RECOMMENDATION ITU-R IS.847-1

DETERMINATION OF THE COORDINATION AREA OF AN EARTH STATION OPERATING WITH A GEOSTATIONARY SPACE STATION AND USING THE SAME FREQUENCY BAND AS A SYSTEM IN A TERRESTRIAL SERVICE*

(Question ITU-R 6/12)

(1992-1993)

The ITU Radiocommunication Assembly,

considering

a) that, where earth stations and terrestrial stations share the same frequency bands, there is a possibility of interference, either the earth-station transmission interfering with reception at terrestrial stations, or terrestrial-station transmissions interfering with reception at earth stations, or both;

b) that, to avoid such interference, it will be desirable for the transmitting and receiving frequencies used by earth stations to be coordinated with the frequencies used by terrestrial services, which might either receive interference from earth-station transmissions or cause interference to reception at earth stations;

c) that this coordination will need to be undertaken within an area surrounding the earth station and extending to distances beyond which the possibility of mutual interference may be considered to be negligible;

d) that this area may extend into territory under the jurisdiction of another administration;

e) that such mutual interference will depend upon several factors, including transmitter powers, type of modulation, antenna gains in the direction of the unwanted signals, the permissible interference levels at the receivers, mechanisms of radio-wave propagation, radio-climatology, the distance between stations and the terrain profile;

f) that the possibility of interference will need to be examined in detail in each case, taking all factors into account;

g) that, as a preliminary to this detailed examination, it is desirable to establish a method of determining, on the basis of broad assumptions, a coordination area around an earth station in such a way that the possibility of mutual interference with terrestrial stations situated outside this area may be regarded as negligible, mutual coordination between administrations only being required when the coordination area of the earth station overlaps territory under the jurisdiction of another administration;

h) that the World Administrative Radio Conference, Geneva, 1979, adopted the method of determining the coordination area set out in Appendix 28 of the Radio Regulations (RR) and invited the ex-CCIR to continue its studies on the subject (see Recommendation No. 711 of the WARC-79);

j) that the Conference also adopted Resolution No. 60 inviting the ex-CCIR to maintain the relevant texts as a result of these studies in a format which would permit direct insertion into Appendix 28 of the RR in place of existing § 3, 4, 6 or Annex 3 when it is concluded by the ex-CCIR Plenary Assembly that such an insertion is warranted;

k) that it is necessary to develop Recommendations suitable to serve as source texts for the updating of Appendix 28 of the RR,

recommends

1. that the methods for determining coordination areas of transmitting and receiving earth stations described in Annex 1 should be used for the complete or partial updating of the procedures currently set forth in Appendix 28 of the RR;

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* The procedure described in this Recommendation applies only to radiocommunications stations on the surface of the Earth.

2. that any updating of Appendix 28 of the RR be accompanied by the adoption of a Resolution, similar to Resolution No. 60 of WARC-79, but with wider scope to allow Appendix 28 to be amended in light of technical development and newly acquired knowledge that would suggest such amendments.

Note 1 – The procedure described in Annex 1 to this Recommendation applies to situations where the coordination area is to be determined from specified values of permissible interference. The procedure is appropriate for the determination of the coordination area in frequency bands in which the space service operates with a space station in geostationary or slightly inclined geostationary orbit, and has a unidirectional (Earth-to-space or space-to-Earth) allocation.

The procedure to be followed in frequency bands which are bidirectionally (i.e., Earth-to-space and space-to-Earth) allocated to space services is set forth in Recommendation ITU-R IS.848.

The procedure to be followed for earth stations of space services using non-geostationary (e.g. low earth-orbiting) space stations is set forth in Recommendation ITU-R IS.849.

For cases where the coordination area is based on a predetermined coordination distance with respect to the location of an earth station or with respect to the area within which the earth station may operate, Recommendation ITU-R IS.850 applies. Recommendation ITU-R IS.850 is appropriate for use by an earth station operating with both geostationary and non-geostationary space stations, where the use of a predetermined coordination distance is needed, e.g., when the coordination distance cannot be determined by the procedures in Recommendation ITU-R IS.847 or ITU-R IS.849, respectively.

Note that the coordination distances mentioned in Resolution No. 46 of WARC-92 may take precedence over those determined by the above methods in bands where Resolution No. 46 applies.

The maps in Figs. 4, 5 and 6 have been taken from Recommendation ITU-R PN.837. As more statistics on rainfall are collected, this Recommendation will be updated, in which case the new version may be used instead.

Note 2 – The methods of this Recommendation and of Recommendation ITU-R IS.848 for the determination of the coordination area differ from those of Appendix 30A of the RR in several important details. Also, the maps depicting rain climates in RR Appendices 30 and 30A are different from those in this Recommendation. It is considered desirable that, in future revisions of the RR, Appendices 30 and 30A be aligned with the most recent texts of the ITU-R.

ANNEX 1

Determination of the coordination area for an earth station operating with a geostationary space station

1. Introduction

A procedure is given for determining the coordination area around an earth station which transmits radio frequency signals to, or receives such signals from, a geostationary space station in frequency bands between 1 and 60 GHz shared between space and terrestrial radiocommunication services.

This procedure is appropriate for the determination of the coordination area in frequency bands in which the space service has a unidirectional (Earth-to-space or space-to-Earth) allocation. The procedure to be followed in frequency bands which are bidirectionally (i.e., Earth-to-space and space-to-Earth) allocated to space services is set forth in Recommendation ITU-R IS.848. The procedure to be followed for earth stations of space services using non-geostationary (e.g. low earth-orbiting) space stations is set forth in Recommendation ITU-R IS.849.

The operation of transmitting and receiving earth and terrestrial stations in shared frequency bands between 1 and 60 GHz may give rise to interference between stations of the two services. The magnitude of such interference is dependent on the transmission loss along the interfering path which, in turn, depends on such factors as length and general geometry of the interfering path (e.g., site shielding), antenna directivity, radio climatic conditions, and the percentage of the time during which the transmission loss should be exceeded.

The described procedure allows the determination, in all azimuth directions from a transmitting or receiving earth station, of a distance beyond which the transmission loss would be expected to exceed a specified value for all but a specified percentage of the time. A distance so determined is called the coordination distance and the end points of coordination distances determined for all azimuths define a distance contour around the earth station – the coordination contour – which contains the coordination area. For terrestrial stations located outside the coordination area the probability of causing or experiencing significant interference is considered to be negligible.

The coordination area is obtained by determining, in all azimuth directions from an earth station, the coordination distances, and drawing to scale on an appropriate map the coordination contour which is the boundary of the coordination area.

Although based on technical data, the coordination area is an administrative concept. Since the coordination area is determined before any specific cases of potential interference are examined in detail, it must perforce rely on assumed parameters of the terrestrial systems, while the pertinent parameters of the earth stations are known. So as not to inhibit the technical development of terrestrial systems, the parameters assumed for them need to lie somewhat beyond those presently employed.

It should be emphasized that the presence or installation of a terrestrial station within the coordination area of an earth station may, but does not generally, affect the successful operation of either the earth station or the terrestrial station, since the procedure for the determination of the coordination area is based on unfavourable assumptions as regards mutual interference.

It is also emphasized that the operation of a terrestrial station inside a coordination area is not affected if that station has been coordinated. There is, thus, no need for administrations to avoid the installation or deployment of new terrestrial facilities within a coordination area.

For the determination of the coordination area two cases may have to be considered:

– for the earth station when it is transmitting (and hence capable of interfering with reception at terrestrial stations);

– for the earth station when it is receiving (and hence capable of being interfered with by emissions from terrestrial stations).

When an earth station is intended to transmit or to receive a variety of classes of emissions, the earth station parameters to be used in the determination of the coordination contour shall be those which lead to the greatest coordination distances, for each earth station antenna beam and in each allocated frequency band which the earth station proposes to share with the terrestrial service.

Together with the coordination contour, auxiliary contours should be drawn which are based on less unfavourable assumptions than those chosen for the determination of the coordination contour. These auxiliary contours may be used to eliminate, without more precise calculations, certain existing or planned terrestrial stations located within the coordination area from further consideration.

In addition, supplementary coordination contours should be prepared where possible to define a smaller coordination area for a different type of terrestrial service where the technical assumptions would apply to all potential conditions for the two affected services. These supplementary contours are particularly important in cases where stations in the fixed service using tropospheric scatter have been assumed yet other stations operating in a line-of-sight configuration may have to be addressed, or where stations in the fixed service are assumed yet stations in the mobile (except aeronautical mobile) service may have to be addressed. Auxiliary contours may also be drawn with respect to a supplementary contour, and should be presented on a map separate from the coordination contour.

The coordination area of an earth station operating with a geostationary space station in a slightly inclined geosynchronous orbit should be determined for the minimum angle of elevation and the associated azimuth at which the space station is visible to the earth station.

2. General considerations

2.1 Concept of minimum permissible transmission loss

The determination of coordination distance, as the distance from an earth station beyond which harmful interference from or to a terrestrial station may be considered to be negligible, is based on the premise that the attenuation of an unwanted signal is, or can be represented by, a monotonically increasing function of distance.

The amount of attenuation required between an interfering transmitter and an interfered-with receiver is given by the "minimum permissible transmission loss for *p*% of the time", a value of transmission loss which should be exceeded by the actual or predicted transmission loss for all but *p*% of the time:*

$$L(p) = P_{t'} - P_r(p) \qquad \text{dB} \qquad (1)$$

where:

$P_{t'}$**: the maximum available transmitting power level (dBW) in the reference bandwidth at the input to the antenna of an interfering station

$P_r(p)$: threshold interference level of an interfering emission (dBW) in the reference bandwidth to be exceeded for no more than *p*% of the time at the terminals of the receiving antenna of an interfered-with station, the interfering emission originating from a single source.

$P_{t'}$ and $P_r(p)$ are defined for the same radio-frequency bandwidth (the reference bandwidth) and $L(p)$ and $P_r(p)$ for the same percentage of the time, as dictated by the performance criteria of the interfered-with system.

Only small percentages of the time are of interest here, and it is necessary to distinguish between two significantly different mechanisms of propagation for an interfering emission:

– propagation of signals in the troposphere via near-great circle paths; mode (1) see § 3;

– propagation of signals by scattering from hydrometeors; mode (2), see § 4.

2.2 The concept of minimum permissible basic transmission loss

In the case of propagation mode (1) the transmission loss is defined in terms of separable parameters, viz.: a basic transmission loss (i.e. attenuation between isotropic antennas) and the effective antenna gains at both ends of an interference path. The minimum permissible basic transmission loss may then be expressed as:

$$L_b(p) = P_{t'} + G_{t'} + G_r - P_r(p) \qquad \text{dB} \qquad (2)$$

where:

$L_b(p)$: minimum permissible basic transmission loss (dB) for *p*% of the time; this value must be exceeded by the actual or predicted basic transmission loss for all but *p*% of the time

$G_{t'}$: gain (dB relative to isotropic) of the transmitting antenna of the interfering station. If the interfering station is an earth station, this is the antenna gain towards the physical horizon on a given azimuth; in the case of a terrestrial station, the maximum expected antenna gain is to be used

G_r: gain (dB relative to isotropic) of the receiving antenna of the interfered-with station. If the interfered-with station is an earth station, this is the gain towards the physical horizon on a given azimuth; in the case of a terrestrial station, the maximum expected antenna gain is to be used.

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* When *p* is a small percentage of the time, in the range 0.001% to 1.0%, it is referred to as "short-term"; if $p \geq 20\%$, it is referred to as "long-term".

** Primes refer to the parameters associated with the interfering station.

Appendix 1 provides the numerical method for determining the minimum angle between the earth-station antenna main beam axis and the physical horizon as a function of azimuth, as well as the corresponding antenna gains. In the case of space stations in slightly inclined geostationary orbits, the minimum angles and corresponding antenna gains will depend on the maximum inclination angle to be coordinated.

2.3 Derivation and tabulation of interference parameters

2.3.1 The threshold interference level of an interfering emission

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

$$P_r(p) = 10 \log (k\, T_e\, B) + N_L + 10 \log (10^{M_s/10} - 1) - W \qquad \text{dBW} \qquad (3)$$

where:

k : Boltzmann's constant, 1.38×10^{-23} J/K

T_e : the thermal noise temperature of the receiving system (K), at the terminal of the receiving antenna (see Note 1)

N_L : link noise contribution (see Note 2)

B : the reference bandwidth (Hz), i.e., the bandwidth in the interfered-with system over which the power of the interfering emission can be averaged

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

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

n : the number of equivalent equal level, equal probability entries of interference, assumed to be uncorrelated for small percentages of the time

M_s : link performance margin (dB) (see Note 3)

W : an equivalence factor (dB) relating interference from interfering emissions to that caused, alternatively, 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 1 and 2 list values for the above parameters.

In certain cases, an administration may have reason to believe that, for its receiving earth station, a departure from the values associated with the earth station, as listed in Table 2, 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 2.

Note 1 – The noise temperature (K) of the receiving system, referred to the output terminals of the receiving antenna, may be determined from:

$$T_e = T_a + (e - 1)\, 290 + eT_r \qquad \text{K} \qquad (4)$$

where:

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

e : numerical loss in the transmission line (e.g. a waveguide) between the antenna terminal and the receiver front end

T_r : noise temperature (K) of the receiver front end, including all successive stages at the front end input.

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

Note 2 – The factor N_L is the noise contribution to the link. In the case of a satellite transponder, it includes the up-link noise, intermodulation, etc. For example, generally:

$N_L = 1$ dB for fixed satellite links

$N_L = 0$ dB for terrestrial links.

Note 3 – M_s is the factor by which the link noise under clear-sky conditions would have to be raised to produce the specified minimum performance. It is the dB sum of two margins M_0 (the natural performance margin) and ΔM (the operational excess margin). The natural performance margin M_0 is the dB difference between the two C/N values that would just produce the specified nominal ("long term") and the specified minimum ("short term") performances, respectively. The excess margin ΔM is the dB difference between the actual clear-sky C/N and that which would produce the nominal specified performance; it may be equal to 0 dB. Thus, M_s is the real fade margin but it is also the margin by which the clear-sky noise floor could be raised (e.g., as the result of interfering emissions) to produce minimum performance conditions.

The performance of analogue terrestrial radio-relay systems is specified for the 2 500 km long hypothetical reference circuit (HRC) by Recommendation ITU-R F.393. A single hop (of 50 km length) of 50 hops is permitted to degrade from a nominal 150 pW0p of voice channel noise (3 pW0p/km) to the maximum 47 500 pW0p for the entire HRC (minimum specified performance). Since predemodulation noise and post-demodulation channel performance are proportional, $M_0 = 10 \log (47\,500/150) = 25$ dB. However, fading behaviour on each hop requires that sufficient margin be provided to satisfy minimum performance specifications; hence, the average hop operates under unfaded conditions with 25 pW0p of noise. From this, $\Delta M = 10 \log (150/25) = 7.8$ dB, and $M_S = 25 + 7.8 \cong 33$ dB.

For digital terrestrial systems, the short-term performance is protected by the provision of a fade margin, M_s, of 25 to 40 dB. Since the probability of short-term enhanced interference occurring simultaneously with carrier fades is negligible, the entire fade margin may be used by this interference.

In analogue systems of the fixed-satellite service, M_0 is given, according to Recommendation ITU-R S.353, by $M_0 = 10 \log (50\,000/10\,000) = 7$ dB. Since this is sufficient to deal with fading at least below about 17 GHz, ΔM is taken as 0 dB, and $M_s = 7$ dB. For frequencies above about 17 GHz, ΔM may have to assume some value greater than 0 dB.

In digital systems of the fixed-satellite service, M_0 can be as little as 1 dB for practical satellite circuits. In real satellite circuits, due to the presence of forward error correction (FEC) codes, the BER versus C/N curve is very steep. In addition, at BERs as low as 10^{-5}, the modem's decoder can lose synchronization to the incoming bit stream as the modem FEC algorithm begins to break down. Especially for very low bit rates, the recovery time could be significantly large. Thus, a degradation in C/N as small as 1.0 dB, when the BER is 10^{-7}, could result in degraded performance and/or downtime to the end-user anywhere from a few seconds to several minutes. The low value of M_0, i.e. 1 dB, is not likely to be sufficient to deal with fading on real links, hence, M_s is to be estimated directly from the expected fading depth for the real percentages of the time of concern. Practical values for M_s are therefore:

f (GHz)	M_s (dB)
< 10	2
10 to 17	4
> 17	6

TABLE 1

Parameters required for the determination of coordination distance for a transmitting earth station

Space radiocommunication service designation		Space operation		Mobile-satellite Land mobile-satellite Maritime mobile-satellite		Mobile-satellite	Space research Space operation Earth exploration-satellite	Fixed-satellite Mobile-satellite	Fixed-satellite		Space research		Fixed-satellite Mobile-satellite Meteorological-satellite		Fixed-satellite		Fixed-satellite		Fixed-satellite	Fixed-satellite	Fixed-satellite
Frequency bands (GHz)		1.427-1.429		1.6100-1.6455 1.6565-1.6600 1.675-1.710		1.970-2.010	2.025-2.110 2.110-2.120 (Deep space)	2.655-2.690	5.725-7.075		7.145-7.235		7.900-8.400		10.7-11.7		12.5-13.25 13.75-14.8		17.7-18.1	24.75-25.25 27-29.5	42.5-51.4
Modulation at terrestrial station (1)		A	N	A	N	A	A	A	A	N	A	N	A	N	A	N	A	N	N	N	N
Terrestrial station interference parameters and criteria	p_0(%)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.005	0.001	0.005	0.01	0.005	0.01	0.005	0.01	0.005	0.005	0.005	0.005
	n	2	2	2	2	2	2	1	2	3	2	2	2	2	2	3	2	2	2	1	1
	p(%)	0.005	0.005	0.005	0.005	0.005	0.005	0.01	0.005	0.002	0.005	0.002	0.005	0.002	0.005	0.002	0.005	0.002	0.002	0.005	0.005
	N_L (dB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	M_s (dB)	33	33	33	33	26(2)	26(2)	26(3)	33	37	33	37	33	37	33	37	33	40	25	25	25
	W (dB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0
Terrestrial station parameters	G_r (dB) (4)	35	35	35	35	52(2)	52(2)	52(3)	45	45	47	47	47	47	50	50	50	50	50	50	50
	ΔG (dB)	–7	–7	–7	–7	10(2)	10(2)	10(3)	3	3	5	5	5	5	8	8	8	8	8	8	8
	T_r (K)	750	750	750	750	500(2)	500(2)	500(3)	750	750	750	750	750	750	1 500	1 500	1 500	1 500	3 200	3 200	3 200
Reference bandwidth	B (Hz)	4×10^3	10^6	4×10^3	10^6	4×10^3	4×10^3	4×10^3	4×10^3	10^6	4×10^3	10^6	4×10^3	10^6	4×10^3	10^6	4×10^3	10^6	1×10^6	1×10^6	10^6
Threshold interference level	$P_r(p)$ (dBW) in B	–131	–107	–131	–107	–140	–140	–140	–131	–103	–131	–103	–131	–103	–128	–100	–128	–97	–109	–109	–109

(1) A: analogue modulation; N: digital modulation.

(2) The parameters for the terrestrial station associated with trans-horizon systems have been used. Line-of-sight radio-relay parameters associated with the frequency band 1.675-1.710 GHz may also be used to determine a coordination area in accordance with § 2.3.1.

(3) The parameters for the terrestrial station associated with trans-horizon systems have been used. Line-of-sight radio-relay parameters associated with the frequency band 5.725-7.075 GHz may also be used to determine a coordination area in accordance with § 2.3.1 with the exception that G_r = 37 dB and ΔG = –5 dB.

(4) Feeder losses are not included.

TABLE 2

Parameters required for the determination of coordination distance for a receiving earth station

Space radiocommunication service designation			Mobile-satellite Land mobile-satellite Maritime mobile-satellite	Space operation	Meteorological-satellite	Space research		Space operation	Earth exploration-satellite	Fixed-satellite		Fixed-satellite		Fixed-satellite		Fixed-satellite meteorological-satellite		Earth exploration-satellite	Space research		Fixed-satellite		Meteorological-satellite	Fixed-satellite	Mobile-satellite
																			Near Earth	Deep space					
Frequency band (GHz)			1.492-1.530 1.555-1.559 2.160-2.200 2.4835-2.5200 (1)	1.525-1.530	1.670-1.710 (2)	1.700-1.710 2.200-2.290	2.290-2.300 (Deep space)	2.200-2.290	2.200-2.290	2.500-2.690		3.400-4.200		4.500-4.800		7.250-7.750		8.025-8.400	8.400-8.500		10.7-12.75		17.7-47.0		
Modulation at earth station (3)			N	N		N	N	N	N	A	N	A	N	A	N	A	N	–	–	–	A	N		N	
Earth station interference parameters and criteria	p_0 (%)		10	1.0		0.1	0.001	1	1	0.03	0.003	0.03	0.005	0.03	0.005	0.03	0.005	1.0	0.1	0.001	0.03	0.003		0.003	
	n		1	1		2	1	2	2	3	3	3	3	3	3	3	3		2	1	2	2		2	
	p (%)		10	1.0		0.05	0.001	0.5	0.5	0.01	0.001	0.01	0.002	0.01	0.002	0.01	0.002		0.05	0.001	0.015	0.002		0.002	
	N_L (dB)		0			–	–	–	–	1	1	1	1	1	1	1	1		–	–	1	1		1	
	M_s (dB)		1(4)			–	–	–	–	7	2	7	2	7	2	7	2		–	–	7	4		6	
	W (dB)		0	0		–	–	–	–	4	0	4	0	4	0	4	0		–	–	4	0		0	
Terrestrial station parameters	E (dBW) in B (5)	A	37(6)	50	92(7)	62(7)(8)	62(7)(8)	62(7)	92(7)	92(7)	92(7)	55	55	92(9)	92(9)	55	55	55	25(8)	25(8)	55	55		–	
		N	37	37								42	42	42(10)	42(10)	45	45	42	–18	–18	42	42		40	
	P_t (dBW) in B	A	0	13	40(7)	10(7)(8)	10(7)(8)	10(7)	40(7)	40(7)	40(7)	13	13	40(9)	40(9)	13	13	13	–17(8)	–17(8)	10	10		–	
		N	0	0								0	0	0	0	3	3	0	–60	–60	–3	–3		–7	
	ΔG (dB)		–5	–5	10(7)	10(7)	10(7)	10(7)	10(7)	10(7)	10(7)	0	0	10(9)(10)	10(9)(10)	0	0	0	0	0	3	3		5	
Reference bandwidth(11)	B (Hz)		4×10^3	10^3	10^6	1	1	10^3	10^6	10^6	10^6	10^6	10^6	10^6	10^6	10^6	10^6	10^6	1	1	10^6	10^6		10^6	
Threshold interference level	$P_r(p)$ (dBW) in B		–176	–184		–216	–222	–184	–154	–	–	–	–	–	–	–	–	–154	–220	–220	–	–		–	

Notes to Table 2:

(1) In these bands the terrestrial station parameters of line-of-sight radio-relay systems have been used. If an administration believes that, in the bands 2.160-2.200 GHz and 2.4835-2.5200 GHz, trans-horizon systems need to be considered, the parameters associated with the frequency band 2.500-2.690 GHz may be used to determine the coordination area in accordance with § 2.3.1.

(2) In the band 1.670-1.700 GHz an additional contour for coordination with the meteorological aids service is required. See Table 2 of Recommendation ITU-R IS.850 for details of the calculation.

(3) A: analogue modulation; N: digital modulation.

(4) This value is based on an interference contribution of 25%. See Note 3 of § 2.3.1.

(5) E is defined as the equivalent isotropically radiated power of the interfering terrestrial station in the reference bandwidth.

(6) This value is reduced from the nominal value of 50 dBW for the purposes of determination of coordination area, recognizing the low probability of high power emissions falling fully within the relatively narrow bandwidth of the earth station.

(7) As in footnote (9) with the exception that $E = 50$ dBW for analogue terrestrial stations; and $\Delta G = -5$ dB. However, for the space research service only, noting footnote (8) when trans-horizon systems are not considered, $E = 20$ dBW and $P_t = -17$ dBW for analogue terrestrial stations, $E = -23$ dBW and $P_t = -60$ dBW for digital terrestrial stations; and $\Delta G = -5$ dB.

(8) These values are estimated for 1 Hz bandwidth and are 30 dB below the total power assumed for emission.

(9) In this band, the parameters for the terrestrial stations associated with trans-horizon systems have been used. If an administration believes that trans-horizon systems do not need to be considered, the line-of-sight radio-relay parameters associated with the frequency band 3.4-4.2 GHz may be used to determine the coordination area in accordance with § 2.3.1.

(10) Digital systems assumed to be non-trans-horizon. Therefore, $\Delta G = 0$. For digital trans-horizon systems, parameters for analogue trans-horizon systems above may be used.

(11) In certain systems in the fixed-satellite service it may be desirable to choose a greater reference bandwidth B when the system requirements indicate that this may be done. However, a greater bandwidth will result in smaller coordination distances and a later decision to reduce the reference bandwidth may require re-coordination of the earth station.

Signals to be received at a mobile earth station may not be amenable to this type of specification of performance criteria. In particular, it may not be possible to quantify the margin components M_0 and ΔM directly. To provide some measure of protection against interference of such earth stations it is only possible to preserve their operating margin by limiting the amount of interfering noise power that may be added to their receiving system noise. The criterion to be used is then given as a permissible receiving system noise power increase ΔN (e.g. 25%) expressed as a percentage not to be exceeded for more than p% (e.g. 10 – 50%) of the time, so that for each station:

$$P_r(p) = 10 \log k\, T\, B + 10 \log (\Delta N/100)$$

This leads to a link performance margin of:

$$M_s = 10 \log (\Delta N/100 + 1)$$

Note 4 – The factor W (dB) is the level of the radio-frequency thermal noise power relative to the received power of an interfering emission which, in the place of the former and contained in the same (reference) bandwidth, would produce the same interference (e.g., an increase in the voice or video channel noise power, or in the bit error ratio). The factor W generally depends on the characteristics of both the wanted and the interfering signals.

For interference between FDM-FM telephony transmissions, W may be calculated from:

$$W = 10 \log \left[f_m \, (1 + r\, m)\, D(f_m, 0) \right] \qquad \text{dB} \qquad (5)$$

where:

m : r.m.s. modulation index of the interfered-with signal

r : multi-channel peak-to-r.m.s. voltage ratio in the interfered-with signal.

Note that the term $f_m(1 + r\, m)$ is equal to one-half of the Carson's rule bandwidth of the interfered-with signal.

The term $D(f_m, 0)$ is a convolution term contained in the interference reduction factor B of equation (3) of Recommendation ITU-R SF.766.

When the r.m.s. modulation index of the wanted signal is greater than about 0.8, W will not exceed a value of about 4 dB when the reference bandwidth is chosen as the radio-frequency "noise" bandwidth of the wanted signal.

For very low r.m.s. modulation indices of the wanted signal, W may assume a large range of values, increasing with decreasing modulation indices of both the wanted and the unwanted signals. For such cases it has proven useful to choose as the reference bandwidth the nominal voice channel bandwidth of 4 kHz, and in this case $W \leq 0$ dB.

When the wanted signal is digital, W is usually equal to or less than 0 dB, regardless of the characteristics of the interfering signal.

Recommendation ITU-R SF.766 contains information which permits W to be determined more precisely.

2.3.2 Auxiliary contours

The coordination contours and the supplementary coordination contours are based upon the most unfavourable assumptions regarding interference possibilities. Such unfavourable assumptions rarely apply in practice, and so auxiliary contours should be drawn to facilitate the elimination from further consideration of stations for which the extreme assumptions do not apply.

For the great-circle propagation mode (1) the use of auxiliary contours is of administrative benefit because the administration of the territory into which a coordination area extends may, without recourse to more detailed analysis or inter-administration dialogue, use the auxiliary contours to eliminate terrestrial stations or station classes from being considered to be affected in cases where the terrestrial service station antenna gain or e.i.r.p. in the direction of the earth station is less than that assumed in Tables 1 and 2.

The application of the auxiliary contours applies equally to the cases of transmitting and receiving earth stations.

The auxiliary contours should be drawn appropriate for a 5, 10, 15, 20 dB etc. reduction in required transmission loss, down to a minimum coordination distance of 100 km.

2.3.3 Supplementary coordination contours

The coordination contour is based on the type of terrestrial station that would yield the largest coordination distances. Hence, insofar as all bands of concern are allocated to the fixed service, fixed stations using tropospheric scatter have been assumed in bands that may typically be used by such systems, and fixed stations operating in line-of-sight configurations and using analogue modulation have been assumed for other bands. However, other terrestrial systems have typically lower antenna gains or otherwise less stringent characteristics than those on which the maximum coordination areas are based. It is possible for the notifying administration to identify a supplementary coordination contour which assumes the role of the coordination contour for such systems. In such cases, for example digital fixed systems, the necessary parameters are provided in Tables 1 and 2. The supplementary coordination contour may be depicted with its auxiliary contours identified separately from the coordination contour.

In the case of bands shared by the fixed and mobile services, such supplementary contours may also be drawn. Parameters for this purpose are not currently included in Tables 1 and 2.

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

3.1 Radio-climatic zones

In the calculation of coordination distance for propagation mode (1), the world is divided into four basic radio-climatic zones. These zones are defined as follows:

– Zone A1: coastal land and shore areas, i.e. land adjacent to a Zone B or Zone C area (see below), up to an altitude of 100 m relative to mean sea or water level, but limited to a maximum distance of 50 km from the nearest Zone B or Zone C area as the case may be; in the absence of precise information on the 100 m contour, an approximation (e.g. 300 feet) may be used;

– Zone A2: all land, other than coastal land and shore defined as Zone A1 above;

– Zone B: “cold” seas, oceans and large bodies of inland water situated at latitudes above 30°, with the exception of the Mediterranean and the Black Sea;

– Zone C: “warm” seas, oceans and large bodies of inland water situated at latitudes below 30°, as well as the Mediterranean and the Black Sea.

Large bodies of inland water

A “large” body of inland water, to be considered as lying in Zone B or C as appropriate, 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 this 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 can present difficulties. Such areas can be declared as “coastal” Zone A1 by administrations if the areas contain more than 50% water, and more than 90% of the land elevation 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 Radiocommunication Bureau (BR) 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 climatic Zone A2.

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

3.2 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, $L_b(p)$ dB, as defined in § 2.2.

$$L_b(p) = P_{t'} + G_e + 42 + \Delta G - P_r(p) \qquad \text{dB} \tag{6}$$

where:

$P_{t'}$ and $P_r(p)$ are as defined in § 2.1

G_e : gain of the earth station antenna (dBi) appropriate towards the horizon at the horizon elevation angle and azimuth of the radial path under consideration

ΔG : difference (dB) between the maximum antenna gain assumed for the terrestrial station and the value of 42 dB. Tables 1 and 2 give values for ΔG for the various frequency bands.

Let:

$$L_1 = L_b(p) - A_1 \qquad \text{dB} \tag{7}$$

in which:

$$A_1 = 120 + 20 \log f + \log p + 5\, p^{0.5} + A_h \qquad \text{dB} \tag{8}$$

where:

f : frequency (GHz)

A_h : correction for the earth-station horizon elevation angle θ°* given by the expression:

$$A_h = \begin{cases} 20 \log \left[1 + 4.5\, \theta f^{0.5} \right] + \theta f^{0.33} & \text{dB} \quad \text{for} \quad \theta \geq 0^\circ & \text{(9a)} \\ 8\, \theta & \text{dB} \quad \text{for} \quad 0^\circ > \theta \geq -0.5^\circ & \text{(9b)} \\ -4 & \text{dB} \quad \text{for} \quad \theta < -0.5^\circ & \text{(9c)} \end{cases}$$

Note 1 – The maximum value for A_h is 30 dB; the use of larger values may not result in the protection being realized in practical situations.

Having determined L_1, the required distance may be determined on the basis of:

$$L_1 = \sum_{i=1}^{n} \beta_i(p)\, d_i \qquad \text{dB} \tag{10}$$

where i = 1 to n refers to the individual path sections, each being of Zone Type A1, A2, B or C as defined in § 3.1. Several sections of each type are possible along each radial path.

d_i : traversed distance (km) of the ith section of the path

$\beta_i(p)$: total specific attenuation (dB/km) for the ith path section, viz:

$$\beta_i(p) = 0.01 + \beta_{dz}(p) + \beta_o + \beta_{vz} \qquad \text{dB/km} \tag{11}$$

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* The horizon elevation 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. 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.

$\beta_{dz}(p)$: (zone specific) attenuation coefficient exceeded for all but p% of time due to the anomalous propagation phenomena

$$\beta_{dz}(p) = C_1 + C_2 \log f + C_3 \, p^{C_4} \qquad \text{dB/km} \tag{12}$$

Values for C_1, C_2, C_3 and C_4 for the four climatic zones are given in Table 3.

TABLE 3

Values for C_1, C_2, C_3, C_4 and ρ

Zone	C_1	C_2	C_3	C_4	ρ (g/m^3)
A1	0.03	0.03	0.15	0.2	10.0
A2	0.04	0.05	0.16	0.1	7.5
B	0.015	0.015	0.05	0.15	10.0
C	0	0.015	0.04	0.15	10.0

β_o and β_{vz} : specific attenuations due to oxygen and water vapour respectively.

$$\beta_o = \begin{cases} \left[7.19 \times 10^{-3} + \dfrac{6.09}{f^2 + 0.227} + \dfrac{4.81}{(f - 57)^2 + 1.50} \right] f^2 \times 10^{-3} \quad \text{dB/km} \quad \text{for} \quad f < 57 \text{ GHz} & \text{(13a)} \\ \beta_o = \beta_{o(57)} + 1.5(f - 57) \quad \text{dB/km} \quad \text{for } 57 \le f \le 60 \text{ GHz} & \text{(13b)} \end{cases}$$

where:

$\beta_{o(57)}$: value of β_o found using equation (13a) and a frequency of 57 GHz.

$$\beta_{vz} = \left\{ 0.050 + 0.0021\,\rho + \frac{3.6}{(f - 22.2)^2 + 8.5} + \frac{10.6}{(f - 183.3)^2 + 9.0} + \frac{8.9}{(f - 325.4)^2 + 26.3} \right\} f^2 \rho \, 10^{-4} \qquad \text{dB/km} \qquad \text{for } f < 350 \text{ GHz} \tag{14}$$

Values of β_{vz} depend upon the climatic zone, and must be calculated using the appropriate values of water vapour density ρ (g/m^3) as shown in Table 3 above.

Equation (10) shows that the overall mode (1) distance may have to be found via an interactive calculation. Using pre-determined path section lengths, D_i, for each radial path from the earth-station location, calculate and add, in dB, the values of the products $\beta_i(p)D_i$ for successive path sections until the sum is greater than L_1 dB; this will yield the value of n. However, the inclusion of the whole length of the nth-section, particularly if it is over the sea, will generally result in a total distance which significantly exceeds that necessary to achieve L_1 dB. Therefore, where:

$$\sum_{i=1}^{n} \beta_i(p)\, D_i > L_1 \qquad \text{dB} \tag{15}$$

the required partial penetration, d_n, into the nth-zone is determined by linear interpolation:

$$d_n = \left[L_1 - \sum_{i=1}^{n-1} \beta_i(p)\, D_i \right] \Big/ \; \beta_n \qquad \text{km} \tag{16}$$

The coordination distance for mode (1), d_1, is then given by:

$$d_1 = \begin{cases} d_n + \sum_{i=1}^{n-1} D_i & \text{km} \quad \text{for } n > 1 \\ L_1 / \beta_1 & \text{km} \quad \text{for } n = 1 \end{cases} \tag{17}$$

However, this value of d_1 is subject to the limits set out in § 3.3.

3.3 Maximum coordination distances for propagation mode (1)

For paths entirely within a single zone, the distance shall not exceed the value given in Table 4 for that zone.

For mixed paths, the coordination distance can comprise contributions from Zones A1, A2, B and C. The aggregate distance for any one zone shall not exceed the value given in Table 4, the combination of distances in Zones A1 and A2 shall not exceed 500 km. The overall coordination distance shall not exceed the value in Table 4 for the zone in the mixed path having the largest Table 4 value.

TABLE 4

Mode (1) maximum coordination distances

Zone	d_{m1} (km)
A1	500
A2	350
B	900
C	1 200

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

The hydrometeor scatter coordination distance is that distance that will result in an available transmission loss, L_2, equal to the minimum permissible transmission loss $L(p)$ as defined in § 2.1.

$$L(p) = P_{t'} - P_r(p) \qquad \text{dB} \tag{18}$$

As noted in § 2, the minimum coordination distance is 100 km. For the general case of interference from hydrometeor scatter this is considered to provide adequate protection, and specific cases need only be evaluated within this distance from the earth station. However, there may be particular combinations of system parameters, i.e. high interfering transmitter powers and/or a low permissible interfering power at the interfered-with receiver, which result in the latter station requiring additional protection from hydrometeor-scatter interference.

Therefore, where the required transmission loss, $L(p)$, exceeds by more than ΔG dB the applicable value in Table 5 for the frequency band and rain climate zone (see Appendix 3) appropriate to the earth station, the procedure given in Appendix 2 should be used to create the appropriately-extended mode (2) contour.

TABLE 5

Transmission loss thresholds (dB) for Mode (2) extended contour calculations

Frequency band (GHz)	Rain climate				
	A, B	C, D, E	F, G, H, J, K	L, M	N, P, Q
1	152	148	144	141	136
4	140	136	132	129	125
6	138	134	130	127	124
8	136	132	129	126	124
10	135	131	129	127	126
12	134	131	129	127	126
14	135	132	130	128	127
18	138	136	134	132	131
20	144	142	140	139	137
22.4	153	151	149	148	146
25	149	147	145	144	142
28	147	145	143	141	139
30	147	145	143	141	140
35	151	149	147	145	143
40-60	157	155	153	151	149

5. Minimum value of coordination distance

If the method for determining d_1, the coordination distance for propagation mode (1), leads to a result less than 100 km, d_1 shall be taken equal to 100 km. Similarly, 100 km shall also be the minimum coordination distance for propagation mode (2), measured from the earth station on any azimuth on which the method for determining the hydrometeor scatter distance identifies a point that lies closer to the earth station than 100 km.

6. The coordination contour

On any azimuth, the greater of the coordination distances d_1 or d_2 is the coordination distance to be used for the construction of the coordination contour. However, in order to facilitate the decision whether either mode of propagation might be ignored in determining if a given terrestrial station class needs to be considered to be affected, that part of the contour of propagation mode (1) lying within the propagation mode (2) area, and that part of the propagation mode (2) contour lying within the propagation mode (1) area may be shown as dashed contours.

An example of a coordination contour is shown in Fig. 1.

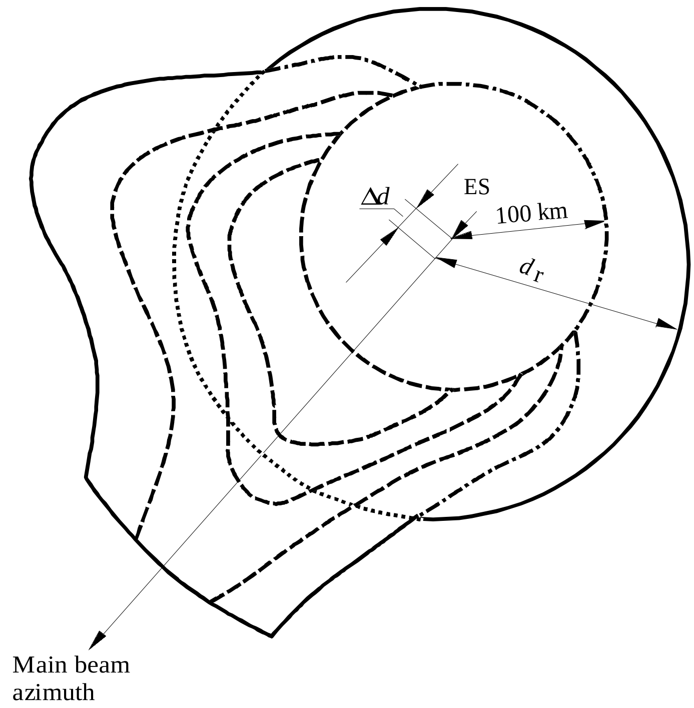
7. Use of computer

Based on the process described above, the coordination contour and auxiliary or supplementary contours could be generated and, where desirable, directly plotted on a map by computer.

The ITU-R Digitized World Map (IDWM) and the software to extract information from it as well as the software to calculate coordination areas according to the Radio Regulations, the Technical Standards and the Rules of Procedure of the ITU-R, are available to administrations. Under the provisions of Article 11 of the Radio Regulations, an administration, and in particular an administration of a country in need of special assistance, can request the BR to calculate and document the coordination area. In addition, a few administrations have submitted to the ITU computer programs which, besides calculating the coordination area and the auxiliary or supplementary contours, also perform some post-processing, such as culling of a set of fixed stations against the contour.

FIGURE 1

Example of a coordination contour for an earth station operating with a geostationary satellite



ES: earth station

Δd: see Appendix 2 to Annex 1, equation (48)

Coordination contour

Contour for propagation mode (1)

Contour for propagation mode (2)

Auxiliary contours for propagation mode (1)

Note 1 – If by using the auxiliary contours it is seen that a terrestrial station can be eliminated with respect to propagation mode (1) then:

– if that terrestrial station is outside the contour for propagation mode (2) it may be eliminated from any further consideration;

– if that terrestrial station is within the contour for propagation mode (2) it must still be considered, but for this mode only;

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8. Operational considerations at frequencies above 10 GHz

At frequencies above 10 GHz rain attenuation will weaken the received signals at earth or space stations for small percentages of the time, increasingly so with increasing frequencies.

Where power margins in the up or down links are insufficient to maintain the required continuity of service, it may be necessary to use site diversity or power control, or both.

When power control is used in the up link to combat rain attenuation on the Earth-to-space path, the increased power will tend to produce greater potential interference to terrestrial systems towards which the attenuation may not have increased. It may therefore be necessary to determine coordination contours taking into account the maximum powers that may be radiated and the percentages of the time during which given levels of power control may have to be exercised. It is understood that the maximum power which may be emitted by a transmitting earth station should be used to determine the coordination area. However, the transmit power will be increased only when rain attenuation exceeds a specified value. Thus, the increased power will not contribute to the interference due to ducting which is a clear sky phenomenon. Therefore, the maximum available transmitting power used to determine the coordination area for propagation mode (1) should be different from that for propagation mode (2). In fact, for propagation mode (1), it seems appropriate to use the maximum transmitting power emitted under clear sky conditions as the maximum available transmitting power.

When site diversity is used to combat attenuation, coordination contours will have to be determined for both sites. Since precipitation is the mechanism largely responsible for attenuation, each of the two sites will be operated, generally, only up to a given attenuation, i.e., to a given rainfall rate, after which the operation is transferred to the other site. As a consequence, rain-scatter coordination distances need to be determined only for those rain rates at which switching to the other site is undertaken. Since the switching rain rates will be substantially lower than the maximum rain rates for the percentage of the time for which continuity of service must be maintained, the rain-scatter coordination areas for the two sites may be significantly smaller than that for a single non-diversity site. It is worth noting that this advantage may accrue to both a transmitting and a receiving earth station.

9. Mobile (except aeronautical mobile) earth stations

For the purpose of establishing whether coordination for a mobile (except an aeronautical mobile) earth station is required, it is necessary to determine the coordination area which would encompass all coordination areas determined for each location within the service area within which operation of the mobile earth stations is proposed.

The preceding method may be used for this purpose by determining the appropriate individual coordination contours for a sufficiently large number of locations within and on the periphery of the proposed service area and by determining from those a composite coordination area which contains all possible individual coordination areas.

In the determination of the coordination area for a geographic area that is to contain mobile earth stations, it is generally only necessary to select a few points on the periphery of the geographical area and construct an envelope of the resulting point coordination contours by straight lines on the map used. The straight line envelope constitutes the effective coordination contour.

10. Transportable earth stations

If a transportable earth station is to be operated on an area basis, the method for mobile (except aeronautical mobile) earth stations described above applies for the determination of the coordination area of the transportable earth station.

11. Revision of propagation data

The material contained in this Annex is based, directly or indirectly, on propagation data compiled, interpreted and documented in other ITU-R texts. This material is given in a form similar to Appendix 28 to the Radio Regulations which is subject to revision pursuant to Resolution No. 60 of the WARC-79. Knowledge regarding propagation is subject to change as new and more reliable data become available, and such change may require or strongly suggest corresponding amendments to the propagation-related material in this Annex based on the findings of the ITU-R.

APPENDIX 1

TO ANNEX 1

Antenna gain in the direction of the earth-station horizon for geostationary satellites

1. General

The gain component of the earth-station antenna in the direction of the physical horizon around an earth station is a function of the angular separation between the antenna main beam axis and the horizon in the direction under consideration. When the earth station is used to transmit to more than one space station along the geostationary orbit, or to one or more space stations in slightly inclined orbits, all possible pointing directions of the antenna main beam axis must be considered. For earth-station coordination, knowledge of $\varphi(\alpha)$, the minimum possible value of the angular separation that will occur during the operation of the space station, is required for each azimuth.

When a geostationary satellite maintains its location close to its nominal orbital position, its elevation ε, and azimuth α, as seen from an earth station at a latitude ζ are uniquely related. Figure 2 shows the possible location arcs of positions on the geostationary orbit in a rectangular azimuth/elevation plot. It shows arcs corresponding to a set of earth-station latitudes and the intersecting arcs correspond to points on the orbit with a fixed difference in longitude East or West of the earth station. Figure 2 also shows a portion of the horizon profile $\varepsilon(\alpha)$. The off-beam angle $\varphi(\alpha)$ between the horizon profile at an azimuth of 190° and a space station located 28° W of an earth station at 43° N latitude is indicated by the great-circle arc shown dashed on Fig. 2.

When the North-South station-keeping of a geostationary satellite is relaxed, the orbit of the satellite becomes inclined with an inclination that increases gradually with time. As viewed from the Earth, the position of the satellite traces a figure eight during each 24-hour period. Figure 3 shows the trajectories of a set of satellites, each with 10° inclination, spaced by 3° along the geostationary orbit from 28° W to 44° E of an earth station at 43° N longitude. For purposes of coordination area determination, only a bounding envelope of these trajectories needs to be considered. A simple bounding envelope based on the maximum excursions in latitude and longitude of the sub-satellite points of satellites at all possible positions along the arc, as shown in Fig. 3, may be used. Figure 3 also shows, with a dashed curve, the great-circle arc corresponding to the minimum off-beam angle $\varphi(\alpha)$ between this envelope and the horizon profile at an azimuth of 110°.

The bounding curve used to determine the minimum off-beam angle should be based on the maximum orbital inclination which will be allowed during the operational life of the space stations on this portion of the geostationary orbit. The use of the bounding envelope simplifies the calculation of the minimum off-beam angle. It does not require the specific values of the space station locations on the arc. Not all of these may be known beforehand, and some space stations may require repositioning at a later time.

2. Determination of $\varphi(\alpha)$

For the determination of $\varphi(\alpha)$, four cases may be distinguished. These depend on whether a single space station or a portion of the geostationary orbit is to be considered, and whether or not the earth station will operate with space stations in slightly inclined orbits. The following equations may be used in all of these cases:

$$\psi_s(i, \delta) = \arc\cos(\sin\zeta \sin i + \cos\zeta \cos i \cos\delta) \tag{19}$$

$$\varepsilon_s(i, \delta) = \arcsin\left[\frac{K\cos\psi_s(i, \delta) - 1}{(1 + K^2 - 2K\cos\psi_s(i, \delta))^{1/2}}\right] \tag{20}$$

$$\alpha'_s(i, \delta) = \arccos\left[\frac{\sin i - \cos\psi_s \sin\zeta}{\sin\psi_s \cos\zeta}\right] \tag{21}$$

$$\alpha_s(i, \delta) = \alpha'_s(i, \delta) \qquad \text{for space stations located East of the earth station } (\delta \geq 0) \tag{22}$$

$$\alpha_s(i, \delta) = 360° - \alpha'_s(i, \delta) \qquad \text{for space stations located West of the earth station } (\delta \leq 0) \tag{23}$$

$$\varphi(\alpha, i, \delta) = \text{arc cos}\,[\cos \varepsilon(\alpha) \cos \varepsilon_s(i, \delta) \cos(\alpha - \alpha_s(i, \delta)) + \sin \varepsilon(\alpha) \sin \varepsilon_s(i, \delta)] \tag{24}$$

where:

- ζ : latitude of the earth station (positive for North; negative for South)
- δ : difference in longitude from the earth station to the space station
- i : latitude of the sub-satellite point (positive for North; negative for South)
- $\psi_s(i, \delta)$: great-circle arc between the earth station and the sub-satellite point
- $\alpha_s(i, \delta)$: space station azimuth as seen from the earth station
- $\varepsilon_s(i, \delta)$: space station elevation angle as seen from the earth station
- $\varphi(\alpha, i, \delta)$: angle between the main beam and the horizon direction corresponding to the pertinent angle, α, when the main beam is steered towards a space station with a sub-satellite point at latitude i and longitude difference δ
- α : azimuth of the pertinent direction
- ε : elevation angle of the horizon in the pertinent azimuth, α
- $\varphi(\alpha)$: angle to be used for horizon gain calculation at the pertinent azimuth, α
- K : orbit radius/Earth radius, assumed to be 6.62.

All arcs mentioned above are in degrees.

Case 1: Single space station, no orbital inclination

For a single space station operating with no orbital inclination at an orbital position with difference in longitude δ_0, equations (19) to (24) may be applied directly, using $i = 0$, to determine $\varphi(\alpha)$ for each azimuth α. Thus:

$$\varphi(\alpha) = \varphi(\alpha, 0, \delta_0) \tag{25}$$

where:

- δ_0 : longitude difference from the earth station to the space station.

Case 2: Space stations on a portion of the geostationary orbital arc, no orbital inclination

For space stations operating with no orbital inclination on a portion of the geostationary orbital arc, equations (19) to (24) may be applied directly, using $i = 0$ to develop the minimum value of off-axis angle. For each azimuth α, the angle $\varphi(\alpha)$ is the minimum value of $\varphi(\alpha, 0, \delta)$ for any position along the arc. Thus:

$$\varphi(\alpha) = \min_{\delta_w \leq \delta \leq \delta_e} \varphi(\alpha, 0, \delta) \tag{26}$$

where:

- δ_e : difference in longitude at the eastern extreme of the operational portion of the orbital arc
- δ_w : difference in longitude at the western extreme of the operational portion of the orbital arc.

FIGURE 2

Position arcs of geostationary satellites with horizon and the arc from the horizon at azimuth 190° to a satellite 28° W of an earth station at 43° N latitude

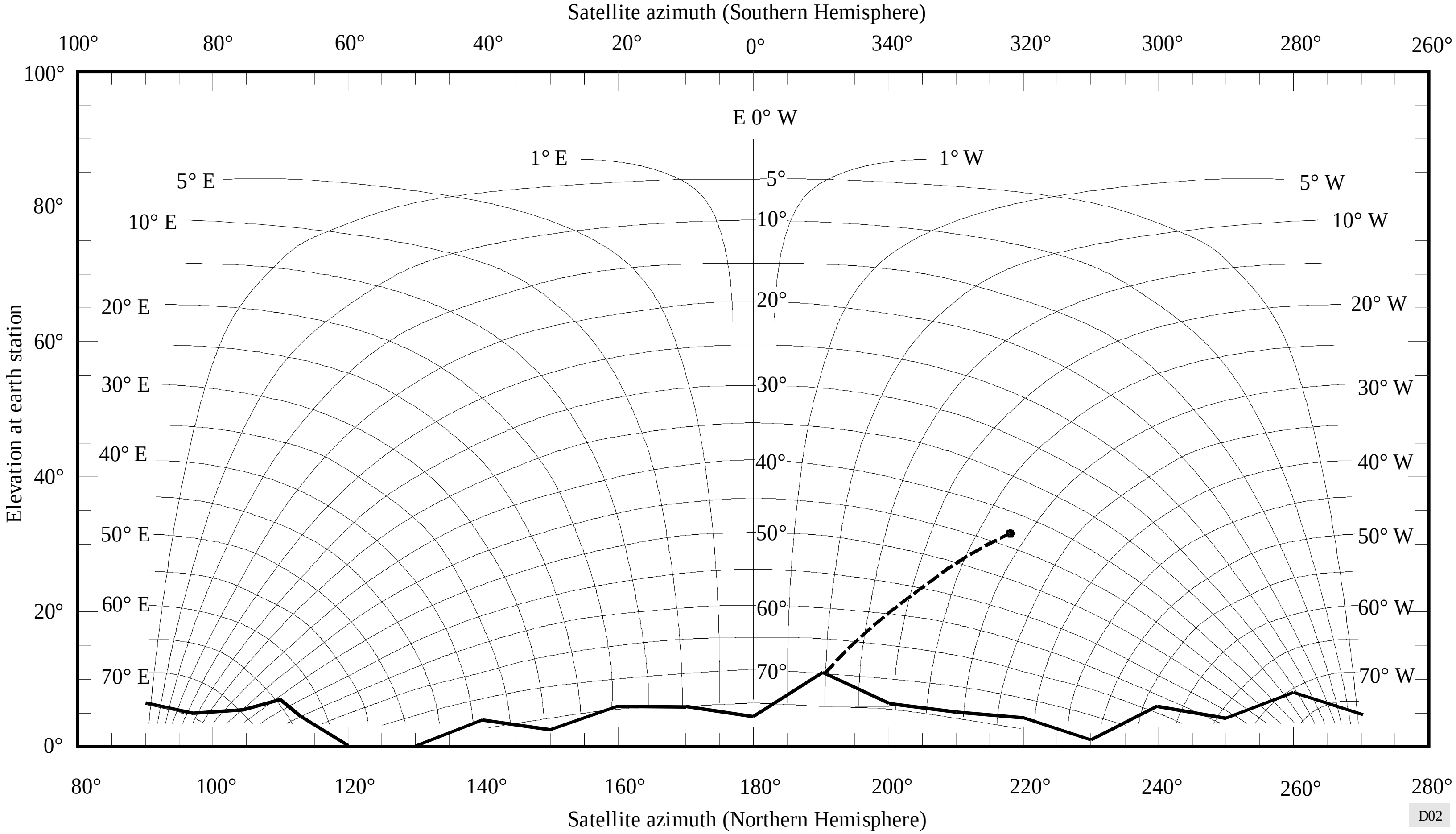
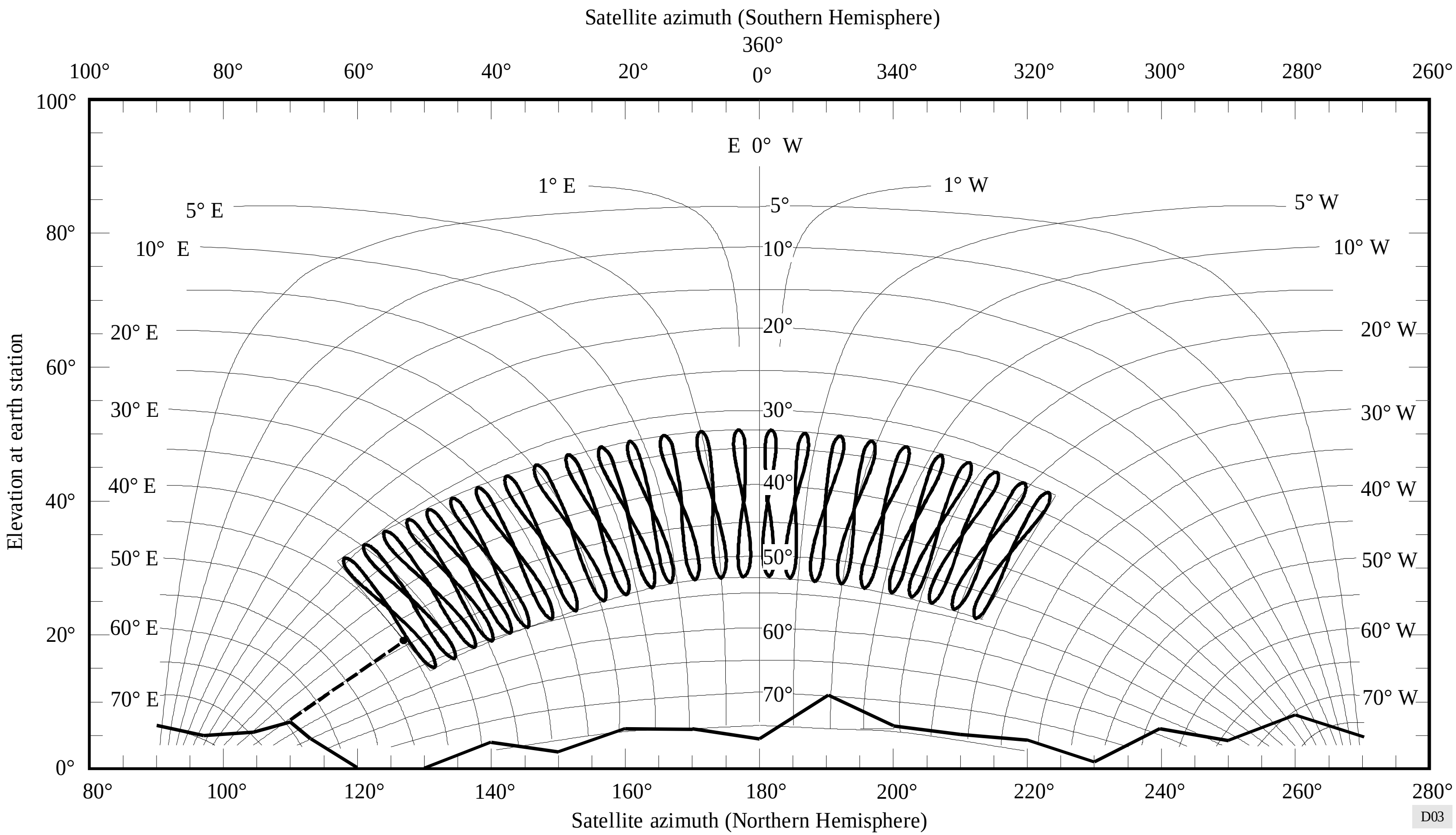


FIGURE 3

Position arcs of geostationary satellites with horizon and the arc from the horizon at azimuth 110° to the envelope of satellites with 10° inclination on the geostationary orbital arc from 28° W to 44° E of an earth station at 43° N latitude



Case 3: Space stations on a portion of the geostationary orbital arc, with orbital inclination

For space stations operating in slightly inclined orbits on a portion of the geostationary arc with nominal longitude difference between δ_e, and δ_w, the maximum orbital inclination over their lifetimes, i_s, must be considered. Equations (19) to (24) may be applied to develop the minimum off-axis angle to each of four arcs in azimuth/elevation space that bound the trajectory of the space station in angle and elevation. The bounding arcs correspond to the maximum and minimum latitudes of the sub-satellite points and the extremes of the difference in longitude between the earth and space stations when the space station is operating at its maximum inclination. Thus:

$$\varphi(\alpha) = \min_{n = 1 \text{ to } 4} \varphi_n(\alpha) \tag{27}$$

with:

$$\varphi_1(\alpha) = \min_{\delta_w - \delta_s \le \delta \le \delta_e + \delta_s} \varphi(\alpha, -i_s, \delta) \tag{28}$$

$$\varphi_2(\alpha) = \min_{\delta_w - \delta_s \le \delta \le \delta_e + \delta_s} \varphi(\alpha, i_s, \delta) \tag{29}$$

$$\varphi_3(\alpha) = \min_{-i_s \le i \le i_s} \varphi(\alpha, i, \delta_w - \delta_s) \tag{30}$$

$$\varphi_4(\alpha) = \min_{-i_s \le i \le i_s} \varphi(\alpha, i, \delta_e + \delta_s) \tag{31}$$

$$\delta_s = (i_s / 15)^2 \tag{32}$$

where:

i_s : maximum operational inclination angle of the satellite orbit

δ_s : maximum longitude change from nominal value of the sub-satellite point of a satellite with orbital inclination i_s.

Case 4: Single space station, with inclined orbits

For a single space station, operating at a nominal longitude difference of δ_0, with a maximum orbital inclination of i_s over its lifetime, the determination of $\varphi(\alpha)$ is the same as for Case 3, except that here $\delta_e = \delta_w = \delta_0$.

It should be noted that the determination of the minimum off-axis angles in equations (26), (28), (29), (30) and (31) may be made by taking increments along a bounding contour. The step size in i or δ should be between 0.5° and 1.0° and the end points of the respective ranges should be included in the determination.

Note that the horizon profile $\varepsilon(\alpha)$ used in the determination of $\varphi(\alpha)$ should be specified at increments in azimuth α that should not exceed 5°.

3. Determination of antenna gain

The relationship $\varphi(\alpha)$ may be used to derive a function for the horizon antenna gain, G(dB) as a function of the azimuth α, by using the actual earth-station antenna pattern, or a formula giving a good approximation. For example, in cases where the ratio between the antenna diameter and the wavelength is not less than 35, the following equation should be used:

$$G(\varphi) = \begin{cases} G_{max} - 2.5 \times 10^{-3} \left(\dfrac{D}{\lambda}\varphi\right)^2 & \text{for } 0 < \varphi < \varphi_m \\ G_1 & \text{for } \varphi_m \le \varphi < \varphi_r \\ 29 - 25 \log \varphi & \text{for } \varphi_r \le \varphi < 36° \\ -10 & \text{for } 36° \le \varphi \le 180° \end{cases} \tag{33}$$

where:

$$\left.\begin{array}{ll} D: & \text{antenna diameter} \\ \lambda: & \text{wavelength} \end{array}\right\} \text{expressed in the same unit}$$

G_1 : gain of the first side lobe

$$G_1 = \begin{cases} -1 + 15 \log (D/\lambda) & \text{dBi} \quad \text{for } D/\lambda \geq 100 \\ -21 + 25 \log (D/\lambda) & \text{dBi} \quad \text{for } D/\lambda < 100 \end{cases}$$

$$\varphi_m = \frac{20\,\lambda}{D}\sqrt{G_{max} - G_1} \qquad \text{degrees}$$

$$\varphi_r = \begin{cases} 15.85\,(D/\lambda)^{-0.6} & \text{degrees} \quad \text{for } D/\lambda \geq 100 \\ 100\,(\lambda/D) & \text{degrees} \quad \text{for } D/\lambda < 100 \end{cases}$$

The above patterns may be modified as appropriate to achieve a better representation of the actual antenna pattern.

In cases where D/λ is not given, it may be estimated from the expression:

$$20 \log \frac{D}{\lambda} \approx G_{max} - 7.7$$

where:

G_{max}: main lobe antenna gain (dB).

It should be noted that the above equations may be different from those given in Recommendation ITU-R S.465.

APPENDIX 2

TO ANNEX 1

Calculation of contours for propagation mode (2)

The value of d_r, the distance between the region of maximum scattering and the location of a terrestrial station on the coordination contour for this propagation mode, can be found by an iterative calculation using the algorithm in this Appendix.

The basic equation for transmission loss due to hydrometeor scatter is:

$$\begin{aligned} L_2 = {} & 168 + 20 \log d_r - 20 \log f - 13.2 \log R - G_T + 10 \log A_b \\ & - 10 \log C + \Gamma + H + \beta_o d_o + \beta_v d_v \qquad \text{dB} \end{aligned} \tag{34}$$

Determine the appropriate values for the following parameters:

– R : surface rainfall rate (mm/h) for the time percentage p, given in Appendix 3 for various rain-climatic zones

– k and α, for the appropriate frequency, from Table 6 (for values of k between the frequencies shown use logarithmic interpolation, and for values of α use linear interpolation).

Set:

$G_T = 42 + \Delta G$ dBi (assumed antenna gain for the terrestrial station)

and calculate:

$$\gamma_R = k\, R^{\alpha} \qquad \text{dB} \tag{35}$$

$$d_s = 3.5\, R^{-0.08} \qquad \text{km} \tag{36}$$

$$C = \begin{cases} \dfrac{2.17}{\gamma_R\, d_s}\left(1 - 10^{-\gamma_R\, d_s/5}\right) & \text{dB} \quad \text{for } f > 4 \text{ GHz} \\ 1 & \text{dB} \quad \text{for } f \le 4 \text{ GHz} \end{cases} \tag{37}$$

$$\Gamma = \frac{631\,\gamma_R}{\sqrt{R}}\, 10^{-(R+1)^{0.19}} \qquad \text{dB} \tag{38}$$

$$h_{FR} = \begin{cases} 5 - 0.075\,(\zeta - 23) & \text{km} \quad \text{for} \quad \zeta > 23° & \text{Northern Hemisphere} & (39a) \\ 5 & \text{km} \quad \text{for} \quad 0° \le \zeta \le 23° & \text{Northern Hemisphere} & (39b) \\ 5 & \text{km} \quad \text{for} \quad 0° \ge \zeta \ge -21° & \text{Southern Hemisphere} & (39c) \\ 5 + 0.1\,(\zeta + 21) & \text{km} \quad \text{for} \quad -71° < \zeta \le -21° & \text{Southern Hemisphere} & (39d) \\ 0 & \text{km} \quad \text{for} \quad \zeta \le -71° & \text{Southern Hemisphere} & (39e) \end{cases}$$

where h_{FR} is in km and ζ is the latitude in degrees.

Set:

$$x = 168 - 20 \log f - 13.2 \log R - G_T - 10 \log C + \Gamma - L_2 \tag{40}$$

where:

L_2: available transmission loss (see Annex 1, § 4).

The equation for gaseous specific attenuation, β_o (for oxygen) and β_v (for water vapour), is given in equations (13) and (14). The water vapour specific attenuation β_v is to be calculated for an assumed water vapour density of $\rho = 7.5$ g/m^3.

The maximum hydrometeor scatter distance, d_{m2}, is given by:

$$d_{m2} = \sqrt{17\,000\,(h_{FR} + 3)} \qquad \text{km} \tag{41}$$

The following formulae should then be evaluated to give the basis for the iterative procedure:

$$h_{cv} = \frac{(d_r - 40)^2}{17\,000} \qquad \text{km} \tag{42}$$

$$H = \begin{cases} 6.5(h_{cv} - h_{FR}) & \text{dB} \quad \text{for } h_{cv} > h_{FR} \\ 0 & \text{dB} \quad \text{for } h_{cv} \le h_{FR} \end{cases} \tag{43}$$

$$10 \log A_b = \begin{cases} 0.005\,(f - 10)^{1.7}\, R^{0.4} & \text{dB} \quad \text{for} \begin{Bmatrix} 10 \text{ GHz} < f \le 60 \text{ GHz} \\ \text{and } h_{cv} < h_{FR} \end{Bmatrix} \\ 0 & \text{dB} \quad \text{for} \begin{Bmatrix} f \le 10 \text{ GHz} \\ \text{or } h_{cv} \ge h_{FR} \end{Bmatrix} \end{cases} \tag{44}$$

$$d_o = \begin{cases} 0.7\, d_r + 32 & \text{km} \quad \text{for } d_r < 340 \text{ km} \\ 270 & \text{km} \quad \text{for } d_r \ge 340 \text{ km} \end{cases} \tag{45}$$

$$d_v = \begin{cases} 0.7\, d_r + 32 & \text{km} \quad \text{for } d_r < 240 \text{ km} \\ 200 & \text{km} \quad \text{for } d_r \ge 240 \text{ km} \end{cases} \tag{46}$$

$$Y = x + 20 \log d_r + 10 \log A_b + H + \beta_o\, d_o + \beta_v\, d_v \qquad \text{dB} \tag{47}$$

The required value of d_r is that which gives $Y = 0$.

TABLE 6

Values of *k* and α as a function of the frequency

Frequency (GHz)	k	α
1	0.000 0352	0.880
2	0.000 138	0.923
4	0.000 591	1.075
6	0.001 55	1.265
7	0.002 65	1.312
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

Note 1 – Y is a monotonically increasing function of d_r. It is therefore possible to use a simple method of iteration, e.g. bisection.

In summary, the value of d_r may be found as follows:

Calculate Y for $d_r = 100$ km, $Y(100 \text{ km})$

If $Y(100 \text{ km}) \geq 0$ then use $d_r = 100$ km for coordination

Or else, calculate Y for $d_r = d_{m2}$, $Y(d_{m2})$

If $Y(d_{m2}) \leq 0$ then use $d_r = d_{m2}$ for coordination

If neither of these values of d_r can be used for coordination then find the appropriate value of d_r using equations (42) to (47) in an iterative process. Initial boundary values are $d_r = 100$ km and $d_r = d_{m2}$.

The rain-scatter coordination contour is determined as a circle having as radius the smaller of the two distances d_r and d_{m2}, designated Min$[d_r, d_{m2}]$, and centred on a point which is offset from the earth station along the main beam azimuth to the satellite by the distance Δd (km) to be obtained from:

$$\Delta d = \frac{\left(\text{Min}\,[d_r, d_{m2}] - 40 \right)^2 \cot \varepsilon_s}{17\,000} \qquad \text{km}^* \qquad (48)$$

where ε_s is the elevation angle to the satellite (degrees).

The distance from the earth station to this circle or 100 km, also measured from the earth station, whichever is the greater, is the rain-scatter coordination distance d_2.

For an earth station operating with a geostationary satellite having a slightly inclined orbit, the rain-scatter coordination contour for each of the satellite's two most inclined orbit positions should be determined individually, using the relevant elevation angles and their associated azimuths to the satellite. The rain scatter area is then the total area contained within the two resulting overlapping coordination contours.

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* Where, exceptionally, operating elevation angles to a satellite are smaller than 3°, Δd should be determined from:

$$\Delta d = \text{Min}\,[d_r - 40, (d_r - 40)^2 \cot \varepsilon_s / 17\,000].$$

For an earth station intended to operate with satellites at various orbit locations, the rain-scatter coordination contours for the easternmost and for the westernmost orbit location should be determined individually. The rain-scatter area is then the total area contained within the two resulting overlapping coordination contours.

APPENDIX 3

TO ANNEX 1

Classification of rain climates

As shown in Figs. 4, 5 and 6, the world has been divided into a number of rain climatic zones which show different precipitation characteristics. The curves shown in Fig. 7 represent consolidated rain-rate distributions, each applicable to several of the rain climates of Figs. 4 to 6. The distribution of Fig. 7 should be extended beyond 0.3% to such greater percentages of the time p_c at which the rainfall rate is assumed to approach zero, using the expression:

$$R(p) = R(0.3\%) \left[\frac{\log(p_c / p)}{\log(p_c / 0.3)} \right]^2 \quad \text{mm/h} \qquad (49)$$

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.

The rain-rate distributions of Fig. 7 are approximated numerically by the following expressions:

Climates A, B

$$R = 1.1\, p^{-0.465} + 0.25 \left[\log(p / 0.001) \log^3(0.3 / p)\right] - \left[\,\left|\log(p / 0.1)\right| + 1.1\right]^{-2} \quad \text{mm/h} \qquad (50)$$

Climates C, D, E

$$R = 2\, p^{-0.466} + 0.5 \left[\log(p / 0.001) \log^3(0.3 / p)\right] \quad \text{mm/h} \qquad (51)$$

Climates F, G, H, J, K

$$R = 4.17\, p^{-0.418} + 1.6 \left[\log(p / 0.001) \log^3(0.3 / p)\right] \quad \text{mm/h} \qquad (52)$$

Climates L, M

$$R = 4.9\, p^{-0.48} + 6.5 \left[\log(p / 0.001) \log^2(0.3 / p)\right] \quad \text{mm/h} \qquad (53)$$

Climates N, P, Q

$$R = 15.6 \left(p^{-0.383} + \left[\log(p / 0.001) \log^{1.5}(0.3 / p)\right] \right) \quad \text{mm/h} \qquad (54)$$

for the range $0.001 \le p \le 0.3\%$.

FIGURE 4

Rain climatic zones (see Table 7)

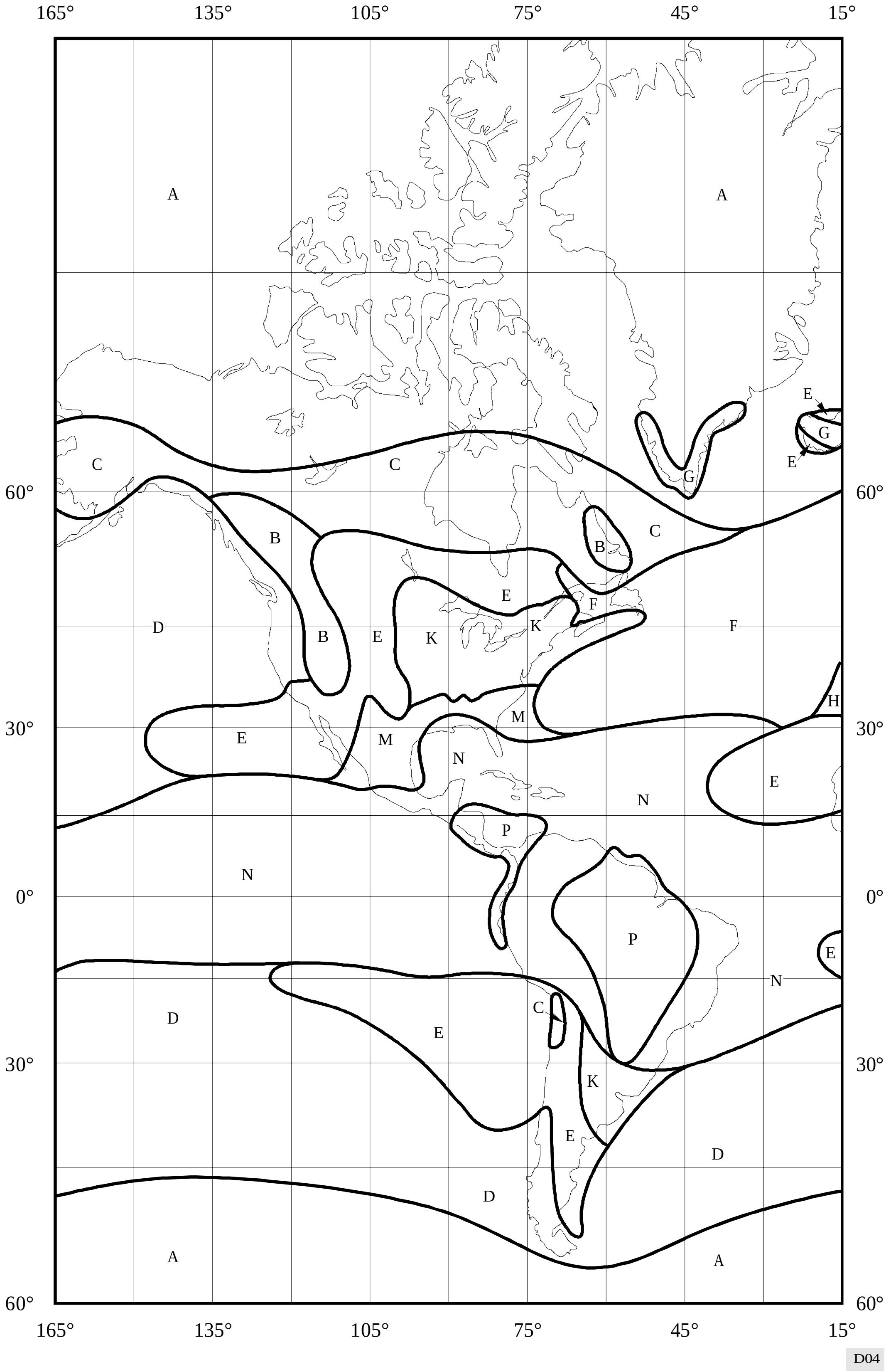

FIGURE 5

Rain climatic zones (see Table 7)

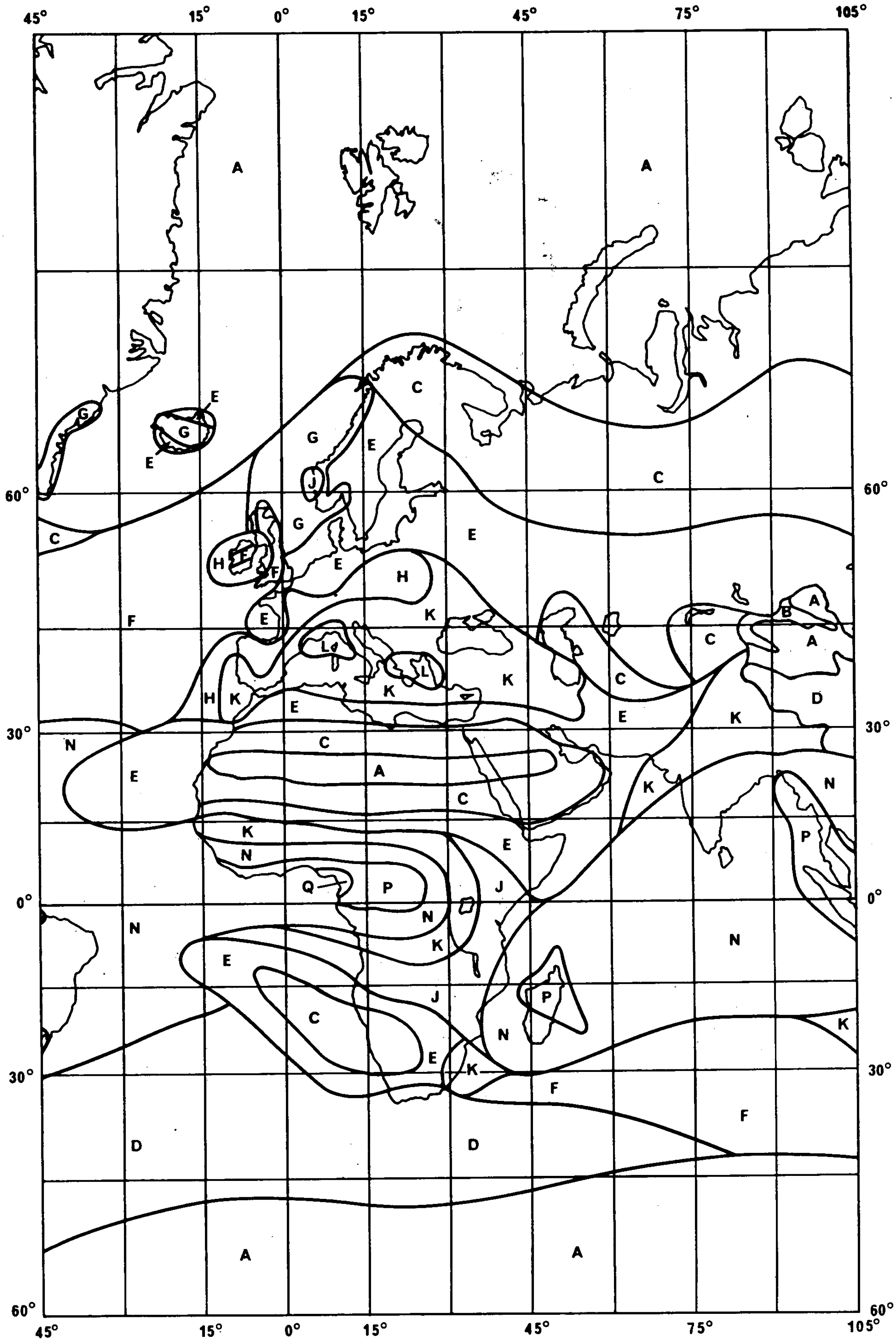

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FIGURE 6

Rain climatic zones (see Table 7)

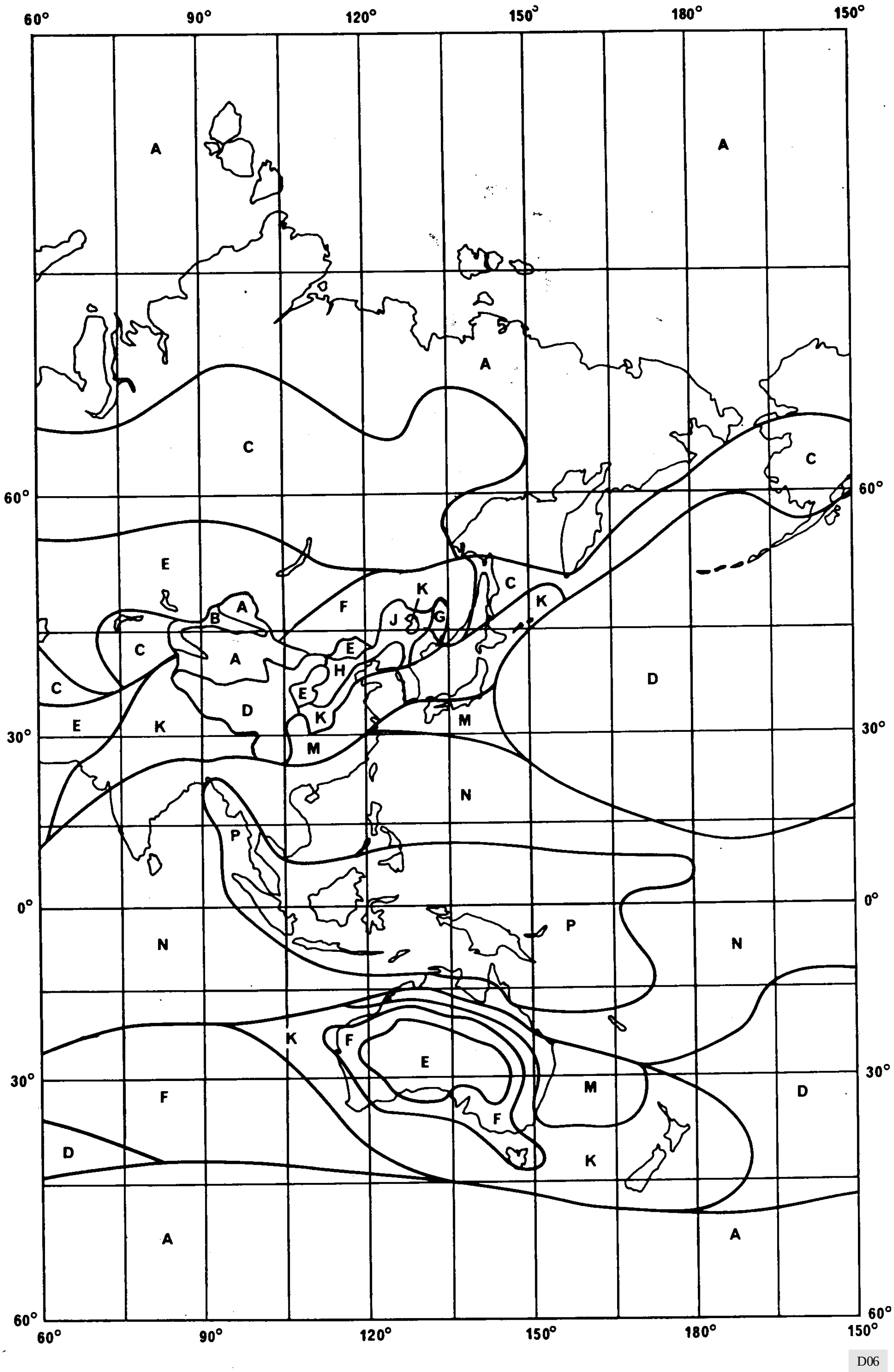

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TABLE 7

Rain climatic zones

Rainfall intensity exceeded (mm/h) (Reference to Figs. 4 to 6)

Percentage of time (%)	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q
1.0	< 0.1	0.5	0.7	2.1	0.6	1.7	3	2	8	1.5	2	4	5	12	24
0.3	0.5	2.0	2.8	4.5	2.4	4.5	7	4	13	4.2	7	11	15	34	49
0.1	2	3	5	8	6	8	12	10	20	13	15	22	35	65	72
0.03	5	6	9	13	12	15	20	18	23	23	33	40	65	105	96
0.01	8	12	15	19	23	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250	170

FIGURE 7

Consolidated cumulative distributions of rainfall rate for the rain climatic zones of Figs. 4 to 6