XVII A.P.
DÜSSELDORF
21.5-1.6 1990
CCIR

XVIIth PLENARY ASSEMBLY
DÜSSELDORF, 1990

INTERNATIONAL TELECOMMUNICATION UNION

RECOMMENDATIONS OF THE CCIR, 1990

(ALSO RESOLUTIONS AND OPINIONS)

VOLUME V

PROPAGATION IN NON-IONIZED MEDIA

CCIR INTERNATIONAL RADIO CONSULTATIVE COMMITTEE

Geneva, 1990

CCIR

1. The International Radio Consultative Committee (CCIR) is the permanent organ of the International Telecommunication Union responsible under the International Telecommunication Convention "... to study technical and operating questions relating specifically to radiocommunications without limit of frequency range, and to issue recommendations on them..." (International Telecommunication Convention, Nairobi 1982, First Part, Chapter I, Art. 11, No. 83).*

2. The objectives of the CCIR are in particular:

a) to provide the technical bases for use by administrative radio conferences and radiocommunication services for efficient utilization of the radio-frequency spectrum and the geostationary-satellite orbit, bearing in mind the needs of the various radio services;

b) to recommend performance standards for radio systems and technical arrangements which assure their effective and compatible interworking in international telecommunications;

c) to collect, exchange, analyze and disseminate technical information resulting from studies by the CCIR, and other information available, for the development, planning and operation of radio systems, including any necessary special measures required to facilitate the use of such information in developing countries.

* *See also the Constitution of the ITU, Nice, 1989, Chapter 1, Art. 11, No. 84.*

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92-61-04211-2

Geneva, 1990

PLAN OF VOLUMES I TO XV
XVIIth PLENARY ASSEMBLY OF THE CCIR

(Düsseldorf, 1990)

VOLUME I (Recommendations) *Annex to Vol. I* (Reports)	Spectrum utilization and monitoring
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All references within the texts to CCIR Recommendations, Reports, Resolutions, Opinions, Decisions and Questions refer to the 1990 edition, unless otherwise noted; i.e., only the basic number is shown.

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DISTRIBUTION OF TEXTS OF THE XVIIth PLENARY ASSEMBLY OF THE CCIR IN VOLUMES I TO XV

Volumes and Annexes I to XV, XVIIth Plenary Assembly, contain all the valid texts of the CCIR and succeed those of the XVIth Plenary Assembly, Dubrovnik, 1986.

1. Recommendations, Resolutions, Opinions are given in Volumes I-XIV and Reports, Decisions in the Annexes to Volumes I-XII.

1.1 *Numbering of texts*

When a Recommendation, Report, Resolution or Opinion is modified, it retains its number to which is added a dash and a figure indicating how many revisions have been made. Within the text of Recommendations, Reports, Resolutions, Opinions and Decisions, however, reference is made only to the basic number (for example Recommendation 253). Such a reference should be interpreted as a reference to the latest version of the text, unless otherwise indicated.

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 XIV.

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* Not reprinted, see Dubrovnik, 1986.

(1) Published separately.

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* Not reprinted, see Dubrovnik, 1986.

(1) Published separately.

1.3.1 *Note concerning Reports*

The individual footnote "Adopted unanimously" has been dropped from each Report. Reports in Annexes to Volumes have been adopted unanimously except in cases where reservations have been made which will appear as individual footnotes.

1.4 *Resolutions*

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2. **Questions** (Vols. XV-1, XV-2, XV-3, XV-4)

2.1 *Numbering of texts*

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.

Note – The numbers of the Questions of Study Groups 7, 9 and 12 start from 101. In the case of Study Groups 7 and 9, this was caused by the need to merge the Questions of former Study Groups 2 and 7 and Study Groups 3 and 9, respectively. In the case of Study Group 12, the renumbering was due to the requirement to transfer Questions from other Study Groups.

2.2 *Assignment of Questions*

In the plan shown on page II, the relevant Volume XV in which Questions of each Study Group can be found is indicated. A summary table of all Questions, with their titles, former and new numbers is to be found in Volume XIV.

2.3 *References to Questions*

As detailed in Resolution 109, the Plenary Assembly approved the Questions and assigned them to the Study Groups for consideration. The Plenary Assembly also decided to discontinue Study Programmes. Resolution 109 therefore identifies those Study Programmes which were approved for conversion into new Questions or for amalgamation with existing Questions. It should be noted that references to Questions and Study Programmes contained in the texts of Recommendations and Reports of Volumes I to XIII are still those which were in force during the study period 1986-1990.

Where appropriate, the Questions give references to the former Study Programmes or Questions from which they have been derived. New numbers have been given to those Questions which have been derived from Study Programmes or transferred to a different Study Group.

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VOLUME V

PROPAGATION IN NON-IONIZED MEDIA

(Study Group 5)

TABLE OF CONTENTS

NUMERICAL INDEX OF TEXTS

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STUDY GROUP 5

PROPAGATION IN NON-IONIZED MEDIA

Terms of reference:

To study with the object of improving radiocommunication the propagation of radio waves (and the study of associated radio noise):

- at the surface of the Earth,
- through the non-ionized regions of the Earth's atmosphere,
- and in space where the effect of ionization is negligible.

1986-1990	*Chairman:*	A. KALININ (USSR)
	Vice-Chairmen:	F. FEDI (Italy)
		Y. HOSOYA (Japan)

As from the next study period, in conformity with Resolution 61 adopted at the XVIIth Plenary Assembly, Düsseldorf (May-June 1990), the scope of the work which will be undertaken and the names of the Chairman and Vice-Chairmen are as follows:

STUDY GROUP 5

RADIO WAVE PROPAGATION IN NON-IONIZED MEDIA

Scope:

Propagation of radio waves and related noise phenomena in non-ionized media at and above the surface of the Earth for the purpose of improving radiocommunication systems.

1990-1994	*Chairman:*	A. KALININ (USSR)
	Vice-Chairmen:	F. FEDI (Italy)
		Y. HOSOYA (Japan)

INTRODUCTION BY THE CHAIRMAN, STUDY GROUP 5

In the 1986-1990 study period, Study Group 5 continued to give thorough consideration to the various aspects of radio-wave propagation in non-ionized media, having regard to the requirements of the different terrestrial and space services. The fact that more than 400 documents were examined at the Interim and Final Meetings of Study Group 5 provides an indication of the volume of work accomplished.

Study Group 5 continued to reinforce its cooperation with other Study Groups with a view to meeting the practical needs of the Study Groups responsible for specific services. In particular, it was decided at the Final Meeting that Study Group 5 should participate in two Joint Interim Working Parties, one to prepare the CCIR Report to the WARC-92 and the second concerning the determination of the coordination area with a view to updating Appendix 28 of the Radio Regulations.

Activities of the Interim Working Parties

The work undertaken within the four IWPs of Study Group 5 since the XVIth Plenary Assembly is outlined below.

IWP 5/1 (Decision 3)

Influence of the surface of the Earth and aspects of tropospheric propagation of general interest

Chairman: A Blomquist (Sweden)

IWP 5/1 held two meetings but much of its work was carried out by correspondence and by the Secretariat. The main areas of work have been:

- preparation of a Handbook of curves for propagation over the surface of the Earth, in accordance with Resolution 72;
- refinements to Recommendation 368, including allowance for the effect of the near field;
- methods for treating diffraction propagation over multiple knife-edges and self-contained prediction methods for paths over irregular terrain;
- a review of the texts of a general nature contained in Volume V including a proposed revision of the "Introduction to Texts".

At its Final Meeting, the Study Group considered that the IWP had successfully fulfilled its terms of reference and that Decision 3 should be cancelled. As a consequence, IWP 5/1 was disbanded.

However, the Study Group recognized the need to undertake certain specific studies relating to the effects of terrain and man-made structures. In particular, such work could benefit significantly from the use of digital terrain data bases. As a result, the Study Group adopted Decision 102 (Propagation predictions based on digital terrain data bases including terrain roughness and man-made structures) which establishes new IWP 5/6 to undertake relevant studies.

IWP 5/2 (Decision 4)

Tropospheric propagation data for planning space and point-to-point terrestrial telecommunication systems and determining likely interference between systems

Chairman: M.P.M. Hall (United Kingdom)

Meeting twice during the study period, the IWP's work has chiefly involved:

- the review and development of the data banks of Study Group 5, recently implemented on a computerized data base management system;
- an examination of the results of Testing Groups responsible for the testing of prediction methods contained in Sections E, F and G; arising from this work was the recommendation of one single method for rain attenuation on an Earth-space path;
- the preparation of responses to questions put to Study Group 5 by other Study Groups.

Decision 4 was revised at the Final Meeting which, in addition to covering the broader aspects of the topics contained in Sections E, F and G, calls for emphasis to be placed on:

- propagation data relevant to the prediction of interference levels and determination of coordination distance;
- the consequences of new data from tropical regions on the recommended rain attenuation prediction methods in Reports 338 and 564.

IWP 5/3 (Decision 5)

Influence of the non-ionized regions of the atmosphere on wave propagation

Chairman: F. Fedi (Italy)

The IWP met twice during the study period and prepared significant modifications to many of the basic texts on radiometeorology. In addition, it was responsible for Report 1147 on the statistical assessment of data which has particular relevance to current work in the Study Group concerning the testing of prediction methods against measurement data.

Further topics studied include:

- the vertical and horizontal structure of rain;
- the latitudinal behaviour of the height of the zero degree isotherm;
- frequency scaling;

- the examination of rainfall rate data from low latitudes and the initiation of a CCIR rainfall intensity data bank;
- the influence of cloud and fog at frequencies greater than about 20 GHz;
- tropospheric scintillation modelling and associated measurement data.

In addition to general studies of radiometeorological phenomena, a newly revised Decision 5 requests specific studies on:

- climatology and natural variability of rain and its effects;
- meteorological data and models for attenuation prediction on Earth-space paths for time percentages from 0.1% to 10%.

IWP 5/5 (Decision 50)

Tropospheric propagation data for broadcasting and mobile services

Chairman: H. Berthod (France)

With two meetings, the work of the IWP has been dominated by the inter-sessional work for the RARC AFBC. In the preparation of the chapter on propagation for the CCIR Report to the Second Session of the Conference, use was made of the valuable measurement data obtained from Burkina Faso, Tel Aviv and southern Africa as well as studies undertaken on available refractivity data; material was also prepared relating to sharing in TV Band V and to the use of circular polarization in television broadcasting.

Additionally, the IWP has initiated a far-reaching reappraisal of the prediction method contained in Recommendation 370 for the broadcasting service in the VHF and UHF bands, with a view to developing a universal method for all point-to-area propagation paths, thereby including mobile systems. The IWP has also been responsible for a thorough revision of Report 567 concerning land mobile propagation data and prediction methods.

At the Final Meeting of the Study Group, it was decided to cancel Decision 50 and, in consequence, to disband IWP 5/5. However, it was recognized that further work was required in connection with the terrestrial broadcasting and land mobile services and as a consequence the Study Group invited the Chairman, in consultation with the Director, CCIR, to identify the required studies which would subsequently be undertaken by a new IWP. The terms of reference of this new Working Party (IWP 5/7) focus in particular on the specification of a uniform prediction method suitable for both broadcasting and land mobile services.

JIWP ORB(2) (CCIR studies to be carried out in the inter-sessional period for submission to the Second Session of the WARC ORB-88)

Study Group 5's contribution to the JIWP was undertaken by a Special Rapporteur who, prior to the meeting, reviewed the propagation information contained in Volume V relevant to the inter-sessional studies and summarized it for subsequent reference by the JIWP.

JIWP AFBC(2) (CCIR preparatory work for the RARC AFBC(2))

During the study period, this JIWP held two meetings. Input from Study Group 5 was channelled mainly through IWP 5/5 which prepared the chapter of the CCIR report addressing propagation.

Main results

At the Interim and Final Meetings of Study Group 5, additions and refinements were made to most of the Study Group's texts, new Recommendations and Reports were prepared and considerable time was devoted to updating Questions and Study Programmes. The additions and amendments made to the texts of all the sections of Volume V are outlined briefly below.

Section 5A – Texts of general interest

Report 1144 was drafted on the establishment of radio-wave propagation data banks required for the updating of existing prediction methods and the development of new methods. The Report gives formats for presenting data on the various aspects of radio-wave propagation. Recommendation 311 was amended in the light of the new Report. The introduction to the texts of Study Group 5 was updated. Additions and amendments were made to Recommendation 310 "Definitions of terms relating to propagation in non-ionized media" and Report 1007 "Probability distributions in radio-wave propagation". It was decided not to reprint Report 227 "General methods of measuring the field strength and related parameters" in the next edition of Volume V, since it is essentially a reference text. A cross-reference to Volume V of the XVIth CCIR Plenary Assembly, where the Report appears, will suffice.

Section 5B – Effects of the ground (including ground-wave propagation)

Report 1145 was prepared entitled "Propagation over irregular terrain with and without vegetation", in which different approximation models of terrain irregularity and methods for predicting transmission loss over irregular terrain are examined, and evaluations are given for attenuation due to the effects of woods and bushland. Additions and amendments were made to Report 715 "Propagation by diffraction" and Report 1008 "Reflection from the surface of the Earth". As for Report 227, the Study Group decided that Report 336 would not be reprinted and that reference be made to the version contained in Volume V (Dubrovnik, 1986).

Section 5C – Effects of the atmosphere (radiometeorology)

Three new Recommendations were drafted: Recommendation 676 "Attenuation by atmospheric gases", Recommendation 677 "Radio emission from natural sources at frequencies above 50 MHz" and Recommendation 678 "Characterization of the natural variability of propagation phenomena". Report 1147 was also prepared entitled "Statistical assessment of data", in which specific models are proposed for evaluating the variability of propagation data. Additions and amendments were made to Report 563 "Radiometeorological data"; Report 721 "Attenuation by hydrometeors, in particular precipitation and other atmospheric particles"; Report 718 "Effects of tropospheric refraction on radio-wave propagation"; Report 723 "Worst-month statistics"; Report 722 "Cross-polarization due to the atmosphere"; Report 719 "Attenuation by atmospheric gases"; and Report 882 "Scattering by precipitation".

Section 5D – Aspects relative to the terrestrial broadcasting and mobile services

Additions and amendments were made to Report 567 "Propagation data and prediction methods for the terrestrial land mobile service using the frequency range 30 MHz to 3 GHz" concerning depolarization phenomena, the effects of vegetation and buildings on field strength and the evaluation of multipath signal structure. Some new findings were included in the text of Report 239 "Propagation statistics required for broadcasting services using the frequency range 30 to 1000 MHz" and Report 562 "Propagation data required for terrestrial broadcasting and point-to-multipoint communication systems in the frequency bands above 10 GHz".

Section 5E – Aspects relative to the terrestrial fixed service

Substantial amendments were made to the text of Recommendation 530 "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems". This Recommendation now gives details of the aspects of radio-wave propagation dealt with in Report 338 and applicable to such systems. Report 338 has been supplemented with new information. New data have been included in Report 238 "Propagation data and prediction methods required for terrestrial trans-horizon systems".

Section 5F – Aspects relative to space communication systems

Four new Recommendations were drafted. The first one, "Propagation data required for the design of broadcasting-satellite systems", proposes that the data given in Report 565 should be used for these systems. The second, "Propagation data required for the design of Earth-space maritime mobile telecommunication systems", proposes that the data contained in Report 884 should be used for these systems. Recommendation 681 "Propagation data required for the design of Earth-space land mobile telecommunication systems", proposes that the methods given in Report 1009 should be used for these systems. Recommendation 682, "Propagation data required for the design of Earth-space aeronautical mobile telecommunication systems", proposes that the data in Report 1148 should be used for these systems; the new Report describes the specific propagation effects of aircraft flying at high altitudes and high speeds. Amendments were made to Recommendation 618, "Propagation data and prediction methods required for the design of Earth-space telecommunication systems". New data were added in all the Section 5F Reports.

Section 5G – Propagation data required for the evaluation of interference: Space and terrestrial systems

Report 1146 on "Terrain scatter as a factor in interference" was prepared. Additions were made to Report 569 "The evaluation of propagation factors in interference problems between stations on the surface of the Earth at frequencies above about 0.5 GHz" and Report 885 "Propagation data required for evaluating interference between stations in space and those on the surface of the Earth".

Questions and Study Programmes

A great deal of work was done to bring the Questions and Study Programmes up to date. Priority was given to formulating the Questions in such a way as to give sufficiently detailed guidelines for research into aspects of propagation having regard to needs of the different services. On the basis of the existing Questions and Study Programmes, 13 new and two revised Questions were prepared:

- Question 1-4/5 — Influence of the ground on propagation below 30 MHz
- Question 2-5/5 — Radiometeorological data required for the planning of terrestrial and space communication systems and space research applications
- Question 9/5 — Propagation predictions taking into account detailed terrain features and digital terrain data bases
- Question 10/5 — Influence of terrain irregularities, vegetation and buildings on tropospheric propagation
- Question 11/5 — Propagation data required for the terrestrial broadcasting service in the frequency range 30 MHz to 10 GHz
- Question 12/5 — Propagation data required for the land mobile (terrestrial) service in the frequency range 30 MHz to 10 GHz
- Question 13/5 — Propagation data required for terrestrial broadcasting above 10 GHz
- Question 14/5 — Propagation data and prediction methods required for line-of-sight systems
- Question 15/5 — Propagation data and prediction methods required for trans-horizon systems
- Question 16/5 — Propagation and noise data, and prediction methods, required for space telecommunication systems
- Question 17/5 — Propagation data and prediction methods required for the satellite-broadcasting service in the frequency bands above about 0.5 GHz
- Question 18/5 — Propagation data and prediction methods required for satellite mobile and radiodetermination services in the frequency bands above about 0.5 GHz
- Question 19/5 — Propagation factors affecting frequency-sharing
- Question 20/5 — Scattering from precipitation as a factor in interference between terrestrial and space systems
- Question 21/5 — Terrain scatter as a factor in interference.

Main tasks for the next study period

The most urgent task for the next study period is to work out standard methods of predicting the statistical characteristics of signals for the various services. At present many of the Reports in Volume V unfortunately contain alternative methods, usually based on national data. It is necessary to go on comparing these methods with each other and with the wealth of experimental data in the data banks. These comparisons should show which methods are most acceptable, giving the required accuracy of prediction over the widest variety of climatic and topographical conditions, so that they can be recommended for application world-wide.

A routine task which continues to be important is to gather further experimental data on propagation in different natural conditions and in different frequency bands having regard to the specific operational features of different radio systems.

The intensive development of mobile-satellite systems (land, maritime, aeronautical, navigational) will make it very necessary to do research into the effect of the environment on signal characteristics in these systems: signal attenuation due to terrain irregularities, vegetation and buildings, wave scattering and reflection and multipath.

The increasing popularity of high bit rate digital line-of-sight radio-relay systems makes it essential to undertake experimental and theoretical research on amplitude-frequency and phase-frequency signal distortion, which has an extremely adverse effect on the operation of these systems. It will be particularly important to investigate such distortion on flat paths, where the effect of reflections from the Earth's surface is considerable and a three-path statistical signal model has to be used to describe the processes.

As in the past, it will be necessary to continue efforts to determine the precise dependence of interfering signal levels on distance, antenna height, frequency and climatic and topographical conditions.

SECTION 5A: TEXTS OF GENERAL INTEREST

INTRODUCTION TO TEXTS OF STUDY GROUP 5

PROPAGATION IN NON-IONIZED MEDIA

It is the responsibility of Study Group 5 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 outer space wherever the effect of ionization is negligible,

with the object of improving communications. Terrain effects are due either to the topography or to the electrical characteristics of the Earth's surface, and these effects occur throughout the radio-frequency spectrum. The most important part of the non-ionized atmosphere is the troposphere. Its influence on propagation is of major importance for frequencies above about 30 MHz, but becomes less important for decreasing frequencies. Propagation in outer space is mainly an extension of the free-space concepts widely used in general calculations. These factors therefore define the primary areas of activity of the Study Group.

The fundamental problem confronting a radiocommunications engineer in setting up a service is that he must achieve a satisfactory wanted-to-unwanted signal ratio in analogue systems or a very low error ratio in digital systems. In this context, the unwanted signal may include:

- noise arising in the terminal equipment or inherent in the system due to multipath propagation (e.g. intermodulation noise in FM-FDM links);
- man-made noise, that is to say man-made radio noise as distinct from other sources of emissions;
- noise of natural origin, including extra terrestrial noise;
- echoes due to multipath;
- interference signals from other radio-communication systems.

The engineer must establish a signal adequate to satisfy performance requirements of the service in question, given the circumstances in which it is to operate. To solve this problem, a knowledge is required of the level and variation of the wanted signal on the one hand, and the unwanted signal on the other. The unwanted signal level may or may not be controllable.

Data on the expected loss and fading of a signal are used to determine the power, the antenna characteristics, the service range or the hop length, from which the performance of the service can be evaluated for a particular percentage of the time (e.g. 99%) at a given receiving location or at a specified percentage of locations (e.g. 50%) within a reception area. Such propagation data are also required to evaluate the level of interfering signals exceeded only for some small percentage of the time (e.g. 0.1%), again at the reception point or reception points of concern.

Propagation information can be gained most effectively from the collection and analysis of long-term measurement data. For example, measurements of received field strength resulting from a transmission on the frequency of interest can provide statistics of the signal level to be expected. The usefulness of such data may be increased significantly when simultaneous measurement is made of the dominant characteristic influencing the propagation, for example, simultaneous measurements of rainfall rate and the received signal level from a satellite transmission at gigahertz frequencies. In turn, these two sets of data can form the basis of a propagation prediction method which may then be employed in other regions displaying similar propagation characteristics (for example, similar rates of rainfall). The accuracy of such a prediction technique relies heavily on the extent and quality of the data on which it was based, and in many regions of the world, the development of a satisfactory prediction method awaits the acquisition of a suitably large collection of measurement data.

Recommendations provide data and methods with sufficient reliability to be used for planning or establishing services. Reports provide additional information and data or describe the provisional state of methods which may eventually become Recommendations. In some reports, a choice of methods is provided, none of which is considered the preferred method.

One Report, World Atlas of Ground Conductivities (Report 717) is published separately. Study Group 5 has also prepared a Handbook of Curves for Radio-Wave Propagation over the Surface of the Earth. Data banks of measured data for the testing of prediction methods contained in Volume V have been compiled by Study Group 5. Details of the data banks are found in Report 1144.

1. Types of service

Services may be broadly classified into two categories:

- point-to-point services; and
- point-to-area services, for example, sound broadcast, television and the mobile services.

The above two categories of service may in general again be subdivided as follows:

- those in which the propagation paths are exclusively terrestrial; and
- those in which the propagation paths are Earth-space or space-space.

The terrestrial point-to-point services are planned with due regard to the topographical characteristics of the propagation path between the points in question. In the case of terrestrial point-to-area services propagation can be considered to take place over a multiplicity of individual paths, but up to now the problem of determining service performance has mainly been considered on a basis of statistical coverage because of the practical impossibility of making surveys of all the individual paths in question. However, the recent development of suitable computer techniques together with improved estimation of propagation characteristics over typical paths may allow a more rigorous approach to be made to the point-to-area problem.

2. Propagation characteristics

2.1 *Frequency aspects*

The propagation of radio waves along the transmission path is influenced by many factors, the relative importance of which depends mainly on frequency. In the LF and MF bands, propagation is influenced strongly by the electrical characteristics of the ground and, depending on the time of day and season, by the ionosphere. Propagation in the HF band is dominated by ionospheric refraction, although at short distances, direct paths between the transmitter and the receiver are affected by terrain obstructions. As the frequency increases through the VHF band, ionospheric effects decrease in importance so that at VHF and UHF, propagation depends mainly on terrain features and meteorological characteristics of the lower atmosphere, or troposphere. These last two factors are also of fundamental importance at microwave frequencies but above about 6 GHz, the effects of rain must also be taken into account; at frequencies above about 12 GHz, for example, rain may become the dominant consideration.

2.2 *Terrain effects*

When radio waves propagate over or through the Earth, the propagation characteristics are determined by:

- the electrical properties of the surface of the Earth;
- the physical configuration of the surface of the Earth, including vegetation and man-made structures of arbitrary dimensions.

At frequencies above about 30 MHz it is the physical configuration that matters most. The relevant effect on overall transmission loss is determined by the frequency concerned, the electrical characteristics in question and/or the topography of the terrain. It should be noted that in the case of tropospheric propagation near the surface of the Earth terrain irregularities are important at all times.

2.3 *Tropospheric effects*

Waves propagated through the non-ionized regions of the atmosphere are affected by the gaseous constituents of the atmosphere and also by all forms of cloud and precipitation. The relative importance of these factors depends on climate and on frequency.

The gaseous constituents of the atmosphere influence propagation of radio waves both by the absorption of energy and by the variations in refractive index, which cause reflection, refraction and scattering of the waves. Absorption takes place principally due to the presence of oxygen, water vapour and liquid water and is not significant at frequencies lower than about 3 GHz. However, while phenomena associated with variations in refractive index are known to occur at frequencies lower than 30 MHz, such phenomena are primarily significant in system planning at frequencies above about 30 MHz.

Clouds and precipitation influence propagation in two basic ways:

- by the absorption of part of the energy passing through them;
- by scattering and changing the polarization of radio waves.

Scattering clearly contributes to the attenuation of the forward beam, but is also important because it deflects energy into other directions, including directly back towards the transmitter. Once again, these effects are of importance at frequencies greater than about 3 GHz.

Changes in polarization occur when the scattering particles are non-spherical in shape. In the case of scattering by water particles there is significant associated attenuation, while in the case of ice particles the attenuation is generally insignificant.

The variability in propagation characteristics due to atmospheric effects is of paramount importance in determining the interference likely to be experienced in radio systems, especially in those modes of propagation associated with transmission well beyond the horizon.

2.4 *Multipath*

This covers all cases in which the effective received signal is made up of several components which arrive at the receiving antenna over different transmission paths. These components may have differing phases and differing amplitudes, and their relationships with one another may vary continuously with time. This phenomenon results from a multiplicity of paths in the troposphere, reflections from objects such as aircraft and buildings, specular and diffuse reflections from the surface of the Earth, and from horizontal interfaces between different layers in the atmosphere. Such multipath (which is the cause of all fast fading observed on radio links) can seriously degrade the quality of a service, especially with regard to bandwidth.

2.5 *Radio noise*

Study Group 5 is concerned with natural radio noise at frequencies above about 50 MHz which limits or impairs systems which employ tropospheric propagation. Particular emphasis is placed on radio noise emitted by oxygen and water vapour molecules in the atmosphere, extra-terrestrial noise from solar, planetary, galactic and cosmic sources and thermal radio noise emitted by the Earth. (For other forms of radio noise, see Volume VI.)

3. Arrangement of texts

It is believed that the following arrangement of texts is most convenient for practical application of propagation data. However, it is important to recognize the inter-relationship between many propagation characteristics. In many cases, the effects of more than one propagation mode are superimposed and a clear understanding of the individual phenomena and their probability of occurrence is essential in evaluating the overall effect on a particular system.

Section 5A: Texts of general interest

This section consists of Recommendations on definitions of propagation terms, general propagation concepts including the concept of transmission loss, the calculation of free-space attenuation and the presentation of data in studies of tropospheric-wave propagation. Reports on statistical distributions used in radio-wave propagation and on the measurements of field strength and related parameters are included.

Section 5B: Effects of the ground (including ground-wave propagation)

This section contains Recommendations on ground-wave propagation curves for frequencies below 30 MHz and propagation by diffraction. The subjects of electrical characteristics of the surface of the Earth as well as the influence of the ground on tropospheric propagation are dealt with in specific Reports.

Section 5C: Effects of the atmosphere (radiometeorology)

This section contains information on the meteorological and physical characteristics of the atmosphere that influence radio propagation. Information on the statistics of these atmospheric factors as well as their relation to a variety of radio propagation effects are given, without discussing the impact of these effects on particular systems or services.

Section 5D: Aspects relative to the terrestrial broadcasting and mobile services

This section concerns studies and measurements for the development of the statistical methods and propagation curves needed to predict the wanted and unwanted field strengths which have to be known for the efficient operation of terrestrial broadcasting and mobile services and, if necessary, for the planning of these services.

The section also considers the conditions required for interpreting and using these curves and methods in relation to the variations of certain parameters, which can have substantial effects on practical applications, such as receiving antenna height, nature of the propagation path, environment of the receiving location, etc., without neglecting the parameters, which, whether or not changing the field strength, may affect the quality of services in both analogue and digital systems.

Section 5E: Aspects relative to the terrestrial fixed service

This section provides service-oriented information for planning terrestrial line-of-sight (radio-relay) paths and trans-horizon (troposcatter) paths.

Report 338 covers propagation effects that influence terrestrial line-of-sight paths, and gives detailed prediction methods wherever this is possible. The primary concern is the prediction of significant propagation loss, and improvement that may be achieved by diversity systems, although consideration is also given to reduction in cross-polarization discrimination and distortion due to propagation effects.

Propagation data and prediction methods required for the design of trans-horizon radio-relay systems are given in Report 238. The primary concern is the prediction of significant propagation loss, both for annual statistics and for the worst month. Again, some consideration is given to diversity improvement.

Section 5F: Aspects relative to space telecommunication systems

Report 564 covers propagation data and prediction methods for Earth-space telecommunication systems. Primarily, the Report is concerned with applications to satellite fixed services, although some of the methods are applicable to other services. Attenuation may be caused by atmospheric gases, precipitation, clouds and by sand and dust storms. Step-by-step prediction methods are given so far as is possible. Scintillation and multipath effects are also described. Prediction of cross-polar performance is also important and prediction methods are given. Estimation of propagation delays and bandwidth limitations are also covered.

The remaining four Reports cover specific problems relating to broadcasting from satellites (Report 565), maritime mobile-satellite systems (Report 884), land mobile-satellite systems (Report 1009) and aeronautical mobile-satellite systems (Report 1148). In each case there are specific problems in addition to those referred to in Report 564. Prediction methods are given.

Section 5G: Propagation factors in interference: space and terrestrial systems

Reports in this section are directed towards the prediction of the possible occurrence of signal levels that may give rise to co-channel interference, and propagation information for the calculation of coordination distances. The former is covered in Report 569 for the prediction of interference that may occur between earth stations and terrestrial stations or between terrestrial stations. Report 885 covers interference between stations in space and those on the Earth's surface. Propagation data for calculation of coordination distance are covered in Report 724 for coordination between earth stations and terrestrial stations. Report 1010 covers coordination between earth stations (which may be relatively closely spaced and using small antennas). Generally, within these Reports, it has been found appropriate to separate consideration of prediction for clear-air conditions, and those where scatter from hydrometeors may cause interference.

RECOMMENDATION 525-1

CALCULATION OF FREE-SPACE ATTENUATION

(1978–1982)

The CCIR,

CONSIDERING

that free-space propagation is a fundamental reference for radio-engineering,

UNANIMOUSLY RECOMMENDS

that the methods in Annex I be used for the calculation of attenuation in free-space.

ANNEX I

1. Introduction

As free-space propagation is often used as a reference in other CCIR texts, this Annex lists certain relevant formulae, together with nomograms for rough graphical calculations which may be useful in many cases.

2. Basic formulae for telecommunication links

Free-space propagation may be calculated in two different ways, each of which is adapted to a particular type of service.

2.1 *Point-to-area links*

If there is a transmitter serving several randomly-distributed receivers (broadcasting, mobile service), the field is calculated at a point located at some appropriate distance from the transmitter, and in a given direction, by the expression:

$$E = \frac{\sqrt{30\,p}}{d} \tag{1}$$

in which:

E: is the r.m.s. field strength in volts per metre (Note 1)

p: is the equivalent isotropically radiated power (e.i.r.p.) of the transmitter in the direction of the point in question (Note 2), in watts

d: is the distance from the transmitter to the point in question, in metres.

Expression (1) is often replaced by (2) which uses practical units:

$$E_{\mathrm{mV/m}} = 173 \frac{\sqrt{p_{\mathrm{kW}}}}{d_{\mathrm{km}}} \tag{2}$$

These two relations are shown in Fig. 1.

For antennas operating in free-space conditions the cymomotive force may be obtained by multiplying together E and d in expression (1). Its dimension is volts.

Note 1. – If the wave is elliptically polarized and not linear, and if the electric field components along two orthogonal axes are expressed by E_x and E_y, the left-hand term of equation (1) should be replaced by $\sqrt{E_x^2 + E_y^2}$. E_x and E_y can be deduced only if the axial ratio is known. E should be replaced by $E\sqrt{2}$ in the case of circular polarization.

Note 2. – In the case of antennas located at ground level and operating on relatively low frequencies with vertical polarization, radiation is generally considered only in the upper half-space. This should be taken into account in determining the e.i.r.p. (see Recommendation 368).

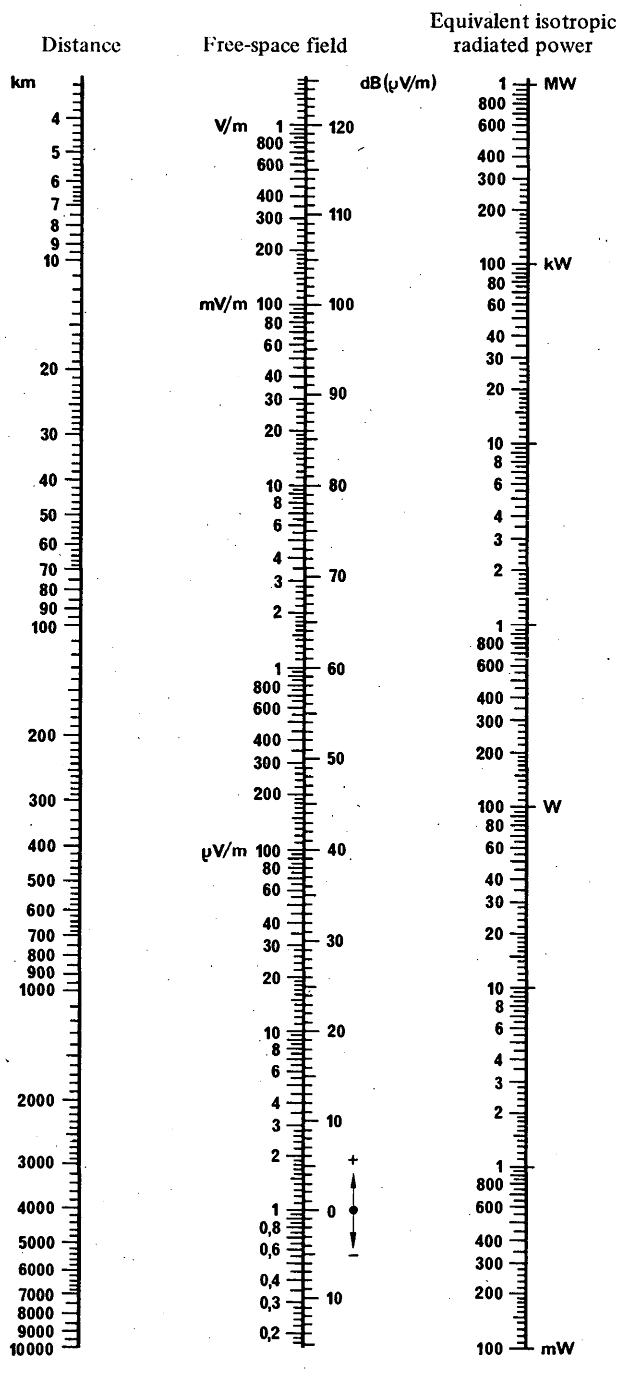

FIGURE 1 – *Electro-magnetic field in free space*

2.2 *Point-to-point links*

With a point-to-point link it is preferable to calculate the free-space attenuation between isotropic antennas, also known as the basic free-space transmission loss (symbols: L_{bf} or A_0), as follows:

$$L_{bf} = 20 \log \left(\frac{4\pi d}{\lambda} \right) \quad \text{dB} \tag{3}$$

in which:

L_{bf}: the free-space basic transmission loss in dB,

d: the distance,

λ: the wavelength, and

d and λ are expressed in the same unit.

Expression (3) can also be written using the frequency instead of the wavelength.

$$L_{bf} = 32.5 + 20 \log f_{\text{MHz}} + 20 \log d_{\text{km}} \quad \text{dB} \tag{4}$$

Expressions (3) and (4) are shown in Fig. 2.

2.3 *Relations between the characteristics of a plane wave*

There are also relations between the characteristics of a plane wave (or a wave which can be treated as a plane wave) at a point:

$$S = \frac{E^2}{120\pi} = \frac{4\pi \, p_r}{\lambda^2} \tag{5}$$

in which:

S: is the power flux-density in watts per square metre,

E: is the r.m.s. field strength in volts per metre,

p_r: is the power in watts available from an isotropic antenna located at this point,

λ: is the wavelength in metres.

Expression (5) is shown in Fig. 3.

3. **The free-space basic transmission loss for a radar system** (symbols: L_{br} or A_{0r})

Radar systems represent a special case because the signal is subjected to a loss while propagating both from the transmitter to the target and from the target to the receiver. For radars using a common antenna for both transmitter and receiver, a radar free-space basic transmission loss, L_{br}, can be written as follows:

$$L_{br} = 103.4 + 20 \log f + 40 \log d - 10 \log \sigma \quad \text{dB} \tag{6}$$

in which:

σ: the radar target cross-section in m^2,

d: the distance from the radar to the target in km, and

f: the frequency of the system in MHz.

The radar target cross-section of an object is the ratio of the total isotropically equivalent scattered power to the incident power density.

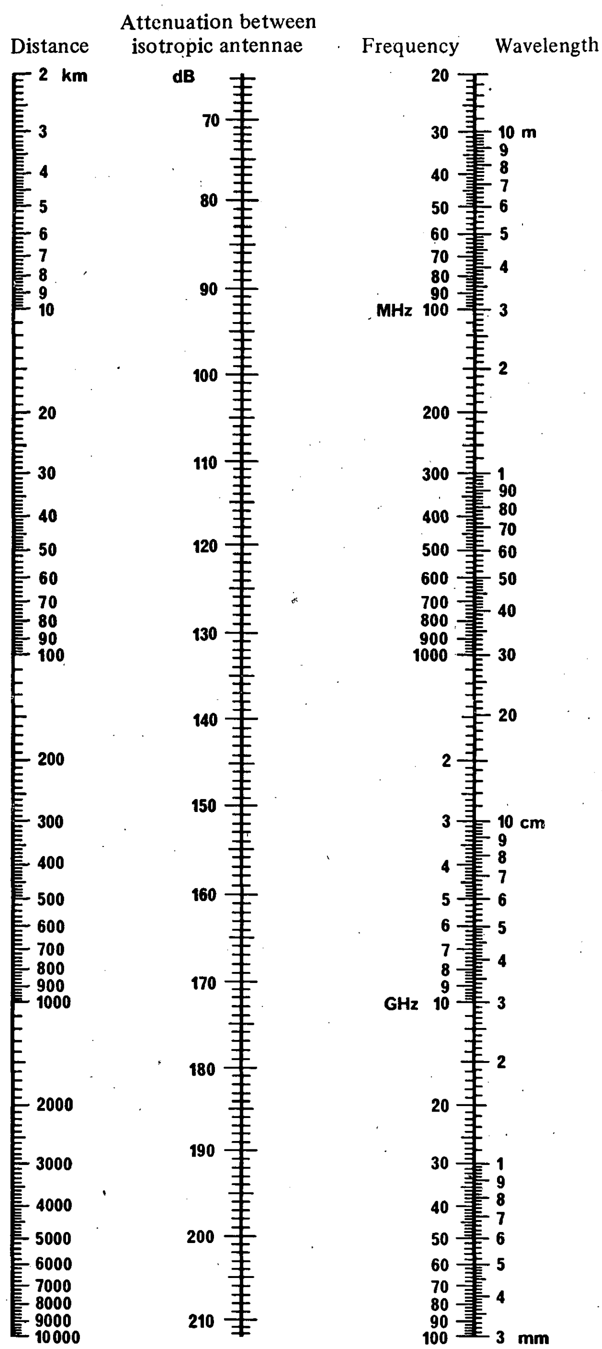

FIGURE 2 – *Free-space attenuation between isotropic antennae*

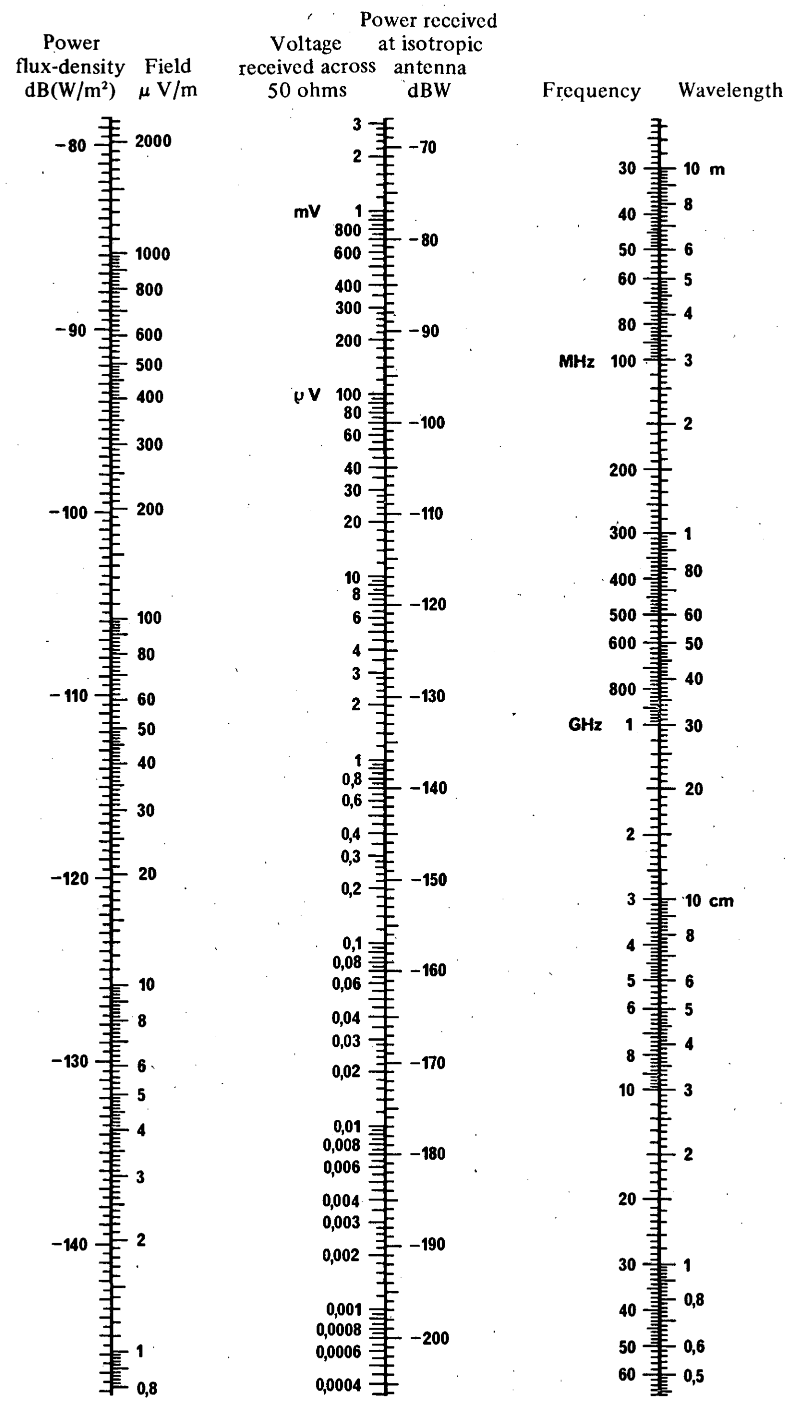

FIGURE 3 – *Characteristics of a plane wave*

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RECOMMENDATION 341-2*

THE CONCEPT OF TRANSMISSION LOSS FOR RADIO LINKS**

(1959–1982–1986)

The CCIR,

CONSIDERING

(a) that in a radio link between a transmitter and a receiver, the ratio between the power supplied by the transmitter and the power available at the receiver input depends on several factors such as the losses in the antennas or in the transmission feed lines, the attenuation due to the propagation mechanisms, the losses due to faulty adjustment of the impedances or polarization, etc.;

(b) that it is desirable to standardize the terminology and notations employed to characterize transmission loss and its components;

(c) that Recommendation 525 provides the free-space reference conditions for propagation,

UNANIMOUSLY RECOMMENDS

that, to describe the characteristics of a radio link involving a transmitter, a receiver, their antennas, the associated circuits and the propagation medium, the following terms, definitions and notations should be employed:

1. **Total loss (of a radio link)***** (symbols: L_l or A_l)

The ratio, usually expressed in decibels, between the power supplied by the transmitter of a radio link and the power supplied to the corresponding receiver in real installation, propagation and operational conditions.

Note. – It is necessary to specify in each case the points at which the power supplied by the transmitter and the power supplied to the receiver are determined, for example:

- before or after the radio frequency filters or multiplexers that may be employed at the sending or the receiving end,
- at the input or at the output of the transmitting and receiving antenna feed lines.

2. **System loss** (symbols: L_s or A_s)

The ratio, usually expressed in decibels, for a radio link, of the radio frequency power input to the terminals of the transmitting antenna and the resultant radio frequency signal power available at the terminals of the receiving antenna.

Note 1. – The available power is the maximum real power which a source can deliver to a load, i.e. the power which would be delivered to the load if the impedances were conjugately matched.

Note 2. – The system loss may be expressed by:

$$L_s = 10 \log (p_t/p_a) = P_t - P_a \quad \text{dB} \tag{1}$$

where

p_t: radio frequency power input to the terminals of the transmitting antenna and

p_a: resultant radio frequency signal power available at the terminals of the receiving antenna.

Note 3. – The system loss excludes losses in feeder lines but includes all losses in radio-frequency circuits associated with the antenna, such as ground losses, dielectric losses, antenna loading coil losses, and terminating resistor losses.

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* This Recommendation should be brought to the attention of the CMV.

** Throughout this Recommendation, capital letters are used to denote the ratios, expressed in decibels, of the corresponding quantities designated with lower-case type, e.g. $P_t = 10 \log p_t$. P_t is the input power to the transmitting antenna, expressed in decibels relative to 1 W when p_t is the input power in watts.

*** A graphical depiction of this and subsequent definitions is shown in Fig. 1.

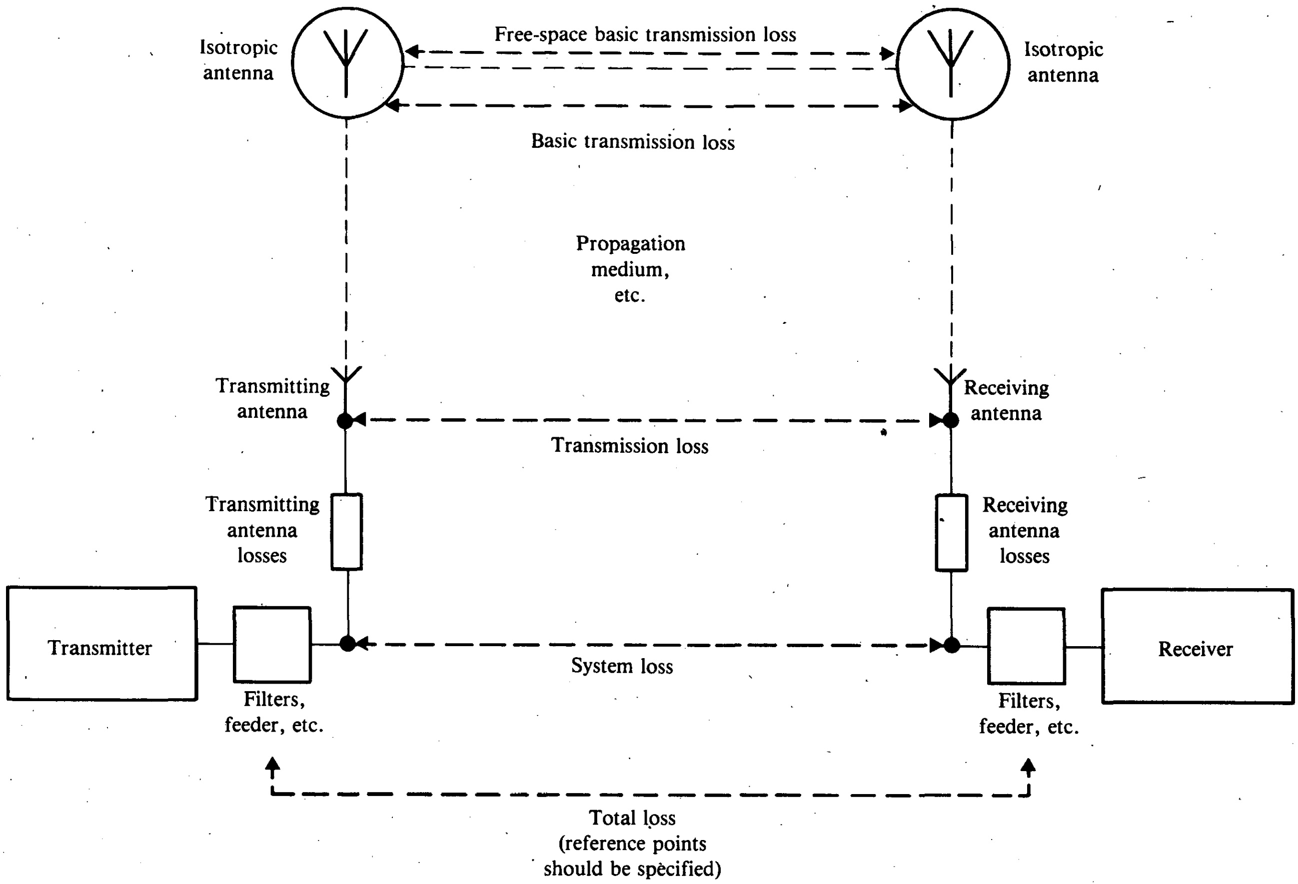

FIGURE 1 – *Graphical depiction of terms used in the transmission loss concept*

3. **Transmission loss (of a radio link)** (symbols: L or A)

The ratio, usually expressed in decibels, for a radio link between the power radiated by the transmitting antenna and the power that would be available at the receiving antenna output if there were no loss in the radio frequency circuits, assuming that the antenna radiation diagrams are retained.

Note 1. – The transmission loss may be expressed by:

$$L = L_s - L_{tc} - L_{rc} \qquad \text{dB} \tag{2}$$

where L_{tc} and L_{rc} are the losses, expressed in decibels, in the transmitting and receiving antennas circuits respectively, excluding the dissipation associated with the antennas radiation, i.e., the definitions of L_{tc} and L_{rc} are $10 \log (r'/r)$, where r' is the resistive component of the antenna circuit and r is the radiation resistance.

Note 2. – Transmission loss is equal to system loss minus the loss in the radio frequency circuits associated with the antennas.

4. **Basic transmission loss (of a radio link)** (symbols: L_b or A_i)

The transmission loss that would occur if the antennas were replaced by isotropic antennas with the same polarization as the real antennas, the propagation path being retained, but the effects of obstacles close to the antennas being disregarded.

Note 1. – The basic transmission loss is equal to the ratio of the equivalent isotropically radiated power of the transmitter system to the power available from an isotropic receiving antenna.

Note 2. – The effect of the local ground close to the antenna is included in computing the antenna gain, but not in the basic transmission loss.

5. Free-space basic transmission loss (symbols: L_{bf} or A_0)

The transmission loss that would occur if the antennas were replaced by isotropic antennas located in a perfectly dielectric, homogeneous, isotropic and unlimited environment, the distance between the antennas being retained (see Recommendation 525).

Note. – If the distance d between the antennas is much greater than the wavelength λ, the free-space attenuation in decibels will be:

$$L_{bf} = 20 \log \left(\frac{4\pi d}{\lambda} \right) \quad \text{dB} \tag{3}$$

6. Ray path transmission loss (symbols: L_t or A_t)

The transmission loss for a particular ray propagation path, equal to the basic transmission loss minus the transmitting and receiving antenna gains in the ray path directions (see Annex I).

Note. – The ray path transmission loss may be expressed by:

$$L_t = L_b - G_t - G_r \quad \text{dB} \tag{4}$$

where G_t and G_r are the plane-wave directive gains (see Annex I) of the transmitting and receiving antennas for the directions of propagation and polarization considered.

7. Loss relative to free space (symbols: L_m or A_m)

The difference between the basic transmission loss and the free-space basic transmission loss, expressed in decibels.

Note 1. – The loss relative to free space may be expressed by:

$$L_m = L_b - L_{bf} \quad \text{dB} \tag{5}$$

Note 2. – Loss relative to free space (L_m) may be divided into losses of different types, such as:

- *absorption loss* (ionospheric, atmospheric gases or precipitation);
- *diffraction loss* as for ground waves;
- *effective reflection or scattering loss* as in the ionospheric case including the results of any focusing or defocusing due to curvature of a reflecting layer;
- *polarization coupling loss*; this can arise from any polarization mismatch between the antennas for the particular ray path considered;
- *aperture-to-medium coupling loss* or antenna gain degradation, which may be due to the presence of substantial scatter phenomena on the path;
- *effect of wave interference between the direct ray and rays reflected* from the ground, other obstacles or atmospheric layers.

ANNEX I

1. Directivity

Directivity in a given direction is defined as the ratio of the intensity of radiation (the power per unit solid angle (steradian)), in that direction, to the radiation intensity averaged over all directions.

When converting transmission loss, or, in specific cases, ray path transmission loss to basic transmission loss the plane wave directivities for the transmitting and receiving antennas at the particular direction and polarization must be taken into account. In cases where the performance of the antenna is influenced by the presence of local ground or other obstacles (which do not affect the path) the directivity is the value obtained with the antenna *in situ*.

In the particular case of ground wave propagation with antennas located on or near the ground, although the directivity of the receiving antenna G_r is determined by the above definition, the aperture for signal capture, and hence the available power, is reduced below its free-space value. Thus the value to be used for G_r must be reduced (see Annex II).

2. Reference standard antennas

In the study of propagation over radio links in different frequency bands, a number of reference antennas are used and referred to in CCIR texts. According to Recommendation 311 this reference should be clearly defined in each case with respect to an isotropic antenna.

The power gain of an antenna is defined as the ratio, usually expressed in decibels, of the power required at the input of a loss-free reference antenna to the power supplied to the input of the given antenna to produce, in a given direction, the same field strength or the same power flux-density at the same distance. When not specified otherwise, the gain refers to the direction of maximum *radiation.* The gain may be considered for a specified polarization.

Depending on the choice of the reference antenna a distinction is made between:

(a) *absolute or isotropic gain* (G_i), when the reference antenna is an isotropic antenna isolated in space;

(b) *gain relative to a half-wave dipole* (G_d), when the reference antenna is a half-wave dipole isolated in space, whose equatorial plane contains the given direction;

(c) *gain relative to a short vertical antenna* (G_v), when the reference antenna is a linear conductor much shorter than one quarter of the wavelength, normal to the surface of a perfectly conducting plane which contains the given direction.

(The power gain corresponds to the maximum directivity for lossless antennas.)

Table I gives the directivity G_t for some typical reference antennas. The corresponding values of the cymomotive force are also shown for a radiated power of 1 kW.

TABLE I – *Directivity for typical reference antennas and its relation to cymomotive force*

Reference antenna	g_t	G_t (1) (dB)	Cymomotive force for a radiated power of 1 kW (V)
Isotropic in free space	1	0	173
Hertzian dipole in free space	1.5	1.75	212
Half-wave dipole in free space	1.65	2.15	222
Hertzian dipole, or a short vertical monopole on a perfectly conducting ground (2)	3	4.8	300
Quarter wave monopole on a perfectly conducting ground	3.3	5.2	314

(1) $G_t = 10 \log g_t$
The values of G_r (g_r) equal the values of G_t (g_t) for antennas in free space. See Annex II for values of G_r for antennas on a perfectly conducting ground.

(2) In the case of the hertzian dipole, it is assumed that the antenna is near a perfectly conducting ground.

ANNEX II

Influence of the environment on the antennas

When antennas are installed on or near the ground and the ground-wave propagation mode is used (i.e. $h < \lambda$, particularly when using frequencies less than 30 MHz) the free-space value of the antenna radiation resistance is modified by the presence of the ground. Consequently the power flux-density at the receiving antenna (resulting from the vector sum of direct and reflected rays) is dependent on the height of the transmitting antenna, and the effective capture area of the receiving antenna is dependent on the height of the antenna above the ground.

The influence of the environment on the operation of a pair of antennas (forming an elementary circuit) is illustrated by considering the transmission loss between two vertical loss-free short electric dipoles at heights h_t and h_r above a plane perfectly conducting surface. The separation, d, along the surface is very large compared to the wavelength. The power flux-density S in W/m^2 at height h_r is given by:

$$S = \frac{p'_t \cos^4 \psi}{4\pi\, d^2 \,(1 + \Delta_t)} \times 1.5 \left[2 \cos (kh_t \sin \psi) \right]^2 \tag{6}$$

The following should be noted:

– the distance between the antennas is increased to $d \sec \psi$

where

$$\psi = \text{arc tan} \frac{h_r - h_t}{d}$$

– the electric field due to the dipole varies as $\cos \psi$;

– the free-space radiation resistance is multiplied by $(1 + \Delta_t)$,

where

$$\Delta_t = \frac{3}{(2\, kh_t)^2} \left[\frac{\sin 2\, kh_t}{2\, kh_t} - \cos 2\, kh_t \right] \qquad (7)^*$$

where

$k = 2\pi/\lambda$

when

$h_t = 0$, $\Delta_t = 1$; when $h_t > \lambda$, $\Delta_t \rightarrow 0$;

– due to the vector addition of the direct and reflected rays the free-space value of the power flux is multiplied by:

$$\frac{\left[2 \cos (kh_t \sin \psi) \right]^2}{(1 + \Delta_t)}$$

This is equivalent to the change in directive gain due to the presence of the reflecting surface. The multiplying factor has the value of 2 when $h_t = h_r = 0$.

The effective capture area of the receiving antenna is given by:

$$a_e = \frac{1.5\, \lambda^2 \cos^2 \psi}{4\pi\, (1 + \Delta_r)} \tag{8}$$

The following should be noted:

– the capture area in the direction of the transmitting antenna is decreased by $\cos^2 \psi$;

– the change in radiation resistance is based on equation (7), where Δ_t and h_t are replaced by Δ_r and h_r;

– the free-space value of the capture area is multiplied by $\frac{\cos^2 \psi}{(1 + \Delta_r)}$; thus the presence of the reflecting surface reduces the capture area below its free-space value by a factor of 2 when $h_t = h_r = 0$;

– since g_t has the value 2×1.5 (by definition) when $h_t = h_r = 0$ it is important to note that this is not the appropriate value to use for g_r; the correct value for g_r is $1.5/2 = g_t/4$.

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* This relation is derived by S. A. Schelkunoff in Chapters VI and IX of the book *Electromagnetic Waves*, D. Van Nostrand Co., 1943.

Since $p'_a = Sa_e$ expressions (6) and (8) may be combined to give an expression for the transmission loss between two short vertical loss-free electric dipoles above a plane perfectly conducting surface.

$$L = L_{bf} - 6.0 - 10 \log \left[(1.5 \cos^2 \psi)^2 \frac{(\cos^2 kh_t \sin \psi)}{(1 + \Delta_r)(1 + \Delta_t)} \right] \quad \text{dB} \qquad (9)$$

Consider two cases.

$$h_t = h_r = 0; \qquad \Delta_t = \Delta_r = 1; \qquad \psi = 0$$

$$L = L_{bf} - 3.5 \qquad \text{dB}$$

Thus L is equal to the free-space value.

$$h_t = h_r \gg \lambda; \qquad \Delta_t = \Delta_r \rightarrow 0; \qquad \psi \rightarrow 0$$

$$L = L_{bf} - 3.5 - 6.0 \qquad \text{dB}$$

RECOMMENDATION 311-5

ACQUISITION, PRESENTATION AND ANALYSIS OF DATA IN STUDIES OF TROPOSPHERIC-WAVE PROPAGATION

(1953-1956-1959-1970-1974-1978-1982-1990)

The CCIR,

CONSIDERING

that, to facilitate the comparison of results, it is desirable to acquire and present propagation data in a uniform manner,

UNANIMOUSLY RECOMMENDS

1. that the information contained in Report 1144 should be applied:

– for the selection of the relevant parameters for measuring or calculating propagation data,

– for the presentation of results;

2. that for the analysis of data, the probability distributions described in Report 1007 should be used.

RECOMMENDATION 310-7 *

DEFINITIONS OF TERMS RELATING TO PROPAGATION IN NON-IONIZED MEDIA

(1951-1959-1966-1970-1974-1978-1982-1986-1990)

The CCIR,

CONSIDERING

that it is important to have agreed definitions of propagation terms used in Volume V,

UNANIMOUSLY RECOMMENDS

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

VOCABULARY OF TERMS USED IN RADIO PROPAGATION IN NON-IONIZED MEDIA

	Term	Definition
A.	*Terms related to radio waves*	
A1.	*Cross-polarization*	The appearance, in the course of propagation, of a polarization component which is orthogonal to the expected polarization.
A2.	*Cross-polarization discrimination*	For a radio wave transmitted with a given polarization, the ratio at the reception point of the power received with the expected polarization to the power received with the orthogonal polarization. *Note* – The cross-polarization discrimination depends both on the characteristics of the antennas and on the propagation medium.
A3.	*Cross-polarization isolation*	For two radio waves transmitted at the same frequency with the same power and orthogonal polarization, the ratio of the co-polarized power in a given receiver to the cross-polarized power in that receiver.
A4.	*Depolarization*	A phenomenon by virtue of which all or part of the power of a radio wave transmitted with a defined polarization may no longer have a defined polarization after propagation.
B.	*Terms related to ground effects on radio-wave propagation*	
B1.	*Free-space propagation*	Propagation of an electromagnetic wave in a homogeneous ideal dielectric medium which may be considered of infinite extent in all directions. *Note* – For propagation in free space, the magnitude of each vector of the electromagnetic field in any given direction from the source beyond a suitable distance determined by the size of the source and the wavelength is proportional to the reciprocal of the distance from the source.
B2.	*Line of sight propagation*	Propagation between two points for which the direct ray is sufficiently clear of obstacles for diffraction to be of negligible effect.
B3.	*Radio horizon*	The locus of points at which the direct rays from a point source of radio waves are tangential to the surface of the Earth. *Note* – As a general rule, the radio and geometric horizons are different because of atmospheric refraction.
B4.	*Penetration depth*	The depth within the Earth at which the amplitude of a radio wave incident at the surface falls to a value 1/e (0.368) of its value at the surface.
B5.	*Smooth surface; specular surface*	A surface separating two media which is large compared to the wavelength of the incident wave and the irregularities of which are sufficiently small to cause specular reflection.

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* This Recommendation should be brought to the attention of the CCV.

B6.	*Rough surface*	A surface separating two media which is large compared to the wavelength of the incident wave and the irregularities of which are randomly located and cause diffuse reflection.
B7.	*Diffuse reflection coefficient*	The ratio of the amplitude of the incoherent wave reflected from a rough surface to the amplitude of the incident wave.
B8.	*Measure of terrain irregularity; Δh*	A statistical parameter which characterizes the variations in ground height along part or all of a propagation path. *Note* – For example, Δh is often defined as the difference between the heights exceeded by 10% and 90% respectively of the terrain heights measured at regular intervals (the interdecile height range) along a specified section of a path.
B9.	*Obstacle gain*	The ratio of the electromagnetic field due to edge diffraction by an isolated obstacle to the field which would occur due only to spherical diffraction in the absence of the obstacle.

C. *Terms related to tropospheric effects on radio-wave propagation*

C1.	*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. This part of the atmosphere extends to an altitude of about 9 km at the Earth's poles and 17 km at the equator.
C2.	*Temperature inversion (in the troposphere)*	An increase in temperature with height in troposphere.
C3.	*Mixing ratio*	The ratio of the mass of water vapour to the mass of dry air in a given volume of air (generally expressed in g/kg).
C4.	*Refractive index; n*	Ratio of the speed of radio waves in vacuo to the speed in the medium under consideration.
C5.	*Refractivity; N*	One million times the amount by which the refractive index n in the atmosphere exceeds unity: $N = (n - 1)\ 10^6$
C6.	*N-unit*	A dimensionless unit in terms of which refractivity is expressed.
C7.	*Modified refractive index*	The sum of the refractive index n of the air at height h and the ratio of this height to the radius of the Earth, a: $n + \frac{h}{a}$
C8.	*Refractive modulus; M*	One million times the amount by which the modified refractive index exceeds unity: $M = \left(n + \frac{h}{a} - 1\right) 10^6 = N + 10^6 \frac{h}{a}$
C9.	*M-unit*	A dimensionless unit in terms of which refractive modulus M is expressed.
C10.	*Standard refractivity gradient*	A standard value of vertical gradient of refractivity used in refraction studies; namely $-40\ N$/km. This corresponds approximately to the median value of the gradient in the first kilometre of altitude in temperate regions.
C11.	*Standard radio atmosphere*	An atmosphere having the standard refractivity gradient.
C12.	*Reference atmosphere for refraction*	An atmosphere in which $n(h)$ decreases with height as given by equation (2) of Recommendation 369.

C13. *Sub-refraction* — Refraction for which the refractivity gradient is greater than the standard refractivity gradient.

C14. *Super refraction* — Refraction for which the refractivity gradient is less than the standard refractivity gradient.

C15. *Effective radius of the Earth* — Radius of a hypothetical spherical Earth, without atmosphere, for which propagation paths are along straight lines, the heights and ground distances being the same as for the actual Earth in an atmosphere with a constant vertical gradient of refractivity.

Note 1 – The concept of effective radius of the Earth implies that the angles with the horizontal planes made at all points by the transmission paths are not too large.

Note 2 – For an atmosphere having a standard refractivity gradient, the effective radius of the Earth is about 4/3 that of the actual radius, which corresponds to approximately 8500 km.

C16. *Effective Earth-radius factor; k* — Ratio of the effective radius of the Earth to the actual Earth radius.

Note – This factor k is related to the vertical gradient dn/dh of the refractive index n and to the actual Earth radius a by the equation:

$$k = \frac{1}{1 + a \dfrac{dn}{dh}}$$

C17. *Ducting layer* — A tropospheric layer characterized by a negative M gradient, which consequently may generate a tropospheric radio-duct.

C18. *Tropospheric radio-duct* — A quasi-horizontal stratification in the troposphere within which radio energy of a sufficiently high frequency is substantially confined and propagates with much lower attenuation than would be obtained in a homogeneous atmosphere.

Note – The tropospheric radio-duct consists of a ducting layer and, in the case of an elevated duct, the portion of the underlying atmosphere in which the refractive modulus exceeds the minimum value attained in the ducting layer.

C19. *Ground-based duct (Surface duct)* — A tropospheric radio-duct in which the lower boundary is the surface of the Earth.

C20. *Elevated duct* — A tropospheric radio-duct in which the lower boundary is above the surface of the Earth.

C21. *Duct thickness* — The difference in height between the upper and lower boundaries of a tropospheric radio-duct.

C22. *Duct height* — The height above the surface of the Earth of the lower boundary of an elevated duct.

C23. *Duct intensity* — The difference between the maximum and minimum values of the refractive modulus in a tropospheric radio-duct.

Note – The intensity of a duct is the same as that of its ducting layer.

C24. *Ducting* — Guided propagation of radio waves inside a tropospheric radio-duct.

Note – At sufficiently high frequencies, a number of electromagnetic modes of guided propagation can coexist in the same tropospheric radio-duct.

C25. *Trans-horizon propagation* — Tropospheric propagation between points close to the ground, the reception point being beyond the radio horizon of the transmission point.

Note – Trans-horizon propagation may be due to a variety of tropospheric mechanisms such as diffraction, scattering, reflection from tropospheric layers. However ducting is not included because in a duct there is no radio horizon.

C26. *Tropospheric-scatter propagation* — Tropospheric propagation due to scattering from many inhomogeneities and discontinuities in the refractive index of the atmosphere.

C27. *Hydrometeors*	Concentrations of water or ice particles which may exist in the atmosphere or be deposited on the surface of the Earth. *Note* – Rain, fog, clouds, snow and hail are the main hydrometeors.
C28. *Aerosols*	Small particles in the atmosphere (other than fog or cloud droplets) which do not fall rapidly under gravity.
C29. *Precipitation-scatter propagation*	Tropospheric propagation due to scattering caused by hydrometeors, mainly rain.
C30. *Multipath propagation*	Propagation of the same radio signal between a transmission point and a reception point over a number of separate propagation paths.
C31. *Scintillation*	Rapid and random fluctuation in one or more of the characteristics (amplitude, phase, polarization, direction of arrival) of a received signal, caused by fluctuations in the refractive index of the transmission medium.
C32. *Gain degradation; antenna to medium coupling loss*	The apparent decrease in the sum of the gains (expressed in decibels) of the transmitting and receiving antennas when significant scattering effects occur on the propagation path.
C33. *Precipitation rate; rainfall rate; rain rate*	A measure of the intensity of precipitation expressed by the height of water reaching the ground per unit time. *Note* – Rain rate is generally expressed in millimetres per hour.

SECTION 5B: EFFECTS OF THE GROUND (INCLUDING GROUND-WAVE PROPAGATION)

RECOMMENDATION 368-6*

GROUND-WAVE PROPAGATION CURVES FOR FREQUENCIES BETWEEN 10 kHz AND 30 MHz

(1951-1959-1963-1970-1974-1978-1982-1986-1990)

The CCIR,

CONSIDERING

that, in view of the complexity of the calculation, it is useful to have a set of ground-wave curves for a range of standard frequency values and ground characteristics,

UNANIMOUSLY RECOMMENDS

1. that the curves of Annex I, applied in the conditions specified below, should be used for the determination of ground-wave field strength at frequencies between 10 kHz and 30 MHz;

2. that, as a general rule, these curves should be used to determine field strength only when it is known that ionospheric reflections will be negligible in amplitude. Ionospheric propagation is treated in Volume VI;

3. that these curves not be used in those applications for which the receiving antenna is located well above the surface of the Earth;

Note. – That is, when $\varepsilon_r \ll 60\ \lambda\sigma$ the curves may be used up to a height $h = 1.2\ \sigma^{1/2}\ \lambda^{3/2}$.

4. that these curves, plotted for homogeneous paths under the conditions established in Annex I, may also be used to determine the field strength over mixed paths as indicated in Annex II.

ANNEX I

CONDITIONS OF VALIDITY (HOMOGENEOUS PATHS)

The propagation curves in this Recommendation are calculated for the following assumptions:

- they refer to smooth homogenous spherical Earth;
- in the troposphere, the refractive index decreases exponentially with height, as described in Recommendation 369;
- both the transmitting and the receiving antennas are at ground level;
- the radiating element is a short vertical monopole. (The equivalent dipole moment is $5\lambda/2\pi$, see Report 714.) Assuming such a vertical antenna to be on the surface of a perfectly conducting plane Earth, and excited so as to radiate 1 kW, the field strength at a distance of 1 km would be 300 mV/m; this corresponds to a cymomotive force of 300 V (see Recommendation 525);
- the curves are drawn for distances measured around the curved surface of the Earth;
- the curves give the value of the vertical field-strength component of the radiation field, i.e. that which can be effectively measured in the far-field region of the antenna.

* This Recommendation is brought to the attention of Study Groups 8 and 10.

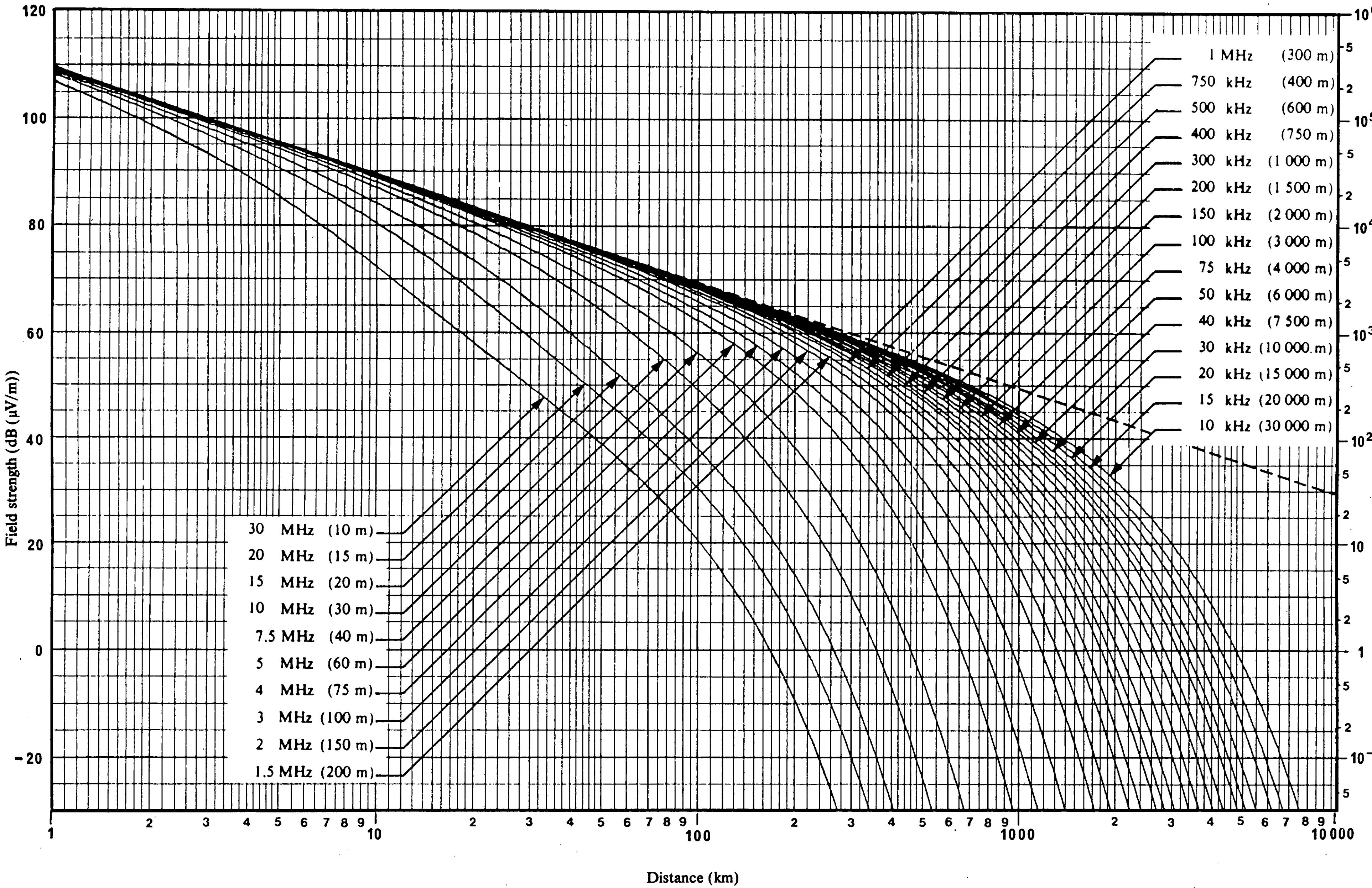


FIGURE 1 – *Ground-wave propagation curves; Sea water, low salinity, σ = 1 S/m, ε = 80*

– – – Inverse distance curve

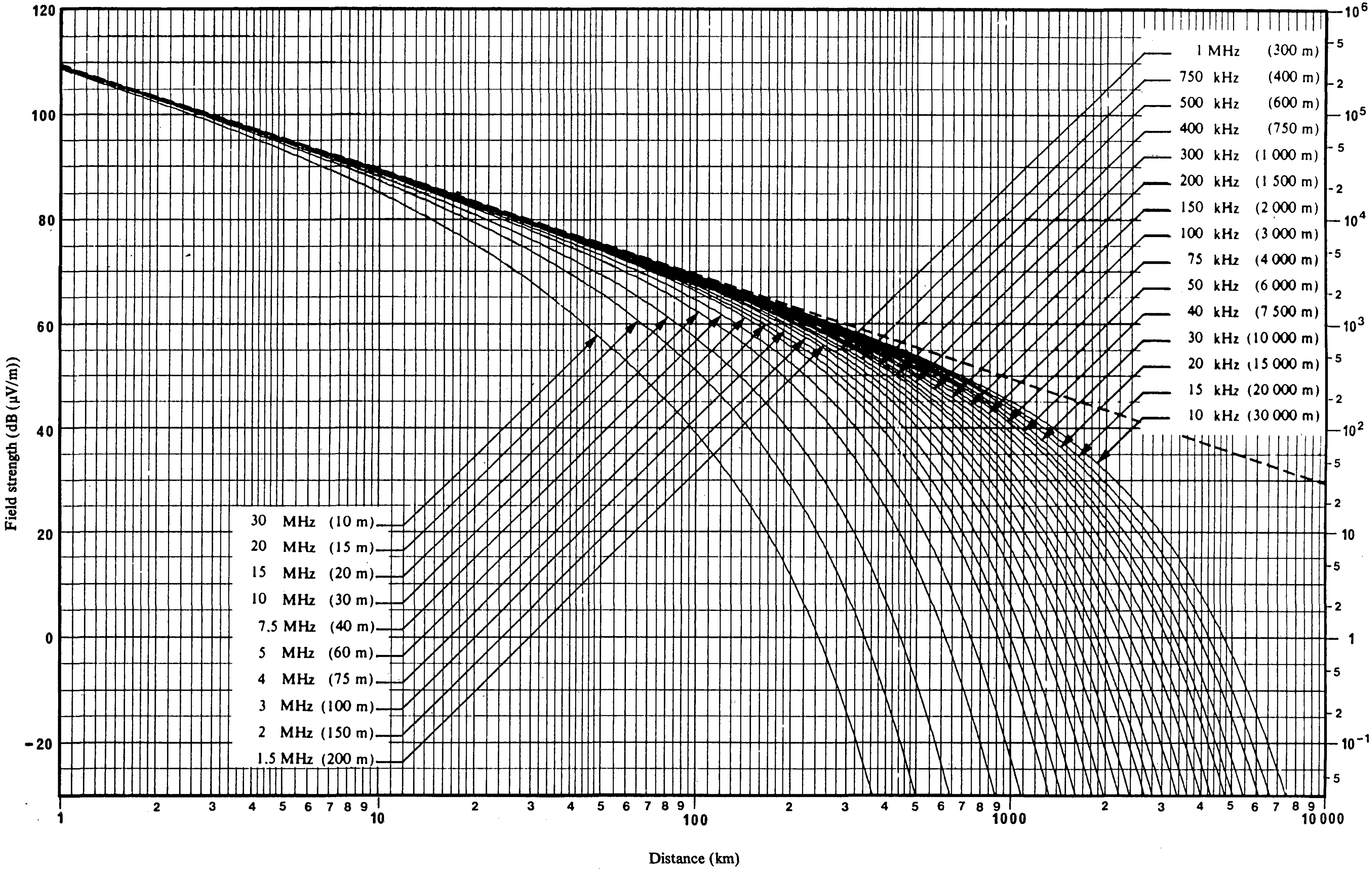


FIGURE 2 – *Ground-wave propagation curves; Sea water, average salinity, σ = 5 S/m, ε = 70*

– – – – Inverse distance curve

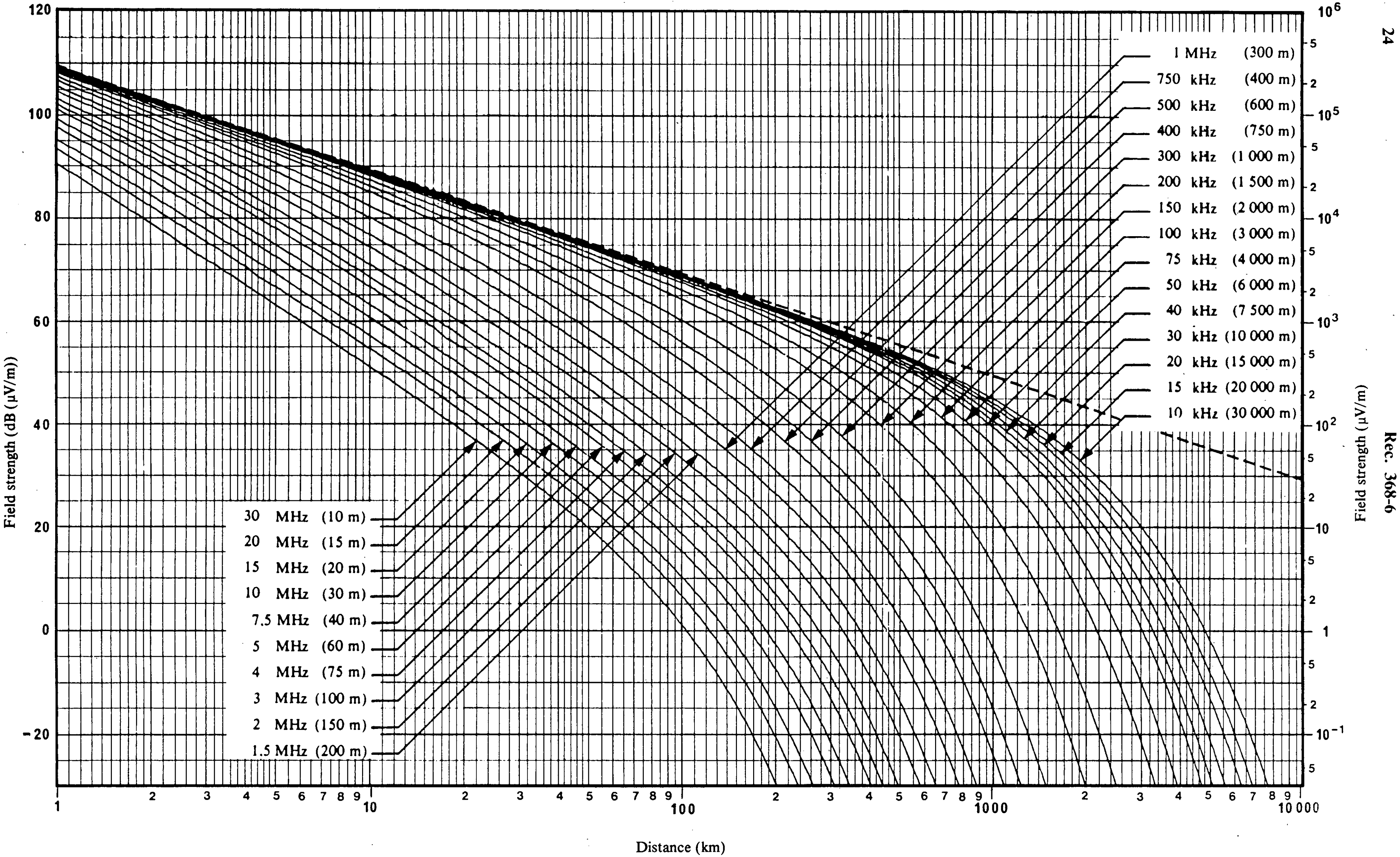


FIGURE 3 – *Ground-wave propagation curves; Fresh water, $\sigma = 3 \times 10^{-3}$ S/m, $\varepsilon = 80$*

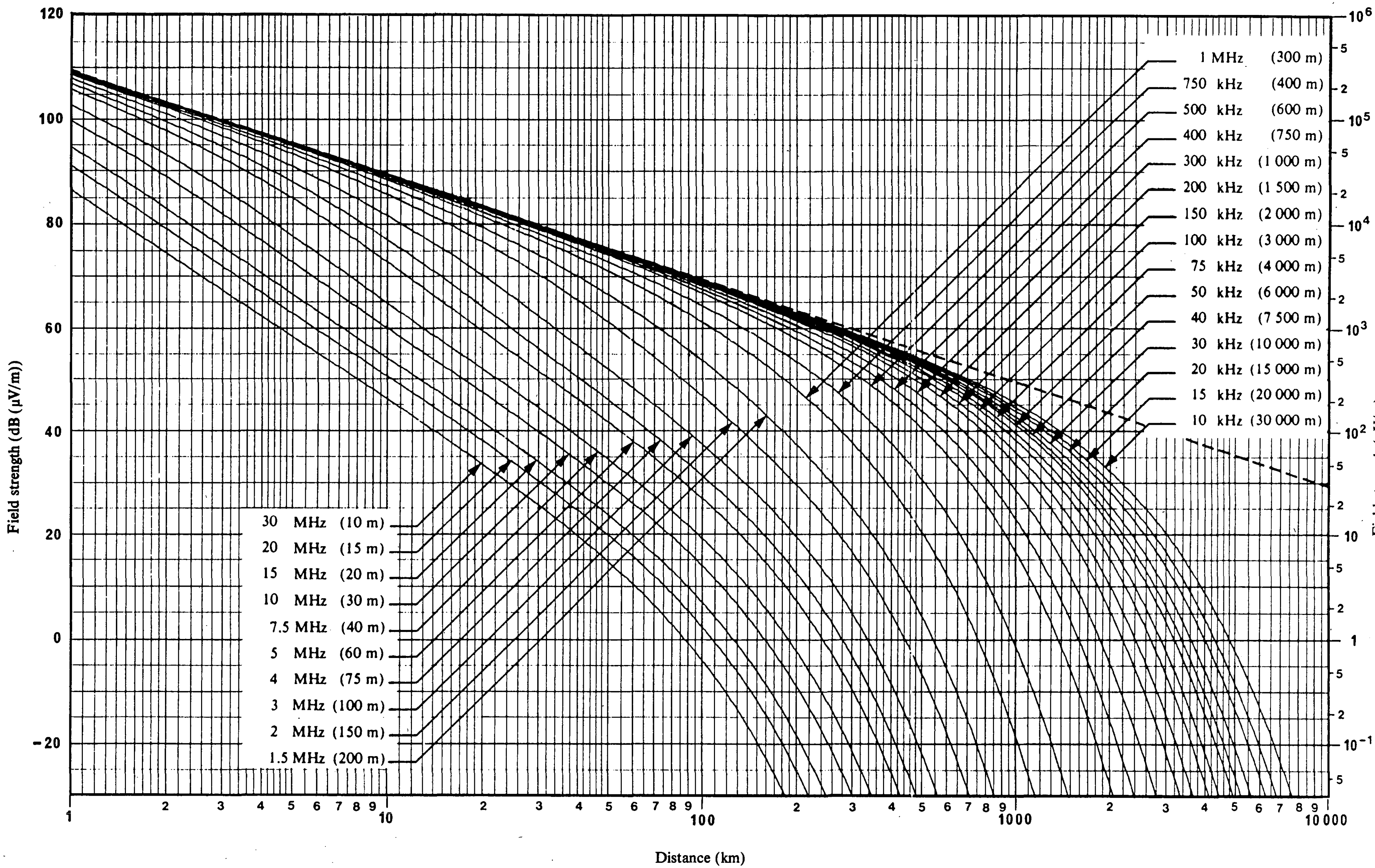


FIGURE 4 – *Ground-wave propagation curves; Land,* $\sigma = 3 \times 10^{-2}$ *S/m,* $\varepsilon = 40$

– – – – Inverse distance curve

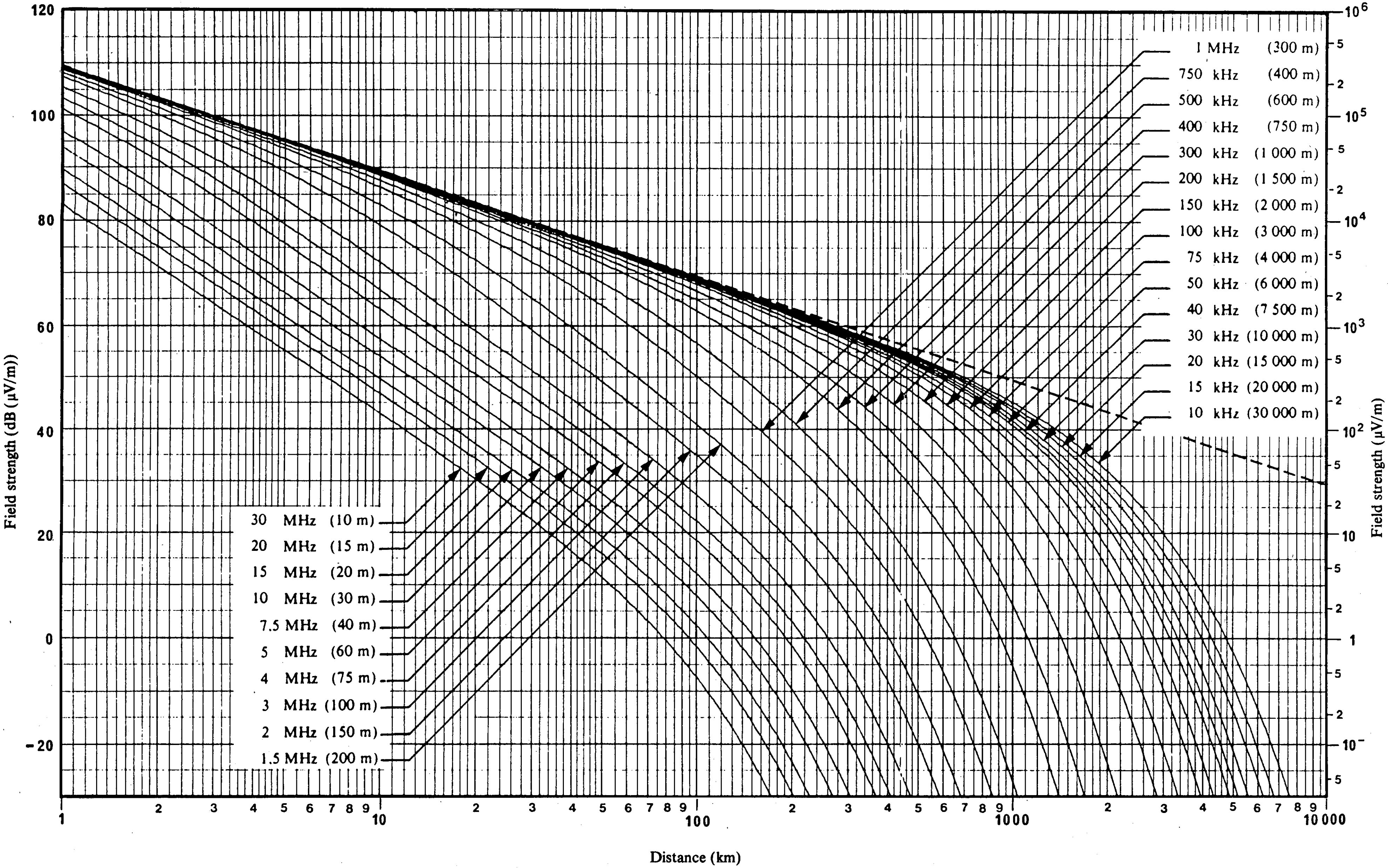


FIGURE 5 – *Ground-wave propagation curves; Wet ground,* $\sigma = 10^{-2}$ *S/m,* $\varepsilon = 30$

– – – – Inverse distance curve

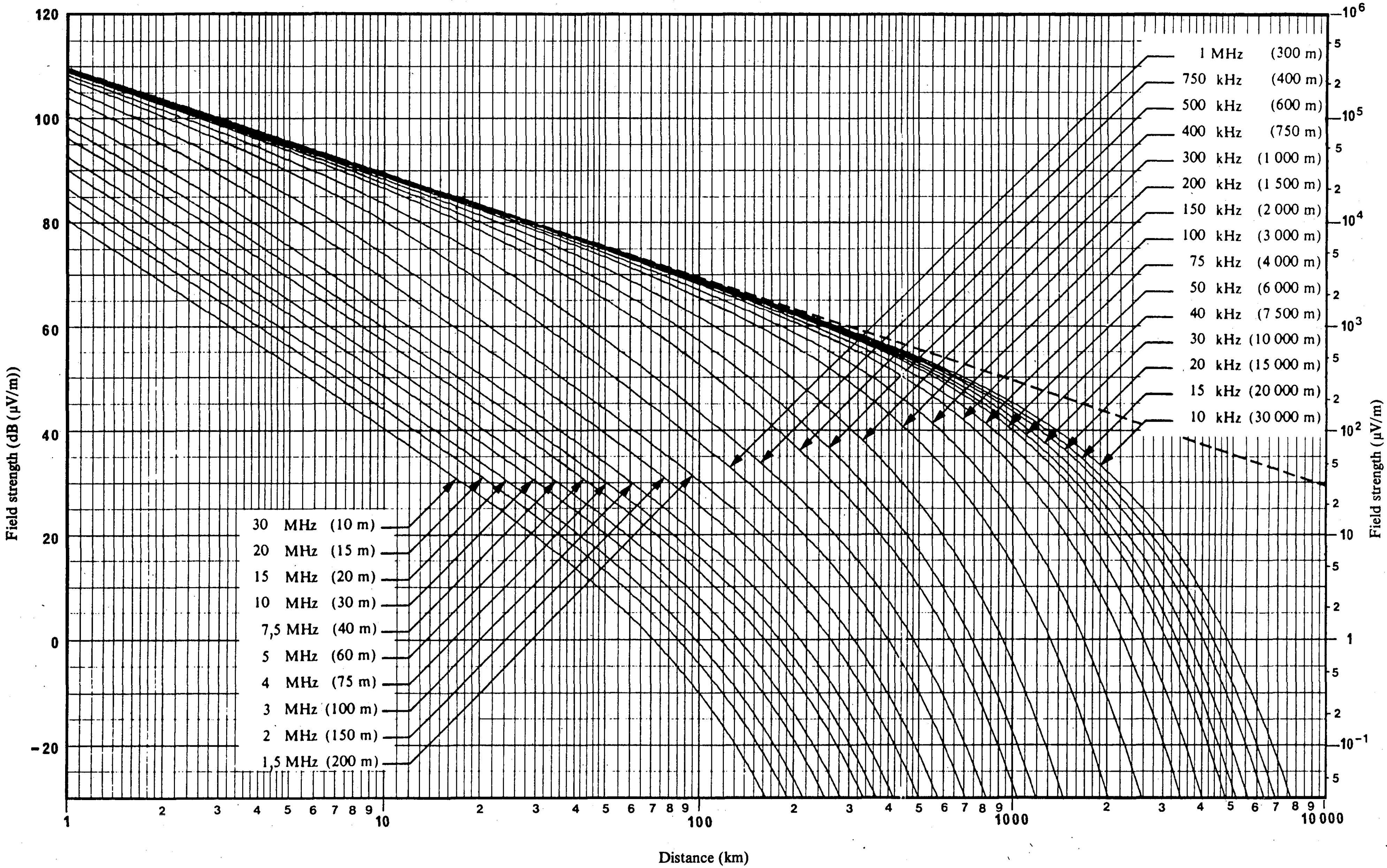


FIGURE 6 – *Ground-wave propagation curves; Land, $\sigma = 3 \times 10^{-3}$ S/m, $\varepsilon = 22$*

– – – – Inverse distance curve

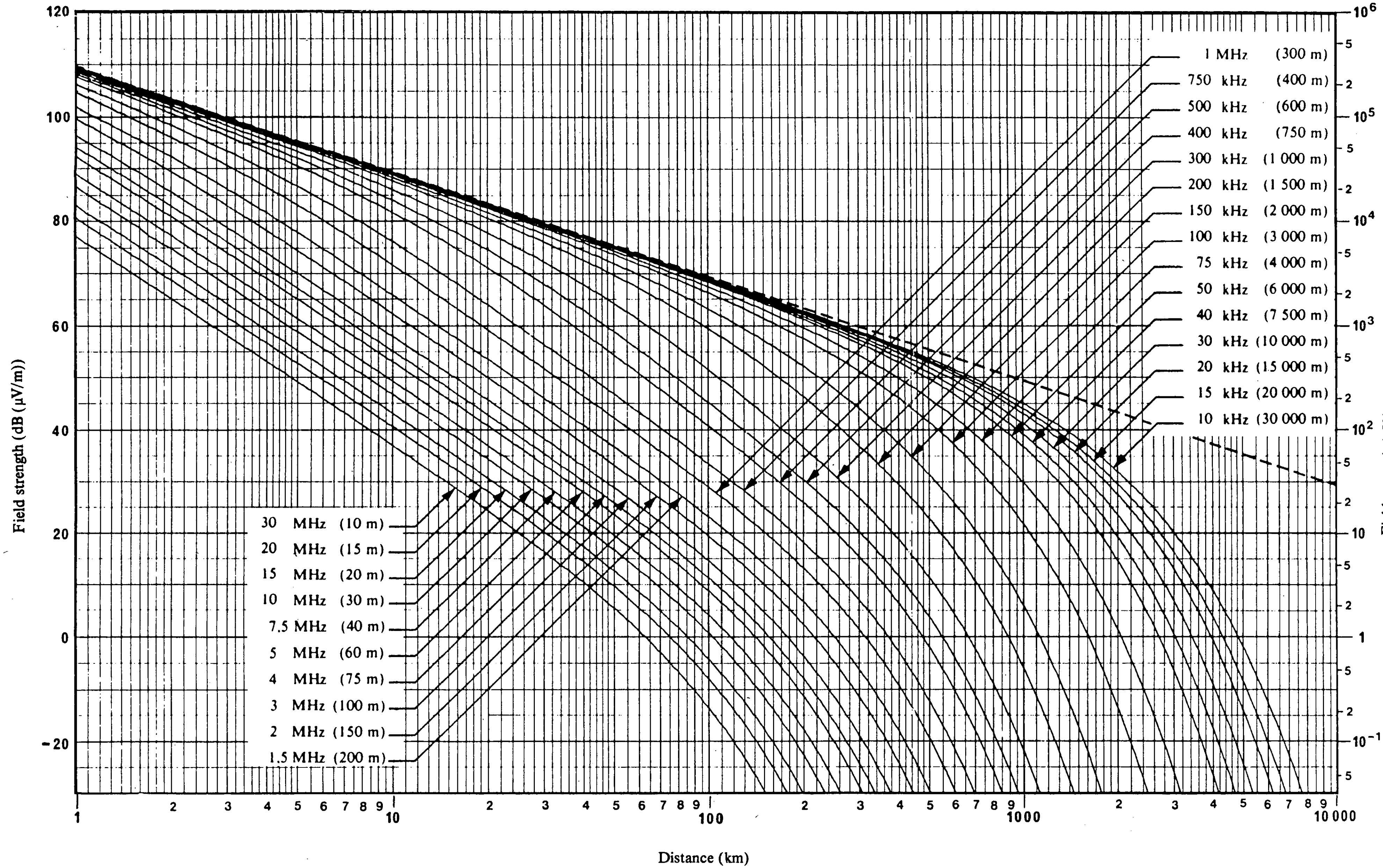


FIGURE 7 – *Ground-wave propagation curves; Medium dry ground, σ = 10⁻³ S/m, ε = 15*

– – – – Inverse distance curve

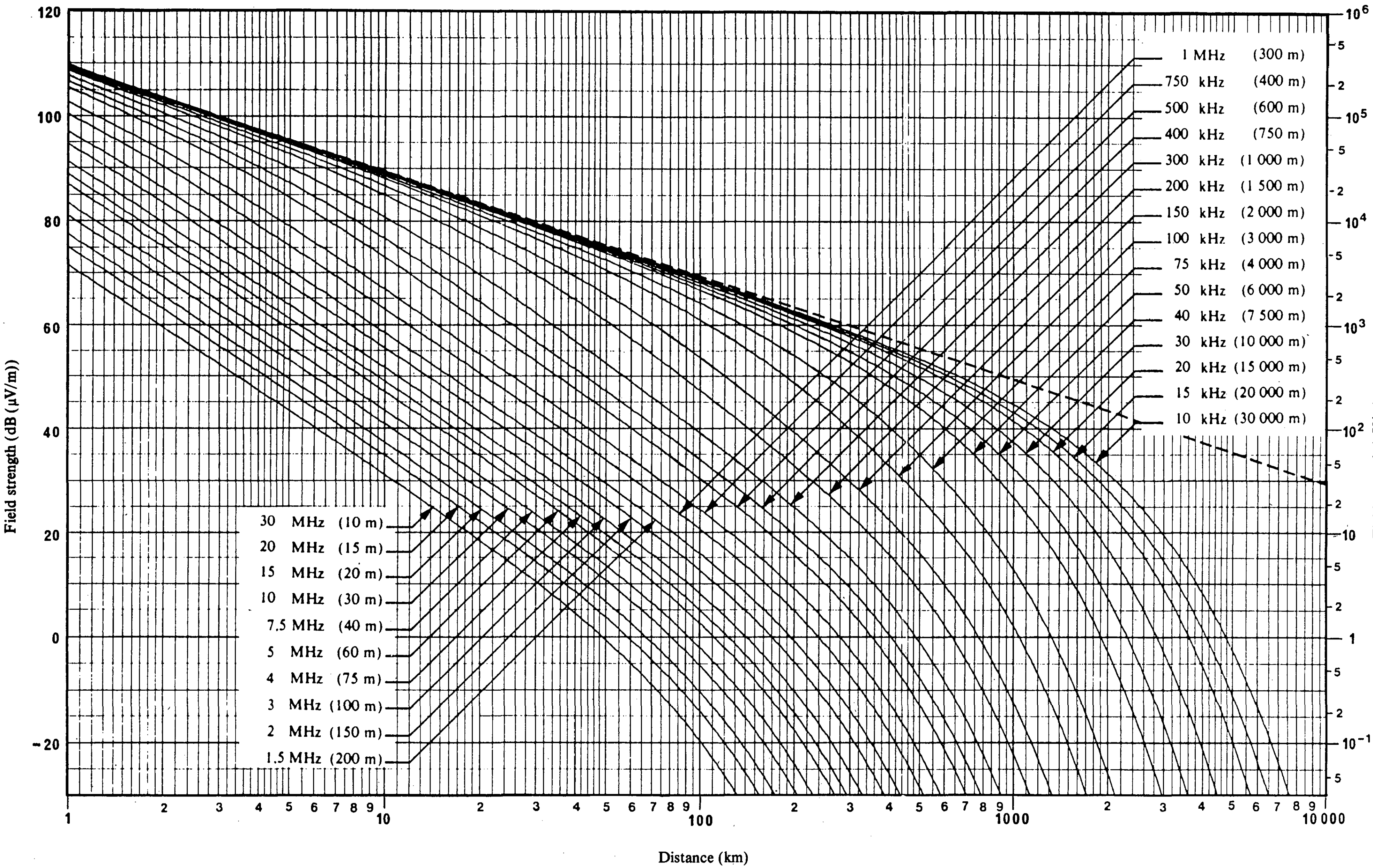


FIGURE 8 – *Ground-wave propagation curves; Dry ground,* $\sigma = 3 \times 10^{-4}$ *S/m,* $\varepsilon = 7$

– – – – Inverse distance curve

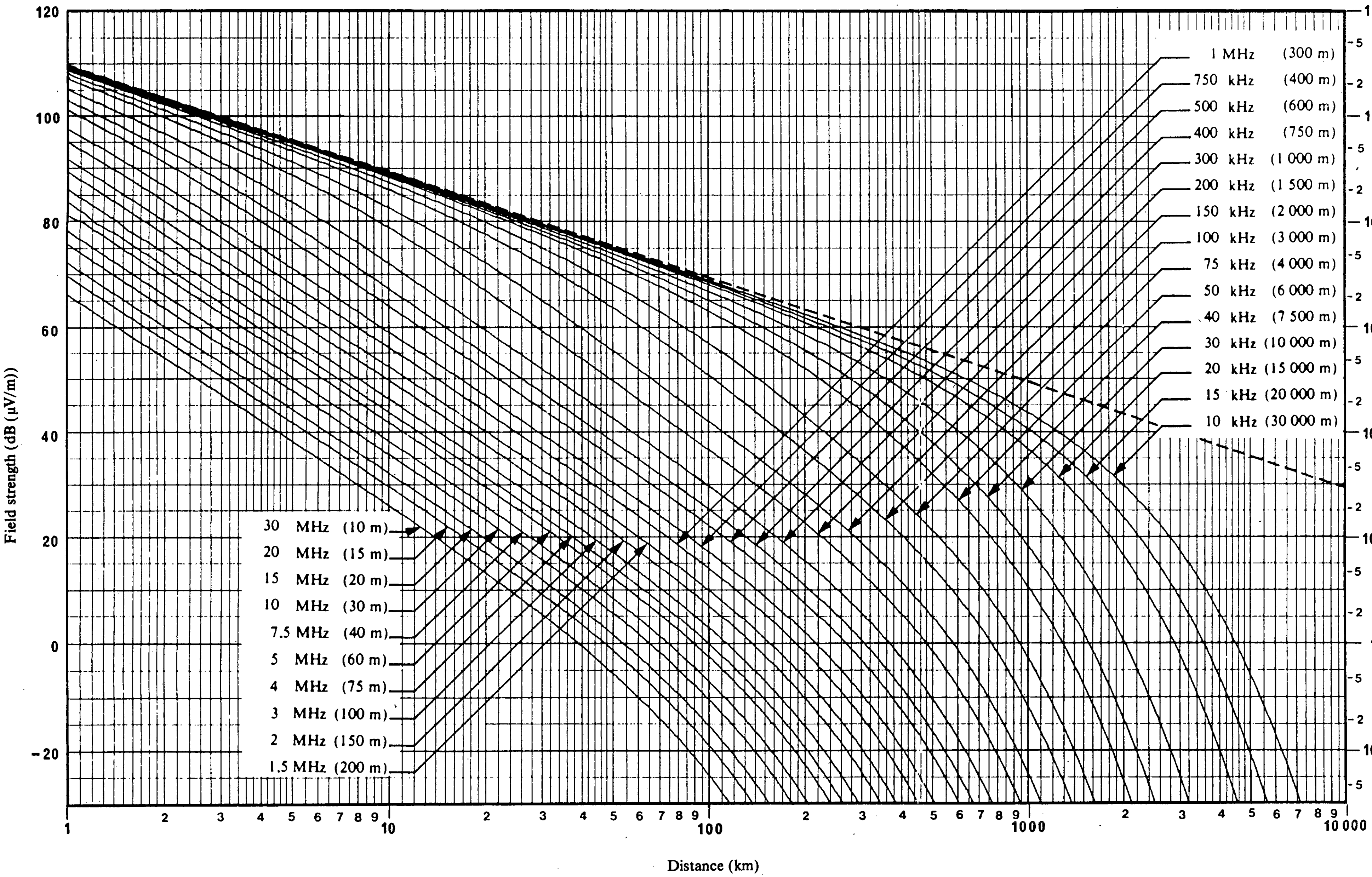


FIGURE 9 – *Ground-wave propagation curves; Very dry ground, σ = 10⁻⁴ S/m, ε = 3*

– – – – Inverse distance curve

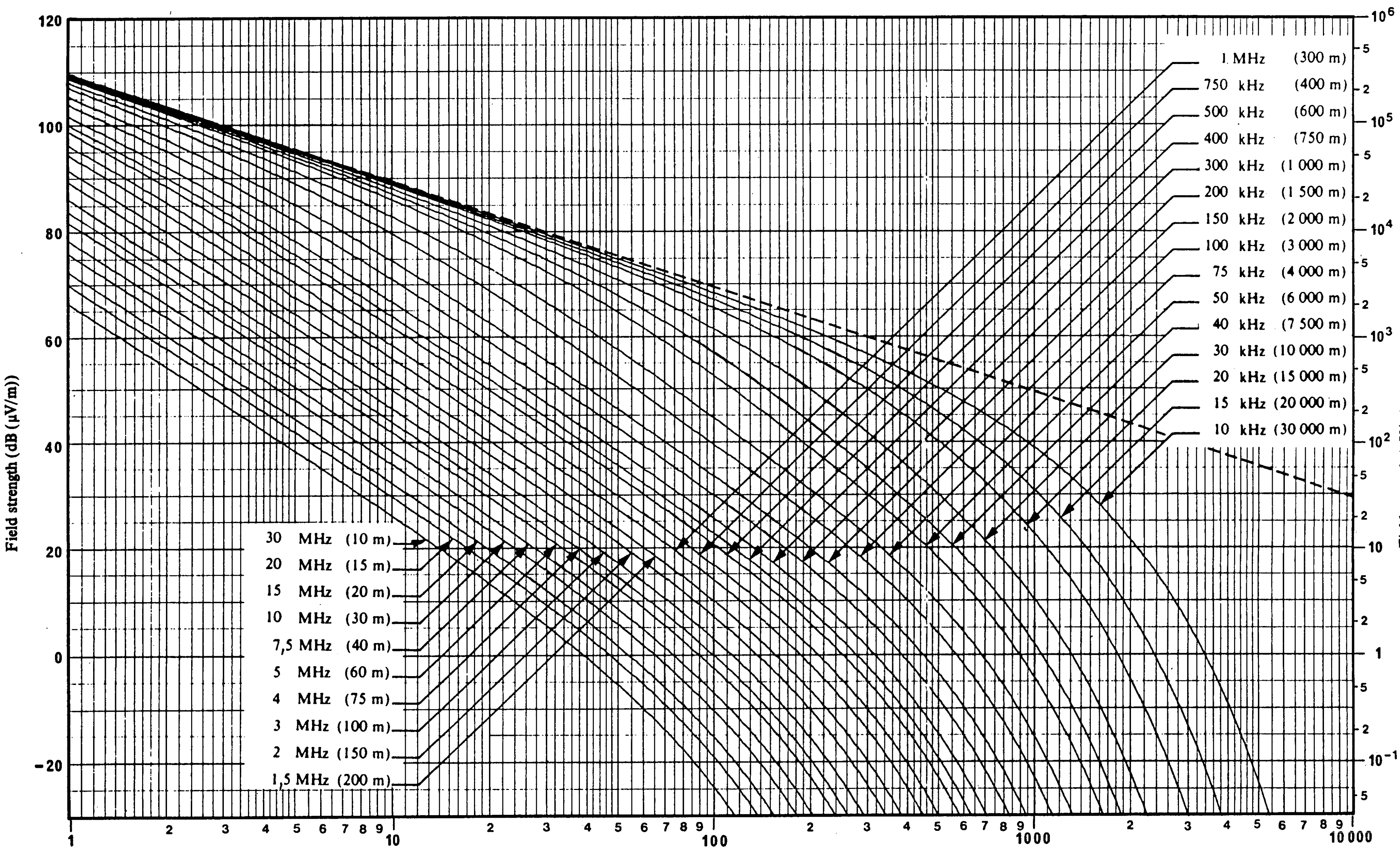


FIGURE 10 – *Ground-wave propagation curves; Fresh water ice, −1 °C, σ = 3 × 10^{-5} S/m, ε = 3*

– – – – Inverse distance curve

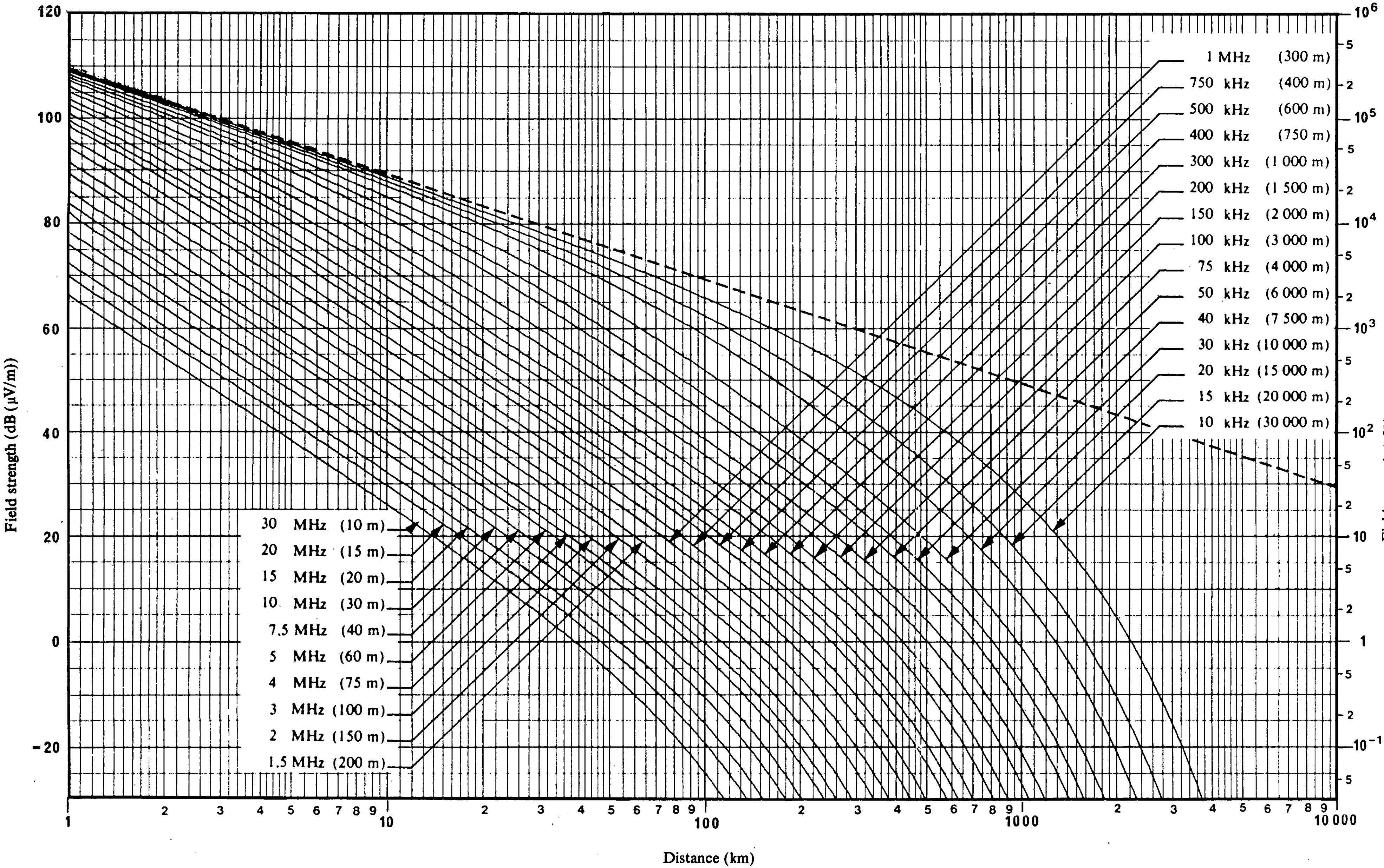


FIGURE 11 – *Ground-wave propagation curves; Fresh water ice, $-10\,°C$, $\sigma = 10^{-5}$ S/m, $\varepsilon = 3$*

– – – – Inverse distance curve

Note 1 – The inverse-distance curve shown in the figures, to which the curves are asymptotic at short distances, passes through the field value of 300 mV/m at a distance of 1 km. To refer the curves to other reference antennas, see Table I of Recommendation 341.

Note 2 – The GRWAVE program and the methods described in Report 714 have been used for these calculations.

Note 3 – The basic transmission loss corresponding to the same conditions for which the curves were computed may be obtained from the value of field strength E (dB(μV/m)) by using the following equation:

$$L_b \equiv A_i = 142.0 + 20 \log f_{MHz} - E \qquad \text{dB}$$

For the influence of the environment on both the transmitting and the receiving antenna, refer to Recommendation 341.

Note 4 – The curves give the total field at distance, r, with an error less than 1 dB when kr is greater than about 10, where $k = 2\pi/\lambda$. Near-field (i.e. induction and static field) effects may be included by increasing the field strength (in decibels) by:

$$10 \log \left\{ 1 - \frac{1}{(kr)^2} + \frac{1}{(kr)^4} \right\}$$

This gives the total field within ± 0.1 dB for sea and wet ground, and within ± 1 dB for any ground conductivity greater than 10^{-3} S/m.

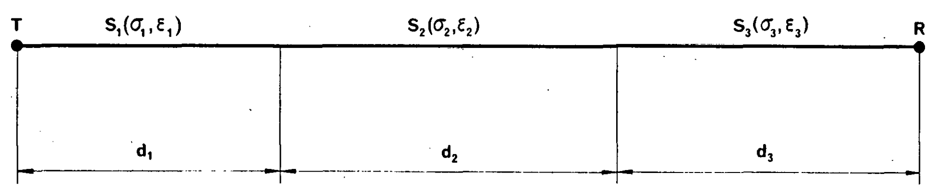
Note 5 – For either antenna, if the antenna site location is higher than the average terrain elevation along the path between the antennas, then the effective antenna height is the antenna height above the average terrain elevation along the path. This effective antenna height value should be compared to the computed value of antenna height limit in RECOMMENDS 3 to determine if the curves are valid for the path.

ANNEX II

APPLICATION TO MIXED PATHS

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

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



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

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

A received field strength E_R is then defined by:

$$E_R = E_1(d_1) - E_2(d_1) + E_2(d_1 + d_2) - E_3(d_1 + d_2) + E_3(d_1 + d_2 + d_3) \qquad (1)$$

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

$$E_T = E_3(d_3) - E_2(d_3) + E_2(d_3 + d_2) - E_1(d_3 + d_2) + E_1(d_3 + d_2 + d_1) \quad (2)$$

The required field is given by ½ $[E_R + E_T]$, the extension to more sections being obvious.

The method can in principle be extended to phase changes if the corresponding curves for phase as a function of distance over a homogeneous earth are available. Such information would be necessary for application to navigational systems. The Millington method is generally easy to use, particularly with the aid of a computer.

2. For planning purposes where the coverage of a certain transmitter is needed, *a graphical procedure*, based on the same method, is convenient for a rough and quick estimation of the distance at which the field strength has a certain value.

A short description of the graphical method is given here.

Figure 12 applies to a path having two different sections characterized by the values σ_1, ε_1 and σ_2, ε_2, and extending for distances d_1 and d_2 respectively. It is supposed that the modulus of the complex permittivity* (dielectric constant) $|\varepsilon'(\sigma_1, \varepsilon_1)|$ is greater than $|\varepsilon'(\sigma_2, \varepsilon_2)|$. For the distances $d > d_1$ the field-strength curve obtained by the Millington method (§ 1) lies between the curves corresponding to the two different electrical properties $E(\sigma_1, \varepsilon_1)$ and $E(\sigma_2, \varepsilon_2)$. At the distance $d = 2\ d_1$, where d_1 is the distance from the transmitter to the border separating the two sections, the Millington curve goes through the mid-point between the curves $E(\sigma_1, \varepsilon_1)$ and $E(\sigma_2, \varepsilon_2)$ provided that the field strength is labelled linearly in decibels. In addition, the same curve approaches an asymptote, which differs by m dB from the curve $E(\sigma_2, \varepsilon_2)$ as indicated in Fig. 12, where m is half the difference in decibels between the two curves $E(\sigma_1, \varepsilon_1)$ and $E(\sigma_2, \varepsilon_2)$ at $d = d_1$. The point at $d = 2\ d_1$ and the asymptote make it easy to draw the resulting field-strengh curve.

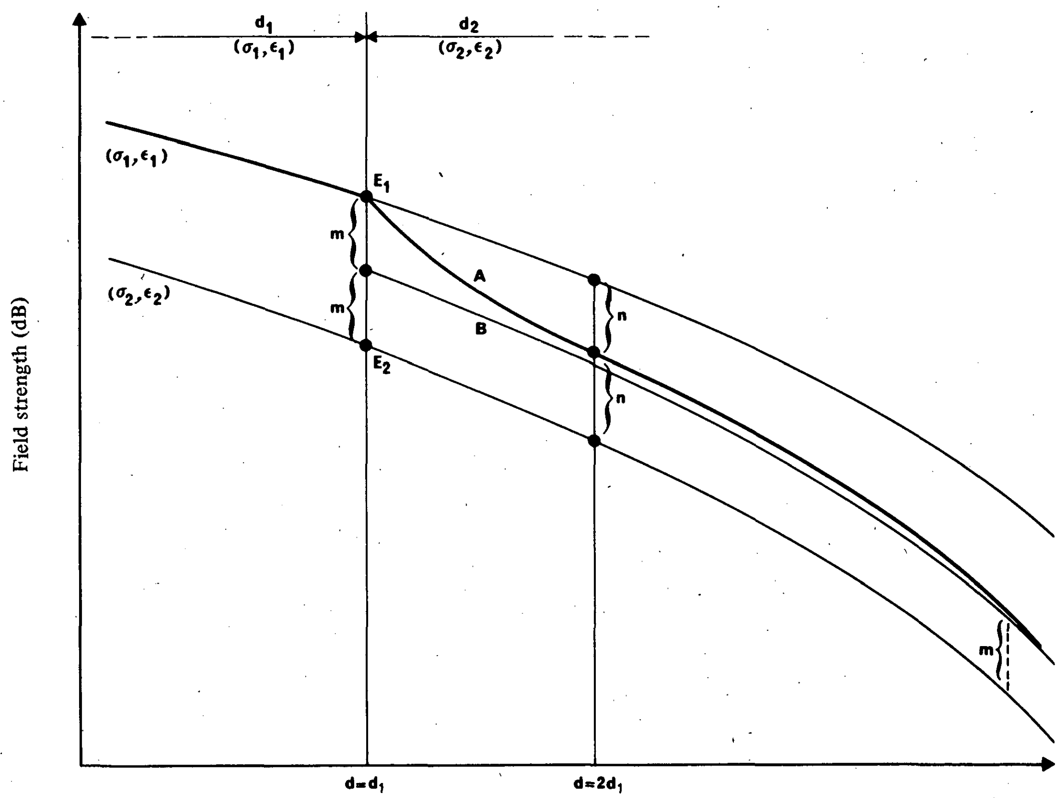


FIGURE 12 – *Comparison of results*

A: Millington field-strength curve
B: Asymptote

* See Report 229.

Figure 13 shows the Millington curve for a two-section path with electrical constants changing from σ_2, ε_2 to σ_1, ε_1 where the modulus of the complex permittivity $|\varepsilon'(\sigma_1, \varepsilon_1)| > |\varepsilon'(\sigma_2, \varepsilon_2)|$. The above-mentioned procedure can be applied here bearing in mind that the asymptote is now parallel to the curve of the $E(\sigma_1, \varepsilon_1)$.

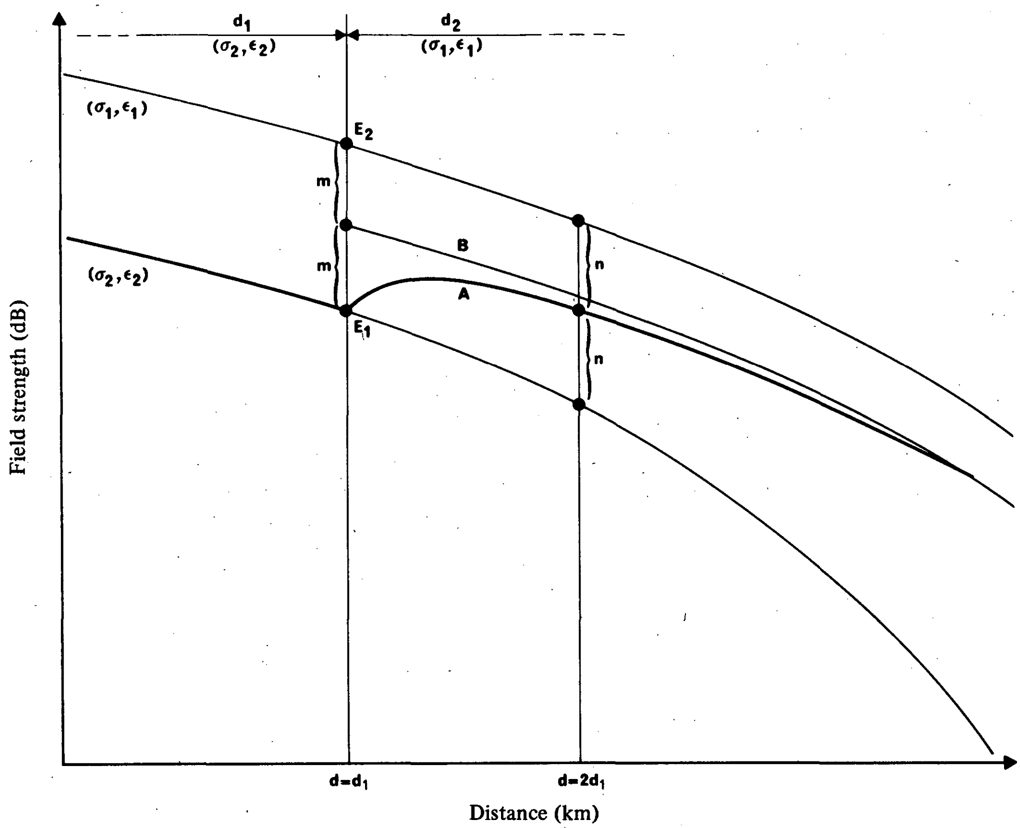


FIGURE 13 – *Comparison of results*

A: Millington field-strength curve
B: Asymptote

For paths consisting of more than two sections, each change can be considered separately in the same way as the first change. The resulting curve has to be a continuous curve, and the portions of curves are displaced parallel to the extrapolated curve at the end of the previous section.

For the use of the graphical method it would be convenient to have ground-wave propagation curves for some different sets of electrical constants at each frequency concerned. Such curves may be prepared from the curves of Annex I. However, suitable curves for the LF and MF bands can be found in Report 717 (published separately), which also contains samples of calculations over mixed paths.

The accuracy of the graphical method is dependent on the difference in slope of the field-strength curves, and its therefore to an extent dependent on the frequency. For the LF band, the difference between the method described in § 1 and this approximate method is normally negligible, but for the highest part of the MF band the differences in most cases will not exceed 3 dB. A full description of the graphical method is given in Stokke [1975].

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RECOMMENDATION 526-1

PROPAGATION BY DIFFRACTION

(1978–1982)

The CCIR,

CONSIDERING

that there is a need to provide engineering information for the calculation of field strengths over diffraction paths,

UNANIMOUSLY RECOMMENDS

that the information contained in Report 715 be used for calculation of field strengths over diffraction paths.

RECOMMENDATION 527-2

ELECTRICAL CHARACTERISTICS OF THE SURFACE OF THE EARTH*

(1978-1982-1990)

The CCIR,

CONSIDERING

(a) that ground-wave propagation is mainly governed by the electrical characteristics of the ground, including its vegetation; and the extent to which lower strata influence the effective values of the electrical characteristics of the Earth depends on the depth of penetration of the radio energy;

(b) that values of the relative permittivity and the conductivity are needed as a function of frequency for various types of surface;

(c) that information on the variation of the penetration depth with frequency is required,

UNANIMOUSLY RECOMMENDS

that the curves in Annex I be used in the calculation of ground-wave field strength at the frequencies concerned and under the conditions stated.

ANNEX I

The following points are to be especially noted with regard to the curves:

- The values of relative permittivity (dielectric constant) and conductivity in Fig. 1 for different types of ground indicate the approximate range of values which may be met under different conditions, but in extreme cases values outside this range may occur. In very wet fertile areas higher values of conductivity will be found, while in mountainous and arctic regions the conductivity at frequencies below 100 MHz may be as low as 10^{-5} S/m. Also in cases of snow-covered ground, lower values of permittivity than shown in curve E of Fig. 1 may be encountered. The water in lakes and rivers has a conductivity that increases with the concentration of impurities.
- At low frequencies, except for sea water, strata down to a depth of 100 m or more must be taken into account as shown in Fig. 2. This is of particular importance when the upper strata are of lower conductivity and the energy can therefore penetrate more readily to lower levels. Such cases, for example, occur for ice-covered lakes and ocean areas.
- A description of attenuation due to vegetation is given in Report 1145.

* See also Report 229.

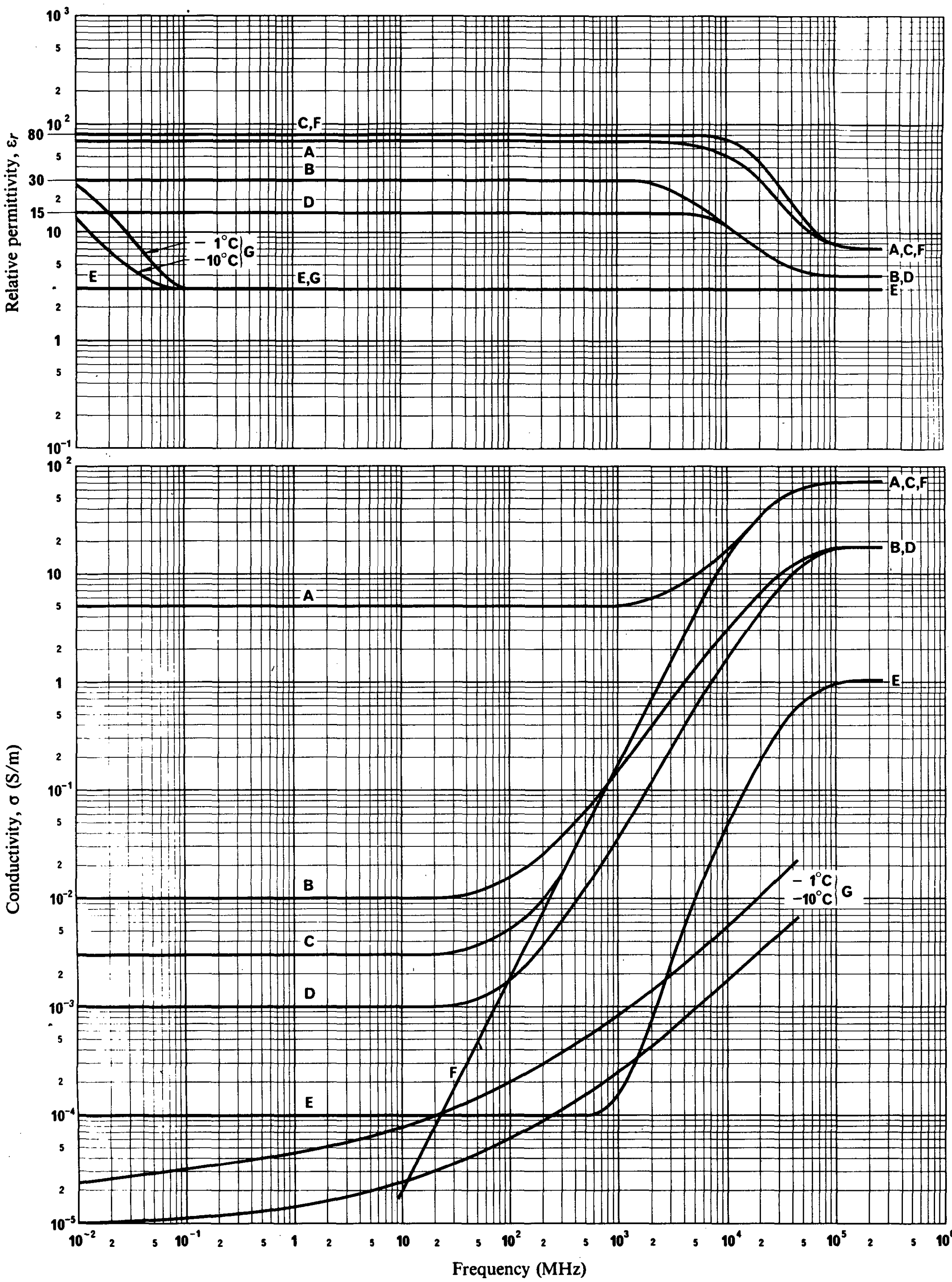

FIGURE 1 – *Relative permittivity, ε_r, and conductivity, σ, as a function of frequency*

A: sea water (average salinity), 20° C
B: wet ground
C: fresh water, 20° C
D: medium dry ground
E: very dry ground
F: pure water, 20° C
G: ice (fresh water)

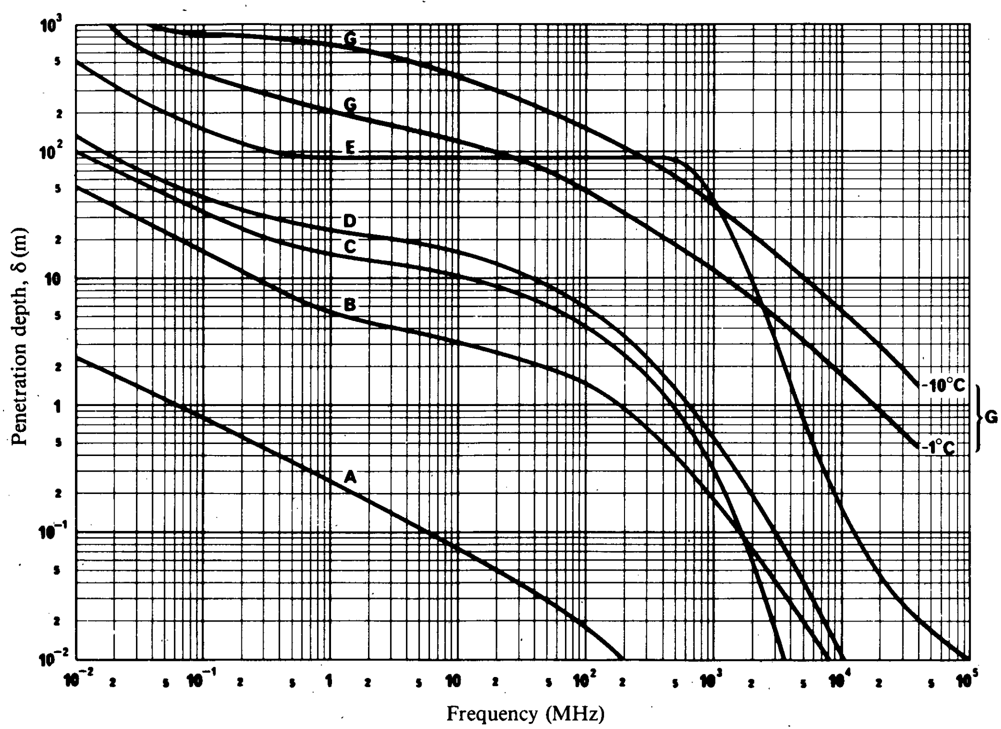

FIGURE 2 – *Penetration depth δ as a function of frequency*

A: sea water
B: wet ground
C: fresh water
D: medium dry ground
E: very dry ground
G: ice (fresh water)

SECTION 5C: EFFECTS OF THE ATMOSPHERE (RADIOMETEOROLOGY)

RECOMMENDATION 369-4

REFERENCE ATMOSPHERE FOR REFRACTION

(Question 2/5)

(1959-1963-1966-1978-1982-1990)

The CCIR,

CONSIDERING

(a) that the dependence of the refractive index n of the atmosphere at radio frequencies upon the height h is well expressed by an exponential law:

$$n(h) = 1 + a \times \exp(-bh) \tag{1}$$

where a and b are parameters which can be determined statistically for different climates,

(b) that there is a need for a common reference to facilitate comparisons of calculation,

UNANIMOUSLY RECOMMENDS

that the reference atmosphere for refraction be given by the following formula:

$$n(h) = 1 + 315 \times 10^{-6} \times \exp(-0.136\ h) \tag{2}$$

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

RECOMMENDATION 453-2

THE FORMULA FOR THE RADIO REFRACTIVE INDEX

(Question 2/5)

(1970–1986–1990)

The CCIR,

CONSIDERING

the necessity of utilizing a single formula for calculation of the index of refraction of the atmosphere,

UNANIMOUSLY RECOMMENDS

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

$$n = 1 + N \times 10^{-6} \tag{1}$$

where

N is the refractivity expressed by:

$$N = \frac{77.6}{T} \left(P + 4810 \frac{e}{T} \right) \tag{2}$$

P: atmospheric pressure (mb),*
e: water vapour pressure (mb),*
T: absolute temperature (K).

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* It should be noted that the World Meteorological Organization has recommended the adoption of hPa, which is numerically identical to mb, as the unit of atmospheric pressure.

RECOMMENDATION 676

ATTENUATION BY ATMOSPHERIC GASES

(Question 2/5)

(1990)

The CCIR,

CONSIDERING

the necessity of estimating the attenuation by atmospheric gases on terrestrial and slant paths,

UNANIMOUSLY RECOMMENDS

that the procedures specified in Report 719 be used for the calculation of attenuation by atmospheric gases.

RECOMMENDATION 677

RADIO EMISSION FROM NATURAL SOURCES AT FREQUENCIES ABOVE 50 MHz

(Question 2/5)

(1990)

The CCIR,

CONSIDERING

that knowledge of the sky brightness temperature is required for assessing the limitations of system performance by noise,

UNANIMOUSLY RECOMMENDS

the use of Report 720 for the calculation of sky brightness temperature for frequencies above 50 MHz.

RECOMMENDATION 678

CHARACTERIZATION OF THE NATURAL VARIABILITY OF PROPAGATION PHENOMENA

(Question 2/5)

(1990)

The CCIR,

CONSIDERING

(a) that knowledge of the natural variability of propagation phenomena is required for use in telecommunication system design;

(b) that a prediction procedure exists for the estimation of the statistics of the year-to-year variations in the annual worst month time fraction of excess as defined in Recommendation 581,

UNANIMOUSLY RECOMMENDS

1. that Fig. 2 of Report 723 be used for the estimation of the expected year-to-year variation of the annual worst month time fraction of excess;

2. that the expected variation about a long-term average predicted value be reported as a function of return period.

Note – The return period is defined as $1/p$ where p is the probability of exceeding the specified value in an analysis interval. For example, the median value of a long series of annual worst month time fraction of excess values would have a 2 year return period.

RECOMMENDATION 581-2

THE CONCEPT OF "WORST MONTH"

(Question 2/5)

(1982-1986-1990)

The CCIR,

CONSIDERING

(a) that performance criteria for radiocommunication systems often refer to "any month" as the period of reference;

(b) that for the design of such systems it is necessary to have statistics of propagation effects that are relevant to the period of reference of the performance criteria;

(c) that consequently there is a need for an unambiguous definition for the period of reference,

UNANIMOUSLY RECOMMENDS

1. that the fraction of time during which a preselected threshold is exceeded in the worst month of a year is referred to as "the annual worst-month time fraction of excess";

2. that the statistic relevant for the performance criteria referring to "any month" is the long-term average of the annual worst-month time fraction of excess;

3. that the worst month of a year for a preselected threshold for any performance degrading mechanism, be that month in a period of twelve consecutive calendar months, during which the threshold is exceeded for the longest time. The worst month is not necessarily the same month for all threshold levels.

Note – Report 723 presents a model for the conversion of the average annual time fraction of excess to the average annual worst-month time fraction of excess. Global values of the parameters of this model are given, as well as more detailed values for several regions of the world.

SECTION 5D: ASPECTS RELATIVE TO THE TERRESTRIAL BROADCASTING AND MOBILE SERVICES

RECOMMENDATION 370-5*

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

Broadcasting services

(Study Programme 7D/5)

(1951-1953-1956-1959-1963-1966-1974-1978-1982-1986)

The CCIR,

CONSIDERING

(a) that there is a need to give guidance to engineers in the planning of broadcast services in the VHF and UHF bands for all climatic conditions;

(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),

UNANIMOUSLY RECOMMENDS

that the curves given in Annex I be adopted for provisional use with the following conditions:

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

2. The curves are based upon measurement data mainly relating to temperate climates containing "cold" and "warm" seas, e.g. the North Sea and the Mediterranean Sea. Recent extensive studies reveal that propagation conditions in certain areas of super-refractivity bounded by "hot" seas are substantially different. Interim proposals for dealing with this situation are contained in § 3.6 of Report 239.

3. 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.

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

5. The parameter Δh (see Recommendation 310) is used to define the degree of terrain irregularity; for broadcasting services it is applied in the range 10 km to 50 km from the transmitter (see Fig. 6 and Report 239).

6. Methods for determining field strengths over mixed land and sea paths are described in Report 239.

7. The field strength depends upon the height of the receiving antenna as well as the nature of its immediate surroundings. Data describing antenna height gain are given in § 2.4, 3.4 and Fig. 17. Further information concerning both effects is given in Reports 239 and 567.

8. Account should be taken of the attenuation through forest and vegetation (see Fig. 2, Report 236).

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* This Recommendation is brought to the attention of Study Groups 10 and 11.

** It must be emphasized that the curves of this Recommendation are intended for use in the planning of broadcasting 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.

9. Improved accuracy of predicted field strengths can be obtained by taking into account terrain local to the receiving location by means of a terrain clearance angle. The method is described in Report 239. In hilly and mountainous regions the effects of scattering from the terrain should also be taken into account.

ANNEX I

1. Introduction

1.1 The propagation curves represent field-strength values in VHF and UHF bands as a function of various parameters; some curves refer to land paths, others refer to sea paths. The land path curves were prepared from data obtained mainly from temperate climates as encountered in Europe and North America. The sea path curves were prepared from data obtained mainly from the Mediterranean and the North Sea regions.

1.2 The propagation curves represent the field-strength values exceeded at 50% of the locations for different percentages of time. They correspond to different transmitting antenna heights and a receiving antenna height of 10 m. The land path curves refer to a value of Δh = 50 m which generally apply to rolling terrain commonly found in Europe and North America.

1.3 For locations other than 50%, probability distribution curves are also presented in this Annex.

1.4 Estimates of mixed-path field strengths should be made in accordance with the methods described in Report 239.

1.5 Since most of the measurements relate to distances less than 500 km, the results given by these curves are less reliable above this distance. The sections of the curves in dashed lines, obtained by extrapolation, are only intended as a general guide to likely values of field strength.

1.6 All these curves are based on long-term values (several years) and may be regarded as representative of the mean climatic conditions prevailing in all the temperate regions. It should be noted, however, that for brief periods of time (e.g., for some hours or even days), field strengths may be obtained which are much higher than those shown by these curves, particularly over relatively flat terrain.

1.7 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. 1a and 1b 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 $-0.5\ (\Delta N + 40)$ 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 $0.2\ (N_s - 310)$ 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.

2. VHF bands

2.1 The curves in Figs. 1a, 2a, 3a and 4a represent field-strength values exceeded at 50% of the locations and for 50%, 10%, 5% and 1% of the time for land paths where Δh of 50 m is considered representative. For a different value of Δh, a correction should be applied to the curves as shown in Fig. 7. (See also Report 239.) For locations other than 50%, corrections may be obtained from the distribution curve in Fig. 5.

2.2 The curves in Figs. 1b, 2b, 2c, 3b, 3c, 4b and 4c represent field-strength values exceeded at 50% of the locations for 50%, 10%, 5% and 1% of the time for sea paths in cold seas and warm seas, the climatic characteristics of those areas being likened to those observed in the North Sea and the Mediterranean, respectively.

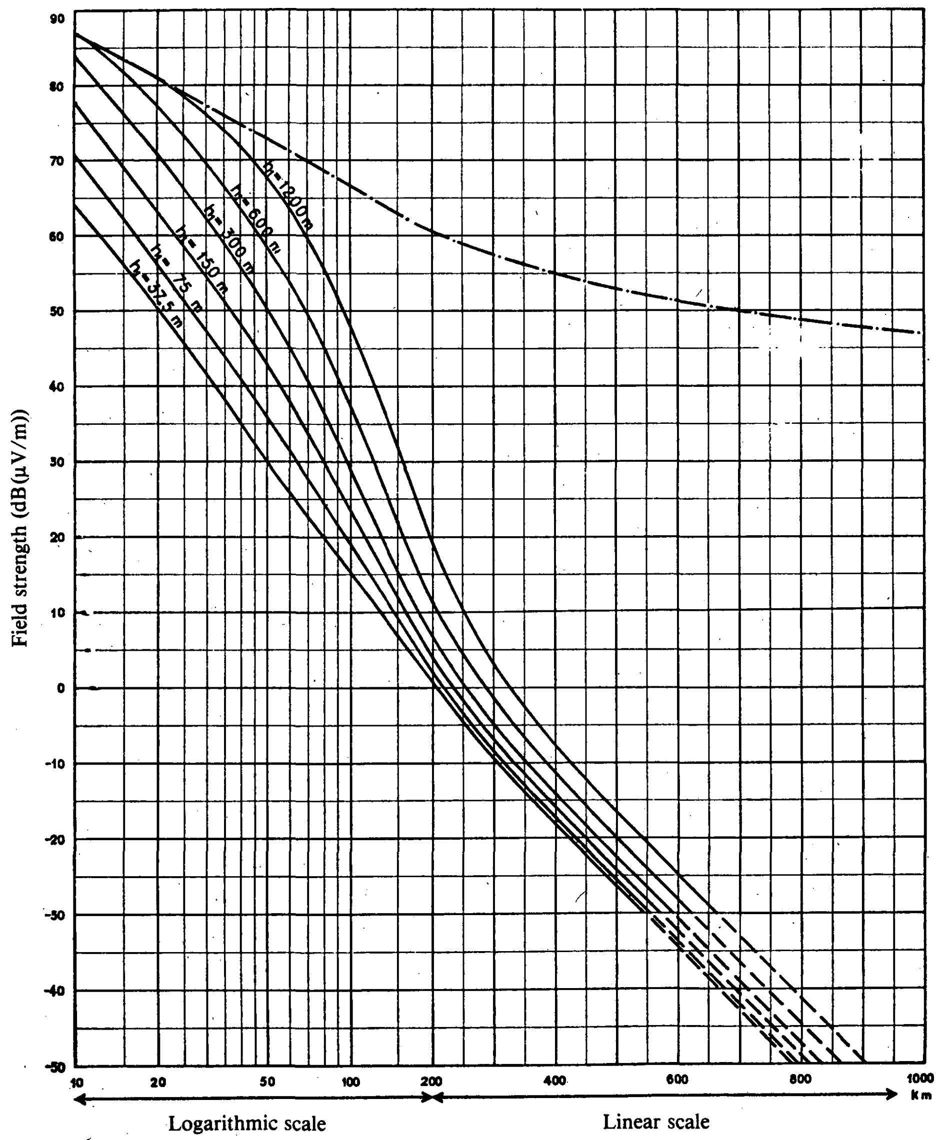

FIGURE 1a – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

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

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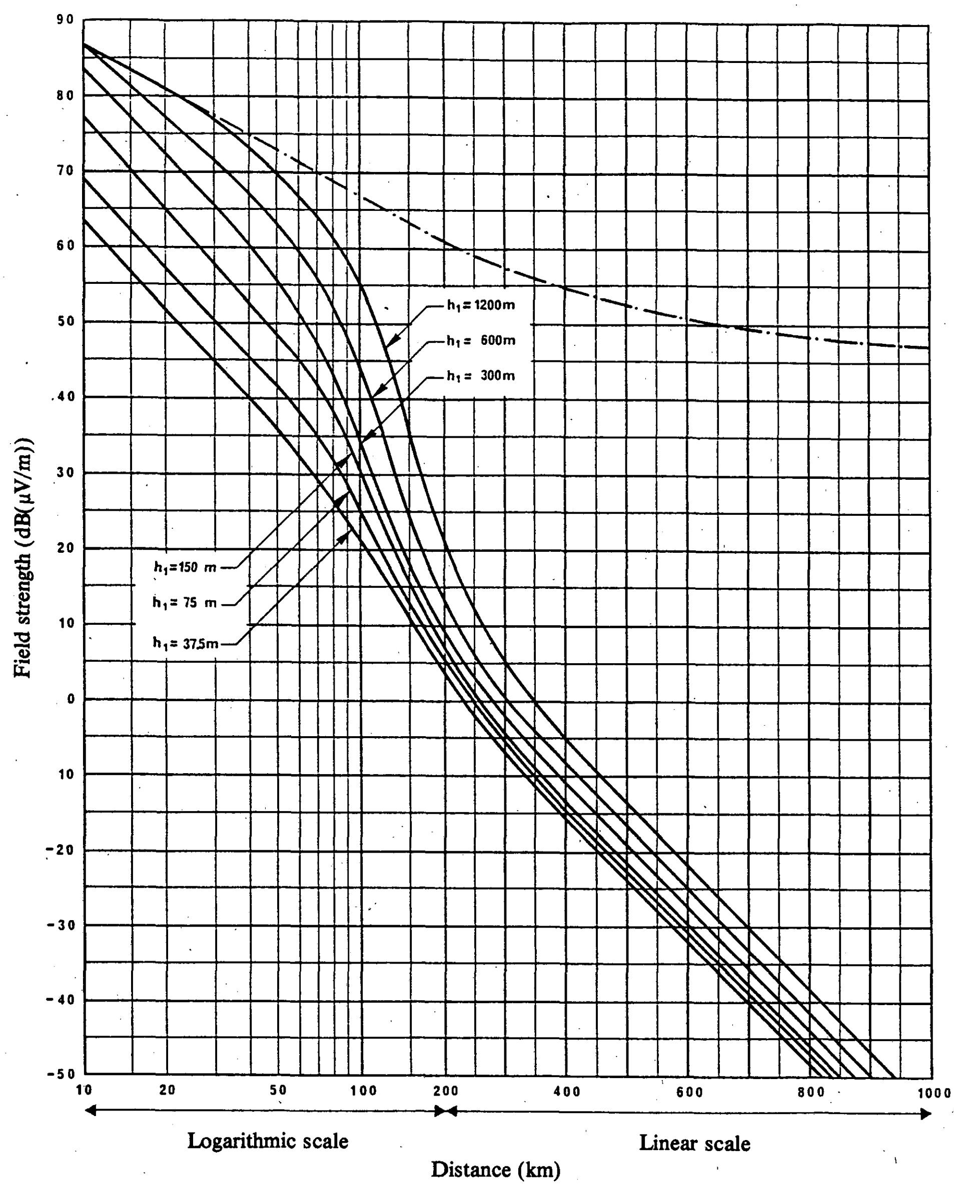

FIGURE 1b – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

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

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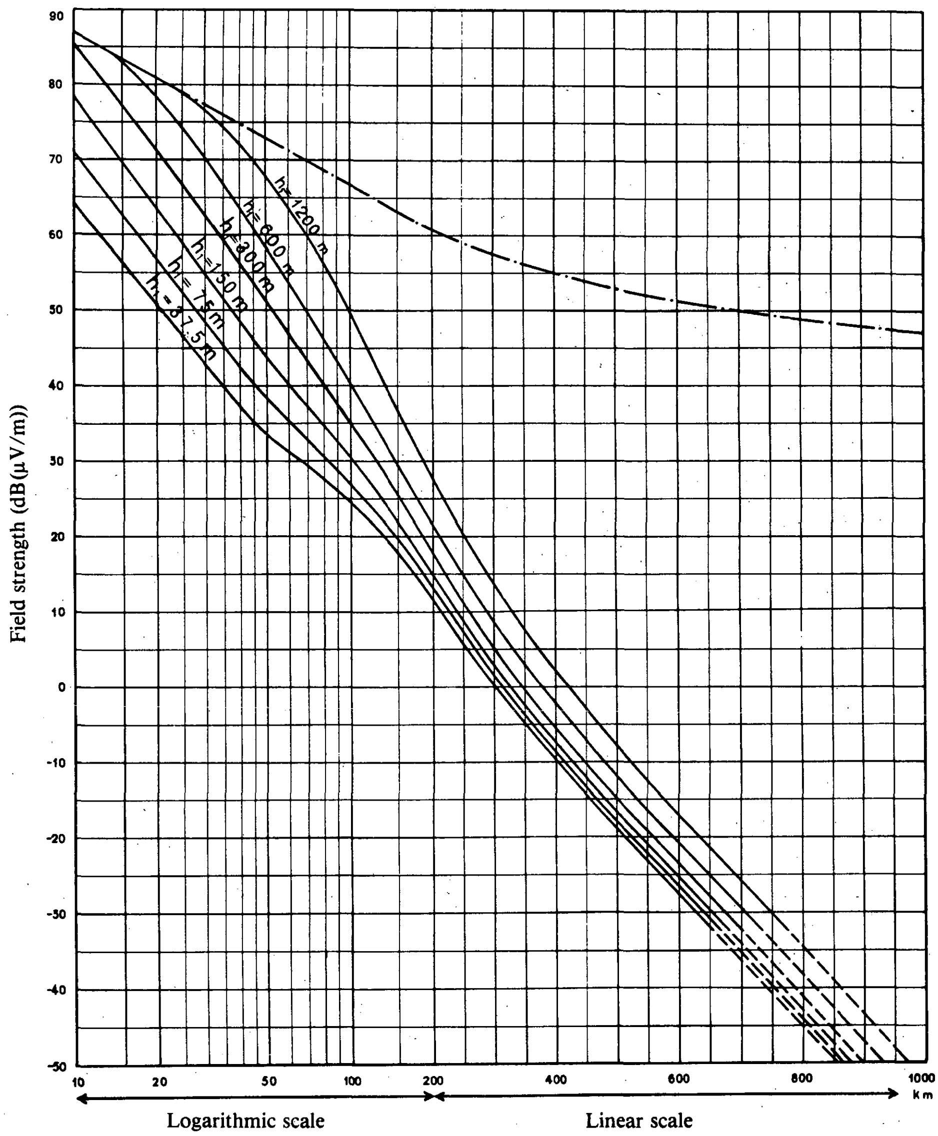

FIGURE 2*a* – *Field strength (dB(µV/m)) for 1 kW e.r.p.*

Frequency: 30 to 250 MHz (Bands I, II and III) - Land - 10% of the time - 50% of the locations - h_2 = 10 m - Δh = 50 m

—·— Free space

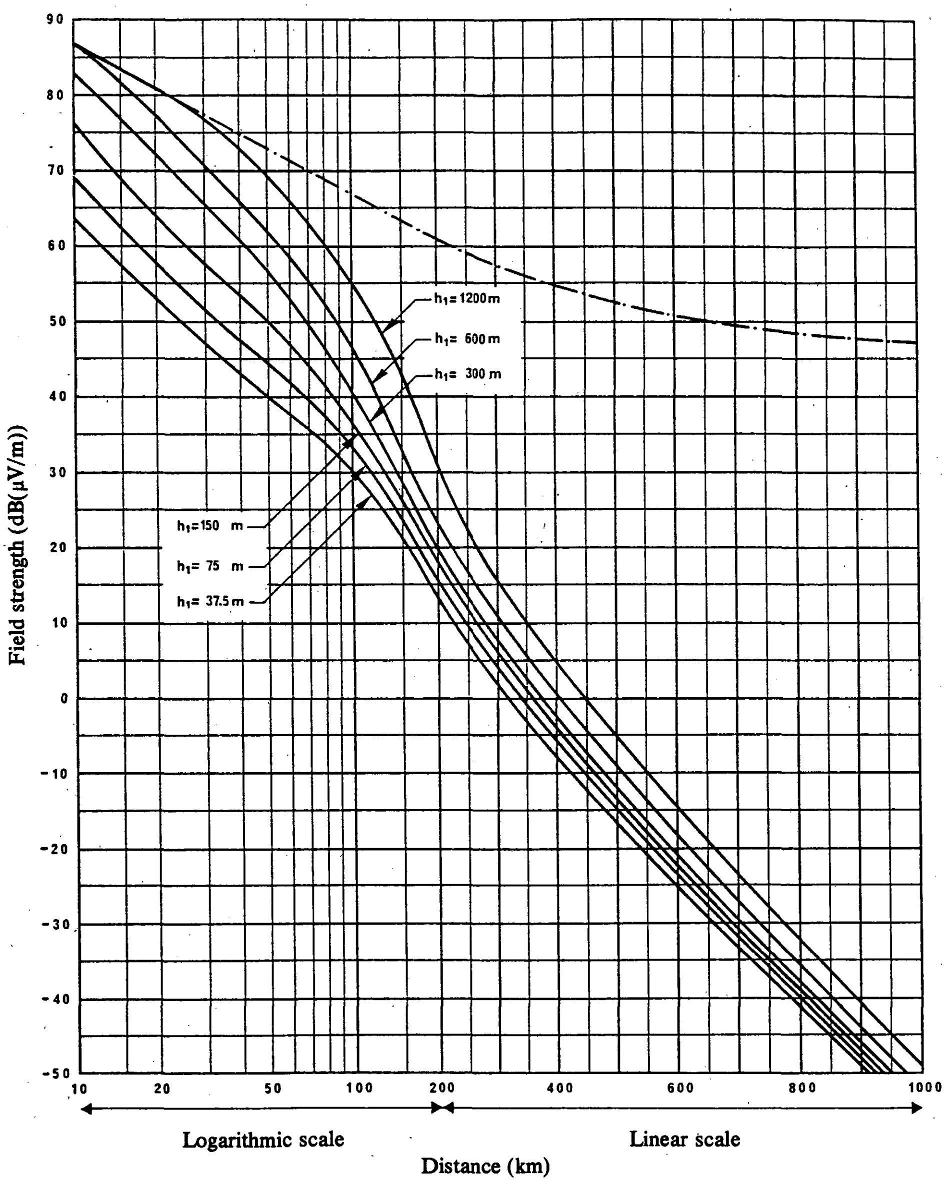

FIGURE 2b – *Field strength (dB(µV/m)) for 1 kW e.r.p.*

Frequency: 30 to 250 MHz (Bands I, II and III) – Cold sea – 10% of the time – 50% of the locations – h_2 = 10 m

— · — Free space

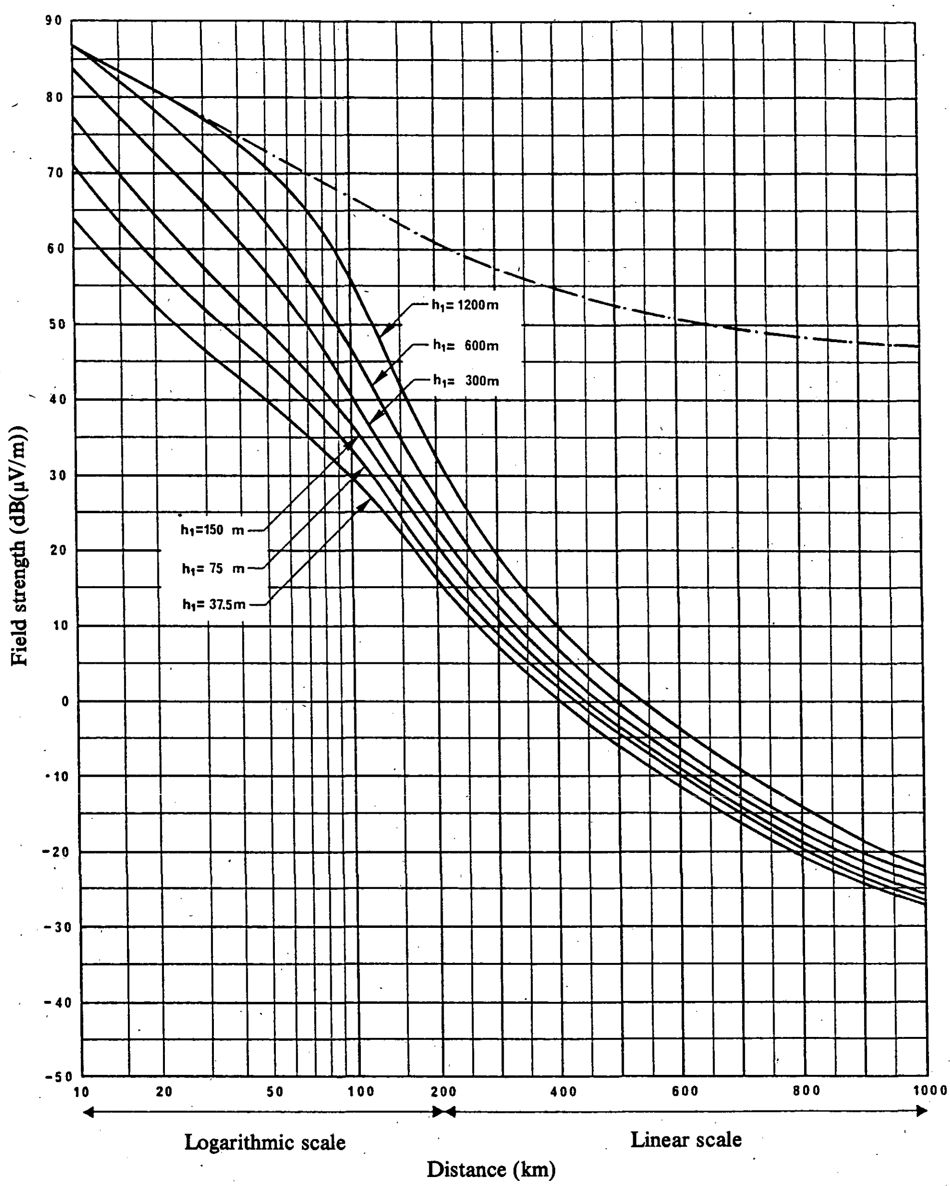

FIGURE 2c – *Field strength (dB(µV/m)) for 1 kW e.r.p.*

Frequency: 30 to 250 MHz (Bands I, II and III) - Warm sea - 10% of the time - 50% of the locations - h_2 = 10 m

—·— Free space

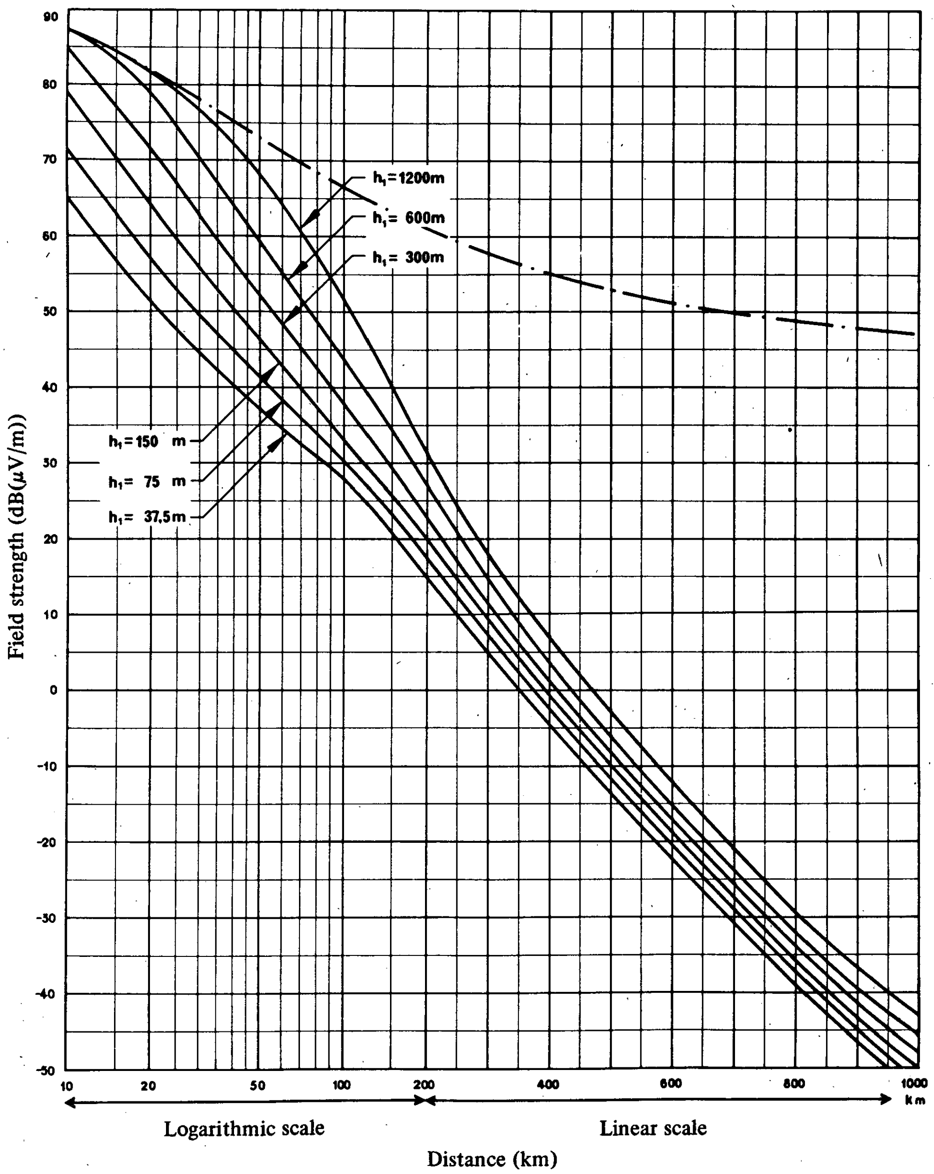

FIGURE 3*a* – *Field strength (dB(µV/m)) for 1 kW e.r.p.*
Frequency: 30 to 250 MHz (Bands I, II and III) - Land - 5% of the time - 50% of the locations - $h_2 = 10$ m - $\Delta h = 50$ m

— · — Free space

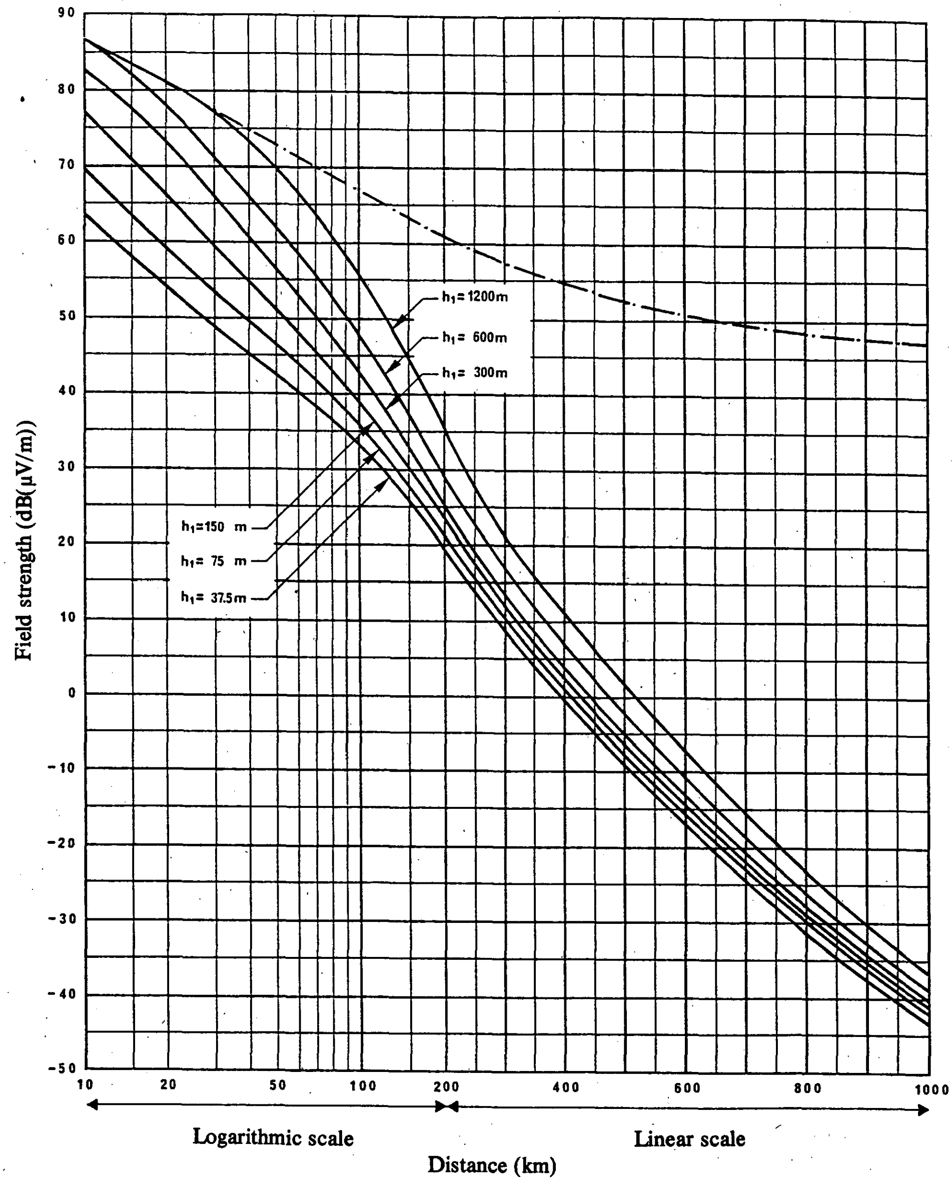

FIGURE 3b – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 30 to 250 MHz (Bands I, II and III) – Cold sea - 5% of the time - 50% of the locations - h_2 = 10 m

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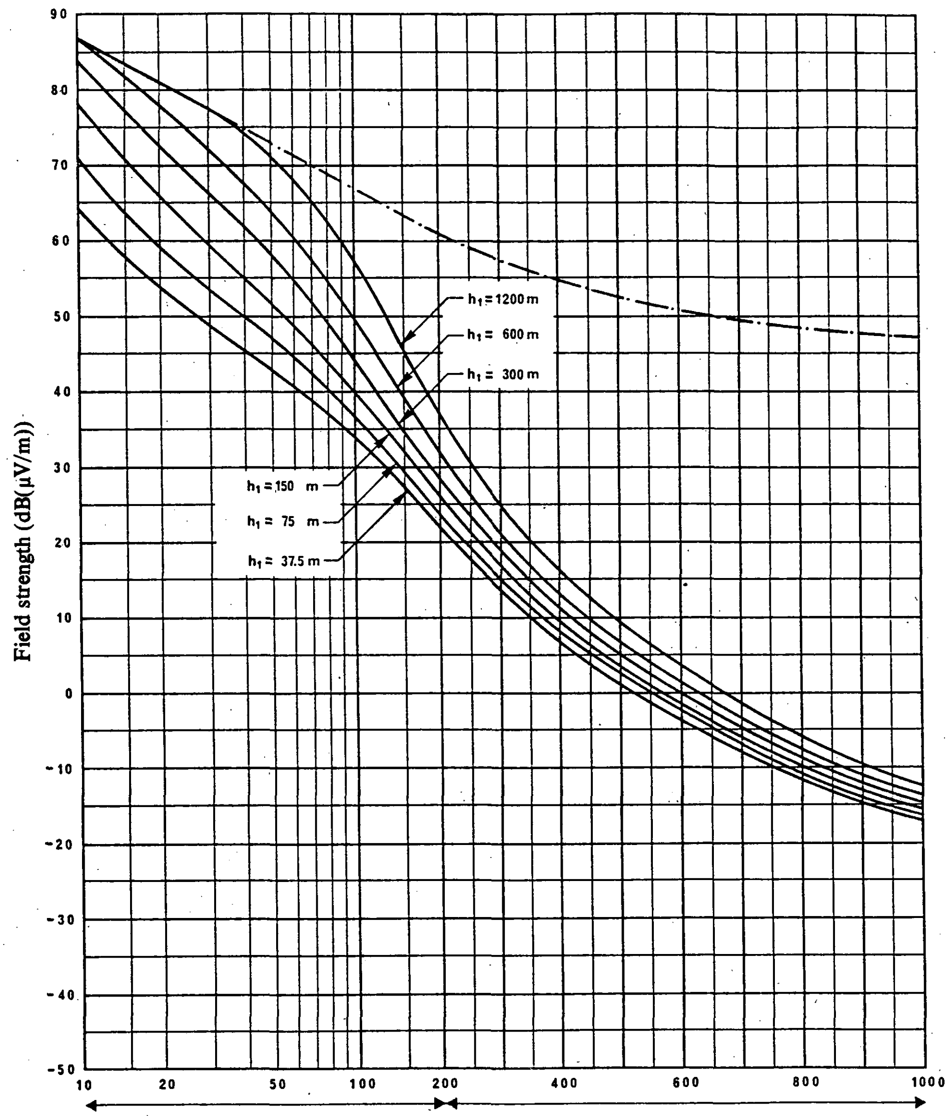

FIGURE 3c – *Field strength (dB(µV/m)) for 1 kW e.r.p.*

Frequency: 30 to 250 MHz (Bands I, II and III) - Warm sea - 5% of the time - 50% of the locations - h_2 = 10 m

— · — Free space

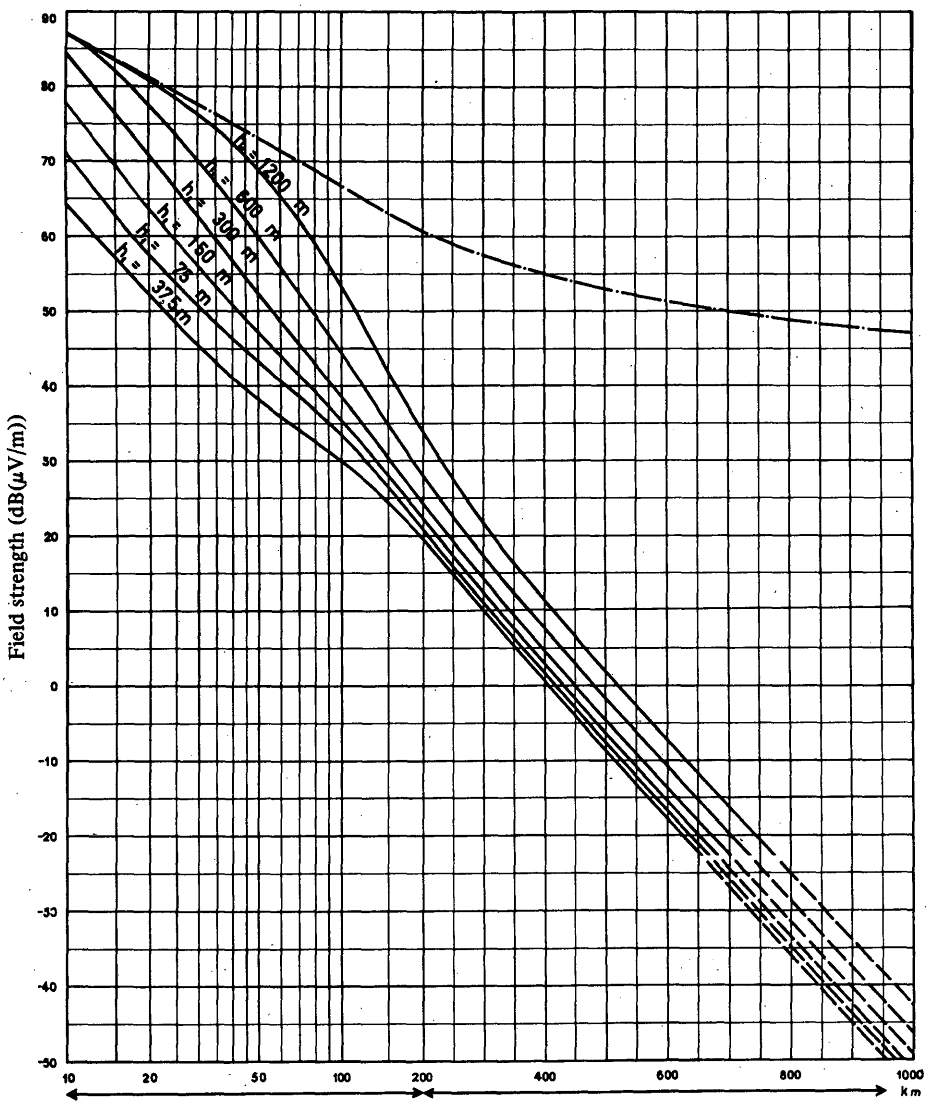

FIGURE 4*a* – *Field strength (dB(μV/m)) for 1 kW e.r.p.*
Frequency: 30 to 250 MHz (Bands I, II and III) - Land - 1% of the time - 50% of the locations - $h_2 = 10$ m - $\Delta h = 50$ m

—·— Free space

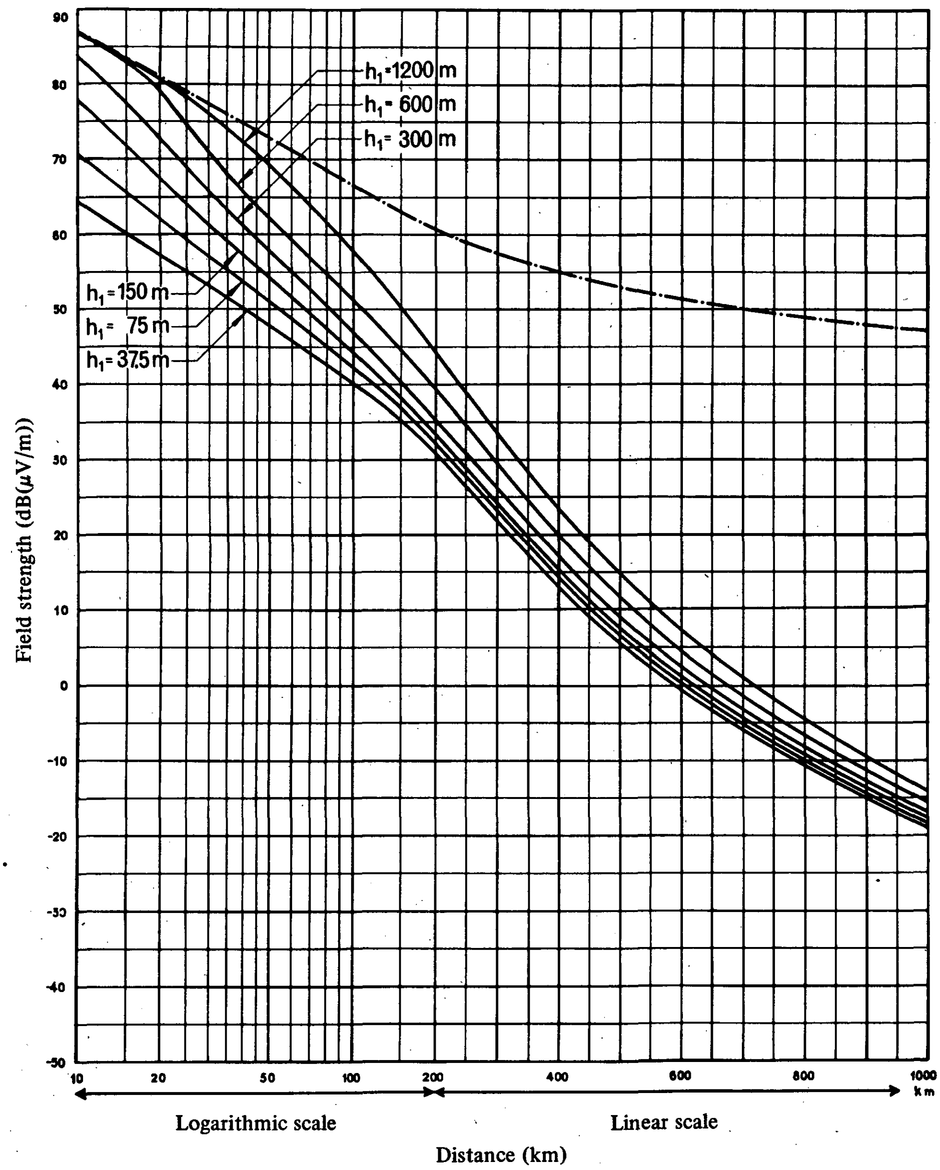

FIGURE 4*b* – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 30 to 250 MHz (Bands I, II and III) - Cold sea - 1% of the time - 50% of the locations - h_2 = 10 m

—·— Free space

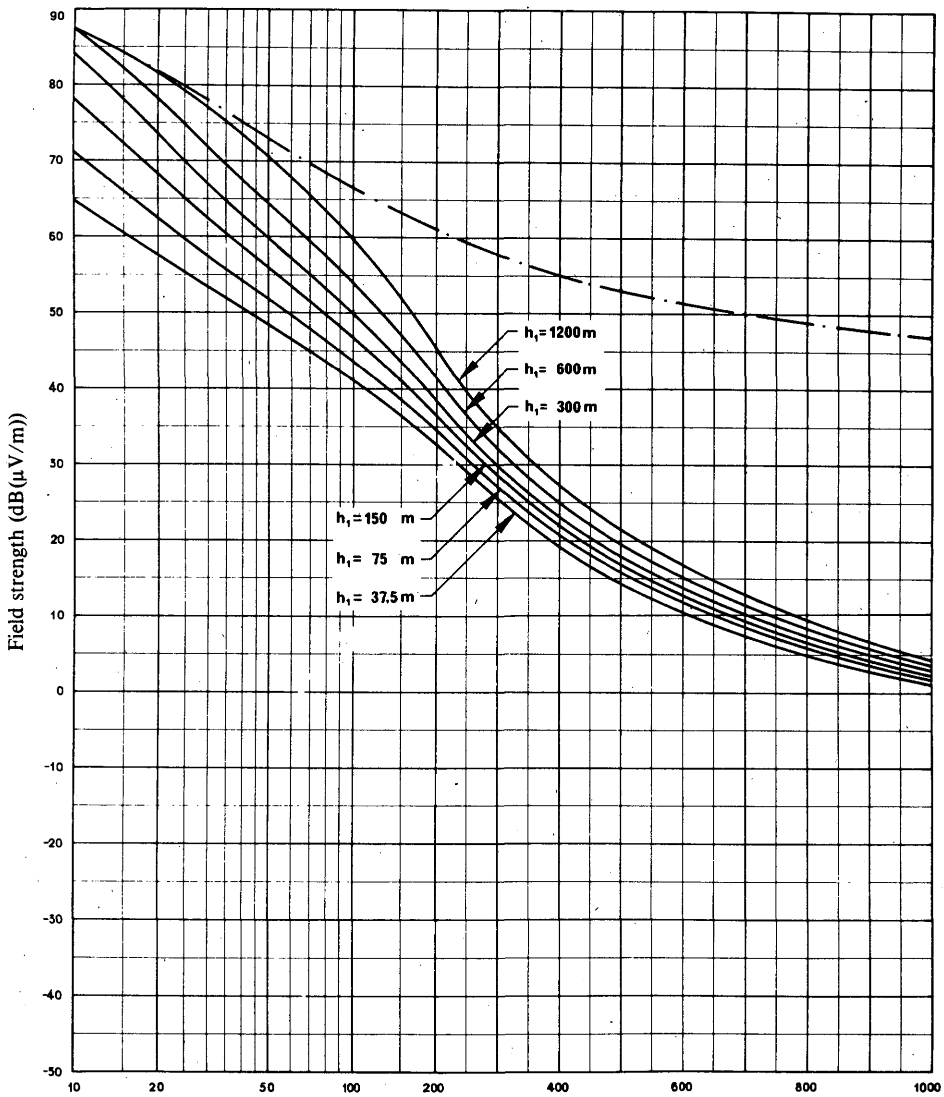

FIGURE 4*c* – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 30 to 250 MHz (Bands I, II and III) – Warm sea (excluding areas subject to extreme super-refraction) – 1% of the time – 50% of the locations – h_2 = 10 m

—— · —— Free space

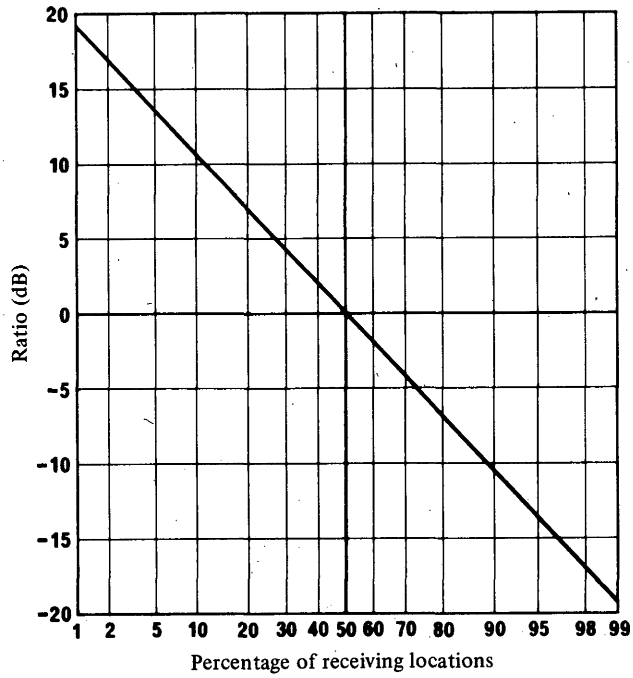

FIGURE 5 – *Ratio (dB) of the field strength for a given percentage of the receiving locations to the field strength for 50% of the receiving locations*

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

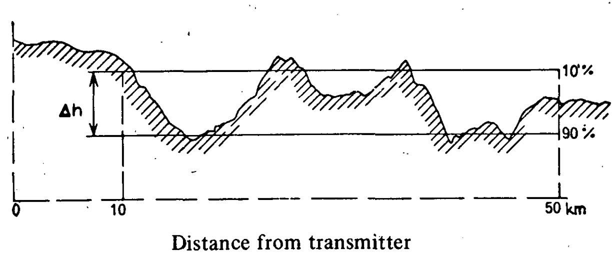

FIGURE 6 – *Application of the parameter Δh for broadcasting services*

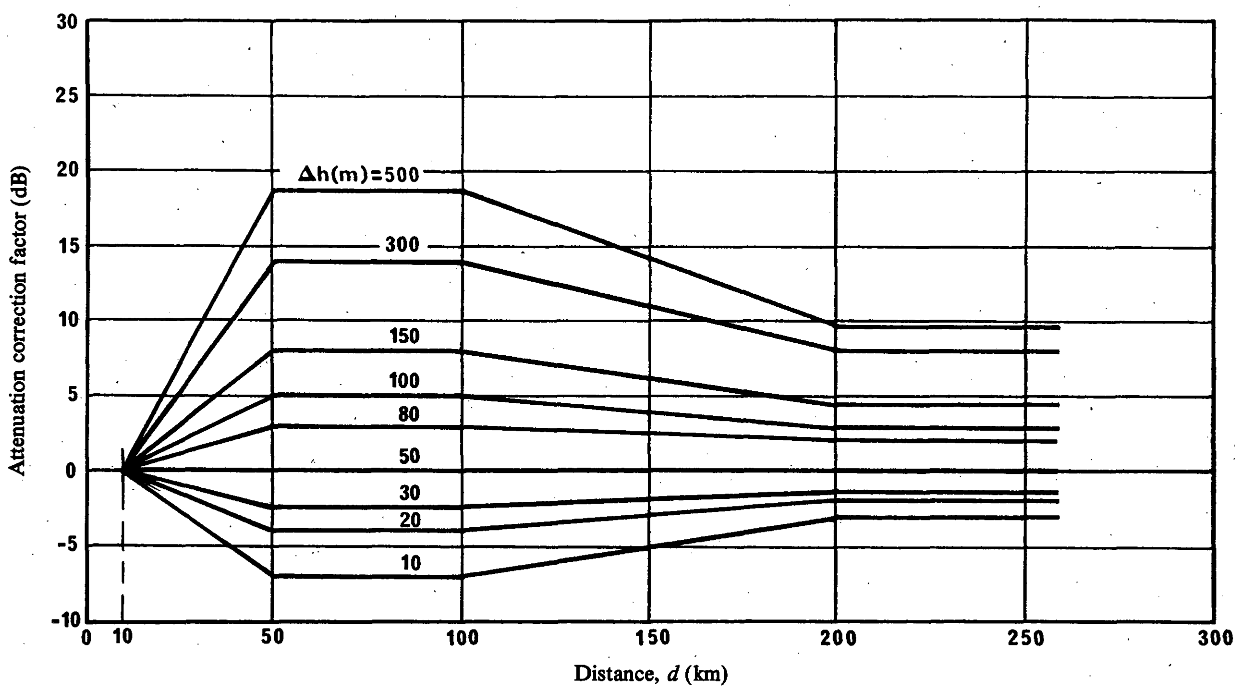

FIGURE 7 – *Attenuation correction factor as a function of the distance d (km) and Δh*

Frequencies 80 to 250 MHz (Bands II and III)

2.3 In areas subject to pronounced super-refraction phenomena, account may be taken of the information contained in § 3.6 of Report 239.

2.4 The following reduction in the median field-strength values may be expected by changing the receiving antenna height from 10 to 3 m above ground: in Bands I and II, 9 dB in hilly or flat terrain for both urban and rural areas; in Band III, 7 dB for flat terrain in rural areas and 11 dB for urban or hilly terrain. These values apply for distances up to 50 km. For distances in excess of 100 km the values should be halved, with linear interpolation for intermediate distances. Refer also to Report 239.

2.5 The ionosphere, primarily through the effects of sporadic-E ionization, can influence propagation in the lower part of the VHF band, particularly at frequencies below about 90 MHz. In some circumstances this mode of propagation may influence the field strength exceeded for small percentages of the time at distances beyond some 500 km, and near the magnetic equator and in the auroral zone higher percentages of the time may be involved. However these ionospheric effects can usually be ignored in most applications covered by this Recommendation and the propagation curves of this Annex have been prepared on this assumption. Report 259 and Recommendation 534 should be consulted to determine whether the assumption is reasonable.

3. UHF bands

3.1 The curves in Figs. 9, 10 and 11 represent field-strength values exceeded at 50% of the locations and for 50%, 10% and 1% of the time for land paths where Δh of 50 m is considered representative. For different values of Δh, a correction should be applied to the curves as shown in Fig. 8. Correction factors for locations other than 50% may be obtained from the distribution curves in Fig. 12.

3.2 The curves in Figs. 13, 14a, 14b, 15a, 15b, 16a and 16b represent field-strength values exceeded at 50% of the locations and for 50%, 10%, 5% and 1% of the time for sea paths in cold seas and warm seas, the climatic characteristics of those areas being likened to those observed in the North Sea and the Mediterranean, respectively.

3.3 In areas subject to pronounced super-refraction phenomena, account may be taken of the information contained in § 3.6 of Report 239.

3.4 A reduction in the median field-strength values may be expected by changing the receiver antenna height from 10 m to 3 m above ground. Figure 17 shows how the median value varies with Δh in rural areas. In suburban areas the median value may be taken as 7 dB, and in urban areas as 14 dB. These values apply for distances up to 50 km. For distances in excess of 100 km the values should be halved, as in Fig. 17, with linear interpolation for intermediate distances.

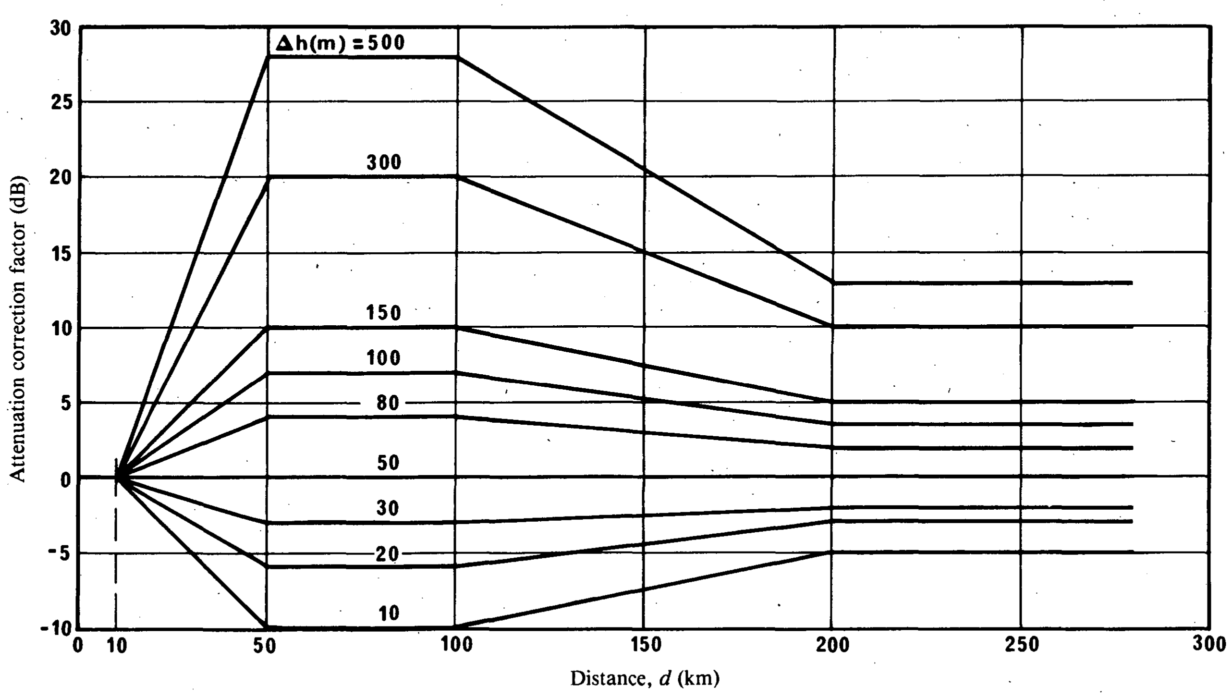

FIGURE 8 – *Attenuation correction factor as a function of the distance d (km) and Δh*

Frequencies 450 to 1000 MHz (Bands IV and V)

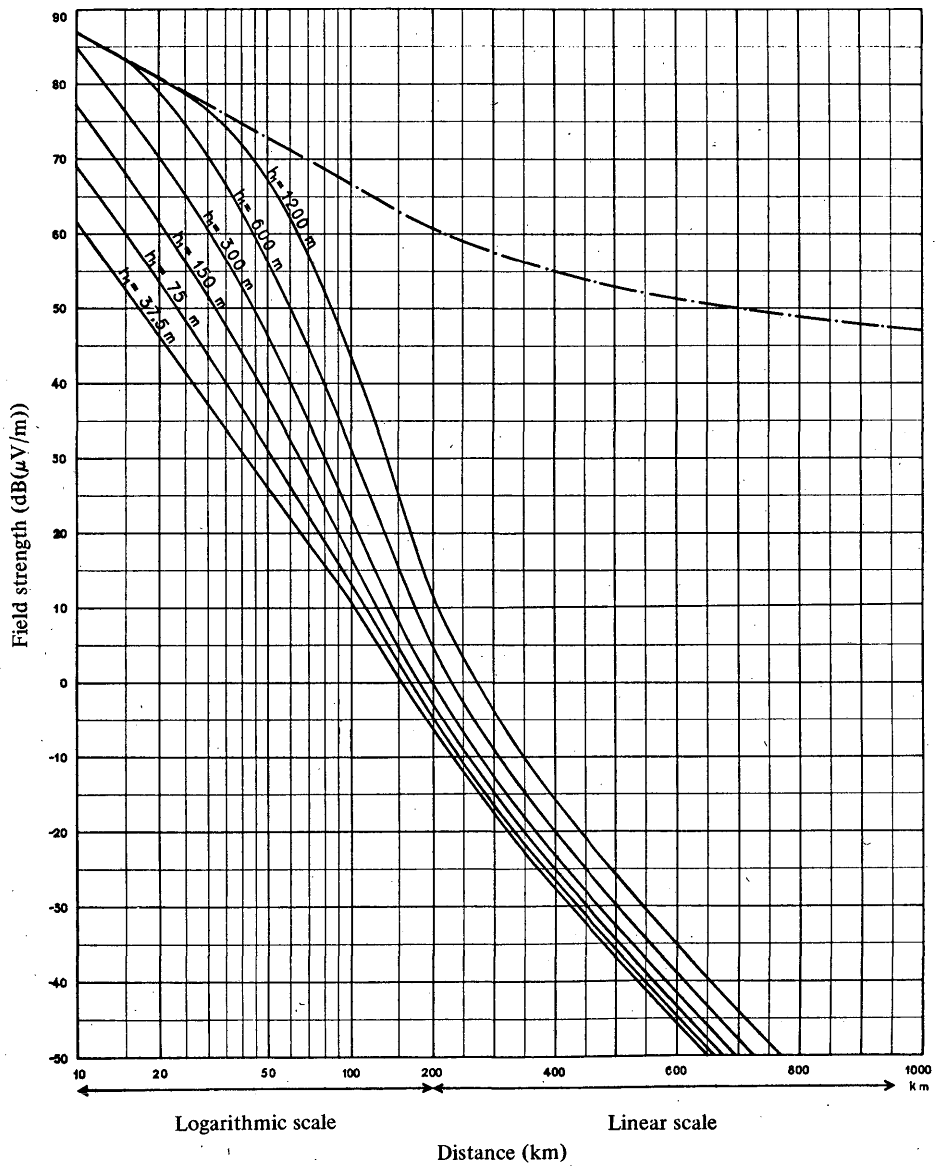

FIGURE 9 – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 450 to 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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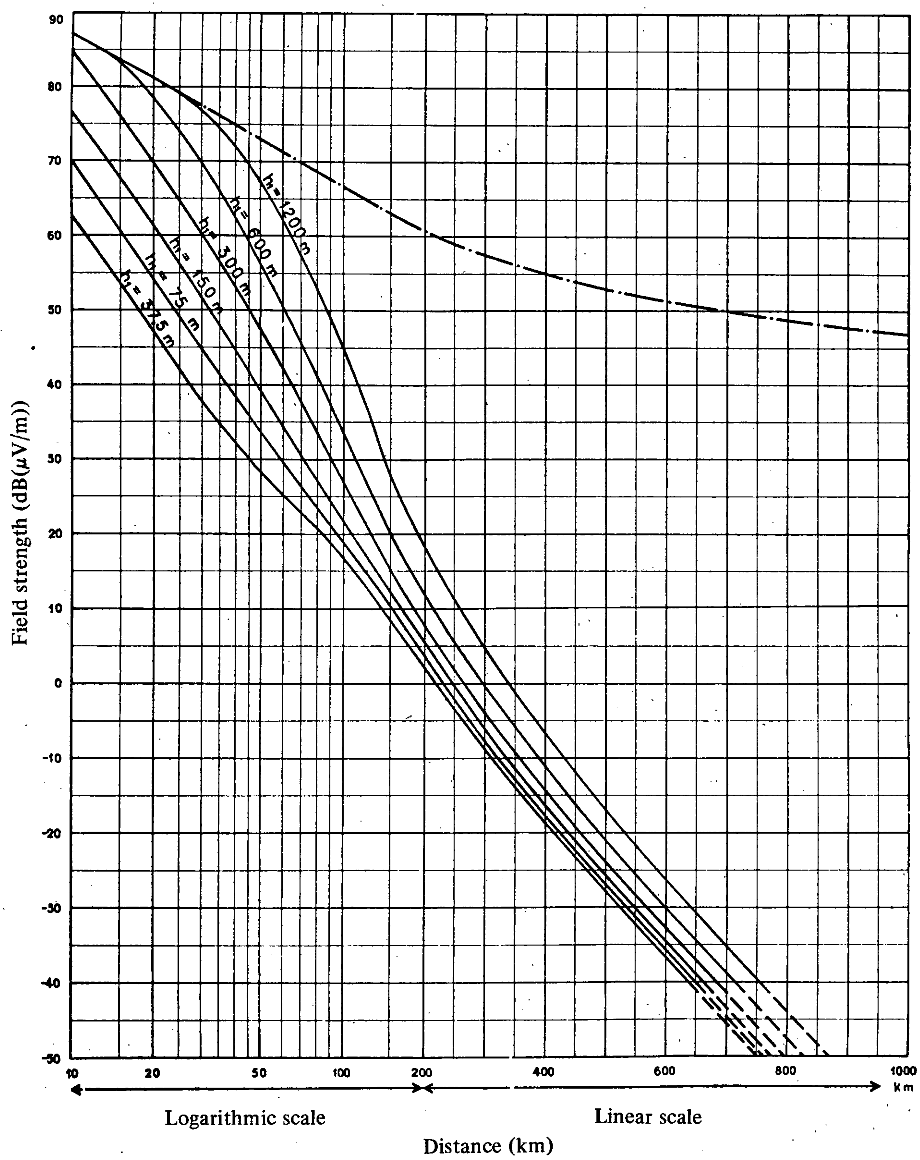

FIGURE 10 – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 450 to 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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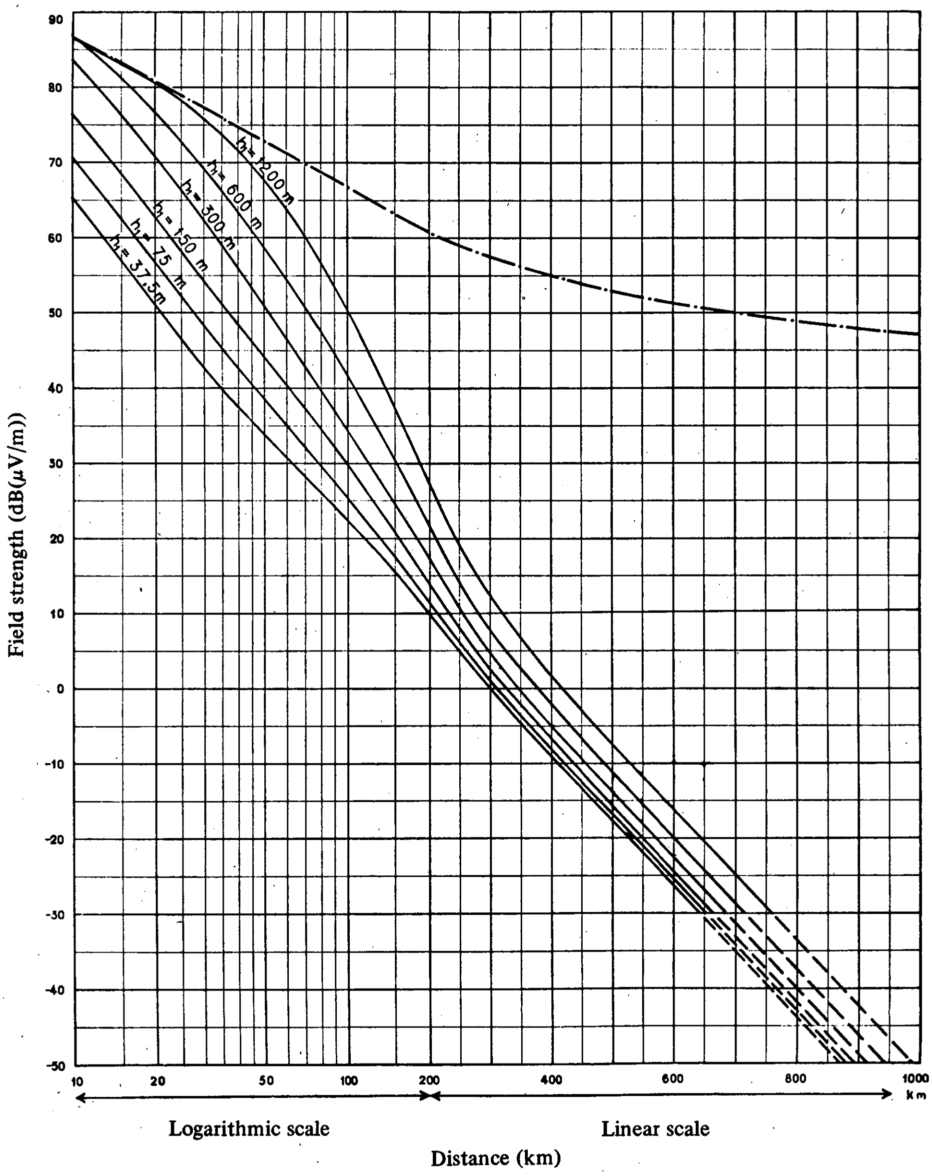

FIGURE 11 – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 450 to 1000 MHz (Bands IV and V) - Land - 1% of the time - 50% of the locations - $h_2 = 10$ m - $\Delta h = 50$ m

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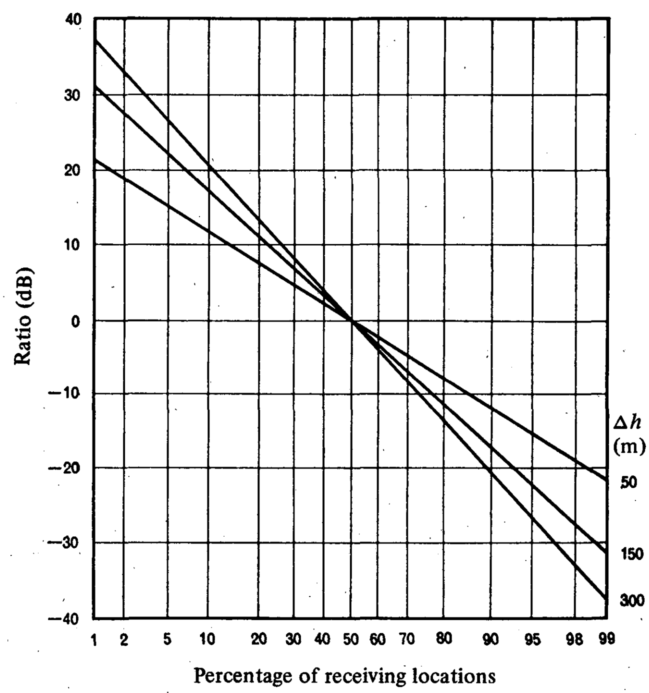

FIGURE 12 – *Ratio (dB) of the field strength for a given percentage of the receiving locations to the field strength for 50% of the receiving locations*

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

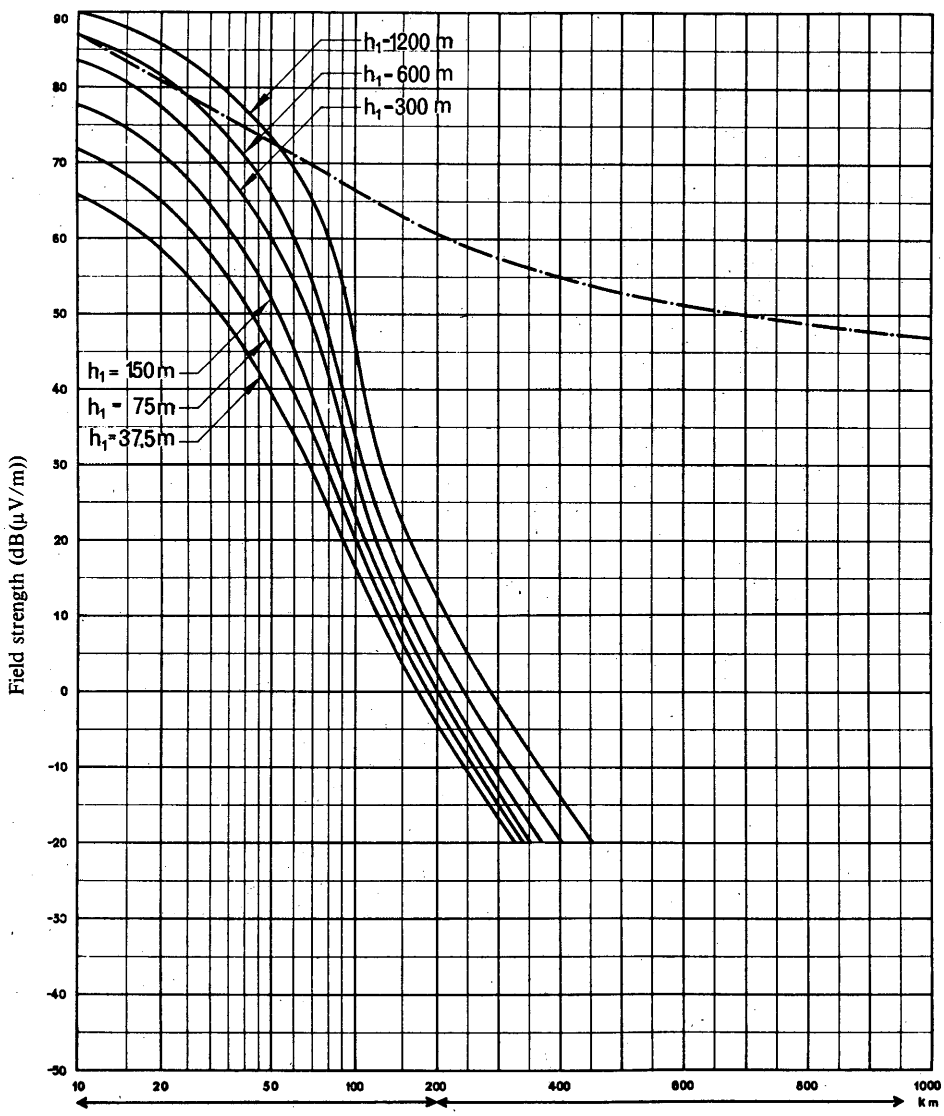

FIGURE 13 – *Field strength (dB(μV/m)) for 1 kW e.r.p.*
Frequency: 450 to 1000 MHz (Bands IV and V) – Sea – 50% of the time – 50% of the locations – h_2 = 10 m

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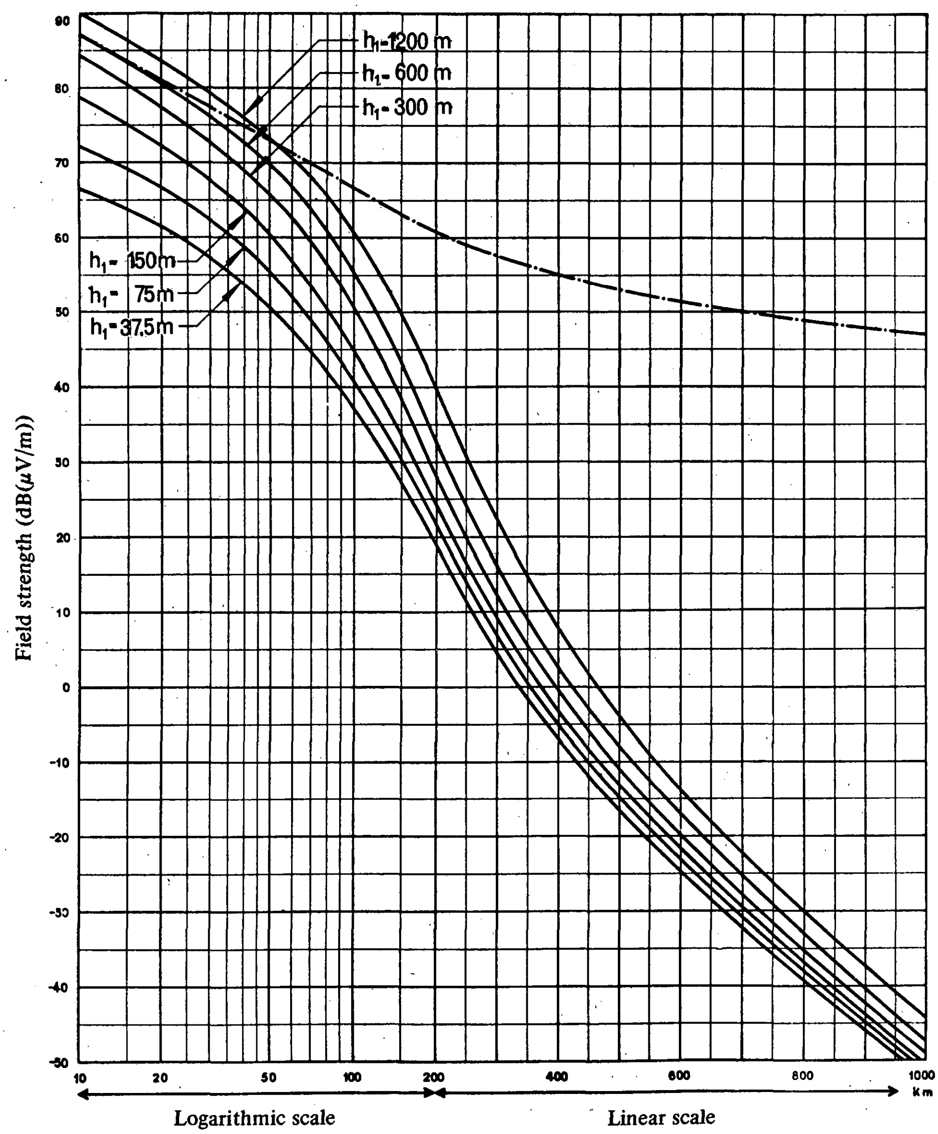

FIGURE 14*a* – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 450 to 1000 MHz (Bands IV and V) - Cold sea - 10% of the time - 50% of the locations - $h_2 = 10$ m

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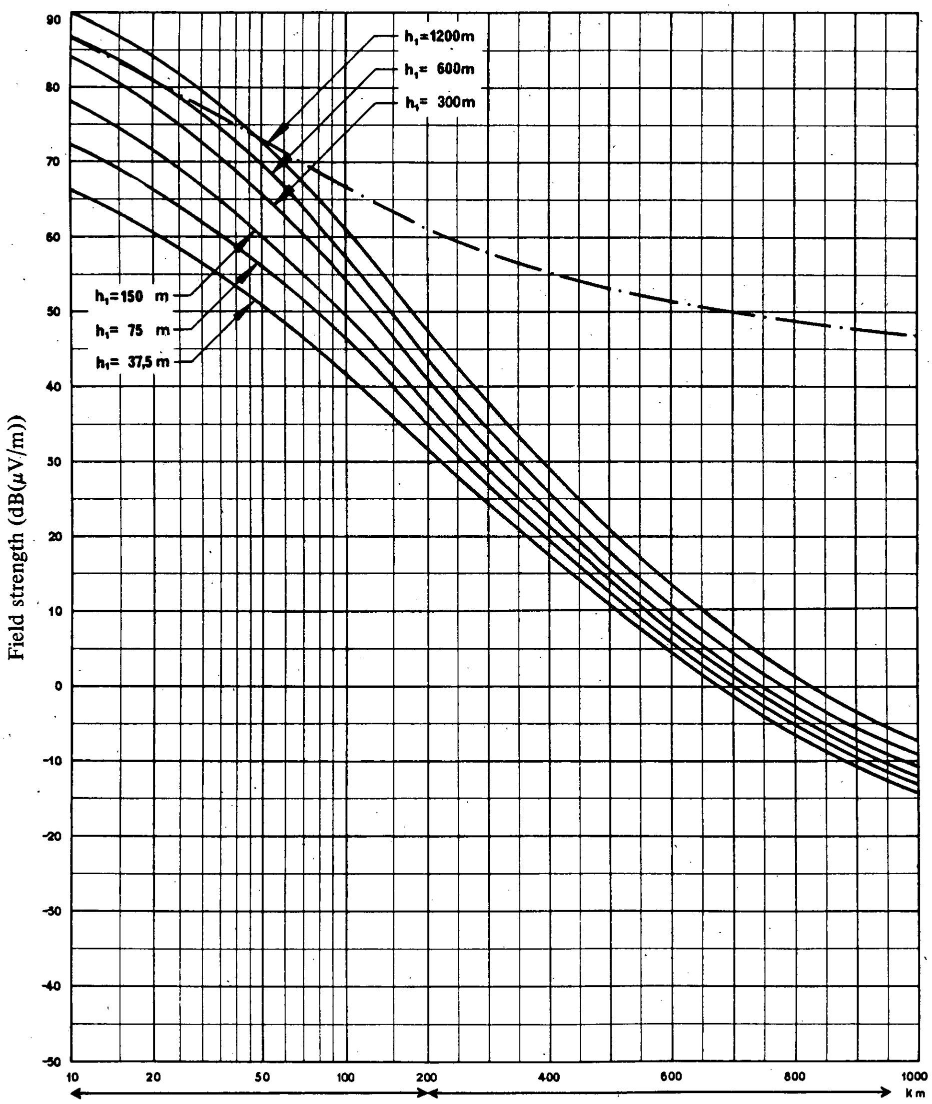

FIGURE 14*b* – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 450 to 1000 MHz (Bands IV and V) – Warm sea – 10% of the time – 50% of the locations – h_2 = 10 m

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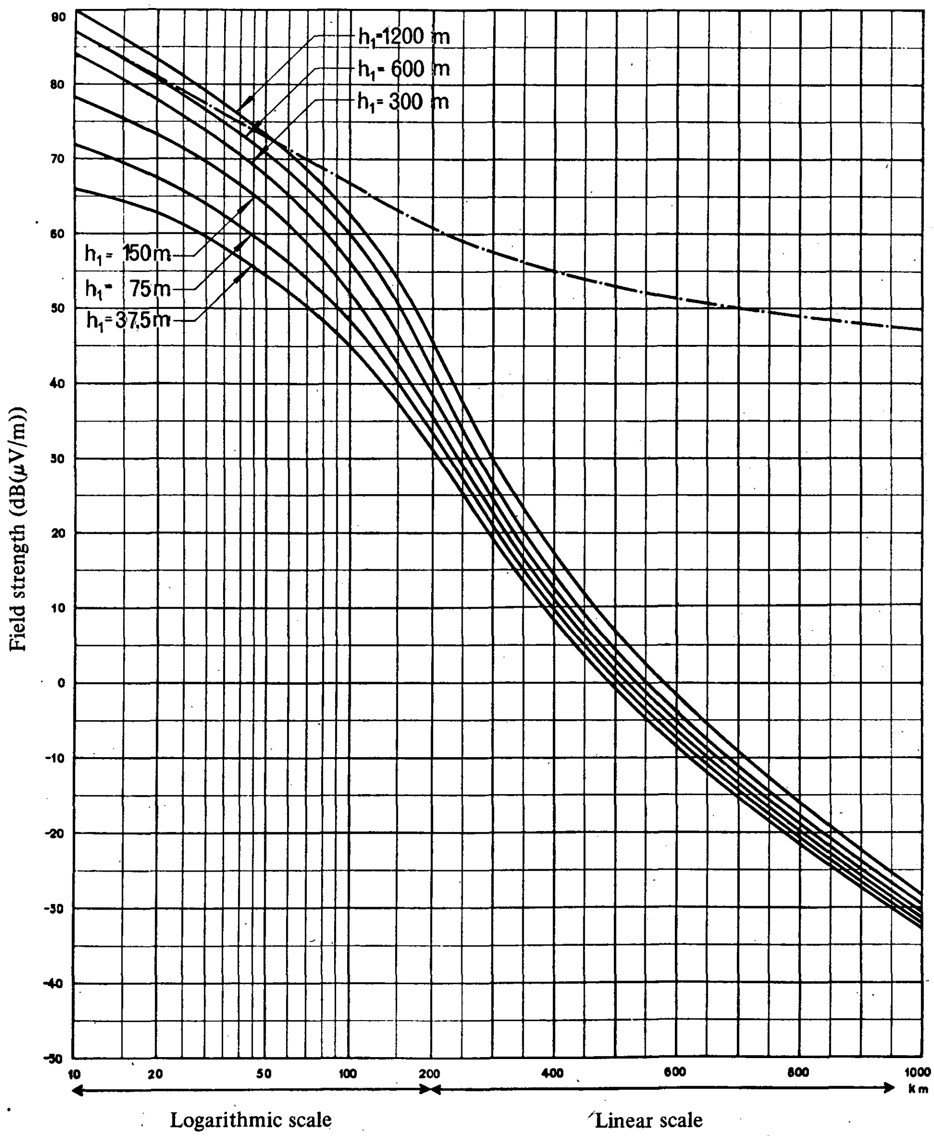

FIGURE 15*a* – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 450 to 1000 MHz (Bands IV and V) – Cold sea – 5% of the time – 50% of the locations – h_2 = 10 m

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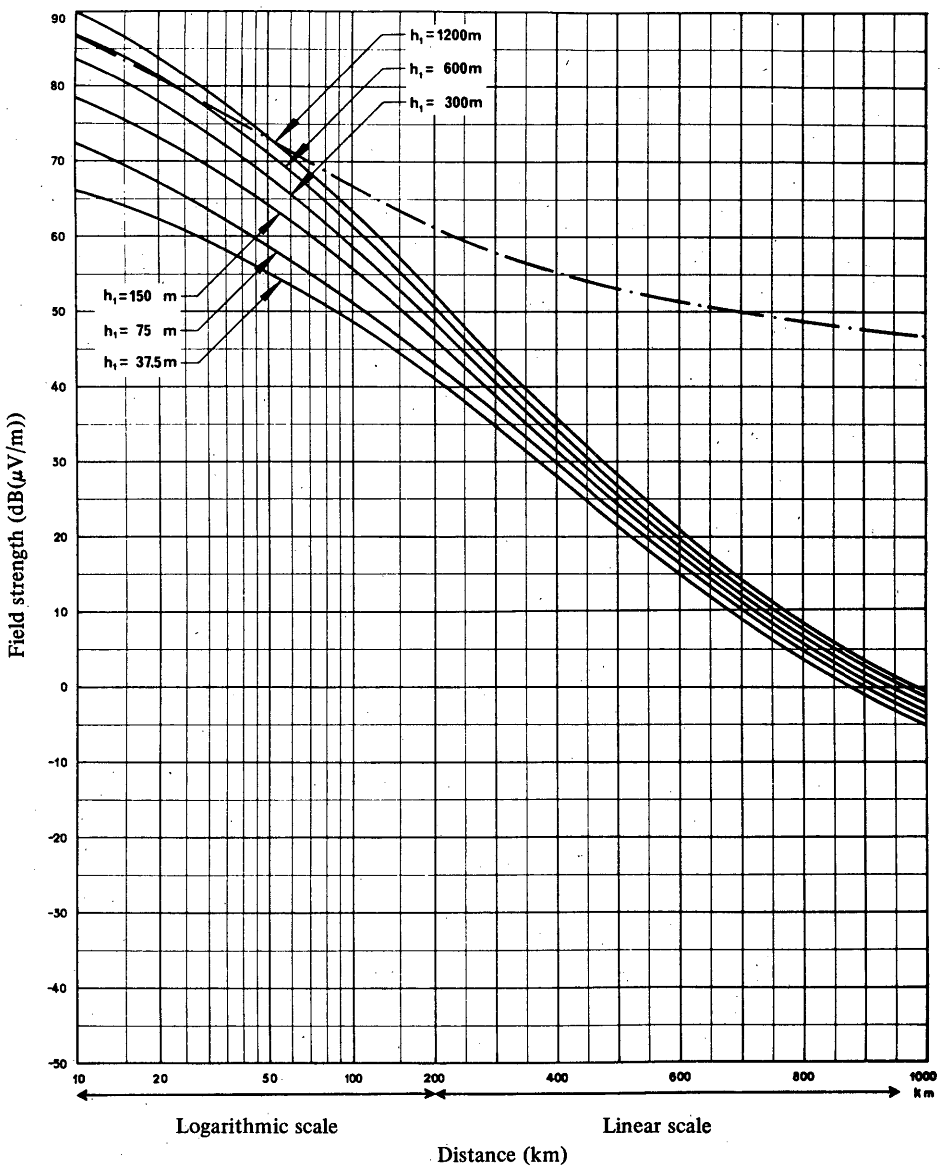

FIGURE 15*b* – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 450 to 1000 MHz (Bands IV and V) – Warm sea – 5% of the time – 50% of the locations – h_2 = 10 m

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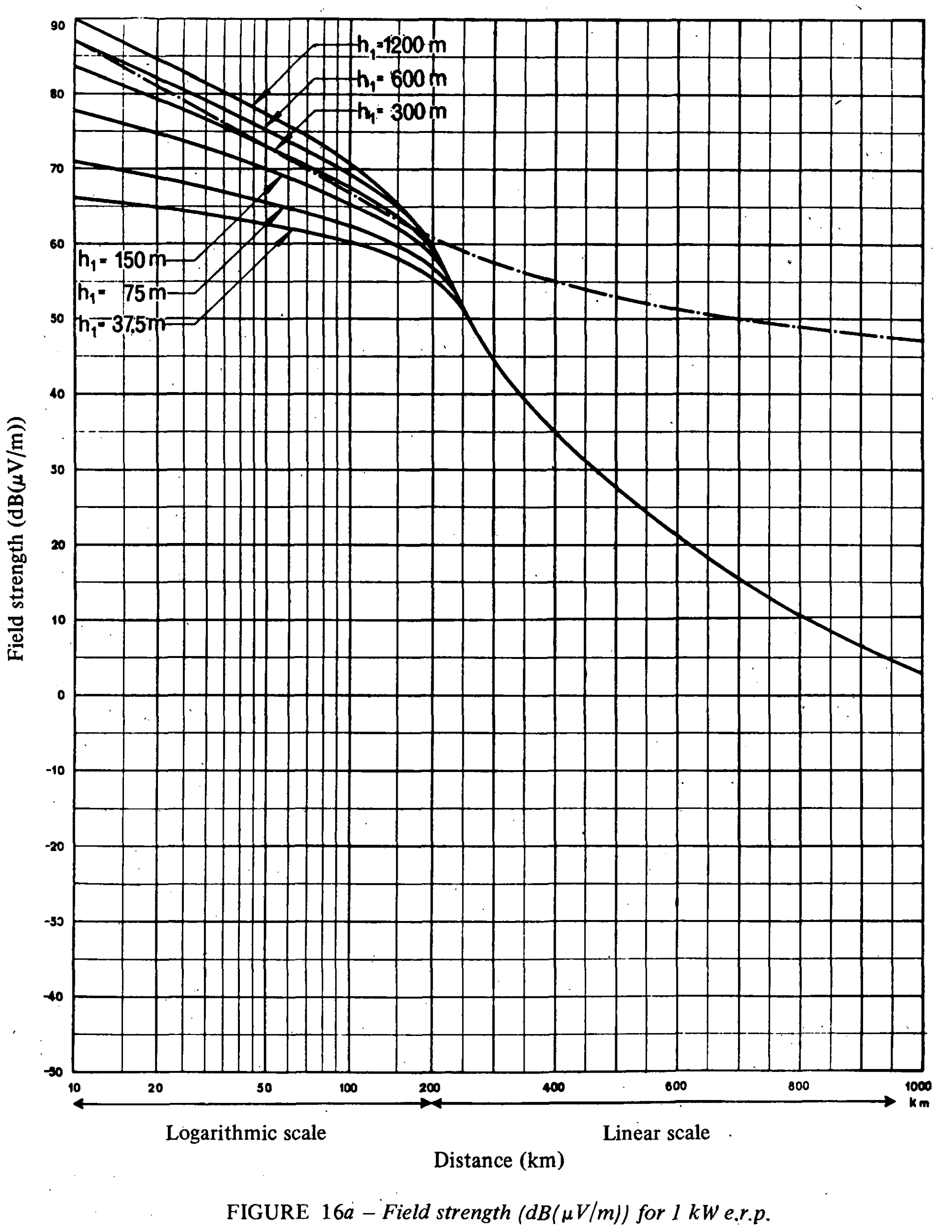

FIGURE 16*a* – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 450 to 1000 MHz (Bands IV and V) – Cold sea – 1% of the time – 50% of the locations – h_2 = 10 m

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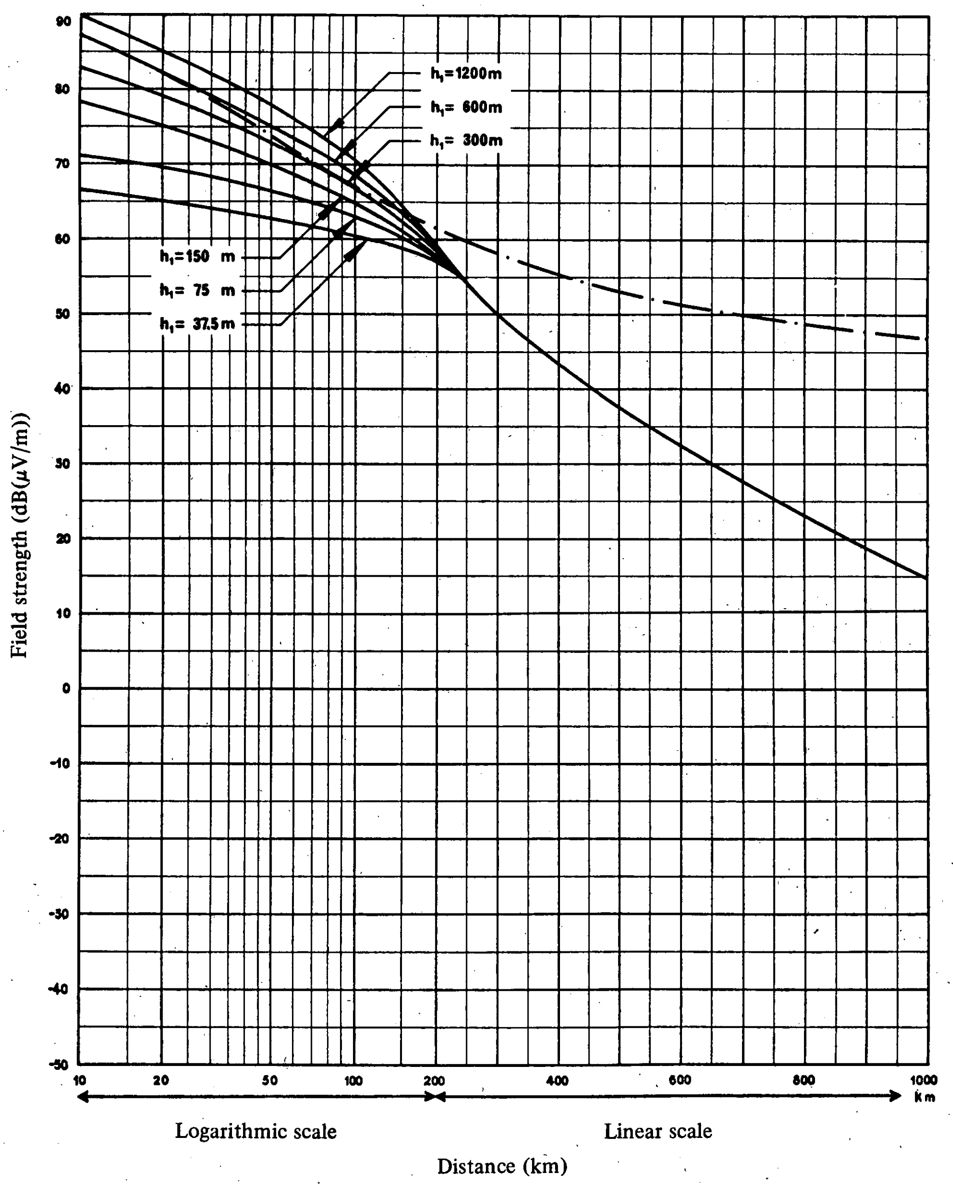

FIGURE 16*b* – *Field strength (dB(μV/m)) for 1 kW e.r.p.*

Frequency: 450 to 1000 MHz (Bands IV and V) – Warm sea (excluding areas subject to extreme super-refraction) – 1% of the time – 50% of the locations – $h_2 = 10$ m

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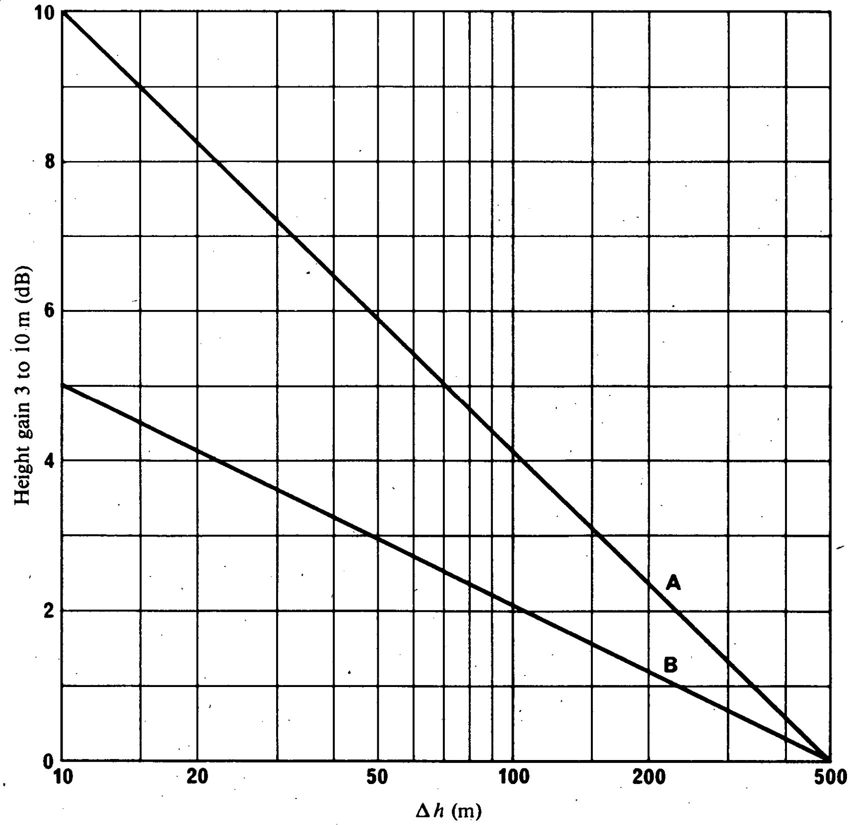


FIGURE 17 – *Height-gain factor 3 to 10 m as a function of* Δ *h for frequency 450 to 1000 MHz (Bands IV and V); parameter d represents distance from the transmitter*

A: $d \leqslant 50$ km
B: $d \geqslant 100$ km

RECOMMENDATION 616

PROPAGATION DATA FOR TERRESTRIAL MARITIME MOBILE SERVICES OPERATING AT FREQUENCIES ABOVE 30 MHz

(Study Programme 7F/5)

(1986)

The CCIR,

CONSIDERING

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

(b) that the factors affecting propagation in terrestrial maritime mobile services, including those in harbours, coastal areas and inland waterways, may differ from those associated with other services in these bands;

(c) that propagation data are needed for different types of maritime environment and specifically for vertical polarization;

(d) that field-strength curves are given in Annex I of Recommendation 370 for oversea paths in certain maritime areas,

UNANIMOUSLY RECOMMENDS

1. that the curves given in Annex I of Recommendation 370 be used provisionally for the planning of the terrestrial maritime mobile service recognizing the particular conditions to which they apply;

2. that provisionally, field strengths over mixed land and sea paths be calculated by the methods described in Report 239.

RECOMMENDATION 528-2*

PROPAGATION CURVES FOR AERONAUTICAL MOBILE AND RADIONAVIGATION SERVICES USING THE VHF, UHF AND SHF BANDS

(Study Programme 7F/5)

(1978–1982–1986)

The CCIR,

CONSIDERING

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

(b) that the propagation model used to generate the curves given in Annex II is based on a considerable amount of experimental data (see Annex I);

(c) that the aeronautical service often provides a safety of life function and therefore requires a higher standard of availability than many other services;

(d) that a time availability of 0.95 should be used to obtain more reliable service,

UNANIMOUSLY RECOMMENDS

that the curves given in Annex II be adopted to determine the basic transmission losses for 5%, 50% and 95% of the time for antenna heights (for both the ground station and aircraft) likely to be encountered in the aeronautical services.

Note. – It must be emphasized that these curves are based on data obtained mainly for a continental temperate climate. The curves should be used with caution for other climates.

ANNEX I

DEVELOPMENT AND APPLICATION OF THE CURVES

Transmission loss prediction methods given in [NBS, 1967] have been extended and incorporated into the IF-77 propagation model [Johnson and Gierhart, 1979] that determine basic transmission losses for 5%, 50% and 95% of the time for antenna heights applicable to the aeronautical services [Johnson and Gierhart, 1978]. These methods are based on a considerable amount of experimental data, and extensive comparisons of predictions with data have been made [Johnson and Gierhart, 1979]. In performing these calculations, a smooth (terrain parameter $\Delta h = 0$) Earth with an effective Earth radius factor k of 4/3 (surface refractivity $N_s = 301$) was used along with compensation for the excessive ray bending associated with the $k = 4/3$ model at high altitudes. Constants for average ground horizontal polarization, isotropic antennas, and long-term power fading statistics for a continental temperate climate were also used. Although these parameters may be considered either reasonable or worst-case for many applications, the curves should be used with caution if conditions differ drastically from those assumed.

With the exception of a region "near" the radio horizon, values of median basic 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 median basic transmission loss as increasing monotonically with distance.

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. However, the lobing structure is given statistical consideration in the calculation of variability.

* This Recommendation is brought to the attention of Study Group 8.

For time availabilities other than 0.50, the basic transmission loss, L_b, curves do not always increase monotonically with distance. This occurs because variability changes with distance can sometimes overcome the median level changes. Variability includes contributions from both hourly-median or long-term power fading (Report 238) and within-the-hour or short-term phase interference fading. Both surface reflection and tropospheric multipath are included in the short-term fading.

The curves provided in Annex II are selected curves from a much larger set of computer-generated smoothed curves [Johnson and Gierhart, 1980].

The basic transmission loss, $L_b(0.05)$ curves may be used to estimate L_b values for an unwanted interfering signal that is exceeded during 95% (100% – 5%) of the time. Median (50%) propagation conditions may be estimated with the $L_b(0.50)$ curves. The $L_b(0.95)$ curves may be used to estimate the service range for a wanted signal at which service would be available for 95% of the time in the absence of interference.

The expected protection ratio or wanted-to-unwanted signal ratio exceeded at the receiver for at least 95% of the time, $R(0.95)$, can be estimated using the Annex II curves as follows:

$$R(0.95) = R(0.50) + Y_R(0.95) \tag{1}$$

$$R(0.50) = [P_t + G_t + G_r - L_b(0.50)]_{Wanted} - [P_t + G_t + G_r - L_b(0.50)]_{Unwanted} \tag{2}$$

and

$$Y_R = - \sqrt{[L_b(0.95) - L_b(0.50)]^2_{Wanted} + [L_b(0.05) - L_b(0.50)]^2_{Unwanted}} \tag{3}$$

In equation (2), P_t is the transmitted power, and G_t and G_r are the isotropic gains of the transmitting and receiving antennas expressed in dB.

Additional variabilities could easily be included in equation (3) for such things as antenna gain when variabilities for them can be determined. Continuous (100%) or simultaneous channel utilization is implicit in the $R(0.95)$ formulation provided above so that the impact of intermittent transmitter operation must be considered separately.

REFERENCES

JOHNSON, M. E. and GIERHART, G. D. [1978] Applications guide for propagation and interference analysis computer programs (0.1 to 20 GHz). DOT-Rep. FAA-RD-77-60, NTIS Accession No. ADA 053242. National Technical Information Service, Springfield, Va., 22161, USA.

JOHNSON, M. E. and GIERHART, G. D. [1979] Comparison of measured data with IF-77 propagation model predictions. DOT-Rep. FAA-RD-79-9, NTIS Accession No. ADA076508. National Technical Information Service, Springfield, Va., 22161, USA.

JOHNSON, M. E. and GIERHART, G. D. [1980] An atlas of basic transmission loss (0.125, 0.3, 1.2, 5.1, 9.4, 15.5 GHz). DOT-Rep. FAA-RD-80-1, NTIS Accession No. ADA 088153. National Technical Information Service, Springfield, Va., 22161, USA.

NBS [1967] National Bureau of Standards, Technical Note No. 101, Revised, I and II, AD 687820 and AD 687821, National Technical Information Service, Springfield, Va., 22161, USA.

ANNEX II

DESCRIPTION OF THE CURVES

The aeronautical curves are contained in Figs. 1 to 6. The following points are to be noted:

1. Figures 1 to 6 show median values of the basic transmission loss, L_b, for the frequencies 125, 300, 1200, 5100, 9400 and 15 500 MHz.

2. Each figure consists of three curve sets where the upper, middle and lower sets provide $L_b(0.05)$, $L_b(0.50)$, and $L_b(0.95)$, respectively. These correspond to time availabilities of 5, 50 and 95%. For example, $L_b(0.95) = 200$ dB means that the basic transmission loss would be 200 dB or less during 95% of the time.

Code for antenna heights

Code	H_1 (m)	H_2 (m)
A	15	1000
B	1000	1000
C	15	10000
D	1000	10000
E	15	20000
F	1000	20000
G	10000	10000
H	10000	20000
I	20000	20000

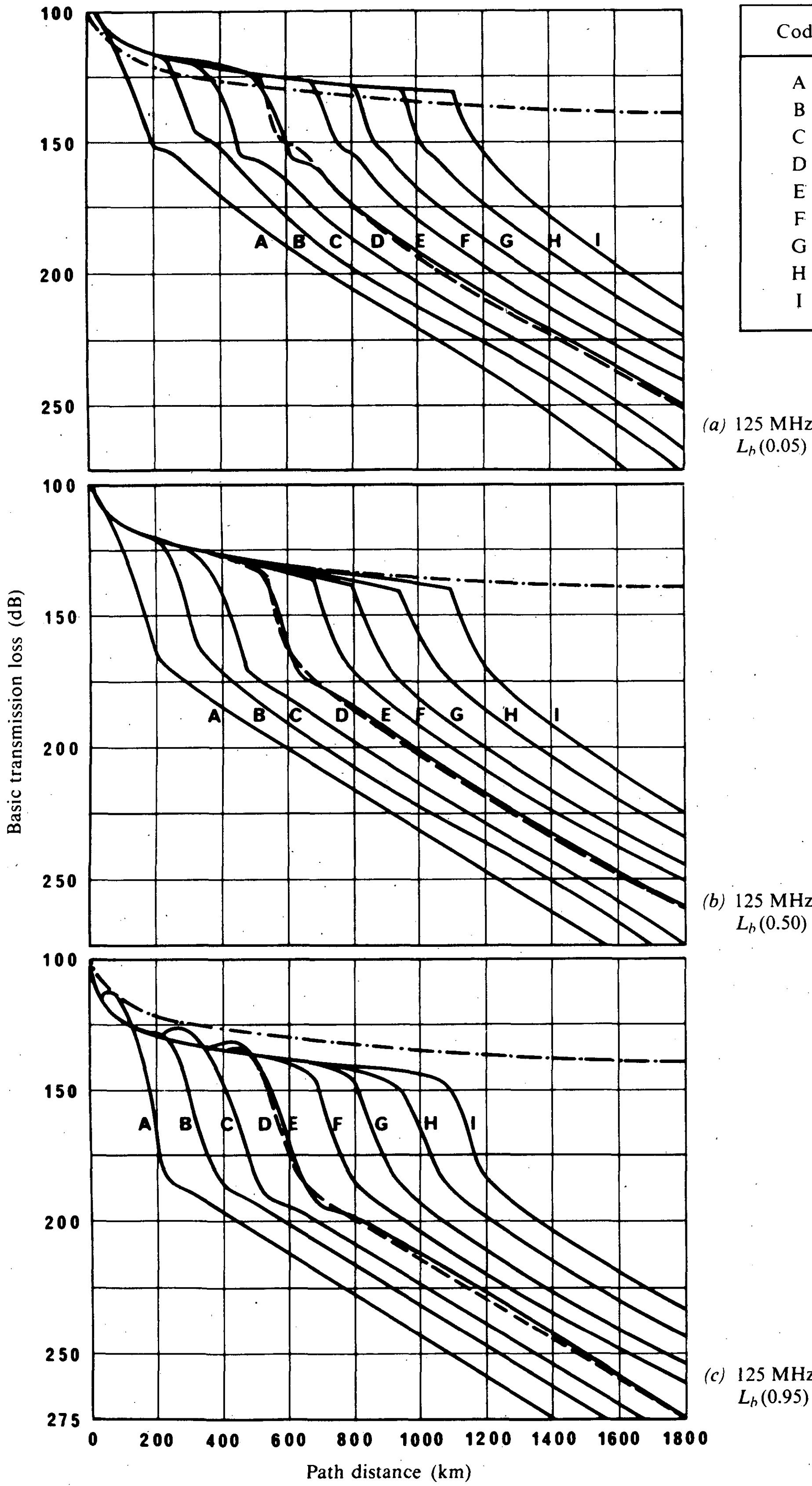


FIGURE 1 – *Basic transmission loss at 125 MHz for 5%, 50% and 95% of the time*

The dotted-line curve is that for free space

Code for antenna heights

Code	H_1 (m)	H_2 (m)
A	15	1000
B	1000	1000
C	15	10000
D	1000	10000
E	15	20000
F	1000	20000
G	10000	10000
H	10000	20000
I	20000	20000

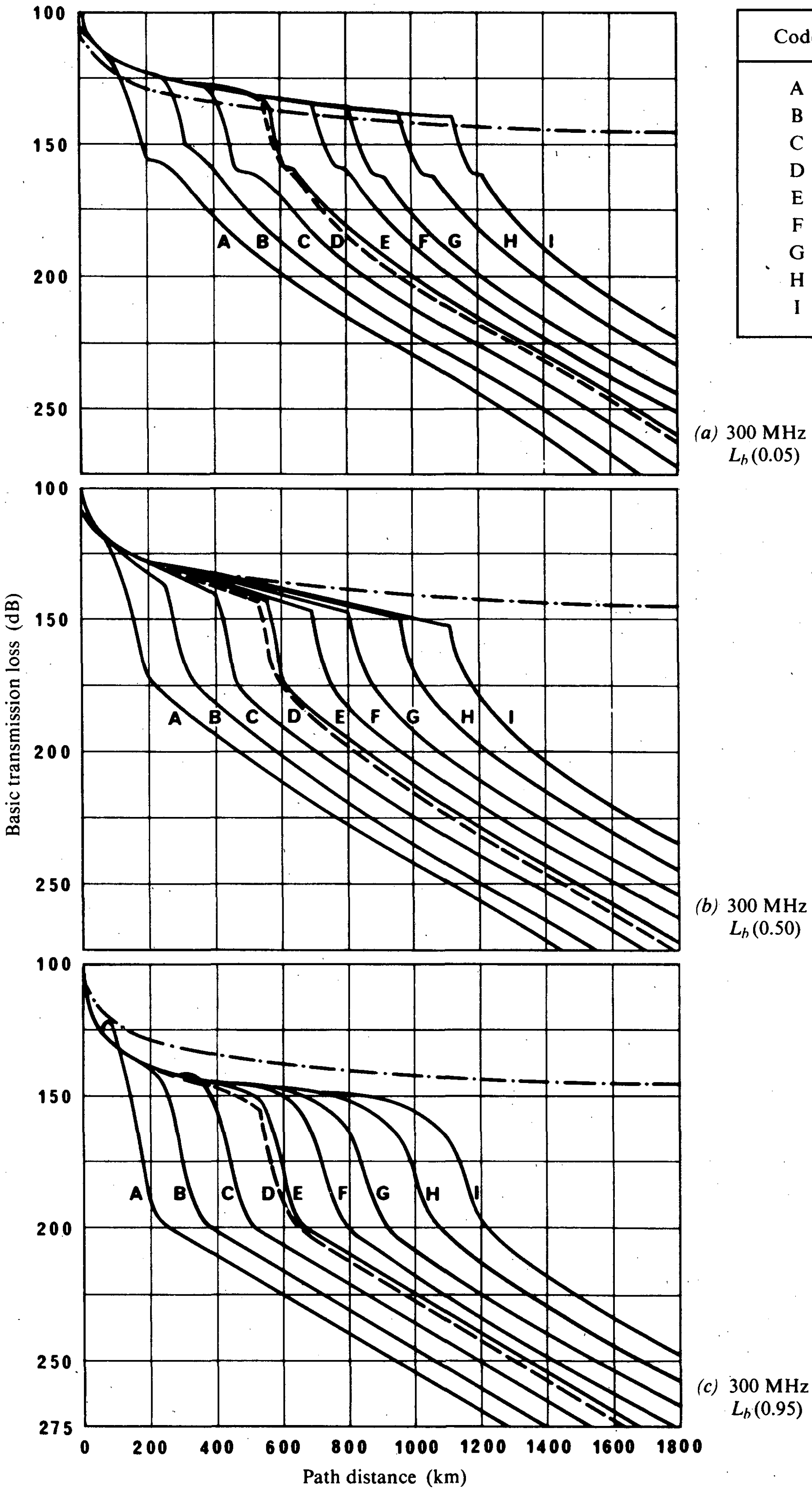


FIGURE 2 – *Basic transmission loss at 300 MHz for 5%, 50% and 95% of the time*

The dotted-line curve is that for free space

Code for antenna heights

Code	H_1 (m)	H_2 (m)
A	15	1000
B	1000	1000
C	15	10000
D	1000	10000
E	15	20000
F	1000	20000
G	10000	10000
H	10000	20000
I	20000	20000

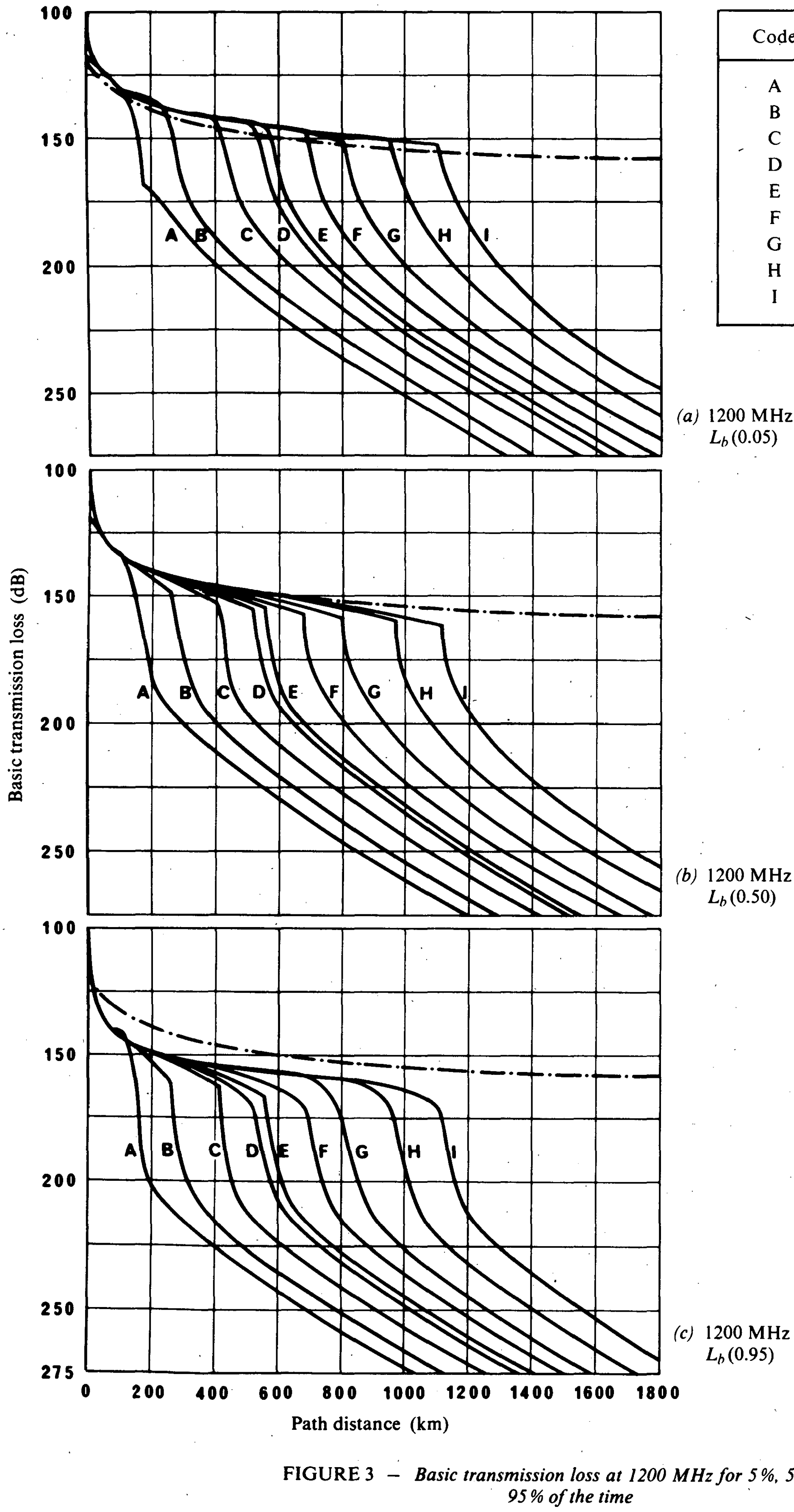


FIGURE 3 – *Basic transmission loss at 1200 MHz for 5%, 50% and 95% of the time*

The dotted-line curve is that for free space

Code for antenna heights

Code	H_1 (m)	H_2 (m)
A	15	1000
B	1000	1000
C	15	10000
D	1000	10000
E	15	20000
F	1000	20000
G	10000	10000
H	10000	20000
I	20000	20000

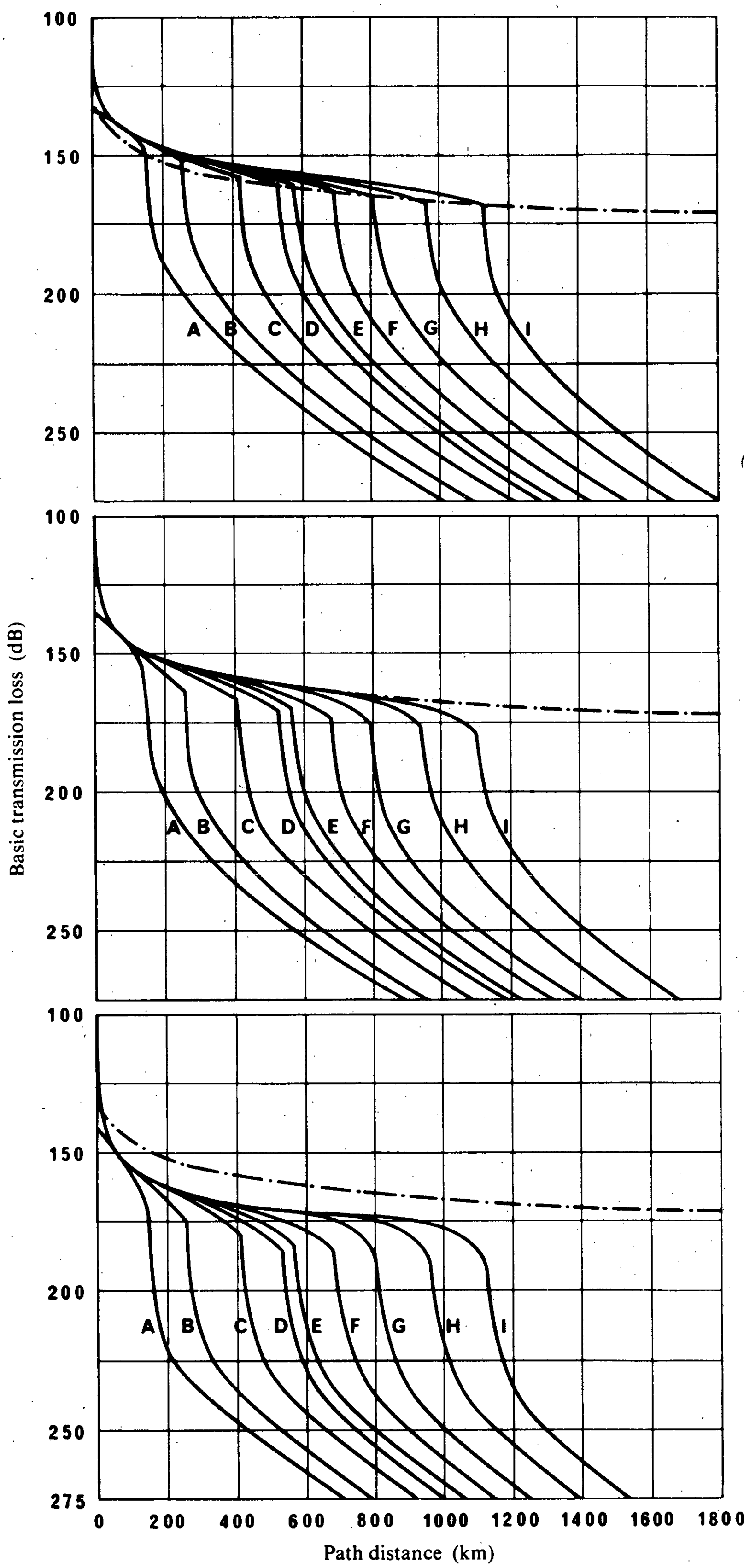
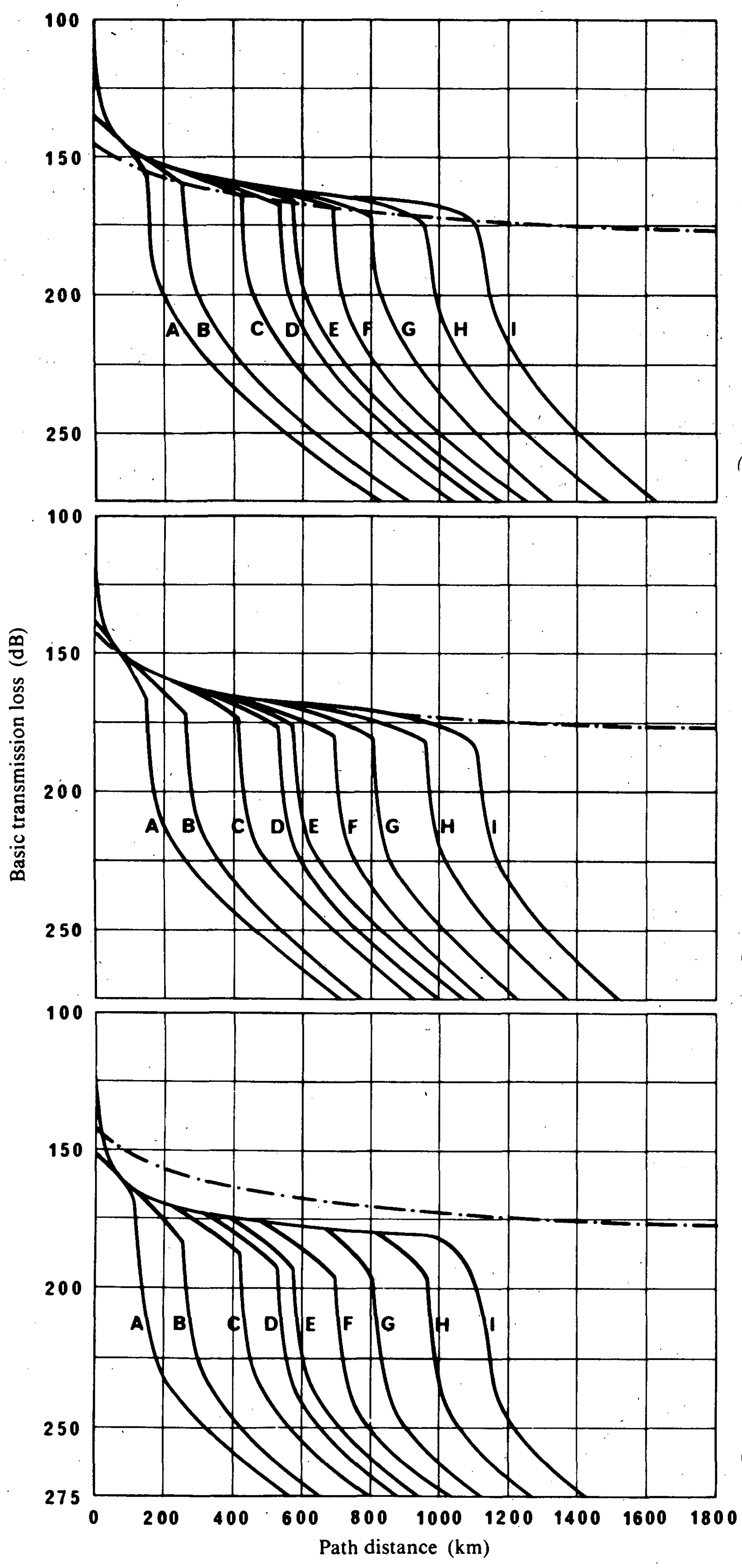


FIGURE 4 – *Basic transmission loss at 5100 MHz for 5%, 50% and 95% of the time*

The dotted-line curve is that for free space

Code for antenna heights

Code	H_1 (m)	H_2 (m)
A	15	1000
B	1000	1000
C	15	10000
D	1000	10000
E	15	20000
F	1000	20000
G	10000	10000
H	10000	20000
I	20000	20000



(a) 9400 MHz
$L_b(0.05)$

(b) 9400 MHz
$L_b(0.50)$

(c) 9400 MHz
$L_b(0.95)$

FIGURE 5 – *Basic transmission loss at 9400 MHz for 5%, 50% and 95% of the time*

The dotted-line curve is that for free space

Code for antenna heights

Code	H_1 (m)	H_2 (m)
A	15	1000
B	1000	1000
C	15	10000
D	1000	10000
E	15	20000
F	1000	20000
G	10000	10000
H	10000	20000
I	20000	20000

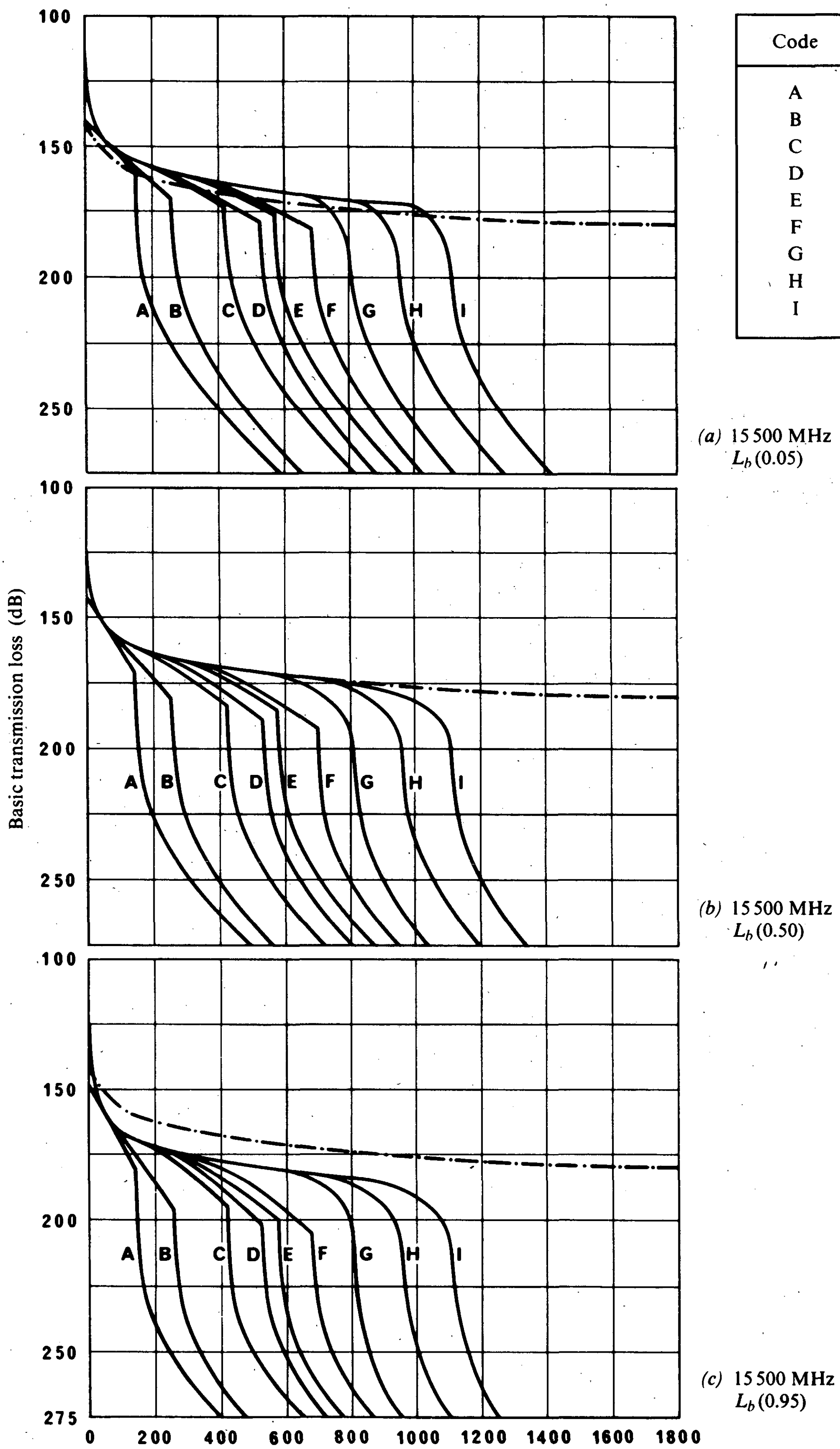


FIGURE 6 – *Basic transmission loss at 15 500 MHz for 5%, 50% and 95% of the time*

The dotted-line curve is that for free space

3. The antenna heights shown vary from 15 m to 20 000 m covering both ground station and aircraft heights.

4. The development and application of these curves are discussed in Annex I.

5. At zero distance $L_b(0.50)$ is simply the free-space value corresponding to a path length equal to the difference in antenna heights. The free-space curves shown were calculated for a 19 985 m height difference.

ANNEX III

EXPERIMENTAL RESULTS

Propagation tests at 930 MHz were conducted on air-to-ground paths in Japan in November 1982 and April and June 1983. According to the test results, propagation losses within line-of-sight agreed well with free space values. The line-of-sight distance as calculated from the measured data at an altitude of 10 000 m was shorter than the distance implied by the curves in Annex II [Akeyama *et al.*, 1984].

REFERENCES

AKEYAMA, A., SAKAGAMI, S. and YOSHIZAWA, K. [March, 1984] 900 MHz band propagation characteristics on air-to-ground paths. National Convention Record No. 669, Institute of Electronics and Communication Engineers of Japan, Tokyo, Japan.

RECOMMENDATION 529-1 *

VHF AND UHF PROPAGATION DATA AND PREDICTION METHODS REQUIRED FOR THE TERRESTRIAL LAND MOBILE SERVICES

(Question 12/5)

(1978-1990)

The CCIR,

CONSIDERING

that there is a need to give guidance to engineers in the planning of land mobile radio services in the VHF and UHF bands,

UNANIMOUSLY RECOMMENDS

that the methods given in Report 567 be adopted ** for use to determine the field strength and other signal characteristics likely to be encountered in the terrestrial land mobile service.

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* This Recommendation is brought to the attention of Study Group 8.

** It must be emphasized that the curves relating to UHF bands are based on data for specific urban areas, and should be used with caution in other areas.

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SECTION 5E: ASPECTS RELATIVE TO THE TERRESTRIAL FIXED SERVICE

RECOMMENDATION 530-3*

PROPAGATION DATA AND PREDICTION METHODS REQUIRED FOR THE DESIGN OF TERRESTRIAL LINE-OF-SIGHT SYSTEMS

(Question 14/5)

(1978-1982-1986-1990)

The CCIR,

CONSIDERING

(a) that for the proper planning of terrestrial line-of-sight systems it is necessary to have appropriate propagation prediction methods and data;

(b) that methods have been developed that allow the prediction of the most important propagation parameters affecting the planning of terrestrial line-of-sight systems;

(c) that as far as possible these methods have been tested against available measured data and have been shown to yield an accuracy that is both compatible with the natural variability of propagation phenomena and adequate for most present applications in system planning;

(d) that for certain propagation parameters, however, the existing information is not yet sufficient to allow prediction methods to be established and tested adequately, particularly in some geographic regions,

UNANIMOUSLY RECOMMENDS

1. that the methods for predicting the following parameters set out in Report 338 be adopted for planning terrestrial line-of-sight systems in the respective ranges of validity indicated in the Report:

1.1 gaseous attenuation;

1.2 diffraction fading statistics, and associated criteria for path clearance;

1.3 multipath fading distribution in a narrow-band, at both small percentages of time (Methods 1 or 2, as appropriate) and other percentages of time;

1.4 long-term distribution of rain attenuation from point rainfall rate;

1.5 long-term distribution of rain attenuation at one frequency from that at another (frequency scaling);

1.6 long-term distribution of XPD from that of CPA;

1.7 long-term distribution of XPD at one frequency/polarization from that at another;

2. that the current data, and other information in all other parts of Report 338 be used in the planning of terrestrial line-of-sight systems.

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* This Recommendation is brought to the attention of Study Group 9.

RECOMMENDATION 617*

PROPAGATION DATA REQUIRED FOR THE DESIGN OF TRANS-HORIZON RADIO-RELAY SYSTEMS

(1986

The CCIR,

CONSIDERING

(a) that for the proper planning of trans-horizon radio-relay systems it is necessary to have appropriate propagation data;

(b) that the data available so far do not allow reliable prediction methods to be developed which would give adequate accuracy in all regions of the world;

(c) that, however, methods are available which yield sufficient accuracy in at least some regions,

UNANIMOUSLY RECOMMENDS

that the methods set out in Report 238 be adopted for provisional use in the planning of trans-horizon radio-relay systems.

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* This Recommendation is brought to the attention of Study Groups 1 and 9.

SECTION 5F: ASPECTS RELATIVE TO SPACE TELECOMMUNICATION SYSTEMS

RECOMMENDATION 618-1 *

PROPAGATION DATA AND PREDICTION METHODS REQUIRED FOR THE DESIGN OF EARTH-SPACE TELECOMMUNICATION SYSTEMS

(Question 16/5)

(1986-1990)

The CCIR,

CONSIDERING

(a) that for the proper planning of Earth-space systems it is necessary to have appropriate propagation data and prediction techniques;

(b) that methods have been developed that allow the prediction of the most important propagation parameters needed in planning Earth-space systems;

(c) that as far as possible, these methods have been tested against available data and have been shown to yield an accuracy that is both compatible with the natural variability of propagation phenomena and adequate for most present applications in system planning;

(d) that, however, for certain propagation parameters the existing information is not yet sufficient, in particular, in some geographical regions, to allow prediction methods to be established and tested adequately,

UNANIMOUSLY RECOMMENDS

1. that the methods for predicting the following parameters, set out in Report 564, be adopted for planning Earth-space radiocommunication systems, in the respective ranges of validity indicated in the Report:

1.1 gaseous attenuation;

1.2 long-term statistics of rain attenuation from point rainfall rate;

1.3 long-term frequency scaling of rain attenuation statistics;

1.4 site-diversity improvement factor or site-diversity gain;

1.5 monthly or long-term statistics of amplitude scintillations;

1.6 long-term cross-polarization statistics due to hydrometeors, derived from co-polar attenuation statistics;

1.7 long-term frequency and polarization scaling of cross-polarization statistics due to hydrometeors;

2. that the current data, and other information in all other parts of Report 564 be used.

Note – Supplementary information related to the planning of broadcasting-satellite systems as well as maritime, land and aeronautical mobile-satellite systems may be found in Reports 565, 884, 1009 and 1148 respectively.

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* This Recommendation is brought to the attention of Study Groups 4, 6, 7, 8, 10 and 11.

RECOMMENDATION 679*

PROPAGATION DATA REQUIRED FOR THE DESIGN OF BROADCASTING-SATELLITE SYSTEMS

(Question 17/5)

(1990)

The CCIR,

CONSIDERING

(a) that for the proper planning of broadcasting-satellite systems it is necessary to have appropriate propagation data and prediction methods;

(b) that the methods of Report 564 are recommended for the planning of Earth-space telecommunication systems;

(c) that further development of prediction methods for specific application to broadcasting-satellite systems is required to give adequate accuracy for all operational conditions;

(d) that, however, methods are available which yield sufficient accuracy for many applications,

UNANIMOUSLY RECOMMENDS

that the current propagation data contained in Report 565 be adopted for use in the planning of broadcasting-satellite systems, in addition to the methods recommended in Recommendation 618.

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* This Recommendation is brought to the attention of Study Groups 10 and 11.

RECOMMENDATION 680*

PROPAGATION DATA REQUIRED FOR THE DESIGN OF EARTH-SPACE MARITIME MOBILE TELECOMMUNICATION SYSTEMS

(Question 18/5)

(1990)

The CCIR,

CONSIDERING

(a) that for the proper planning of Earth-space maritime mobile systems it is necessary to have appropriate propagation data and prediction methods;

(b) that the methods of Report 564 are recommended for the planning of Earth-space telecommunication systems;

(c) that further development of prediction methods for specific application to maritime mobile-satellite systems is required to give adequate accuracy for all operational conditions;

(d) that, however, methods are available which yield sufficient accuracy for many applications,

UNANIMOUSLY RECOMMENDS

that the current methods set out in Report 884 be adopted for use in the planning of Earth-space maritime mobile telecommunication systems, in addition to the methods recommended in Recommendation 618.

* This Recommendation is brought to the attention of Study Group 8.

RECOMMENDATION 681 *

PROPAGATION DATA REQUIRED FOR THE DESIGN OF EARTH-SPACE LAND MOBILE TELECOMMUNICATION SYSTEMS

(Question 18/5)

(1990)

The CCIR,

CONSIDERING

(a) that for the proper planning of Earth-space land mobile systems it is necessary to have appropriate propagation data and prediction methods;

(b) that the methods of Report 564 are recommended for the planning of Earth-space telecommunication systems;

(c) that further development of prediction methods for specific application to land mobile-satellite systems is required to give adequate accuracy in all regions of the world and for all operational conditions;

(d) that, however, methods are available which yield sufficient accuracy in some regions and for many applications,

UNANIMOUSLY RECOMMENDS

that the current propagation data contained in Report 1009 be adopted for use in the planning of Earth-space land mobile telecommunication systems, in addition to the methods recommended in Recommendation 618.

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* This Recommendation is brought to the attention of Study Group 8.

RECOMMENDATION 682*

PROPAGATION DATA REQUIRED FOR THE DESIGN OF EARTH-SPACE AERONAUTICAL MOBILE TELECOMMUNICATION SYSTEMS

(Question 18/5)

(1990)

The CCIR,

CONSIDERING

(a) that for the proper planning of Earth-space aeronautical mobile systems it is necessary to have appropriate propagation data and prediction methods;

(b) that the methods of Report 564 are recommended for the planning of Earth-space telecommunication systems;

(c) that further development of prediction methods for specific application to aeronautical mobile-satellite systems is required to give adequate accuracy for all operational conditions;

(d) that, however, methods are available which yield sufficient accuracy for many applications,

UNANIMOUSLY RECOMMENDS

that the current propagation data contained in Report 1148 be adopted for current use in the planning of Earth-space aeronautical mobile telecommunication systems, in addition to the methods recommended in Recommendation 618.

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* This Recommendation is brought to the attention of Study Group 6.

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SECTION 5G: PROPAGATION DATA REQUIRED FOR THE EVALUATION OF INTERFERENCE: SPACE AND TERRESTRIAL SYSTEMS

RECOMMENDATION 452-4*

PROPAGATION DATA REQUIRED FOR THE EVALUATION OF INTERFERENCE BETWEEN STATIONS ON THE SURFACE OF THE EARTH

(1970-1974-1978-1982-1986)

The CCIR,

CONSIDERING

(a) that for the proper evaluation of interference between stations on the surface of the Earth it is necessary to have appropriate propagation data that are based on both terrain and atmospheric factors;

(b) that the data available so far do not allow reliable prediction methods to be developed which would give adequate accuracy in all regions of the world;

(c) that, however, several methods are available which yield sufficient accuracy in at least some regions,

UNANIMOUSLY RECOMMENDS

1. that, for the evaluation of interference between stations of point-to-point services on the surface of the Earth at frequencies higher than about 500 MHz, administrations make use of the propagation prediction method set out in Report 569;

2. that, in the case of the prediction of the propagation of interference signals between stations of point-to-point services on the surface of the Earth operating at frequencies below about 500 MHz, the data of Recommendation 370 are to be used as follows:

- to derive information relative to 1% of the time with respect to point-to-point services, the appropriate Recommendation 370 curves for 1% of the time are to be used, and the conversion factor relative to 1% of locations is to be applied as obtained from Fig. 5 of that Recommendation;
- the curves in question are to be found in Figs. 4a, 4b and 4c of Recommendation 370 which correspond to land, cold seas and warm seas respectively and therefore are equivalent to zones defined in § 3.2.3 of Report 569;
- due to insufficient data being available at the present time, it is not yet possible to propose a method for the prediction of the propagation of interference signals for less than 1% of the time;

3. that, for the evaluation of interference to point-to-area services between 30 MHz and 1 GHz, administrations make use of the propagation prediction methods set out in Recommendations 370, 528 and 529 as appropriate.

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* This Recommendation is brought to the attention of Study Groups 1, 2, 4, 7, 8, 9, 10 and 11.

RECOMMENDATION 619*

PROPAGATION DATA REQUIRED FOR THE EVALUATION OF INTERFERENCE BETWEEN STATIONS IN SPACE AND THOSE ON THE SURFACE OF THE EARTH

(1986)

The CCIR,

CONSIDERING

(a) that for the proper evaluation of interference between stations in space and those on the surface of the Earth, it is necessary to have appropriate propagation data that are based on both terrain and atmospheric factors;

(b) that the data available so far do not allow reliable prediction methods to be developed which would give adequate accuracy in all regions of the world;

(c) that, however, several methods are available which yield sufficient accuracy in at least some regions,

UNANIMOUSLY RECOMMENDS

that for the evaluation of interference between stations in space and those on the surface of the Earth, administrations provisionally use the propagation calculation methods set out in Report 885.

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* This Recommendation is brought to the attention of Study Groups 1, 2, 4, 7, 8, 9, 10 and 11.

RECOMMENDATION 620*

PROPAGATION DATA REQUIRED FOR THE CALCULATION OF COORDINATION DISTANCES

(1986)

The CCIR,

CONSIDERING

(a) the terms of Resolution No. 60 of the World Administrative Radio Conference, Geneva, 1979;

(b) that the coordination area is that area, around an earth station, so defined that any interference between the earth station in question and terrestrial stations outside this area may be considered as negligible;

(c) that the determination of the coordination area should be based on the best propagation data available and that methods of predicting attenuation along an interference path should be compatible with those of determining the relevant coordination area,

UNANIMOUSLY RECOMMENDS

that, for the determination of the coordination area with respect to frequencies between 1 and 40 GHz, administrations provisionally use the propagation calculation methods set out in Report 724 for domestic (i.e. non-international) planning.

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* This Recommendation is brought to the attention of Study Groups 1, 2, 4, 7, 8, 9, 10 and 11.

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RESOLUTIONS

RESOLUTION 72-2

HANDBOOK OF GROUND-WAVE PROPAGATION CURVES

(1982-1986-1990)

The CCIR,

CONSIDERING

(a) that there is still a need to provide ground-wave propagation curves for frequencies above 10 MHz relative, in particular, to different antenna heights and polarizations;

(b) that the computer program GRWAVE is now available to revise the curves found in the Handbook of Ground-Wave Propagation Curves to account for the CCIR refractive profile described in Recommendation 369;

(c) that the acquisition and dissemination of computer programs is standard practice for the CCIR Secretariat,

UNANIMOUSLY DECIDES

that the Director, CCIR, should be requested:

1. to calculate and publish ground-wave propagation curves using the GRWAVE program for the frequencies, terminal heights, refractive index profile and ground conditions specified by Study Group 5;

2. to make available on request the GRWAVE computer program to member administrations and others;

3. to make such comparisons with other existing programs as may be considered appropriate by Study Group 5.

RESOLUTION 73-1

WORLD ATLAS OF GROUND CONDUCTIVITIES

(1982-1990)

The CCIR,

CONSIDERING

the needs of administrations for suitable conductivity charts when planning all types of radiocommunication, including navigational services, in the VLF, LF and MF bands,

UNANIMOUSLY DECIDES

1. that the Director of the CCIR should continue with further development of the World Atlas of effective ground conductivity values, using the most up-to-date information as it becomes available;

2. that the Atlas, contained in Report 717, should continue to be published separately,

AND REQUESTS ADMINISTRATIONS

to supply information in the form of suitable maps and correct as necessary information already provided (see Report 717); in all such cases the frequency concerned should be mentioned. In particular, data for countries not represented in the Atlas are urgently needed.

RESOLUTION 79

RADIO PROPAGATION STUDIES IN TROPICAL REGIONS

(1982)

This Resolution is published in Volume XIV-1.

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