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A SHORT GUIDE TO HF GROUND WAVE CIRCUIT AVAILABILITY.(U)

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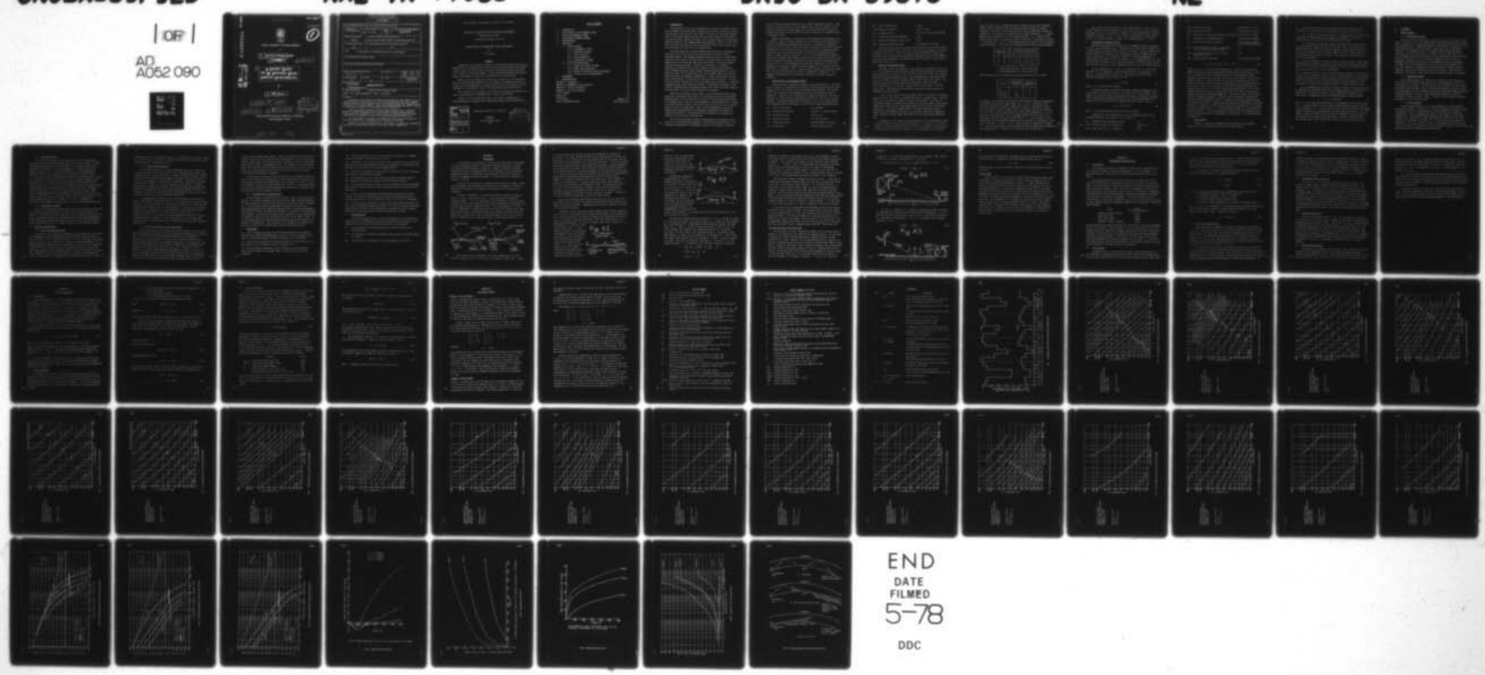

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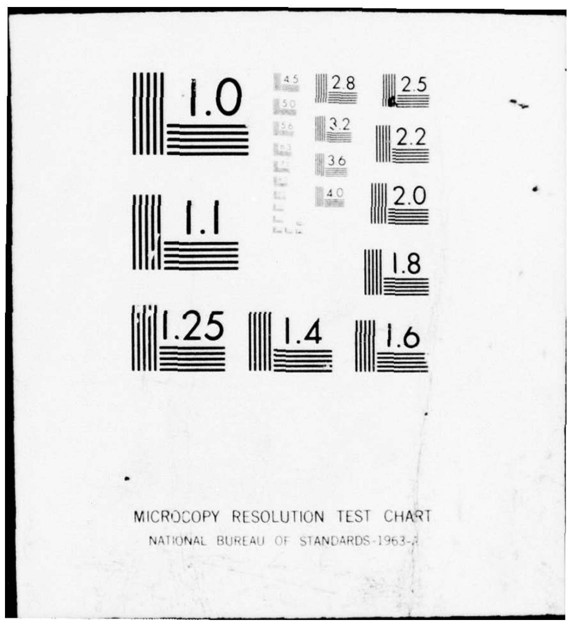
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17. Abstract

Atmospheric noise statistics presented by the CCIR have been applied to the problem of circuit availability of an air to ground HF ground wave voice communications system. The best and worst case noise conditions have been considered for a location in the United Kingdom. Curves are presented showing the expected ranges of the system in terms of its stipulated circuit availability.

Means are provided whereby the results may be applied to air to ground or ground to ground systems generally, for the purpose of performance prediction. Ground wave radio propagation is reviewed and the statistical concept of circuit availability is explained in terms of the underlying noise characteristics.

The limitations to the scope of this Report are discussed and attention is drawn to problem areas; recommendations for further work are made.

Subject to the stated qualifications, this Report is proposed as an engineering guide to HF ground wave communication system circuit availability.

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Means are provided whereby the results may be applied to air to ground or ground to ground systems generally, for the purpose of performance prediction. Ground wave radio propagation is reviewed and the statistical concept of circuit availability is explained in terms of the underlying noise characteristics.

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1 INTRODUCTION

The performance of any radio communications circuit is determined largely by two parameters, received signal strength and the level of electrical noise in the pass band of the receiver. The former is a function of the total radiated power of the sending station and the radio path loss between the sending and receiving stations. Thus the strength of the received signal is to some degree under the control of the communications system designer. That is not the case with electrical noise which is often determined by natural and man made causes totally outside the control of the system designer.

On HF the situation is further complicated by additional considerations affecting both the path loss and the limiting electrical noise levels at receiving stations. The notable advantage in the use of HF is its long range capability, which derives from the ability of the ionosphere to reflect radio signals back to the earth far beyond the radio horizon. Such radio signals are known as sky wave signals. However, the phenomenon of ionospheric reflection is capricious and very much depends on a good match between the carrier frequency and the widely variable 'optimum working frequency' for that particular path. On the other hand, for 'line of sight' paths the so-called ground wave mode of propagation predominates. In this case the path loss and hence received signal strength may be determined fairly precisely. At intermediate distances, ground wave and sky wave signals may be received at comparable strengths and may cause interference fading. It then may be desirable to use reception techniques which discriminate against the variable sky wave component and concentrate on the more reliable ground wave component.

The level of electrical noise present in the receiver pass band is also particularly variable on HF circuits. All electrical circuits and amplifying devices possess a certain lower limit of noise (so-called thermal noise) which is inescapable and is often the sole determinant of system sensitivity. However, the HF band overlaps a band of electrical noise which is often far in excess of expected levels of thermal noise. This is called atmospheric noise and is conducted over large distances via ionospheric reflections from regions of thunder-storm activity. It characteristically exhibits wide variations of intensity in both the short and long term.

The CCIR have published[1] detailed characteristics of atmospheric noise
081 based on a 4 year monitoring programme at 16 locations around the world. The
statistical representation of atmospheric noise at a UK location is applied

here to problems involving relatively short range HF ground wave circuits. Both surface to surface and air to surface communication links are studied. In particular the maximum and minimum ranges for a Reference System are obtained by examining the seasonal and circadian (24 hourly) variations in the median levels of atmospheric noise.

Results are presented in terms of circuit availability (see Appendix C) as a function of range for several frequencies in the HF band, several types of terrain and for maximum and minimum noise conditions. In addition to providing direct predictions of system ranges and circuit availability the results also lend themselves to an interpretation of the statistical nature of atmospheric noise. Conversion curves are presented and their usefulness for generalizing these results to other systems is explained. Air to surface communication systems in the HF band introduce further unknown quantities such as aerial efficiency, polarization, height gain effects; the predictions facilitated by this Report may be used as an aid to trials planning and retrospective evaluation. Ground wave propagation is surveyed in Appendix A whilst Appendix B is a précis of the CCIR publication on atmospheric noise. Signal and noise factors are combined to determine the statistical parameters of circuit availability in Appendix C. Two examples of the application of prediction to different systems are given in Appendix D.

2 SPECIFICATION OF THE REFERENCE SYSTEM

The ground to air communication problem is especially difficult. Man made noise is known to be associated with aircraft electrical systems and static discharges but the levels have not been established quantitatively. The aircraft may fly into areas where the geographical variation of atmospheric noise is significant. Finally, little is known about atmospheric noise as a function of altitude. In view of these considerations ground to air circuits will not be analysed. The Reference System has been chosen to be an air to ground HF SSB voice communications (A3J Telephony) circuit with the following specification:

(i)	Direction of service	air to ground
(ii)	Distance from receiver	variable, d nautical miles
(iii)	Aircraft altitude	leads to (iv)
(iv)	Height gain factor	H = 0 dB (ie unity)
(v)	Transmitting aerial	half-wave dipole (electric) 081
(vi)	Polarization	vertical electric field

(vii) Total radiated power — 1 watt

(viii) Radiation efficiency — 0 dB (ie 100%)

(ix) Propagation mode — vertically polarized ground wave

(x) Receiver predetection bandwidth — 3 kHz

(xi) Predetection signal to noise ratio — 22 dB

(xii) Receiver aerial directivity — 0 dB (relative to dipole)

Receiving aerials need only possess sufficient gain to allow radio signals to overcome the effective front end noise of the receiver, and must be vertically polarized. The choice of 3 kHz for the SSB receiver bandwidth follows conventional practice in the HF band, although some advantage in speech clarity might accrue for wider bandwidths. The significance of 22 dB signal to noise ratio is discussed in section 6.1.

3 RESULTS FOR REFERENCE SYSTEM

The great variety of atmospheric noise conditions experienced at one location during different seasons and particularly at different times of the day have been simplified and presented in Fig 1 for the location 55°N 05°W. The values of the hourly averages exceeded for 10% of days (see Appendix B) have been plotted for 4 hour periods of the day throughout each 3 month season (time block). The pattern has been illustrated, taking two frequencies 2 MHz and 7.5 MHz. A service probability, or 'certainty' margin of 90% has been added to the basic noise levels. This reflects the uncertainties involved in forecasting noise statistics (see Appendix C).

It can be seen that for both frequencies there is a circadian (24 hourly) pattern of noise level which is somewhat modified by a seasonal cycle. Generally noise levels are highest at night and lowest in the morning. The effect of increasing frequency is shown by the reduction in the daily range of noise levels. Higher noise levels persist during summer nights and lower noise levels during spring days. For practical applications, it has been considered useful to present circuit availability results for two extreme conditions of atmospheric noise, typified by summer night, 2000-2400 hour and spring morning, 0800-1200 hour.

Propagation of the signal has been considered at three frequencies, 2 MHz, 7.5 MHz and 15 MHz over sea, good soil and poor soil in each case. For each of
081 a number of distances from the transmitter the field strengths of the signal and the median hourly noise have been obtained. After allowing for the specified

signal to noise ratio the remaining excess of signal over the noise threshold (median level) has been divided in varying proportion between the margins required to determine 'time availability' and 'service probability' (defined in Appendix C). Thus Figs 2 to 19 show curves of service probability, Y plotted against time availability, T% for constant distance, d . A family of such curves span the range of distances of practical interest. The greatest distance, d , satisfying the T and Y requirements becomes the range for that particular system performance. The results are arranged with the following Figure numbers.

Frequency MHz	Sea		Good soil		Poor soil	
	A	B	A	B	A	B
2	2	3	8	9	14	15
7.5	4	5	10	11	16	17
15	6	7	12	13	18	19

A : summer 2000-2400 hour - noise levels high

B : spring 0800-1200 hour - noise levels low.

The following electrical characteristics have been taken for the terrain:

Terrain	Electrical conductivity $S\ m^{-1}$	Relative permittivity
Sea	4	80
Good soil	0.01	4
Poor soil	0.001	4

For example, Fig 2 presents the results for the Reference System for propagation over the sea at 2 MHz on a summer night. The Y and T coordinates have specially calibrated 'arithmetic probability' scales, ie they are not linear. If one considers a distance (range) of 50 n miles the circuit may be sustained for T = 99.6% of days (summer nights) but the service probability Y is only one half. That means that there is no margin against long term drift in the basic statistics underlying the determination of T . If a reduction in time availability can be tolerated a greater service probability is determined. Thus, if T = 95% then Y = 0.82 or if T = 90% the service probability is almost 081
0.9. Low time availability could be guaranteed with very high service probability, for the same range, Y = 0.99 for T = 54% but this is unrealistic.

The overall circuit availability is the combination of T and Y the relative importance of each depending on the particular short term and long term requirements of the circuit operator. However, for most applications the simple arithmetic product of T and Y may be taken as indicative of circuit availability. For a given distance or range, TY is maximized when $T = 100\ Y\%$.

4 APPLICATION TO GENERAL SYSTEMS

Many different ground wave systems can be accommodated within the compass of this circuit availability guide. The ground to air direction of communication is complicated by the noise effects peculiar to aircraft. A single scaling factor permits quantitative comparison with the Reference System and enables the new circuit availability to be predicted. Figs 20 to 22 show the dependence of received signal strength $P = N(d)$ on distance d for propagation over sea, good soil and poor soil respectively. The signal strength, in decibels above 1 microvolt per metre, relates to a total radiated power of 1 watt, vertically polarized.

For any combination of T and Y , a unique distance d_1 can be read from Figs 2 to 19, appropriate to the Reference System. Corresponding to d_1 there is a threshold signal strength P_t which may be obtained from the appropriate propagation curve (Figs 20 to 22),

$$P_t = N(d_1) \tag{1}$$

where N is some function of distance.

In general, another system would determine a different propagation curve, a new signal to noise ratio criterion, and hence a new noise threshold. The range, d_2, of the new system satisfying the new signal to noise ratio criterion can be found simply by reading the distance on the original propagation curve (Figs 20 to 22) at which the field strength equals $(P_t - Q)$ dB. That is,

$$d_2 = N^{-1}(P_t - Q) \tag{2}$$

where Q is the decibel scaling factor for the new system.

Suppose that the new system differs from the Reference System in the following parameters (item numbers refer to section 2).

(i)	Transmitter mode launching efficacy	Γ dB
081 (iii)	Aircraft altitude (if applicable)	leads to (iv)
(iv)	Height gain factor of transmitter	H dB

(vii)	Total radiated power	W dB relative to 1 watt
(viii)	Radiation efficiency	A dB relative to unity
(vi)	Transmitter polarization mismatch (to vertical)	M dB relative to unity
(v)	Directivity of transmitting aerial	G dB relative to DIPOLE
(x)	Receiver predetection bandwidth	J dB relative to 3000 Hz (10 log (bandwidth ratio))
(xi)	Excess predetection signal to noise ratio to that of Reference System (22 dB)	X dB
(ix)	Extra transmission loss due to special propagation effects	L dB
(xii)	Receiver aerial directivity	Δ dB (relative to dipole)

$$Q = W + H + A + M + G - J - X - L + \Gamma + \Delta \quad . \qquad (3)$$

Items (vii), (v), (x) and (xi) are design factors. Items (vi) and (viii) are always less than zero and represent practical departures from the ideal. Item (iv), the height gain factor, expresses the ratio of the ground wave field strength at some particular altitude to its value at the surface. Figs 23 to 25 present curves of H versus altitude for the three frequencies and types of terrain of interest. Notice that over the sea there are two altitudes for which $H = 0$, one is trivial but the other is a practical flying altitude (viz the Reference System itself). Item (i), the mode launching efficacy, is 0 dB for an elevated source (air to surface system) and -3 dB for a surface located source (surface to surface system), see Appendix A. Item (xii), receiver aerial directivity is discussed at Appendix C. Item (ix) whilst relating to any departure from the standard propagation curves, is included to anticipate special propagation effects over the sea. Barrick has shown[2] that extra transmission loss can be incurred by a rough sea. Curves, based on his work are presented in Fig 26 where the extra transmission loss L is plotted against distance for three frequencies and two sea states. For fully developed wind waves sea state 3 corresponds to a 15 knot wind and sea state 6 corresponds to a 30 knot wind. For further guidance see Appendix D.

5 QUALIFICATIONS

A number of simplifying assumptions have been made in the foregoing analysis of circuit availability that will not always hold up.

(a) Sky wave modes have been ignored altogether. The effects on circuit availability of a strong sky wave (ionospheric reflection) are two-fold:

(i) In general the system range will be extended but the circuit will be unavailable at times, depending on ionospheric conditions. Thus circuit reliability may be low, outside the purely ground wave range.

(ii) Sky waves are generally randomly polarized and so simple aerials cannot discriminate against sky waves by more than 3 dB. Using a vertically polarized receiving aerial the vertical component of a sky wave mode can interfere with the ground wave mode and deep fading can result. Unless adaption of the receiving aerial system is envisaged, the performance inside ground wave range will be degraded.

(b) Anomalous atmospheric refraction effects have been ignored. Under certain conditions known as super refraction the radio horizon can be extended considerably thereby enhancing ground wave propagation. Terrain irregularities such as urban areas, mountains etc have been disregarded.

(c) Man made and galactic noise levels have not been estimated in the Reference System. When the atmospheric noise is low the received signal to noise ratio may at times be determined by man made or galactic noise, which ever is the greater. This is more likely to occur at higher frequencies because atmospheric noise decreases with frequency more rapidly than either man made or galactic noise.

It is recommended that the signal strength at range, in any particular case, be compared with the absolute noise field strengths indicated in Figs 20 to 22. Suppose that the use of the prediction charts determines a threshold level ϕ dB (μV/m) of atmospheric noise in the 3kHz bandwidth (Reference System).

$$\phi = U + Q - 22 \text{ dB } (\mu\text{V/m}) \tag{4}$$

where U is the Reference System signal field strength at the new system range. If ϕ is greater than the level of galactic and man made noise then correction is not necessary. If ϕ is less than the level of galactic noise, etc the system signal to noise ratio is determined by the larger noise contribution. Then the signal to noise ratio falls below that based on atmospheric noise alone and can be restored only by reducing the system range, to obtain a stronger signal. The man made noise values in Figs 20 to 22 are for a quiet receiving location.

6 DISCUSSION

6.1 General Remarks

6.1.1 Enlargement of scope

Bearing in mind the limitations, listed in section 5, to the use of this Report as a guide to HF radio communications, some consideration might be given to the feasibility of a comprehensive guide. It would have to take account of sky wave propagation since ranges attainable on ground wave only are inherently limited to a few hundreds of miles. For longer ranges the sky wave must be considered. Sky wave propagation is a subject in its own right, and, short of full computer modelling, its effects on circuit availability cannot be easily quantified. Moreover, it is believed that atmospheric noise and sky wave propagation may exhibit correlation in some parameters, having the ionosphere in common. How to treat man made noise in general is another problem area. Thus, any attempt at a comprehensive circuit availability 'reckoner' would be a formidable task and may be defeated on more than one front. The following discussion areas relate to those applications to which this Report is addressed.

6.1.2 Frequency coverage

The frequency range 2 to 15 MHz was not extended to cover the whole of the HF band (2 to 30 MHz) because beyond about 15 MHz atmospheric noise falls away rapidly with frequency. Galactic and man made noise take over above 20 MHz and determine system range. Whilst a statistical description of galactic noise is not precluded, it is the variability of man made noise which cannot be handled. Receiving sites may be quiet or noisy depending on proximity to centres of population, industry, and power lines. In course of time, regional development may render once quiet locations noisy.

6.1.3 Voice reception

For A3J telephony (SSB voice in 3 kHz bandwidth) the CCIR recommend[3] a post-detection signal to noise ratio of 15 dB for 'marginally commercial' quality. An allowance of 6 dB is recommended for the speech form factor, ie peak to average ratio. Hence the predetection signal to noise ratio (at IF and RF), R becomes 21 dB. The Reference System just exceeds that figure by 1 dB. Voice circuits are considered 'just usable' for R = 12 dB and of 'good commercial' quality for R = 33 dB , a span of 21 dB. It is possible that speech intelligibility may depend on other characteristics of the noise such as its burst nature 081
which are not described completely by the rms level.

6.1.4 Data transmission

If a binary FSK data system were substituted for the voice system the performance could be predicted in terms of the bit error rate (BER). The short term amplitude probability distribution (APD) for atmospheric noise may be specified by the parameter V_d (see Appendix B). A typical value for the Reference System is $V_d = 14$ dB (3 kHz bandwidth), the corresponding APD expresses the fact that statistically the noise envelope exceeds a level $C = 22$ dB above the rms noise envelope for 0.09% of the time (see Ref 1, Fig 27). For a signal to noise (rms) ratio of $R = 22$ dB the signal envelope to noise envelope ratio, C, is also 22 dB (both envelopes being 3 dB above their respective rms levels). Thus the noise envelope will exceed the signal envelope, using envelope (non-coherent) detection, for 0.09% of the time. Assuming an ideal reconstituter, eg a slicer and centre-point decision circuit, there exists a 50% probability that the instantaneous envelope of the noise will overcome the signal and lead to an incorrect output from the decision circuit. The resulting BER would then be $0.5 \times 0.09\% = 4.5 \times 10^{-4}$. Montgomery[4] has generalized this treatment for narrow band, binary frequency modulation systems.

6.1.5 Geographical coverage

Out of the 16 monitoring stations that provided the data base for the CCIR noise statistics only one (Kekaha) was located in an ocean area, namely the Pacific. It is debatable whether atmospheric noise propagation over ocean areas can be represented accurately by interpolating between land-based measurements. Whilst this question may not have much effect on the results for the Reference System, being based on the UK, it remains important in the world-wide context.

6.2 Aircraft considerations

6.2.1 Effect of altitude on range

An inspection of the ground wave propagation curves (Figs 20 to 22) reveals that transmission losses are much greater over land paths than over the sea. This observation is also reflected in Figs 8 to 19 by the relatively short ranges especially for the case of 'poor soil'. However, misleading estimates of air to ground ranges may be gathered from a consideration of Figs 8 to 19 by themselves. From Figs 23 to 25 it may be seen that the height gain factors for over land paths are much greater than for over sea paths. Moreover, the greater the ground wave transmission loss, for a fixed distance, the greater is the height gain
081 factor. The variability of transmission losses with different types of terrain is

always diminished as the propagation path is lifted away from the surface. Hence, air to ground ranges will not be curtailed in the same ratio as ground to ground ranges, when land is substituted for sea.

6.2.2 Height gain predictions

It is clearly important to know how the height gain factor varies with altitude especially over types of terrain and at frequencies that exhibit large transmission losses in the ground wave. A computer program[5] designed to predict VLF and LF field strengths has been adapted to produce the height variation of received field strength at frequencies in the HF band. These height gain functions, plotted in Figs 23 to 25, are offered as a first attempt at computer modelling of the height gain function. Some experimentally derived height gain functions for propagation over the sea have shown good agreement with these theoretical curves. Some minor deviations from agreement were put down to super refraction effects which occurred during the experiment.

A warning against indiscriminate use of the height gain curves must be given. The purpose of height gain curves is to interpolate the ground wave field strength in the region between the surface and the space above the radio horizon, where ray-optics theory takes over (see Appendix A). The curves are considered valid up to but not beyond an altitude determined by the radio horizon. The height of the radio horizon h_r is given by $h_r = 0.66d^2$ where h_r is expressed in feet, d in n miles, for normal atmospheric refraction. However, if range estimates are sought it is very likely that, for a well engineered system, one will be concerned with field strengths that are found well below the radio horizon.

6.2 3 Effect of altitude on noise environment

In view of the general observation that signal strengths (below the radio horizon) increase with altitude it may be surmised that atmospheric noise does so also. The CCIR[1] have not indicated whether atmospheric noise depends on altitude but it is understood to consist partly of signals propagating from tropical thunder-storm belts via ionospheric reflections. At distances of a few thousand miles (temperate latitudes) the noise signals will be propagated by a mixture of multi-hop sky wave and ground wave modes. The analysis can be simplified in terms of three composite modes depicted in Fig 27. Mode (a) is a multi-hop propagation mode (three or more reflections) which is not expected to lead to any height variation in received signal strength. Mode (b) arises when 081
the receiver is in the diffraction region (below the radio horizon) and is

associated with a height gain function. Mode (c) is purely ground wave and will propagate noise only from relatively local thunder-storms. Only very elaborate computer simulations, could show which modes are important and hence what height gain factors to expect for atmospheric noise. The complexity of the simulation would arise from the world-wide characteristics of ionospheric factors, terrain variations, meteorological statistics and statistical correlations between meteorological and ionospheric phenomena.

It was partly on account of this uncertainty in noise height gain function that the air to ground predictions have not been complemented with ground to air predictions; the airborne environment must not be assumed to be similar to that of the ground. Additional aircraft problems are the levels of locally generated noise, static discharge noise and electromagnetic compatibility offenders, which may exceed the levels of atmospheric noise.

6.2.4 Aircraft aerial characteristics

Further problems are associated with the air to ground direction of transmission. For a given transmitter power the effective signal radiated depends on the aerial efficiency and polarization relative to the dominant mode of propagation. At HF aircraft aerials are generally electrically short and often horizontally polarized; the radiation efficiency falls off rapidly with decreasing frequency[6] and often more than half the power is radiated in the horizontally polarized mode. Thus the trend towards greater transmission losses with increase in frequency is offset by increased aerial efficiency in the range 2-10 MHz. On the other hand inefficient ground station aerials can degrade the ground to air direction of transmission. The theoretical 3 dB advantage of a monopole may in practice be entirely lost through aerial losses, eg poor ground-plane.

7 CONCLUSIONS

(1) Circuit availability predictions have been presented for a specified reference air to ground HF communications system for three frequencies, three types of terrain and maximum and minimum atmospheric noise environments.

(2) Means have been supplied for applying the Reference System results to any specification of air to ground or ground to ground circuit.

(3) The generalized results may be used as predictions for studying the feasibility of systems at the design stage or retrospectively for trials evaluation.

(4) Circuit availability is at a minimum during the night and at a maximum during the morning, or daylight hours in winter.

(5) Propagation losses tend to be greater over land than over the sea but the differences are reduced progressively when one participant is elevated above the surface, as in the case of air to ground communications.

(6) The levels of atmospheric noise display a marked 24 hour cyclic variation. This variation decreases with frequency.

(7) The height gain curves may be used when seeking to estimate ranges of well engineered communications systems (*ie* below the radio horizon)

(8) The frequency dependence of the circuit availability has been incorporated into the main results but these exclude the important factor of aircraft aerial efficiency.

(9) There are serious problems in estimating ground to air circuit availability. It would be a formidable task to attempt a comprehensive guide to two-way ground and air circuit availability, even if sky wave were disregarded.

(10) For high circuit availability, without real time frequency planning, sky wave is not recommended although a penalty has to be paid in accepting relatively short ranges of typically a few hundred miles. Only with the aid of computer modelling could sky wave circuit availability predictions be made.

8 RECOMMENDATIONS

A truly comprehensive guide to circuit availability for HF communication systems would be a formidable task but certain extensions to the scope of this limited work could be made if the following areas were investigated:

(1) Electromagnetic interference generated by aircraft electrical and avionic systems.

(2) The influence of altitude on atmospheric noise levels for different types of terrain.

(3) Characteristics of atmospheric noise prevailing over ocean areas.

Appendix A

PROPAGATION

In the HF band the ionosphere can reflect radio waves back to the ground at usable strengths and often to considerable distances by means of a series of ionosphere-ground-ionosphere reflections. However, because of the great variability in the reflecting properties of the ionosphere, and the resulting unpredictable nature of ionospheric reflected waves (sky waves) it has been decided to disregard sky waves altogether. Sky wave effects are discussed in section 5, item (a).

At HF the term ground wave is commonly used to describe the mode or modes of electromagnetic wave propagation that obtain over the spherical surface of the earth in the absence of ionospheric reflections (ie as if there were no ionosphere).

Consider a transmitter C located on the earth's surface, as shown in Fig A1a. A line of sight path joins C to any point above the geometric horizon through C . At radio frequencies normal atmospheric refraction curves the paths of radio waves downwards so that they can propagate, unattenuated, into a narrow region below the geometric horizon. The lower boundary is, in fact, part of a sphere with a radius about four times the earth's radius and is known as the radio horizon. Ray tracing may be facilitated if the radio horizon is mapped into a plane, radio 'rays' then become straight lines, Fig A1b, and the earth is represented by a curvature of radius 4/3 the true earth radius, a .

Fig A1 (a)

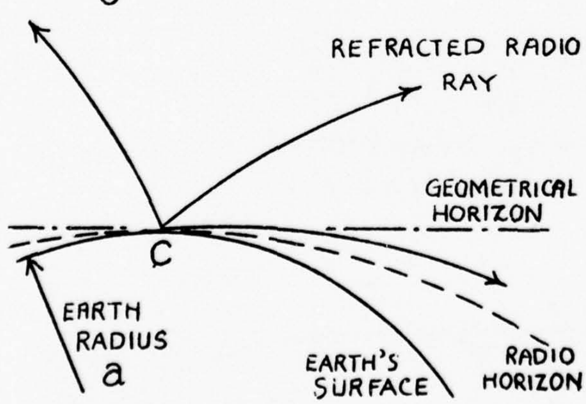
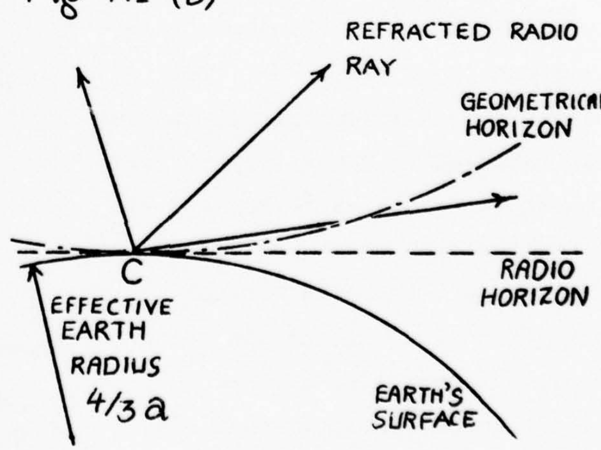


Fig A1 (b)



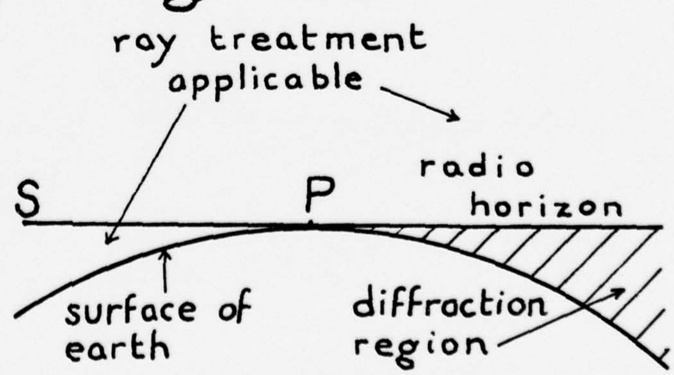
081 More often than not, knowledge of the field strength below the radio horizon is required, that is in the region inaccessible to radio 'rays'. Owing

to its wave nature, radio energy can pass round obstacles by a process of diffraction. The region between the radio horizon and the earth's surface, the diffraction region, contains radio field strengths that are much weaker than the fields above the radio horizon. For a given distance from C , the field strength decreases on passing below the radio horizon and continues to decrease downwards until ground level is reached. The ground level value of the field strength in the diffraction region is a convenient parameter for the whole diffraction region. In the diffraction region, solution of Maxwell's equations has been undertaken by several workers using protracted numerical evaluation of residue series. Bremmer[7], for instance, presents plots of the ground level field strength as a function of distance from C and also height gain factors versus height to cover the vertical extent of the diffraction region. The height gain factor is the ratio of the field strength at altitude to that given at ground level (assuming a perfectly smooth earth) and for a given set of conditions, its functional dependence on altitude is little affected by distance. *It ceases to be valid at altitudes approaching and above the radio horizon.*

Ground wave propagation may comprise horizontal and vertical components of the electric field but close to the ground the horizontally polarized wave component is severely attenuated. Consequently ground wave is regularly considered to be vertically polarized.

Published curves of ground wave field strength versus distance conventionally relate to a transmitting source located on the surface. In this Report the Reference System source is an airborne transmitter and consequently new ground wave field strength curves must be derived. The radio horizon (Fig A2) now passes through the source, S , and is a tangent to the earth's surface at P , the distance SP being the 'radio horizon range' from S . The region of validity for ray tracing is enlarged to cover not only the space above the radio horizon but also the area above the earth's surface within radio horizon range of S . Beyond the radio horizon range lies another diffraction region where field strengths are related to the ground wave values by, now, two

Fig A2



factors. One is the same height gain factor that obtains in the diffraction region when the source is on the surface. The other factor expresses the general propagation advantage of an elevated source.

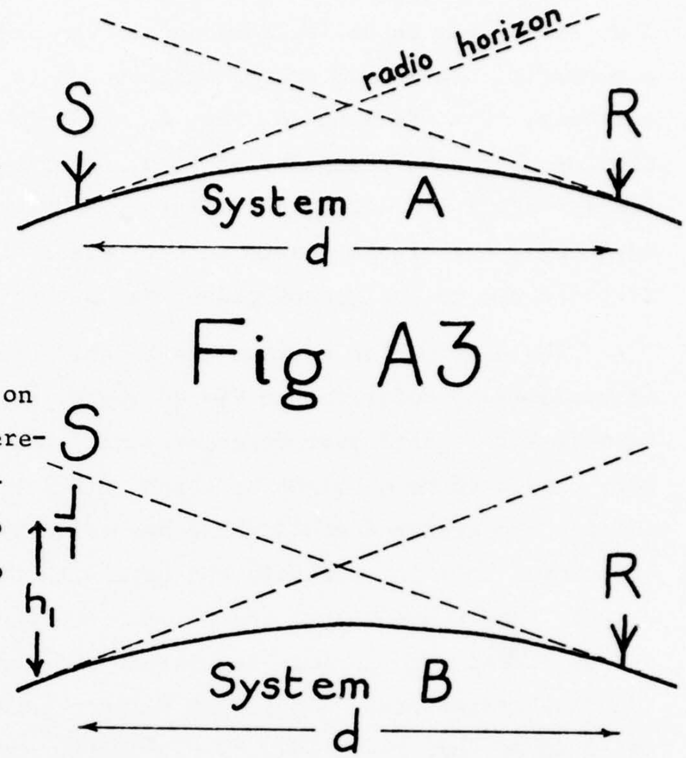


Fig A3

Consider the transmission systems depicted in Fig A3. In system A the source is a monopole on a conducting flat ground plane whereas in system B it is a dipole elevated to a height H_1. The end to end transmission losses of the two systems will be compared. The receiving cross-section (RC) of an aerial will be defined here to be the signal power produced to its matched load when it is illuminated by an electrical field of unit (rms) intensity. It is found (qv) that the RC of a monopole is 3 dB less than that of a dipole.

Let the field strength incident at receiver, R be E_A dB when, in system A, S radiates unit power. The received power at R is then $E_A + \Xi_m$ dB where Ξ_m is the monopole RC. By application of the Reciprocity Theorem, the signal received at S when R is made to radiate unit power is also $E_A + \Xi_m$ dB. Now in system B, the incident field strength received at S is given by $E_A + H(h_1)$ dB, where $H(h_1)$ is the height gain factor. The received signal then becomes $E_A + H(h_1) + \Xi_D$ dB, where Ξ_D is the dipole RC . This is the same signal (by Reciprocity) that is received by R when S is made to radiate unit power. Thus, for the same power radiated by S , the ratio, ρ , of the signals received at R in system B to that received in system A is given by:

$$\rho = \left(E_A + \Xi_D + H(h_1)\right) - (E_A + \Xi_m) \quad \text{dB}$$

$$= H(h_1) + \Xi_D - \Xi_m \quad \text{dB}$$

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$$= H(h_1) + 3 \quad \text{dB} \qquad \text{(A-1)}$$

Therefore, in addition to the height gain factor of the transmitter an extra 3 dB factor has to be included due to the difference in RC between a dipole and a monopole. This 3 dB factor corresponds to the transmitter mode launching efficacy, Γ . If both S and R were elevated, and consequently were both dipoles, then the transmission gain, relative to system A, would become $H(h_1) + H(h_2) + 6$ dB by a similar argument. In order to gain the 3 dB (Γ) advantage, the dipole has to be well clear of ground proximity effects; a dipole, if too close to the ground plane, may behave as though it were a monopole.

The distinction between the height gain factor and the Γ factor may be illustrated by reference to Fig 23 where, over the sea, the height gain factor is zero for a particular (non-zero) altitude. If, in system B (Fig A3), h_1 were chosen to be a height at which $H(h_1) = 0$ then the transmission gain relative to system A would still be 3 dB, simply due to the mode launching efficacy. This is precisely the case with the Reference System defined in this Report. The conventional ground wave propagation curves have been replotted with a 3 dB increase to reflect the larger mode launching efficacy of the airborne (dipole) transmitter. Thus, for surface to surface systems, Γ is made equal to -3 dB so that the dipole (Γ = 0 dB) is normalized to the Reference System.

In Figs 20 to 22 the ground wave field strength has been plotted against distance for three types of terrain. The vertical scale in each case relates to a total radiated power of 1 watt from a hypothetical short vertical lossless dipole (elevated). The curves for 2 MHz and 7.5 MHz were obtained from the CCIR[8] and for 15 MHz, from Bremmer[7] (not corrected for 4/3 earth radius). The corresponding height gain functions, Figs 23 to 25 were supplied by courtesy of Leicester University[9] using a computer program, WAVE HOP[5] (see section 6.2).

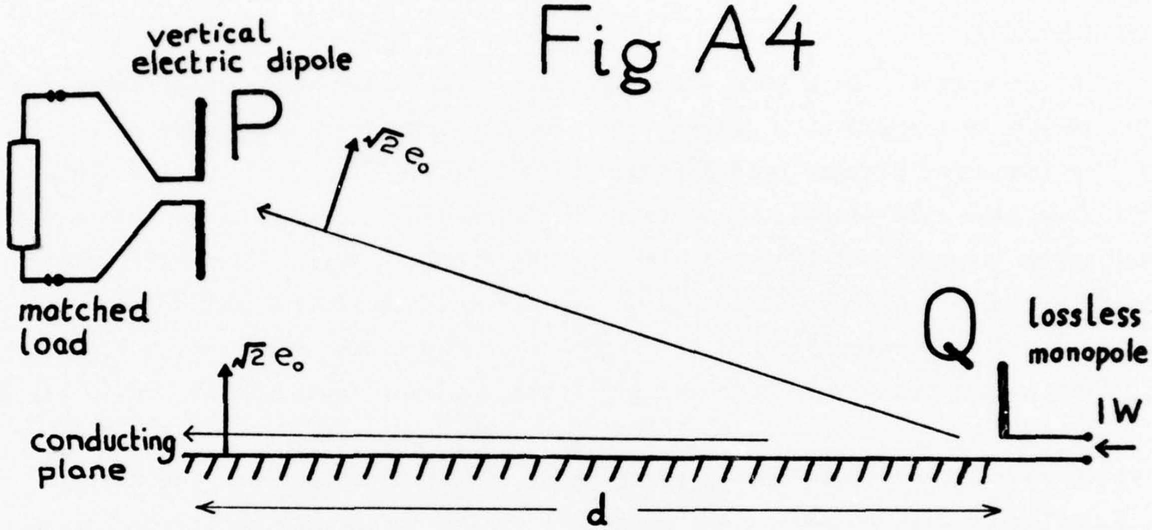
<u>Gain and receiving cross-section (RC)</u>

In this Report, the term 'directivity' implies only the relative gain, in azimuth, of an aerial due to the shape of its radiation pattern. In this sense a monopole and a dipole have the same shape of pattern and hence the same directivity (G = 0 dB). However, for the same radiated power, a monopole on a perfectly conducting ground plane has an effective radiated power (ERP) of twice that of a dipole in free space, since a monopole illuminates only one hemisphere. Consider a matched transmission system, as in Fig A4, obeying the Reciprocity Theorem. Ray tracing may be used to derive field strengths if the ground plane is flat and highly conducting. For unit power radiated from the dipole at P the field strength in free space, at distance d , is e_0 V/m. The field 081 strength at P for unit power radiated from Q is, however, $\sqrt{2}e_0$ because of the extra 3 dB ERP of the monopole at Q (Fig A4).

If the dipole RC is θ_D then the signal received at P is:

$$\theta_D(\sqrt{2}e_0)^2 = 2e_0^2\theta_D \quad W \quad . \tag{A-2}$$

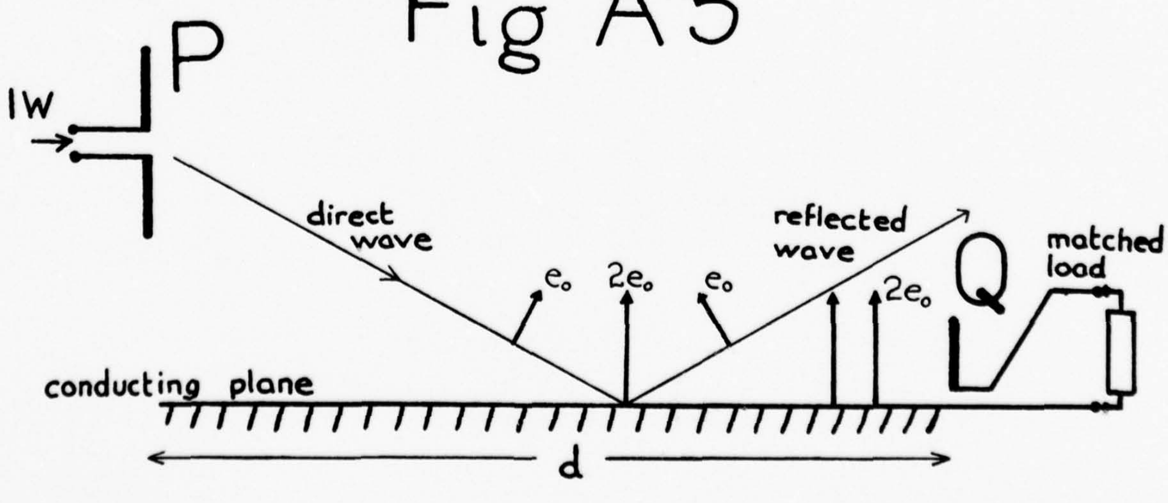
Fig A4



If, now, P transmits to Q (Fig A5), radiating unit power, the direct and reflected rays both have vertical electric field strengths of e_0 at Q . The rays interfere constructively to give rise to a surface field strength of $2e_0$ (negligible path difference). If θ_m is the monopole RC, the signal received at Q is:

$$\theta_m(2e_0)^2 = 4e_0^2\theta_m \quad W \quad . \tag{A-3}$$

Fig A5



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By the principle of reciprocity, the signal powers received must be the same for both directions of transmission, hence from equations (A-2) and (A-3)

$$\theta_D = 2\theta_m \quad . \tag{A-4}$$

Thus the monopole has twice the ERP but only half the receiving cross-section of the dipole.

Surface waves

Surface wave[10] is a term strictly reserved for evanescent modes where radio wave energy is trapped near the surface. Surface waves are supported when the surface impedance becomes predominantly inductive. A highly conducting (low resistive impedance) inductive surface is provided by the rough sea, the inductance being proportional to the surface corrugations. Barrick[2] has calculated the inductive effects of wind waves on the sea and also investigated the energy trapping and scattering effects of rough seas. The extra transmission loss L dB referred to the standard smooth sea propagation curves has been plotted in Fig 26. As expected, the transmission loss is negative for certain sea states, showing that the surface wave, or energy trapping is effective. However, the energy trapping effect is dwarfed by the magnitude of the energy scattering mechanism which takes over in higher sea states. The long wavelengths of wind waves are most effective in radio wave scattering and they also tend to be excited by stronger winds.

Appendix B

ATMOSPHERIC NOISE STATISTICS

B.1 Introduction

The statistical behaviour of atmospheric noise is quite complex and for a full account the reader is referred to CCIR Report 322 [1] on the subject. An abbreviated account is given here to cover the applications of concern to this Report.

Noise measurements were collated by the CCIR over a period of 4 years (1957-1961) from 16 stations around the world and for all hours of the day and night. The presentation of the data was simplified by grouping together measurements according to location, season, time of day and frequency. Data were not labelled with hour of day but were sorted into six 4 hour periods. The aggregate of corresponding 4 hour periods throughout a season was designated a time block, the statistically significant data package. The year was divided into four 3 month seasons, as shown below although it was realized that the seasonal pattern of noise variations existing in temperate regions was not necessarily followed at lower latitudes.

Month	Season (northern hemisphere)
December, January, February	winter
March, April, May	spring
June, July, August	summer
September, October, November	autumn

One key parameter was presented explicitly as a function of time block, geographic location, and frequency. The CCIR chose it to be the median hourly value of the average noise power, taken over a complete time block, ie 365 hours in each year. Variations in the median over the 24 possible time blocks manifested systematic circadian and seasonal rhythms. Variations of the hourly values within a time block were analysed statistically and the upper D_U and lower D_ℓ deciles of the variations about the median were obtained. The treatment adopted by the CCIR will be described in the order in which it was applied.

B.2 Hourly values

Atmospheric noise is characterized by large, rapid fluctuations but if the noise power is averaged over a period of several minutes, the average values
081 are not found to differ by more than ±2 dB during a given hour except near sunrise

or sunset, or when there are local thunder-storms. The ARN-2 Radio Noise Recorder yielded values of average power at each of eight frequencies for 15 minutes each hour, and it was assumed that the resulting values of F_a (*qv*) used in the analysis were representative of the hourly values.

It is convenient to convert the atmospheric noise measurements into an effective aerial noise factor f_a which is defined by

$$f_a = p_n/kT_0b \tag{B-1}$$

$$= T_a/T_0 \tag{B-2}$$

where p_n = noise power available from an equivalent loss free aerial, watts
k = Boltzmann's constant, 1.38×10^{-23} joule/kelvin
T_0 = reference temperature, taken to be 288 K
b = effective receiver noise bandwidth, hertz
T_a = effective aerial temperature is the presence of external noise, K .

Both f_a and T_a are independent of bandwidth because the available noise power from all sources may be assumed to be proportional to bandwidth, as is the reference power level, kT_0b . Expressed in decibels,

$$F_a = 10 \log f_a \quad . \tag{B-3}$$

B.3 Short term characteristics

For certain types of communications systems, eg Radio Teletype (RATT) it is useful to have some knowledge of the amplitude probability distributions (APD) of the noise in the short term. By short term is meant periods of time of the order of b^{-1} . The APD shows the percentage of time for which any level is exceeded; usually it is the noise envelope which is so described. The APD is dependent upon the short term characteristics of the noise and, therefore, cannot be deduced from the hourly values of F_a alone.

For presenting the data in an operationally useful form, the CCIR constructed a family of idealized curves one of which could be chosen to represent a practical APD to a sufficient accuracy. The construction of these curves involved quantities related to the rms average, and mean logarithmic values of the distri- 081
bution, parameters which had been recorded in routine noise measurements. In

practice, because the average voltage and mean logarithmic voltage are found to be closely correlated, the ratio of rms to average voltage V_d dB was sufficient to specify the curve which could be used to represent the distribution. Unlike F_a, D_U and D_ℓ, the values of V_d were not independent of bandwidth but were presented in the CCIR Report for a bandwidth of 200 Hz. Conversion curves were also provided to enable the corresponding value of V_d in a different bandwidth to be obtained.

B.4 Variations within a time block

The value of F_a for a given hour of the day varies from day to day because of random changes in thunder-storm and propagation conditions. The median of the hourly values within a time block (the time block median) was designated F_{am}. Variations of the hourly values during the time block could be represented by the values exceeded for 10% and 90% of the hours, expressed as deviations D_U and D_ℓ from the time block median. When plotted on a normal probability graph (level in dB), the amplitude distribution of the deviations, D, above the median could be represented with reasonable accuracy by a straight line through the median and upper decile values, and a corresponding line through the median and lower decile values could be used to represent values below the median.

B.5 Long term observations

The use of the time block median, F_{am}, for the purposes of prediction will be subject to inevitable errors, a measure of which can be obtained from a consideration of the variance $\sigma(F_{am})$. The values of $\sigma(F_{am})$ have been derived by comparing actual observations with predictions for the same locations, and include such uncertainties as those due to the unpredictable variations from year to year and the errors introduced by the necessity of presenting a large volume of data in summarized and homogeneous form. Larger values may be expected at locations where no measurements have been made since there is an additional uncertainty in the process of geographical interpolation but this cannot be assessed.

B.6 General characteristics

In addition to the temporal structure (short term, hourly, day to day and seasonal) of the atmospheric noise there are also broad trends dependent on frequency and geographical locations. The CCIR have presented world maps for the
081 time block medians, F_{am}, for each of the 24 time blocks. Contours have been

drawn for the values of F_{am} at 1 MHz and supporting curves relate F_{am} at other frequencies in the range 10 kHz to 30 MHz to the 1 MHz value, occurring at any particular location. Also shown as a function of frequency for each time block are D_U, D_ℓ, the variances of D_U and D_ℓ, the APD parameter V_d (at 200 Hz), and $\sigma(F_{am})$.

The time block medians are generally highest within tropical latitudes and especially well inland. One ocean area, the Pacific, was represented by the Kekaha station but elsewhere ocean regions have been ascribed values interpolated from land based measurements. In western Europe, noise levels tend to increase towards the south east.

The general variation of F_{am} with frequency in the range 10 kHz to about 1 MHz is described by a rate of fall of 40 to 50 dB per decade. The fall rate is arrested somewhat between 1 MHz and 10 MHz and then atmospheric noise falls abruptly at about 15 MHz and man made and galactic sources predominate.

Appendix C

CIRCUIT AVAILABILITY

C.1 Introduction

The basic determinant of circuit availability is the signal to noise ratio at the input to the radio receiver. The signal to noise ratio is related to the electromagnetic wave field strength ratio at the aerial by directivity (Δ dB). This is because the signal arrives from the direction of maximum gain, whereas the atmospheric noise is approximately omni-directional. The following analysis assumes an aerial directivity of $\Delta = 0$ dB for simplicity. Atmospheric noise data produced by the CCIR[1] relate entirely to measurements of the vertical electric field, and therefore are directly comparable with the vertically polarized electric fields of the supposed ground wave propagation mode.

For a given hourly value of the effective aerial noise factor F_a dB the CCIR produced the following expression for the rms noise strength of the vertical electric field.

$$E = F_a - 65.5 + 20 \log (f \text{ MHz}) \qquad \text{(C-1)}$$

where E = rms noise field strength for a 1 kHz bandwidth (dB μV/m).

The value of the field strength for any other bandwidth b Hz can be obtained by adding $(10 \log b - 30)$ to E. The other statistical parameters (Appendix B) such as D_U, D_ℓ, $\sigma(F_{am})$ apply equally well to noise field strength E as to F_a.

Circuit availability is considered, here, as comprising two statistically distinct factors for any system that is signal limited and requires a minimum (threshold) received signal to noise ratio. The two factors are time availability and service probability.

C.2 Time availability

On account of the day to day variation of the received noise level in a particular time block, any signal to noise ratio determined relative to the time block median of noise field strength will be achieved for only half the time. If the signal strength were to be increased by the margin D dB then the proportion of time (days) for which the required signal to noise ratio were achieved would
081 increase.

Let E_m be the median hourly noise field strength, corresponding to F_{am} for a given system

P be the signal field strength

R be the required signal to noise ratio $(\Delta = 0 \text{ dB})$

and let E_S be the noise field strength exceeded on S% of days

define
$$D(S) = E_S - E_m \tag{C-2}$$

assuming that
$$P = E_m + R \quad . \tag{C-3}$$

Therefore the signal to noise will be better than R for only half the time.

Now let $P(T)$ be the signal strength required so that the signal to noise ratio will be better than R for T% of the time (days). The signal to noise ratio will be less than R for (100-T) = S% of the time. That is equivalent to saying that the noise will exceed the level

$$E_S = P(T) - R \tag{C-4}$$

for S% of the time.

Substituting equation (C-2)

$$E_m + D(S) = P(T) - R \tag{C-5}$$

substituting equation (C-3)

$$P(T) = P + D(S) \quad . \tag{C-6}$$

The statistical margin, $D(S)$, is obtained from a knowledge of the upper and lower deciles of the hourly time block values (Appendix B), remembering that

$$D(S) = E_S - E_m$$

$$= F_a - F_{am} \quad . \tag{C-7}$$

C.3 Service probability

The section on 'long term observations' (Appendix B) pointed out that the median values of noise are themselves subject to a measure of uncertainty, represented by the parameter $\sigma(F_{am})$. It is aduced from the way in which $\sigma(F_{am})$ was established, that in a large number of trials in which observed time block medians are compared with predicted values, the errors should be normally distributed. The standard deviation would approach a constant value as the number of trials increases, a value not much removed from the established value of $\sigma(F_{am})$. The chance that the predicted time block median should not be exceeded on a given trial is, classically, one half. In order to guarantee a system performance prediction against this random error, the time block median noise has to be over estimated by a certain margin, Z dB . The probability that a prediction error will not exceed the margin Z dB is given by

$$Y' = \tfrac{1}{2}\,\mathrm{erf}\left(Z/\sigma(F_{am})\right) \quad . \tag{C-8}$$

The larger the margin Z the greater is the probability that the system will perform better than or as well as predicted. That is to say the performance (eg circuit availability) prediction is guaranteed to a probability of Y' . Equation (C-8) is based on the over simplification that the only statistically uncertain parameter is F_{am} . For a system performance specification which itself comprises statistical quantities, eg a minimum level of time availability, a number of other variances have to be considered alongside $\sigma(F_{am})$. In general the following parameters and their variances may need to be considered

		Parameter	Variance
F_{am}	=	time block median noise level	$\sigma(F_{am})$
D(S)	=	time availability margin (noise)	$\sigma(D)$
P	=	calculated signal strength	$\sigma(P)$
R	=	required signal to noise (rms) ratio	$\sigma(R)$
C	=	APD determined signal to noise envelope ratio	$\sigma(C)$

(In the Reference System, and voice communications systems in general $\sigma(R)$ and $\sigma(C)$ are not applicable.) Assuming that the random errors in each of the parameters are uncorrelated, the overall variance σ_0 appropriate to equation (C-8) becomes

$$\sigma_0^2 = \sigma(F_{am})^2 + \sigma(D)^2 + \sigma(P)^2 \quad . \tag{C-9}$$

The variance of the time availability margin is assumed to be proportional to the margin,

$$\sigma(D) \propto D(S) \tag{C-10}$$

hence, knowing the variance of the upper decile, $\sigma(D_U)$ the variance $\sigma(D)$ can be obtained by ratios

$$\sigma(D)/D(S) = \sigma(D_U)/D_U \tag{C-11}$$

for $T > 50\%$. Similarly $\sigma(D_\ell)$ and D_ℓ are used for $T < 50\%$.
The propagation uncertainty, $\sigma(P)$, has been taken as 3 dB for the Reference System but in general it would have to be estimated from an assessment of the stability of the propagation conditions.

The comprehensive variance, σ_0, leads to a new determination of performance prediction guarantee Y, known as service probability. Thus

$$Y = \tfrac{1}{2} \operatorname{erf} (Z/\sigma_0) \quad . \tag{C-12}$$

Recalling equation (C-6), which yields the signal strength required for T% time availability, regardless of prediction errors, we can write

$$P(T,Y) = P(T) + Z \tag{C-13}$$

where Y (always less than unity) is given by equation (C-12).

Appendix D

TWO WORKED EXAMPLES

Example 1 Air to surface

Problem: to predict the range of an air to ground SSB voice circuit on the International Distress Frequency, 2181 kHz. The transmitter CW output power is 100 watts and total aerial efficiency is assumed to be -30 dB at 2 MHz. Equal powers are radiated, as though from a dipole, in vertical and horizontal polarizations. Aircraft altitudes may be below 5000 ft. A 'just usable' voice quality is required in a 3kHz bandwidth, *ie* a predetection signal to noise ratio of 12 dB. The time availability is 90% and service probability 0.9. The receiving location is 55°N 05°W, with open sea between the aircraft and receiver.

Looking at Figs 1 and 2 (2 MHz), the worst case is summer night, Fig 1. The Reference System range for T = 90% and Y = 0.9 can be read as 49 n miles. The scaling factor for this sytem, $Q = W + H + A + M + G - J - X - L + \Gamma + \Delta$ in dB where (referring to section 4)

$W = 20$	$G = 0$	$\Gamma = 0$
$H = 0$	$J = 0$	$\Delta = 0$
$A = -30$	$X = -7$	
$M = -3$	$L = 0$	

therefore

$$Q = -3 \text{ dB} \quad .$$

The propagation law for a smooth sea at 2 MHz (Fig 20) gives, for the Reference System, a field strength of 41 dB (μV/m) at 49 n miles. Subtracting Q (viz section 4) gives 44 dB which yields a new range of 35 n miles. Notice that, from Fig 26, even the roughest sea hardly adds any extra transmission loss. Referring to equation (4), section 5(c), the Reference System field strength, U = 44 dB to (μV/m) and hence the atmospheric noise threshold, ϕ , equals $44 + Q - 22 = + 19$ dB (μV/m). This 27 dB above the levels of man made and galactic noise (viz Fig 20) and therefore atmospheric noise alone determines the range.

Example 2 Ship to shore

Problem: to predict the circuit availability of a 'marginally commercial' SSB voice circuit on 15 MHz over a rough sea path of 90 n miles. The ship transmit-
081 ting aerial is a vertical monopole which radiates a total power of 200 watts, ground plane losses may be neglected. The receiver bandwidth is 4.75 kHz and

the required prediction signal to noise ratio is 18 dB. The shore station is at 55^{o}N 05^{o}W.

Comparing Figs 6 and 7 it can be seen that there is not a large difference in ranges for the Reference System, morning or night. Fig 7 will be used. Setting the service probability parameter, $Y = 0.5$ the time availability can be read as 54%. The field strength (Fig 20) at 90 n miles is 11 dB (μV/m).

The scaling factor $Q = W + H + A + M + G - J - X - L + \Gamma + \Delta$

where

$W = 23$	$G = +3$	$\Gamma = -3$
$H = 0$	$J = +2$	$\Delta = 0$
$A = 0$	$X = -4$	
$M = 0$	$L = +12$	

$$Q = +10 \text{ dB} \quad .$$

This expresses the fact that at 90 n miles the system has 10 dB in hand for a time availability of 54%. This margin can be put to use in the form of increased circuit availability. Consider motion up the $Y = 0.5$ ordinate in Fig 7, distance is being reduced whilst time availability, T, is increasing. From Fig 20 the change of distance corresponding to a 10 dB signal increase is from 90 to 65 n miles. On Fig 7, 65 n miles corresponds to a new time availability of 98%. Thus a trade-off between distance and time availability has enabled the effect of signal strength on time availability to be ascertained. The same method could be used for service probability instead of time availability, and any combination of the two.

The given system can be expected to work with a service probability, $Y = 0.5$ for a time availability, $T = 98\%$ up to a range of 90 n miles. The atmospheric noise threshold level for this range is given by equation (4), section 5(c): $\phi = U + Q - 22$ dB (μV/m) where U is the Reference System field strength at 90 n miles. Thus $\phi = 11 + 10 - 22 = -1$ dB (μV/m), in a 3kHz bandwidth, which is 12 dB above the level of man made and galactic noise. Alternatively, the given system could have a range of 120 n miles for the lower time availability $T = 54\%$ ($Y = 0.5$). In this case, $U' = +1$ dB (μV/m) and $\phi' = 1 + 10 - 22 = -11$ dB (μV/m) which is only 2 dB above the level of man made and galactic noise. The range of the system cannot be increased further by reducing time availability alone because the corresponding atmospheric noise threshold may not be taken below the level of man made noise, etc.

LIST OF SYMBOLS

A	aerial radiation power efficiency (dB)
APD	amplitude probability distribution (of noise)
BER	bit error rate
b	effective noise bandwidth Hz
C	the ratio of the signal envelope to the noise envelope (dB) as read from the APD for a particular BER
D	deviation of an hourly value of F_a from the time block median F_{am} (dB)
D_ℓ	value of the average noise power exceeded for 90% of the hours within a time block (dB below the median value for the time block)
D(S)	value of the average noise power exceeded for S% of the hours within a time block (dB above the median value for the time block)
D_U	value of the average noise power exceeded for 10% of the hours within a time block (dB above the time block median)
d	distance or range (nautical miles)
E	vertical electric field intensity, as measured in a 1kHz bandwidth, of atmospheric noise (dB above 1μV/m)
E_m	rms value of the vertical electric field of the time block median of atmospheric noise
E_S	rms value of the vertical electric field of the average noise level exceeded for S% of the hours within a time block
F_a	decibel equivalent of f_a *qv* ($F_a = 10 \log f_a$)
f_a	effective aerial noise factor which results from the external noise power available from a loss free aerial
F_{am}	median of the hourly values of F_a within a time block
f	frequency, MHz
G	directivity of transmitting aerial relative to a dipole (dB)
H	height gain factor, for the ground wave field strength (dB)
h	altitude of airborne transmitter (ft)
h_r	altitude corresponding to the radio horizon of a distant transmitter (ft)
J	ratio of receiver effective noise bandwidth to 3000 Hz (dB) J = 10 log (bandwidth ratio)
k	Boltzmann's constant = 1.38×10^{-23} joules per kelvin
L	extra transmission loss, referred to standard propagation curves, (dB)
M	transmitter aerial polarization mismatch to the vertically polarized propagation mode (dB)
N,N(d)	function relating ground wave signal field P strength to distance d
P	vertical electric field strength (rms) of the ground wave signal (dB above 1μV/m)
081 P_t	threshold signal field for specified circuit availability (dB above 1μV/m)

LIST OF SYMBOLS (concluded)

P(T)	value of P which yields required signal to noise ratio (R) for T% of the hours in a time block (dB above 1μV/m)
P(T,Y)	value of P which yields required signal to noise ratio (R) for T% of the hours in a time block and with a service probability equal to Y (dB above 1μV/m)
p	noise power available from an equivalent loss free aerial (W)
Q	scaling factor for a new system (dB)
R	signal to noise power ratio required (dB)
S	percentage of hourly average values of noise in a time block
T	time availability (%)
T_a	effective aerial temperature in the presence of external noise, K
T_0	reference temperature, taken as 288 K
U	Reference System signal field strength evaluated at the new system range (dB μV/m)
V_d	voltage deviation: the ratio (dB) of the root mean square voltage to the average voltage of the noise envelope
W	transmitter output power (peak envelope power on SSB) (dB above 1 watt)
X	excess predetection signal to noise ratio to that of the Reference System (19 dB)
Y	service probability
Y'	probability that a prediction of the value of time block median noise will not be exceeded on a given trial
Z	extra signal strength margin required to increase the service probability from one half to Y
Γ	transmitter mode launching efficacy (dB)
Δ	receiving aerial directivity relative to a dipole (dB)
Ξ	receiving cross-section (dB: watt metre $volt^{-1}$)
Θ	receiving cross-section (watt metre $volt^{-1}$)
ρ	ratio of signal powers received (viz Appendix A) (dB)
σ(C)	standard deviation of C
σ(D)	standard deviation of D(S)
$\sigma(D_U)$	standard deviation of D_U
$\sigma(F_{am})$	standard deviation of F_{am}
σ(P)	standard deviation of P or P(T,Y)
σ(R)	standard deviation of R
σ_0	total standard deviation

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No.	Author	Title, etc
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2	D.E. Barrick	Theory of HF, VHF propagation across the rough sea. II Application to HF and VHF propagation above the sea. Radio Science, Vol.6, No.5, May 1971
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4	G.F. Montgomery	A comparison of amplitude and angle modulation for narrow band communication of binary coded messages in fluctuation noise. Proc IRE, 42, 447, (1954)
5	L.A. Berry J.E. Herman	A wave hop propagation program for an anistropic ionosphere. Telecommunications Research Report, US Dept of Commerce, Office of Telecommunications, Boulder, Colorado (1971)
6	R.M. Harris	Radiation characteristics of some helicopter HF wire aerials. RAE Technical Memorandum Rad-Nav 1057 (1974)
7	H. Bremmer	Terrestrial radio waves: theory of propagation. Elsevier, p 118 (1949)
8	CCIR	Twelfth Plenary Assembly, New Delhi. Vol.2, Part 1, p 219, Recommendation 368-1 (1970)
9	Leicester University (Dr T. Jones)	Private communication
10	S. Silver	Radio waves and circuits

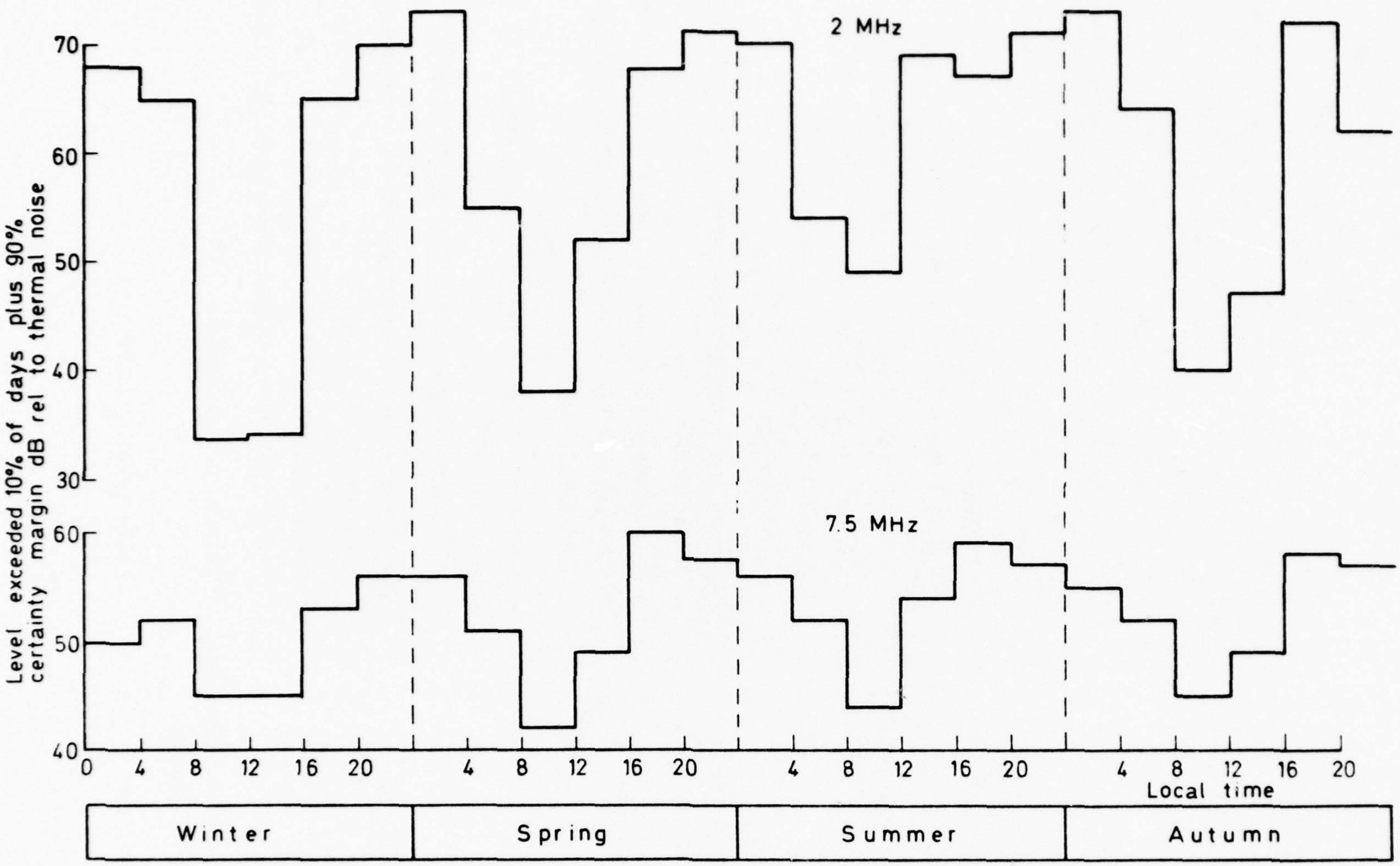


Fig 1 Atmospheric noise. 24 hour cyclic variation through the year

Stranraer (55°N 05°W)
Summer season, 2000-2400 h
Frequency: 2 MHz
Bandwidth: 3 kHz

Reference System
Sea

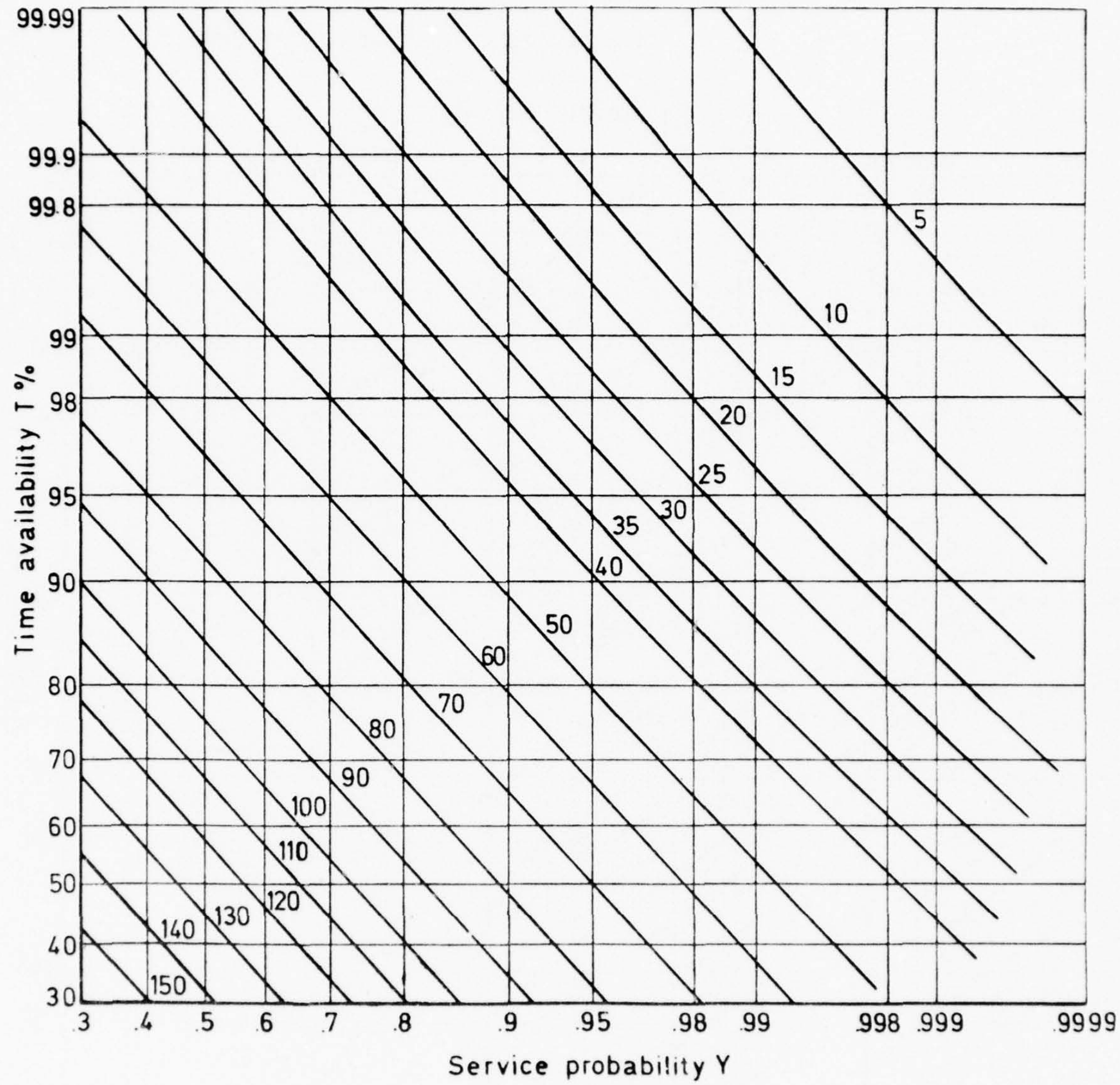


Fig 2 Time availability as a function of service probability

Stranraer (55°N 05°W)
Spring season, 0800-1200h
Frequency: 2 MHz
Bandwidth: 3 kHz

Reference System
Sea

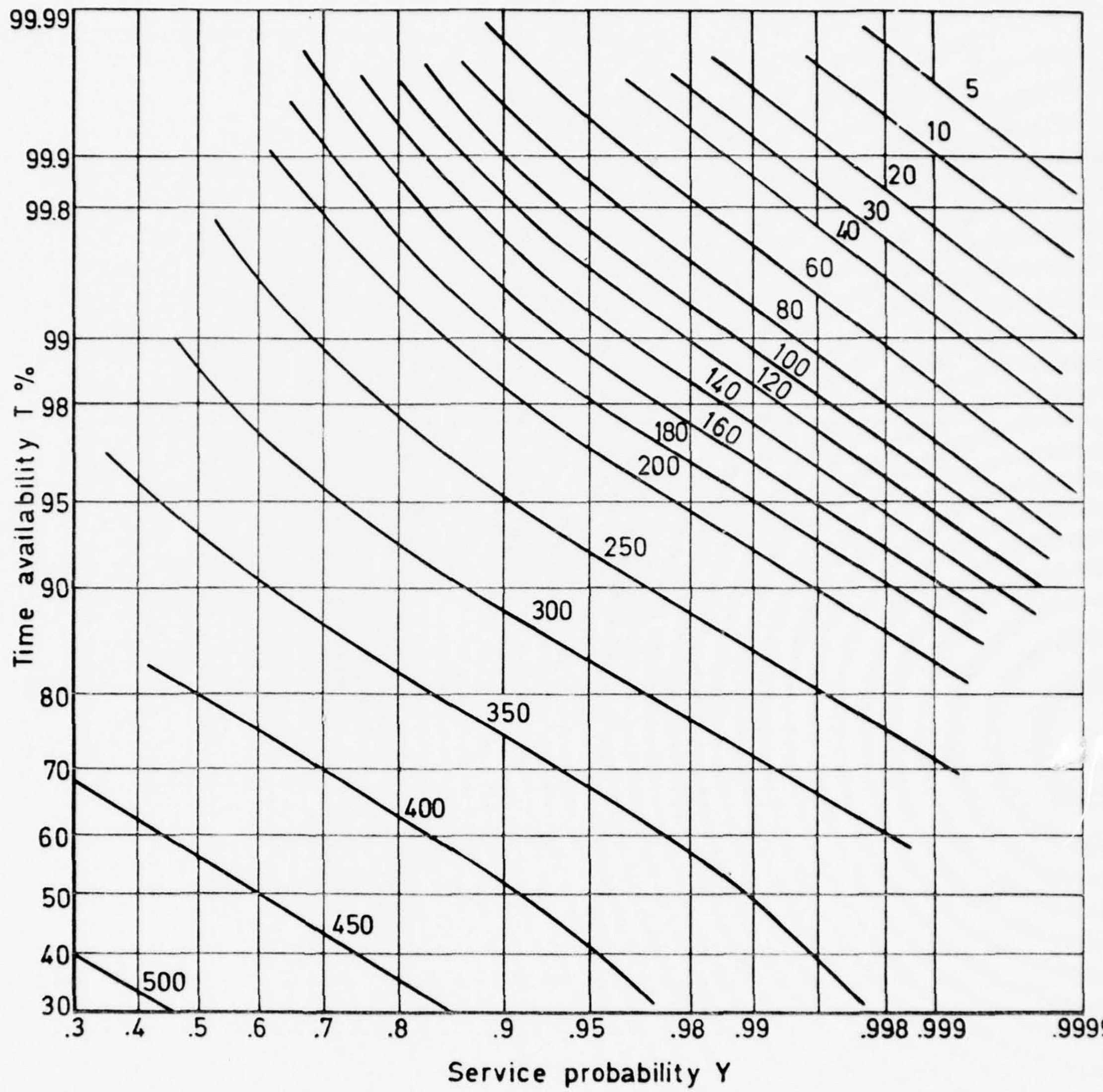


Fig 3 Time availability as a function of service probability

Stranraer (55° N 05° W)
Summer season, 2000-2400 h
Frequency: 7·5 MHz
Bandwidth: 3 kHz

Reference System
Sea

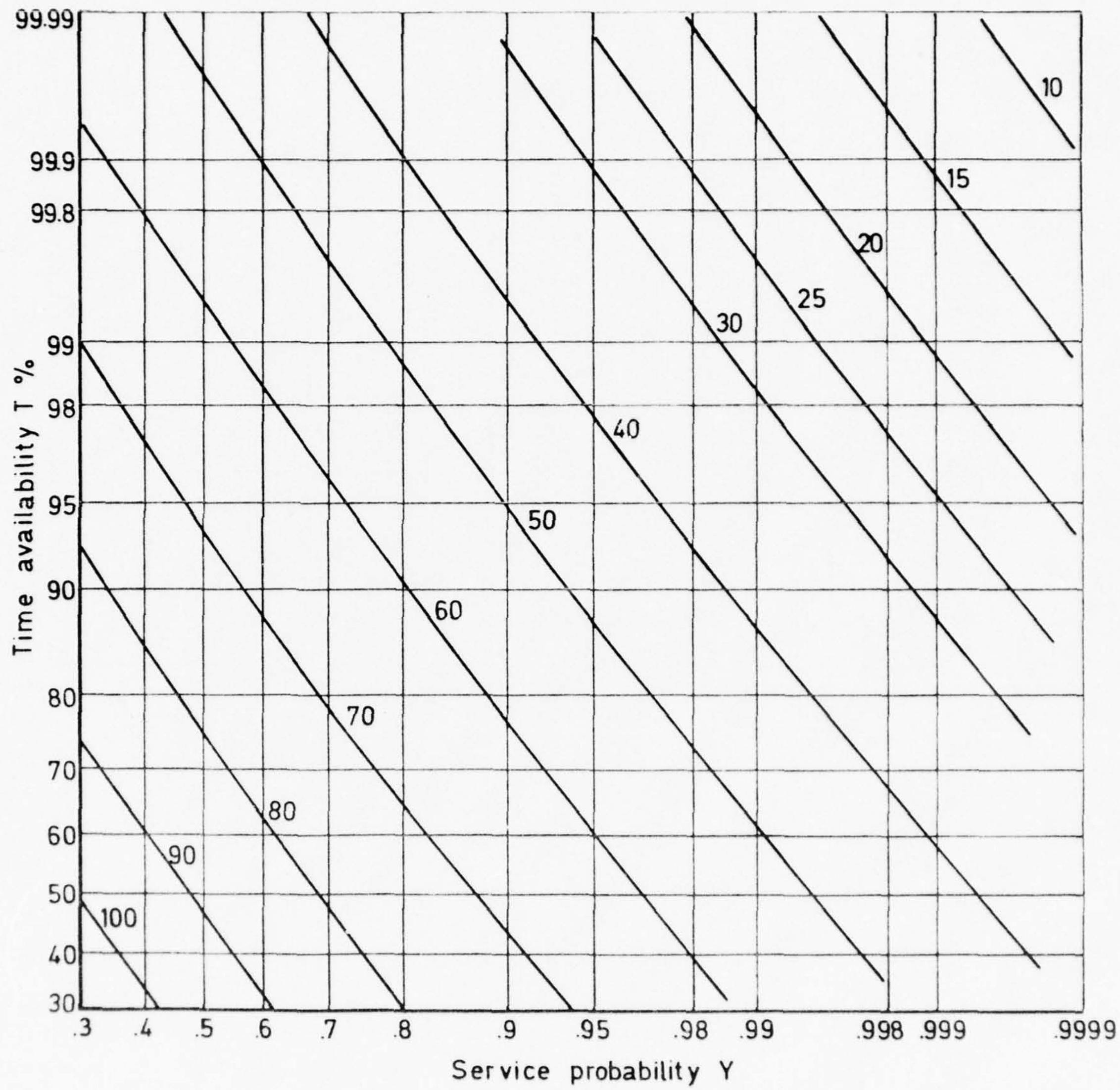


Fig 4 Time availability as a function of service probability

Stranraer (55° N 05° W)
Spring season, 0800-1200 h
Frequency: 7.5MHz
Bandwidth: 3 kHz

Reference System
Sea

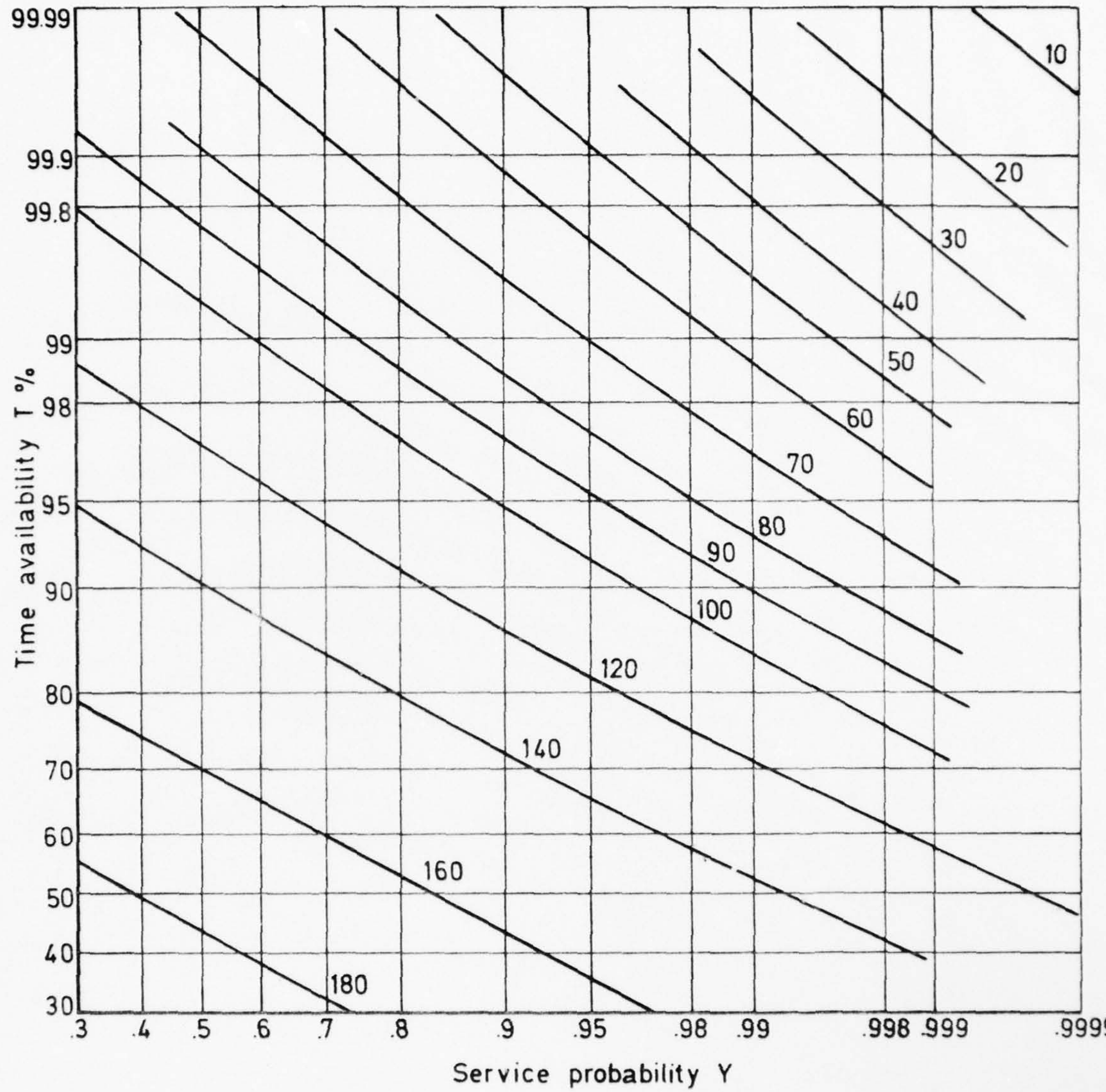


Fig 5 Time availability as a function of service probability

Stranraer (55° N 05° W)
Summer season, 2000-2400 h
Frequency: 15 MHz
Bandwidth: 3 kHz

Reference System
Sea

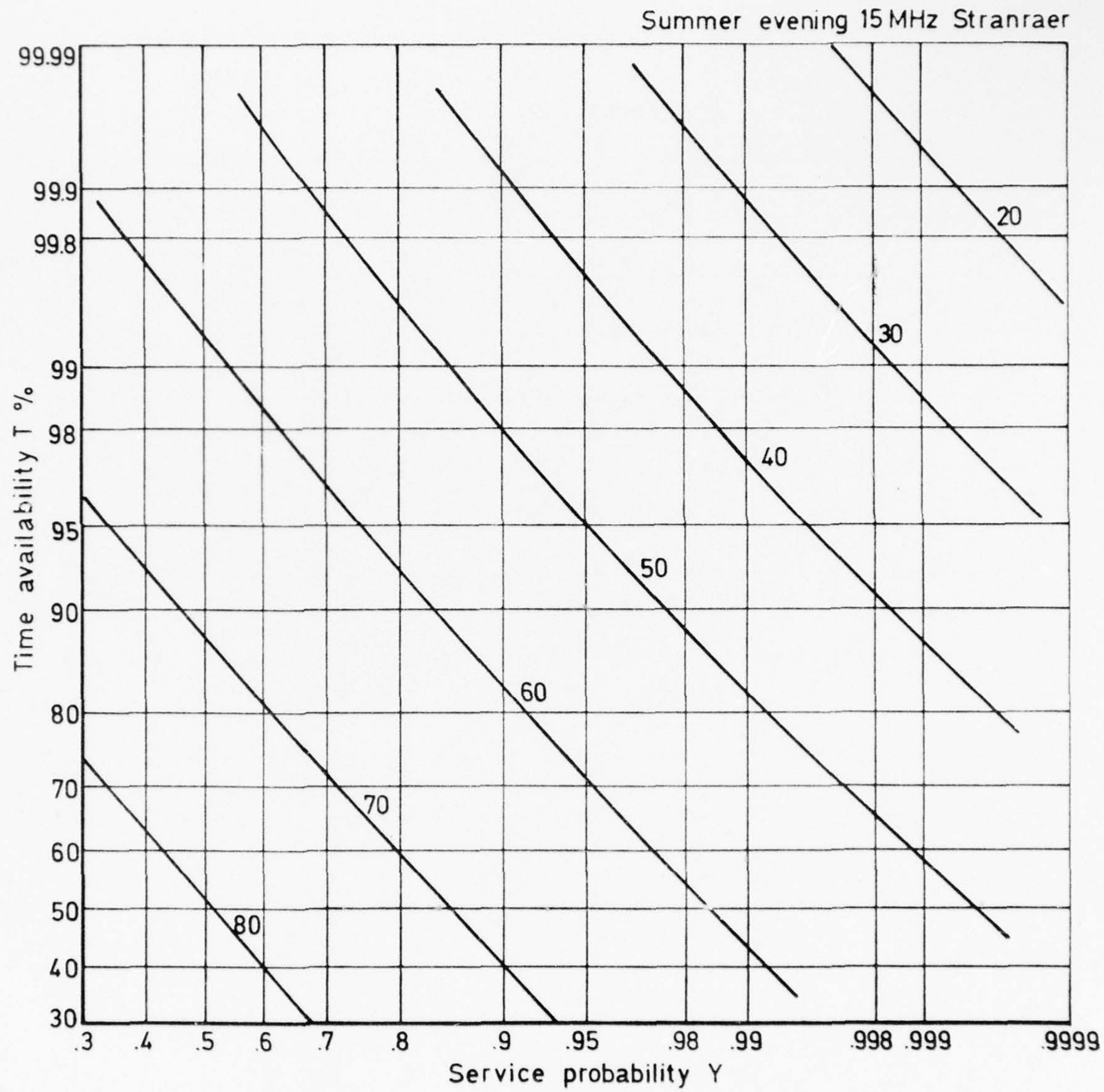


Fig 6 Time availability as a function of service probability

Stranraer (55° N 05° W)
Spring season, 0800-1200h
Frequency: 15 MHz
Bandwidth: 3 kHz

Reference System
Sea

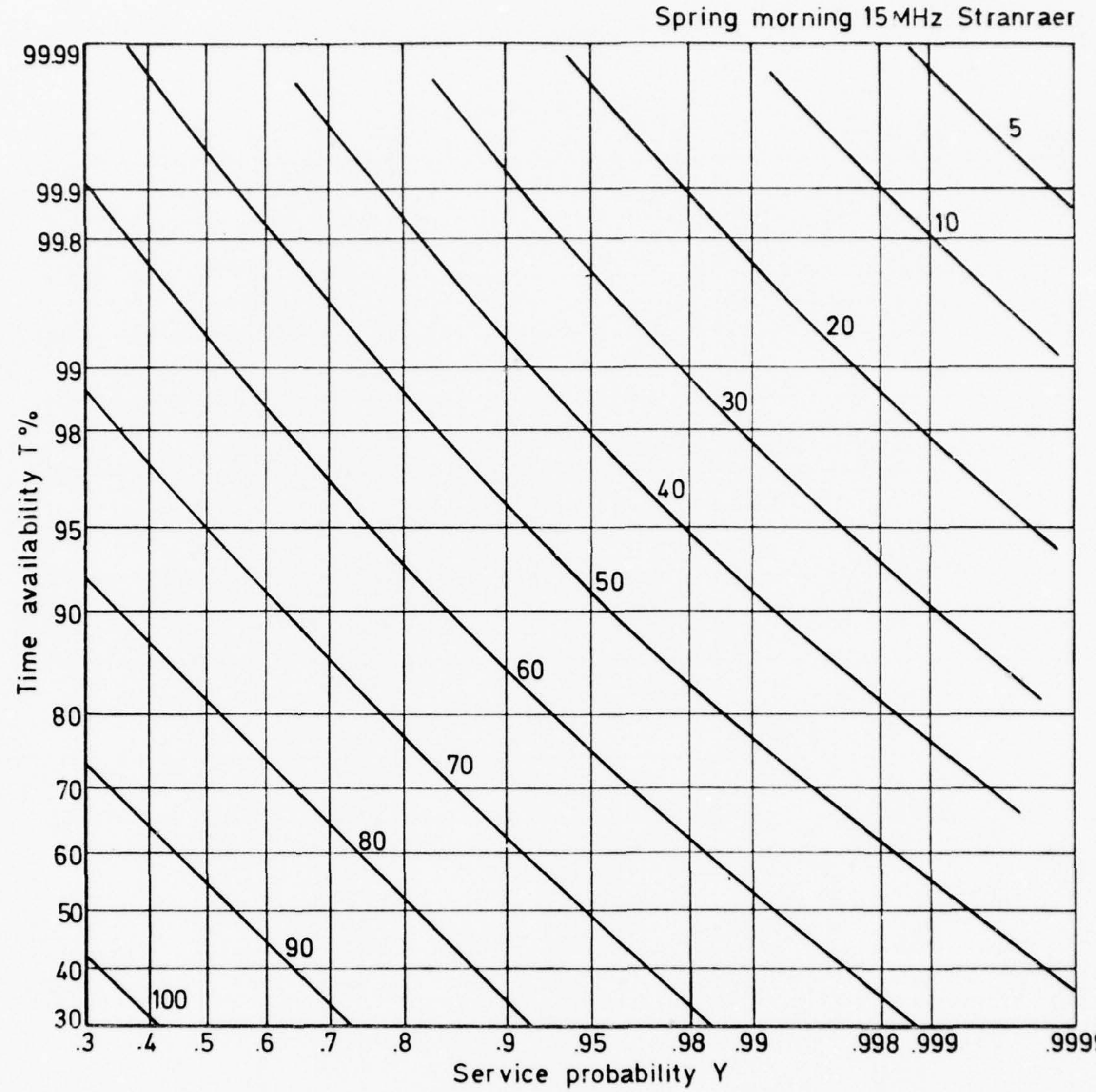


Fig 7 Time availability as a function of service probability

Stranraer (55°N 05°W)
Summer season, 2000 - 2400 h
Frequency: 2 MHz
Bandwidth: 3 kHz

Reference System
Good soil
$\sigma = 10^{-2}$ S/m, $\varepsilon = 4$

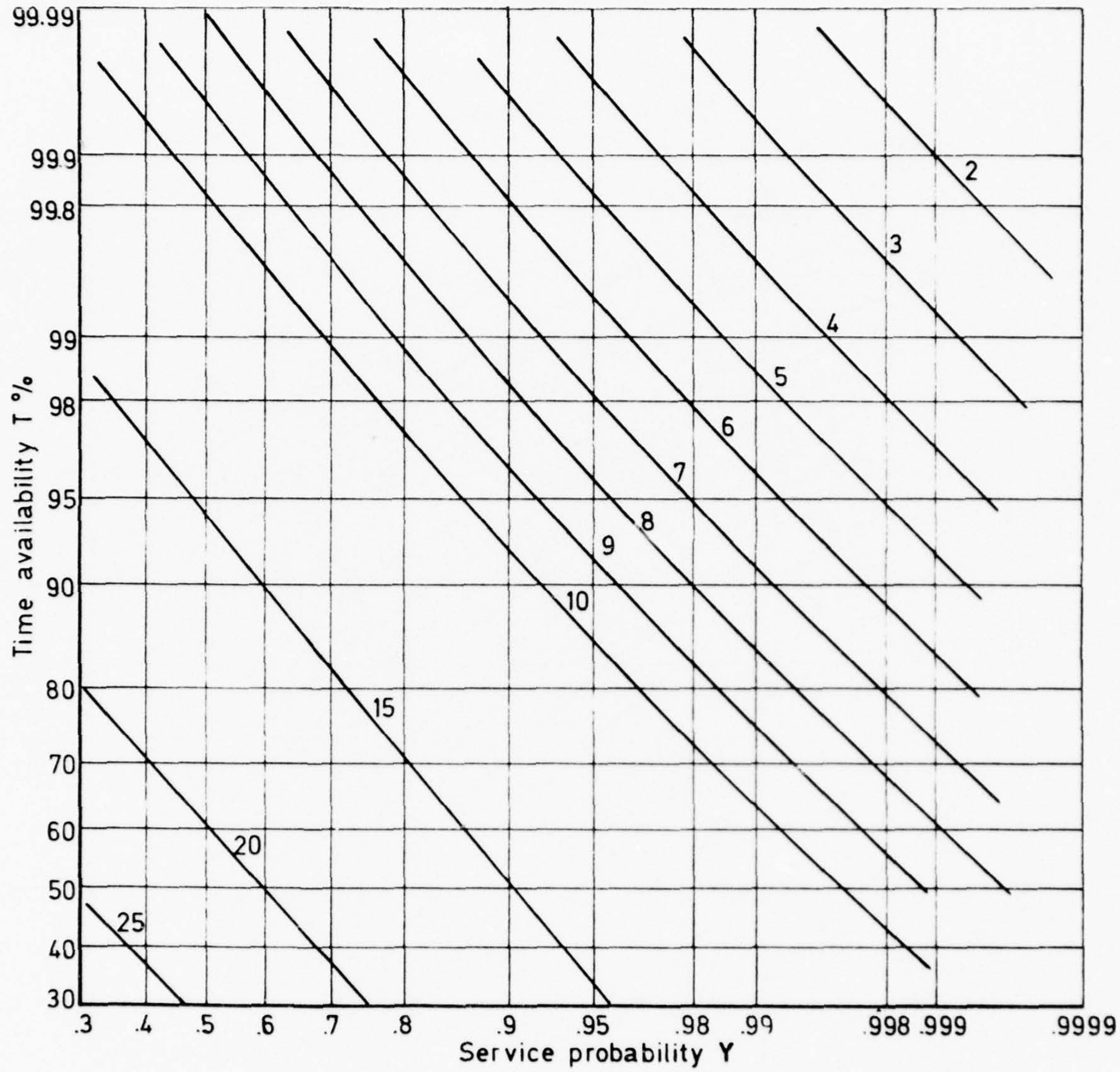


Fig 8 Time availability as a function of service probability

Stranraer (55°N 05°W)
Spring season, 0800 - 1200h
Frequency: 2 MHz
Bandwidth: 3 kHz

Reference System
Good soil
$\sigma = 10^{-2}$ S/m, $\varepsilon = 4$

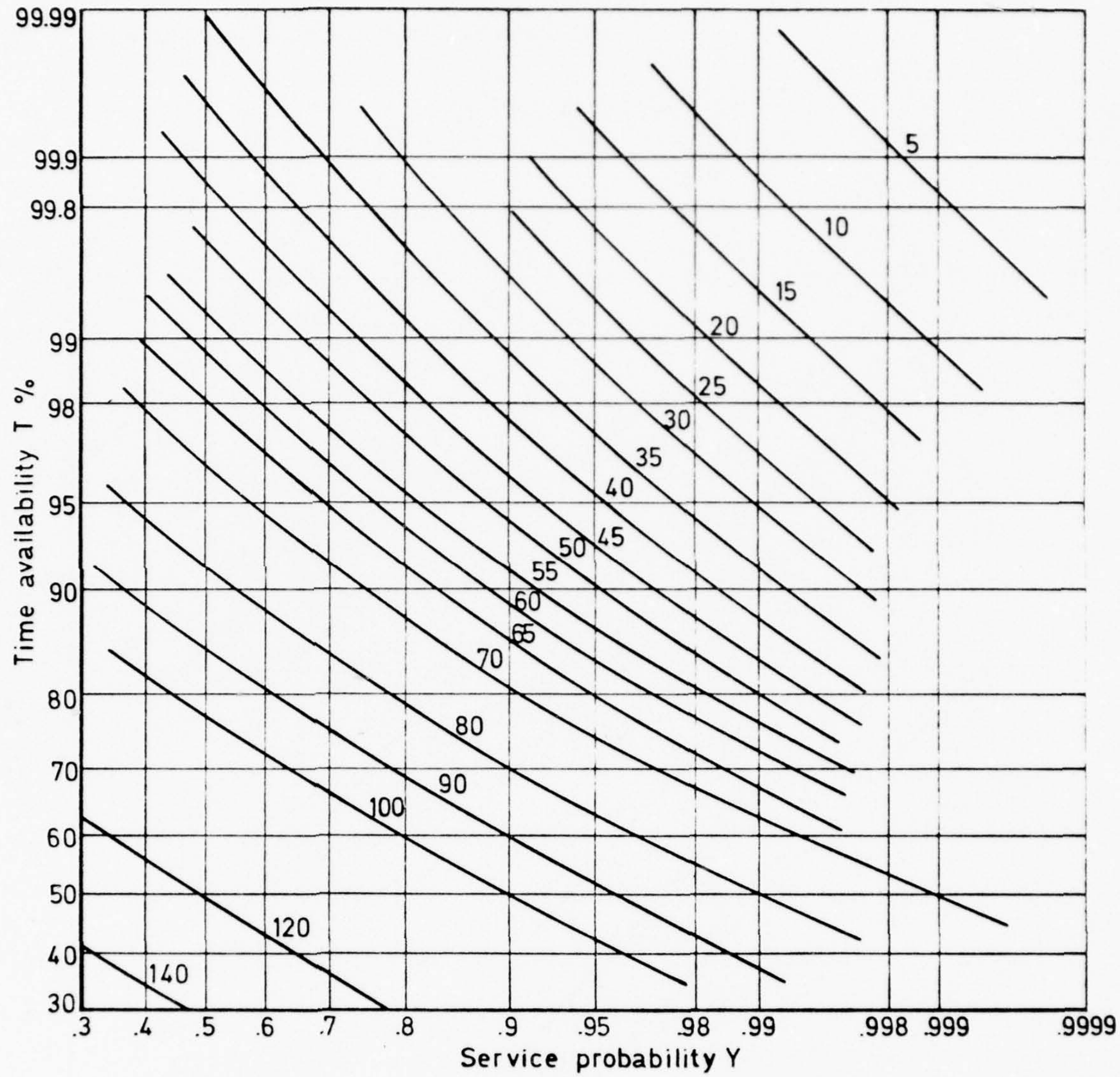


Fig 9 Time availability as a function of service probability

Stranraer (55°N 05°W)
Summer season, 2000-2400h
Frequency: 7.5 MHz
Bandwidth: 3 kHz

Reference System
Good soil
$\sigma = 10^{-2}$ S/m, $\varepsilon = 4$

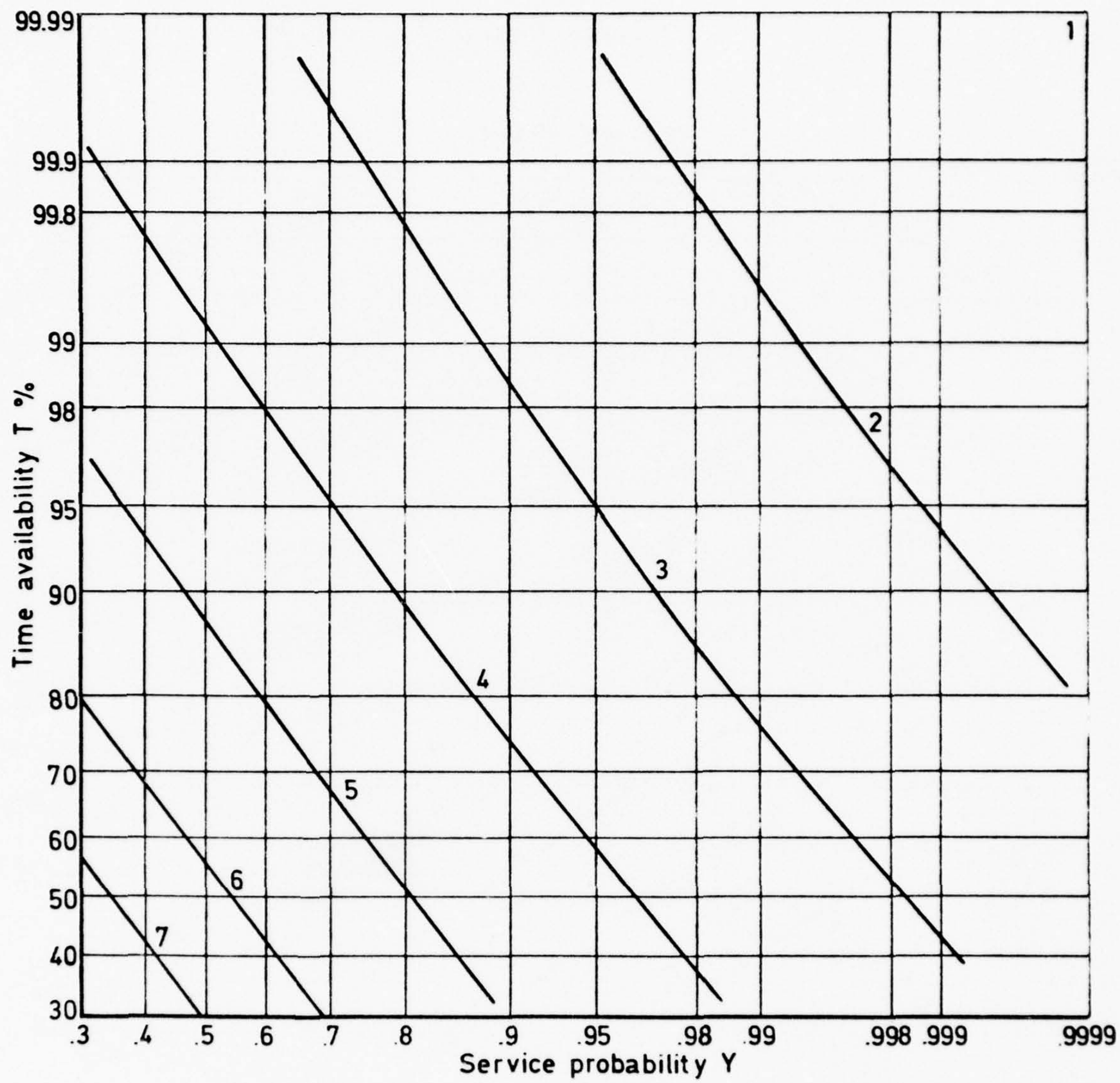


Fig 10 Time availability as a function of service probability

Stranraer (55° N 05° W)
Spring season, 0800 -1200 h
Frequency: 7.5 MHz
Bandwidth: 3 kHz

Reference System
Good soil
$\sigma = 10^{-2}$ S/m, $\varepsilon = 4$

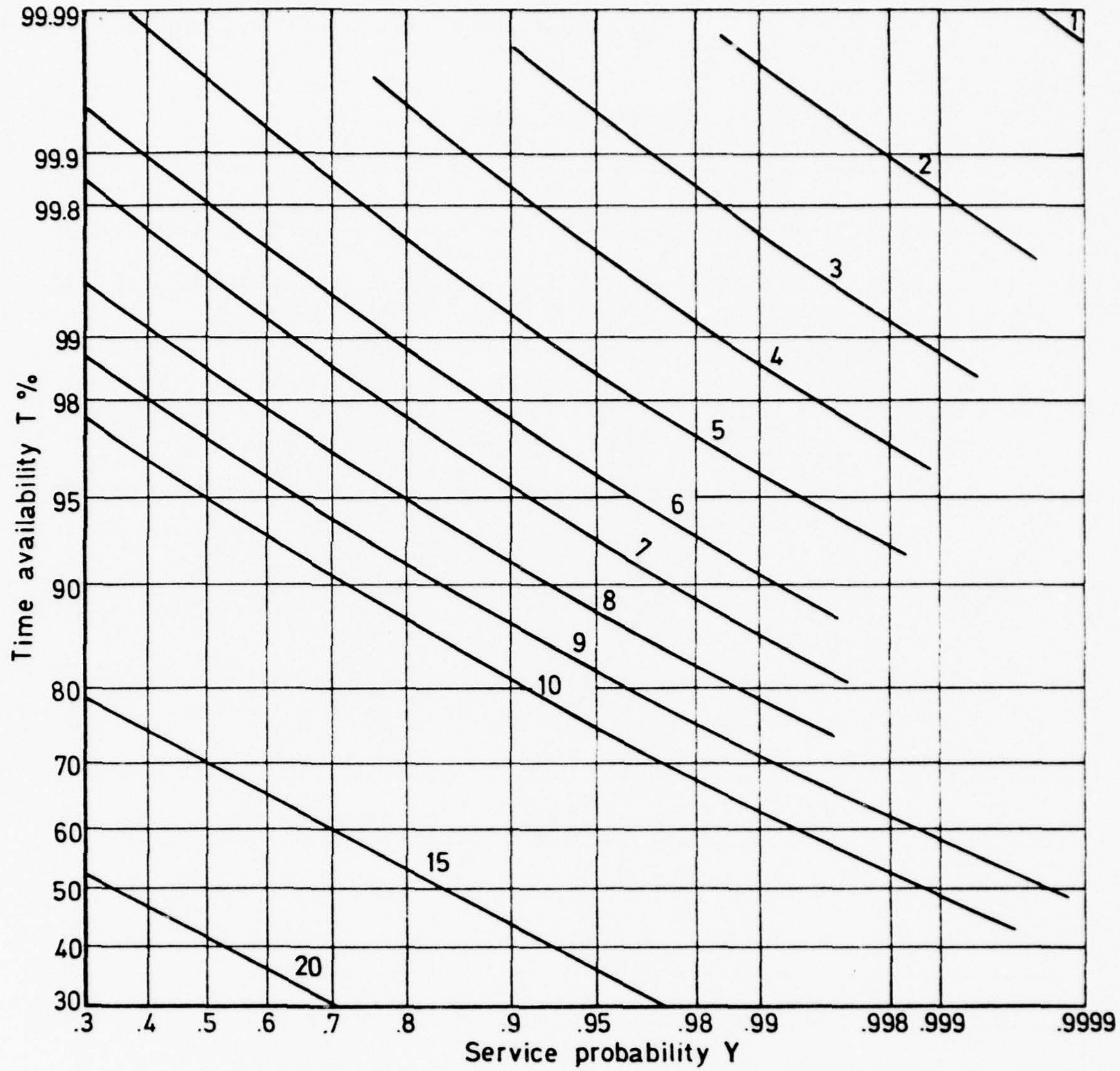


Fig 11 Time availability as a function of service probability

Stranraer (55°N 05°W)
Summer season, 2000-2400h
Frequency: 15MHz
Bandwidth: 3 kHz

Reference System
Good soil
$\sigma = 10^{-2}$ S/m, $\varepsilon = 4$

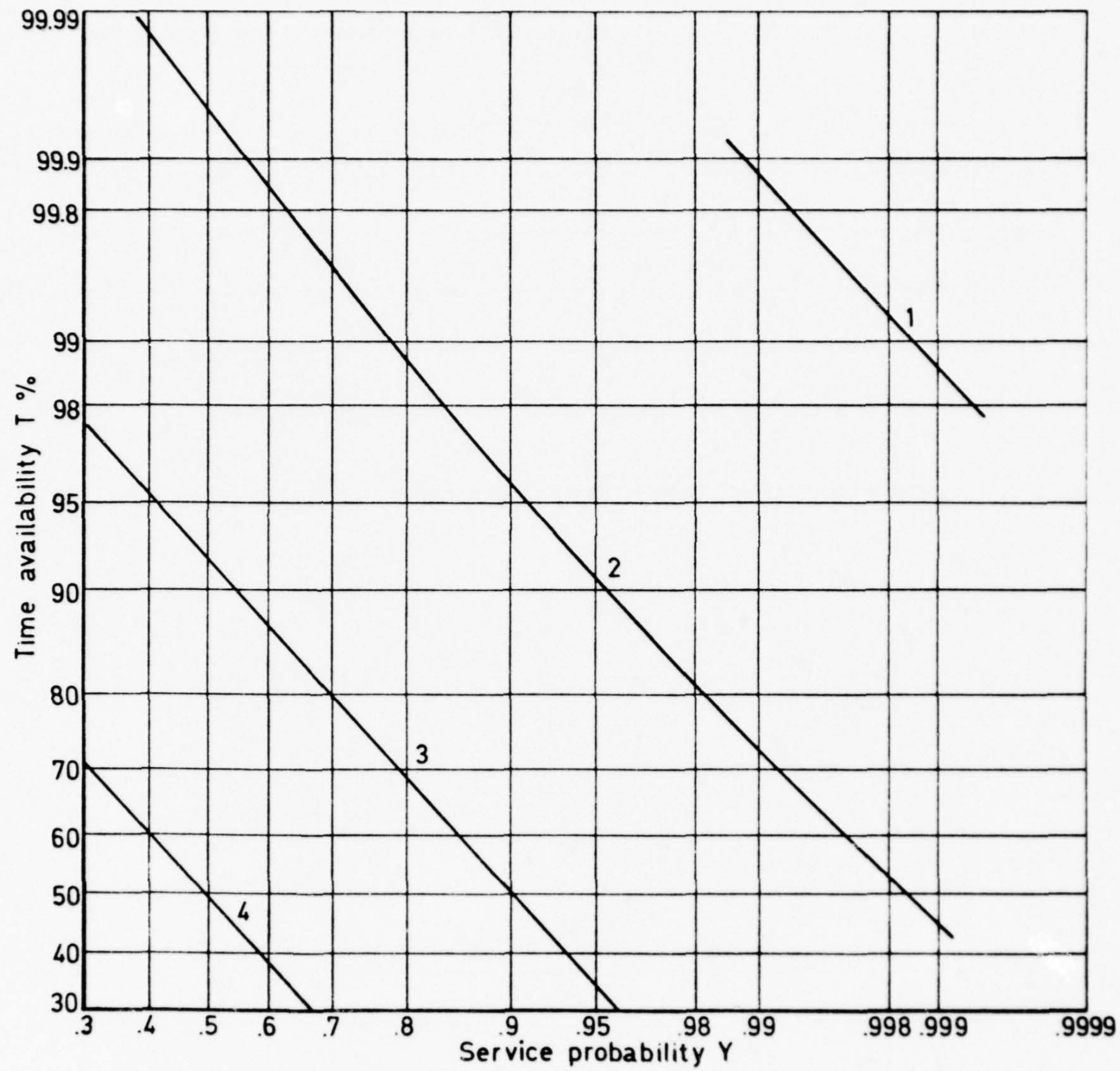


Fig 12 Time availability as a function of service probability

Stranraer (55°N 05°W)
Spring season, 0800-1200 h
Frequency: 15 MHz
Bandwidth: 3 kHz

Reference System
Good soil
$\sigma = 10^{-2}$ S/m, $\varepsilon = 4$

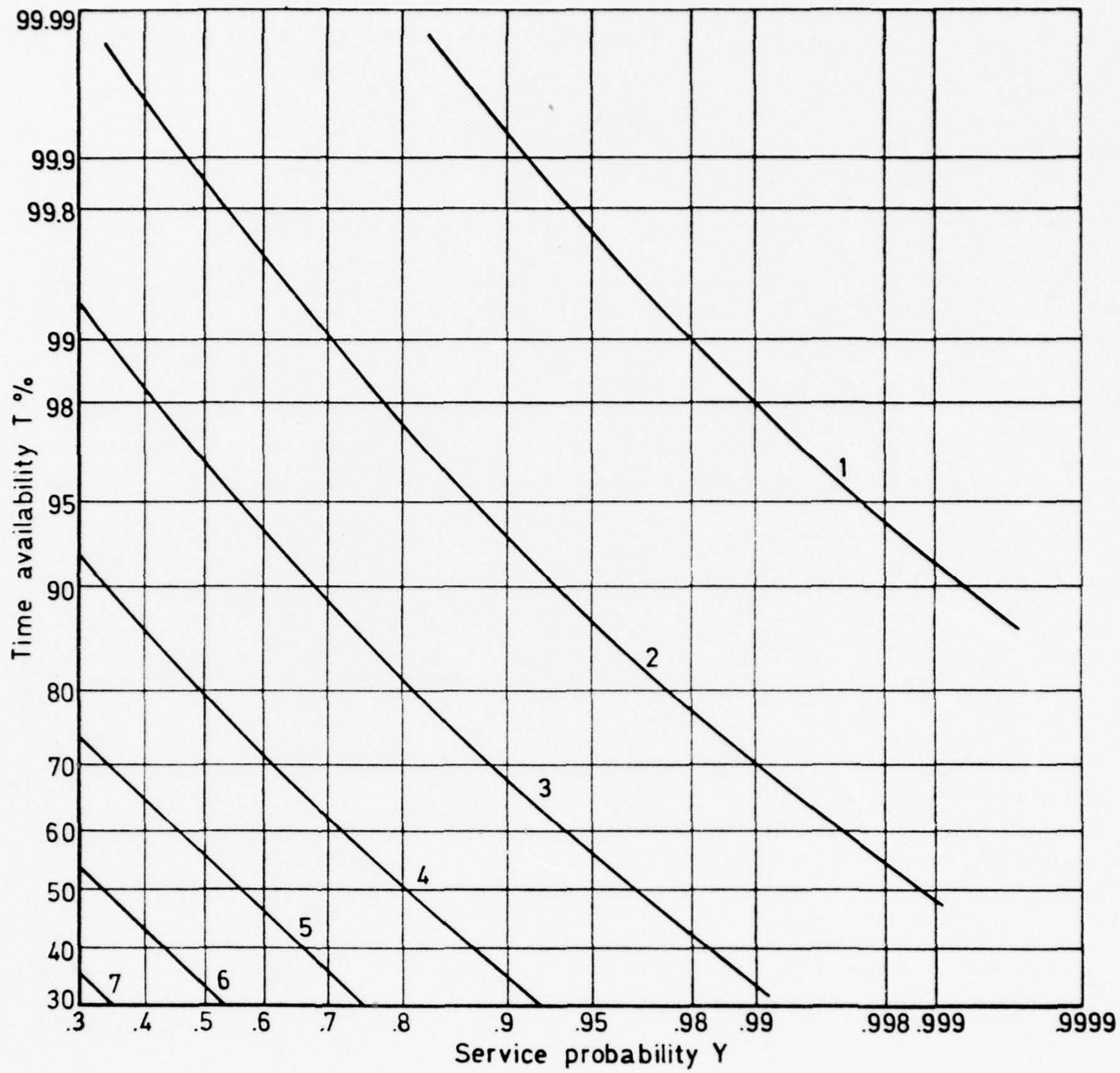


Fig 13 Time availability as a function of service probability

Stranraer (55°N 05°W)
Summer season, 2000-2400h
Frequency 2 MHz
Bandwidth 3 kHz

Reference System
Poor soil
$\sigma = 10^{-3}$ S/m, $\varepsilon = 4$

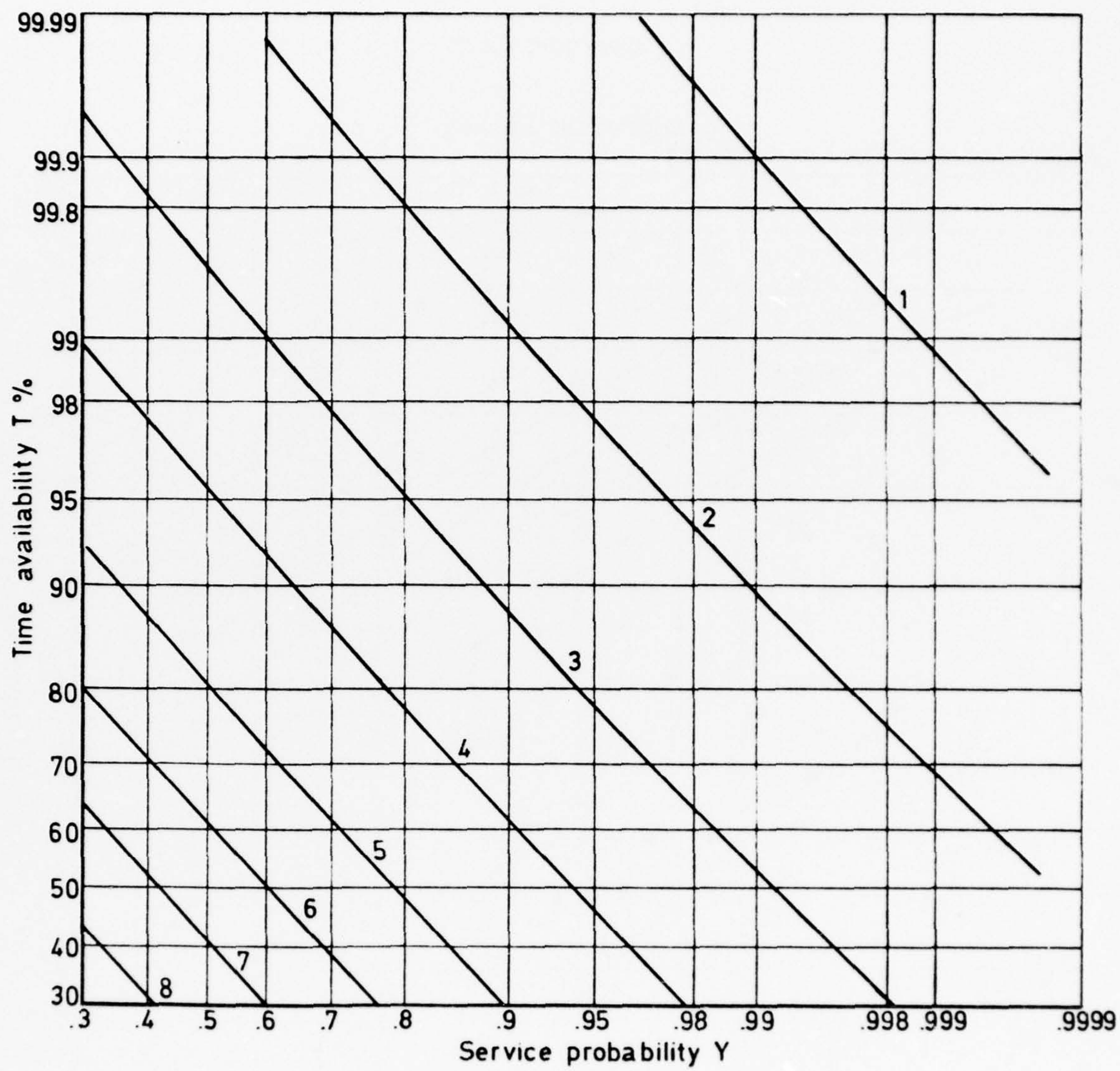


Fig 14 Time availability as a function of service probability

Stranraer (55° N 05° W)
Spring season, 0800-1200 h
Frequency: 2 MHz
Bandwidth: 3 kHz

Reference System
Poor soil
$\sigma = 10^{-3}$ S/m, $\varepsilon = 4$

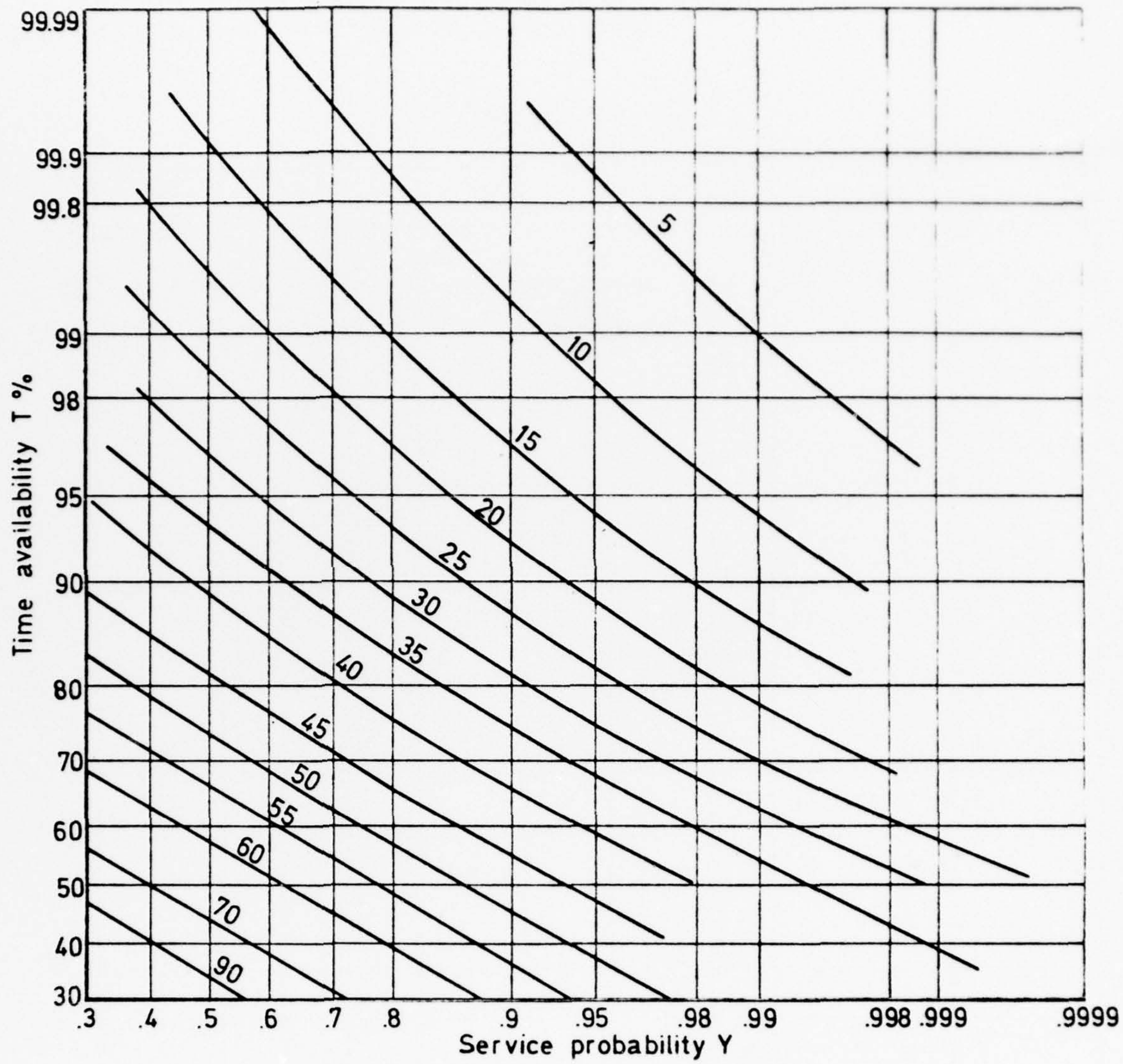


Fig 15 Time availability as a function of service probability

Stranraer (55° N 05° W)
Summer season, 2000–2400 h
Frequency 7 5 MHz
Bandwidth 3 kHz

Reference System

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

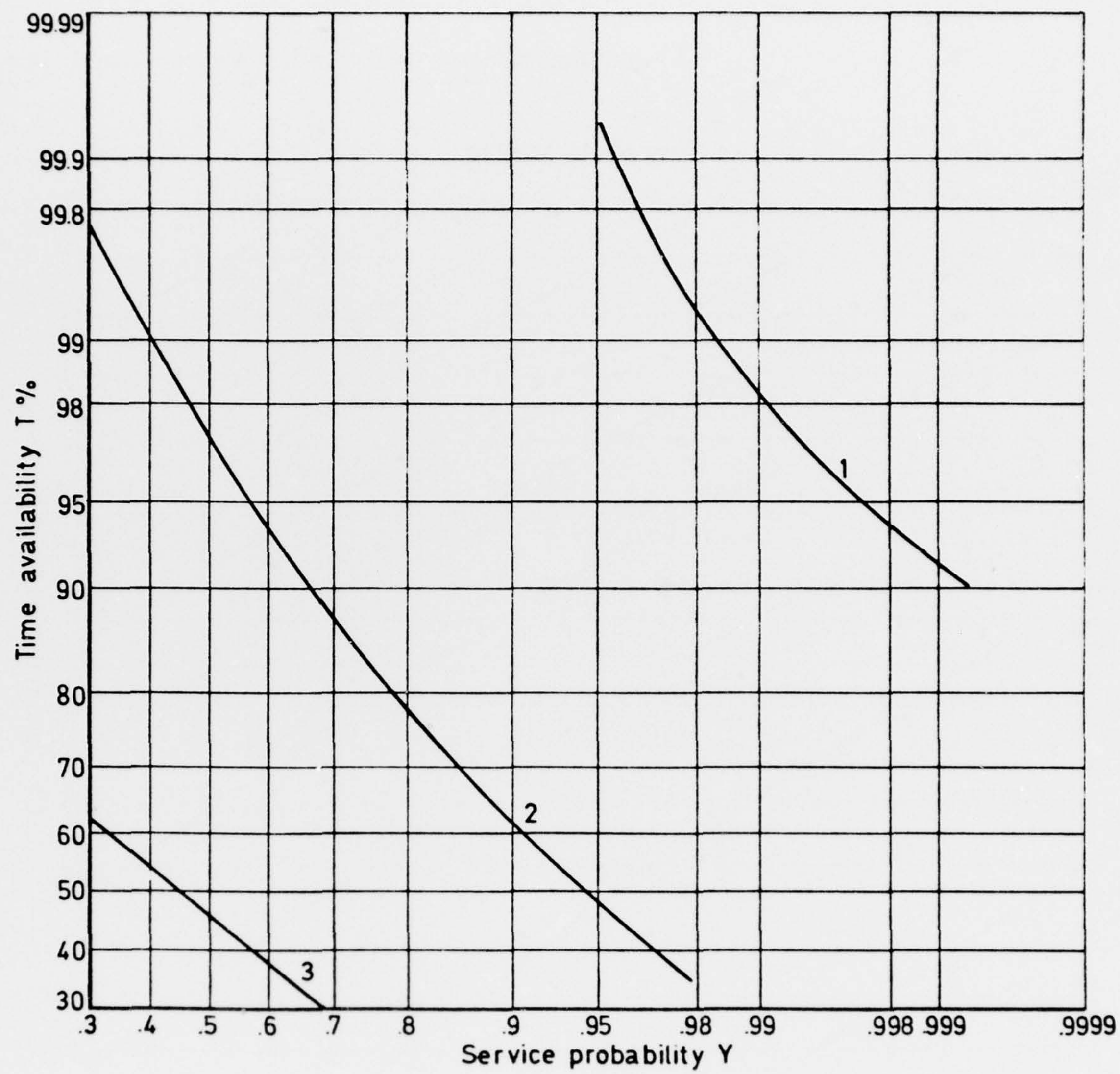


Fig 16 Time availability as a function of service probability

Stranraer (55° N 05° W)
Spring season, 0800-1200 h
Frequency: 7.5 MHz
Bandwidth: 3 kHz

Reference System
Poor soil
$\sigma = 10^{-3}$ S/m, $\varepsilon = 4$

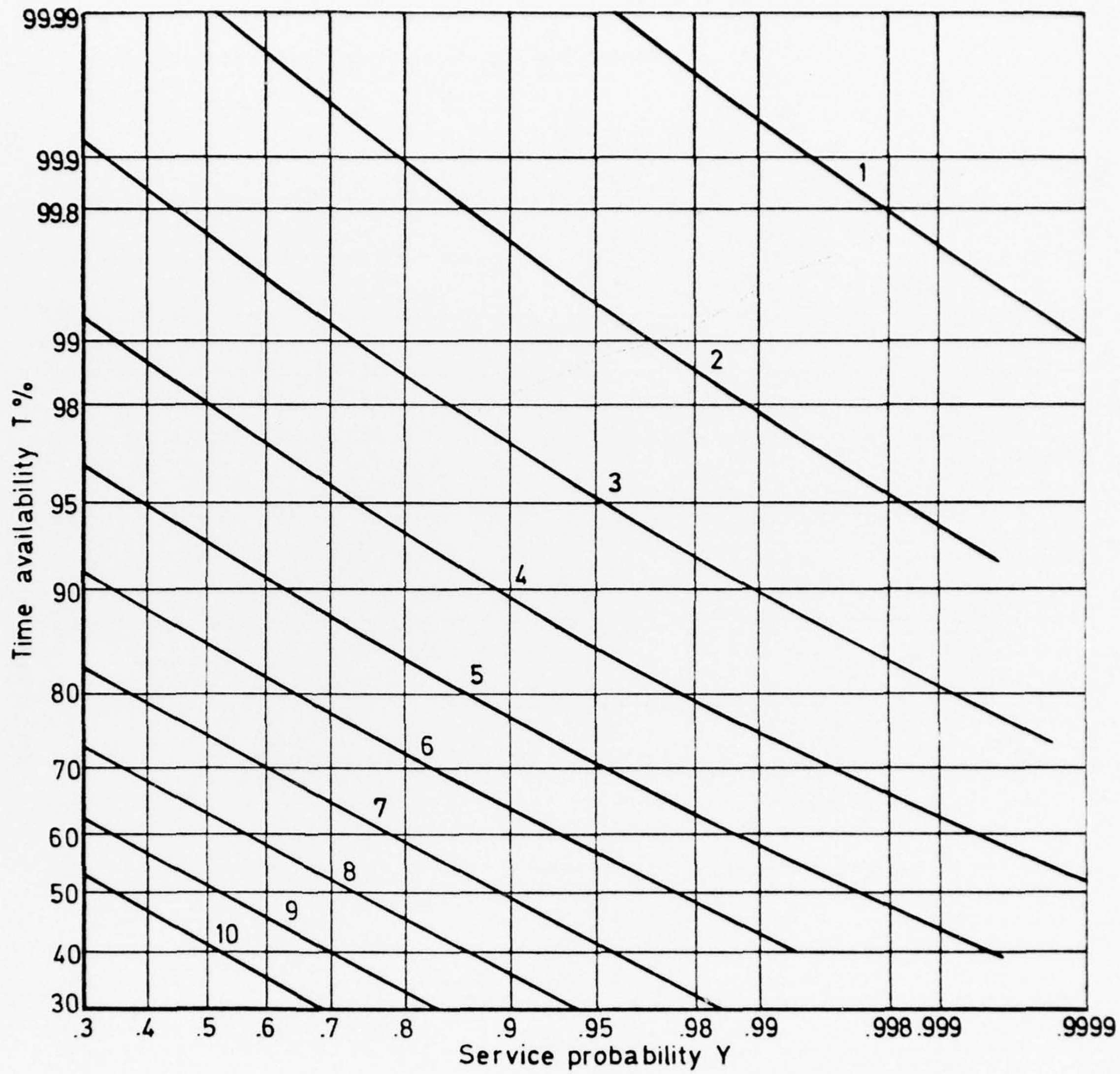


Fig 17 Time availability as a function of service probability

Stranraer (55° N 05° W)
Summer season, 2000-2400 h
Frequency: 15 MHz
Bandwidth: 3 kHz

Reference System
Poor soil
$\sigma = 10^{-3}$ S/m, $\varepsilon = 4$

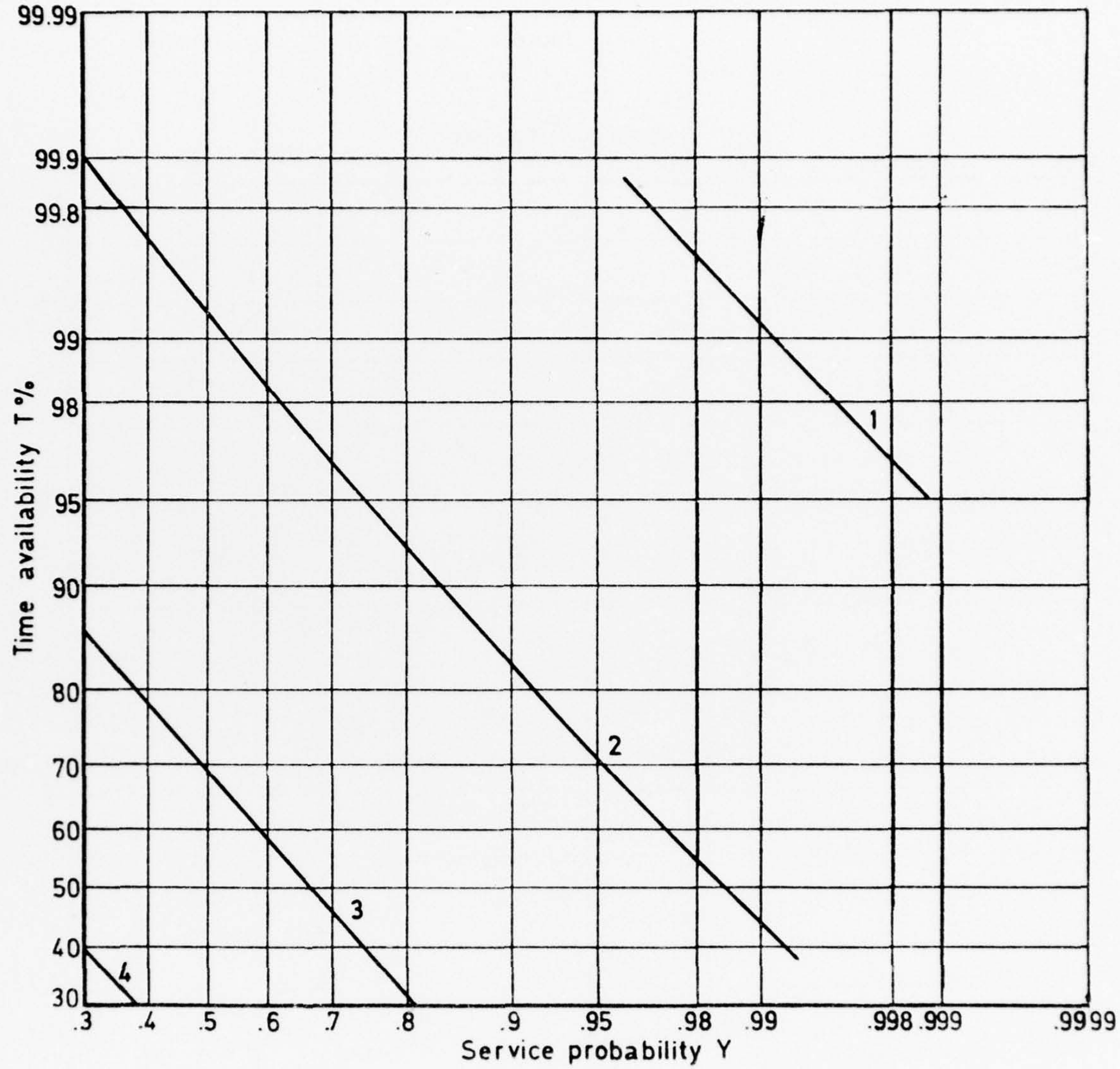


Fig 18 Time availability as a function of service probability

Stranraer (55°N 05°W)
Spring season, 0800-1200h
Frequency: 15MHz
Bandwidth 3 kHz

Reference System
Poor soil
$\sigma = 10^{-3}$ S/m, $\varepsilon = 4$

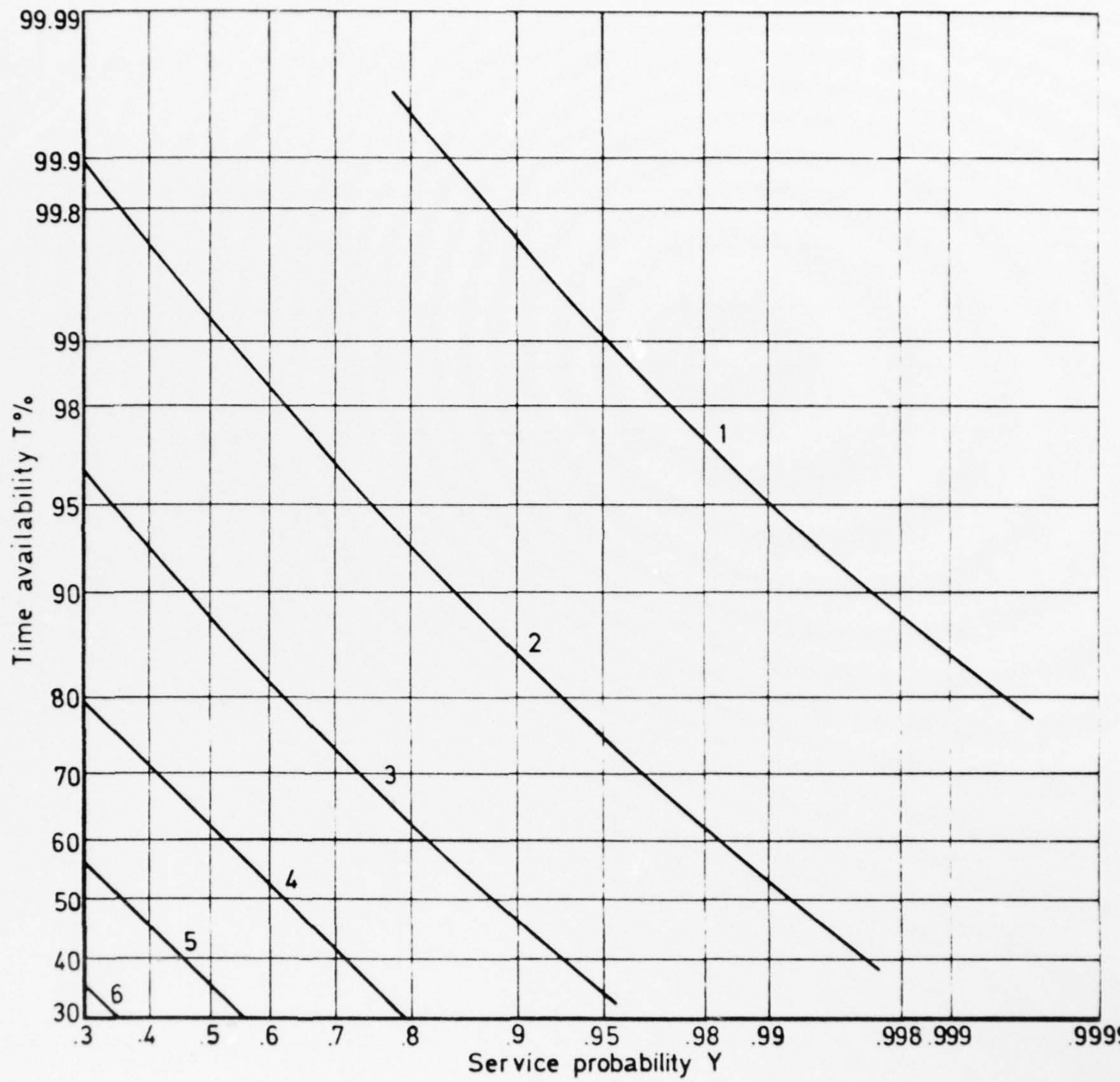


Fig 19 Time availability as a function of service probability

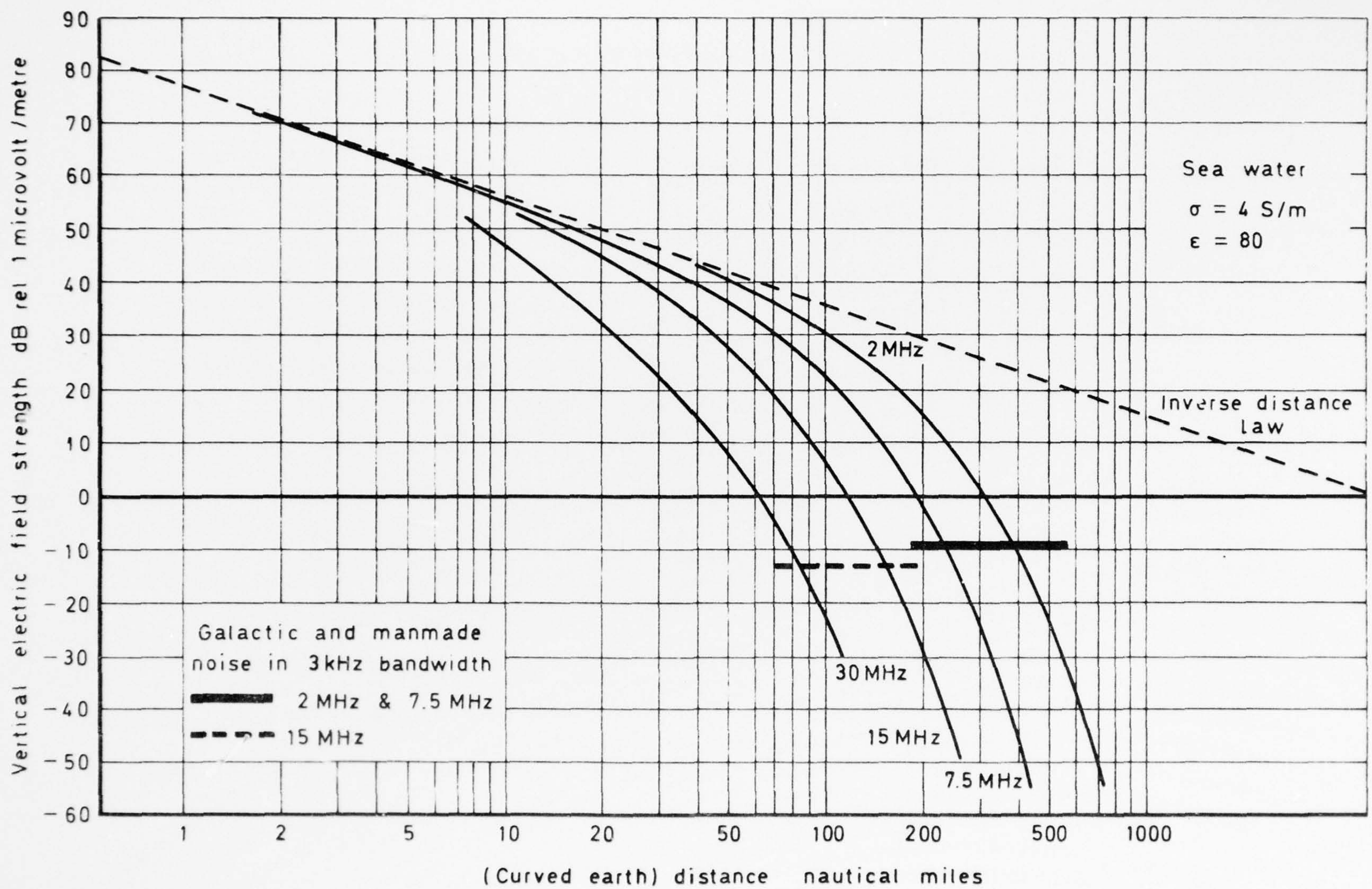


Fig 20 Received field strengths for reference system: sea water

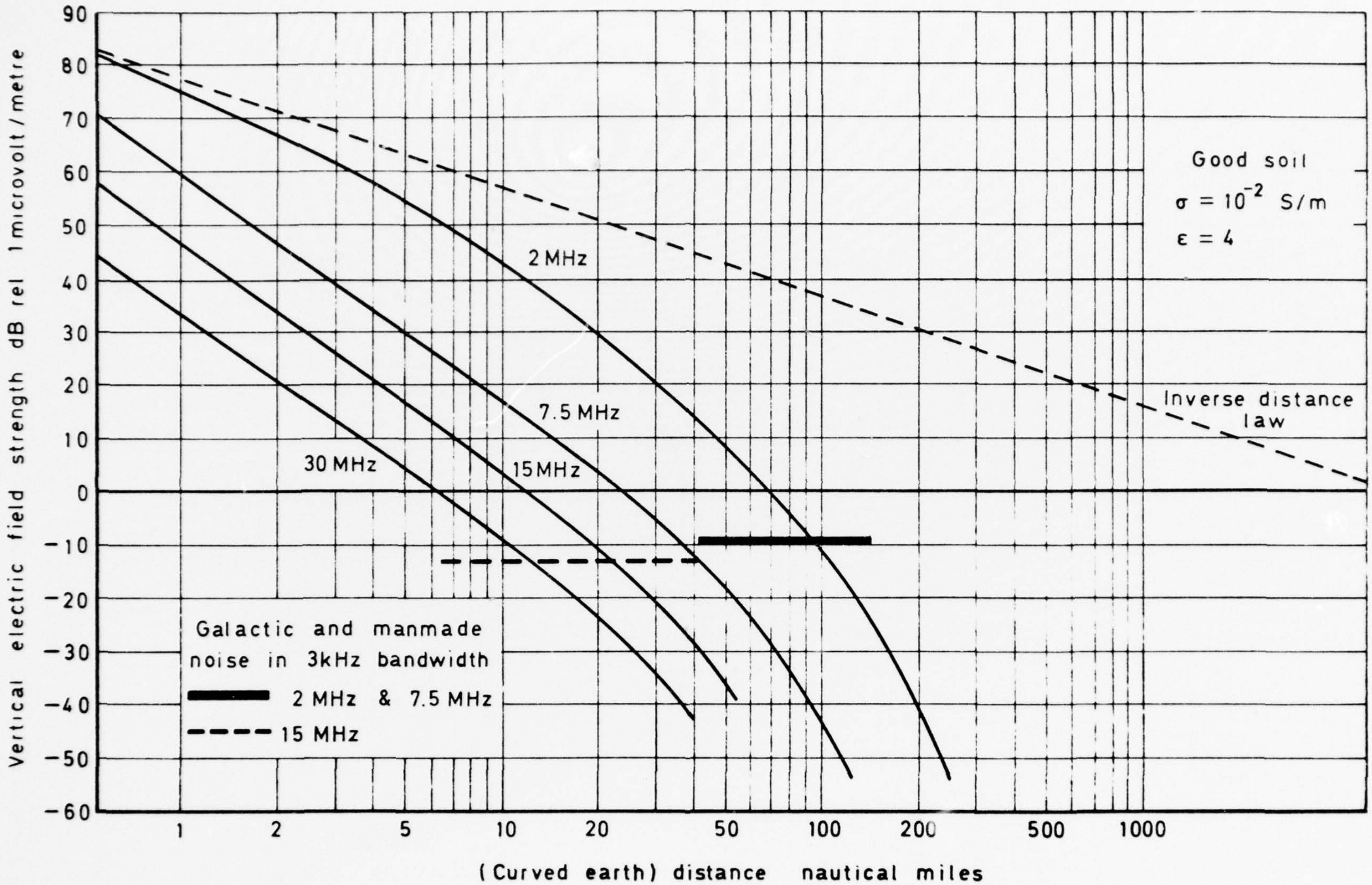


Fig 21 Received field strengths for reference system: good soil

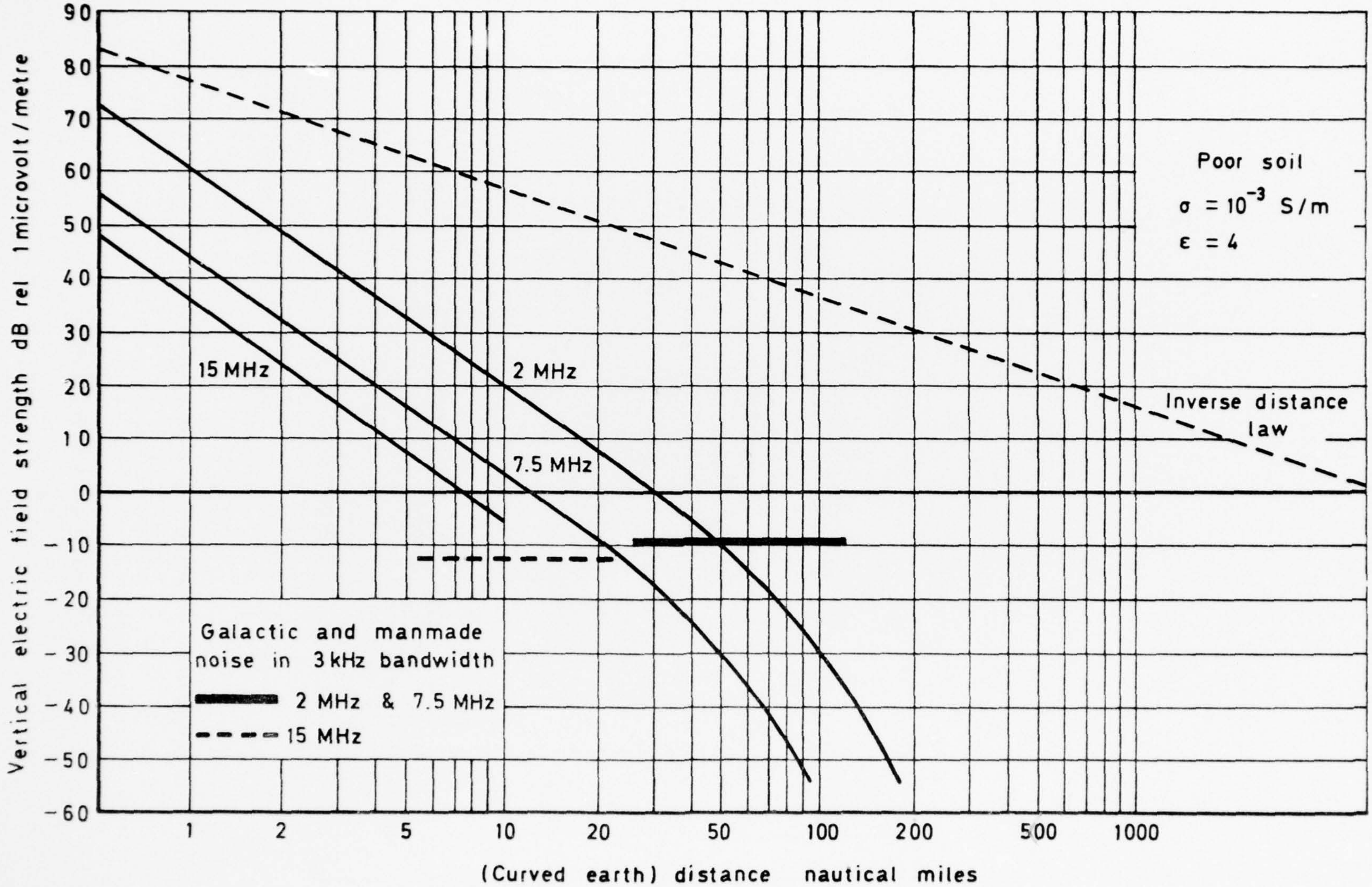
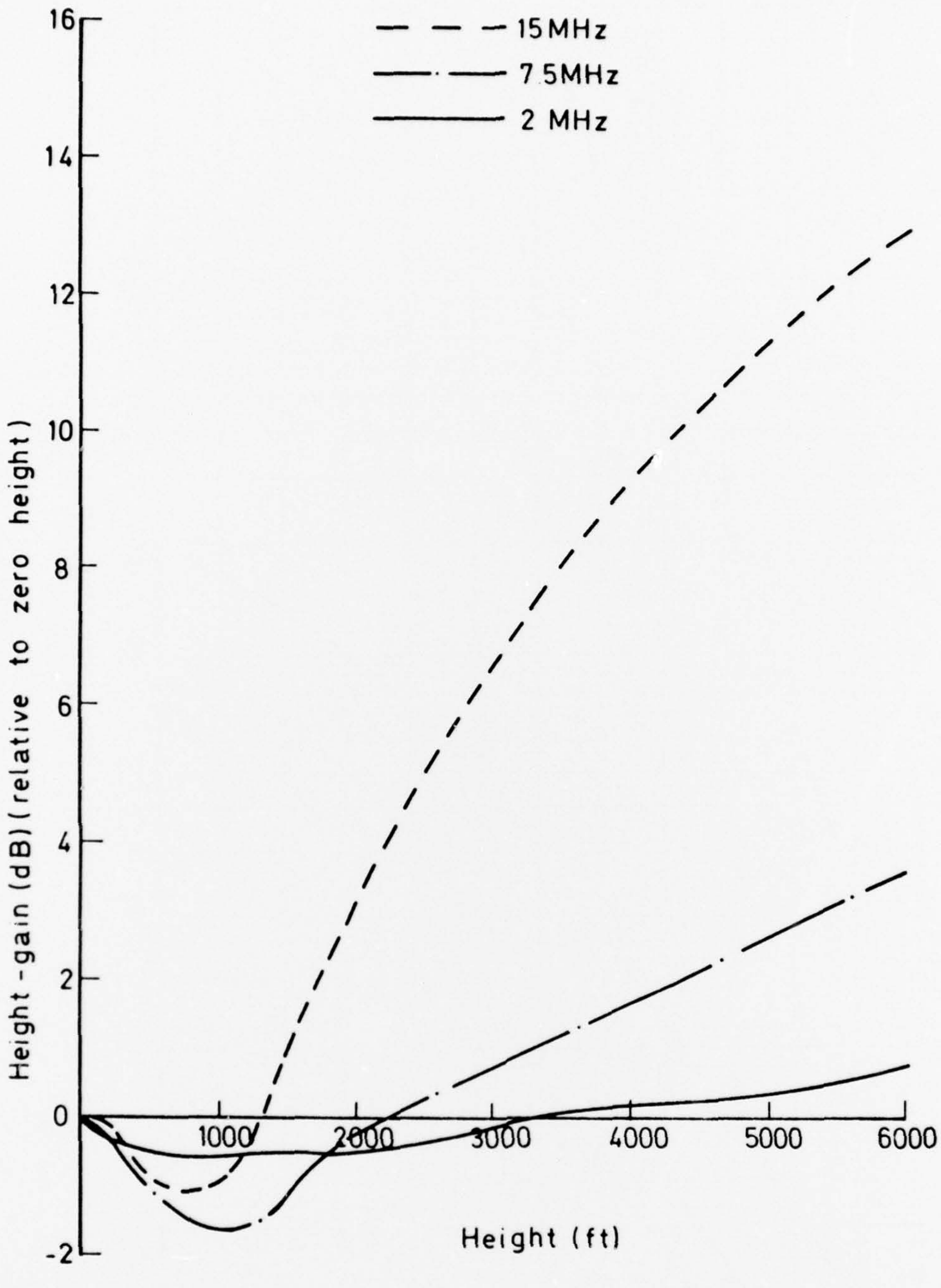


Fig 22 Received field strength for reference system: poor soil



For σ=4 height-gain/height curves, for the frequencies: 2, 7.5, 15 MHz

Fig 23 Height gains above sea water

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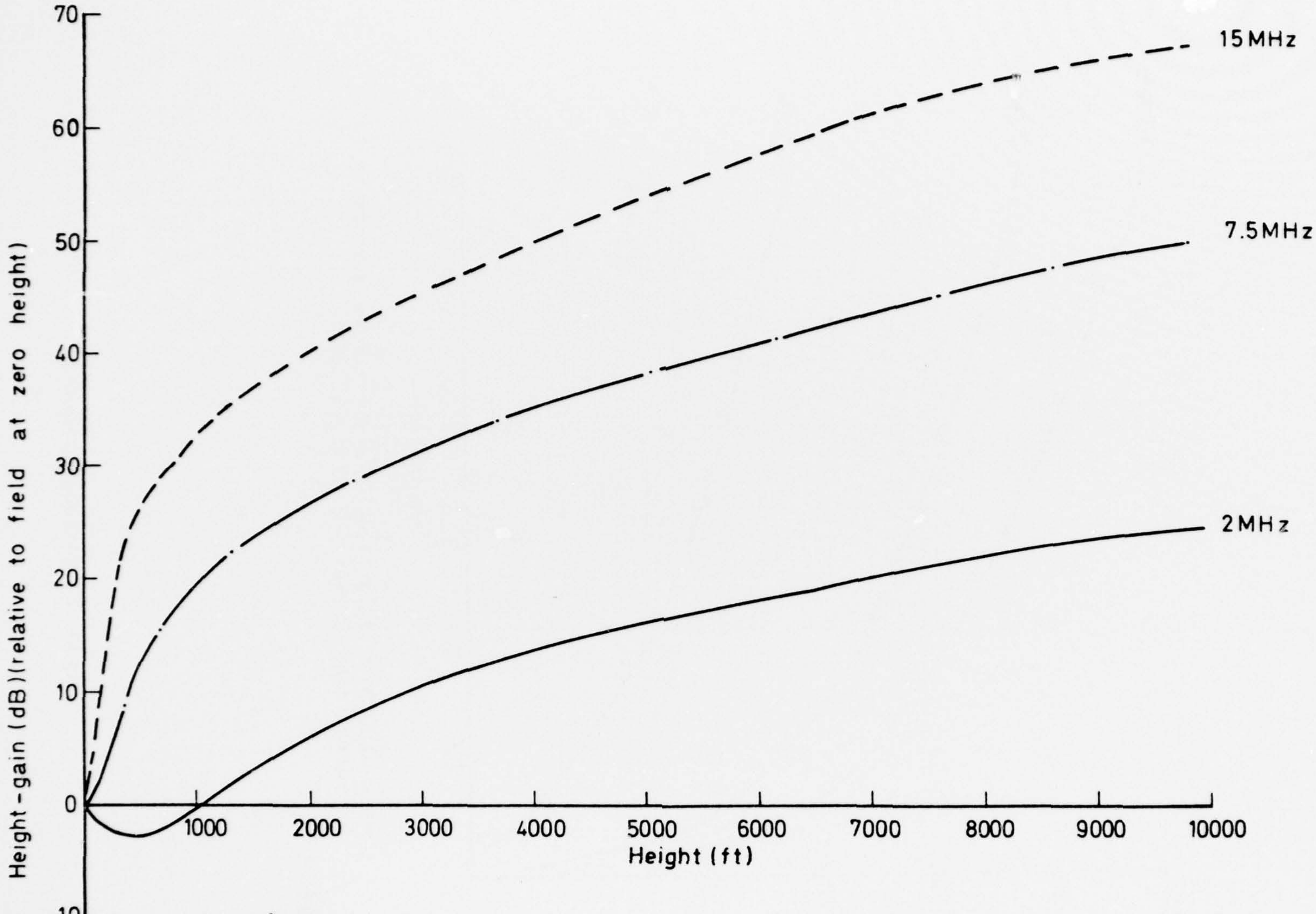
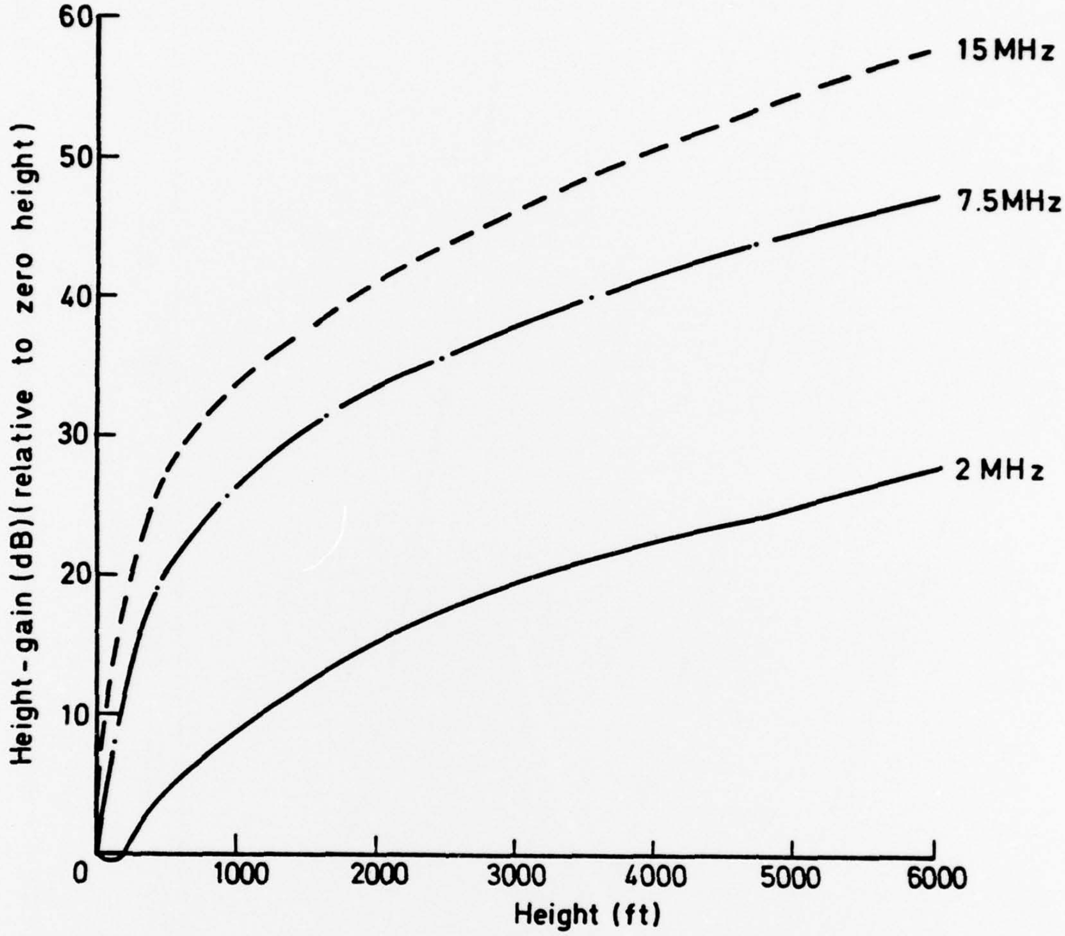


($\sigma=10^{-2}$ S/m) height-gain/height curves for the following frequencies : 2, 7.5, 15 MHz

Fig 24 Height gains above good soil



For σ=0.001 S/m : height-gain/height curves for the following frequencies : 2, 7.5, 15 MHz

Fig 25 Height gains above poor soil

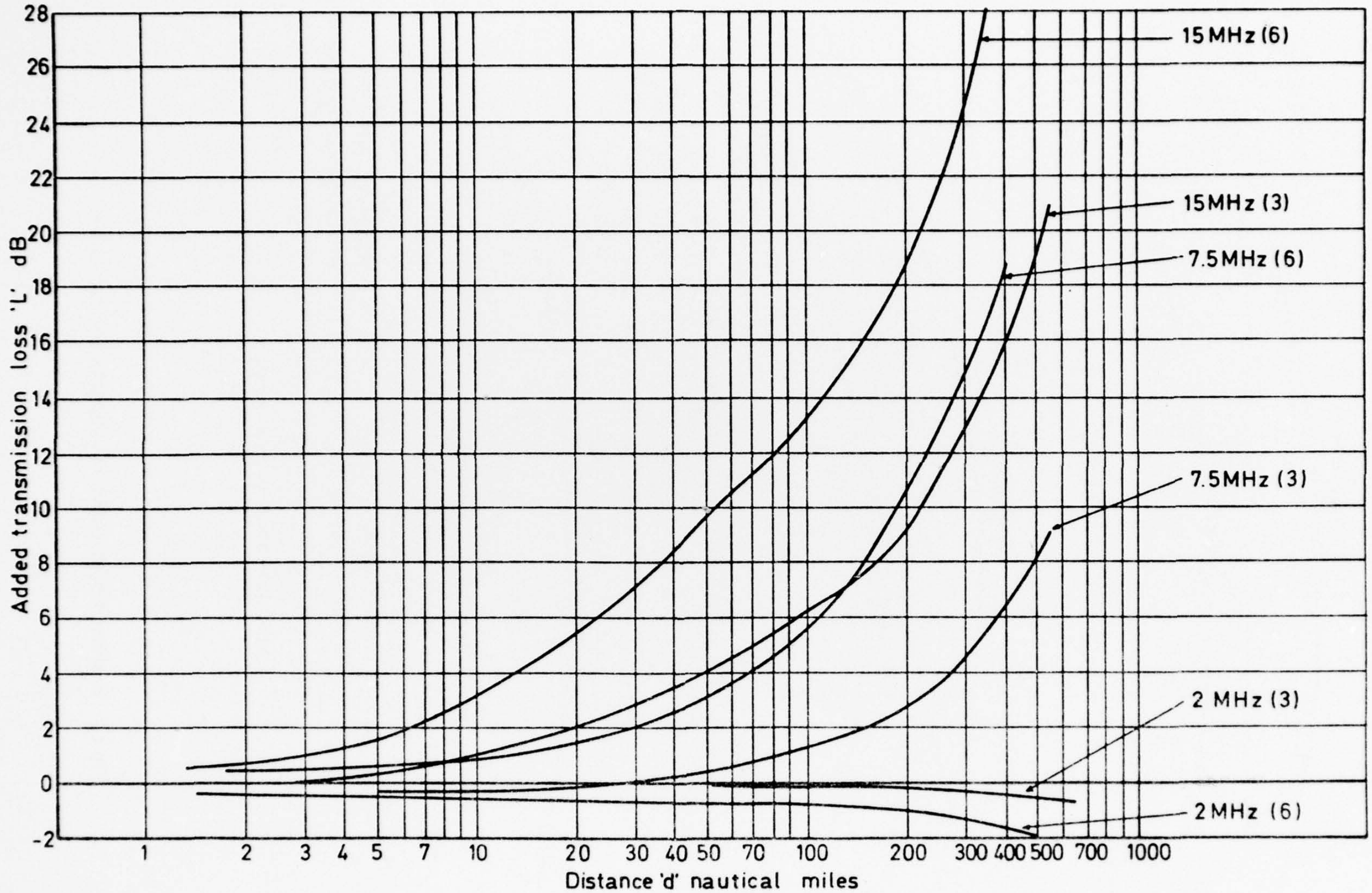


Fig 26 Added loss 'L' due to sea states 6 and 3

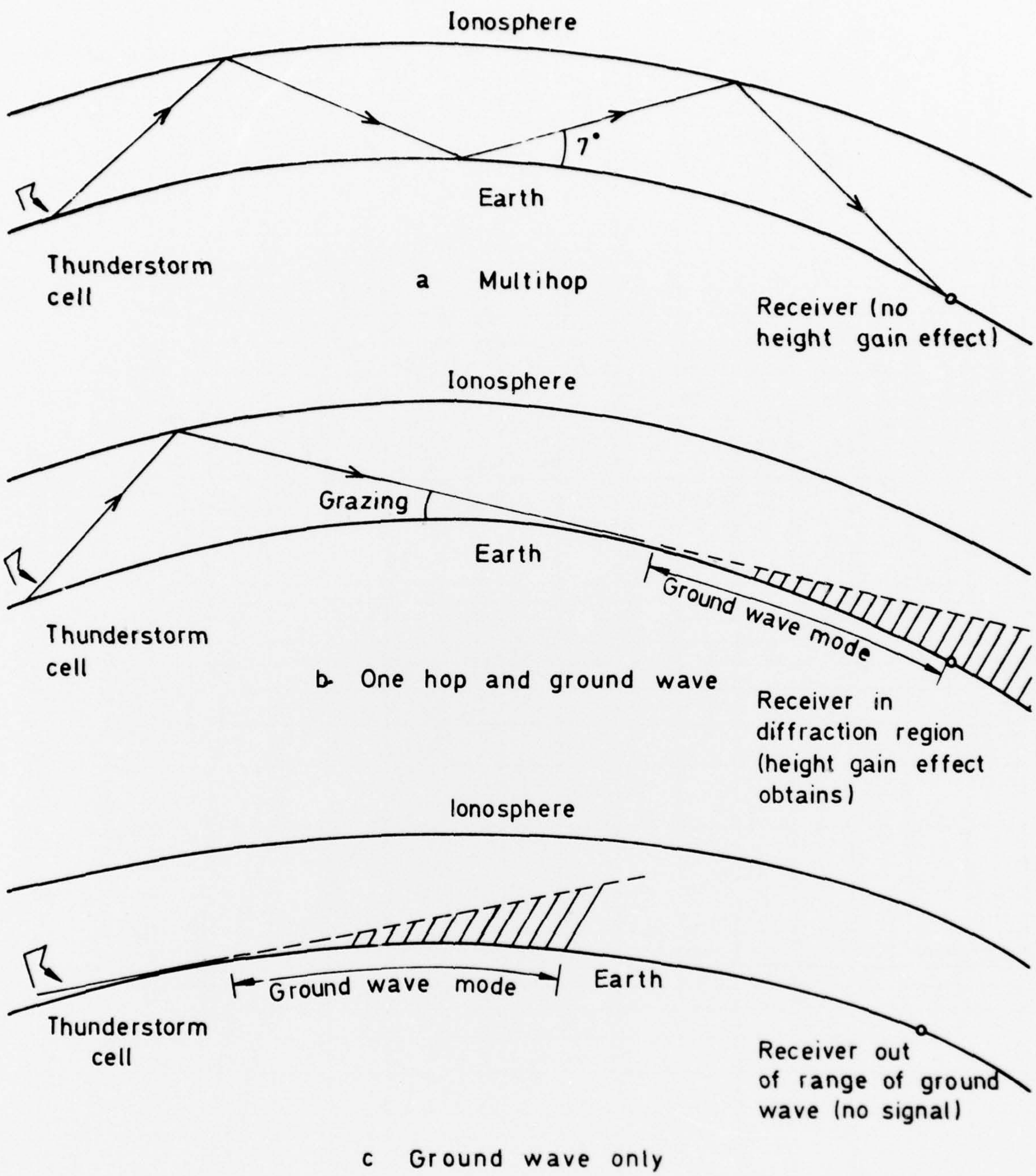


Fig 27 Possible propagation modes for atmospheric noise