RECOMMENDATION ITU-R P.620-3

PROPAGATION DATA REQUIRED FOR THE EVALUATION OF COORDINATION DISTANCES IN THE FREQUENCY RANGE 0.85-60 GHz

(Question ITU-R 208/3)

(1986-1992-1995-1997)

The ITU Radiocommunication Assembly,

considering

a) the terms of Resolution No. 60 of the World Administrative Radio Conference (Geneva, 1979) (WARC-79);

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

c) that the determination of the coordination area should be based on the best propagation data available and should be adequately conservative,

recommends

1 that, for the determination of the coordination area with respect to frequencies above 1 GHz, administrations use the propagation calculation methods set out in Annex 1.

ANNEX 1

1 Introduction

This Annex provides propagation data for use in the calculation of a coordination area and sets out a straightforward method for the assessment of the propagation factors concerned in the determination of coordination distances.

The coordination area represents the area outside of which interference between the earth station and terrestrial stations operating within the conservative assumptions given in Tables 1 and 2 of Recommendation ITU-R IS.847 may be considered negligible. The determination of coordination distance therefore necessitates the comparison of the required transmission loss, based on system and interference model considerations, with the transmission loss contributed by the propagation medium. The required coordination distance is that at which these two losses become equal.

It is important to note that the coordination area does not represent a zone within which the sharing of frequencies between the earth station and the terrestrial station is excluded. Such sharing is often possible, and the coordination area serves to assist this arrangement by indicating where the potential for interference between the earth station and any terrestrial stations needs to be evaluated using Recommendation ITU-R P.452.

In addition to providing the method of calculation for the primary coordination contour, this Recommendation now provides information in § 5 that enables the preparation of auxiliary contours to assist in the rapid elimination of the majority of potential interference cases during the subsequent coordination analysis for terrestrial stations falling within the primary contour.

2 General considerations

The determination of coordination distance propagation characteristics for an earth station is based here on the assumption that:

– the locations of terrestrial stations with which coordination is to be sought are not known;

– in the interference path geometry, only information pertaining to the earth station is available;

– for the geometry over the remainder of the interference path, cautious limiting assumptions must be made as shown in the following text.

In this Annex propagation phenomena are classified into two modes as follows:

– *mode (1)*: propagation phenomena in clear air, and affected by the presence of the Earth’s surface (diffraction, refraction, ducting). These phenomena are confined to propagation along the great-circle path;

– *mode (2)*: hydrometeor scatter which is not limited to the great-circle path, but is, as dealt with in this Annex, limited to earth stations operating with geostationary satellites.

For each azimuth from the earth station, and for each of the above two modes of propagation, it is necessary to determine a distance corresponding to the required transmission loss; the “coordination distance” will be the greater of the two distances found. Recommendation ITU-R IS.847 provides full information on the required transmission loss.

The coordination distance in any given direction is determined by a number of factors set out above and, based on propagation factors alone, the distances could extend from relatively close-in to the earth station to many hundreds of kilometres. However, for practical reasons it is necessary for both modes of propagation to set lower limits to the distances within which to search for potential interference situations. These distances are defined as the mode (1) and mode (2) minimum coordination distances respectively.

In the case of mode (1), the requirement for the precautionary lower limit comes about because of the risk of significant errors in determining basic transmission loss (especially due to the diffraction propagation mechanism) over relatively short distances when the details of the actual path geometry are not known. The coordination distance should therefore always be kept sufficiently large to ensure that the diffraction fields will be negligible under all likely practical path conditions.

For mode (2) the requirement arises because the assumptions inherent in the hydrometeor scatter propagation modelling become unreliable at very short distances. By keeping the coordination distances at or beyond a pre-set minimum the model is not exercised in the region where it could become misleading.

Values for the appropriate minimum coordination distances are provided for each mode in the relevant sections below. The overall coordination contour traced out by the coordination distances determined radially around the earth station could of course be at all points greater than the “minimum distances” if the propagation calculations so determine.

3 Determination of coordination distance for propagation mode (1) – great-circle propagation mechanisms

3.1 Radioclimatic information

For the calculation of the coordination distance for propagation mode (1), the world has been classified in terms of a radiometeorological parameter, β_p, which reflects the relative incidence of clear-air anomalous propagation conditions. The value of β_p is latitude dependent. The correct value of β_p is the value at the latitude, φ_r which is 1.8° closer to the Equator than the earth station, or at the Equator, whichever point is the nearer to the earth station.

The relative point incidence of anomalous propagation, β_p%, is then determined using:

$$\beta_p = \begin{cases} 10^{-0.015|\varphi_r| + 1.67} & \% \qquad \text{for } |\varphi_r| \le 70° \\ 4.17 & \% \qquad \text{for } |\varphi_r| > 70° \end{cases} \tag{1}$$

3.2 Coordination distances based on worst-month time percentages

The propagation calculations in § 3.3 below are based on the required average annual time percentage, p. For cases where the coordination needs to be based on a worst-month time percentage, p_w, the equivalent annual time percentage, p, required by the method can be determined from:

$$p = \frac{p_w}{Q} \qquad \% \tag{2}$$

where:

p_w: required worst-month time percentage:

$$Q = \frac{0.85 \times 10^{-0.184 \log p + 0.515}}{G_L} \tag{2a}$$

The value of Q must be limited to $Q \leq 12$.

$$G_L = \begin{cases} \sqrt{1.1 + |\cos 2\varphi_r|^{0.7}} & \text{for } |\varphi_r| \leq 45° \\ \sqrt{1.1 - |\cos 2\varphi_r|^{0.7}} & \text{for } |\varphi_r| > 45° \end{cases} \tag{2b}$$

3.3 Procedure for the calculation of mode (1) coordination distance

The coordination distance for propagation mode (1) is that distance d_1 (km) which will result in a value of available basic transmission loss which is equal to the minimum permissible basic transmission loss, $L_b(p)$. Here p is the required time percentage, limited to the range $0.001\% \leq p \leq 1\%$.

Let:

$$L_1(p) = L_b(p) - A_1 \qquad \text{dB} \tag{3}$$

in which:

$$A_1 = 122.43 + 16.5 \log f + A_h + A_c \qquad \text{dB} \tag{4}$$

where:

f: frequency (GHz)

A_h: correction for the earth station horizon elevation angle θ° (see Note 1) given by the expression:

$$A_h = \begin{cases} 20 \log \left[1 + 4.5\ \theta f^{1/2} \right] + \theta f^{1/3} & \text{dB} \quad \text{for} \quad \theta \geq 0° \\ 3\left(\sqrt{f} - 1\right)\theta & \text{dB} \quad \text{for } 0° > \theta \geq -0.5° \\ -1.5\left(\sqrt{f} - 1\right) & \text{dB} \quad \text{for} \quad \theta < -0.5° \end{cases} \tag{5}$$

NOTE 1 – The horizon angle is defined here as the angle, viewed from the centre of the earth station antenna, between the horizontal plane and a ray that grazes the visible physical horizon in the direction concerned. The value of θ is positive when the physical horizon is above the horizontal. It is necessary to determine horizon angles for all azimuths around an earth station. In practice it will generally suffice to do this in azimuth increments of 5°. However, every attempt should be made to identify and take into consideration minimum horizon elevation angles that may occur between those azimuths examined in 5° increments.

NOTE 2 – The maximum value of A_h is 30 dB; the use of larger values may not result in the protection being realized in practical situations.

A_c: correction (dB) for direct coupling into over-sea ducts.

$$A_c = -6 / (1 + d_c) \qquad \text{dB} \tag{6}$$

where d_c is the distance from the earth station to the coast in the direction being considered.

Having determined L_1, the required distance must be determined on the basis of an iterative calculation. Commencing at the minimum coordination distance, d_{min} (km), the distance from the earth station is incremented until the required basic transmission loss is achieved (see Note 3). The preferred distance increment, s (km), is 1 km. However, for fast preliminary calculations, values for s of up to 5 km could be used without undue loss of accuracy.

$$d_{min} = 100 + \frac{\beta_p - f}{2} \qquad \text{km} \tag{7}$$

NOTE 3 – For computer implementations, modern numerical methods can offer faster techniques than this simple distance incrementing for finding d_1. Where computational speed is important such techniques should be explored.

For iterations $i = 0,1....n$, calculate equations (9) to (19) until at $i = n$ either $L_2(p) \geq L_1(p)$ or the maximum coordination distance, d_{max} (km), given by equation (19) for the particular azimuth is reached.

The required coordination distance d_1, is then given by:

$$d_1 = \begin{cases} d_{min} + n \cdot s & \text{km} \qquad \text{for } d_n < d_{max} \\ d_{max} & \text{km} \qquad \text{for } d_n \geq d_{max} \end{cases} \tag{8}$$

The loss L_2 is evaluated from:

$$L_2(p) = \left(\gamma_d + \gamma_g\right) d_i + \left(1.2 + 3.7 \times 10^{-3}\, d_i\right) \log\,(p / \beta) + 12\,(p / \beta)^{\Gamma} \qquad \text{dB} \tag{9}$$

where:

d_i: current distance (km) from earth station:

$$d_i = d_{min} + i \cdot s \qquad \text{km} \tag{10}$$

γ_g: specific attenuation (dB/km) due to gaseous absorption:

$$\gamma_g = \gamma_o + \gamma_w \cdot \frac{1}{3}\left(4 - \frac{d_t}{d_i}\right) \qquad \text{dB/km} \tag{11}$$

γ_o and γ_w can be found from the equations in Recommendation ITU-R P.676, using a value of 7.5 g/m^3 for the water vapour concentration, ρ.

$$\gamma_d = 0.05\, f^{1/3} \qquad \text{dB/km} \tag{12}$$

d_t: current aggregate land distance (km); (Zone A1 + Zone A2) within the distance d_i:

$$\Gamma = \left[\frac{-1.079 + \log\left(142 - (1.2 + 3.7 \times 10^{-3}\, d_i)\ \ (2 - \log \beta)\right)}{2 - \log \beta}\right] \tag{13}$$

$$\beta = \beta_p \cdot \mu_1 \cdot \mu_2 \cdot \mu_4 \qquad \% \tag{14}$$

where β_p is given by equation (1).

The parameter μ_1 depends on the degree to which the path is over land (inland and/or coastal) and water and is given by:

$$\mu_1 = \left[10^{\frac{-d_{tm}}{16 - 6.6\tau}} + \left[10^{-(0.496 + 0.354\tau)} \right]^5 \right]^{0.2} \tag{15}$$

with:

$$\tau = \left[1 - e^{-\left(4.12 \times 10^{-4} \; d_{lm}^{2.41}\right)} \right] \tag{16}$$

where the value of μ_1 shall be limited to $\mu_1 \leq 1$;

where:

d_{lm}: longest continuous inland distance (km) (Zone A2) within the distance d_i

d_{tm}: longest continuous land (i.e. inland + coastal) distance (km) (Zone A1 + Zone A2) within the distance d_i.

The radioclimatic zones to be used for the derivation of d_{tm} and d_{lm} are defined in Table 1.

where:

$$\mu_2 = \left[2.48 \times 10^{-4} \; d_i^2 \right]^{\alpha} \tag{17}$$

$$\alpha = -0.6 - \varepsilon \times 10^{-9} \; d_i^{3.1} \cdot \tau \tag{17a}$$

where ε is an allowance for additional distance-dependent and other losses, including those associated with terrain height:

$\varepsilon = 3.5$ which represents the worst-case smooth-Earth assumption;

$\varepsilon = 8.5$ for conservative inland coordination contours, compatible with measured propagation data but with a small allowance for an assumed minimum terrain clearance height (as defined by the parameter h_m of Recommendation ITU-R P.452), viz., $h_m = 70$ m at 300 km, 180 m at 400 km and 415 m at 500 km;

$\varepsilon = 200$ for reduced inland zone coordination distances which are broadly similar to those of Appendix 28 (S7) of the Radio Regulations.

The scaling of inland coordination distances varies approximately in proportion to the logarithm of ε.

NOTE 4 – ε has no effect on coordination distances in coastal or sea areas.

$$\mu_4 = \begin{cases} 10^{(-0.935 + 0.0176 |\varphi_r|) \log \mu_1} & \text{for } |\varphi_r| \leq 70° \\ 10^{0.3 \log \mu_1} & \text{for } |\varphi_r| > 70° \end{cases} \tag{18}$$

The maximum coordination distance for propagation mode (1) is given by:

$$d_{max} = 230 + 970 \cdot \mu_1 \cdot \mu_4 \qquad \text{km} \tag{19}$$

d_{max} must be recalculated using the current values of μ_1 and μ_4 for each value of d_i.

TABLE 1

Radioclimatic zones

Zone type	Code	Definition
Coastal land	A1	Coastal land and shore areas, i.e., land adjacent to the sea up to an altitude of 100 m relative to mean sea or water level, but limited to a distance of 50 km from the nearest sea area. Where precise 100 m data is not available an approximate value, i.e., 300 ft, may be used
Inland	A2	All land, other than coastal and shore areas defined as "coastal land" above
Sea	B	Seas, oceans and other large bodies of water (i.e., covering a circle of at least 100 km in diameter)

Large bodies of inland water

A "large" body of inland water, to be considered as lying in Zone B, is defined for the administrative purpose of coordination as one having an area of at least 7 800 km^2, but excluding the area of rivers. Islands within such bodies of water are to be included as water within the calculation of this area if they have elevations lower than 100 m above the mean water level for more than 90% of their area. Islands that do not meet these criteria should be classified as land for the purposes of the water area calculation.

Large inland lake or wetland areas

Large inland areas of greater than 7 800 km^2 which contain many small lakes or a river network should be declared as "coastal" Zone A1 by administrations if the area comprises more than 50% water, and more than 90% of the land is less than 100 m above the mean water level.

Climatic regions pertaining to Zone A1, large inland bodies of water and large inland lake and wetland regions are difficult to determine unambiguously. Therefore administrations are requested to register with the ITU Radiocommunication Bureau (BR) those regions within their territorial boundaries that they wish identified as belonging to one of these categories. In the absence of registered information to the contrary, all land areas will be considered to pertain to climate Zone A2.

For maximum consistency of results between administrations it is strongly recommended that the calculations of this procedure be based on the ITU-R Digitized World Map (IDWM) which is available from the ITU for mainframe or personal computer environments.

4 Determination of the coordination contour for propagation mode (2) – Scattering from hydrometeors

4.1 General

The determination of the coordination contour for scattering from hydrometeors (e.g., rain scatter) is predicted on a path geometry which is substantially different from that of the great-circle propagation mechanisms. As a first approximation, energy is scattered isotropically by rain, so that interference may result for large scattering angles, and for beam intersections away from the great-circle path.

For this propagation mode the previous classification of the Earth's surface into inland, coastal and sea zones is no longer appropriate.

The following procedure, together with the supplementary information in Appendix 1, should be used to determine the mode (2) coordination distance.

4.2 Coordination distances based on worst-month time percentages

The propagation calculations in § 4.3 below are based on the required average annual time percentage, p. For cases where the coordination needs to be based on a worst-month time percentage, p_w, the equivalent annual time percentage, p, required by the method can be determined using the method given in Recommendation ITU-R P.841 for the category Global.

4.3 Calculation of contours for propagation mode (2)

The material is presented in terms of the basic equations for the relationship between rainfall rate, transmission loss and rain-scatter distance. The equations allow transmission loss to be expressed versus rainfall rate for any given distance, with the cumulative time distributions of rainfall rate in various "rain climatic zones" given in Appendix 1.

The transmission loss may be calculated as a function of distance *r* (km) (see Note 1), frequency *f* (GHz) and surface rainfall rate *R* (mm/h) from:

$$\begin{aligned} L = {} & 168 + 20 \log r - 20 \log f - 13.2 \log R - g_T + 10 \log A_b \\ & - 10 \log C + \Gamma + E + \gamma_o d_0 + \gamma_w d_v \qquad \text{dB} \end{aligned} \tag{20}$$

where:

R: surface rainfall rate (mm/h), as given in Appendix 1 for various rain-climatic zones

g_T: gain of the terrestrial station antenna (dB), assumed to be 42 dB

and:

$$10 \log A_b = \begin{cases} 0.005\,(f - 10)^{1.7} R^{0.4} \quad \text{dB} & \text{for } 10 \text{ GHz} < f < 40 \text{ GHz} \quad (21) \\ 0 \quad \text{dB} & \text{for } f < 10 \text{ GHz or when } E \neq 0 \quad (21a) \end{cases}$$

C is given by:

$$C = \begin{cases} \dfrac{2.17}{\gamma_R d_s} \left(1 - 10^{-\gamma_R d_s / 5}\right) & \text{for } f > 4 \text{ GHz} \quad (22) \\ 1 & \text{for } f < 4 \text{ GHz} \quad (22a) \end{cases}$$

γ_R is given by:

$$\gamma_R = k R^{\alpha} \qquad \text{dB} \tag{23}$$

NOTE 1 – *r* is the distance between the region of maximum scattering and the location of an eventual terrestrial station.

Table 2 gives values for *k* and α for vertical polarization (which yields minimum specific attenuation).

Further:

$$d_s = 3.5 R^{-0.08} \qquad \text{km} \tag{24}$$

where:

$$\Gamma = 631\, k R^{(\alpha - 0.5)} \times 10^{-(R+1)^{0.19}} \qquad \text{dB} \tag{25}$$

E: loss in scatter coupling for heights above the melting layer, given by:

$$E = \begin{cases} 6.5 \left[6\,(r - 50)^2 \times 10^{-5} - H_{FR} \right] \quad \text{dB} & \text{for } 6\,(r - 50)^2 \times 10^{-5} > H_{FR} \quad (26) \\ 0 \quad \text{dB} & \text{for } 6\,(r - 50)^2 \times 10^{-5} \le H_{FR} \quad (26a) \end{cases}$$

where:

H_{FR}: mean annual rain height (km) in the region of the earth station, as defined in Recommendation ITU-R P.839.

$$d_0 = \begin{cases} 0.7\, r + 32 \quad \text{km} & \text{for } r < 340 \text{ km} \quad (27) \\ 270 \quad \text{km} & \text{for } r \ge 340 \text{ km} \quad (27a) \end{cases}$$

$$d_v = \begin{cases} 0.7\, r + 32 \quad \text{km} & \text{for } r < 240 \text{ km} \quad (28) \\ 200 \quad \text{km} & \text{for } r \ge 240 \text{ km} \quad (28a) \end{cases}$$

TABLE 2

Values of *k* and α for vertical polarization as a function of the frequency

Frequency (GHz)	*k*	α
<1	0	0
1	0.000 0352	0.880
4	0.000 591	1.075
6	0.001 55	1.265
8	0.003 95	1.31
10	0.008 87	1.264
12	0.016 8	1.20
14	0.029	1.15
18	0.055	1.09
20	0.069 1	1.065
22.4	0.090	1.05
25	0.113	1.03
28	0.150	1.01
30	0.167	1.00
35	0.233	0.963
40	0.310	0.929
45	0.393	0.897
50	0.479	0.868
60	0.642	0.824

The equations for gaseous specific attenuation, γ_o (for dry air) and γ_w (for water vapour), are given in Recommendation ITU-R P.676. The water vapour specific attenuation γ_w is to be calculated for an assumed water vapour density of $\rho = 7.5$ g/m^3.

Equation (20) allows transmission loss, L, to be obtained as a monotonic function of rainfall rate, R, and with the hydrometeor scatter distance, r, as a parameter. The procedure to determine the hydrometeor scatter contour is as follows:

a) The value of R should be found for the required time percentage, p, and the appropriate rain climate A to Q from the data in Appendix 1.

b) Values of L are then calculated for incremental values of r, starting at 45 km. The correct value of r is that for which the corresponding value of L equals or exceeds the required transmission loss. This value of r is denoted d_r.

c) If the iterative calculation results in r equalling or exceeding the appropriate maximum distance given in Table 3, then the calculation is terminated and d_r is assumed to have this maximum value.

TABLE 3

Maximum hydrometeor scatter distances (km)

Latitude (degrees)	0-30	30-40	40-50	50-60	> 60
Distance (km)	350	360	340	310	280

d) Determine a point at distance Δd along the earth station beam azimuth. This can be obtained from the following formula:

$$\Delta d = \frac{H_{FR}}{2 \tan \varepsilon_s} \qquad \text{km} \qquad (29)$$

where ε_s is the earth station antenna main beam elevation angle.

e) Draw a circle of radius d_r around this point. This is the hydrometeor scatter coordination contour (coordination contour for propagation mode (2)). The coordination distance for propagation mode (2) on a given azimuth from the earth station is the distance from the earth station to the coordination contour on that azimuth, denoted d_2.

As the only significant hydrometeor scatter is that occurring in the general vicinity of the earth station, the question of a mixed path loss does not arise.

5 Auxiliary contours

5.1 General

The coordination contours, together with the supplementary coordination contours as described in Recommendation ITU-R IS.847 are based upon the most unfavourable assumptions regarding interference geometry. Such assumptions rarely apply in practice, and so auxiliary contours should be drawn to eliminate terrestrial stations from further consideration for which the extreme assumptions do not apply, e.g., in cases where the terrestrial station antenna gain or e.i.r.p. in the direction of the earth station is less than that assumed in § 3 and 4.

For mode (1), the derivation of auxiliary contours in terms of the reduced power levels is straightforward. The mode (2) auxiliary contours however are generated not for different power levels but for different values of the avoidance angle, this angle being the offset azimuth angle of the terrestrial station main beam axis away from the direction of the earth station. When an earth station is to be coordinated with a group of terrestrial stations, it is necessary to consider the actual parameters of the terrestrial stations and to generate a supplementary coordination contour corresponding to those parameters. If some of the terrestrial stations fall inside the supplementary contour, a further elimination can be achieved through the use of auxiliary contours that have to be generated for the actual parameters of the group of terrestrial stations. In other words, these contours are most usefully applied in conjunction with the supplementary contour rather than the main contour.

5.2 Clear-air conditions (mode (1))

The auxiliary contours should be drawn by introducing into equation (3) a reduced loss of 5, 10, 15, 20 dB, etc., in required transmission loss, down to the minimum coordination distance.

5.3 Hydrometeor scatter (mode (2))

The coordination contour for mode (2) propagation around an earth station is calculated assuming the worst possible scenario, namely that the terrestrial station and the earth station point directly towards one another, and that the two main beams intersect exactly. This produces a large coordination area within which detailed calculations of hydrometeor scatter interference levels need to be performed. In practice, mode (2) propagation is far more likely to occur outside this great-circle plane than on it, and, furthermore, the antenna mainlobes are unlikely to intersect exactly. In either case, it is possible to generate auxiliary contours which would yield areas that are smaller than the coordination area. Appendix 2 provides a procedure for determining auxiliary contours on the basis of the avoidance angle, φ. Any station which lies outside the relevant contour for its avoidance angle need not be considered as a significant source of interference.

In the case of mode (2), the minimum coordination distance is determined by different criteria from the mode (1) case and a distance of 45 km should be applied. The mode (2) auxiliary contours should be prepared for avoidance angles of 2°, 5°, 10°, 20° and 30°, with additional angles as appropriate. The auxiliary contours should be applied when considering terrestrial station antennas conforming to Recommendation ITU-R F.699.

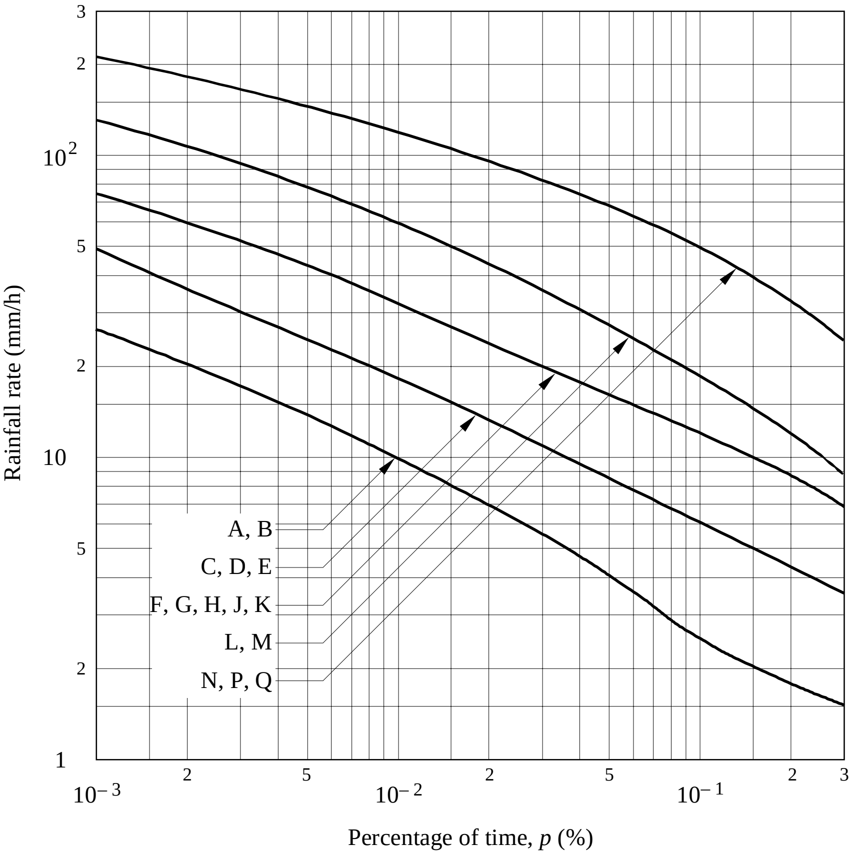
APPENDIX 1
TO ANNEX 1

Classification of rain climates

As shown in Recommendation ITU-R P.837 the world has been divided into a number of rain climatic zones which show different precipitation characteristics. The curves shown in Fig. 1 represent consolidated rainfall-rate distributions, each applicable to several of these rain climates, and are based on rainfall rate distributions as defined in Recommendation ITU-R P.837.

FIGURE 1

Consolidated cumulative distributions of rainfall rate for the rain climatic zones of Recommendation ITU-R P.837



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The distributions of Fig. 1 have been extended beyond 0.3% to such greater percentages of time p_c at which the rainfall rate is assumed to approach zero, using the expression:

$$R(p) = R(0.3\%) \left[\frac{\log (p_c / p)}{\log (p_c / 0.3)} \right]^2 \qquad \text{mm/h} \qquad (30)$$

and using, for $R(0.3\%)$ and p_c, the following values:

Rain climatic zone	$R(0.3\%)$ (mm/h)	p_c (%)
A, B	1.5	2
C, D, E	3.5	3
F, G, H, J, K	7.0	5
L, M	9.0	7.5
N, P, Q	25.0	10

This approach is appropriate for the numerical evaluation of the rain-scatter distance. It is, however, of concern only for frequencies above 8 GHz.

For numerical evaluation of $R(p)$ in the range $0.001\% < p < 0.3\%$, the curves in Fig. 1 have been converted into equations (31) to (35).

Climates A, B

$$R(p) = 1.1\, p^{-0.465} + 0.25\left[\log(p/0.001)\log^3(0.3/p)\right] - \left[\log(p/0.1) + 1.1\right]^{-2} \quad \text{mm/h} \qquad (31)$$

Climates C, D, E

$$R(p) = 2\, p^{-0.466} + 0.5\left[\log(p/0.001)\log^3(0.3/\mathrm{p})\right] \quad \text{mm/h} \qquad (32)$$

Climates F, G, H, J, K

$$R(p) = 4.17\, p^{-0.418} + 1.6\left[\log(p/0.001)\log^3(0.3/\mathrm{p})\right] \quad \text{mm/h} \qquad (33)$$

Climates L, M

$$R(p) = 4.9\, p^{-0.48} + 6.5\left[\log(p/0.001)\log^2(0.3/p)\right] \quad \text{mm/h} \qquad (34)$$

Climates N, P, Q

$$R(p) = 15.6\left(p^{-0.383} + \left[\log(p/0.001)\log^{1.5}(0.3/p)\right]\right) \quad \text{mm/h} \qquad (35)$$

APPENDIX 2

TO ANNEX 1

Calculation of contours for propagation mode (2)

Table 4 gives the definition of terms used in this section. Figure 2 shows the plan view of the hydrometeor scatter projected on to the horizontal plane, where A is the earth station, B is the terrestrial station at an arbitrary position, X and Y represent the locations of the terrestrial station that correspond to the maximum and minimum distance away from the centre of the contour respectively and M is the maximum horizontal extent of the potential common volume (CV).

TABLE 4

Hydrometeor scatter terms

H_{FR}	Rain cell height
r_b	Distance from the CV centre to the auxiliary contour
b	Horizontal distance between earth station and most distant CV possible
ε_s	Earth station elevation angle
α	Polar angle of terrestrial station with respect to the centre of the common volume
ψ	Angle subtended by b at terrestrial station (“look angle”)
δ	Required minimum protection angle
φ	Avoidance angle ($= \psi + \delta$)
d	Distance from the earth station to a point on the auxiliary contour
θ_d	Azimuth relative to the main beam direction from the earth station to a point on the auxiliary contour

The shaded area in Fig. 2 represents the critical region along the earth station beam which, if intersected by the terrestrial station main beam, would result in significant hydrometeor scatter interference via main lobe to main lobe coupling. This critical region, whose extent is annotated by b in the figure, is bounded by the earth station on one side and the maximum rain height (H_{FR}) on the other. For a given point within the coordination zone, the angle subtended by this region is termed the look angle, ψ. The protection angle, δ, represents the angle of the terrestrial station beam away from the critical region. The avoidance angle, φ, is the sum of these two angles ψ and δ and it is this quantity φ which will remain fixed along its own auxiliary contour.

The reference point of the contour is at the centre of the common volume (at a distance $b/2$ away from the earth station). Each contour is generated by varying the polar angle, α, and deriving corresponding values of r_b, as α changes from 0° to 360°, the angles ψ and δ will rise and fall, but their sum remains the same. The most favourable position for a terrestrial station occurs when $\alpha = 0$ (position Y), at which point the protection angle reaches its maximum. The distance from the centre of the common volume to the terrestrial station is then a minimum, denoted by $r_{b\,min}$ in the figure. At the other extreme, when $\alpha = 90°$ (position X), the look angle reaches its maximum, the protection angle will be at its minimum and r_b will have its largest value $r_{b\,max}$ for the contour.

1 The step-by-step algorithm

The following algorithm can be used to calculate the auxiliary mode (2) coordination contour for a given value of the avoidance angle φ.

– The limits of the minimum protection angle, δ_0, are:

$\delta_{0\,min} = 1.0°$

$\delta_{0\,max} = 48.0°$

– Compute b using:

$$b = H_{FR} \cot \varepsilon_s \tag{36}$$

– Calculate the value of δ_0 that corresponds to the chosen φ, as follows:

a) Set $\delta_0 = \delta_{0\,min}$.

b) Calculate the transmitter sidelobe gain at this angle δ_0 off boresight, according to Recommendation ITU-R F.699.

c) Use the resulting gain in place of the parameter g_T in equation (20) to compute the maximum distance for the auxiliary contour, $r_{b\,max}$, for the required transmission loss threshold.

d) Calculate ψ_0 using:

$$\psi_0 = 2 \text{ arc } \sin \left(\frac{b/2}{r_{b\,max}} \right) \tag{37}$$

e) Calculate the avoidance angle, φ', for the selected δ_0 using:

$$\varphi' = \psi_0 + \delta_0 \tag{38}$$

f) If $|\varphi' - \varphi| > 0.01\ \varphi$ then use the standard bisection technique to determine a new estimate for δ_0 and repeat from step b) until convergence is achieved as defined by $|\varphi' - \varphi| \leq 0.01\varphi$.

g) Use the final value of δ_0 and $r_{b\,max}$ hereafter.

– Derive $r_{b\,min}$ by:

a) calculating the antenna sidelobe gain for the above value of φ using Recommendation ITU-R F.699;

b) using this sidelobe gain in place of the parameter g_T in equation (20) to compute the distance for the auxiliary contour, for the required transmission loss threshold. This distance is $r_{b\,min}$.

– Generate the contour for values of α from 0° to 180° in steps of 1° as follows:

a) Set $r_b = 0.5\ (r_{b\,min} + r_{b\,max})$.

b) Compute ψ from:

$$\psi = \psi_1 + \psi_2 \tag{39}$$

where:

$$\psi_1 = \text{arc tan}\left(\frac{b\ \sin\alpha}{2r_b - b\cos\alpha}\right)$$

and:

$$\psi_2 = \text{arc tan}\left(\frac{b\ \sin\alpha}{2r_b + b\ \cos\alpha}\right)$$

c) Compute $\delta = \varphi - \psi$.

d) Compute $G(\delta)$ using Recommendation ITU-R F.699.

e) Using the resulting side lobe gain, $G(\delta)$, in place of the parameter g_T in equation (20), compute the distance, r'_b, for the required transmission loss threshold.

f) If $|r'_b - r_b| < 0.5$ km, then the desired value has been found.

If not, a new value is given to r_b:

$$r_b = 0.5\ (r_b + r_{b\,max}) \qquad \text{for } r'_b > r_b$$

$$r_b = 0.5\ (r_b + r_{b\,min}) \qquad \text{for } r'_b \leq r_b$$

and steps b) to f) are repeated.

– Once the value of r_b has been found, calculate the distance, d, and the azimuth, θ_d, from the location of the earth station to that contour point using:

$$d = 0.5\ b\ \sin\alpha / \sin\psi_2 \tag{40}$$

$$\theta_d = \text{arc sin}\ (r_b\ \sin\psi_2 / 0.5\ b) \qquad \text{for } \left(d^2 - r_b^2 + 0.25\ b^2\right) / (b\ d) > 0 \tag{41a}$$

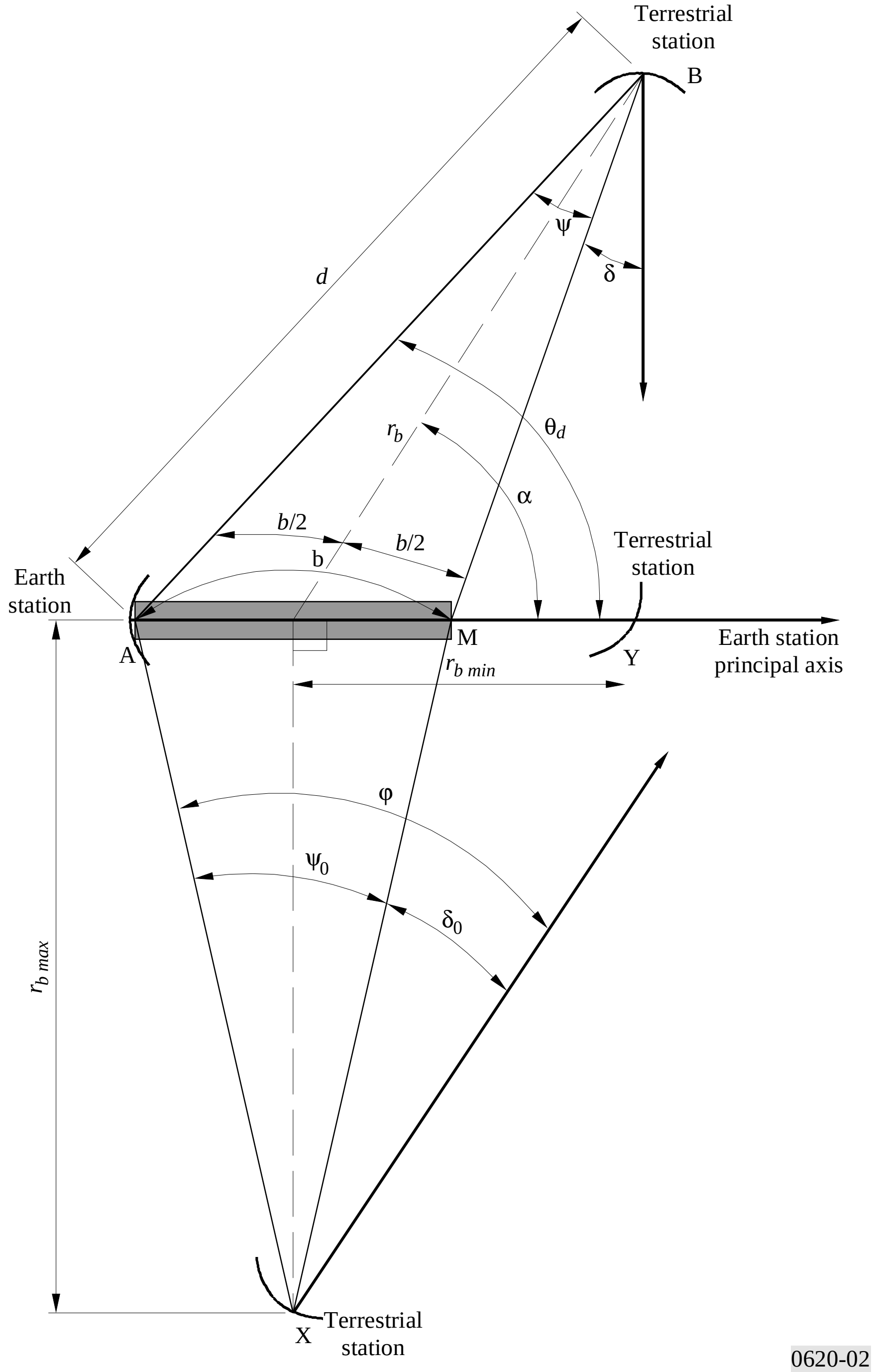
$$\theta_d = \pi - \text{arc sin}\ (r_b\ \sin\psi_2 / 0.5\ b) \qquad \text{for } \left(d^2 - r_b^2 + 0.25\ b^2\right) / (b\ d) \leq 0 \tag{41b}$$

– The values of r_b for α from 181° to 359° can be found by using the symmetry relationship:

$$r_b(\alpha) = r_b(-\alpha) = r_b(360° - \alpha) \tag{42}$$

FIGURE 2

Propagation geometry in the horizontal plane



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