CHAPTER 8

PROPAGATION EFFECTS ON INTERFERENCE

8.1 INTRODUCTION

As a result of the congestion of the frequency spectrum and the geostationary orbit and the related widespread use of frequency sharing, consideration of interference has assumed an important role in earth-station siting and other aspects of telecommunication-system design. Interference may arise between terrestrial systems, between terrestrial and space systems, and between space systems. Attention is given here to interference involving space systems, whether between space systems or between space and terrestrial systems. Space-system earth stations, which commonly transmit high power and have sensitive receivers, may cause interference to terrestrial systems when transmitting and may be interfered with by terrestrial systems when receiving. In addition, one earth station may interfere with another. Also, earth stations may receive interfering, unwanted transmissions, as well as wanted signals, from satellites. Likewise satellites may receive interfering transmissions from other than the intended earth station, and terrestrial systems may receive interference from space stations. In Sec. 8.2, some basic considerations are presented concerning the signal-to-interference ratio for a single wanted transmission and a single interfering transmission arriving over a direct path.

In considering the problem of interference to or from an earth station, analysis may be separated into two stages. In the first, a coordination area surrounding the earth station is determined. This area, based on calculating coordination distances in all directions from the earth station, is defined such that terrestrial stations outside the area should experience or cause only a negligible amount of interference. To determine coordination distances information on transmitter powers, antenna gains, and permissible interference levels is needed. For the earth station, the gain towards the physical horizon on the azimuth considered is used. When considering interference due to scatter from rain, it is assumed that the beams of the two antemas intersect in a region where rain is falling. The coordination procedure is thus based on unfavorable assumptions with respect to mutual interference.

After the coordination area has been established, potential interference between the earth station and terrestrial stations within the coordination area can be analyzed in more detail. In this stage of analysis, the actual antenna gains of the terrestrial stations in the directions toward the earth station will be used. Also, it is determined whether the beams of the earth station and terrestrial stations truly do intersect, in considering scatter from rain. Terrestrial stations within the coordination area may or may not be sub ject to or cause significant interference depending on the factors taken into account in the second stage of analysis.

Two propagation modes are considered for determining coordination area. One involves propagation over near-great-circle paths, and one involves scatter from rain. Coordination distances d_1 and d_2 are determined forthe modes and the larger of the two values is used as the final coordination distance. Determination of the two distances is considered in Sees. 8.3 and 8.4. Interference between space stations and terrestrial systems is discussed in Sec. 8.5. Procedures for interference analysis are summarized in Sec. 8.6, and certain practical matters about the siting of earth stations are discussed in Sec. 8.7.

From the propagation viewpoint, interference between terrestrial systems and earth stations is concerned very much with transhorizon propagation. In the late 1950's and early 1 960's, transhorizon propagation became of considerable interest as a means of communication over long distances. The rather weak but consistent troposcatter signals were and are utilized for this purpose. The stronger but sporadic signals due to ducting and rain scatter do not occur for the high percentages of time needed for reliable communication, and much of the interest in transhorizon propagation at present is related to interference. Ducting and rain scatter contribute to the higher levels of interfering signals that occur for small percentages of time, and they are highly important in interference analysis (Crane, 1981). The occurrence of ducting is vividly displayed on PPI radar screens showing ground clutter echoes. At times ducting causes ground clutter or targets to appear at considerably greater ranges than normal. Actually there is no fixed normal appearance of the molar screen, as the maximum range at which ground-clutter echoes appear fluctuates continuously.

In this chapter, attention is given to propagation effects on interference and to determination of coordination area, with emphasis on basic concepts. Additional details are given in Appendix 8.1. CCIR Reports 569, 724, and 382 (CCIR, 1986a, b, c) and Appendix 28 to Radio Regulations (ITU, 1982) treat these topics and have been utililized in the preparation of this chapter. Person carrying out coordination analysis should refer to these reports, especially to Appendix 28 for legal purposes; all of the charts, tables, and other details of the reports are not reproduced here. Instead an effort is made to provide explanatory background material and summaries of procedures for use as an introduction and reference on interference analysis. The material in the CCIR reports is subject to a continuing pecess of revision and updating as a comparison of reports for 1978, 1982 and 1986 indicates.

The procedure described in Appendix 28 of Radio Regulations must be followed in determining coordination area if legal requirements are to be met, The material of Appendix 28 concerning coordination area is essentially the same as that of CCIR Report 382. Study Groups 4 (Fixed Service Using Communication Satellites) and 9 (Fixed Service Using Radio-Relay Systems) have primary responsibility for coordination area; Report 382 is in Volume 9, prepared by Study Group 9. Reports 569 and 724, prepared by Study Group 5 (Propagation in Non-ionized Media), represent its input to the coordination problem. As this handbook is concerned primarily with propagation effects, we describe the approaches of Reports 569 and 724 as well as the procedures of Report 382 and Appendix 28.

8.2 THE SIGNAL-TO-INTERFERENCE RATIO

The signal-to-noise ratio C/X of a telecommunication link was given in Chap. 1 in the form of

$$(C/X)_{dB} = (EIRP)_{dBW} - (L_{FS})_{dB} - L_{dB} + (G_R/T_{sys})_{dB} - k_{dBW} - B_{dB} \quad (8.1)$$

m

In this section, attention is given to a corresponding signal-to-interference ratio, C/I. To consider this ratio, first separate EIRP into P_T and G_T where EIRP stands for effective isotropic radiated power, P_T represents the transmitted power, and G_T represents transmitting antenna gain. Also the loss factor L_{dB} can be separated into $A(p,\theta)$, attenuation in dB expressed as a function of prcentage of occurrence p and elevation angle θ, and the factor $-20 \log \delta$ representing polarization mismatch (Dougherty, 1980). As δ varies form O to 1, $-20 \log \delta$ is a positive quantity. Separating EIRP and L as indicated, C_{dBW} by itself becomes

$$C_{dBW} = (P_T)_{dBW} + (G_T)_{dB} + (G_R)_{dB} - (L_{FS})_{dB} - A(p,\theta) + 20 \log \delta \tag{8.2}$$

For I_{dBW}, the interfering power arriving over a direct path, a similar expression applies, namely

$$I_{dBW} = (P_{Ti})_{dBW} + (G_{Ti})_{dB} + (G_{Ri})_{dB} - (L_{FS})_{dB} - A_i(p,\theta) + 20 \log \delta_i \tag{8.3}$$

where the subscript i refers to the interfering signal. The quantity GT_i represents the gain of the antenna of the interfering transmitter in the direction of the affected receiving system. A similar interpretation applies to the other terms. Interference due to scatter from precipitation will be considered in Sec. 8.3. On the basis of Eqs. (8.2) and (8.3), the C/I ratio may be expressed as follows.

$$\begin{aligned}(C/I)_{dB} = {} & (P_T)_{dBW} - (P_{Ti})_{dBW} + (G_T)_{dB} - (G_{Ti})_{dB} \\ & + (G_R)_{dB} - (G_{Ri})_{dB} + 20 \log (d_i/d) \\ & + A_i(p,\theta) - A(p,\theta) + 20 \log (\delta/\delta_i)\end{aligned} \tag{8.4}$$

The term 20 log (d_i/d) arises from the L_{FS} free-space basic transmission loss terms which have the form of $(4\pi d/\lambda)^2$ where d is distance. In Eq. (8.4), d is the length of the path of the wanted signal and d_i is the length of the path of the interfering signal,

For analyzing transmissions from space to Earth or vice versa, the polarization mismatch factor δ equals cos θ where θ is a polarization mismatch angle to which there may be three contributions such that

$$\theta = \theta_o + \theta_i + \theta_r \tag{8.5}$$

The angle θ_o arises from geometrical considerations and can be determined from

$$\theta_o = \delta B - \alpha\, \delta A \tag{8.6}$$

with δB, the difference in back azimuths between the service path (to the intended earth station) and the interfering path (to the earth station being interfered with). The back azimuth is the angle to the earth station measured from the north-south meridian of the subsatellite point. The factor δA represents the difference in azimuths of the two earth stations, azimuth in this case being measured at the earth station as the angle from geographic north to the great circle path from the earth station to the subsatellite point (Fig. 8.1). The quantity a depends on the great circle distance Z between the earth stations. On this topic, we follow the treatment by Dougherty (1980) and reproduce two of his illustrations showing θ_0 as a function of B and A (Fig. 8.2) and B and Z as a function of earth station latitude and longitude with respect to the subsatellite point (Fig. 8.3).

The angle θ_i represents the Faraday rotation of a linearly polarized wave that may take place in propagation through the ionosphere. The concept of Faraday rotation is not applicable to circularly polarized waves. The relation for θ_i used by Dougherty (1980) is

$$\theta_i = 108^{\circ}/f^2 \tag{8.7}$$

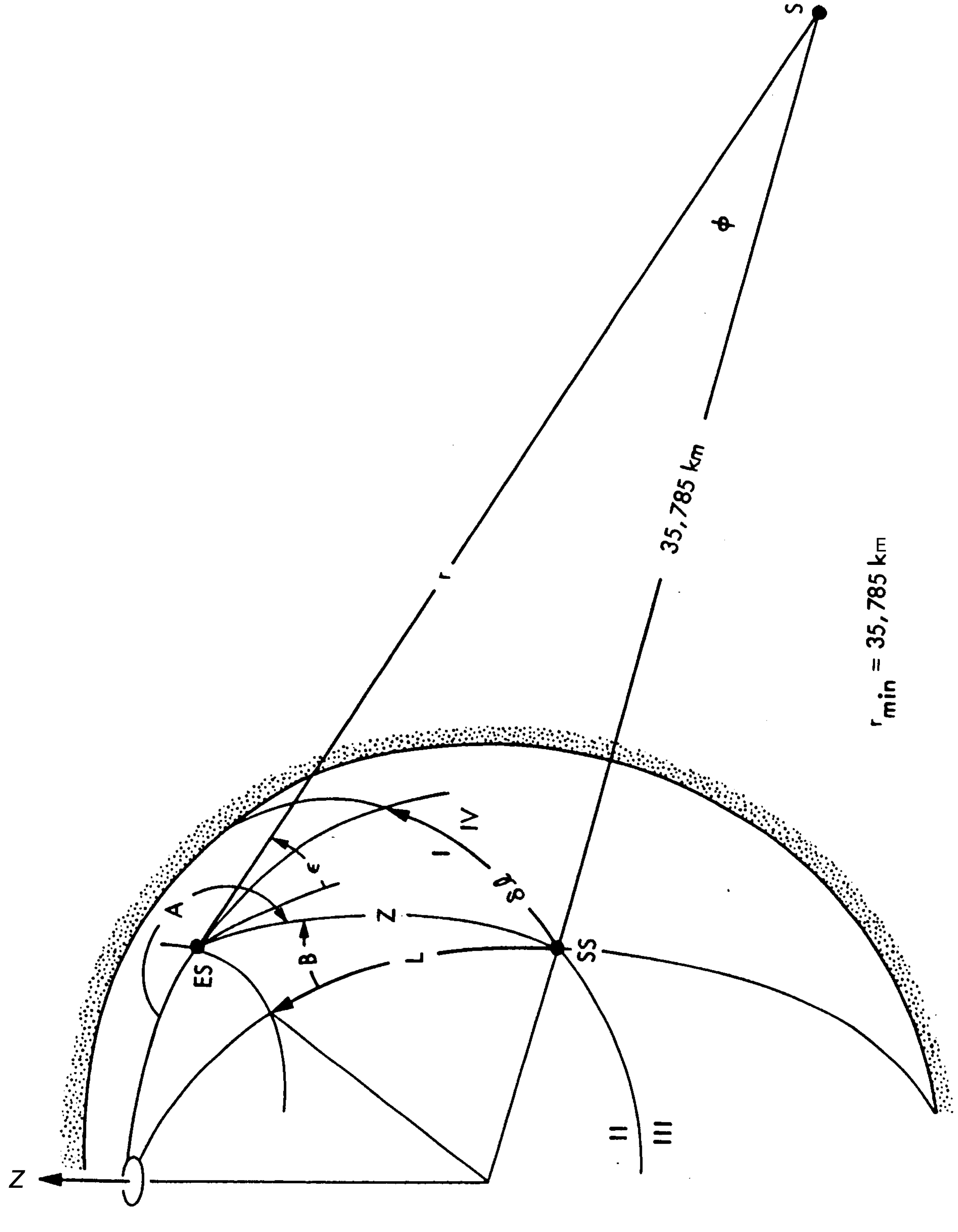

Figure 8.1. Synchronous satellite geometry (Dougherty, 1980).

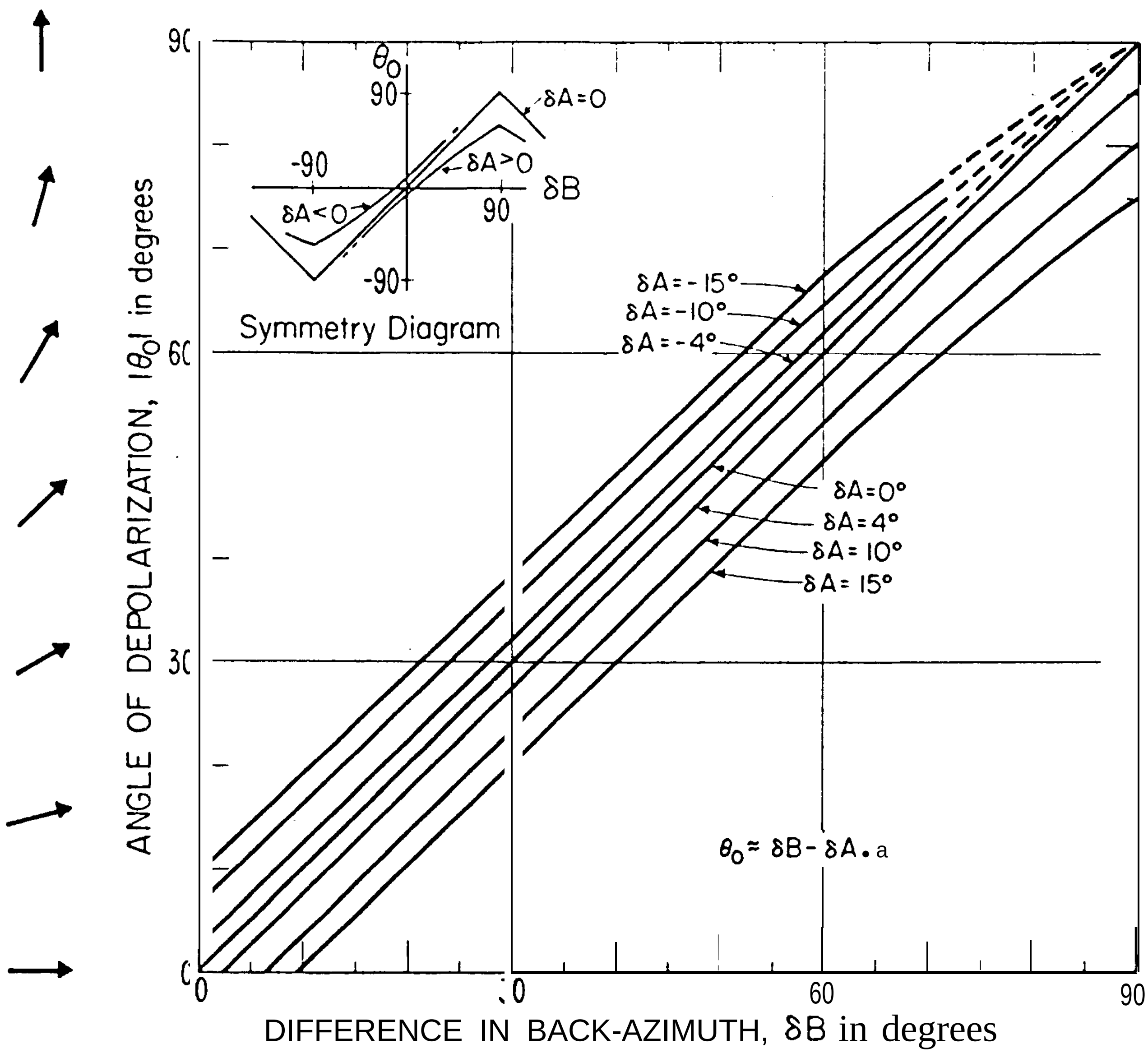

Figure 8.2. The depolarization angle for linear polarization for a potential interference situation (Dougherty, 1980).

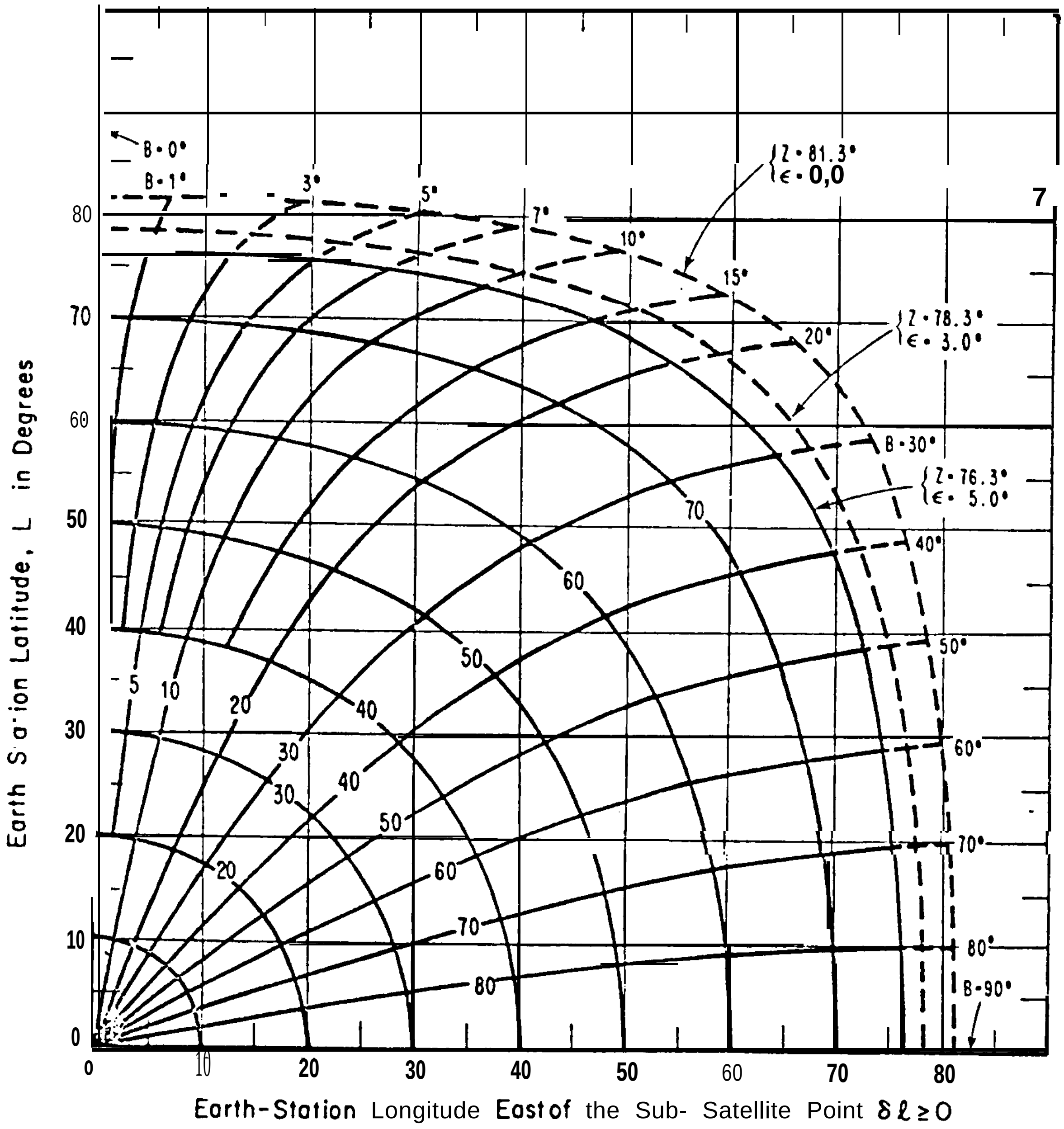

Figure 8.3 The great-circle arc (Z and back-azimuth (B, from SS to ES) as a function "of the earth-station (ES) latitude L and degrees of longitude (δℓ) east of the sub-satellite point (SS) (Dougherty, 1980).

with f the frequency in GHz. This value of θ_i corresponds to the maximum one-way effect of the ionosphere for an elevation angle of 30 deg. The subject of Faraday rotation is treated in Sec. 2.2. The angle θ_r represents the possible rotation of the electric field intensity due to depolarization caused by precipitation or other effect. By definition , the cross polarization discrimination (XPD) is given by

$$XPD = 20 \log (E_{11}/E_{12})$$

where E_{11} is the amplitude of the copolarized signal (having the original polarization and after taking account of any attenuation along the path) and E_{12} is the amplitude of the orthogonal y polarized signal produced by depolarization. The angle θ_r is $\tan^{-1} E_{11}/E_{12}$.

For determining the values of A(p, θ) and δ in Eqs. (8.2) and (8.3), one evaluates the service path under unfavorable conditions, using the loss occurring for a small percentage of the time, corresponding to p = 0.01 percent, for example. The interference path, however, is evaluated with the minor losses occurring for, say, 50 percent of the time. This practice takes into account such possibilities as the wanted signal propagating through an intense rain cell while the unwanted signal follows a path which misses the rain cell and encounters negligible attenuation.

8.3 COORDINATION AREA BASED ON GREAT CIRCLE PROPAGATION

8.3.1 Basic Concepts

For determining coordination area, attenuation needs to be estimated for the two modes of propagation of interfering signals (CCIR, 1986a, b,c). Propagation mode one (mode 1), referring to propagation over a direct near-great-circle path, occurs essentially all of the time to some degree. The second propagation mode (mode 2) is primarily via scatter from rain and may occur infrequently. In this section some general considerations are presented, and propagation mode 1 is discussed. Scatter from rain (mode 2) is treated in Sec. 8,4.

In system planning, it is generally required to estimate the relatively intense interference level which is exceeded for some small percentage, p of the time (e. g., p = 0.01 percent) and also perhaps the interference level exceeded for about 20 percent (p = 20 percent) of the time. Corresponding to high interference levels are low values of basic transmission loss Lb (Fig. 8.4). Note that in considering attenuation due to rain (Chap. 4) concern was directed to the small percentages of time for which maximum values of attenuation occur. Here the concern is for the small percentages of time for which the highest interfering signal intensities occur.

The total loss factor, L_t, relating the transmitted interfering power, P_{ti}, and the received interfering power, P_{Ri}, is defined by

$$L_t = P_{Ti}/P_{Ri} \tag{8.8}$$

An expression for the basic transmission loss, Lb, referred to above can be obtained by a modification of Eq. (1 .2), namely from $P_{Ri} = P_{Ti}G_{Ti}G_{Ri}/L_{FS}L$. Identifying $L_{FS}L$ as Lb,

$$L_b = L_{FS}L = \frac{P_{Ti}\,G_{Ti}\,G_{Ri}}{P_{Ri}} \tag{8.9}$$

where L_{FS} is the free-space basic transmission loss and L represents other system losses. In decibel values referring to p percent of the time Eq. (8.8) becomes

$$[L_t(p)]_{dB} = (P_{Ti})_{dBW} - [P_{Ri}(p)]_{dBW} \tag{8.10}$$

and Eq. (8.9) becomes

$$[L_b(p)] = (P_{Ti})_{dBW} + (G_T)_{dB} + (G_R)_{dB} - [P_{Ri}(p)]_{dBW} \tag{8.11}$$

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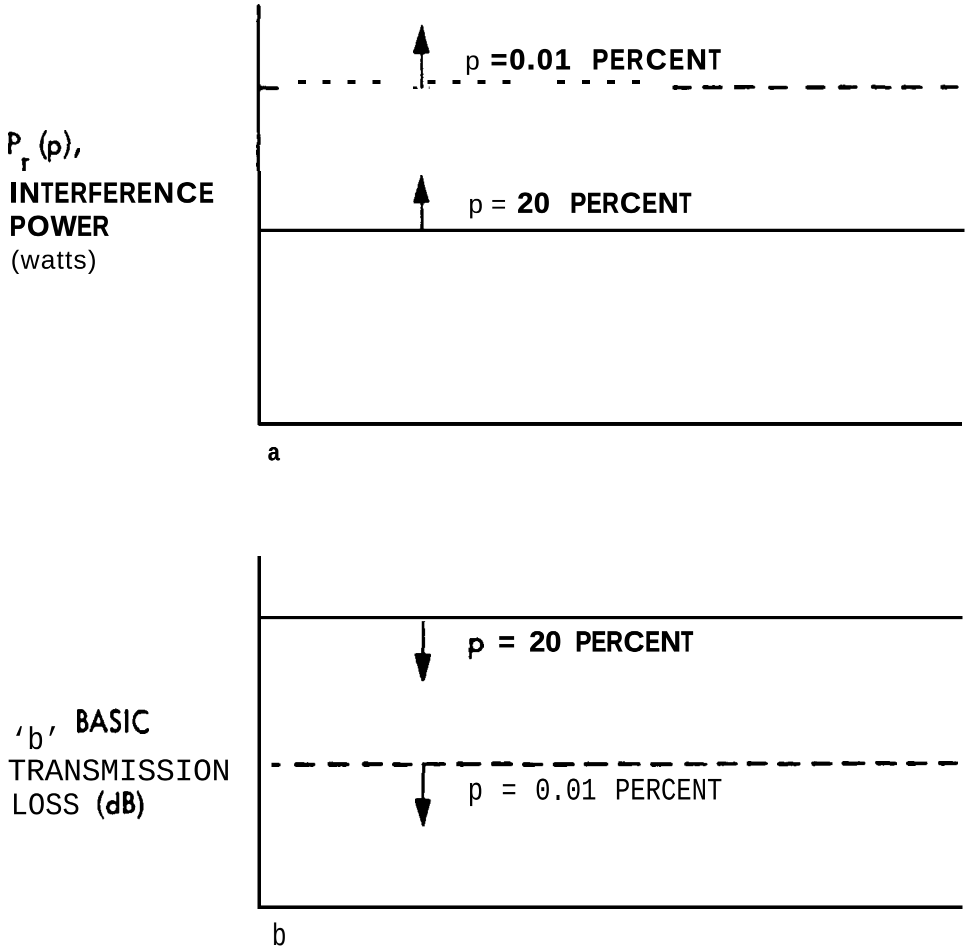

Figure 8.4. Correspondence between interference level and basic transmission 10ss. The interfering signal power will be above a certain level for 0.01 percent of the time, as suggested by the arrow extending upwards from the dotted line of Fig. 8.4a. The high interference levels above the dotted line of Fig. 8.4a correspond to the low values of basic transmission loss below the dotted line of Fig. 8.4b. For 20 percent of the time, the interference level will be above the solid line of Fig. 8.4a, and the corresponding values of basic transmission loss will be below the solid line of Fig. 8.4b.

In Eqs. (8. 10) and (8.11), P_{Ri} (p) is the maximum permissible interfering power level to be exceeded for no more than p percent of the time. Further information about permissible interference levels is given in Appendix 8.1. The gains G_T and G_R are the gains of the transmitting and receiving antennas. For determining coordination distance, the horizon gain at the azimuth in question is used for the earth-satellite station and the maximum gain is used for the terrestrial station, From Eq. (8,9), it can be seen that if $G_T = G_R = 1$ then Lb = P_{Ti}/P_{Ri}. For this reason, Lb is said to be the loss that would occur between isotropic antennas.

The basic transmission loss Lb is seen to be the product of L_{FS} and L. For a line-of-sight path and for frequencies below 10 GHz, Lb is roughly but not necessarily exactly equal to L_{FS}. In any case, L_{FS} makes a major contribution to Lb The free-space transmission loss was introduced in Sec. 1.1.1 and defined by

$$L_{FS} = (4\pi d/\lambda)^2 \qquad (8.12)$$

where d is distance from the transmitting to receiving locations and λ is wavelength. At higher frequencies, the dissipative attenuation associated with water vapor and oxygen may make significant contributions to Lb. Attenuation of the interfering signal due to rain is not included in Lb for the low values of p normally considered in applying Eq. (8.11) as Lb(p) then represents the low values of basic transmission loss that can be tolerated for only small percentages of time. When considering interfering signals, high values of Lb can be readily tolerated. It is the low values of Lb that are of concern. In terms of decibel values, Eq. (8. 12) can be written as

$$(L_{FS})_{dB} = 20 \log(4\pi) + 20 \log d - 20 \log \lambda \qquad (8.13)$$

where d and λ are in meters. Commonly, however, L_{FS} is expressed in terms of frequency f rather than wavelength λ. By replacing λ by c/f where c = 2.9979 x 10^8 m/s, one obtains

$$(L_{FS})_{dB} = -147.55 + 20 \log f + 20 \log d \quad (8.14)$$

If f is expressed in GHz rather than Hz, a factor of 180 dB must be added to the right-hand side of Eq. (6. 13), and if d is expressed in km rather than m an additional factor of 60 dB must also be included, with the "result that

$$(L_{FS})_{dB} = 92.45 + 20 \log f_{GHz} + 20 \log d_{km} \quad (8.15)$$

8.3.2 Line-of-Sight Paths

Although L_b may equal L_{FS} approximately for frequencies below 10 GHz for a certain range of values of p, in the absence of horizon or obstacle effects, the actual received interfering signal on even a clear line-of-sight path fluctuates due to the effects of atmospheric multipath propagation, scintillation, and defocusing and may be greater or less than L_{FS}. Thus although L of Eq. (8.9) has been referred to asa loss factor, it must be able to assume values either greater or less than unit y if. it is to be applicable to the situation considered here. The variation of the received level P_{Ri} 'ith 'ime provides the basis for specifying P_{Ri} as a function 'f Po 'or line-of-sight paths, L can be expressed as A_o + Ad - G_p and Lb is given by

$$(L_b)_{dB} = (L_{FS})_{dB} + A_o + A_d - G_p \quad (8.16)$$

where A_o is attenuation in dB due to oxygen and water vapor. (See Fig. 3.1 0 for attenuation due to oxygen. That due to water vapor can be neglected below about 15 GHz.) The coefficient Ad represents attenuation due to defocusing in dB, and G_p is an empirical factor in dB given by Table 8.1 for paths of 50 km or greater (CCIR, 1986a).

Table 8.1 G_p of Eq. (8. 16) versus percent of time p exceeded.

p (percent)	0.001	0.01	0.1	1
G_p (dB)	8.5	7.0	6.0	4.5

For distances shorter than 50 km, the values of G_p can be proportionally reduced. To estimate the signal exceeded for percentages of the time between 1 and 20, CCIR Report 569 recommends adding 1.5 dB to the value of L_{FS} (thereby increasing Lb by 1.5 dB with respect to what it would 'be otherwise). The coefficient G_p can be taken to be zero for p = 20 percent and greater.

Attenuation due to defocusing results when the variation of refractivity with height dN/dh (Sec. 3.2) itself varies with height so that rays at different heights experience different amounts of bending. Rays representing energy propagation, rays which were originally essentially parallel for example, may then become more widely separated than otherwise and signal intensity is consequently reduced. It develops that the variation of dN/dh with height h is proportional to ΔN, the decrease in refractivity N in the first km above the surface. Figure 8.5 shows attenuation due to defocusing as a function of ΔN and elevation angle θ (CCIR, 1986d).

A given path may be a clear line-of-sight path for certain values of dN/dh (Sec. 3.1) but may have part of the first Fresnel zone obstructed for other values of dN/dh. The effect of obstruction is considered in Sec. 8.3.3.

8.3.3 Transhorizon Paths

Major attention in the analysis of interference between terrestrial systems and earth stations of space systems is directed to transhorizon propagation. The term transhorizon path refers to a path extending beyond the normal radio horizon for which diffraction is a relevant propagation mechansim, as distinguished from a clear line-of sight pathat one extreme and a stricty troposcatter pathat the opposite extreme. For transhorizon paths, a diffraction loss term As (dB) must be added to the free-space loss L_{FS}. In addition, account must be taken of ducting and super-refraction which can be expected to occur for some percentage of the time,

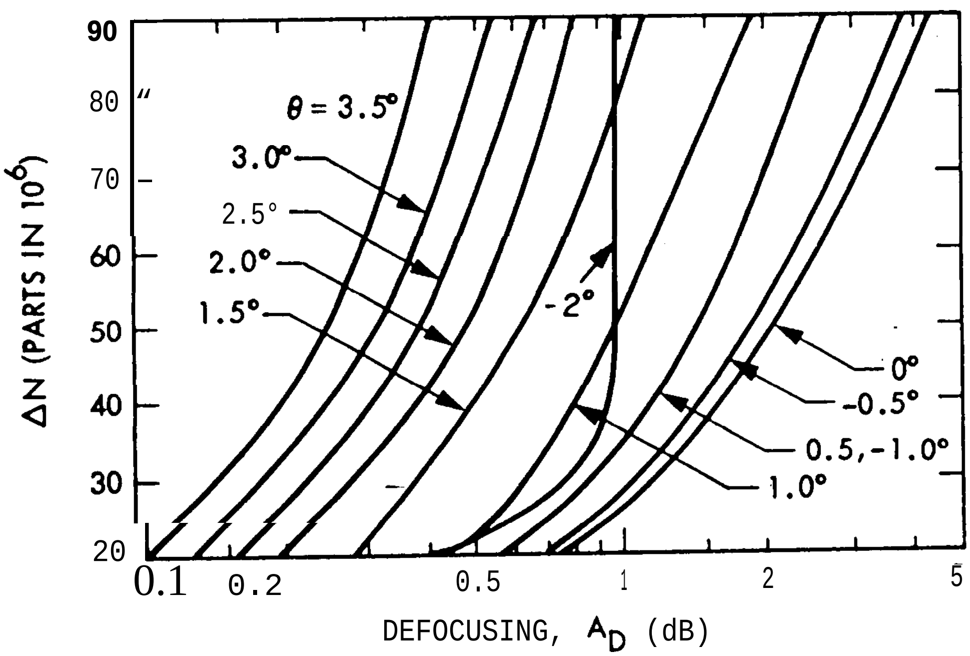

Figure 8.5. Defocusing on near-horizontal paths as a function of ΔN (the decrease in refractivity in the first km) for various values of grazing angle θ (CCIR, 1986d).

A relation for the basic transmission loss Lb between transmitting and receiving terminals which are both immersed in a duct is (CCIR, 1982; CCIR, 1986a but with 92.5 instead of 92.45)

$$(L_b)_{dB} = 92.45 + 20 \log f_{GHz} + 10 \log d_{km} + A_c + (\gamma_d + \gamma_o + \gamma_w)\, d_{km} + A_s \qquad \textbf{(8.17)}$$

This equation includes terms like those of Eq. (8. 17) for L_{FS}, except that 10 log d appears instead of 20 log d. The basis for using 10 log d is that a wave in a duct is constrained in the vertical direction and spreads out only horizontally, whereas in free space a wave spreads in both directions. Because Lb for a duct includes 10 log d rather than 20 log d, L_b tends to be significantly less than L_{FS}. The quantity A_c represents a coupling loss that takes account of the fact that not' all the rays leaving the transmitting antema are trapped within the duct. The γ's are attenuation constants, γ_d being a duct attenuation constant reported to have a theoretical minimum value of 0.03 dB/km (Dougherty and Hart, 1979). The constants γ_o and γ_w represent attenuation due to oxygen and water vapor, respectively . The quantity As takes account of loss caused by obstacles along the path. CCIR Report 382-5 (CCIR, 1986c) and CCIR Report 724-2 (CCIR, 1986b), however, use, for Lb for ducting,

$$(L_b)_{dB} = 120 + 20 \log f_{GHz} + \gamma\, d_{km} + A_h \qquad (8.18)$$

The term y includes the y's of Eq. (8. 17), and **Ah** is a modified form of As of Eq. **(8. 17).** Equation (8. 17) has the advantage of being closely related to the physical phenomena involved, but it has the computational disadvantage of having a term involving the logarithm of distance and also a term that is linear with distance. One needs to solve for d, the coordination distance for great-circle propagation, and for this purpose Eq. (8. 18) has the advantage of having only a term that is linear with distance. The basis for the conversion from Eq. (8.17) to (8.18) is that the term 10 log d can be approximated by

$$10 \log d_{km} = 20 + 0.01 d_{km} \qquad 100 \text{ km} (d (2000 \text{ km} \qquad (8.19)$$

Also the coupling loss A_c of Eq. (8. 1 7) has been assigned the value of 7.5 dB whereas in CCIR Report 569-3 (CCIR, 1986a) this loss is given by a table showing it as varying from 6 to 11 dB over water and coastal areas and 9 to 14 dB over inland areas. The value of 120 is obtained by setting 92.45 equal to 92.5 and noting that 92.5 + 20 + 7.5 = i20. The coefficient 0.01 of Eq. (8. 19) is included as part of the y of Eq. (8. i 8), and y is then given by

$$Y = 0.01 + \gamma_d + \gamma_o + \gamma_w \qquad (8.20)$$

The quantity As of Eq. (8. 17), expressed in dB, has the form of

$$A_s = 20 \log [1 + 6.3 \ \theta (f d_h)^{1/2}] + 0.466 (f \ Cr)^{1/3} \qquad (8.21)$$

where f is frequency in GHz, d_h is distance to the horizon in km, θ is elevation angle in deg above the horizon, and Cr is the radius of curvature of the horizon. If d_h is set equal to 0.5 km and Cr is taken to be 10 m, one obtains the horizon angle correction Ah of Eq. (8. 18), namely

$$A_h = 20 \log (1 + 4.5 f^{1/2} \ \theta) + f^{1/3} \ \theta \qquad (8.22)$$

Figure 8.6 shows Ah as a function of elevation angle and frequency. The factor γ_d is given by (CCIR, 1986b)

$$\gamma_d = [c_1 + c_2 \log (f + c_3)] p^{c_4} \quad \text{dB/km} \qquad (8.23)$$

where the c's have different values for four different zones and are given in Table 8.2. The frequency f is in GHz, and p is percentage of time.

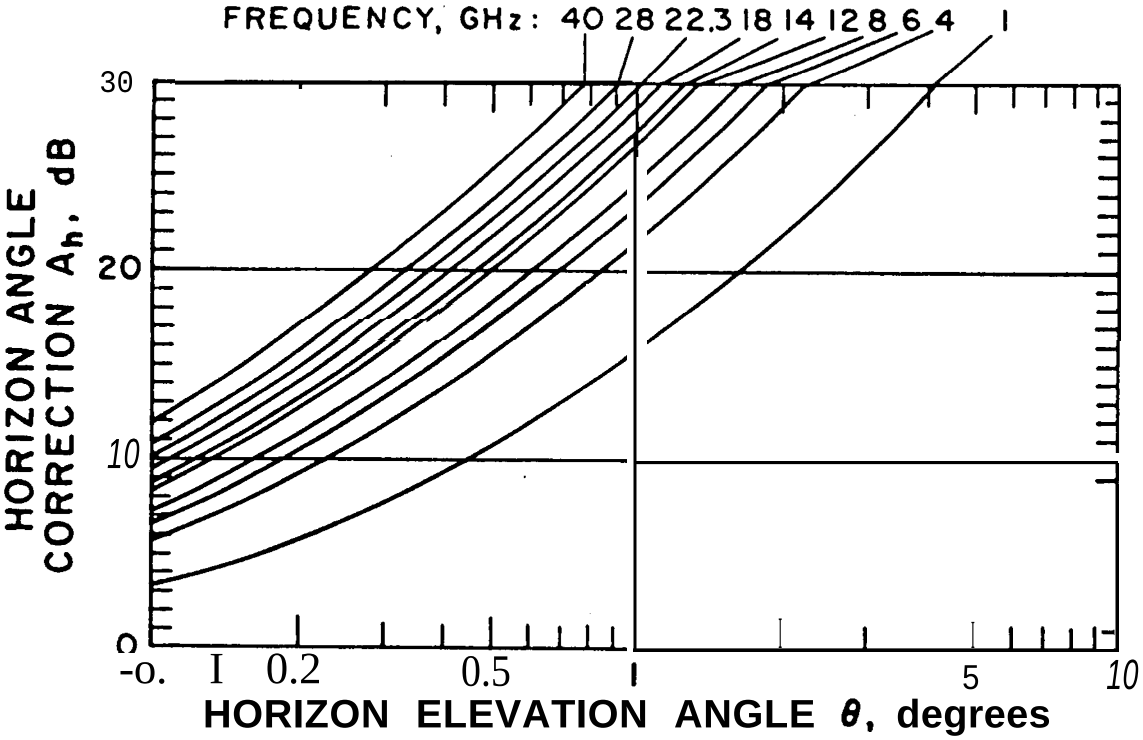

Figure 8.6. The horizon angle correction, **Ah,** Eq. (8.22).

Table 8.2 Values of Constants for Determination of γ_d.

	c_1	c_2	C_3	C_4
Zone **Al**	0.109	0.100	-0.10	0.16
Zone **AZ**	0.146	0.148	-0.15	0.12
Zone B	0.050	0.096	0.25	0.19
Zone C	0.040	0.078	0.25	0.16

The zones referred to in Table 8.2 are

Zone Al: Coastal land and shore areas, adjacent to zones B or C, up to an elevation of 100 m relative to mean water level, but limited to a maximum distance of 50 km from the nearest zone B or C area, Zone A2: All land, other than coastal land and shore areas.

Zone B: "Cold" seas, oceans, and other substantial bodies of water, encompassing a circle 100 km in diameter at latitudes greater than 23.5 deg N or S, but excluding all of the Black Sea, Caribbean Sea, Gulf of Mexico, Mediterranean Sea, Red Sea, and the sea from the Shatt-al-Arab to and including the Gulf of Oman .

Zone C: "Warm" seas, oceans, and other substantial bodies of water, encompassing a circle i 00 km in diameter, and including in their entirety the bodies of water mentioned as being excluded from zone B.

The constant γ_o for oxygen is given in CCIR Report 724-2 (CCIR, 1986b) in dB/km for f (40 GHz by

$$\gamma_o = \left[0.00719 + \frac{6.09}{f + 0.227} + \frac{4.81}{(f - 57)^2 + 1.50} \right] f^2/10^3 \tag{8.24}$$

Attenuation due to water vapor can be neglected for frequencies less than 15 GHz, and the expression for γ_w is therefore not given here.

CCIR Report 724-2 includes plots for a graphical solution for coordination distance for ducting, or great-circle propagation. We do not include these illustrations here, but Eq. (8. 1 8) can be solved algebraically for the distance d by making use of the accompanying irormation about the parameters appearing in it.

Troposcatter signals, resulting predominantly from inhomogeneous scattering by random fluctuations of the index of refraction of the atmosphere, are normally weaker than the interfering signals due to ducting and super-refraction. However, the tropospheric scatter signals may be dominant for percentages of time between about 1 and 50 percent and for percentages less than one when high site shielding (A_h values of 30 dB and greater) is encountered.

8.4 COORDINATION AREA FOR SCATTERING BY RAIN

For considering interference due to scatter from rain, one can start with a slightly modified version of Eq. (4.53) which refers to bistatic scatter from rain. Inverting this relation to obtain a total loss factor L_t, using G_T, G_{ES}, R_T, and R_{ES} to refer to the gains of the terrestrial and earth-station antennas and their distances from the region of rain scatter, and replacing W_T and W_R by P_T and P_R results in

$$L_t = \frac{P_T}{P_R} = \frac{(4\pi)^3 R_T^2 R_{ES}^2 L}{G_T G_{ES} \eta V \lambda^2} \qquad (8.25)$$

In this expression, L is a loss factor (greater than unity if truly a loss), V is the common scattering volume, and η is the radar cross-section per unit volume. For Rayleigh scattering η has the form of

$$\eta = \frac{\pi^5}{\lambda^4} \left| \frac{K_c - 1}{K_c + 2} \right|^2 Z \quad m^2/m^3 \qquad (8.26)$$

where K_c is the complex dielectric constant of water and is a function of frequency and temperature. When expressed in mm^6/m^3, the quantity Z is related to rainfall rate R in mm/h for a Laws and Parsons distribution of drop sizes by the empirical expression

$$Z = 400 R^{1.4} \qquad (8.27)$$

Physically, Z represents $\sum d^6$ where d is the drop diameter and the summation is carried out for all of the drops in a unit volume. For frequencies higher than 10 GHz for which Rayleigh scattering does not apply, an effective of modified value of Z, designated as Z_e, is used for coordination distance calculations.

Usually the earth-station antenna has a smaller beamwidth than the terrestrial antema. Assuming that such is the case and noting that the scattering volume V is defined by the antema with the smallest beamwidth, V is given approximately by

$$V = (\pi/4)\ \theta^2 R_{ES}^2\ D \qquad (8.28)$$

where θ is the beamwidth of the earth-station antenna, R_{ES} is the distance from the earth station to the common scattering volume V, and **D** is the extent of the common scattering volume along the path of the earth-station antenna beam. Assuming a circular aperture antenna for which the beamwidth θ is given approximately by λ/d where d is diameter and making use of the relation between effective antenna area A and gain G, namely $G = 4\pi A/\lambda^2$, it develops that $\theta^2 = \pi^2/G$ and

$$v = \pi^3 R_{ES}^2\ D/\ (4\ GE-) \qquad (8.29)$$

Substituting for η and V in Eq. (8.25) and recognizing that in η $|(K_c - 1)/(K_c + 2)|$ has a value of about 0.93 (Battan, 1973),

$$L_t = \frac{4^4 R_T^2\ L\ \lambda^4}{G_T\ D\ \lambda^2 \pi^5\ (0.93)\ Z} \qquad (8.30)$$

Combining the numerical factors of Eq. (8.30) and replacing λ by c/f results in

$$L_t = \frac{0.9\ R_T^2\ c^2\ L}{f^2\ G_T\ D\ Z} \qquad (8.31)$$

Note that R_{ES} and G_{ES} have dropped out of the expression for L_t but that R_T and G_T remain. Taking logarithms results in

$$(L_t)_{dB} = -0.46 + 20\ \log R_T + 169.54 + 10 \log L$$
$$-20\ \log f - 10 \log\ G_T - 10 \log D - 10\ \log Z$$

$$(L_t)_{dB} = 199 + 20 \log (R_T)_{km} + 10 \log\ L - 20 \log\ f_{GHz}$$
$$- 10 \log D_{km} - 10 \log Z_{mm^6/m^3} - 10 \log G_T \qquad (8.32)$$

The number 199 is arrived at from 169.54-0.46 + 60-30, where +60 is introduced when replacing R_T in m by R_T in km and -30 is introduced when replacing D in m by D in km. Changing from f in Hz to f in GHz and from Z in m^6/m^3 to Z in mm^6/m^3 introduce two 180 dB factors of opposite sign which cancel out. The relation of Eq. (8.32) can be modified to express D and Z in terms of rain rate R. The distance D is taken to be given by

$$D = 3.5\ R^{-0.08} \tag{8.33}$$

based on modeling of rain cells and assuming an elevation angle of - 20 deg as a conservative assumption. For Z, assuming a Laws and Parsons distribution of drop sizes,

$$Z = 400\ R^{1.4} \tag{8.34}$$

Taking 10 log D, one obtains 5 -0.8 log R , and taking 10 log Z gives 26 + 14 log R. Subtracting 26 + 5 from 199 leaves 168, and combining the log R terms results in – 13.2 log R. The resulting equation derived from Eq. (8.32), after also specifying the contributions to L, is

$$(L_t)_{dB} = 168 + 20 \log (R_T)_{km} - 20 \log f_{GHz} - 13.2\ R - 10 \log G_T - 10 \log C + \gamma_o r_o + \Gamma \tag{8.35}$$

The quantity C accounts for attenuation in the common scattering volume. The expression for C given in CCIR Report 724-2 (CCIR, 1986b) is

$$C = [2.17/(\gamma_r D)]\ (1 - 10^{-\gamma_r D/5}) \tag{8.36}$$

where γ_r is the attenuation constant for rain for vertical polarization [Eq. (4.11)], D, the path through rain is defined by Eq. (8.33), and $\gamma_o r_o$ is attenuation due to oxygen. The distance r_o is an effective distance equal to 0.7 R_T + 32 km for $R_T < 340$ km and otherwise 270 km. The quantity Γ represents attenuation due to rain outside the common scattering volume. It is given by a rather complicated expression in CCIR Report 724-1 and in the following form in the Report 724-2 (CCIR, 1986 b).

$$\Gamma = 631\ k R^{\alpha} {}^{-0.5}\ 10^{-(R+1)^{0.19}} . \tag{8.37}$$

In Eq. (8.37), kR^{α} is the same quantity as aR^b of Eq. (4.11). It is stated that this expression gives the largest value of Γ for intermediate rain rates. This behavior is in contrast to that of Report 724-1 which shows attenuation increasing continuously with rain rate.

Equation (8.37) can be solved for R_T, the distance from the common scattering volume to the terrestrial station. The distance R_T, however, is not the rain-scatter coordination distance d_2, as R_T is not measured from the earth station. The center of the circle representing the locus of R_T (scatter is assumed to occur equally in all directions from the common scattering volume) is displaced from the earth station by Ad which is a function of elevation angle θ where

$$\tan \theta = \frac{h}{\Delta d} = \frac{(R_T - 40)^2}{17{,}000\ \Delta d}$$

and

$$\Delta d = \frac{(R_T - 40)^2 \cot \theta}{17{,}000} \qquad (8.38)$$

The basis for this relation is shown in Fig. 8.7. The grazing ray from the terrestrial transmitter is assumed to graze the horizon at a distance of40 km, and a k factorof 4/3 (Sec. 3.2) is assumed.

The expression in CCIR Report 382-5 (CCIR, 1986c) that corresponds to Eq. (8.35) has the same form except that a gain G_T of 42 dB is assumed and 168-42 = 126 so that, for f $\leq$ 10 GHz,

$$(L_t)_{dB} = 126 + 20 \log (R_T)_{km} - 20 \log f_{GHz} - 13.2 \log R - 10 \log C + \gamma_o r_o + 10 \log B \qquad (8.39)$$

where 10 log B takes the place of Γ but has the for-m of Γ for CCIR Report 724-1 (CCIR, 1982).

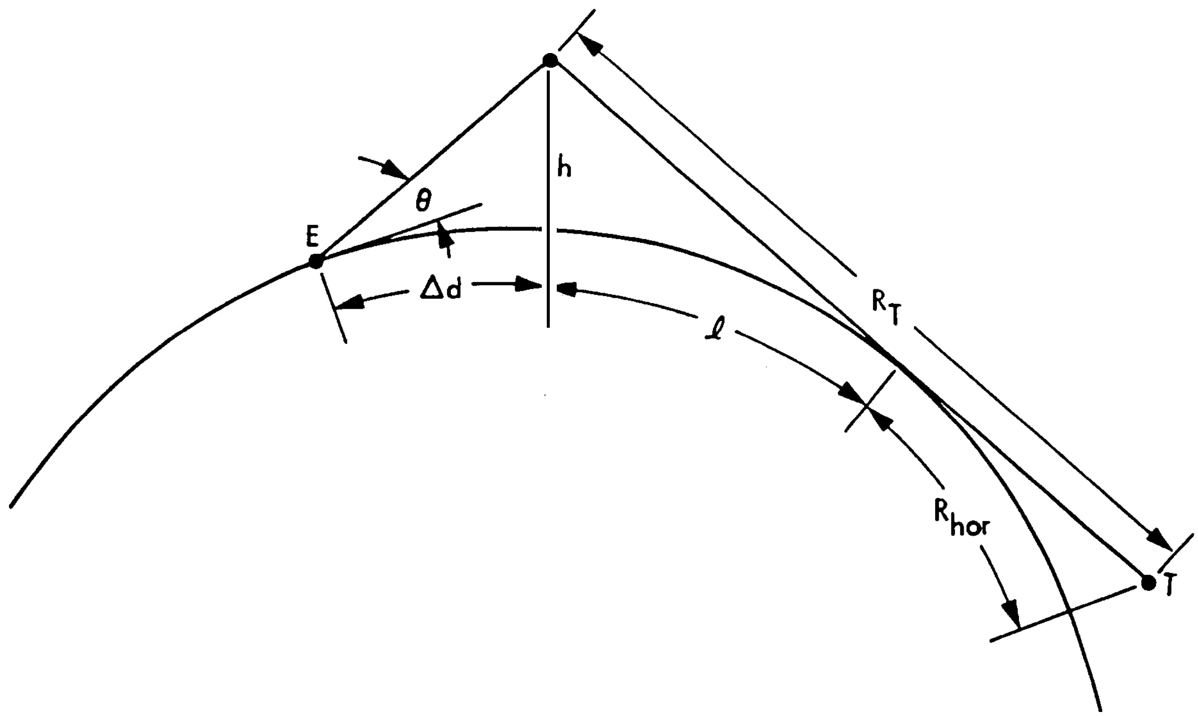

Figure 8.?. Rain scatter involving a transhorizon path from a terrestrial station. A gazing ray at the horizon will reach a height of $\ell^2/2kr_0 = (R_T - R_{hor})^2/2kr_0$ at the distance $R_T - R_{hor}$ from where the ray is tangential to the Earth's spherical surface. The elevation angle θ corresponding to this height h, as seen from the earth station E, is tan-i h/Ad.

Another variation of the equation for interference caused by scatter from rain is

$$[L, (0.01)]_{dB} = 131 - 20 \log (R_T)_{km} - 20 \log f_{GHz} - 10 \log C$$

$$+ \gamma_\theta r_0 - 14 \log R + (R_t - 40)^2/17{,}000 - 10 \log D_{km} \qquad (8.40)$$

This equation was in the 1978 version of CCIR Report 382 and also in Appendix 28 in 1982. The loss in this case is for a percentage of occurrence of 0.0 i. The 10 log D_{km} term is retained as such and the "5" referred to following Eq. (8.34) does not appear, so the numerical coefficient of Eq. (8.40) is 131 rather than 126. Also the quantity Z is assumed to decrease at a rate of 1 dB/km, and this decrease is accounted for by subtracting h of Eq. (8.38) from Z [$h = (R_T - 40)^2/17{,}000$]., As it is -10 log Z that occurs in the " original equation, Eq. (8.40) includes +h.

8.5 INTERFERENCE BETWEEN SPACE AND SURFACE STATIONS

Interference between a space station and one on the Earth's surface may take place, for example, when an earth station receives unwanted transmissions from an interfering satellite as weil as wanted transmissions from the satellite that serves the earth station. The analysis of Sec. 8.2, presented there as an introduction to the analytical aspects of interference, applies directly to this case,. and some additional considerations follow. Because the spacings of satellites in the geostationary orbit may be as close as 2 deg, limitations on the uplink and downlink antenna gains off axis have been prescribed by the FCC. Uplink antenna gain is limited to 32 -25' log 0, where θ is the off-axis angle in degrees, for values of θ of 1 deg and greater. For downlinks, the corresponding expression is 29 -25 log θ. A different appreach to combat interference, however, is to use the spread-spectrum technique. Small earth-station antennas can then be employed and discrimination against unwanted signals can be obtained by using code-division multiple access.

Scatter from rain,' which was not considered in Sec. 8.2 but may also cause interference, can be analyzed by a modification of the approach of Sec. 8.4 with R_T and G_T now taken to refer to the interfering satellite transmitter rather than to a terrestrial transmitter.

Solar power satellites, which would intercept solar energy and transmit energy to the Earth's surface as microwave radiation at a frequency of 2450 MHz according to preliminary plans, present a potential interference problem for communication satellite systems. According to one analysis (CCIR, 1986d) based on likely harmonic content, the interfering signal scattered from rain, even at the fourth harmonic, would be comparable with the signal level received in the fixed satellite service.

In the absence of precipitation, the signal on a line-of-sight path from a satellite will be attenuated by the atmospheric gases and perhaps by defocusing but may experience a gain due to multipath and scintillation effects, for a small fraction of the time, as mentioned in Sec. 8.3.2. The gain due to multipath effects and scintillation may be assumed tobe zero for elevation angles above 5 deg and percentages of time greater than one percent (CCIR, 1986d).

8.6 PROCEDURES FOR INTERFERENCE ANALYSIS

8.6. 1 Introduction

Previous sections of this chapter have outlined the theoretical basis for interference analysis, with emphasis on basic concepts. In this Sec. 8.6, practical considerations, including procedures for determining coordination distance, are summarized.

The procedures for interference analysis are subject to continuing development and updating. The procedures of Appendix 28 of 'Radio Regulations (ITU, 1982) carry legal authority, but they may be revised in the future. (Resolution No. 60 of WARC-79 called for a revision in Appendix 28, and the 1982 version of Report 382, utilizing certain data from Reports 724, 563, and 569, has been proposed as a basis for any changes in the radio regulations). The differences in the treatments of the several CCIR reports are in detail and refinement and relate to what losses need to be taken into account and how to achieve the necessary compromise between a satisfactory degree of accuracy on the one hand and convenience and practicality on the other. A basic problem is that the phenomena must be treated in a largely empirical way and the available data bases are limited.

8.6.2 Off-axis Antenna Gain

For calculating the predicted intensity of a terrestrial interfering signal at an earth station or of an interfering signal from an earth station at a terrestrial station, it is necessary to know the gain of the earth station antenna at the horizon at the azimuth of the terrestrial station (or for determining coordination distance at all azimuthal angles). To determine the gain, one must first find the angle of the horizon from the axis of the main antenna beam at the azimuth of interest. For the case that the horizon is at zero elevation angle, the horizon angle ϕ, measured from the axis of the antenna beam, is found by applying the law of cosines for sides ofa spherical triangle, namely

$$\text{Cos}\ \phi = \text{Cos}\ \theta_s \cos(\alpha - \alpha_s) \tag{8.41}$$

where θ_s is the elevation angle of the satellite the earth station is servicing , α_s is the azimuth 'of the satellite, and a is the azimuthal angle of interest. If the horizon is at an elevation angle θ, the corresponding relation becomes

$$\text{Cos}\ \phi = \cos\theta \cos 0s \cos(a - \alpha_s) + \sin\theta \sin\theta_s \tag{8.42}$$

Having determined ϕ, it remains to specify a value for the antenna gain at this angle. If the actual antenna gain is known as a function of ϕ, it should be used. If the gin is not known and the antenna diameter to wavelegt th ratio D/λ is 100 or greater, the following relation, from CCIR Reports 391-5, (CCIR, 1986f) and 382-5 and Appendix 28 of <u>Radio Regulations</u>, can be used for angles ϕ in degrees greater than that of the first side lobe

$$G = 32 - 25 \log \phi \ \text{dB} \tag{8.43}$$

If the D/λ ratio is less than 100, the corresponding relation is

$$G = 52 - 10 \log (D/\lambda) - 25 \log \phi \tag{8.44}$$

The same sources give relations between the maximum gain G_{max} and D/λ, that in Report 382-5 and Appendix 28 being

$$20 \log D/\lambda = G_{max} - 7.7 \text{ dB} \tag{8.45}$$

More preciesly and completely than stated above, Report 382-5 and Appendix 28 give the following set of relations for $D/\lambda \geq 100$.

$$G(\phi) = G_{max} - 2.5 \times 10^{-3} (D\phi/\lambda) \quad 0 < \phi < \phi_m \tag{8.46a}$$

$$G(\phi) = G, \quad \phi_m < \phi < \phi_r \tag{8.46b}$$

$$G(\phi) = 32- 25 \log \phi \quad \phi_r < \phi < 48^\circ \tag{8.46c}$$

$$G(\#) = -10 \quad 48°(\phi (180° \tag{8.46d}$$

where $\phi_m = (20\lambda/D) (G_{max} \cdot G_1)^{0.5}$ deg

$$\phi_r = 15.85 (D/\lambda)^{-0.6}$$

$$G_1 = 2 + 15 \log D/\lambda \text{ (gain of first side lobe)} \tag{8.47}$$

For $D/\lambda \leq 100$

$$G(\phi) = G_{max} -2.5 \text{ X } 10^{-3} (D\phi/\lambda)^2 \quad 0 < \phi < \phi_m \tag{8.48a}$$

$$G(\phi) = G_1 \quad \phi_m < \phi < 100\lambda/d \tag{8.48b}$$

$$G(\phi) = 52-10 \log D/\lambda - 25 \log(\#), \quad 100\lambda/D (\phi (48° \tag{8.48c}$$

$$G(\phi) = 10-10 \log D/\lambda \quad 48°< \phi (180° \tag{8.48d}$$

For satellite antennas, CCIR Report 558-3 (1986g) gives the following relations:

$$G(\phi) = G_{max} - 3 (\phi/\phi_o)^2 \quad \phi_o < \phi < a \phi_0 \tag{8.49a}$$

$$G(\phi) = G_{max} + L_s \quad a \phi_o (\phi < 6.32\$0 \tag{8.49b}$$

$$G(\phi) = G_{max} + L_s + 20 - 25(\phi/\phi_o) \quad 6.32\phi_o < \phi < \phi_1 \tag{8.49c}$$

$$G \phi) = 0 \quad \phi_1 < \phi \tag{8.49d}$$

where ϕ_o is one half the 3 dB beamwidth and ϕ_1 is the value Of ϕ when G_{max} = O. The parameter "a" has the values of 2.58, 2.88, and 3.16 when L_s, the required near-in side-lobe level relative to the peak, has the values of -20, -25, and -30 dB, respectively.

8.6.3 Procedures for Determining Coordination for Great Circle Propagation

For determining coordination distances d_1 for great circle propagation, it is necessary to first determine the basic transmission loss, L_b, as defined by Eq. (8. 11), that can be tolerated for the percentage of time specified (commonly 0.01 percent and perhaps 20 percent as well). The allowable value of Lb is based primarily on factors other than propagation. The quantity P_{Ri} (p) should be taken to be the maximum permissible interference level for p percent of the time. Consideration of this level is primarily outside the scope of this handbook, but material from Appendix 28 of the Radio Regulations that refers to it is reproduced as Appendix 8.1 The quantity G_T refers to the antenna gain of the transmitting interfering station. If the interfering station is an earth station, the gain towards the physical horizon on the azimuth in question is to be used. If the interfering station is a terrestrial station, the maximum expected antenna gain is to be used. The quantity G_R refers to the gain of the station that is interfered with If the station is an earth station, the gain towards the horizon on the azimuth in question is to be used. If the station experiencing interference is a terrestrial station, the maximum expected antenna gain is to used. Relations for estimating off-axis antenna gain were given in the previous Sec. 8.6.2. For determining coordination distance for installation of an earth station, one can intially determine coordination distance in all directions without regard to locations of terrestrial stations. In a second stage of analysis after coordination distance has been determined, the locations and gains of the terrestrial stations towards the earth station. can be utilized to determine if an interference problem truly exists.

Having decided on a value for Lb, one can solve for distance d of Eq. (8. 17) from CCIR Report 724-2 (1986b) or for distance d of

Eq. (8. 18). In Eq. (8.20), we show the coefficient γ of Eq. (8. 18) as including a factor of 0.01 in addition to γ_d, γ_o, and γ_w based on Report 724-2 (CCIR, 1986b). CCIR Report 382-5 (CCIR, 1986c) and Appendix 28 of Radio Regulations, however, do not, to our knowledge at the time of writing, include this factor of 0.01. Yet Appendix 28 carries legal authority. A person engaged in determining coordination distances should obtain a copy of the latest version of Appendix 28 and follow whatever instructions it includes. Note that antenna gains were taken into account in determining the value of Lb of Eqs. (8.17 and (8. 18) but do not appear explicitly in either of the two equations. The coordination distance found from these equations is designated as d_1. The reports cited include descriptions of procedures for use when great-circle paths cross more than one zone.

For zones B and C (Sec. 8.3.3), if coordination distances turn out to be greater than the values in Table 8.3, the values in the table should be used instead as the coordination distance.

Table 8.3 Maximum Coordination Distance d_1.

	Percent of Time			
Zone	0.001	0.01	0.1	1.0
B	2000 km	1500 km	1200 km	1000 km
C	2000 km	1500 km	1200 km	1000 km

8.6.4 Procedures for Determining Coordination Distance for Rain Scatter

For determining the coordination distance d_2 for scatter by rain, one must first find the total transmission loss L_t that can be tolerated for some specified percentage of time, commonly 0.01. This loss factor represents the ratio of the transmitted interfering power to the received interfering power as shown in Eqs. (8.10) and (8.25). In addition, or alternatively, certain approaches including that of CCIR Report 382-5 and Appendix 28 of the Radio

Regulations, utilize the normalized loss L_2 which is based upon the assumption that the terrestrial antema in question has a gain of 42 dB. The loss L_2 is reduced by 42 dB with respect to L_t for this reason. For finding the value of L_t, use the definition of L_t of Eq. (8.10). It is necessary to find values for P_{Ti} and to determine P_{Ri} (p), considering it as the maximum permissible interference level for p percent of the time, and the procedure for doing this, the same procedure as when working with 'great circle propagation, is given in Appendix 8.1. Note that, unlike the case for Eq. (8. 1 1), antenna gains do not appear in Eq. (8. 10). Antenna gains G_{ES} and G_T do appear, however, in Eq. (8.25)" which shows the factors determining L_t [as distinct from the quantities needed to define L_t, which is what Eq. (8. 10) shows].

When the required loss factor has been found, then one must determine the rainfall rate R in mm/h that applies for the specified percentage of time for the location or climatic region being considered. If appropriate long-term data are available for the location in question, it can be used. Otherwise one must use one of several models which show the rain rates exceeded as a function of percentage of time for the various geographical regions of the world.

Several such models are described in Sec. 4.3.3, and values of R, as a function of percentage-of time exceeded, are given in Table 4.4 for the 1980 Global Model (No. 5 of Sec. 4.3.3) for regions defined for the United States in Fig. 4.9. The CCIR model, described in CCIR Reports 563-3 (CCIR, 1986e) and 724-2 (CCIR, 1986b) is also included in Sec. 4.3,3 as No. 8. Data concerning this model are presented in two ways. The regions of the world utilized are shown in Figs. 4.13 - 4.15, and Table 4.5 shows the corresponding rain rates as a function of percentage of time exceeded. In addition, Figs. 9.8 - 9.10 from Report 563-3 show contours of fixed values of R that are exceeded for 0.01 percent of the time. The CCIR regions for Canada as modified by Segal are shown in Fig. 4.10.

Once the values of L_t and R have been settled on, one can solve for the value of R_T, the distance of the rain scatter region from the terrestrial station, by use of Eqs. (8.32), (8.35), (8.39), or (8.40). Equation (8.40) is that utilized in Appendix 28 of Radio Regulations and must be followed if legal requirements are to be met. Refer directly to Appendix 28 in that case.

The value of R_T is the radius of a circle centered on the region of rain scatter. The center of this circle is displaced from the earth station by the distance Ad of Eq. (8.38), and d_2, the coordination distance from the earth station to the circle at the azimuth under consideration.

If coordination distances for rain scatter turn out to be greater than those shown in Table 8.4, the values of the table should be used instead.

Table 8.4 Maximum Rain Scatter Distances (km).

Percent of time	Latitude (deg) 0-30	30-40	40-50	50-60	60-70
1.0	360	340	290	260	240
0.1	360	340	310	290	260
0.01	370	360	340	310	280
0.001	380	370	360	340	300

8.7 SITING OF EARTH STATIONS

The siting of earth stations in basins or valleys surrounded by hills is highly advantageous for minimizing radio interference. It is recommended in CCIR Report 385-1 (1986h), however, that the angles of elevation of obstructions should not exceed about 3 deg in order to ensure maximum satellite availability. Where sufficient natural shielding cannot be found, artificial shielding may be desirable. Radar fences built for suppression of signals at low elevation angles have provided 20 dB of protection (Crane, 1981). Placement of the earth station antenna in a pit is reported in CCIR Report 390-5 (1986i) to have provided 25 dB of protection in the 4 and 6 GHz fixed satellite bands. Ducting has the potential for producing the highest-level interference fields, but the effect of ducting can be reduced by the measures mentioned. Other siting precautions mentioned in Report 385-1 include avoiding line-of-sight paths between earth stations and interfering transmitters, avoiding locating the earth station with less than a 5 deg discrimination angle at the interfering transmitter between the path to the earth station and the main beam of the interfering transmitter antenna, and maintaining a minimum distance of 50 km when shielding of 3 to 4 deg is available. A distance of only 20 km is said to be sufficient when the shielding has an elevation angle of 10 deg.

Reflections from aircraft can cause interference, and earth stations should preferably not be located near areas of especially heavy aircraft traffic. In the Federal Republic of Germany, some 19,000 events attributed to aircraft reflections were observed during a period of 10,000 hours on a 1.9 GHz troposcatter link 420 km in length. The average basic transmission loss on this link was about 236 dB but for 0.1, 0.02, and 0.005 percent of the time the losses were 216, 213, and 210 dB respectively. The low levels of loss attributed to aircraft (CCIR, 1986a) show the advisability of considering potential interference due to reflections from aircraft.

Although apparently not mentioned in the literature, reflections from flocks of birds can also cause interference, and the viciniy of major waterfowl refuges or flyways should be avoided if possible. As far as the reflection of electromagnetic waves is concerned, birds are like large blobs of water. They are thus effective scatterers of electromagnetic waves and readily detectable by radar at L band (e.g. 1-.5 GHz) and higher- (Eastwood, 1967). Migrating birds commonly fly at altitudes up to about 3.6 km or higher.

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APPENDIX 8.1

PERMISSIBLE LEVEL OF INTERFERING EMISSION

Information on the permissible level of interfering emission that is included in Appendix 28 of Radio Regulations (ITU, 1982) is reproduced below. Reference is made in the following material to two tables containing detailed listing of parameters for the various frequency bands. These tables are not included here, but notes 1 through 4 discuss the parameters and provide information about their magnitudes.

23 *Derivation and tabulation of interference parameters*

23.1 Permissible level of the interfering emission

The permissible level of the interfering emission (dBW) in the reference bandwidth, to be exceeded for no more than *p*% of the time at the output of the receiving antenna of a station subject to interference, from each source of interference, is given by the general formula below:

$$P_r(p) = 10\log(kT_eB) + J + M(p) - W \qquad (3)$$

where:

$$M(p) = M(p_0/n) - M_0(p_0) \qquad (4)$$

with:

- *k*: **Boltzmann's constant** (138 x 10^{-23} J/K);
- T_e: **thermal noise temperature of the receiving system (K), at the output of the receiving antenna (see *Note 1*);**
- *B*: **reference bandwidth (Hz) (bandwidth of the interfered-with system over which the power of the interfering emission an be averaged);**
- *J*: **ratio (dB) of the permissible long term (20% of the time) interfering emission power to the thermal noise power of the receiving system, referred to the output terminals of the receiving antenna (see Note 2);**

p_0: percentage of the time during which the interference from all sources may exceed the permissible value;

n: number of expected entries of interference, assumed to be uncorrelated;

p: percentage of the time during which the interference from one source may exceed the permissible value; since the entries of interference are not likely to occur simultaneously: $p - p_0/n$;

$M_0(p_0)$: ratio (dB) between the permissible powers of the interfering emission, during p_0% and 200/0 of the time, respectively, for all entries of interference (see *Note 3*);

M(p): ratio (dB) between the permissible powers of the interfering emission during p% of the time for one entry of interference, and during 20% of the time for all entries of interference;

W: equivalence factor (dB) relating interference from interfering emissions to that caused by the introduction of additional thermal noise of equal power in the reference bandwidth. It is positive when the interfering emissions would cause more degradation than thermal noise (see *Note 4*).

Tables I and 11 list values for the above parameters.

In certain cases, an administration may have reason to believe that, for its specific earth station, a departure from the values associated with the earth station, as listed in Table 11, may be justified. Attention is drawn to the fact that for specific systems the bandwidths B or, as for instance in the case of demand assignment systems, the percentages of the time p and p_0 may have to be changed from the values given in Table II. For further information see $2.32.

Note 1: The noise temperature, in kelvins, of the receiving system, referred to the output terminals of the receiving antenna, may be determined from:

$$T_e = T_a + (e-1)\,290 + eT_r \tag{5a}$$

where:

T_a: noise temperature (K) contributed by the receiving antenna;

e: numerical loss m the transmission line (e.g. a waveguide) between antenna and receiver front cnd:

T_r: noise temperature (K) of the receiver front end, including all successive stages, referral to the front end input-

For radio-relay receivers and where the waveguide loss of a receiving earth station is not known, a value of - 1.0 is to be used.

Note 2: The factor *J* (dB) is defined as the ratio of total permissible long term (20% of the time) power of interfering emissions in the system, to the long term thermal radio frequency noise power in a single receiver. In the computation of this factor, the interfering emission is considered to have ● flat power spectral density, its actual spectrum shape being taken into account by the factor *W* (ace below). For example. in ● SO-hop terrestrial hypothetical reference circuit, the total allowable additive interference power is 1000 pWOp (CCIR Recommendation 357-3) and the man thermal noise power in ● single hop maybe assumed to be 25 pW0p. Therefore, since in ● frequency-division multiplex/frequency modulation (FDM/FM) system the ratio of a flat interfering noise power to the thermal noise power in the suns reference band is the same before and after demodulation, *J* is given by the ratio 1 000/25 expressed in dB, i.e.. *J* . 16 dB. In ● fixed-satellite service system, the total allowable interference power is also I 000 pWOp (CCIR Recommendation 356-4), but the thermal noise contribution of the down-link is not likely to exceed 7 000 pW0p, hence *J* ● -B.5dB.

In digital systems interference is measured and prescribed in terms of the bit error rate or its permissible increase. While the bit error rate increase is additive in a reference circuit comprising tandem links, the radio frequency power of interfering emissions giving rise to such bit error rate increase is not additive, because bit error rate is not a linear function of the level of the radio frequency power of interfering emissions. Thus, it may be necessary to protect each receiver individually. For digital radio-relay systems operating above 10 GHz, and for all digital satellite systems, the long term interference power may be of the same order of magnitude as the long term thermal noise, hence *J* = 0 dB. For digital radio-relay systems operating below 10 GHz, long term interference power should not decrease the receiver fade margin by more than 1 dB. Thus the long term interference power should be about 6 dB below the thermal noise power and hence *J* = −6 dB.

Note 3: $M_0(p_0)$ (dB) is the "interference margin" between the short term (p_0%) and the long tam (20%) allowable powers of an interfering emission.

For analogue radio-relay and fixed-satellite systems in bands between 1 GHz and 15 GHz, this is equal to the ratio (dB) between 50000 and I 000 pW0p (17 dB).

In the case of digital systems, system performance at frequencies ● bove 10 GHz can, in most areas of the world, usefully be defined as the percentage of the time p_0 for which the wanted signal is allowed to drop below its operating threshold, defined by ● given bit error rate. During non-faded operation of the system, the desired signal will exceed its threshold level by some margin M_s which depends on the rain climate in which the station operates. The greater this margin, the greater the enhancement of the interfering emission which would degrade the system to threshold performance. As a first order estimate it may be assumed that, for small percentages of the time (of the order of 0.001% to 0.003%), the level of interfering emissions may be allowed to equal the thermal noise which exists at the demodulator input during faded conditions. Thus, M_0 in Tables I and II may, for digital systems operating above 10 GHz, be assumed to be equal to the fade margin M_s of the system. For digital radio-relay systems operating below 10 GHz it is assumed that the short term power of an interfering emission can be allowed to exceed the long term power of the interfering emission by an amount equal to the fade margin of the system minus J, i.e. 41 dB, where J = -6 dB.

Note 4: The factor W (dB) is the ratio of radio frequency thermal noise power to the power of an interfering emission in the reference bandwidth when both produce the same interference after demodulation (e.g. in a FDM/FM system it would be expressed for equal voice channel performance: in a digital system it would be expressed for equal bit error probabilities). For FM signals, it is defined as follows:

$$W = 10 \log \left[\frac{\text{Thermal noise power at the output of the receiving antenna in the reference bandwidth}}{\text{Power of the interfering emission at the radio frequency in the reference bandwidth, at the output of the receiving antenna}} \times \frac{\text{Interference power in the receiving system after demodulation}}{\text{Thermal noise power in the receiving system after demodulation}} \right] \quad (5b)$$

The factor W depends on the characteristics of the wanted and the interfering signals To avoid the need for considering a wide range of characteristics, upper limit values were determined for the factor W. When the wanted signal uses frequency modulation with r.m.s. modulation indices which are greater than unity, W is not higher than 4 dB. In such cases, a conservative figure of 4 dB will be used for she factor W in (3), regardless of the characteristics of the interfering signal. For low-index FDM/FM systems a very small reference bandwidth (4 kHz) implies values of W not greater than O dB. In such cases, a conservative figure of O dB will be used for W in (3), regardless of the characteristics of the interfering signal.

When the wanted signal is digital, W is usually equal to or less than O dB, regardless of the characteristics of the interfering signal.