case, the present programme supplies average or typical values for any parameters not specified, except the first four, which must be specified.

[2] gives a comparison of some data with predictions obtained by this method for very low antenna heights and short distances at 100 MHz. The data values are medians for a number of terrain profiles, and are approximately what is expected for "median" locations at each distance. To obtain median-time, median-location estimates of transmission loss at

the greater distances where atmospheric effects introduce typically as much as 100 decibels range between highest and lowest hourly medians observed in a year, curves through the available data are used. Fig. 13 shows for several groupings of available data the scatter of the decibel ratios of the calculated to the observed transmission loss values, using the calculations of method B.

Both methods, A and B, have features which should make these types of computer programmes of permanent usefulness. Method A is specifically useful for the calculation of the field strength for small percentages of time and should be used for co-channel interference calculation at UHF, while method B is more ambitious and sophisticated, making more use of theory and capable of being fitted to more parameters and a wider range of data. As in method A, a correction factor of 10 dB is added to the calculated transmission loss when using method B if the receiving site is within a heavily built-up area.

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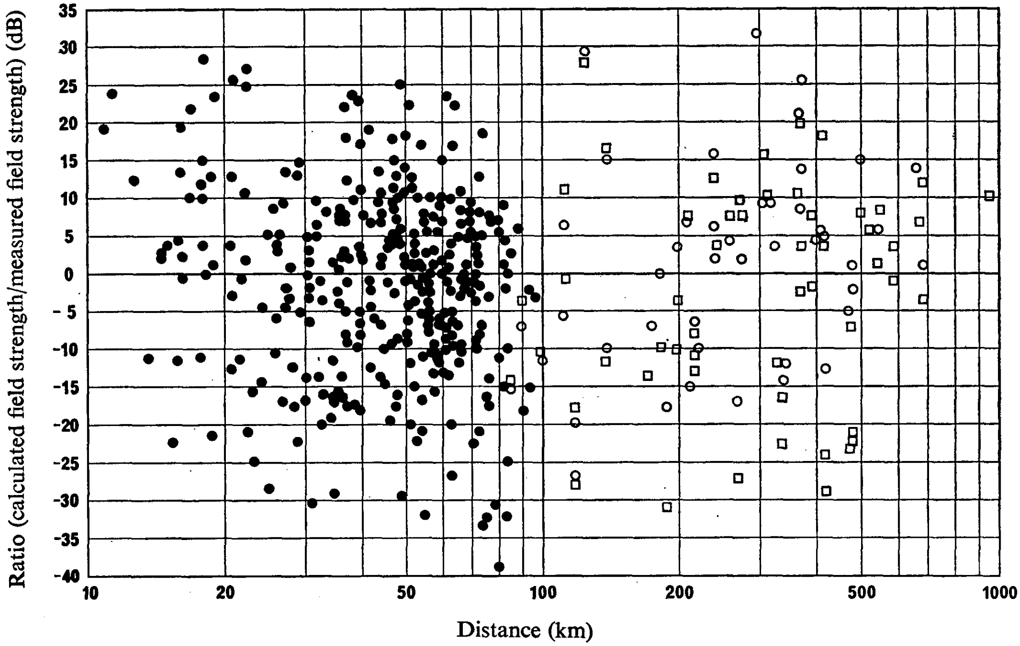

FIGURE 1

Graph of ratio of calculated to observed field strengths versus distance for UHF broadcasting

"Stockholm method" for calculations

● = 50% time

○ = 10% time

□ = 1% time

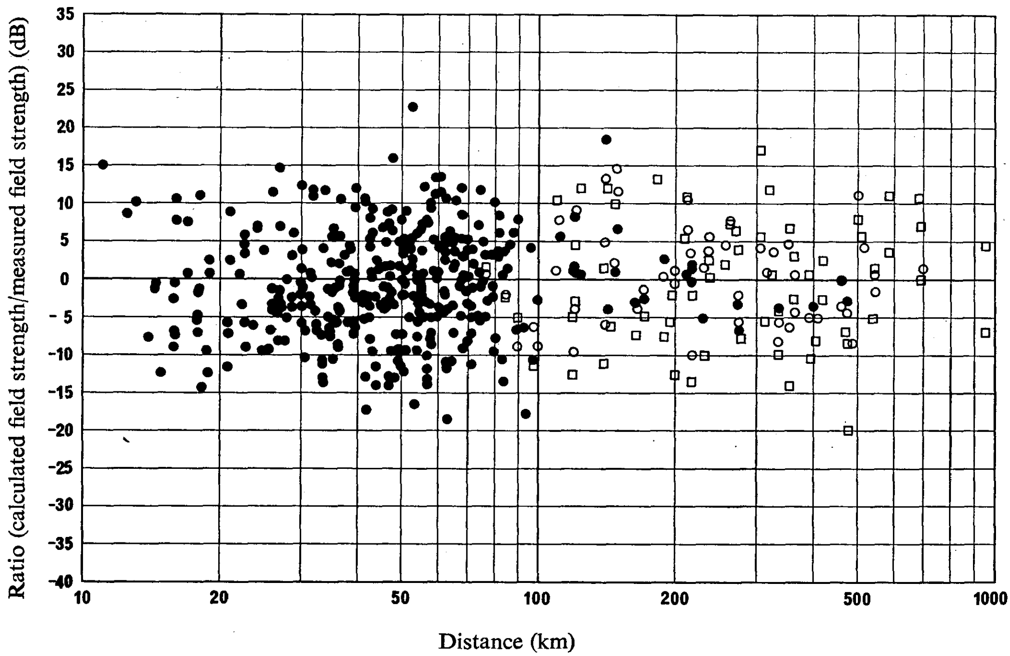

FIGURE 2

Graph of ratio of calculated to observed field strengths versus distance for UHF broadcasting

"Computer Method A"

● = 50% time

o = 5% time

□ = 1% time

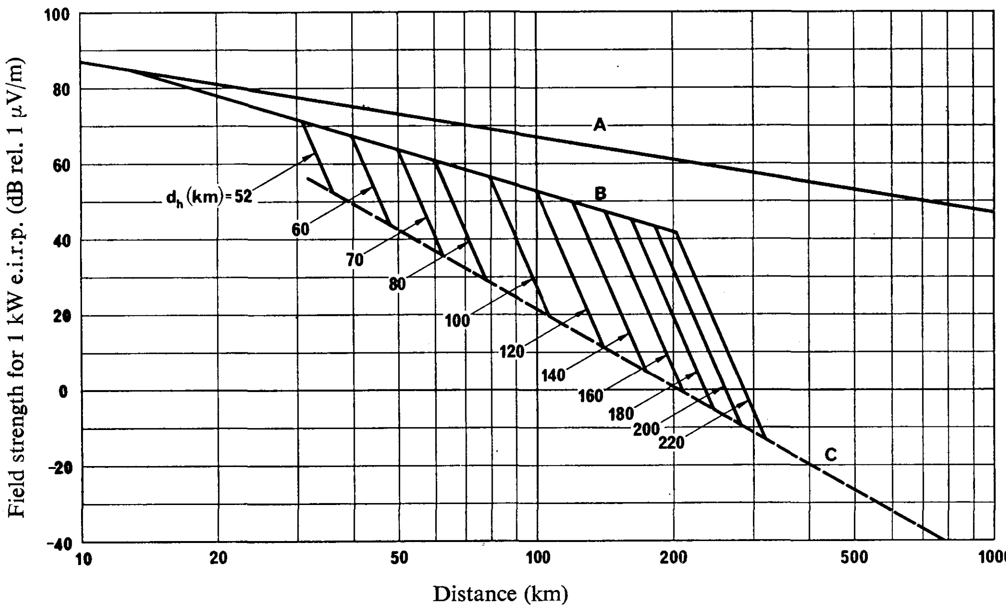

FIGURE 3

Field strength as a function of distance—Land: 50% of the time

Curve A: free space
B: within the horizon
C: beyond the horizon

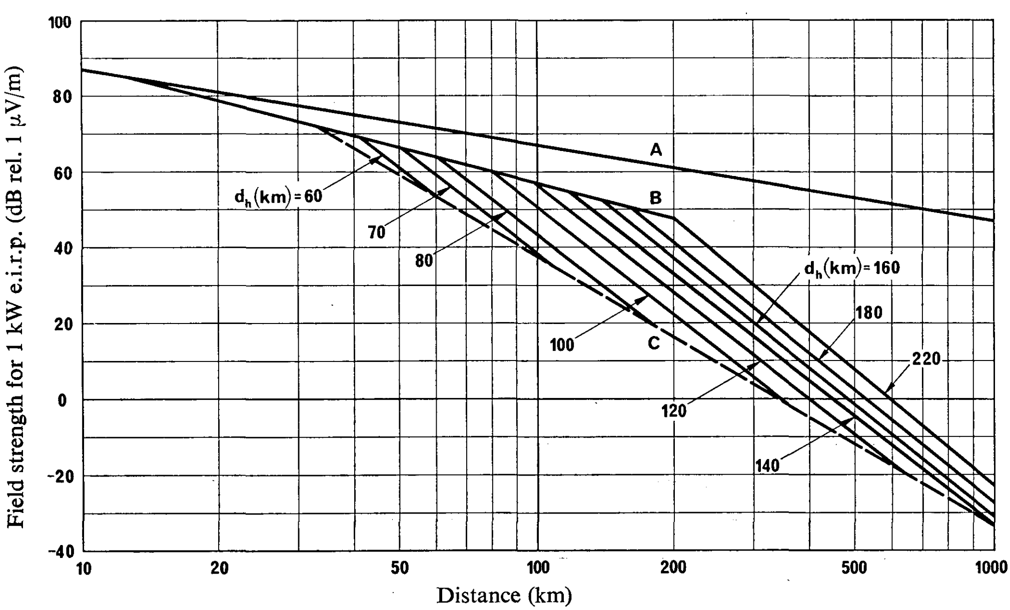

FIGURE 4

Field strength as a function of distance—Land: 5% of the time

Curve A: free space
B: within the horizon
C: beyond the horizon

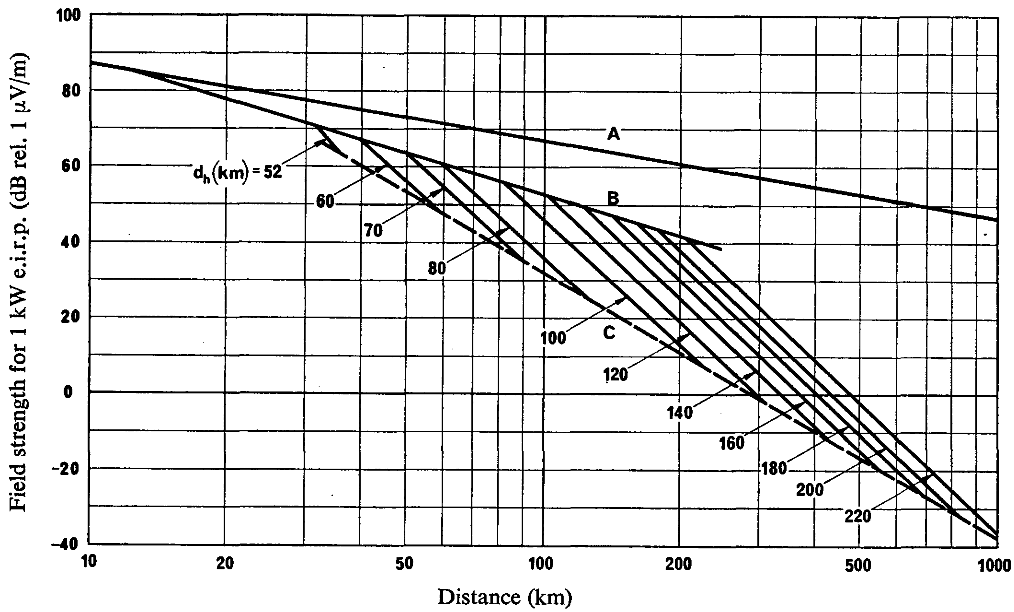

FIGURE 5

Field strength as a function of distance—Land: 1% of the time

Curve A: free space
B: within the horizon
C: beyond the horizon

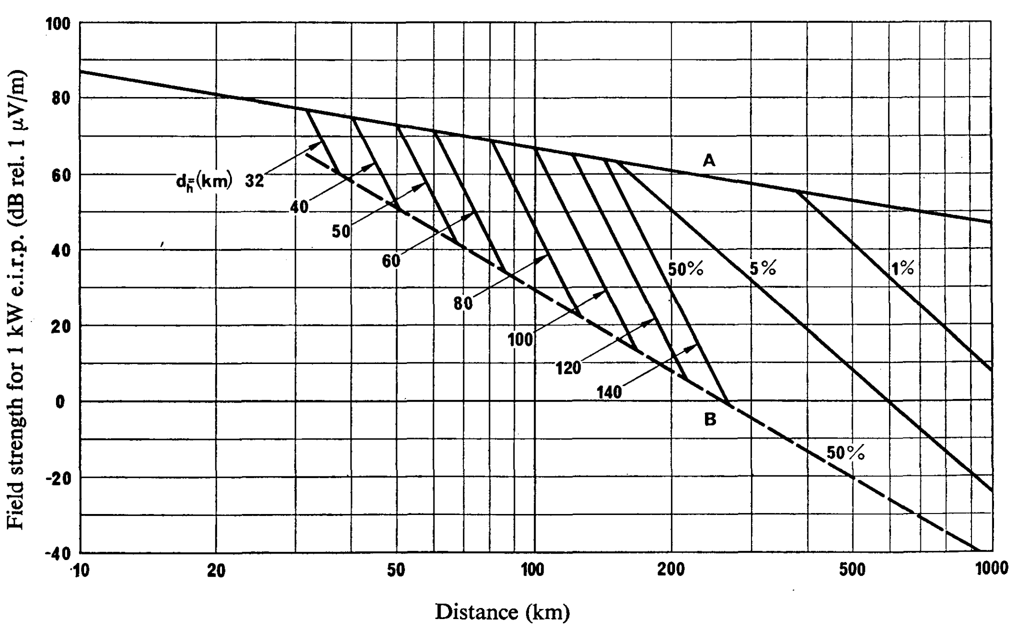

FIGURE 6

Field strength as a function of distance—Sea

Curve A: free space
B: beyond the horizon

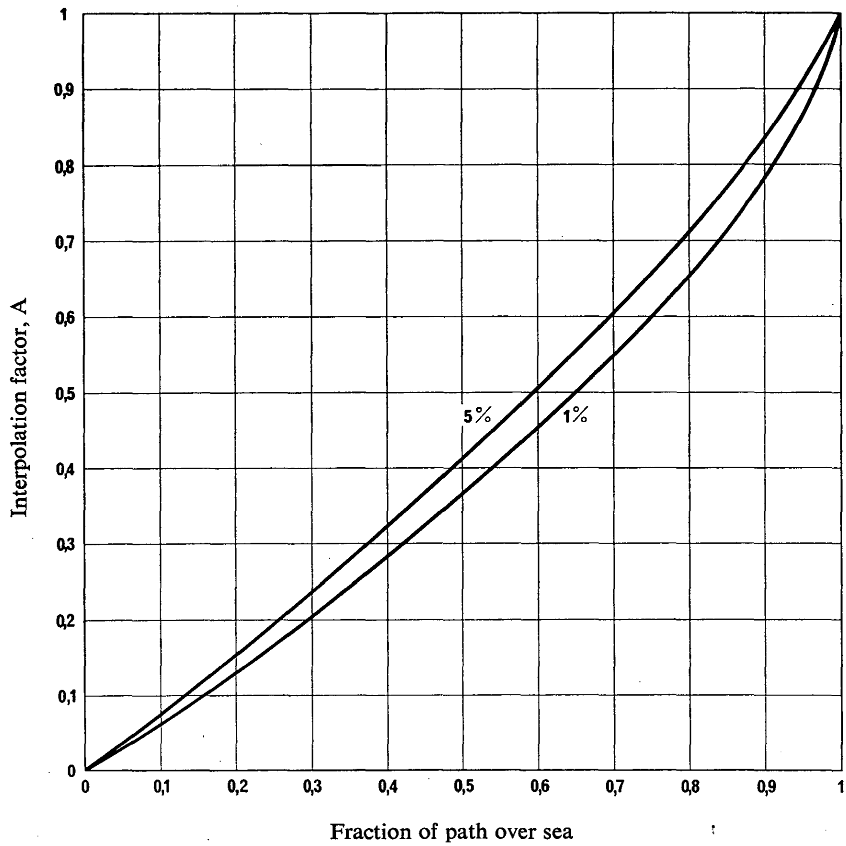

FIGURE 7

Interpolation for mixed land/sea paths

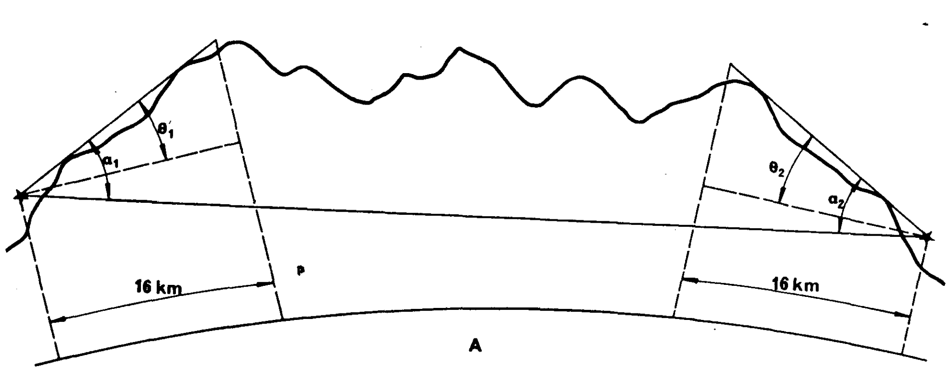

FIGURE 8

Path geometry

A = *Sea level*

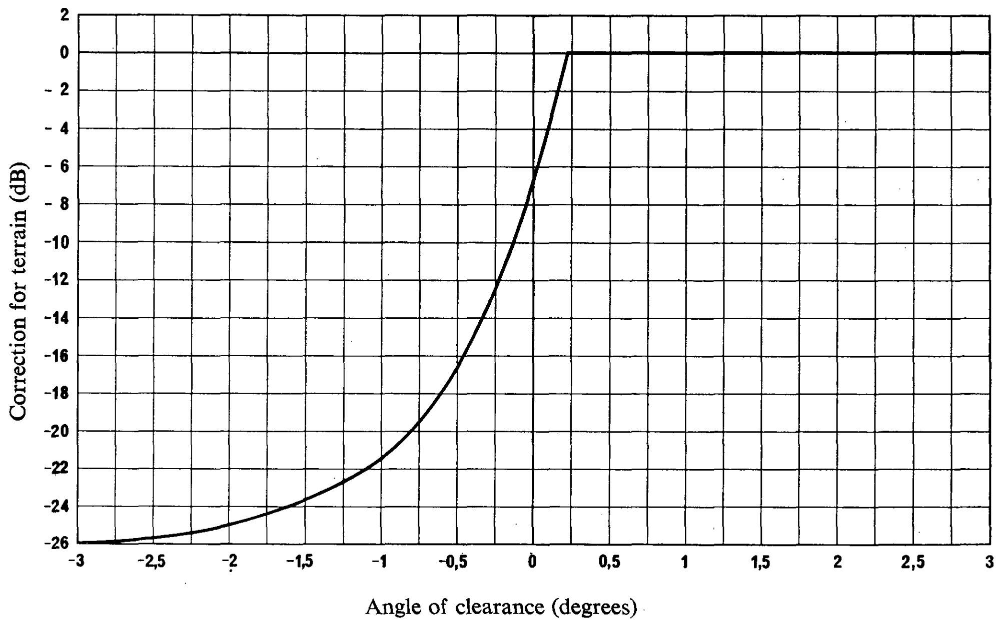

FIGURE 9

Correction for terrain

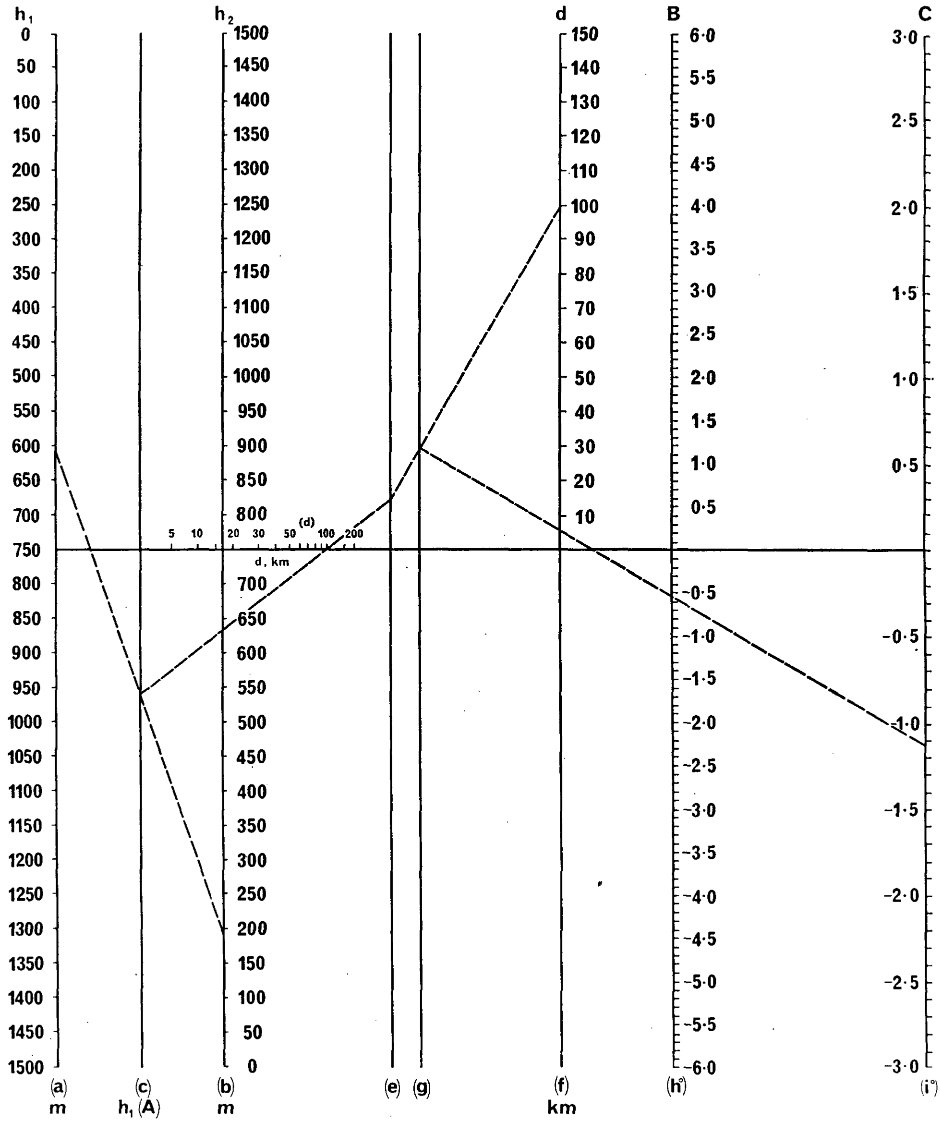

FIGURE 10

Nomogram for re-definition of angle

A: height at terminal to be re-defined
B: angle of clearance of terrain (degrees from the horizontal)
C: re-defined angle, α

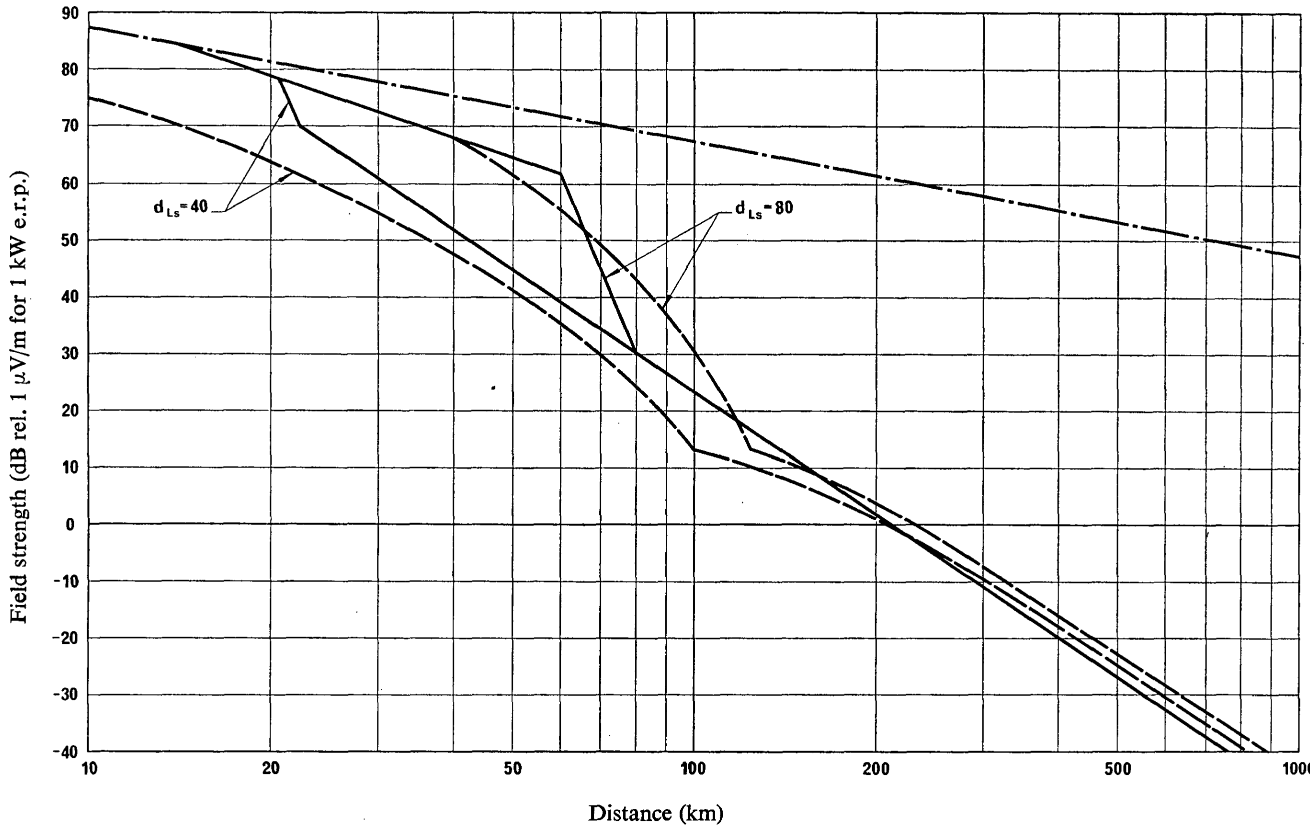

FIGURE 11

Graphs of calculated field strengths for UHF broadcasting, comparing computer methods A and B

—·—·—·— Free space
———————— Method A
— — — — — Method B

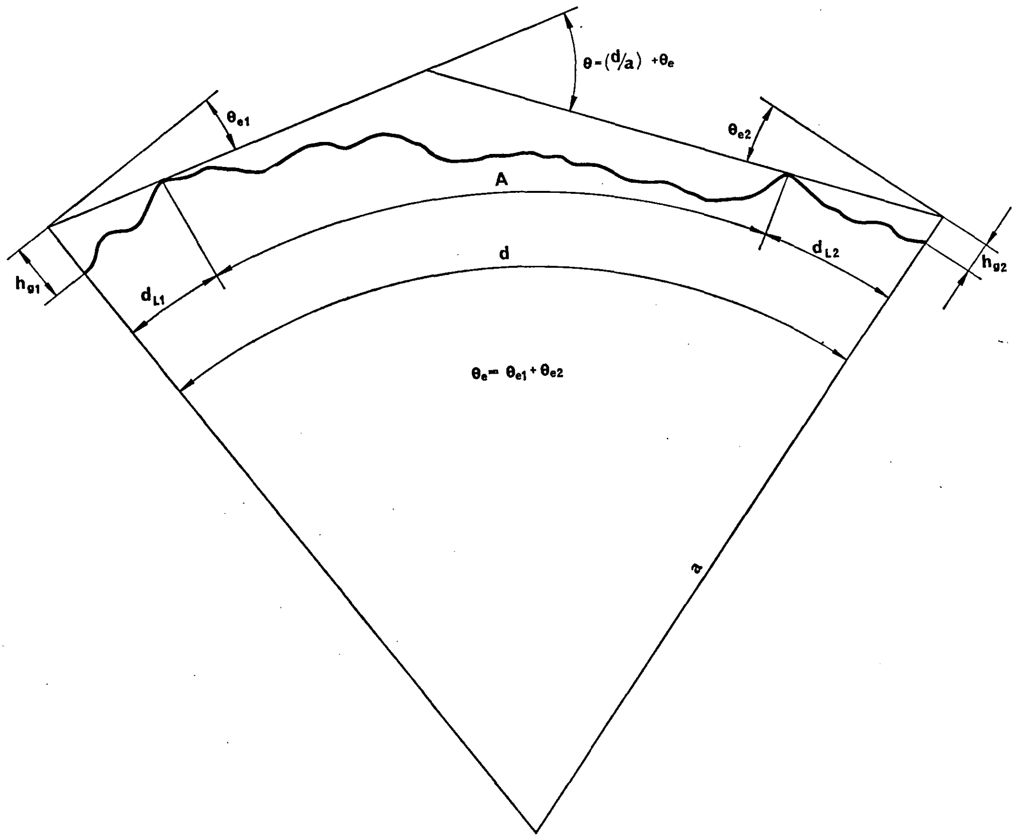

FIGURE 12

Geometry of a trans-horizon radio path

A: sea level

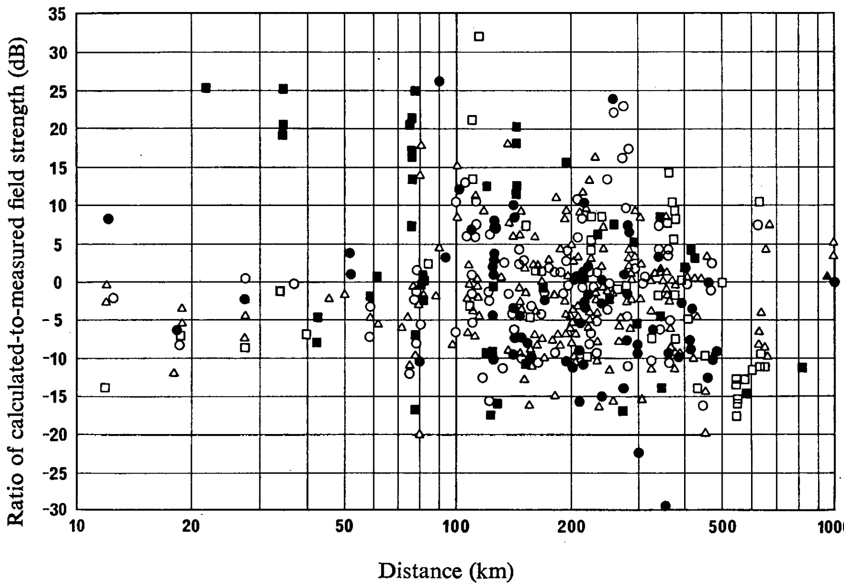

FIGURE 13

Ratio of calculated-to-measured values of field strength as a function of distance

(Calculated on a computer, using method B)

Frequency (MHz):

- △ < 110;
- ○ 110-299;
- ● 300-699;
- □ 700-1100;
- ■ > 1100;

$N = 780$

SECTION 5B : RADIO METEOROLOGY

RECOMMENDATIONS AND REPORTS

Recommendations

RECOMMENDATION 310-2

DEFINITIONS OF TERMS RELATING TO PROPAGATION IN THE TROPOSPHERE

(1951 – 1959 – 1966 – 1970)

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 (A more detailed definition given by the W.M.O. is mentioned in C.C.I.R. Doc. V/9, 1966-1969).
3.	*Temperature inversion*	An increase in temperature with height.
4.	*Mixing ratio*	The ratio of the mass of water vapour to the mass of dry air in a given volume of air (frequently expressed in g/kg).
5.	*Relative humidity with respect to water (or ice)*	Percentage ratio of the vapour pressure of water vapour in moist air to the saturation vapour pressure with respect to water (or ice) at the same temperature and pressure.
6.	*Refractive index (n)*	Ratio of the speed 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.

Term	Definition
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*	An atmosphere having the standard refractive modulus gradient.
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 (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 radio atmosphere the effective radius is 4/3 that of the true radius.)
22. *Tropospheric radioduct*	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 mode (ducting)*	A mode of propagation within a radio-duct. At sufficiently high frequencies several such modes may exist (as in a wave-guide).
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 diffraction, forward scatter, specular and diffuse reflection, and ducting.
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.

Term	Definition
30. *Precipitation-scatter propagation*	Propagation by scattering from precipitation particles.
31. *Multipath propagation*	Propagation by way of a number of transmission paths.

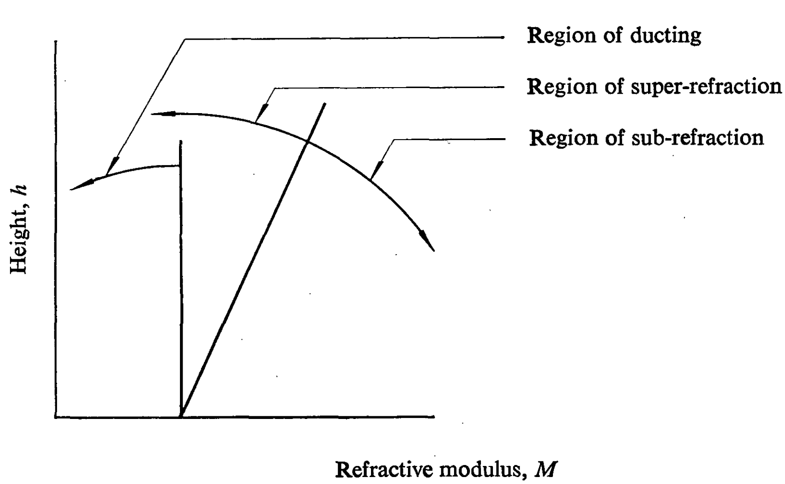

FIGURE 1

M-curves

RECOMMENDATION 369-1

DEFINITION OF A BASIC REFERENCE ATMOSPHERE

The C.C.I.R., (1959 – 1963 – 1966)

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 231-2);

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 453 *

THE FORMULA FOR THE RADIO REFRACTIVE INDEX

(Question 2-1/5)

The C.C.I.R., (1970)

CONSIDERING

(a) the necessity of utilizing a single formula for calculation of the index of refraction of the atmosphere;

(b) the desirability of expressing this formula in a coherent system of units;

UNANIMOUSLY RECOMMENDS

that the atmospheric radio refractive index, n, be given by the following formula:

$$n = 1 + N.10^{-6}$$

where

N is the refractivity expressed by:

$$N = \frac{77{\cdot}6}{T}\left(p + 4810\,\frac{e}{T}\right) \text{ with}$$

p: atmospheric pressure (mb),
e: water vapour pressure (mb),
T: absolute temperature (°K).

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* This Recommendation cancels Report 232.

REPORT 231-2 *

REFERENCE ATMOSPHERES

(Question 2-1/5)

(1959 – 1963 – 1966 – 1970)

Reference atmospheres for the calculation of propagation characteristics

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

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

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

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

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

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

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

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

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

$\Delta N = -7{\cdot}32 \exp(0{\cdot}005577\ N_s)$ in the United States of America [2] (4)

$\Delta N = -9{\cdot}30 \exp(0{\cdot}004565\ N_s)$ in the Federal Republic of Germany [5] (5)

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

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

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.

Several Administrations have suggested that the radio climate of their area may be better represented by a bi-exponential model for $n(h)$ [6, 7, 8].

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REPORT 233-2 *

INFLUENCE OF THE NON-IONIZED ATMOSPHERE ON WAVE PROPAGATION

Ground-ground propagation

(Question 2-1/5)

(1959 – 1963 – 1966 – 1970)

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 ds 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 at a 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

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 ΔN between the refractivity at a height of one kilometre and the refractivity 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 the actual radius multiplied by 4/3. Generally speaking, this factor, usually denoted by k, may be derived for any region from either meteorological observations or propagation measurements. In general, k is determined from propagation measurements represents a spatial average, which could only otherwise be obtained by many simultaneous meteorological soundings along the propagation path. The distribution of k values so determined displays less variability than that derived from single-point meteorological measurements. The variability decreases with increasing distance.

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].

Attempts have been made to improve the correlation between the gradient and the field characteristics by taking into account atmospheric conditions in the neighbourhood of common volume. The influence of stability and air motion has been studied [6, 7, 8, 9]. However, these parameters do not seem to play a comparable role in all climates. Addition of the refractive index gradient at the base of the common volume improves the correlation [11].

It has been demonstrated that a parameter of the form $T = aG_e + bG_c$ is representative of the monthly mean path attenuation for very different distances and climates [10], where the coefficients a and b have been determined experimentally as $a = -3/8$ and $b = -5/4$.

G_e is the equivalent gradient between the ground and the common volume (which can often be replaced by the difference in N value at one kilometre above the ground and the value at the ground).

G_c is the difference between the value of N at a point situated one kilometre above the base of the common volume and the value at the base. The height of the common volume was calculated by means of G_e.

T is then expressed in dB with respect to an arbitrary zero.

A function of the potential refractive index has also been studied [12]. 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, 13, 14, 15], at least for monthly mean values [25]. This correlation has been used to derive a basic reference atmosphere in which N varies exponentially with height as defined in Report 231-2.

Correlation has also been remarked between observed transmission loss and the values of refractive index at the surface [16, 17]; 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, 13, 14, 15]. 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 radiosonde 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 transmission loss 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, where N_s is the value of N at ground level.

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 [18, 19]; others give poor correlation [20]. 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 transmission loss 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 [22], where regressions were run on the annual cycles of monthly mean N_s and monthly median transmission loss, 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.

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.

A knowledge of the variations of all these parameters is important for determining the likelihood of interference between stations and the formation of atmospheric ducts which might disturb line-of-sight links. For example, the variations in the values of the refractive index on the ground seem to be clearly correlated with the refraction of radio waves in the United States for angles of elevation of 1° or more, but for angles of elevation less than ½° the vertical gradient must be taken into account [19, 21]. For this reason in addition to the mean value of ΔN, it may be useful to know the gradient distribution law in the vicinity of the ground and its dependence on climatic conditions.

It does not seem feasible to prepare world-wide charts for all the parameters mentioned above. However, Figs. 1 to 8 show charts of ΔN and of N_0 (see the definition of N_0 in § 3) for representative months.

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_0.

The purpose of this procedure is to reduce the difficulty of mapping N_s, and since there can be no "correct" value of N_0, a certain amount of arbitrary choice may be made in the process to be used. However, for N_0 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_0, 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 [15].

Figs. 1 and 2 show isopleths of the mean value of N_0 for February and August respectively and Fig. 3 whole the area where $N_0 > 350$ (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 inter-tropical areas.

Some national Administrations have made more detailed analyses for their territories. In addition, the Administration of the United States has prepared a large number of charts and graphs relating to the whole world for selected months [23].

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_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 International Geophysical Year), 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 stations in the United States of America 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).

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 [24] and are given to radio engineers for information.

Note 1. — Caution should be exercised in using these data for 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.

Note 2. — Caution also should be exercised in using these charts in mountainous areas and near coasts, especially if the horizontal gradient of the parameter represented (N_0 or ΔN) is large.

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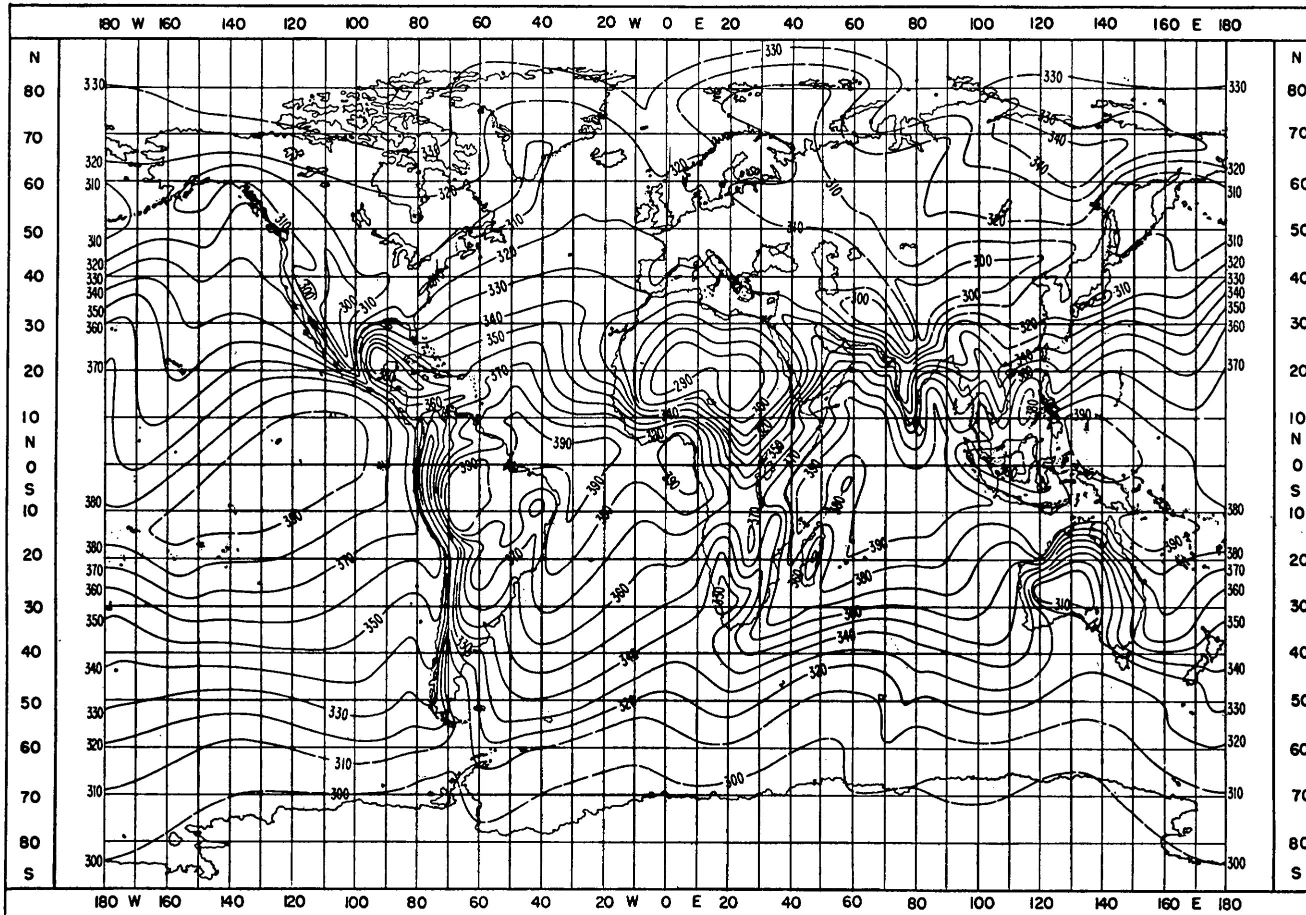


FIGURE 1

World-wide mean value of N_0: February

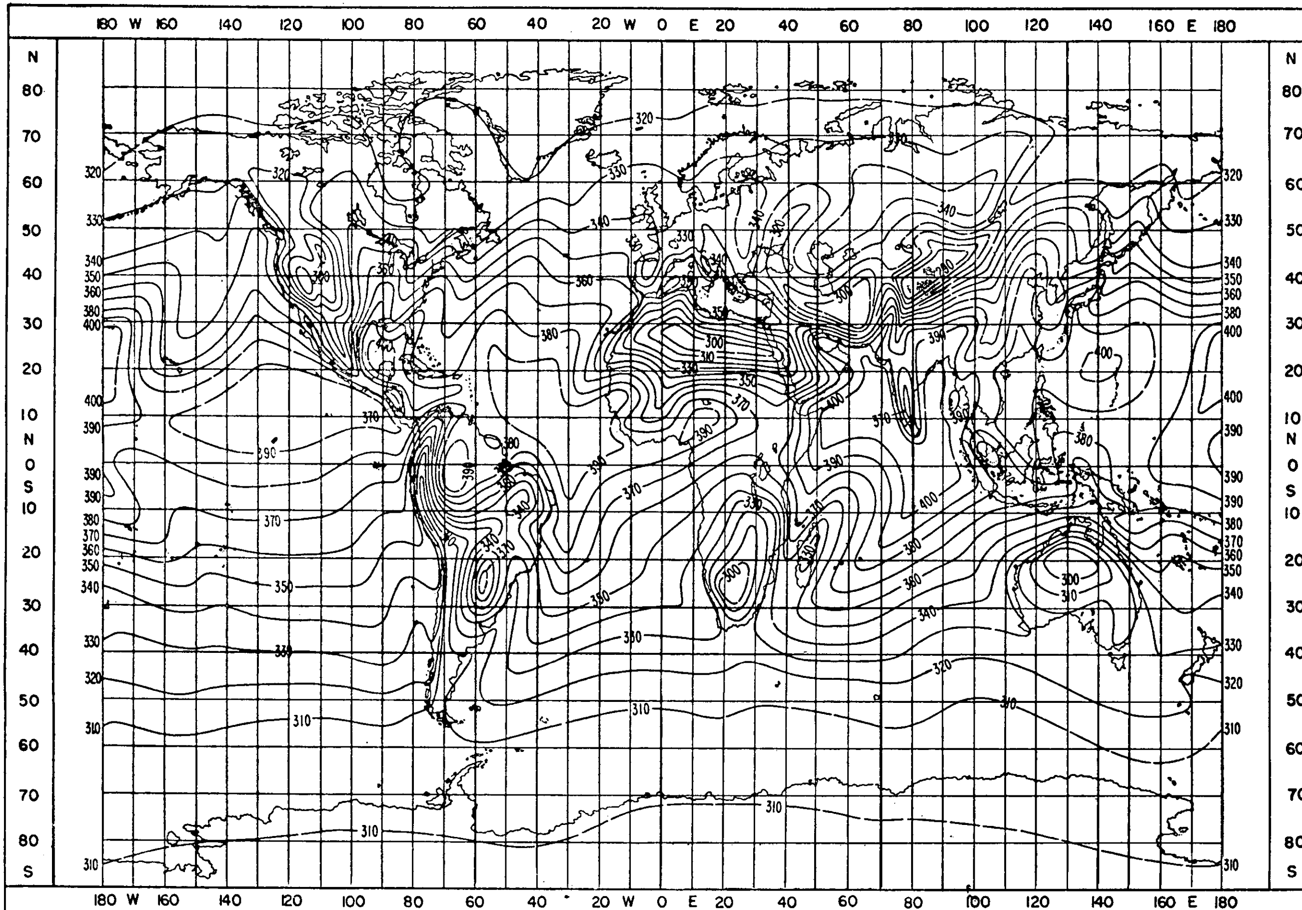


FIGURE 2

World-wide mean value of N_0: August

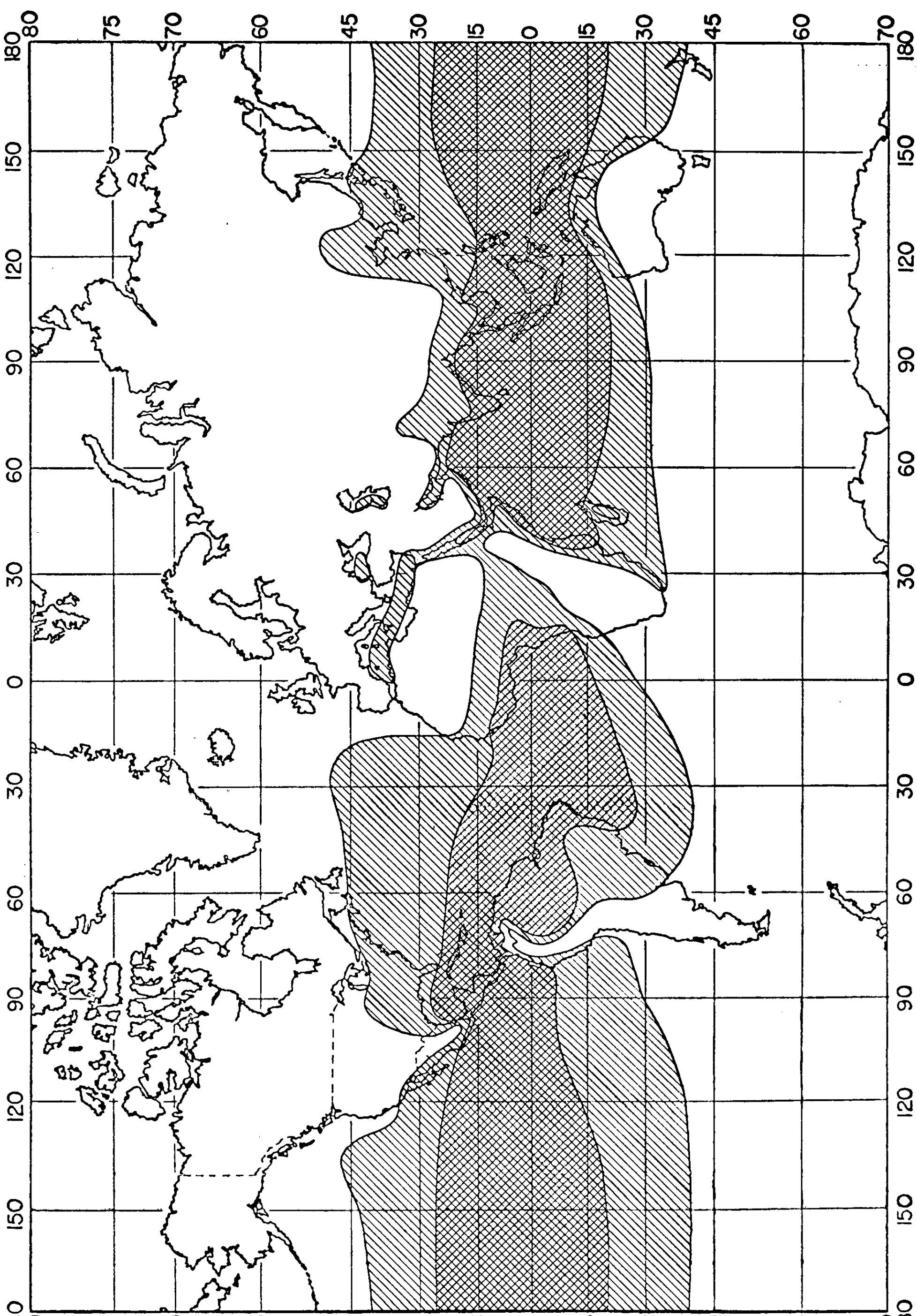


FIGURE 3

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

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

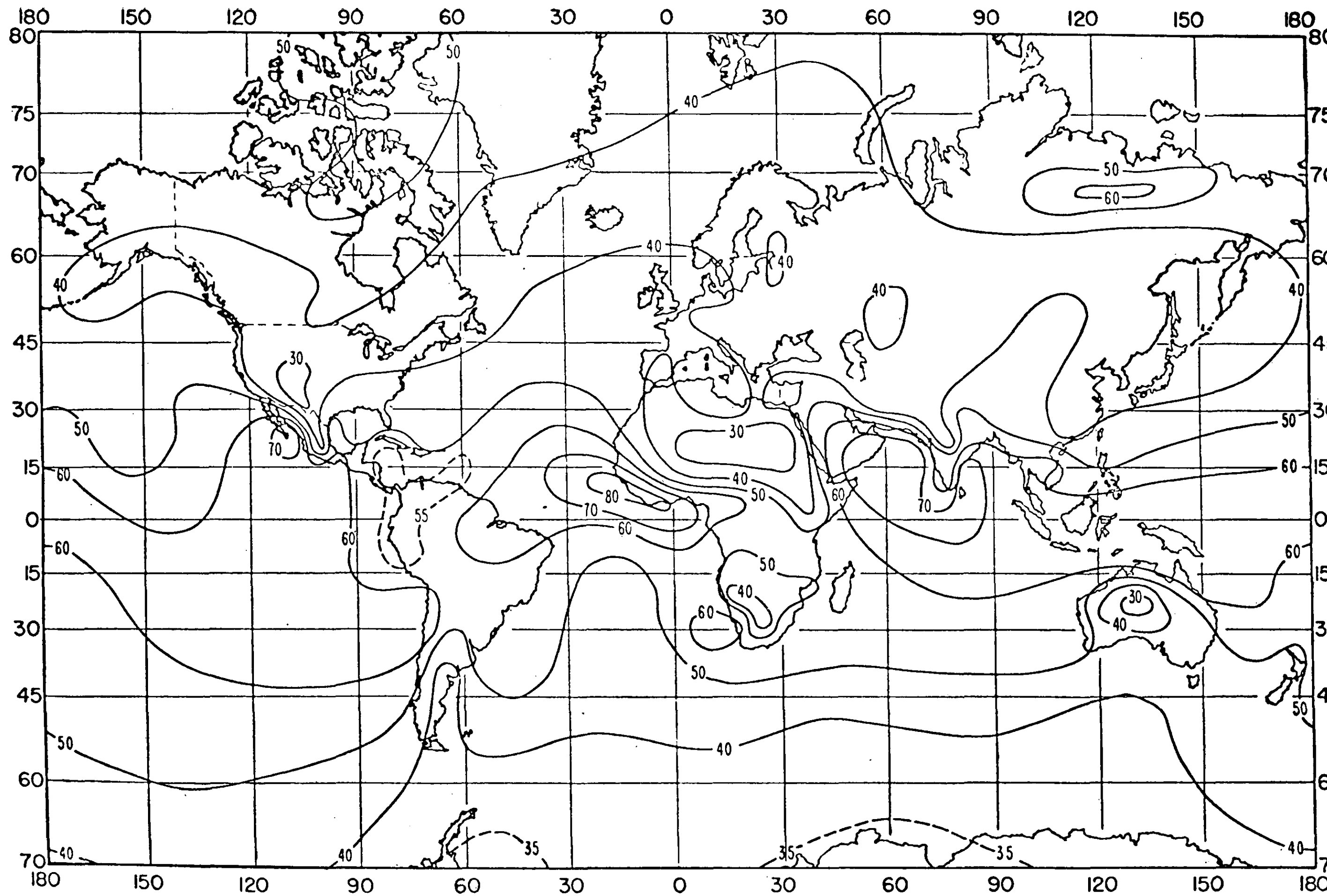


FIGURE 4

Monthly mean values of ΔN : February

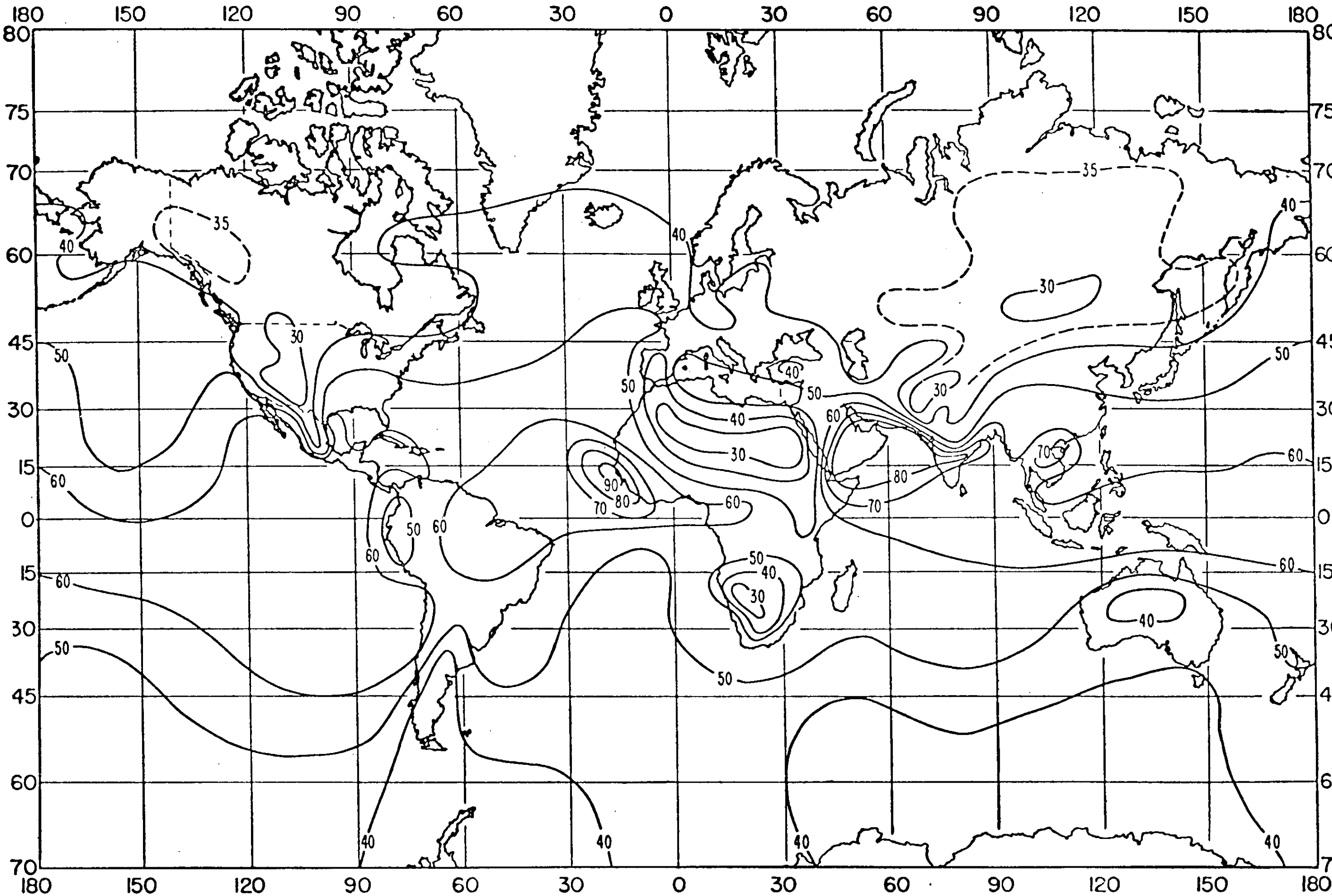


FIGURE 5

Monthly mean values of ΔN : May

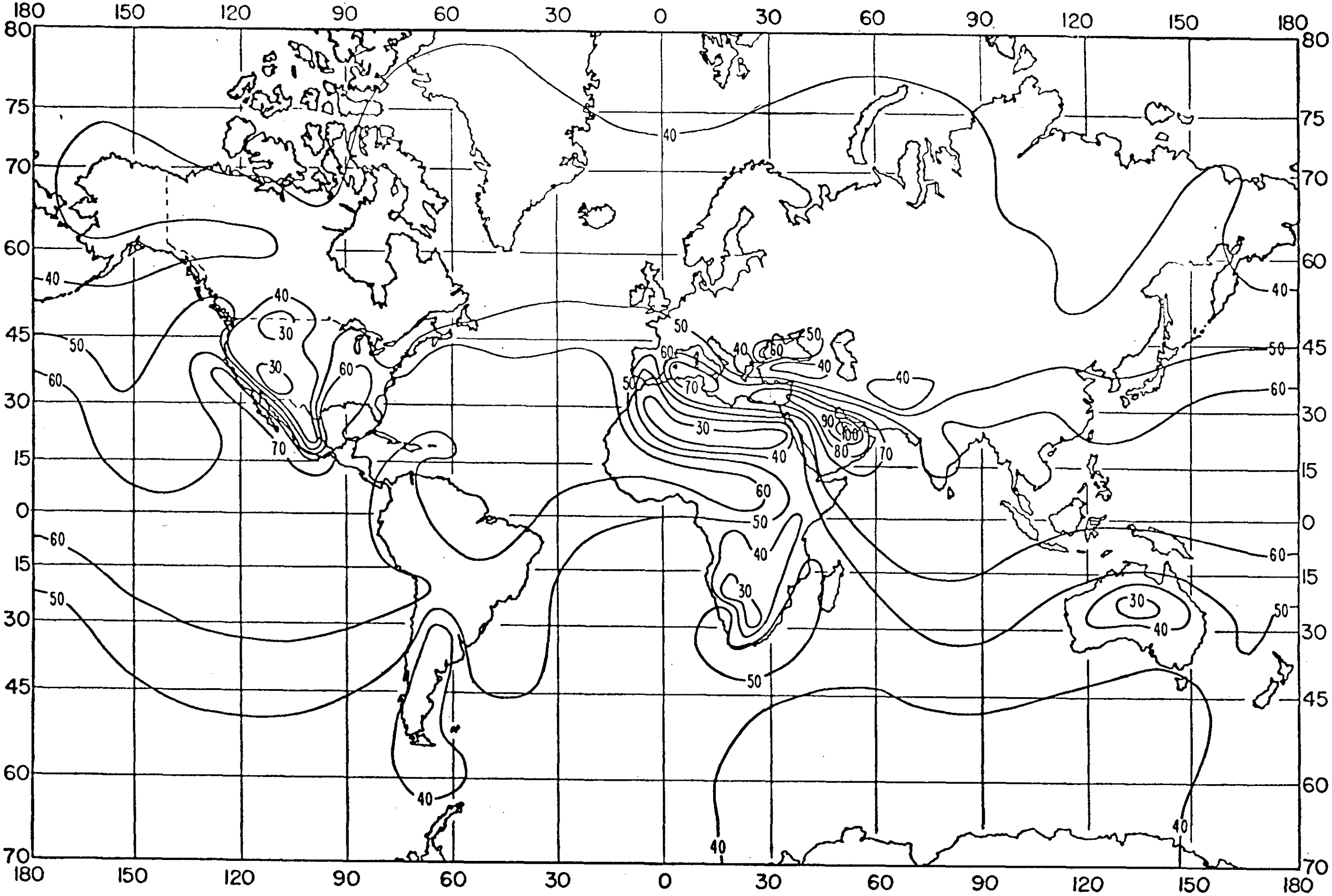


FIGURE 6

Monthly mean values of ΔN : August

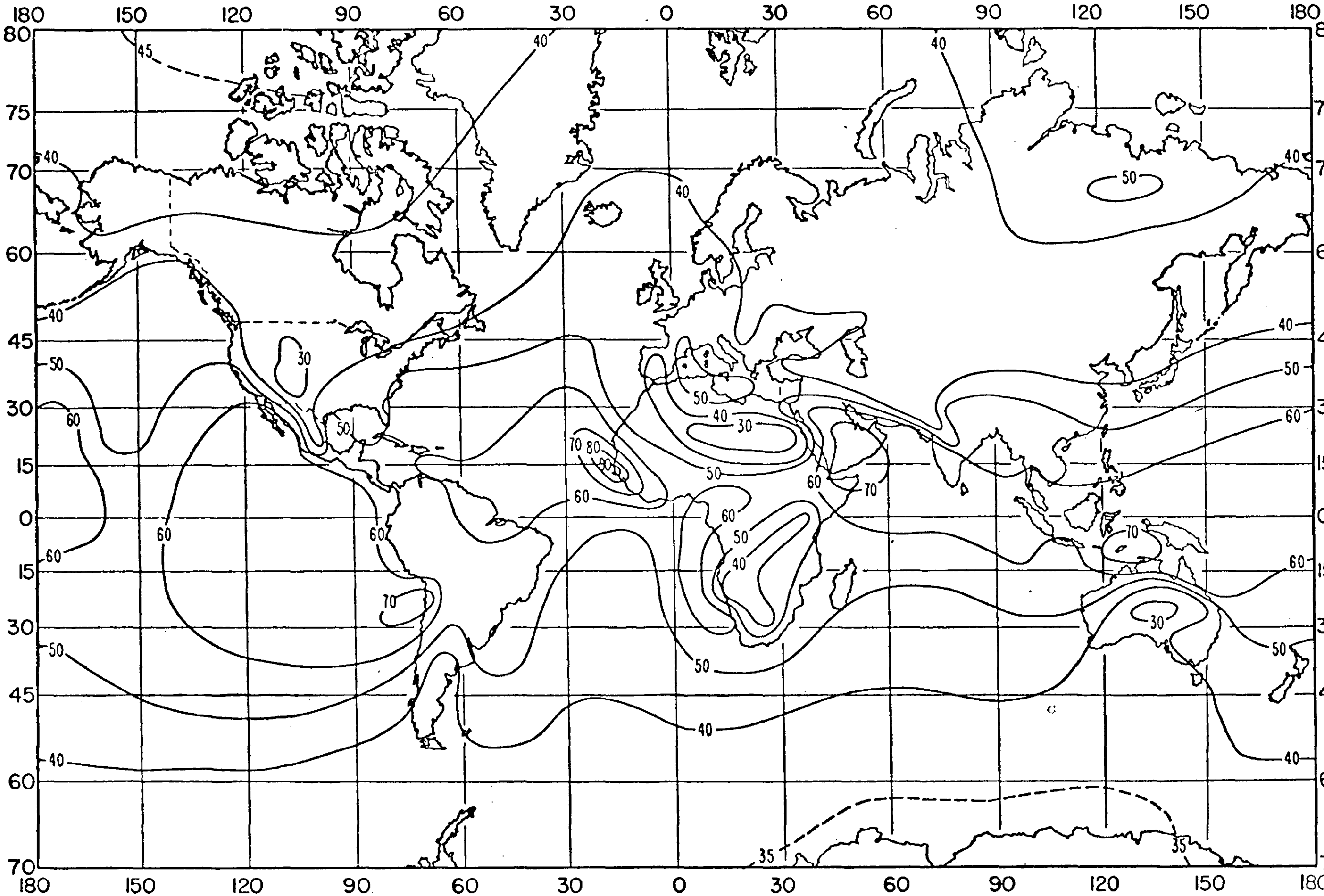
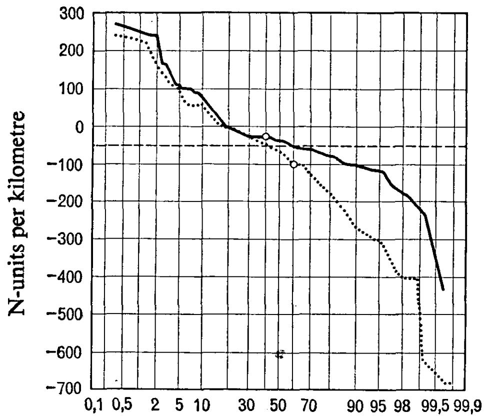


FIGURE 7

Monthly mean values of ΔN : November

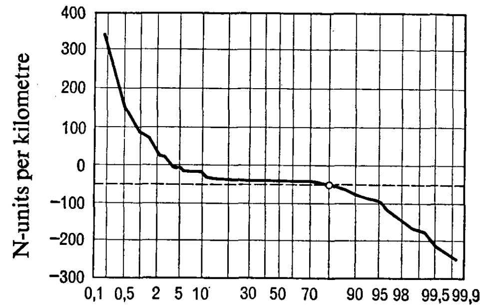


Percentage of time ordinate is exceeded

Nicosia, Cyprus

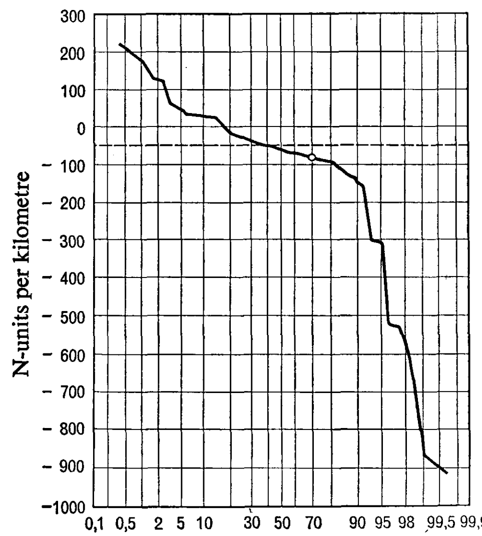
.... 0000 GMT

———— 1200 GMT



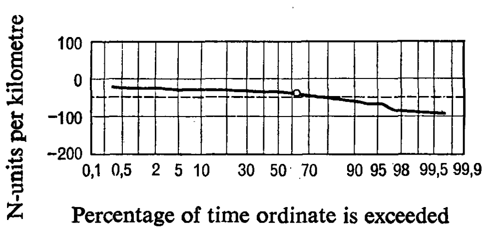
Percentage of time ordinate is exceeded

New York, U.S.A.



Percentage of time ordinate is exceeded

Bangui, Central African Republic



Percentage of time ordinate is exceeded

Ostersund, Sweden

FIGURE 8

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

REPORT 234-2 *

INFLUENCE OF TROPOSPHERIC REFRACTION AND ATTENUATION ON SPACE TELECOMMUNICATION SYSTEMS

Earth-space propagation

(Question 2-1/5, Study Programme 5-1C-1/5)

(1963 – 1966 – 1970)

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

2.1 *Ray-bending in the troposphere*

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. Statistics of ray-bending at low angles of elevation have been derived in the United Kingdom, using tethered-balloon measurements of the variation of refractive index with height in the first kilometre above the Earth's surface [8]. In [6] and [7], it has been shown that N_s is a good parameter to use for predicting refraction through the atmosphere. See also Report 233-2. There has, however, been some doubt expressed as to the applicability of N_s to equatorial regions [9]. 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, $N_s = 450$ in the reference atmosphere (see Report 231-2), the elevation angle correction decreases from 32 to 5 milliradians when the elevation angle increases from 0 to 52 milliradians (0 to 3°) [10]. If such a path goes through the atmosphere at altitudes

* This Report was adopted unanimously. The attention of Study Group 4 and Study Group 9 is directed to this Report.

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 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 231-2 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.

The problem of the effects of refraction on the protection of the geostationary orbit is discussed in Report 393-1.

2.2 *Amplitude, phase and angular scintillations*

In addition to the ray-bending produced by relatively large-scale variations in the vertical distribution of refractive index, rapid fluctuations in amplitude, phase and angle of arrival can be produced by irregular, small-scale variations in refractive index. These effects limit the accuracy of radio tracking systems, which are normally designed on the assumption that there is no phase distortion in the wavefront at the receiver. This phase incoherence also affects the stability of frequencies transmitted through the atmosphere, and it contributes to the gain degradation experienced with large antennae.

For space-space or Earth-space links at large angles of elevation and frequencies below about 20 GHz, small-scale variations in refractive index are generally insignificant. At higher frequencies in some meteorological conditions, their effect may be important. Assuming a source outside the troposphere and a paraboloidal receiving antenna of up to a few metres in diameter, the largest peak-to-peak fades expected in clear air are about ± 4 dB and ± 2 dB at 100 and 35 GHz respectively for elevation angles exceeding 45°. For angles of elevation of about 10°, however, the fades may occasionally reach ± 12 dB and ± 6 dB at 100 and 35 GHz respectively.

It is estimated that for a distance of 6 m across the wavefront (representative of the diameter of a large millimetric antenna) the r.m.s. value of phase differences caused by the troposphere on an Earth-space link may sometimes reach 40° and 15° at 100 GHz and 35 GHz respectively when the elevation angle exceeds 45°. At about 10° elevation, these values increase to approximately 80° and 30° at 100 GHz and 35 GHz respectively.

These estimates of amplitude and phase scintillations have been calculated from theory, using measured values of refractive-index fluctuations [11, 12]. They should therefore be used with caution pending more direct experimental observations under various meteorological conditions.

Short period fluctuations in the angle of arrival at a frequency of about 4 GHz and at elevation angles of about 15° might be expected to have an r.m.s. value of between about 2 and 5×10^{-5} radians.

3. Attenuation

3.1 *General aspects*

At frequencies above about 3 GHz, the attenuation of radio waves, and contributions to the system noise temperature (discussed in § 4) resulting from absorption and scattering by atmospheric gases and liquid water, become increasingly important and must be taken into consideration in the design of space telecommunication systems operating in this frequency range. Attenuation by atmospheric gases is due almost entirely to absorption by neutral oxygen and water vapour. The presence of the water dimer may have an effect. Attenuation by liquid water in the form of rain, cloud or fog results from both scattering and absorption, the relative importance of these phenomena depending on the particle sizes relative to the wavelength. Attenuation resulting from snow may also be significant at frequencies above 3 GHz and, depending on the nature of the snow, may exceed the attenuation produced by rain of equivalent rate [13]. Because of the difference in dielectric properties, ice clouds give attenuations about two orders of magnitude smaller than water clouds of the same water content [14].

Signal loss may also result from atmospheric defocussing which arises because of spreading of the antenna beam due to the variation of atmospheric refraction with elevation angle [15]. This effect should be negligible for all elevation angles above about 3°.

3.2 *Absorption by oxygen and water vapour*

Water vapour absorption has a resonant peak at a frequency of 22·23 GHz, and oxygen absorption has a broad peak centred at 60 GHz, resulting from a series of lines which are pressure-broadened in the lower atmosphere, and a peak at 120 GHz.

The total gaseous absorption in the atmosphere, A_a (in dB), over an Earth-space path of length, r_0 (in km), is given by:

$$A_a = \int_0^{r_0} \left\{ \gamma_o(r) + \gamma_w(r) \right\} \mathrm{d}r \quad \text{(dB)}$$

where γ_o, γ_w are the absorption coefficients (in dB/km) for oxygen and water vapour respectively. This may be expressed as:

$$A_a = \gamma_{o0}\, r_{eo} + \gamma_{w0}\, r_{ew} \qquad \text{(dB)}$$

where γ_{o0} and γ_{w0} are the absorption coefficients of oxygen and water vapour as determined at the surface of the Earth and r_{eo} and r_{ew} are the effective distances of the path through the atmosphere. The effective distance for oxygen absorption, r_{eo}, is the distance a radio wave travels through an atmosphere of constant density extending upwards from the surface to a height of approximately 4 km with a vacuum above. The effective distance for water vapour absorption, r_{ew}, is approximately equal to the corresponding distance through a uniform atmosphere of about 2 km thickness.

Fig. 1, derived from an appraisal of the published literature [16], shows the absorption coefficients, γ_{o0} and γ_{w0}, for both oxygen and water vapour, as determined for standard conditions of temperature and pressure and for a surface value of absolute humidity of 10 g/m^3 (approximately equal to a mixing ratio of 7·6 g/kg).

Fig. 2 shows the theoretical one-way attenuation for vertical and horizontal paths through the atmosphere for the frequency range from 1 to 160 GHz for a moderately humid climate (7·5 g/m^3 at the surface). Also shown are the limits for 0 and 100% relative humidity for the horizontal path through the atmosphere.

Fig. 3 shows the values of the total attenuation at 4, 11 and 18 GHz, due to oxygen and water vapour and atmospheric defocussing, not exceeded for 20% and 0·01% of the least humid month of the year as a function of elevation angle [15].

3.3 *Attenuation due to precipitation*

The attenuation due to rain usually exceeds the combined absorption due to oxygen and water vapour and arises from the absorption of energy in the water droplets and from the scattering of energy out of the beam of the antenna.

In practice, it is usually convenient to express the attenuation due to rain as a function of the rainfall rate, R, which depends on both the liquid water content and the velocity of fall of the drops which in turn depends on the size of the drops. There is evidence that rain of a given rainfall rate has various distributions of drop-size, and the problem of estimating the attenuation of radio waves caused by precipitation is difficult.

The total attenuation, A_r, due to rainfall over a path of length r_0 can be determined by integrating the rain absorption coefficient, $\gamma_r(r)$, along the direct path between the two mutually visible antennae:

$$A_r = \int_0^{r_0} \gamma_r(r)\, \mathrm{d}r \qquad \text{(dB)}$$

Several theoretical studies have been carried out [14, 17, 18] to determine the absorption due to rain as a function of frequency and rainfall rate using standard drop-size distributions [19]. It has been shown [20] that the results of these studies can be approximated by the empirical expression:

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

in which R is the rainfall rate in mm/hr. This relation is plotted in Fig. 4 in which the frequency dependence of K and α is included. These curves are applicable for a temperature of 18° C but may also be used at other temperatures using a correction factor [14].

In practice it has been shown [17, 21] that α may be assumed to be nearly unity over a wide range of frequencies less than about 50 GHz.

Fig. 4 should be used with caution in view of the tendency of the attenuation measured at some frequencies (between about 20 and 35 GHz) to exceed the maximum predicted attenuations [17]. Additional difficulty arises from the lack of uniformity of rainfall over actual transmission paths. As a result of studies of the spatial correlation of rainfall rates, the use of a reduction factor has been proposed for terrestrial paths [22] as a means of relating the statistics of rainfall attenuation over an actual path to the cumulative probability distribution of rainfall at a point. The value of the reduction factor, which is a function of path length, will also depend on the time (and therefore, spatial) averaging of the point rainfall data [23].

Little experimental work has been carried out at frequencies greater than 50 GHz. There is some indication from recent evidence [13, 24] that, except at low rainfall rates, the observed attenuations lie below those expected from theoretical considerations. However, further measurements above 50 GHz are desirable.

With few exceptions [25, 26, 27], experimental measurements of rainfall attenuation have been conducted over terrestrial line-of-sight paths. More information is needed concerning rainfall attenuation along paths with high elevation angles where drop size distributions and fall velocities are particularly uncertain. This may be done using the Sun as a source or by means of aircraft or satellite-borne beacons. Correlation of such measurements with simultaneous backscatter data from weather radars operating at frequencies where the attenuation may be neglected appears desirable, in order to permit the extrapolation of such data to other regions where weather radar data are available. Statistical data would be particularly useful in the design of space telecommunications systems (see for example Report 338-1).

Estimates of the attenuation at 30 GHz on a zenith path in New Jersey (United States) based on observations over a five-month period of the thermal noise generated by rain at 6 GHz, indicate that attenuation might exceed 6 dB at 30 GHz for 0·1 % of the time and 36 dB for 0·01 % of the time [28].

Studies have also been carried out for the central European part of the U.S.S.R. [29] in which the attenuations expected for 0·1 and 1 % of the time at various elevation angles and frequencies from 5 to 20 GHz were derived. These values of attenuation were based on measurements over a period of ten years of the duration and intensity of surface rain (average over one minute), its horizontal and vertical extent, and cloud thickness and cloud cover. It was found, for example, that at 10 GHz, attenuations of 3·5 and 1·2 dB would be expected for 0·1 and 1 % of the time respectively at an elevation angle of 10°. The corresponding zenith values are 0·15 and 0·1 dB respectively. At 20 GHz, attenuations of 18 and 5·5 dB would be expected for 0·1 and 1 % of the time at an elevation angle of 10°.

Direct measurements of attenuation along Earth-space paths have been carried out in Japan [27] at frequencies of 9·4, 11·8 and 17·0 GHz using solar radiometers. For a one-year period the attenuation was found to exceed 4·5, 7 and 14 dB respectively at the three frequencies for 0·01 % of the year, where all measurements were reduced to an elevation angle of 45°. Using four years of data at 9·4 GHz, considerable variation was found from year to year in the statistical results for percentages of time less than about 0·1 %. This is because, as in many climatic regions, the statistics for small percentages of the time are determined by the occurrence of a small number of severe thunderstorms.

Attenuation statistics are expected to vary widely according to the climatology of the region, and the period and method of observation. It is probable that monsoon rainfalls may be a particular problem [30].

Weather radar data from Montreal have also been used to estimate the spacing between earth stations using diversity to overcome the effects of heavy localized rain [28]. It is found that the diameter of storm cells in which the equivalent rain rate exceeds 25 mm/hr is almost independent of altitude and the number of occurrences decreases to fairly low values for equivalent diameters in excess of 16 km. This simple argument, however, neglects the spatial correlation of occurrence of storm cells. For the same reasons the variation with elevation angle of large attenuations observed for small percentages of the time is difficult to estimate.

3.4 *Attenuation due to clouds and fog*

For clouds or fog consisting entirely of small droplets or ice particles, generally less than 0·01 cm, the Rayleigh approximation is valid and it is possible to express the attenuation in terms of the total water content per unit volume [14]. Thus, the absorption within such a cloud or fog can be written as:

$$A_c = K_l M \qquad \text{(dB/km)}$$

where A_c is the absorption coefficient within the cloud, K_l is an attenuation coefficient (in dB/km $(\text{g/m}^3)^{-1}$) and M is the liquid water content of the cloud (in g/m³).

Values of K_l are plotted in Fig. 5 [31] for the frequency range from about 10 to 50 GHz and for various temperatures from $-8°$ C to 20° C. Because of the different dielectric properties, ice clouds give attenuations about two orders of magnitude less than water clouds and are not considered further here.

4. Sky-noise temperature due to absorption by atmospheric gases and precipitation

4.1 *General aspects*

The non-ionized region of the atmosphere, as an absorbing medium, is also a source of noise radiation. The effective sky noise temperature, T_s, in a given direction is given by:

$$T_s = \int_0^{\infty} T(r)\alpha(r) \exp \left\{ - \int_0^{r} \alpha(r')\, \mathrm{d}r' \right\} \mathrm{d}r$$

where $T(r)$ (in °K) and $\alpha(r)$ (in km^{-1}) are the temperature and absorption coefficients respectively, of the medium as a function of position, r, along the ray path. If the temperature $T(r)$ can be replaced by a mean radiating temperature, T_m, the above expression simplifies to:

$$T_s = T_m \left(1 - \frac{1}{L}\right)$$

where L is the loss factor of the absorbing medium expressed as a fraction.

Furthermore, in the case of a horizontally stratified atmosphere, the sky temperature at a zenith angle Φ is given by:

$$T_s(\Phi) = T_m(1 - \beta_0^{\sec \Phi})$$

for zenith angles less than 85°, where $\beta_0 = \frac{1}{L_0}$ is the transmission of the atmosphere in the zenith direction.

In the estimation of antenna temperature, the antenna pattern and radiation from the surface of the Earth must also be considered.

4.2 *Sky-noise temperature due to atmospheric gases*

Fig. 6 shows the sky-noise temperature due to oxygen and water vapour for various angles of elevation and for frequencies between 1 and 100 GHz [32].

More detailed consideration of naturally occurring noise in the range 1 to 10 GHz is given in published work [33]. The values of noise temperature in this paper are somewhat less than those given in Fig. 6 for frequencies below 10 GHz, due to the use of more recent values of line width constants.

4.3 *Sky-noise temperature due to rain and cloud*

The noise due to absorption in rain and cloud can also be calculated from the expressions given above provided the temperature and rate of attenuation and their variation along the path are known.

The studies carried out in the U.S.S.R. [29], referred to previously, have also shown that, at an elevation angle of 10°, for 1% of the time a contribution to the antenna noise temperature due to rain and cloud of about 40° K can be expected at 10 GHz and of about 140° K at 20 GHz. The corresponding values for 0·1% of the time are 90° K and 260° K respectively.

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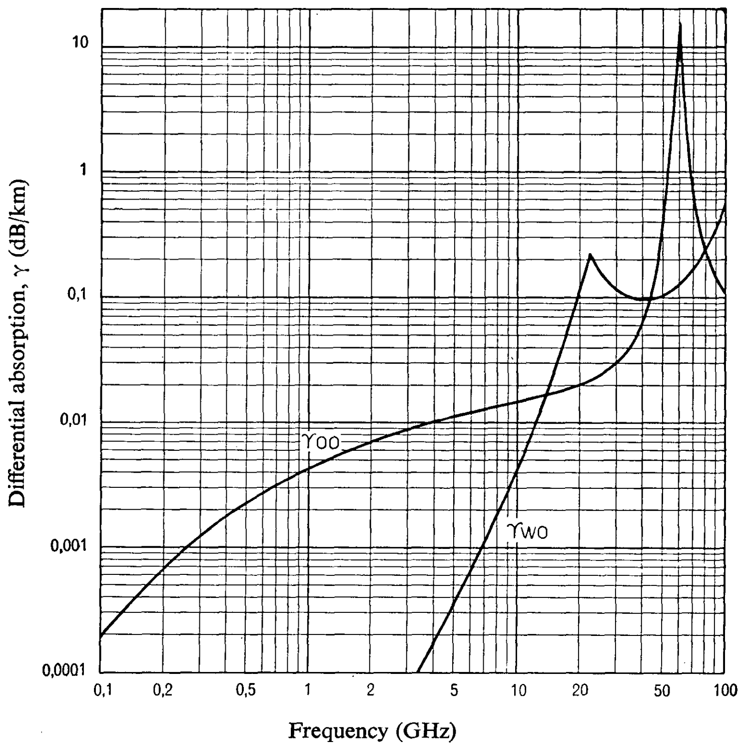

FIGURE 1

Surface values γ_{o0} and $\gamma\omega_0$ of absorption by oxygen and water vapour

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

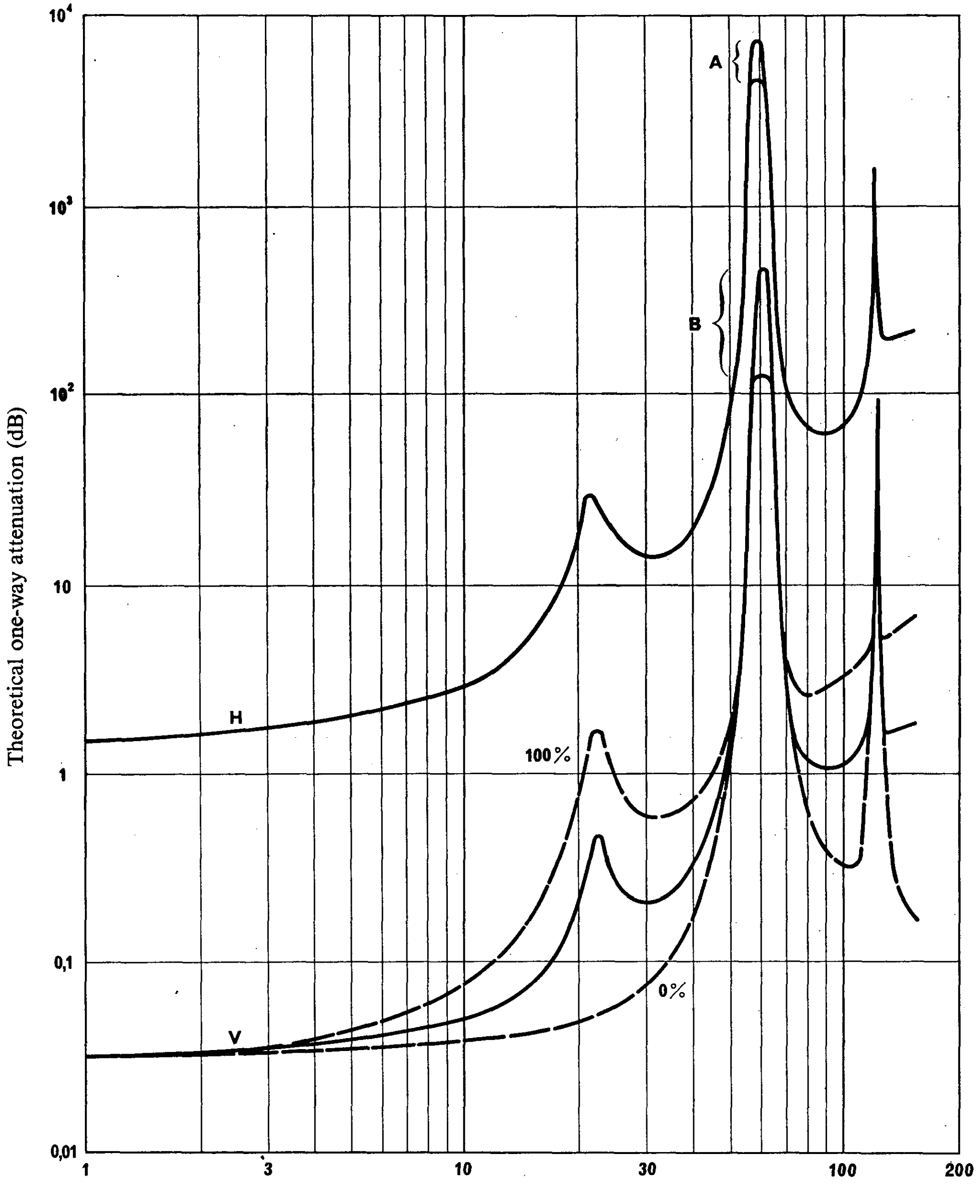

FIGURE 2

Theoretical one-way attenuation for vertical and horizontal paths through the atmosphere (calculated using the United States' standard atmosphere for July at 45° N latitude). Solid curves are for a moderately humid atmosphere, dashed curves for vertical attenuation represent the limits for 0 and 100% relative humidity

A: Limits of uncertainty H: Horizontal
B: Limits of uncertainty V: Vertical

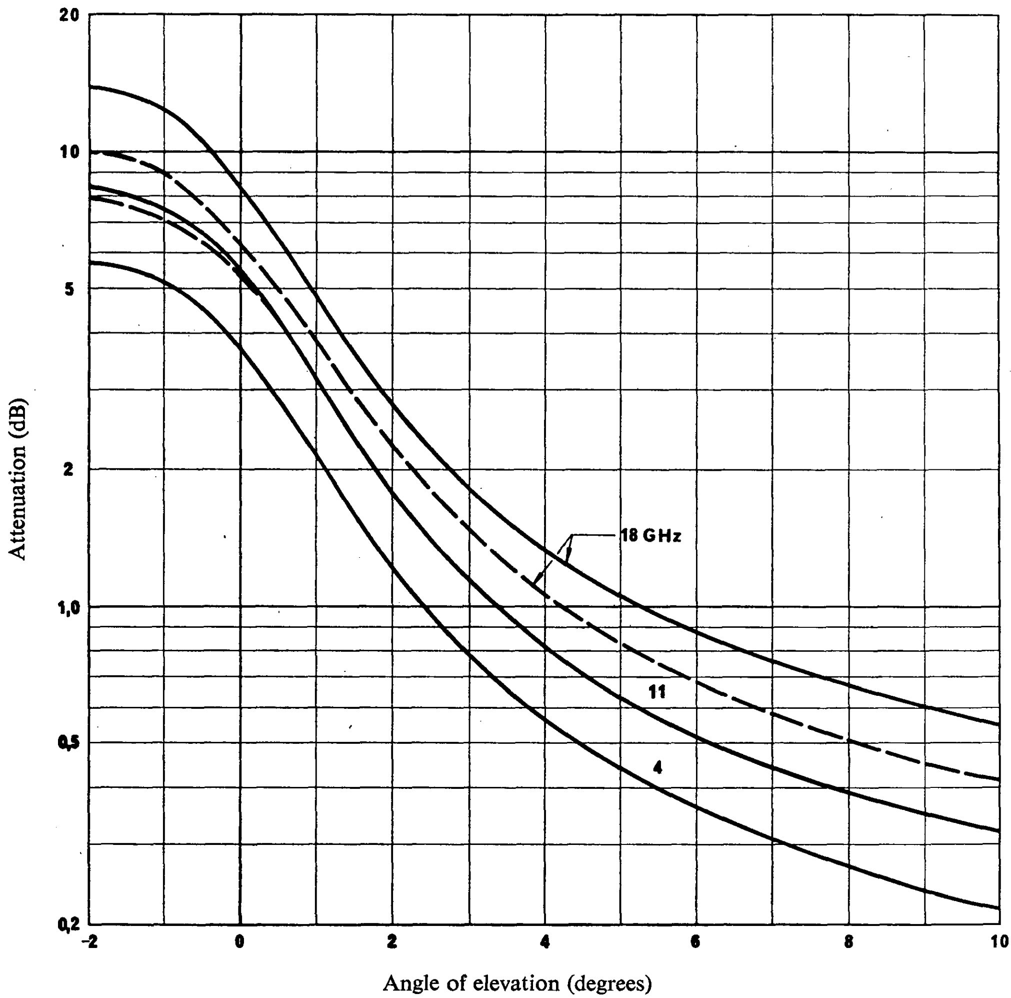

FIGURE 3

Values of total attenuation due to absorption by water vapour and oxygen, and including the effects of defocussing, not exceeded for 20% (solid curves) and 0·01% (dashed curves) of the least humid month

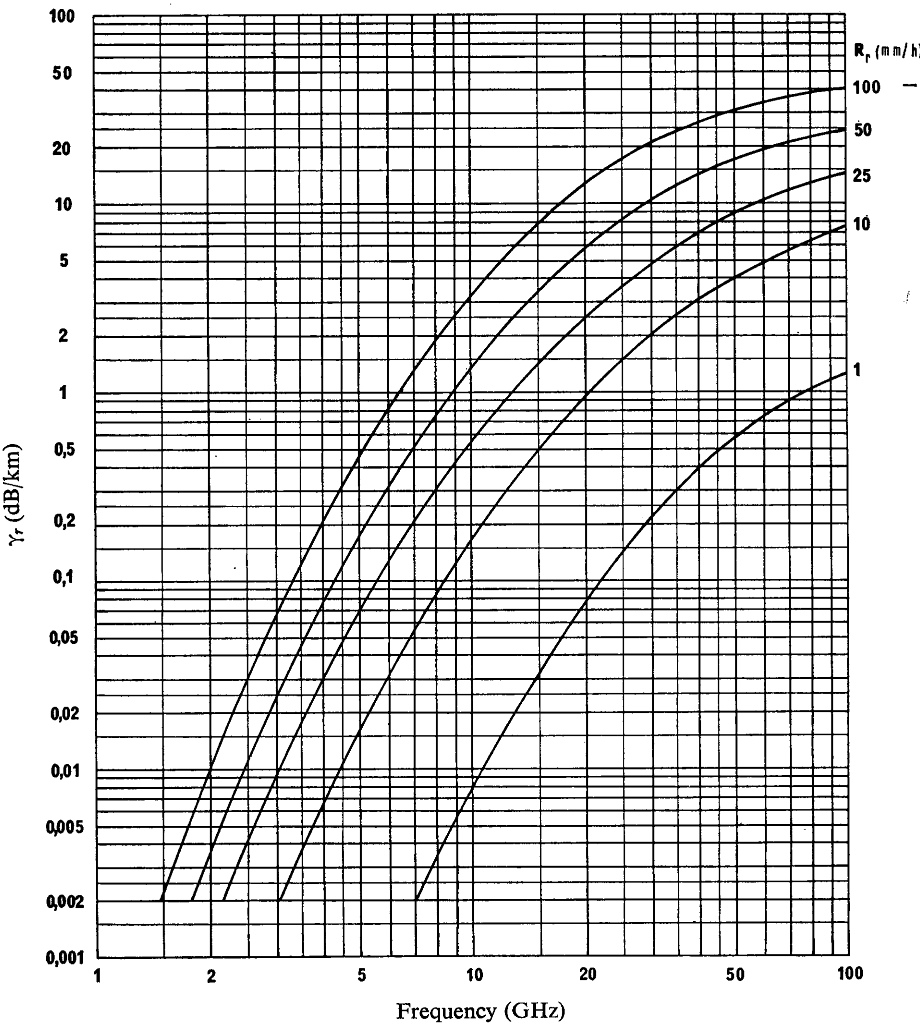

FIGURE 4

Variation of γ_r with frequency

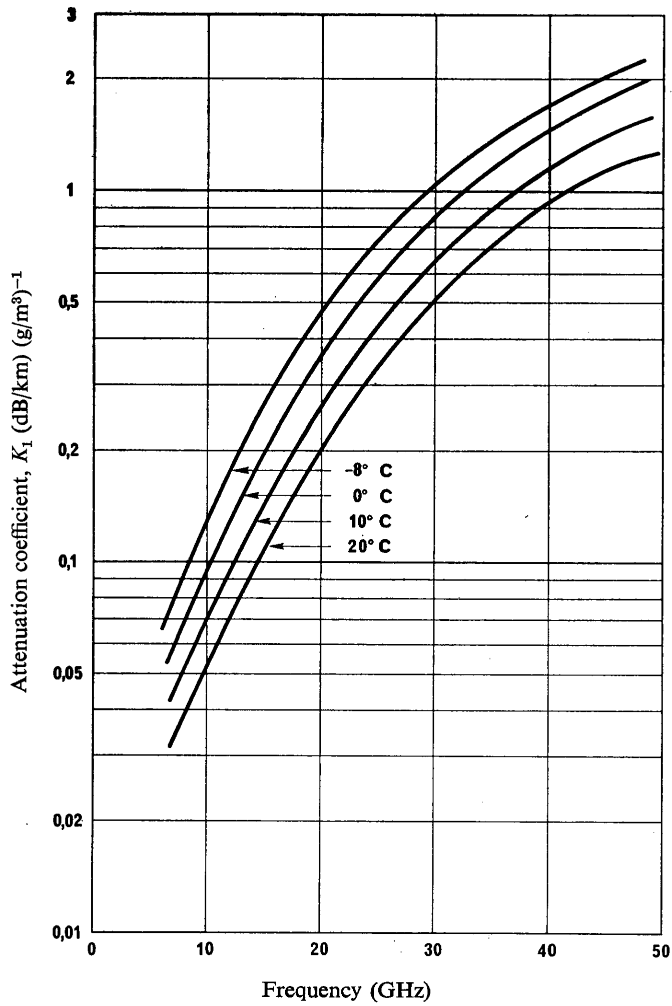

FIGURE 5

Attenuation by water cloud at various temperatures as a function of frequency

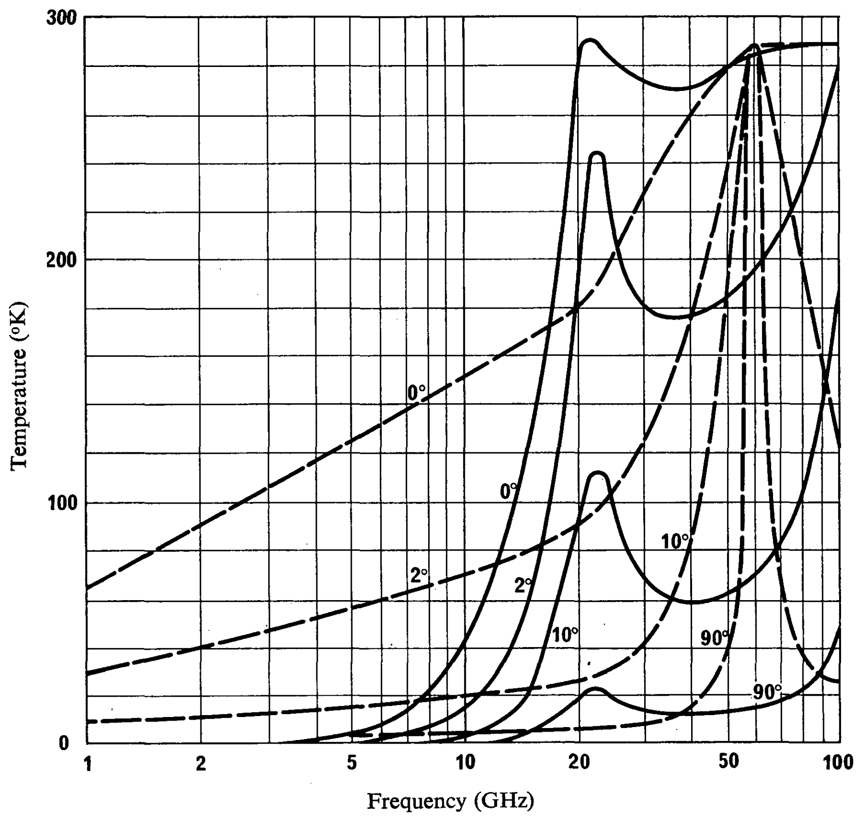

FIGURE 6

Sky-noise temperature due to absorption by oxygen and water vapour
(The angle of elevation above the horizontal is indicated on each curve)

Surface pressure: 760 mm Hg

Surface temperature: 20° C

Water vapour density: 10 g/m^3

———— Water vapour

— — — — Oxygen

REPORT 339-1 *

INFLUENCE OF SCATTERING FROM PRECIPITATION ON THE SITING OF EARTH STATIONS

(Study Programme 5-1D-1/5)

(1966 – 1970)

1. Introduction

It has been shown [1, 2] 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 sharing the same frequency bands. In view of the need for estimates of interference probability, this contribution has been prepared to provide some information on 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 fall into two main categories. The first is long-range interference occurring 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 one of the main beams of one and the side-lobes of the other.

In this Report, after consideration of geometrical and meteorological aspects of the problem, results are derived for both intersecting and non-intersecting beams at 6 GHz as a function of rate of rainfall. Estimates for intersecting beams at 12 and 18 GHz are also presented, considering the extreme cases of attenuation throughout the atmosphere, or of attenuation just in the volume common to the two main beams.

It should be noted that scattering from inhomogeneities in refractive index may also occur at the intersection of beams aimed along or within a few degrees of the great-circle path. However, using measured reflectivity values [8] it can be shown in a typical case (Doc. V/109, (United Kingdom), 1966-1969), that at 4 GHz the losses exceeded 99% of the time are comparable to those of normal trans-horizon propagation and much less than those expected for precipitation scatter except perhaps in dry climates.

2. Intersecting beams

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:

$$P_r/P_t = \int (G_{ts}/4\pi d^2_{ts})(\eta/4\pi d^2_{es})(G_{es}\lambda^2/4\pi)\, \mathrm{d}v \tag{1}$$

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

* This Report was adopted unanimously.

G_{ts} and G_{es} are the gains of the terrestrial-station and earth-station antennae respectively,

d_{ts} and d_{es} are the respective distances from terrestrial and earth-stations to the scattering region,

$\mathrm{d}v$ is an element of the scattering volume,

λ is the wavelength, and

η is the scattering cross-section per unit volume.

Metres are used throughout unless otherwise indicated.

The earth-station is assumed to have an antenna considerably larger than that of the radio-relay station, with the beam elevated at angles of 3° or more above the horizon. Results given in this Report for intersecting beams have been obtained from calculations of the volume common to the two 3 dB beamwidths and from values of η obtained from radar studies. Rayleigh or dipole scattering, which is uniform in the horizontal plane in the case of vertical polarization, is assumed and no account has been taken of the effect of scattering from rain in the side-lobes of the antennae patterns.

Using $\eta \approx Z/3{\cdot}6 \times 10^{15}\lambda^4$ per metre, where Z is the reflectivity factor, in mm^6/m^3, throughout the common volume

$$G_{ts}b^2 = \pi^2 \qquad \text{and}$$

$$\int \mathrm{d}v = (\pi/4)(b_{es}d_{es})^2\, d_{ts}b_{ts}/\sin\theta$$

where b = antenna beamwidth in radians

$$P_r/P_t \simeq \frac{Z\,\sqrt{G_{ts}}}{3\, d_{ts}\lambda^2 \sin\theta \times 10^{17}} \tag{2}$$

where θ = angle between the antenna beams.

3. Non-intersecting beams

The problems of integrating (1) lead to the concept [3] of integrating along each of the two beams where the gains are highest. Using $\eta = Z/3{\cdot}6 \times 10^{15}\lambda^4$ and $\mathrm{d}v = (\pi/4)\, b_{es}^2 d_{es}^2\, ds$,

$$10^{18}\lambda^2(P_r/P_t) = \int_{es}\left(\frac{G_{ts}\,Z_{es}}{d_{ts}^2}\right)\mathrm{d}s + \int_{ts}\left(\frac{G_{es}\,Z_{ts}}{d_{es}^2}\right)\mathrm{d}s' \tag{3}$$

Now the following assumptions are made (Doc. V/145 (United States), 1966-1969):

— the two beams are close, that is, the line perpendicular to both, the minimum separation, has a length y of only a few kilometres;

— Z is either constant in the portion of each beam near the ends of the perpendicular, or equivalent values can be found and used;

— $G_{ts} = 0{\cdot}3/\alpha_{ts}^2$ or $10 \log G_{ts} = 30 - 20 \log \alpha^\circ_{ts}$
although a higher exponent may be more appropriate for a horn antenna;

— $G_{es} = 0{\cdot}3/\alpha_{es}^2$ or $\log 10\, G_{es} = 30 - 20 \log \alpha^\circ_{es}$.

If the precipitation is widespread or may be considered symmetrically disposed with relation to the perpendicular, i.e. earth station elevation is less than about 30°,

$$10^{19}\lambda^2 (P_r/P_t) \sin \theta = (6\, Z_{es}/y + 6\, Z_{ts}/y) \text{ arc tan } (x/y) \tag{4}$$

Recognizing that arc tan $\infty = \pi/2$ and arc tan $1 = \pi/4$, it is seen that, in a uniform atmosphere, one half of the total interference from a given beam arises from a region within $\pm\, (y/\sin \theta)$ about the end of the perpendicular. If the precipitation is limited in area, with an effective diameter $(D \leqq 2y/\sin \theta)$ then $x = (D \sin \theta/2)$ and arc tan $(x/y) \approx (\pi D \sin \theta)/8y$, so that one may write:

$$P_r/P_t = (Z_{es} + Z_{ts})\, D/(4 \times 10^{18}\lambda^2 y^2) \tag{5}$$

with the understanding that with widespread precipitation D must be set equal to $4y/\sin \theta$.

4. Reflectivity of continuous rainfall

The meteorologist distinguishes two main types of precipitation. The simplest is called continuous—rain or snow from a stratiform cloud structure which is uniform over a large area and relatively limited in height. Atlas [4] gives model profiles for stratiform summertime rain which may be approximated as:

$$\log Z = \log Z_0 - 5 \times 10^{-8} \,.\, H^2 \tag{6}$$

where Z_0 = reflectivity factor at the surface, usually considered related to the surface rainfall rate, R (mn/h) [4], by

$$Z_0 = 200\, R^{1.6}\, (\text{mm}^6/\text{m}^3) \tag{7}$$

By way of example, for Washington, D.C., Bussey [5] shows that rain at a rate of 25 mm/h or more occurs for about one hour per year ($Z_0 = 3{\cdot}4 \times 10^4$ for 0·14% of a month) and, for parts of the South-Eastern United States at a rate of 150 mm/h for about five minutes once in two years ($Z_0 = 6 \times 10^5$ for 0·01% of a month). As an indication of possible rainfall, Fig. 5·5 of [4] shows 300 mm of rain in 40 minutes at Holt, Missouri, on 22 June 1947, corresponding to a rate of 450 mm/h for about 0·1% of a month.

From equation (4)

$$\int_0^\infty Z \, ds = \int_0^\infty Z \, dH/\sin E_{es} = 2620\, Z_0/\sin E_{es} \tag{8}$$

so that the antenna beam of the earth station may be considered as traversing uniform precipitation as measured at the ground ($Z = Z_0$) to a height of 2·6 km. The antenna beam of the terrestrial station will be roughly horizontal near the earth station at a height easily calculated, but usually low enough so that Z_0 at the surface is applicable.

5. Reflectivity of convective rainfall

The more complex type of precipitation is called showery or convective. It is not, like the continuous model, uniform in time or space, but varies rapidly over small areas, due to its turbulent origin. If the development reaches eight or nine kilometres in height, it normally becomes a thunderstorm, with strong updrafts repeatedly carrying precipitation to great heights often in the form of hail. Thus the largest particles occur within free-space ranges of many hundreds of kilometres from earth and terrestrial stations. A thunderstorm model has been developed [7] which considers contours of Z arranged in concentric cylindrical shells (incorrectly quoted as spheres in the more readily available [8]) according to:

$$Z = 3{\cdot}8 \times 10^{-6} \, . \, (r_0 - r)^{2{\cdot}5} \tag{9}$$

where r_0 is the radius (m) at minimum detectable reflectivity. Maximum values for r_0 and one-half the height are often about 8000 m [9].

If the beam of the earth station at an angle of elevation E_{es} intersects the axis of the storm, then it can be shown that:

$$\begin{aligned} DZ = \int_{-r_0}^{+r_0} Z \, ds &= 1{\cdot}2 \times 10^{-5} \, r_0^{3{\cdot}5}/\cos E_{es} \quad (E_{es} < 45°) \\ &= 5{\cdot}7 \times 10^8/\cos E_{es} \quad (r_0 = 8000 \text{ m}) \\ &= 6{\cdot}6 \times 10^8 \quad (E_{es} = 30°) \end{aligned} \tag{10}$$

Donaldson [10] has published reflectivity profiles representing 130 thunderstorms observed during two years by a radar in the Boston area. From these, it can be shown that an occasional storm may have a maximum value of Z at 9 km, although a maximum value at 6 km, of 3×10^6 mm^6/m^3, is more probable. For thunderstorms, an approximate maximum value of DZ of 10^{10} mm^6/m^2 seems reasonable.

6. Reflectivity of composite rainfall

For a simple statistical solution to this problem, it is necessary to assume distribution of precipitation reflectivity factor based on uniform sampling in time and space. 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 [6]. 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:

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

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.

It should be particularly noted that surface rainfall data may provide a useful guide to reflectivity in the atmosphere only when the rainfall is mostly continuous or when considering long-term averages. In months with severe thunderstorms, surface rainfall data may be quite misleading.

7. Results

7.1 *Intersecting beams*

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. The probability of interference at 6 GHz (for 0·02% of the worst month) can be determined from Fig. 1, derived using the expressions of § 6, in the following manner. An earth station, *ES*, with an antenna 26 m in diameter pointed at fixed angles of elevation, E_{es}, of 3° 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_{ts}, 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% 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 a 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 (2).

To generalize the application of Fig. 1, the relation between rainfall rate and distance shown in Fig. 2 may be derived (C.C.I.R. Doc. V/113 (United States), 1966-1969) by using a vertical reflectivity profile similar to that of § 6, converting to rain rate by (7), as follows:

$$R(h) = R_0 \, 10^{-0{\cdot}025\, h^2}$$

where h is height in kilometres.

In this figure, it is assumed that $\lambda = 5$ cm, $G_{ts} = 43$ dB, and $P_r/P_t = -140$ dB. To find the coordination distance under other conditions, the actual rainfall rate at the surface, R_0, for the percentage of time of interest, should not be used, but an effective rate R_e should be found from:

$$R_e = R_0 \, (5/\lambda)^{1{\cdot}25} \, 10^{\Delta L_s/16}$$

where λ is in cm and ΔL_s is in dB above $P_t/P_r = 140$ dB.

The effect of attenuation upon scattering at 12 and 18 GHz has been studied (Doc. V/117 and Corr. 1 (United States), 1966-1969). The limiting assumptions of precipitation throughout the atmosphere or just in the volume common to the main beams were made with the results shown in Figs. 3 and 4. It may be noted that in the former case, the scattering is more effective than the attenuation for the case of 1 mm/hr.

7.2 *Non-intersecting beams*

For continuous rain, $\lambda = 5$ cm and θ near 90°,

$$P_r/P_t = 4 \times 10^{-16}(Z_{es} + Z_{ts})/y \tag{11}$$

Using $Z_{ts} = 200\ R^{1\cdot6}$, and $Z_{es} = Z_{ts}$ because in the usual case with the earth station beam above the terrestrial station beam, Z_{es} will be no greater than Z_{ts} and can have an effect of only ±3 dB,

$$P_r/P_t = 8 \times 10^{-14} R^{1\cdot6}/y \qquad (12)$$

Solving for y, one obtains the following values (at 5 GHz):

TABLE I

Radius of critical cylinder for continuous rain (km)

Rainfall rate R (mm/h)	10 log (P_r/P_t) (dB)			
	−130	−140	−150	−160
2·5				3·5
10			3·2	32
25		1·4	13·6	(1)
100	1·3	12·8	(1)	(1)

(1) Calculated values exceed reasonable conditions for uniform rain distribution.

Note. — The values are only valid if the minimum angular separation of the beam axes, as seen from the radio-relay system, exceeds 1·5°; i.e. if $y/d \geqq 0{\cdot}026$, where d is the distance between the two antennae in the same units as y. Thus they do not apply in the vicinity of intersections where the beams are almost coincident.

For convective rainfall, $\lambda = 5$ cm, θ near 90° and $Z_{es} = Z_{ts} = Z$

$$P_r/P_t = 2 \times 10^{-16}\ DZ/y^2 \qquad (13)$$

Solving for y one obtains the following values:

TABLE II

Radius of critical cylinder for thunderstorms (km)

DZ	10 log (P_r/P_t) (dB)			
	−130	−140	−150	−160
10^7		0·45	1·4	4·5
10^8	0·45	1·4	4·5	14·1
10^9	1·4	4·5	14·1	
10^{10}	4·5	14·1		

8. Radar climatology

For a more satisfactory treatment, the problem under consideration obviously requires many detailed distributions of reflectivity based on regular sampling in time and threedimensional space, which so far have been published only for Montreal, Canada [6]. For the rest of the world, it is necessary to rely upon surface observations and some limited radar data representing the percentage probability of seeing some echo between 10·5 and 12 km in height within 160 km.

It may be noted that the correlation between long-term surface rainfall data and thunderstorm reflectivity will be, at least, poor. This is not merely because of the intense vertical development and local character of thunderstorms, but also because the reflectivity factor is not related to the amount of rainfall, but to the rate of rainfall, commonly by $Z = 200 \,.\, R^{1 \cdot 6}$ where R is the rate in mm/h. A useful correlation with Fig. 2 appears in the distribution of thunderstorm days (with the advantage that such maps are readily available for each month throughout the whole world) [12]. Quantitative application of this climatological data is still under study.

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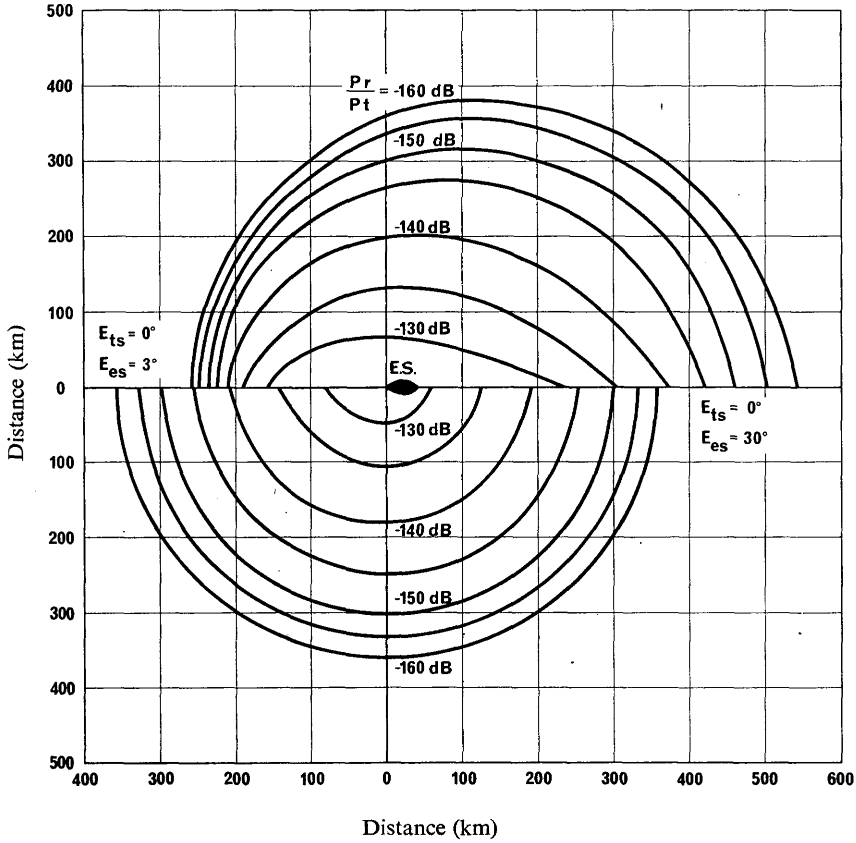

FIGURE 1

Loss contours for intersecting beams

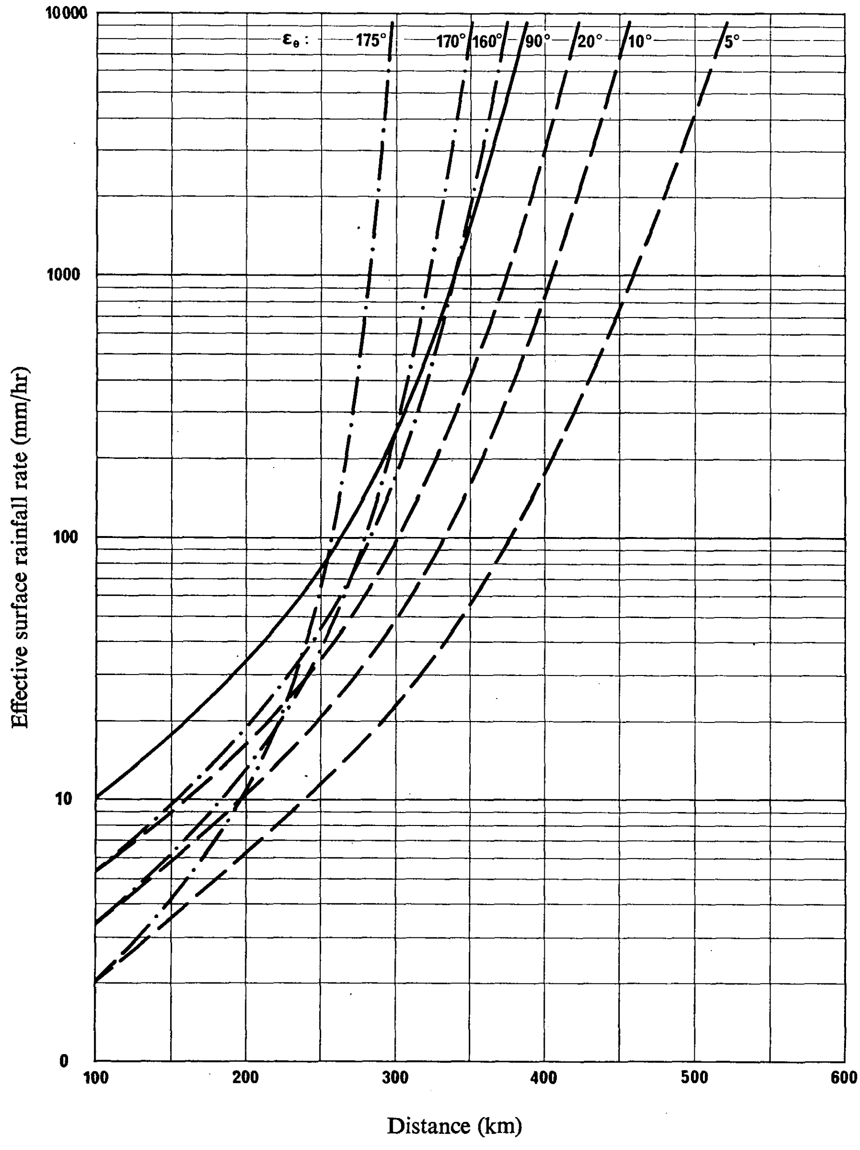

FIGURE 2

Rain-scatter distance as a function of effective surface rainfall rate at 6 GHz for a system transmission loss of 140 dB

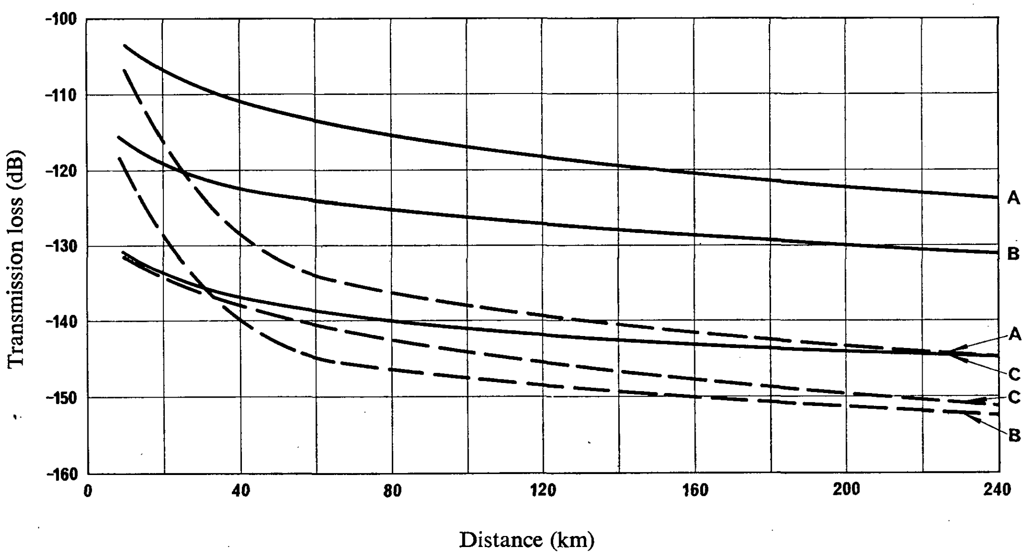

FIGURE 3

Transmission loss vs. distance for given rain rates at 12 GHz

————	Rain in common volume	A: 100 mm/hr
		B: 10 mm/hr
— — —	Rain along path	C: 1 mm/hr

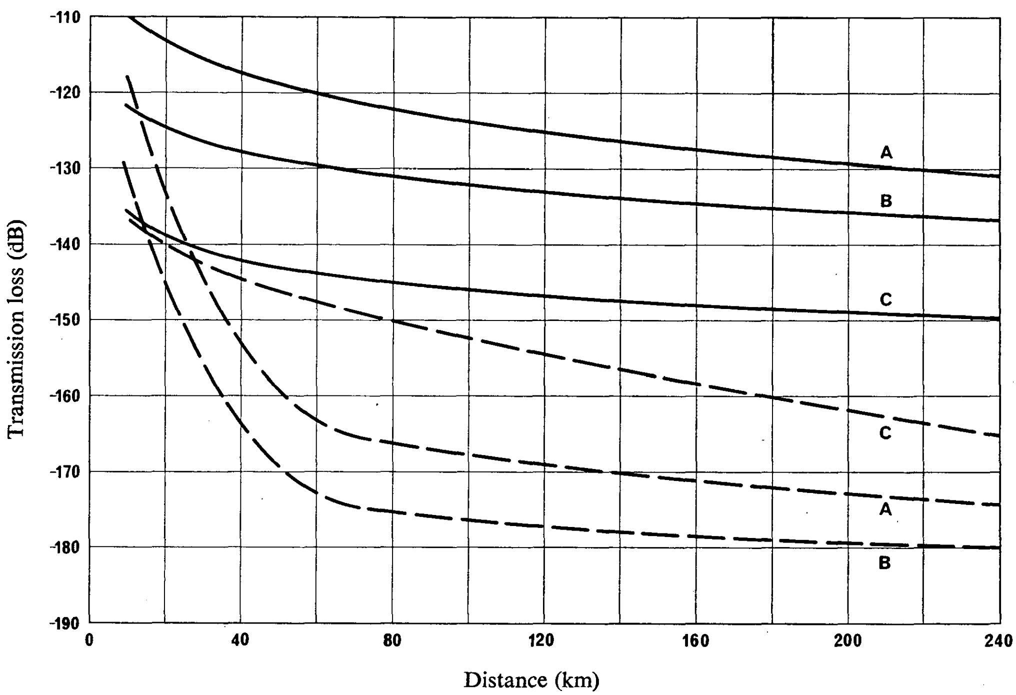

FIGURE 4

Transmission loss vs. distance for given rain rates at 18 GHz

————	Rain in common volume	A: 100 mm/hr
		B: 10 mm/hr
— — —	Rain al ng path	C: 1 mm/hr

REPORT 426 *

METHODS FOR PREDICTING RADIO NOISE AND THE ATTENUATION AND REFRACTION OF RADIO WAVES IN RELATION TO SPACE TELECOMMUNICATION SYSTEMS

Collection of data

(1970)

Study Programme 5-1C-1/5 requests the development of methods for predicting radio noise and the attenuation and refraction of radio waves in relation to space telecommunication systems.

At the present time there is insufficient experimental data available to Study Group 5 for the development of such methods. Nevertheless, it is known that additional experiments are now being undertaken and that further experimental work is planned for the near future. It is hoped, therefore, that at its next meeting Study Group 5 will be able to prepare prediction methods for use by Study Group 4.

In order to expedite this work every Administration is requested to:

— obtain as much experimental data as is possible on the statistical distribution with time of the attenuation and refraction of radio waves passing through the troposphere, and of radio noise;

— forward all available statistical data to the Director of the C.C.I.R. and to the Chairmen of Study Groups 4 and 5 as soon as possible.

Note 1. — It will greatly assist the work of Study Group 5 if Administrations forward the results of their experiments on standard A4 paper in the manner shown in Table A.

Note 2. — Information is also required on:

— attenuation and noise measurements using space diversity techniques;

— the correlation between attenuation due to absorption, and noise;

— relevant statistics on the constituents of the atmosphere such as rainfall data, preferably measured with short integration times. This would be very useful even in the absence of any measured radio data.

* This Report was adopted unanimously. In view of special requirements for the World Administrative Radio Conference for Space Telecommunications to be held in 1971, as much data as possible should be supplied by 30 September 1970. After 1 October 1970, the Director of the C.C.I.R. will send to each Administration two copies of all the data so far received.

TABLE A

1. COUNTRY	
2. Location of earth measuring station . . . . { Latitude / Longitude	° ′ ° ′
3. Source of radio signals (1)	
4. Elevation angle of signal source	°
5. Frequency of radio signals	GHz
6. Type of antenna and nature of feed at measuring station	
7. Is the antenna protected by a radome? Yes or No	
8. Beamwidth of antenna at 3 dB points.	′
9. Total period of measurements from (day/month/year)	/ /
to (day/month/year)	/ /
10. Total number of complete hours of measurements	

(1) e.g. Sun.

A 1

	Attenuation (dB) in excess of free-space attenuation exceeded for following percentages of time								
	99·99	99·9	99	90	50	10	1	0·1	0·01
Total period									
Month with greatest attenuation									

A 2

	Noise (°K) exceeded for following percentages of time								
	99·99	99·9	99	90	50	10	1	0·1	0·01
Total period									
Month with greatest noise									

A 3

	Refraction (degrees of arc) exceeded for following percentages of time								
	99·99	99·9	99	90	50	10	1	0·1	0·01
Total period									

SECTION 5C: TERRAIN EFFECTS

RECOMMENDATIONS AND REPORTS

Recommendations

There are no Recommendations in this Section.

Reports

REPORT 229-1 *

DETERMINATION OF THE ELECTRICAL CHARACTERISTICS OF THE SURFACE OF THE EARTH

(Question 1-1/5)

(1959 – 1963 – 1970)

1. Introduction

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

2. The characteristics of the ground

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

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

where σ is in 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 in the ratio of ε to $60\,\sigma\lambda$, from which their relative importance can be judged. Table I shows some typical earth constants. In the case of water surfaces or very moist ground at frequencies much above 100 MHz, account must be taken of the variation of dielectric constant with frequency and of the total conductivity (dipolar and ionic) [1]. Furthermore, it should be noted that a value of 80 has often been used for the dielectric constant of sea water over a wide range of frequencies. This value is incorrect, except for low temperatures and frequencies below about 1 GHz. The actual value even at low frequencies depends on the temperature and composition of the sea water.

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* This Report was adopted unanimously.

TABLE I

Some types of surface with their earth constants

Type of surface	ε	(σ mho/m)
Sea water (0° C)	80	4 to 5 (up to 1 GHz)
Sea water (10° C)	73	4 to 5 (up to 1 GHz)
Fresh water (10° C)	84	1×10^{-3} to 1×10^{-2} (up to 100 MHz)
Fresh water (20° C)	80	1×10^{-3} to 1×10^{-2} (up to 100 MHz)
Very moist ground	30	5×10^{-3} to 2×10^{-2}
Average ground	15	5×10^{-4} to 5×10^{-3}
Arctic land	15	5×10^{-4}
Very dry ground and large towns (industrial areas)	3	5×10^{-5} to 1×10^{-4}
Polar ice	3	$2{\cdot}5 \times 10^{-5}$

In Table I the range of conductivity values for a specified type of surface corresponds to the differences which exist in different parts of the world. In fertile areas the higher values are applicable, while the water in lakes and rivers has a conductivity that increases with the concentration of impurities.

3. Factors determining the effective ground constants

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

3.1 *Nature of the soil*

Although it has been established by numerous measurements that the constants vary with the nature of the soil, it seems probable that this variation may be due not so much to the chemical composition of the soil as to its ability to absorb and retain moisture. It has been shown that loam, which normally has a conductivity of the order of 10^{-2} 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 earth constants depends upon the depth of penetration of the radio energy, δ, which is defined as that depth at which the wave has been attenuated to 1/e (or 37%) of its value at the surface. It depends upon the values of the earth constants and the frequency and is given in Table II for the frequency range 10 kHz to 1000 MHz for average values of earth constants.

TABLE II

Depth of penetration δ as a function of frequency

Frequency	δ (metres)				
	Sea water	Fresh water	Very moist ground	Average ground	Dry ground
10 kHz	2·5	70	50	160	500
100 kHz	0·8	20	16	52	170
1 MHz	0·25	11	5·5	21	95
10 MHz	0·08	9	3	16	90
100 MHz	0·02	4	2	16	90
1000 MHz	0·01	0·2	0·3	16	90

This Table shows that, particularly for water surfaces and very moist ground, the penetration depth varies considerably with frequency. Only for average or dry ground above 10 MHz is the penetration depth independent of frequency. At low frequencies, except for sea water, strata down to a depth of 100 m or more must be taken into account. This is of particular importance when the upper strata are of lower conductivity and the energy can penetrate more readily to lower levels.

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

3.7 *Energy absorption by surface objects*

Although surface objects have no direct influence on the constants of the ground itself, they can contribute appreciably to the attenuation of ground waves and the 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 [2].

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 rotable 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 [3]. 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 [4].

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

4.4 *Measurements of ground-wave attenuation*

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

4.5 *Attenuation with depth below the surface*

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

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 *Atmospherics : dispersion of 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 constant, it is clear that most of the methods do not give all the information required for propagation calculations and that occasionally an extensive series of measurements is involved.

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

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

The wave-tilt method also takes account of the general structure of the ground around the point of measurement and gives the effective constants of the earth corresponding to the frequency used. The measurements will be in error near regions of large gradient of conductivity or in the vicinity of surface or buried objects of high conductivity. Measurements should not be made too close to the transmitting antenna, the minimum distance being about 10 wavelengths at low and medium frequencies, or one that is large compared with the antenna dimensions at high frequencies. The method becomes rather inaccurate at frequencies below 100 kHz because of the small angles of tilt which occur. In view of the dependence of the tilt on height above the surface, the usefulness of this method is restricted to frequencies below about 40 MHz [4]. It may be used for determining path attenuation if a series of measurements is made along the path [6].

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 that 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. 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.

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REPORT 230-1 *

PROPAGATION OVER INHOMOGENEOUS EARTH

(Question 1-1/5)

(1956 – 1959 – 1963 – 1970)

Considerable progress has been made in the solution of the problem of propagation over inhomogeneous and irregular terrain. This progress has been especially marked in the direction of generalizing the conditions under which it is possible to handle the rigorous mathematical analysis, and to reduce this to a form of practical use to the engineer.

Because of the great complexity of the problem, various idealizations have been introduced in the theoretical analysis, for instance that the transmission path consists of well-defined homogeneous sections or that any stratification of the ground is parallel to the surface of the earth which is assumed to be smooth. Study is now being directed to the extension of the analysis to general cases more usually found in practical conditions. Some progress is being made in the treatment of the case where two sections of a path are separated by a region of transition, and of the case where a change in the constants of the earth is associated with a change in the elevation of the surface. For a comprehensive bibliography see C.C.I.R. Documents of the Plenary Assembly, Oslo, 1966, Vol. II, pp. 79-81.

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.9] of the field in the vicinity of the boundary between two sections of a path may be mentioned, where a more accurate analytical procedure has been adopted.

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* This Report was adopted unanimously.

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.9] 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 a 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 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.7] and Wait, J. R. and Householder, J. [A.8], 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.1, A.4, 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.10], 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.13], 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.11, F.9].

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.6]. On the other hand, the work carried out in the United Kingdom [A.12] 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.2, B.3, B.4, B.5 and A.13], 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.2, B.3, B.4, B.5, B.6, A.13 and A.14].

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.10]. 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 advantage of simplicity where many computations have to be made, but they can sometimes give rise to large errors. It is therefore necessary 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 Furutzu [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 in the horizontal and vertical directions, especially in view of the lack of detailed knowledge regarding this distribution. It has been proposed [D.1], that the equivalent conductivity of the inhomogeneous earth over the path can be determined by measuring the dispersion of suitable spheric 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.

Through the use of modern computer techniques, Johler and Berry [C.9] have been able to predict the phase and amplitude of 100 kHz pulse signals which have propagated over an inhomogeneous and irregular terrain. Although the irregularities were chosen to have Gaussian vertical sections for the purpose of tractability, the method can be applied to shapes as well as earth constants that are completely arbitrary. Here also, an experimental effort is required for comparison with analytical results.

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REPORT 236-2 *

INFLUENCE OF IRREGULAR TERRAIN ON TROPOSPHERIC PROPAGATION

(Study Programme 1-1A/5)

(1951 – 1953 – 1956 – 1959 – 1963 – 1966 – 1970)

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*

In principle, tropospheric propagation depends on the electrical characteristics of the earth, as discussed in detail in Report 229-1. This dependence is of increasing importance with decreasing frequency, but at the higher frequencies it is often difficult to distinguish the effect of the lack of homogeneity of the earth constants from that of the irregularities of the terrain, the latter becoming dominant when the irregularities are large in comparison with the wavelength concerned.

1.2 *Interaction between the terrain and the troposphere*

Reports 231-2, 233-2, 234-2, 235-1, 238-1, 244-2 and 285-2 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 atmospheric refraction increases long-distance diffraction or forward-scatter fields but may also 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 244-2. 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.

* This Report was adopted unanimously.

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 239-2, 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 parameter 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, 28, 29]. 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 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 empirical 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 than 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 239-2 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 239-2, 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] 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 the 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.

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REPORT 427 *

SITE-SHIELDING FACTOR TO BE USED IN CALCULATING COORDINATION DISTANCE

(Study Programme 5-1F-1/5)

(1970)

1. Introduction

Study Group 5 has studied the questions raised in Question 14/4 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 5 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 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-

* This Report, with Report 337-1, replaces Report 337 and was adopted unanimously.

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 244-2 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 244-2.

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 θ 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 244-2 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 from 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. 3 of Report 244-2, can be written as:

$$D = 20 \log_{10} \left[\pi \sqrt{2} \sqrt{\frac{2(d_A + d_B) \tan \alpha_0 \tan \beta_0}{\lambda}} \right] \quad \text{(dB)},$$

where the symbols are defined in Fig. 1. When α_0 and β_0 are less than 10° and d_B is greater than $2d_A$ then the above formula can be approximated within 2 dB, by:

$$D = 20 \log_{10} \left[2\pi\theta \sqrt{\frac{d_A}{\lambda}} \right] \quad \text{(dB)}$$

The distance d_A is very nearly equal to ES (the distance from E to the top of 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 plane 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 $L_{0 \cdot 1}$ between the earth station and the radio-relay station in the absence of the obstacle. This curve was derived from Report 244-2, 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 $l_{0 \cdot 1}$ between the obstacle and the radio-relay station, for those obstacles at heights corresponding to angles of elevation between 1° and 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 $D + l_{0 \cdot 1} - L_{0 \cdot 1}$ 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 values, after making the allowance of 5 dB for an imperfect knife-edge. It will be seen that it is not 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 but may be used for shorter horizon distances when it is known that only the side- or back-lobes of the earth station antenna pattern illuminate the obstacle (Doc. V/131 (Sweden), 1966-1969).

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 the largest numerical value in each column may be used when it is known that only the side- or back-lobes of an earth station antenna pattern illuminate the horizon obstacle.

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 244-2.

4.4 *Use of a distance-dependent site-shielding factor.*

The site-shielding factors given in Table II and Fig. 3 are distance-dependent. The method of calculating coordination distance employed by Study Group 4 (Report 382-1) has sought to simplify the procedure by selecting site-shielding factors which are dependent only on the elevation angle of the horizon.

Another method of including the effect of site shielding is described in [2]. This method utilizes path model profiles similar to those of Fig. 1, chosen after inspection of a large number of real path profiles between earth station and radio-relay sites in the United States.

The method furnishes curves of coordination distance versus required path attenuation for various angles of horizon elevation, and for two radio-climatic zones. The curves were calculated from valid propagation information (Report 244-2), but further work is required to render them universally applicable.

The attention of Study Group 4 and of the Administrations is drawn to reference [2], and it is suggested that it be studied with a view to determining whether it might be preferable to the method of Report 382-1.

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 339-1.

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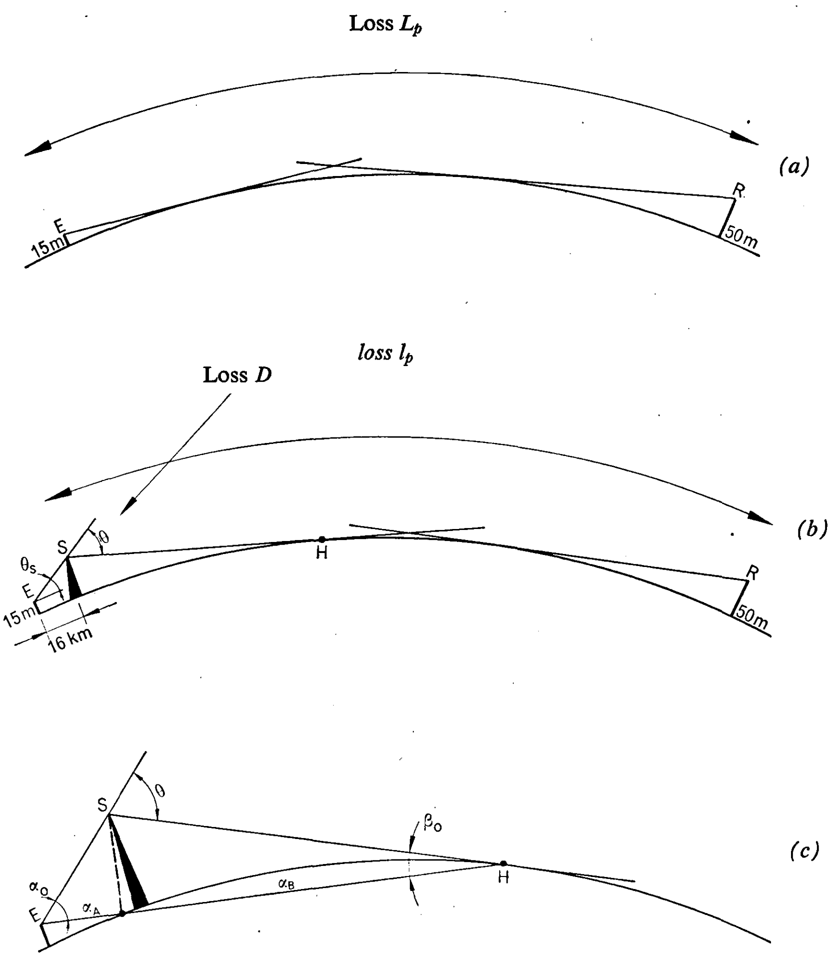

FIGURE 1

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

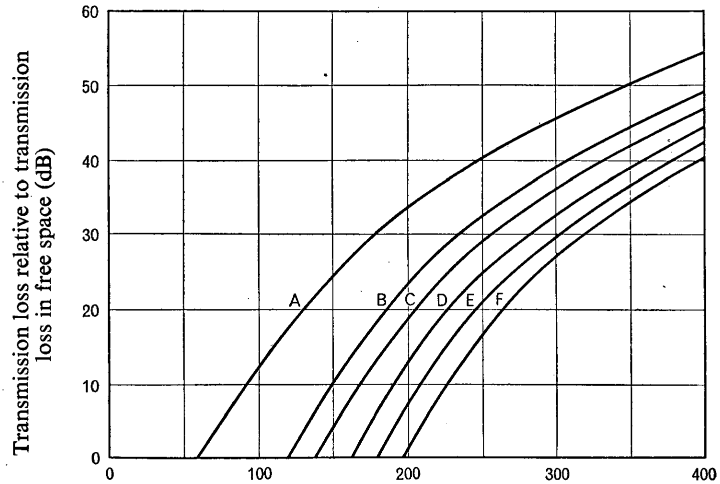

FIGURE 2

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

A: $L_{0\cdot1}$ for path ER
B: $l_{0\cdot1}$ for path SR (θ_s = 1° screen H_r = 311 m)
C: $l_{0\cdot1}$ for path SR (θ_s = 2° screen H_r = 590 m)
D: $l_{0\cdot1}$ for path SR (θ_s = 3° screen H_r = 870 m)
E: $l_{0\cdot1}$ for path SR (θ_s = 4° screen H_r = 1155 m)
F: $l_{0\cdot1}$ for path SR (θ_s = 5° screen H_r = 1425 m)

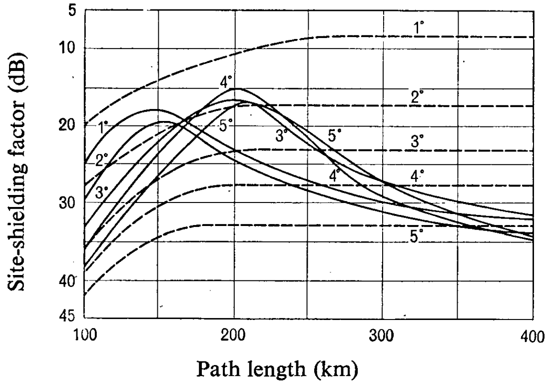

FIGURE 3

Site-shielding factor at 4 GHz for continental temperate climate
(for 0·1% of the time)

——— with diffraction
— — — — with tropospheric scatter

SECTION 5D: GROUND-WAVE PROPAGATION

RECOMMENDATIONS AND REPORTS

Recommendations

RECOMMENDATION 368-1

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

(Question 3/5)

(1951 – 1959 – 1963 – 1970)

The C.C.I.R.,

CONSIDERING

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

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

UNANIMOUSLY RECOMMENDS

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

ANNEX

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

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

1. they refer to a smooth homogeneous earth;

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

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

4. the curves refer to the following conditions:

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

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

— the dipole moment is chosen so that the dipole would radiate 1 kW if the Earth were a perfectly conducting infinite plane, under which conditions the radiation field at a distance of 1 km would be 3×10^5 μV/m;

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

— the inverse-distance curve *A* shown in the figures, to which the curves are asymptotic at short distances, passes through the field value of 3×10^5 μV/m at a distance of 1 km;

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

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

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

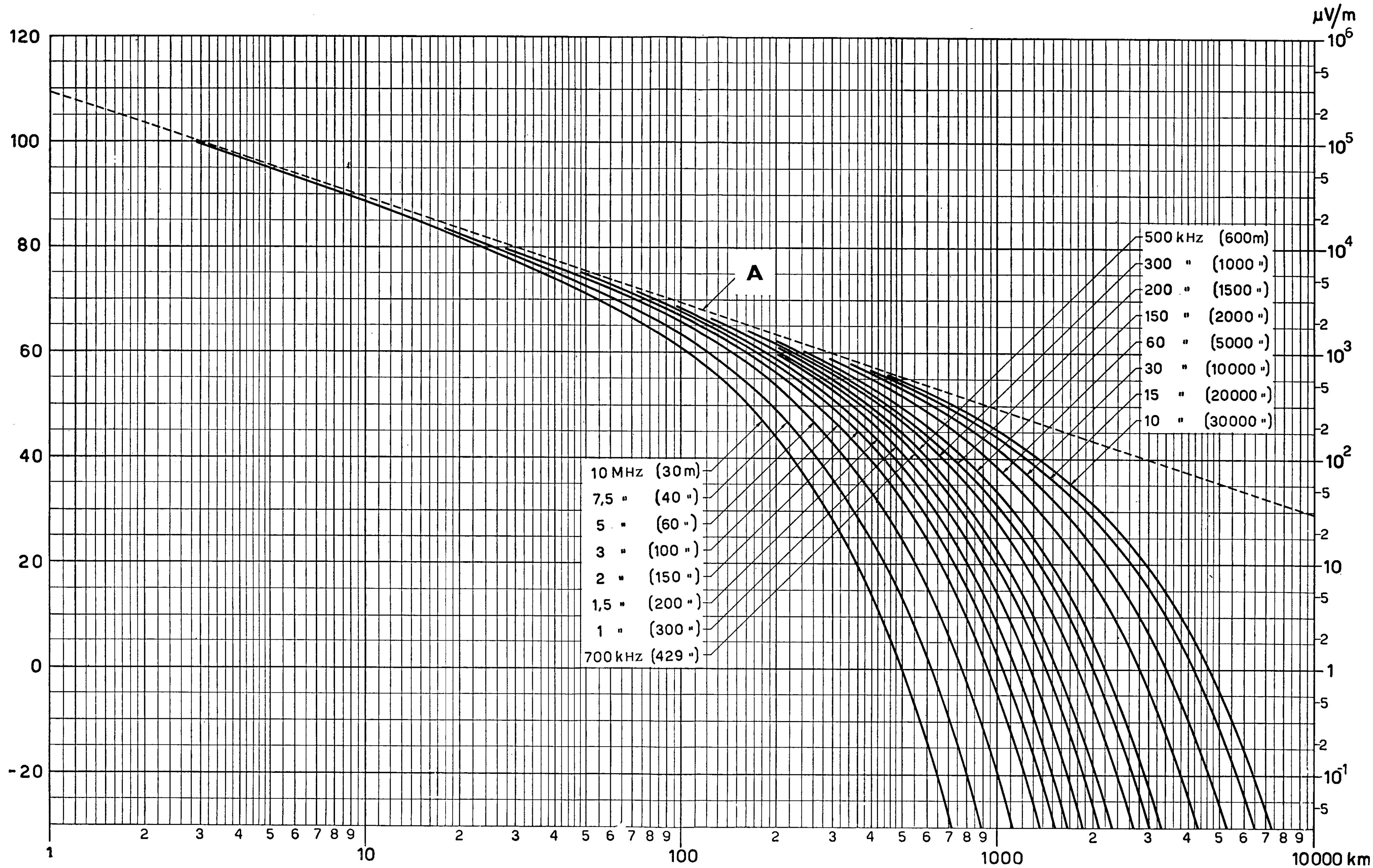

FIGURE 1

Ground-wave propagation curves; Sea, $\sigma = 4$ mho/m, $\varepsilon = 80$
A: Inverse distance curve

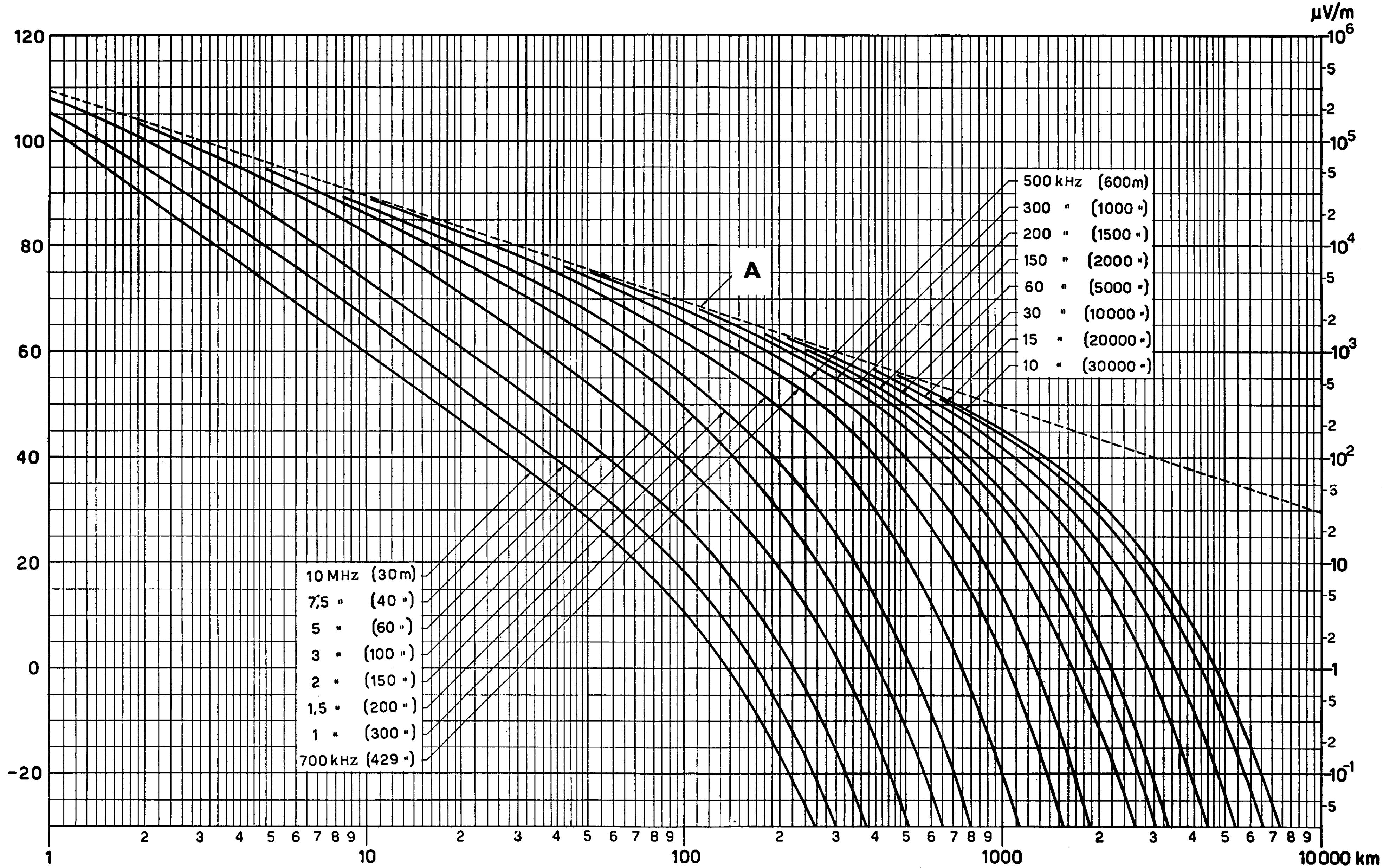

FIGURE 2

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

A: Inverse distance curve

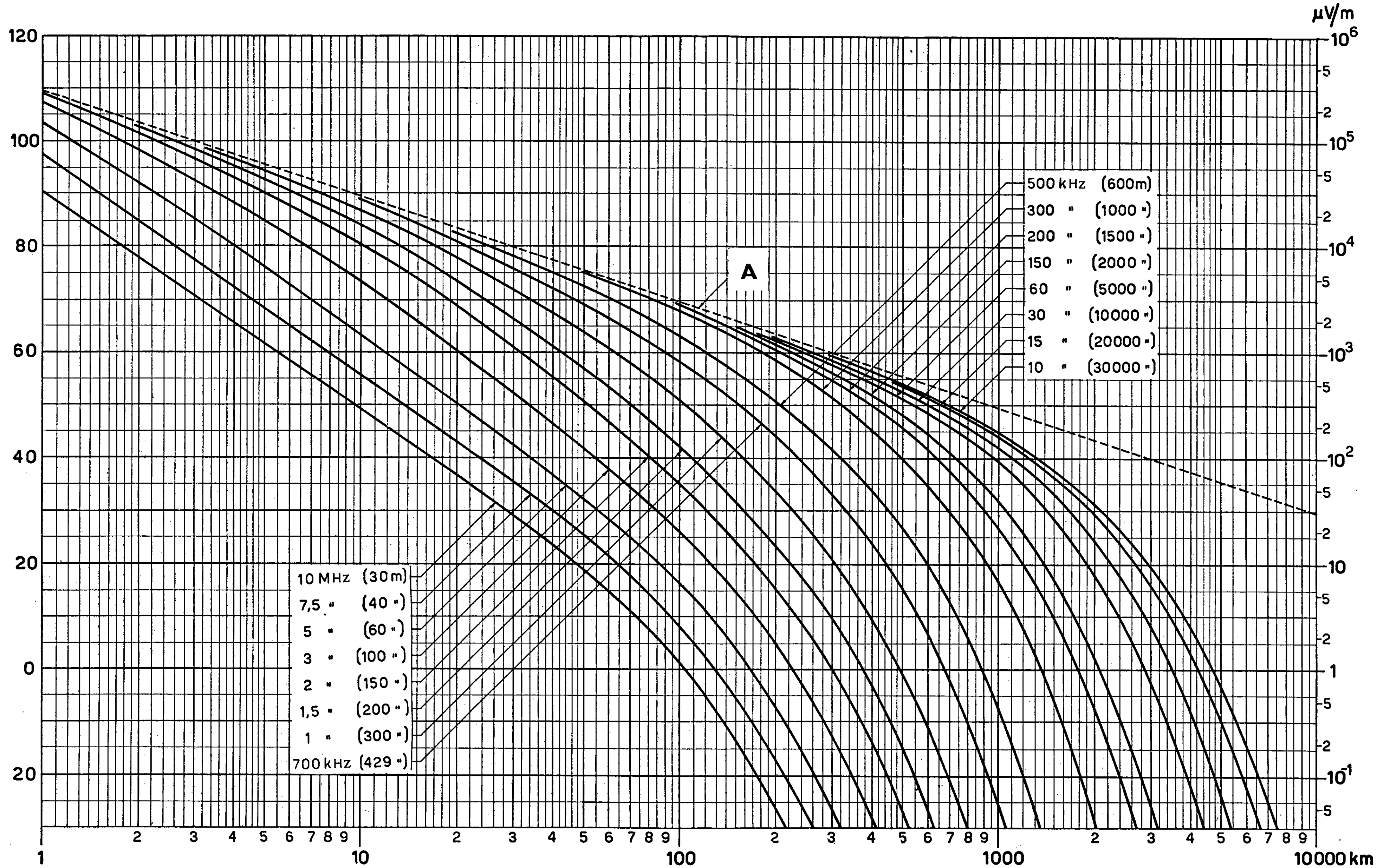

FIGURE 3

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

A: Inverse distance curve

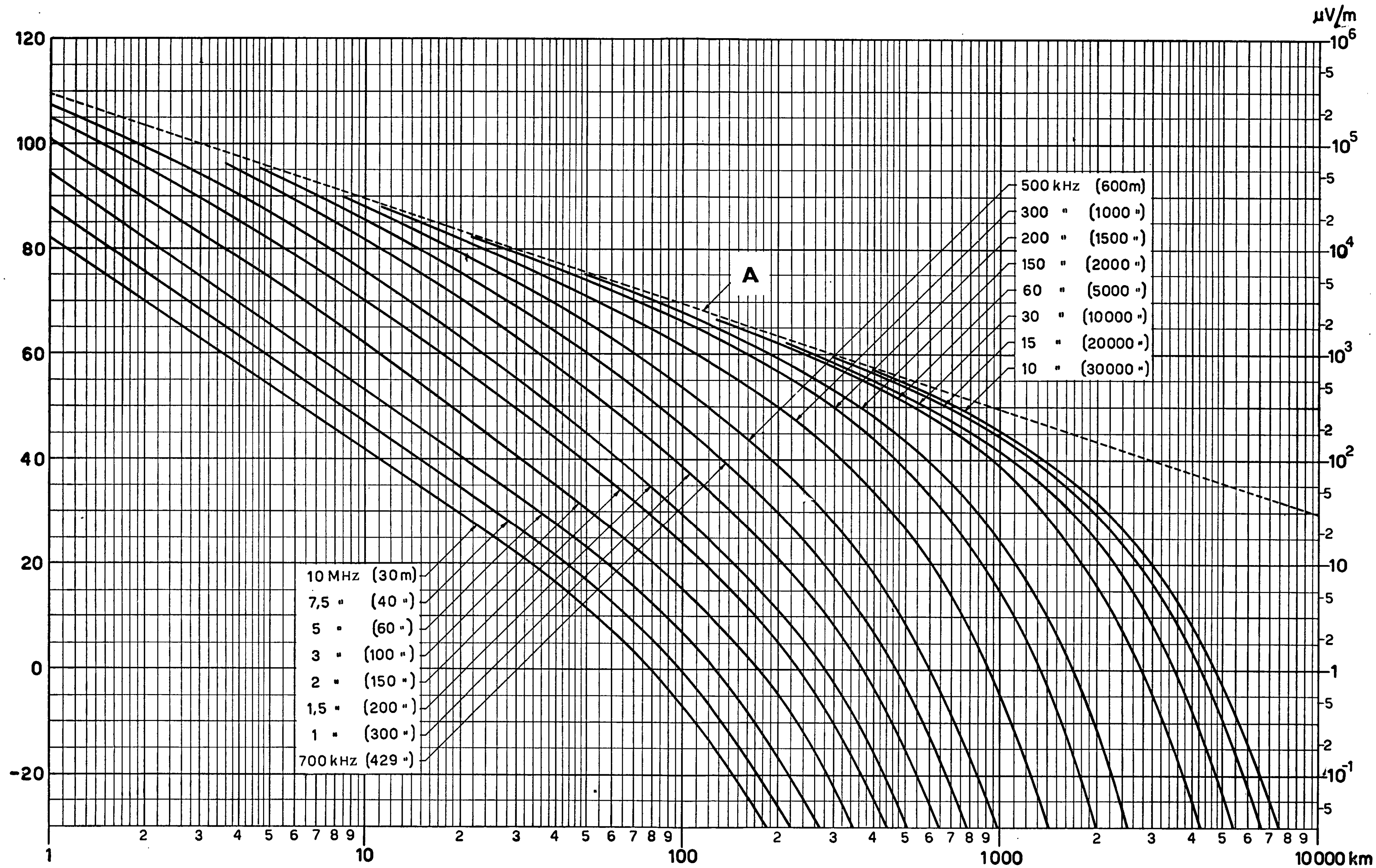

FIGURE 4

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

A: Inverse distance curve

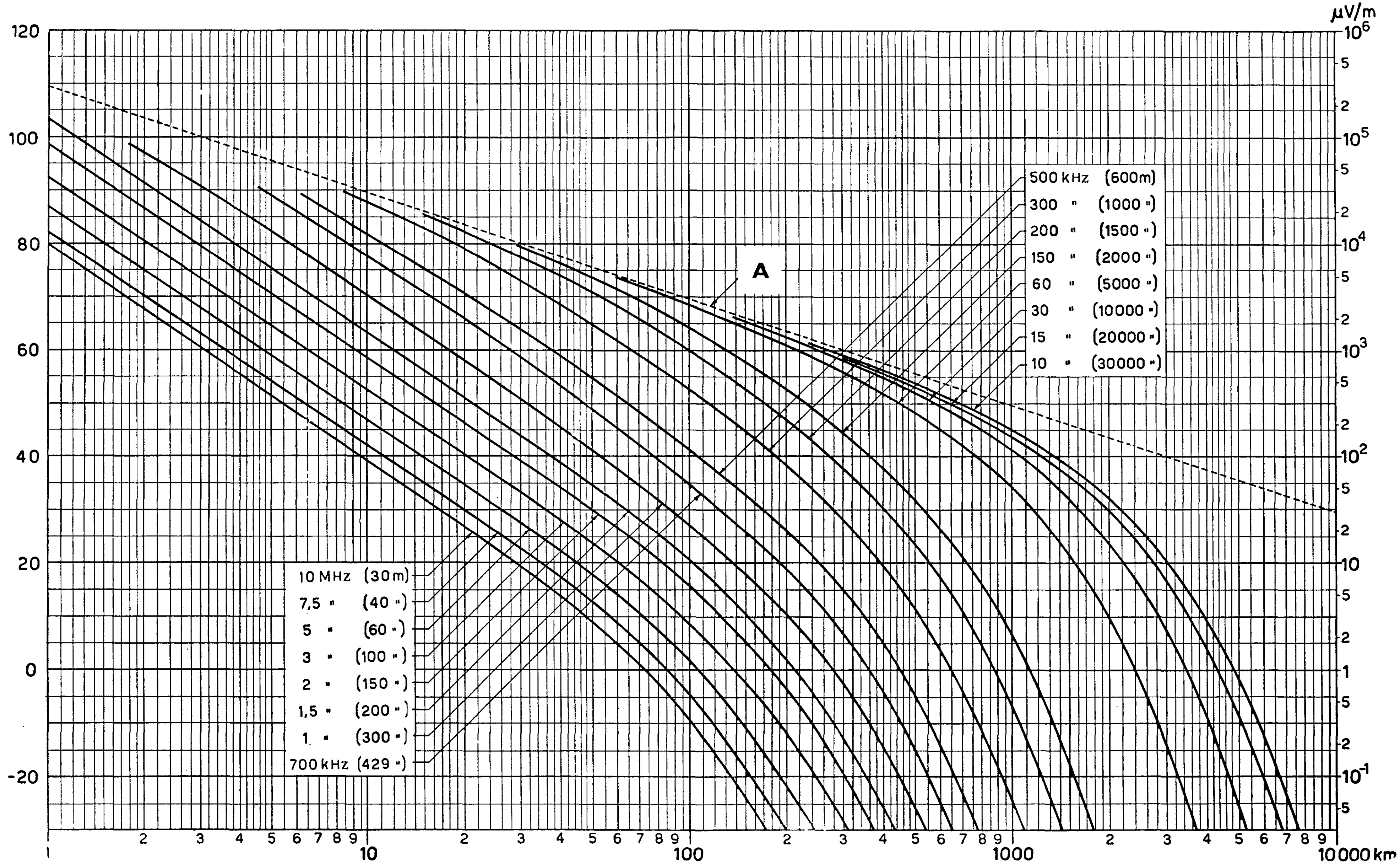

FIGURE 5

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

A: Inverse distance curve

REPORT 235-1 *

EFFECTS OF TROPOSPHERIC REFRACTION AT FREQUENCIES BELOW 10 MHz

(Question 3/5)

(1956 – 1963 – 1970)

In the ground-wave propagation curves in Recommendation 368-1, 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 368-1, 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 3/5.

Progress in this study has, however, been slow for two reasons: firstly 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

* This Report was adopted unanimously.

with decreasing frequency, the ionosphere becomes a dominant factor in propagation to great distances, as is pointed out in § 6 of the Annex to Recommendation 368-1.

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 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 irregularity 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 to Recommendation 368-1.

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 to Recommendation 368-1 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 3/5.

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. This is the 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 to Recommendation 368-1, 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. In addition, such an Atlas would be unduly large as 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, 4, 5, 6], 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.

If this problem can be successfully solved, it is to be hoped that the results will be incorporated in any revision of the ground-wave curves given in the Annex to Recommendation 368-1, as envisaged in Report 428.

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REPORT 428 *

THE COMPUTATION OF GROUND-WAVE PROPAGATION CURVES

(Recommendation 368-1, Report 235-1)

(1970)

Report 235-1 discusses the problem of ground-wave propagation curves with special reference to the effect of the troposphere on frequencies below 10 MHz. It is pointed out that there is a discontinuity in this respect between the C.C.I.R. Atlases of curves for frequencies above 30 MHz and those of Recommendation 368-1 in which no account is taken of the troposphere or of height-gain effects. Moreover, users have found that the range of permittivity and conductivity values given in this Recommendation is not great enough to include the range of values indicated in Table I of Report 229-1.

* This Report was adopted unanimously.

With the availability of an electronic computer at the I.T.U. Headquarters, it would be desirable for the C.C.I.R. Secretariat to undertake the task of setting up a computer programme that could be used for any specified set of ε and σ values and with the intention of extending the curves in Recommendation 368-1. Thus account could be taken of a more comprehensive range of ε and σ values and of the frequency range between 10 and 30 MHz not at present covered by this Recommendation or the C.C.I.R. Atlases.

In the preparation of the programme and of further curves, account should be taken, if possible, of the effect of the troposphere in accordance with the discussion given in Report 235-1, since over a considerable range of frequencies below 10 MHz its neglect may be more serious than errors due to uncertainties in the knowledge of ε and σ along a given transmission path.

As height-gain effects can be of importance at frequencies well below 10 MHz, the opportunity might be taken of providing height-gain curves in due course. However, the limitations of their use would have to be carefully explained, as it is not proposed to adopt the presentation of height-gain information that is employed for frequencies above 30 MHz; such a presentation is undesirable as it would lead to an unduly large Atlas.

In the description of any revised curves, attention should be drawn to the relative importance at any given frequency of the permittivity and conductivity terms, which should be taken into account in the choice of values for which the curves are given. Reference should be made to the relevant information in Report 229-1.

No consideration has been given here to the effect of the ionosphere, but such a programme of work as here envisaged would be of special interest at frequencies in the medium- and low-frequency range where the ground-wave can be isolated by appropriate techniques. It would also represent a part fulfilment of the urgent requirements of medium- and low-frequency broadcasting.

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QUESTIONS AND STUDY PROGRAMMES, RESOLUTIONS AND OPINIONS
(STUDY GROUP 5)

QUESTION 1-1/5

PROPAGATION OVER NON-HOMOGENEOUS AND ROUGH EARTH

(1965 – 1966 – 1970)

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;

(c) that irregularities of the terrain are of special importance when they consist of obstacles large in comparison with the radio-wavelength concerned;

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 where the line of propagation is oblique 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 the atmospherics;

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;

7. the effect of irregularities of terrain, especially of obstacles that are large in comparison with the radio wavelength involved;

8. the effect of irregularities of terrain on propagation characteristics such as fading in tropospheric propagation.

STUDY PROGRAMME 1-1A/5 *

INFLUENCE OF IRREGULAR TERRAIN ON TROPOSPHERIC PROPAGATION

(1951 – 1953 – 1956 – 1959 – 1963 – 1970)

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;

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* This Study Programme replaces Study Programme 6A/V and is identical with that text.

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.

QUESTION 2-1/5

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

Radio-meteorology for telecommunications

(1966 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that the propagation of radio waves is a function of the thermodynamic conditions prevalent in the atmosphere and that numerous relevant measurements have been made;

(b) 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;

(c) that, moreover, the detailed structure of the electromagnetic 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;

UNANIMOUSLY 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);

2. what are the variations in space and time of the refractive index of the air and of its gradient, particularly in the vertical direction;

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 233-2 (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.

ANNEX

1. The refractivity N should be used as defined by the formula given in Recommendation 453.

2. For radio climatological studies, the thermodynamic measurements intended for the calculation of the refractive index of the air and its vertical gradient should, if possible, be determined with an accuracy no less than

   temperature: $\pm 0{\cdot}2°$ C
   humidity (mixing ratio): $\pm 0{\cdot}1$ g/kg

   Continuous measurement equipment should preferably be used. Vertical gradients should be computed for intervals of 100 m between the ground and 2 km in height.

3. For studies of detailed structure, these measurements should be made with the greatest possible accuracy and resolution in time and space. A knowledge of air flow patterns, particularly wind shear, would also be useful.

QUESTION 3/5

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 368-1, 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 235-1;

(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 231-2;

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?

QUESTION 5-1/5

PROPAGATION DATA REQUIRED FOR TERRESTRIAL AND SPACE TELECOMMUNICATION SYSTEMS

(1953 – 1956 – 1959 – 1966 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that the quality of communication by terrestrial radio-relay systems or by space telecommunication systems is determined by the propagation characteristics, 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 to be taken into consideration in the planning of terrestrial and space telecommunication systems, to operate in conformity with Recommendations of the C.C.I.R. regarding system performance and mutual interference?

STUDY PROGRAMME 5-1A-1/5

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

(1963 – 1966 – 1970)

The C.C.I.R.,

CONSIDERING

that a better knowledge of the characteristics of propagation contributes greatly to the design of economic line-of-sight radio-relay systems and to the improvement of system performance;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the distribution with time of the value of basic transmission loss resulting from multipath propagation, diffraction and absorption, etc., in the VHF (metric), UHF (decimetric), SHF (centimetric) and EHF (millimetric) bands for each month of the year;

2. the limitations on the performance of the system imposed by multipath propagation:

3. the statistical properties of the propagation factors resulting in mutual interference between two links;

4. the cumulative effects of the above factors on the overall system performance of multi-hop radio-relay links;

5. the dependence of the above propagation factors on path length, climate and the nature of the terrain over which the path passes;

6. the propagation data to be used for station site selection and for determining the height of antennae and their radiation characteristics:

7. the propagation characteristics, such as correlation between signals, which may be used to improve the system performance.

Note. — Study Group 9 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 estimation be made in such a way that the distribution of the values of noise power (dependent on transmission loss and multipath propagation) at the output of a system, averaged over 5 ms, 1 s, 1 min and 1 h, can be derived.

It is recognized that, in practice, estimates of transmission loss, not exceeded for percentages of time less than 1% and greater than 99%, will be much less reliable than those for percentages of time between 1% and 99%, but that consideration should be given to estimating the transmission loss for very high and very low percentages of the time such as 99·9998%.

STUDY PROGRAMME 5-1B-1/5

PROPAGATION DATA REQUIRED FOR TRANS-HORIZON RADIO-RELAY SYSTEMS

(1963 – 1970)

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. 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. the levels for a given percentage of time corresponding to the most unfavourable month, the most favourable month and those corresponding to the whole year;

3. the hours of the day for which the greatest transmission loss may usually be expected;

4. 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. the dependence of the distributions 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);

6. the dependence of the distributions 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. the extent to which these distributions can be described by simple statistical laws;

8. the limitations imposed on the bandwidth of the system by the propagation process (diffraction, partial reflection, scattering, etc.);

9. the limitations imposed on the system by the effects of solar noise and noise from other external sources.

Note. — The results of these studies should be presented in the form given in Administrative Circular AC/63.

STUDY PROGRAMME 5-1C-1/5 *

ATTENUATION AND REFRACTION DUE TO THE TROPOSPHERE IN SPACE TELECOMMUNICATION SYSTEMS

(1963 – 1970)

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 3 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 usefulness of frequencies above 10 GHz may depend on the use of multiple ground terminals, spaced so as to circumvent the problems associated with the attenuation resulting from precipitation and cloud;

(d) that the above factors are important in the design of space radiocommunication systems,

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. the measurement and development of methods of prediction of distributions of attenuation and fading duration 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 extent to which space diversity or other techniques can be used to overcome the problems associated with attenuation resulting from precipitation and cloud;

4. the measurement and development of methods of prediction of the noise radiation from atmospheric gases, clouds and precipitation.

Note 1. — To meet the needs of Study Group 4, priority should be given to measurements of radio-wave attenuation along paths at elevation angles greater than 5° using as sources aircraft, satellite-borne beacons or the Sun. Correlation of such measurements with simultaneous backscatter data from weather radars, operating at frequencies for which the attenuation may be neglected, is desirable in order to permit the extrapolation of such measurements to other regions where weather radar data are available.

Note 2. — In view of the very urgent need for obtaining information on the effect of attenuation and noise on space radiocommunication systems, in time for the Administrative Radio Conference planned for 1971, Administrations are requested to submit to the Chairmen and Vice-Chairmen of Study Groups 4 and 5, and to the Director, C.C.I.R., any data on the above subject as soon as possible.

* The attention of the Interim Working Parties set up under Resolutions 2-1 and 3-1 is drawn to those aspects of this Study Programme which fall within their terms of reference.

STUDY PROGRAMME 5-1D-1/5

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

(1963 – 1966 – 1970)

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 the calculation of coordination distances, all pertinent propagation mechanisms should be taken into account;

(c) that in the calculation of interference between systems, more detailed consideration of the contributing propagation mechanisms is required;

(d) that the frequencies of interest are generally greater than 1 GHz;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of a suitable method by which contributions of known tropospheric propagation mechanisms, including scatter from precipitation, aircraft and other phenomena both on and off the great circle path, can be taken into account when considering the signal received over trans-horizon paths, including the effects of site-shielding, 25 to 500 km in length, particularly with reference to the signal strengths exceeded for small percentages of time, such as 0·005%, 0·01%, 0·1%, 1% and 20% of a month or 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 0·005%, 0·01%, 0·1%, 1% and 20% 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 25 and 1000 km; however, over oceans in equatorial and tropical regions and other regions where ducting is prevalent, measurements could be useful up to much greater distances;

* It is desirable that sampling periods of less than one hour be used to facilitate the determination of short time fields such as 0·005%. A suggested period is 1 minute.

3. the possibility of division of the world into broad zones to include the effects of different climatic conditions to take into account the relative importance of various tropospheric mechanisms;

4. determination of the losses to be expected over mixed paths (e.g. partly over land and partly over sea);

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 391-1.

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 5-1E-1/5

INFLUENCE OF SCATTERING FROM PRECIPITATION ON THE SITING OF EARTH STATIONS

(1966 – 1970)

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;

(b) that studies of these phenomena need to be undertaken so that their effects may be considered in the selection of antenna sites;

UNANIMOUSLY DECIDES that the following studies should be carried out:

1. determination of the range of angles in which the scattering from precipitation and other atmospheric inhomogeneities can be considered as uniform and, in general, determination of the relation between this range of angles and the scattering angle, polarization and frequency, for frequencies above 1 GHz;

2. determination of the average distribution in time and space of observed values of effective scattering cross-section per unit volume, as a function of:
   - — height above ground,
   - — time of day,
   - — season,
   - — climatic region;
3. the possible existence of a simple dependence of scattering cross-section on the rainfall rate (mm of water per hour), and also for other forms of precipitation giving significant scattering;
4. methods of calculating the interference to be expected, including the case of radio-relay and earth-station beams which do not intersect.

Note. — To meet the needs of Study Groups 4 and 9, priority should be given 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 5-1F-1/5 *

SITE-SHIELDING FACTOR TO BE USED IN CALCULATING COORDINATION DISTANCES

(1965 – 1966 – 1970)

The C.C.I.R.,

CONSIDERING

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;

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 the coordination distance;
2. determination of values of site-shielding factors which are appropriate to the calculation of coordination distances;
3. the influence of the shape of an obstacle and the number of obstacles;
4. the influence of path length, particularly when it is several hundred kilometres, on the value of the site-shielding factor or obstacle gain associated with a given obstacle in the vicinity of an earth station;

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* This Study Programme has been drafted taking account of Question 14-1/4. 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 next C.C.I.R. Plenary Assembly.

5. the methods of calculating site-shielding factors for obstacles less than 5 km from the earth station.

Note. — The results to be furnished under this Study Programme, in particular § 5, are urgently needed by Administrations and the I.F.R.B. Information contained in Report 427 is a partial answer to this Study Programme.

STUDY PROGRAMME 7A/5

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

Broadcasting and mobile services

(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.

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* Many of these studies relate closely to Study Programme 5-1D-1/5.

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 result 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 311-1, to extend the range of application of the curves of Recommendation 370-1.

QUESTION 8/5

PROPAGATION DATA REQUIRED FOR SOUND AND TELEVISION BROADCASTING IN THE FREQUENCY BANDS ABOVE 10 GHz

(1970)

The C.C.I.R.,

CONSIDERING

(a) that, in future, frequencies above 10 GHz will be used for sound and television broadcasting;

(b) that the propagation phenomena occurring in these frequency bands will have a decisive effect on the planning of broadcasting services;

UNANIMOUSLY DECIDES that the following question should be studied:

1. what values of field strength are exceeded for 99%, 90%, 50%, 10% and 1% of the time in the various bands to be considered at frequencies above 10 GHz * and how do they depend on the distance, the height of the transmitting antenna, nature of the terrain and climatic conditions;

2. what is the local distribution of field strength or transmission loss, especially in large towns, and what is the effect of obstacles such as high buildings on coverage?

* At present the band 11·7 to 12·7 GHz is of particular interest.

QUESTION 9/5 *

PROPAGATION CONSIDERATIONS IMPORTANT TO MOBILE SERVICES USING COMMUNICATION OR RADIODETERMINATION SATELLITE SYSTEMS

(1969 – 1970)

The C.C.I.R.,

CONSIDERING

that a number of Administrations are studying satellite systems for aviation and maritime safety, radiodetermination, communication and control;

UNANIMOUSLY DECIDES that the following question should be studied with respect to aircraft and ships:

1. what are the propagation factors affecting the selection of frequencies for such systems, taking into account the case where the satellite is near the horizon;

2. what are the characteristics and effects of land- or sea-reflection and multipath fading on communication or radiodetermination signals via satellites, both geostationary and otherwise, for the use of aircraft and ships?

RESOLUTION 2-1

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

(1963 – 1970)

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 5-1D-1/5);

* The attention of Study Group 5 is directed to Question 19-1/8 and Study Programme 19-1A-1/8 of Study Group 8 and to the relevant documents of Study Group 6. This Question should be brought to the attention of Study Groups 4 and 8.

(c) that new data relevant to both §§ *(a)* and *(b)* above 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 Interim 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 for point-to-point communication systems, which will be readily usable by radio communication engineers, and should propose revisions of Report 244-2 as these appear desirable;
4. that the Working Party should be composed of members nominated by the Administrations of the United States, France, India, Japan, Federal Republic of Germany, the United Kingdom and the U.S.S.R., 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 Interim Working Party established under Resolution 3-1;
6. that, as far as possible, the work of the Party should be conducted by correspondence;
7. that the Working Party should prepare reports as appropriate prior to Plenary Assemblies of the C.C.I.R.

RESOLUTION 3-1

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

(1963 – 1970)

The C.C.I.R.,

CONSIDERING

(a) that the data presented in Reports 233-2 and 234-2 should be kept under review in the light of new measurements;

(b) that there is a need to examine the usefulness of other parameters in radiometeorological studies (see Question 2-1/5) 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 5-1A-1/5);

UNANIMOUSLY DECIDES

1. that an Interim Working Party 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 Party should propose revisions of Reports 233-2 and 234-2 as these appear desirable;
3. that the Working Party should be composed of members nominated by the Administrations of Canada, United States of America, France, India, Japan, Netherlands, Federal Republic of Germany, United Kingdom, Sweden and the U.S.S.R., and that the coordination of the work of the Party should be undertaken by a member of the Administration of France;
4. that the Working Party should work in close collaboration with the Interim Working Party established under Resolution 2-1;
5. that, as far as possible, the work of the Party should be conducted by correspondence;
6. that the Working Party should prepare a report prior to the XIIIth Plenary Assembly of the C.C.I.R.

RESOLUTION 45

PREDICTION OF PHASE AND AMPLITUDE OF GROUND-WAVES

(1970)

The C.C.I.R.,

CONSIDERING

(a) that there is need to develop improved methods of predicting the phase and amplitude of ground-waves propagated over the earth (see Questions 1-1/5 and 3/5);

(b) that the effect of tropospheric refraction is of importance in the prediction of the phase (time-of-arrival) of signals used in precision radiolocation systems;

UNANIMOUSLY DECIDES

1. that an Interim Working Party should be established to examine the practical application of meteorological, topographical and geological data to the prediction of the phase and amplitude of radio waves especially at frequencies below 30 MHz propagated over the surface of the earth and through the non-ionized regions of the atmosphere;
2. that the Interim Working Party propose revisions to Reports 230-1 and 235-1 and amendments to Recommendation 368-1 as they appear desirable;
3. that the Interim Working Party be composed of members from the following Administrations: United States of America, United Kingdom and Sweden;
4. that the coordination of the Interim Working Party be undertaken by the member designated by the Administration of the United Kingdom;
5. that the Interim Working Party collaborate with the Interim Working Party established under Resolution 3-1 concerning matters of mutual interest.

RESOLUTION 46

PUBLICATION OF AN ATLAS OF REFLECTION COEFFICIENTS

(1970)

The C.C.I.R.,

CONSIDERING

(a) that the C.C.I.R. Specialized Secretariat has prepared a computer programme for the calculation of the Fresnel reflection coefficients of a plane electromagnetic wave both for vertical and horizontal polarization, and another programme for the calculation of the Brewster angles and associated reflection coefficients;

(b) that a knowledge of these reflection coefficients enters into the preparation of propagation curves, the calculation of antenna radiation diagrams and the solution of various practical problems;

UNANIMOUSLY DECIDES

1. that the Director of the C.C.I.R. shall publish an Atlas of Fresnel reflection coefficients containing:

1.1 an introduction indicating the formulae used for the calculations, the problems that can be solved with the aid of the Atlas and the restrictions which govern the use of such reflection coefficients in given practical situations;

1.2 the Tables of Brewster angles and the associated reflection coefficients for a plane vertically polarized electromagnetic wave;

1.3 the Tables of Fresnel reflection coefficients for a plane electromagnetic wave both for vertical and horizontal polarization;

2. that the Tables shall be prepared, to 3 significant figures, using appropriate values of ground conductivity σ and dielectric constant ε in the frequency range 10 kHz to 10 GHz.

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