INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392 - I

SMR.379/42

COURSE ON BASIC TELECOMMUNICATIONS SCIENCE

9 January - 3 February 1989

"RADIO REGULATIONS" (APPENDICES 28&29)

R.G.STRUZAK
CCIR-UIT
2.Rue de Varembe
Geneva 1211
SWITZERLAND

APPENDIX 28

Method for the Determination of the Coordination Area Around an Earth Station in Frequency Bands Between 1 GHz and 40 GHz Shared Between Space and Terrestrial Radiocommunication Services

1. *Objectives*

The coordination area (see No. 165) is determined by calculating, in all directions of azimuth from the earth station, the coordination distances (see No. 167) and drawing to scale on an appropriate map the coordination contour (see No. 166).

It must be emphasized that the presence or installation of a terrestrial station within the coordination area of an earth station would not necessarily preclude the successful operation of either the earth station or that terrestrial station, since the method is based on the most unfavourable case assumptions as regards interference.

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

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

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

Where an earth station is intended to transmit 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 services.

Where an earth station is intended 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 services, except in the case where the administration responsible for the earth station determines that a smaller coordination contour would adequately protect all the transmissions intended to be received by the earth station. When the determination of such a smaller coordination contour is based on a departure from the procedure of this Appendix, the notifying administration shall indicate, in detail, the nature of such departure.

If subsequently an administration decides to protect its receiving earth station through notification of a coordination contour which is greater than the one it had notified under a departure from the method of this Appendix, it must recoordinate the earth station. Any resulting greater protection shall be effective from the date of publication of the notice in Part II of the IFRB weekly circular.

This Appendix provides methods which are suitable for either graphical or computer determination of the coordination area.

It is suggested to draw, together with the coordination contour, auxiliary contours based on less unfavourable assumptions than those chosen for the determination of the coordination contour. These auxiliary contours may be used during subsequent negotiations between the administrations concerned with a view to eliminating from the discussions (without the need for more precise calculations) the case of certain existing or planned stations located within the coordination area. The determination and use of these auxiliary contours is explained in Annex 1 to this Appendix.

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 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 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 (dB) for p% of the time, a value which must be exceeded by the predicted transmission loss for $(100 - p)$% of the time.

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

where:

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

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

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

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

For the small percentages of the time which are of interest here, it is necessary to distinguish between two significantly different attenuation mechanisms:

- attenuation of signals subject to tropospheric propagation via near-great circle paths; mode (1) see § 3;
- attenuation of signals subject to scatter due to hydrometeors; mode (2) see § 4.

2.2 *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 antennae) and the effective antenna gains at either end of an interference path. The minimum permissible basic transmission loss may then be expressed as:

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

where:

$L_b(p)$: minimum permissible basic transmission loss (dB) for p% of the time; this value must be exceeded by the predicted basic transmission loss for $(100 - p)$% 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 the azimuth considered; in the case of a terrestrial station, the maximum 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 the azimuth considered; in the case of a terrestrial station, the maximum antenna gain is to be used.

Annex II provides numerical and graphical methods to determine the angle between the earth station antenna main beam and the physical horizon, and also the horizon antenna gain, as functions of azimuth angle.

When considering non-geostationary satellites, G_r or G_t (whichever pertains to the earth station antenna) is variable with time. In such cases, an equivalent time-invariant earth station antenna gain is to be used*. This equivalent gain is either 10 dB less than the maximum horizon antenna gain or is that value of horizon antenna gain exceeded for no more than 10% of the time (if available), whichever is the greater.

2.3 *Derivation and tabulation of interference parameters*

2.3.1 *Permissible level of the interfering emission*

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

$$P_r(p) = 10 \log (kT_r B) + J + M(p) - W \quad (3)$$

where:

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

with:

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

T_r: thermal noise temperature of the receiving system (K), at the output of the receiving antenna (see *Note 1*);

B: reference bandwidth (Hz) (bandwidth of the interfered-with system over which the power of the interfering emission can be averaged);

J: ratio (dB) of the permissible long term (20% of the time) interfering emission power to the thermal noise power of the receiving system, referred to the output terminals of the receiving antenna (see *Note 2*);

* This equivalent antenna gain is not to be used when the earth station antenna points in the same direction for appreciable periods of time (e.g. when working to space probes or to satellites which are almost geostationary).

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

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

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

$M_0(p_0)$: ratio (dB) between the permissible powers of the interfering emission, during p_0% and 20% of the time, respectively, for all entries of interference (see *Note 3*);

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

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

Tables I and II list values for the above parameters.

In certain cases, an administration may have reason to believe that, for its specific earth station, a departure from the values associated with the earth station, as listed in Table II, may be justified. Attention is drawn to the fact that for specific systems the bandwidths B or, as for instance in the case of demand assignment systems, the percentages of the time p and p_0 may have to be changed from the values given in Table II. For further information see § 2.3.2.

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

$$T_r = T_a + (e - 1)\,290 + eT_r \quad (5a)$$

where:

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

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

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

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

Note 2: The factor J (dB) is defined as the ratio of total permissible long term (20% of the time) power of interfering emissions in the system, to the long term thermal radio frequency noise power in a single receiver. In the computation of this factor, the interfering emission is considered to have a flat power spectral density, its actual spectrum shape being taken into account by the factor W (see below). For example, in a 50-hop terrestrial hypothetical reference circuit, the total allowable additive interference power is 1 000 pW0p (CCIR Recommendation 357-3) and the mean thermal noise power in a single hop may be assumed to be 25 pW0p. Therefore, since in a frequency-division multiplex/frequency modulation (FDM/FM) system the ratio of a flat interfering noise power to the thermal noise power in the same reference band is the same before and after demodulation, J is given by the ratio 1 000/25 expressed in dB, i.e. $J = 16$ dB. In a fixed-satellite service system, the total allowable interference power is also 1 000 pW0p (CCIR Recommendation 356-4), but the thermal noise contribution of the downlink is not likely to exceed 7 000 pW0p, hence $J \geq -8.5$ dB.

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

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

For analogue radio-relay and fixed-satellite systems in bands between 1 GHz and 15 GHz, this is equal to the ratio (dB) between 50 000 and 1 000 pW0p (17 dB).

In the case of digital systems, system performance at frequencies above 10 GHz can, in most areas of the world, usefully be defined as the percentage of the time p_0 for which the wanted signal is allowed to drop below its operating threshold, defined by a given bit error rate. During non-faded operation of the system, the desired signal will exceed its threshold level by some margin M_f which depends on the rain climate in which the station operates. The greater this margin, the greater the enhancement of the interfering emission which would

degrade the system to threshold performance. As a first order estimate it may be assumed that, for small percentages of the time (of the order of 0.001% to 0.003%), the level of interfering emissions may be allowed to equal the thermal noise which exists at the demodulator input during faded conditions. Thus, M_0 in Tables I and II may, for digital systems operating above 10 GHz, be assumed to be equal to the fade margin M_f of the system. For digital radio-relay systems operating below 10 GHz it is assumed that the short term power of an interfering emission can be allowed to exceed the long term power of the interfering emission by an amount equal to the fade margin of the system minus J, i.e. 41 dB, where $J = -6$ dB.

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

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

The factor W depends on the characteristics of the wanted and the interfering signals. To avoid the need for considering a wide range of characteristics, upper limit values were determined for the factor W. When the wanted signal uses frequency modulation with r.m.s. modulation indices which are greater than unity, W is not higher than 4 dB. In such cases, a conservative figure of 4 dB will be used for the factor W in (3), regardless of the characteristics of the interfering signal. For low-index FDM/FM systems a very small reference bandwidth (4 kHz) implies values of W not greater than 0 dB. In such cases, a conservative figure of 0 dB will be used for W in (3), regardless of the characteristics of the interfering signal.

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

2.3.2 *Coordination parameters for very narrow-band transmissions (receiving earth station)*

2.3.2.1 *General*

In the case of an earth station which receives both broad-band and very narrow-band transmissions (e.g. single channel per carrier (SCPC) transmissions) it may be desirable to draw two separate coordination contours: one for narrow-band transmissions and one for broad-band transmissions, giving the specific sections of frequency bands used for very narrow-band transmissions.

2.3.2.2 *Pre-assigned narrow-band transmissions*

For such transmissions, it is appropriate to change the value of the reference bandwidth to the value of the bandwidth occupied by one such narrow-band transmission.

2.3.2.3 *Demand-assigned narrow-band transmissions*

For such transmissions, in addition, it may be appropriate to take into account the reduced probability that a particular frequency channel will be suffering interference at the time when it is actually selected for use at an earth station.

Administrations shall furnish all relevant technical data used in the determination of the coordination contour(s) for such transmissions.

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 three basic radio-climatic zones termed Zones A, B and C. These zones are defined as follows:

Zone A: Entirely land.

Zone B: Seas, oceans and substantial bodies of inland water (as a criterion of a substantial body of water, one which can encompass a circle of diameter 100 km) at latitudes greater than 23° 30′ N or S, but excepting the Black Sea and the Mediterranean.

Zone C: Seas, oceans and substantial bodies of inland water (as a criterion of a substantial body of water, one which can encompass a circle of diameter 100 km) at latitudes less than 23° 30′ N or S, and the Black Sea and the Mediterranean.

3.2 *Calculation of coordination distance for paths within a single radio-climatic zone*

3.2.1 *General*

Equation (2) provides the value of minimum permissible basic transmission loss $L_b(p)$ for p% of the time. From this minimum permissible basic transmission loss, the coordination distance in each radio-climatic zone is derived using either of two alternative methods. The first method, described in § 3.2.2, is a numerical method comprising several mathematical equations, and is intended principally for use with the aid of a computer. The second method is a graphical method and is described in § 3.2.3.

Where the distance derived in § 3.2.2 or § 3.2.3 lies entirely within the boundary of the radio-climatic zone appropriate to the earth station, that distance is taken as the actual coordination distance for propagation mode (1). If the distance extends beyond the boundary of one radio-climatic zone, the overall coordination distance is obtained using the method given in § 3.3.

3.2.2 *Numerical method*

The minimum permissible basic transmission loss is related to coordination distance by the following expression:

$$L_b(p) = A_0 + \beta d_1 + A_h \qquad (6)$$

in which:

$A_0 = 120 + 20 \log f$ (dB)

β: rate of attenuation (dB/km);

d_1: coordination distance for propagation mode (1) (km);

A_h: horizon angle correction (dB);

f: frequency (GHz).

A_h is given by:

$$A_h = 20 \log (1 + 4.5 f^{1/2} \varepsilon) + f^{1/3} \varepsilon \quad \text{for } \varepsilon > 0° \qquad (7a)^*$$

$$A_h = 8 \varepsilon \quad \text{for } -0.5° < \varepsilon < 0° \qquad (7b)$$

$$A_h = -4 \quad \text{for } \varepsilon < -0.5° \qquad (7c)$$

* Equation (7a) and thus Fig. 1 should be used with caution at frequencies higher than about 20 GHz or for horizon angles above 5° until further studies have been completed by the CCIR in accordance with Resolution 60.

in which:

ε: horizon angle* (degrees).

From equation (6) the coordination distance d_1 may be found as follows:

$$d_1 = (L_b(p) - A_0 - A_h)/\beta \tag{8}$$

The value of β depends on the radio-climatic zone and the percentage of time p, and is the sum of three components:

$$\beta = \beta_z + \beta_r + \beta_o \tag{9}$$

in which:

- β_z: rate of attentuation (dB/km) due to all effects except atmospheric gases;
- β_r: rate of attenuation (dB/km) due to atmospheric water vapour;
- β_o: rate of attenuation (dB/km) due to oxygen.

β_z depends on the radio-climatic zone, frequency and the percentage of time as follows:

for Zone A,

$$\beta_{zA} = 0.154(1 + 3.05 \log f)^{0.4}(0.9028 + 0.0486 \log p)^2 \tag{10}$$

for Zones B and C,

$$\beta_{zB} = \beta_{zC} = (0.272 + 0.047 \log p)^2 \tag{11}$$

β_r depends on the frequency and the density of water vapour in the air as follows (β_r may be neglected when $f < 15$ GHz):

$$\beta_r = 3.5 \times 10^{-4}\rho\left[\frac{1}{\left(1-\frac{22.3}{f}\right)^2+\frac{9}{f^2}} + \frac{1}{\left(1+\frac{22.3}{f}\right)^2}\right] + 3 \times 10^{-6}\rho f^2 \tag{12}$$

where ρ is the water vapour density (g/m^3), and depends on the radio-climatic zone. The following values are to be used:

Zone A, $\rho = 1$ g/m^3
Zone B, $\rho = 2$ g/m^3
Zone C, $\rho = 5$ g/m^3

β_o depends on the frequency as follows:

$$\beta_o = 68 \times 10^{-4} \times f^2\left\{\frac{1}{(60-f)^2} + \frac{1}{(60+f)^2} + \frac{1}{(f^2+0.36)}\right\} \tag{13}$$

* 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.

Thus the coordination distance in Zone A is derived for the appropriate frequency, percentage of time and horizon angle using equations (7), (8), (9), (10), (12) and (13). Similarly, the coordination distance in Zone B or C is derived using equations (7), (8), (9), (11), (12) and (13).

3.2.3 *Graphical method*

The equations given in § 3.2.2 have been converted into graphical form, to provide a second method of obtaining coordination distance for propagation mode (1). It is emphasized that the procedure described in this Section is an alternative to that described in § 3.2.2 and each administration should use the method which is considered most convenient.

The minimum permissible basic transmission loss $L_b(p)$ is obtained from equation (2). The "coordination loss" L_1 is obtained from the minimum permissible basic transmission loss by subtraction of the horizon angle correction A_h:

$$L_1 = L_b(p) - A_h \tag{14}$$

Values for the horizon angle correction are obtained from Fig. 1 for the appropriate frequency and horizon angle*.

The coordination distance in each radio-climatic zone is to be obtained as follows. Taking Zone A first, the coordination distance for 0.01% of the time d_A (0.01) is obtained with the appropriate value of coordination loss L_1 and frequency from Fig. 2. The Zone A coordination distance for p% of the time is then obtained by multiplying the distance for 0.01% of the time by the factor Δp_A given in Fig. 3.

$$d_A = d_A(0.01) \times \Delta p_A \tag{15}$$

In a similar manner, the coordination distance in Zone B is obtained using values for $d_B(0.01)$ and Δp_{BC} obtained from Figs. 4 and 3 respectively. The coordination distance in Zone C is obtained using values for $d_C(0.01)$ and Δp_{BC} obtained from Figs. 5 and 3 respectively.

* 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.

3.3 *Mixed paths*

If the distance being calculated extends through more than one radio-climatic zone (mixed path), the prediction is made as follows:

Designating the successive path sections in different zones by use of the suffixes i, j, k . . ., it follows that:

$$L_b(p) - A_0 - A_h = \beta_i \, d_i \qquad (16)$$

where β_i is the rate of attenuation in the first zone (i).

Now, in the direction considered, if the value d_i is greater than the distance D_i in the first zone (i), it follows that:

$$L_b(p) - A_0 - A_h - \beta_i \, D_i = \beta_j \, d_j \qquad (17)$$

and so d_j is found. If the value d_j is greater than the distance D_j of the path in the second zone (j), it can then be stated that:

$$L_b(p) - A_0 - A_h - \beta_i \, D_i - \beta_j \, D_j = \beta_k \, d_k \qquad (18)$$

from which d_k may be found. This method may be extended as necessary, and in the case given the total distance d_1 may now be expressed as:

$$d_1 = D_i + D_j + d_k \quad \text{(km)} \qquad (19)$$

Annex III provides examples for the graphical application of this procedure.

3.4 *Maximum coordination distance for propagation mode (1)*

In the process of determining the coordination distance for propagation mode (1), if values result which exceed the appropriate value given in Fig. 6 or in Table III, the coordination distance for propagation mode (1) shall be the value given in Fig. 6 or in Table III. In the case of mixed paths, the values to be considered are those given for Zones B or C, as appropriate. In the case of mixed paths with more than one segment in Zone A, the total distance in Zone A shall not exceed the value given in Fig. 6 or in Table III for Zone A.

4. *Determination of the coordination contour for propagation mode (2) — Scattering from hydrometeors*

The determination of the coordination contour for scattering from hydrometeors (rain-scatter) is predicated 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.

4.1 *Normalized transmission loss L_2 (0.01)*

To determine the coordination contour associated with rain-scatter it is necessary to calculate a "normalized transmission loss", given by:

$$L_2(0.01) = P_{t'} + \Delta G - P_r(p) - F(p, f) \qquad (20)$$

where:

- ΔG: difference (dB) between the maximum gain of terrestrial station antennae in the frequency band under investigation and the value of 42 dB. When the earth station is a transmitting station, the values shown in Table I should be used; when it is a receiving station, the values shown in Table II should be used;
- $F(p, f)$: correction (dB) to relate the effective percentage of the time p to 0.01% in the frequency band under consideration (see Fig. 7).

All other parameters have been defined in § 2. For terrestrial stations, values of $P_{t'}$ are listed in Table II.

4.2 *Rain-climatic zones*

The world has been divided into five basic rain-climatic zones numbered 1 to 5 as shown in Fig. 8. The climatic characteristics of these zones for 0.01% of the time are given in Table IV.

4.3 *Calculation of the rain-scatter distance d_r*

4.3.1 *Numerical method*

The normalized transmission loss is composed of six terms:

$$L_2(0.01) = A_1 - A_2 + A_3 - A_4 - A_5 + A_6 \qquad (21)$$

in which:

$$A_1 = 157 + 20 \log d_r - 20 \log f \text{(dB)} \qquad (22)$$

where d_r is the rain-scatter distance (km).

$$A_2 = 26 + 14 \log R - 5.88 \times 10^{-5} (d_r - 40)^2 \text{(dB)} \qquad (23)$$

where R is the surface rainfall rate in mm/h (Table IV). The horizon distance of the terrestrial station is taken to be 40 km.

$$A_3 = 0.005\,(f - 10)^{1.7}\, R^{0.4}\ \text{(dB)} \qquad \text{for } 10 < f < 40\ \text{GHz} \qquad (24a)$$

$$= 0\ \text{(dB)} \qquad \text{for } f \leqslant 10\ \text{GHz} \qquad (24b)$$

$$A_4 = 10 \log \left[\frac{2.17}{\gamma \cdot D} \left(1 - 10^{-(\gamma \cdot D)/5}\right) \right] \text{(dB)} \qquad \text{for } f > 5\ \text{GHz} \qquad (25a)$$

$$= 0\ \text{(dB)} \qquad \text{for } f \leqslant 5\ \text{GHz} \qquad (25b)$$

where D is the diameter of the rain cell in km (Table IV)

and

$$\gamma = 0.008\, R\, (f - 5) \qquad \text{for } f > 5\ \text{GHz} \qquad (26a)$$

$$= 0 \qquad \text{for } f \leqslant 5\ \text{GHz} \qquad (26b)$$

$$A_5 = 10 \log D\ \text{(dB)} \qquad (27)$$

$$A_6 = d_o\, \beta_o + d_v\, \beta_v \qquad (28)$$

where:

$$d_o = 0.7\, d_r + 32\ \text{km} \qquad \text{for } d_r < 340\ \text{km} \qquad (29a)$$

$$= 270\ \text{km} \qquad \text{for } d_r \geqslant 340\ \text{km} \qquad (29b)$$

$$d_v = 0.7\, d_r + 32\ \text{km} \qquad \text{for } d_r < 240\ \text{km} \qquad (30a)$$

$$= 200\ \text{km} \qquad \text{for } d_r \geqslant 240\ \text{km} \qquad (30b)$$

β_v is given in (12), where ρ is to be replaced by ρ_w (Table IV).

β_o is given in (13).

Thus, for a given rain-climatic zone the parameters in Table IV are used to calculate the rain-scatter distance d_r by an iterative process.

4.3.2 *Graphical method*

The equations of § 4.3.1 have been converted into graphical form to give an alternative method of determining rain-scatter distance d_r.

To obtain the rain-scatter distance for rain-climatic Zone 1, the normalized transmission loss, obtained by solving equation (20), is used together with the appropriate frequency in Fig. 9 to yield the rain-scatter distance d_r.

Figs. 10 to 13 show corresponding curves for rain-climatic Zones 2 to 5. In all cases, the rain climate to be chosen is that which corresponds to the location of the earth station.

4.4 *Maximum rain-scatter distances*

In the process of determining the rain-scatter distance for propagation mode (2), if values result which exceed the appropriate value given in Table V, the rain-scatter distance d_r for propagation mode (2) shall be the value given in that table.

4.5 *Construction of the rain-scatter coordination contour*

Due to the peculiar geometry associated with rain-scatter propagation, the location of the centre of the rain-scatter coordination contour does not coincide with the location of the earth station. The distance by which these locations are separated is designated Δd.

The rain-scatter distance d_r, together with the elevation angle ε_s of the main beam of the earth station antenna, are used to determine Δd using the equation:

$$\Delta d = 5.88 \times 10^{-5} (d_r - 40)^2 \cot \varepsilon_s \qquad \text{(km)} \qquad (31)$$

Alternatively, Δd may be determined from Fig. 14.

The distance Δd is measured on a map of appropriate scale from the earth station location along the azimuth of the main beam of the earth station antenna; a circle of radius d_r is drawn around the point so reached. The circle is the rain-scatter coordination contour.

The rain-scatter coordination distance, to be labelled d_2, is the distance from the earth station site to the rain-scatter coordination contour on the azimuth under consideration.

4.6 *Absence of mixed path effects*

As the only significant rain-scatter is that occurring in the general area of the earth station, the question of a mixed path does not arise. The rain-climatic zone relevant to the earth station is applied, together with the appropriate maximum rain-scatter distance from Table V.

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 as equal to 100 km. Similarly, if the method for determining the rain-scatter distance d_r leads to a result less than 100 km, d_r shall be taken as equal to 100 km.

6. *Coordination distance*

On any azimuth, the greater of the coordination distances d_1 or d_2 is the coordination distance to be used for the coordination procedure.

An example of a coordination contour is shown in Fig. 15.

7. *Mobile (except aeronautical mobile) earth stations*

For the purpose of establishing whether prior agreement with another administration under the provisions of Nos. **1108** to **1111** 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.

8. *Revision of propagation data*

The material contained in sections 3, 4 and 6 and in Annex III of this Appendix is based, directly or indirectly, on propagation data compiled, interpreted and documented in CCIR Reports and Recommendations. Knowledge regarding propagation is subject to change as new data become available, and such change may require or strongly suggest corresponding amendments to the propagation-related material in this Appendix.

Resolution **60** provides for the mechanism by which an updating of the propagation-related elements of this Appendix is to be implemented.

TABLE I

Parameters Required for the Determination of Coordination Distance for a Transmitting Earth Station

Space Radiocommunication Service Designation		Space Operation	Fixed-Satellite Mobile-Satellite	Fixed-Satellite	Space Research	Fixed-Satellite Mobile-Satellite Meteorological-Satellite	Fixed-Satellite (5)	Fixed-Satellite	Fixed-Satellite (5)	Fixed-Satellite (5)	Fixed-Satellite
Frequency Bands (GHz)		1.427–1.429	2.655–2.690	5.725–7.075	7.145–7.235	7.900–8.400	10.7–11.7	12.5–14.5	14.5–14.8	17.7–18.1	27–37.5
Modulation at Terrestrial Station (1)		A	A	A	A	A	A	A	A	N	N
Interference Parameters and	p_0 (%)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.003	0.003
	n	2	1	2	2	2	2	2	2	1	1
	p (%)	0.005	0.01	0.005	0.005	0.005	0.005	0.005	0.005	0.003	0.003
	W (dB)	0	0	0	0	0	0	0	0	0	0
Terrestrial Station Parameters	B (Hz)	4×10^3	4×10^3	4×10^3	4×10^3	4×10^3	4×10^3	4×10^3	4×10^3	1×10^6	1×10^6
	G_r (dB) (2)	35	52(3)	45	47	47	50	50	50	50	50
	ΔG (dB)	−7	10(3)	3	5	5	8	8	8	8	8
	T_r (K)	750	500(3)	750	750	750	1500	1500	1500	3200	3200
Auxiliary Parameters	S (dBW) (4)	166	192	176	178	178	178	178	178	154	154
	$P_r(p)$ (dBW) in B	−131	−140	−131	−131	−131	−128	−128	−128	−104	−104

(1) A = analogue modulation; N = digital modulation.
(2) Feeder losses are not included.
(3) In these bands the parameters for the terrestrial station associated with transhorizon systems have been used.
(4) For a definition of the parameter S see Annex I.
(5) The parameters associated with these columns are for feeder links to broadcasting satellites and are provisional pending further study by the CCIR: see Resolution 101.

TABLE II

Parameters Required for the Determination of Coordination Di[stance for a Receiving Earth Station]

Space Radiocommunication Service Designation		Space Operation (1)	Meteorological-Satellite (1)	Meteorological-Satellite	Space Research: Near Earth	Space Research: Deep Space; Manned	Fixed-Satellite		Fixed-Satellite	
Frequency Bands (GHz)		1.525–1.535	1.670–1.700	1.700–1.790	1.700–1.710 2.290–2.300		2.500–2.690		3.400–4.200	
Modulation at Earth Station (2)					–	–	A	N	A	N
Interference Parameters and Criteria	p_0 (%)				0.1	0.001	0.03	0.003	0.03	0.003
	n				2	1	3	3	3	3
	p (%)				0.05	0.001	0.01	0.001	0.01	0.001
	J (dB)				–	–	–8	0	–8	0
	$M_0(p_0)$ (dB)				–	–	17	5	17	5 (3)
	W (dB)				–	–	4	0	4	0
Terrestrial Station Parameters	E (dBW) in B (8)	55	55	92 (6)	62(4)(6)	62(4)(6)	92 (6)	92 (6)	55	55
	P_t (dBW) in B	13	13	40 (6)	10(4)(6)	10(4)(6)	40 (6)	40 (6)	13	13
	ΔG (dB)	0	0	10 (6)	10 (6)	10 (6)	10 (6)	10 (6)	0	0
Reference Bandwidth (7)	B (Hz)			10^6	1	1	10^6	10^6	10^6	10^6
Permissible Interference Power	$P_r(p)$ (dBW) in B				–220	–222	–	–	–	–

Space Radiocommunication Service Designation		Fixed-Satellite		Fixed-Satellite; Meteorological-Satellite; Mobile-Satellite		Earth Exploration-Satellite	Space Research: Near Earth	Space Research: Deep Space	Fixed-Satellite		Meteorological-Satellite	Fixed-Satellite	Mobile-Satellite
Frequency Bands (GHz)		4.500–4.800		7.250–7.750		8.025–8.400	8.400–8.500		10.7–12.75		17.7–40.0		
Modulation at Earth Station (2)		A	N	A	N	–	–	–	A	N		N	
Interference Parameters and Criteria	p_0 (%)	0.03	0.003	0.03	0.003	1.0	0.1	0.001	0.03	0.003		0.003	
	n	3	3	3	3		2	1	2	1		1	
	p (%)	0.01	0.001	0.01	0.001		0.05	0.001	0.015	0.003		0.003	
	J (dB)	–8	0	–8	0		–	–	–8	0		0	
	$M_0(p_0)$ (dB)	17	5 (3)	17	5 (3)		–	–	17	5 (3)		5 (3)	
	W (dB)	4	0	4	0		–	–	4	0		0	
Terrestrial Station Parameters	E (dBW) in B (8)	92 (6)	92 (6)	55	55	55	25 (4)	25 (4)	55	55		35 (5)	
	P_t (dBW) in B	40 (6)	40 (6)	13	13	13	–17(4)	–17(4)	10	10		–10(5)	
	ΔG (dB)	10 (6)	10 (6)	0	0	0	0	0	3	3		3	
Reference Bandwidth (7)	B (Hz)	10^6	10^6	10^6	10^6	10^6	1	1	10^6	10^6		10^6	
Permissible Interference Power	$P_r(p)$ (dBW) in B	–	–	–	–	–154	–220	–220	–	–		–	

(1) Parameters associated with these services may vary over a rather wide range. Further study is required before representative v[a]lues become available.

(2) A = analogue modulation; N = digital modulation.

(3) See *Note 3* in section 2. M_0 (p_0) may assume values between 5 and 40 dB, depending on frequency, rain-climatic zone and sy[]stem design.

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

(5) These values assume a radio frequency bandwidth of no less than 100 MHz, and are 20 dB below total power assumed per em[]ission.

(6) In these bands, the parameters for the terrestrial stations associated with transhorizon systems have been used. If an admin[]istration believes that transhorizon systems do not need to be considered the line-of-sight radio-relay parameters associated with the frequency band 3 400 – 4 200 MHz may be used to determine the coordination area in accord[]ance with paragraph 2.3.1.

(7) In certain systems in the fixed-satellite service it may be desirable to choose a greater reference bandwidth B when the sy[]stem 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 recoordination of the earth sta[]tion. For narrow-band transmissions the reference bandwidth B should be assumed to be equal to the bandwidth occupied.

(8) For the definition of E, see Annex 1.

TABLE III

Maximum Coordination Distance for Propagation Mode (1)

	Percentage of Time			
	$p = 0.001$	$p = 0.01$	$p = 0.1$	$p = 1$
Zone A	375	350	300	200
Zone B	1 050	1 000	900	700
Zone C	1 400	1 350	1 200	950

TABLE IV

Characteristic Values of Parameters for the Five Rain-Climatic Zones (0.01% of the time)

Parameter	Rain-Climatic Zone					Unit
	1	2	3	4	5	
Surface Rainfall Rate (R)	75	55	37	26	14	mm/h
Rain Cell Diameter (D)	2.5	2.8	3	3	4.5	km
Water Vapour Density (ρ_w)	10	5	2	2	2	g/m³

TABLE V

Maximum Rain-Scatter Distances (km)

Rain-Climatic Zone	Percentage of Time		
	$0.001 < p < 0.01$	$0.01 < p < 0.1$	$p = 0.1$
1	540	470	390
2	470	390	330
3, 4 and 5	390	330	270

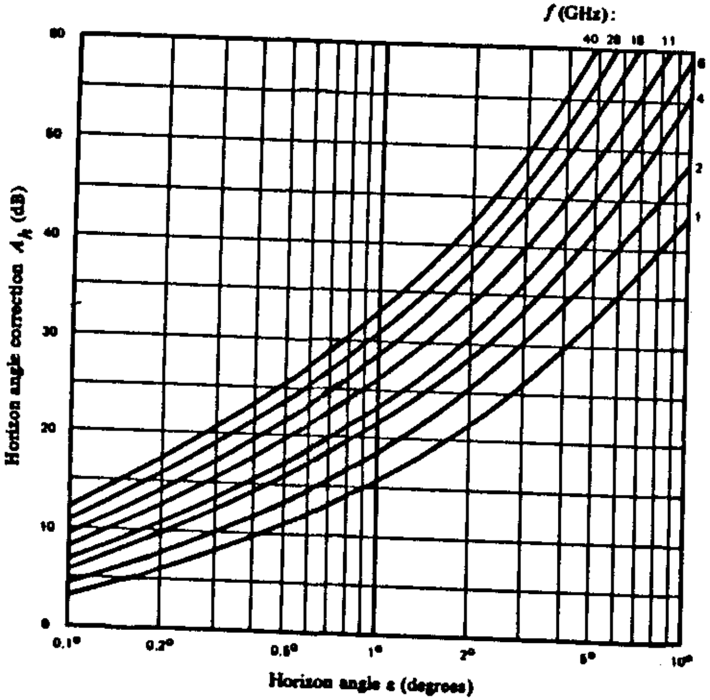

FIGURE 1

Horizon angle correction A_h as a function of horizon angle and frequency

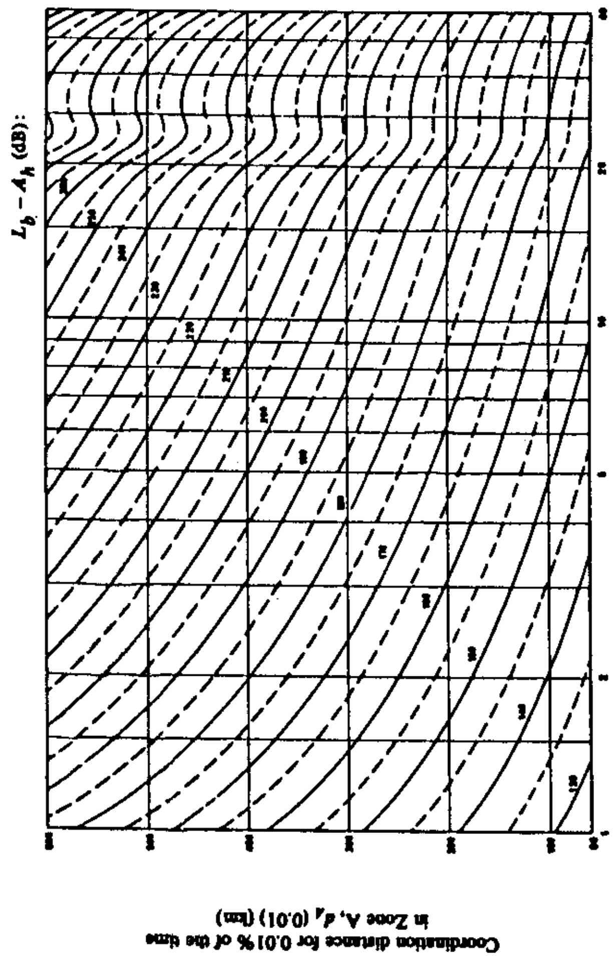

FIGURE 2

Coordination distance d_A (0.01) for 0.01 % of the time due to propagation mode (1) as a function of frequency and coordination loss in Zone A

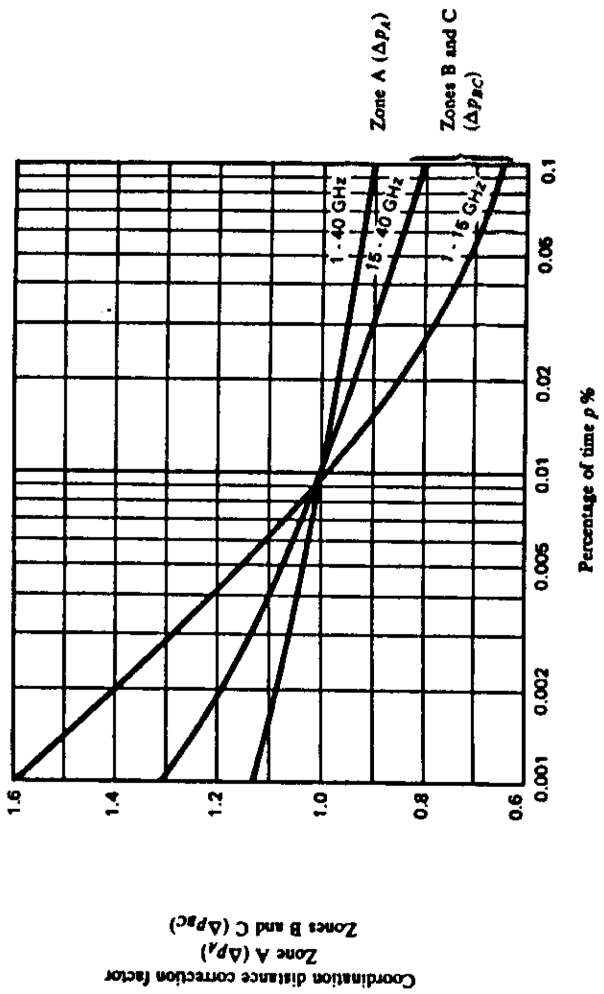

FIGURE 3

Coordination distance correction factor for propagation mode (1) for percentages of time other than 0.01

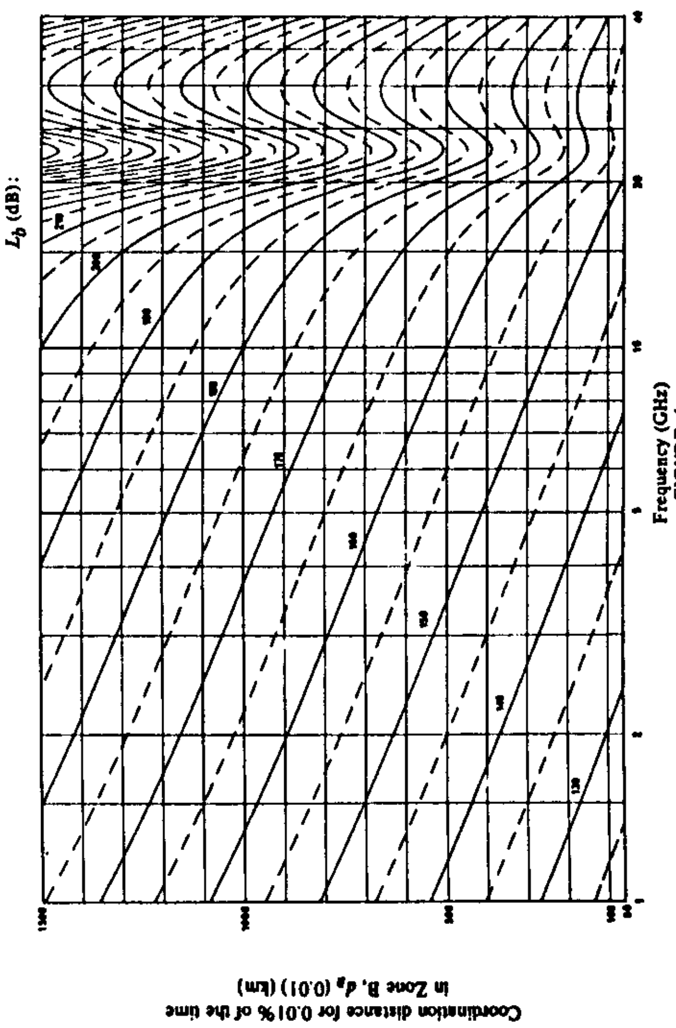

FIGURE 4

Coordination distance d_B (0.01) for 0.01% of the time due to propagation mode (1) as a function of frequency and coordination loss in Zone B

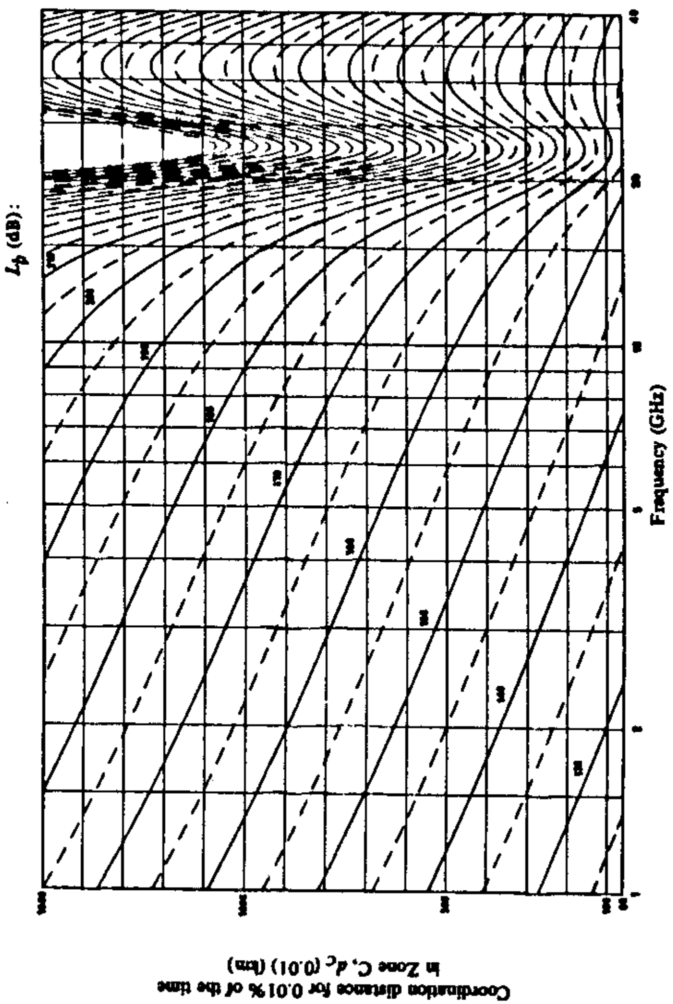

FIGURE 5

Coordination distance d_c (0.01) for 0.01 % of the time due to propagation mode (1) as a function of frequency and coordination loss in Zone C

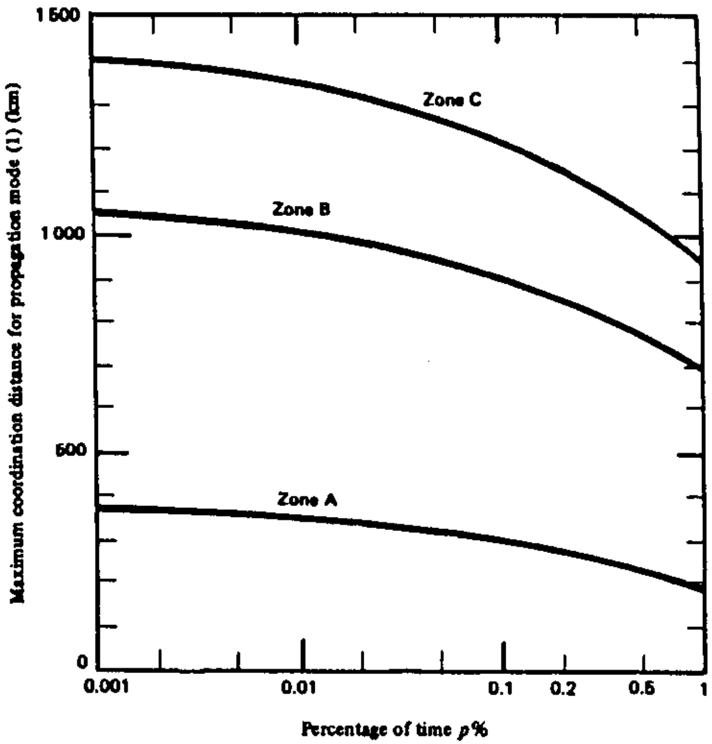

FIGURE 6

Maximum coordination distance for propagation mode (1) as a function of percentage of time

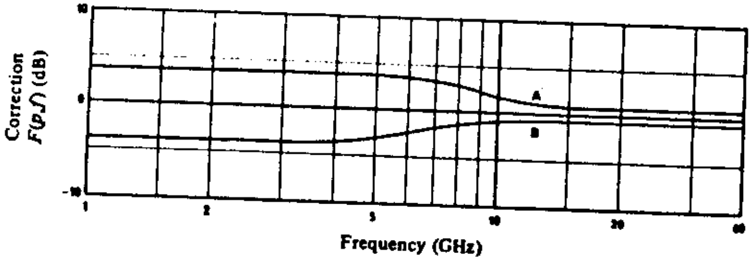

FIGURE 7

Correction for conversion from 0.01% of the time for all rain-climatic zones

Curve A: Conversion to 0.1%
Curve B: Conversion to 0.001%

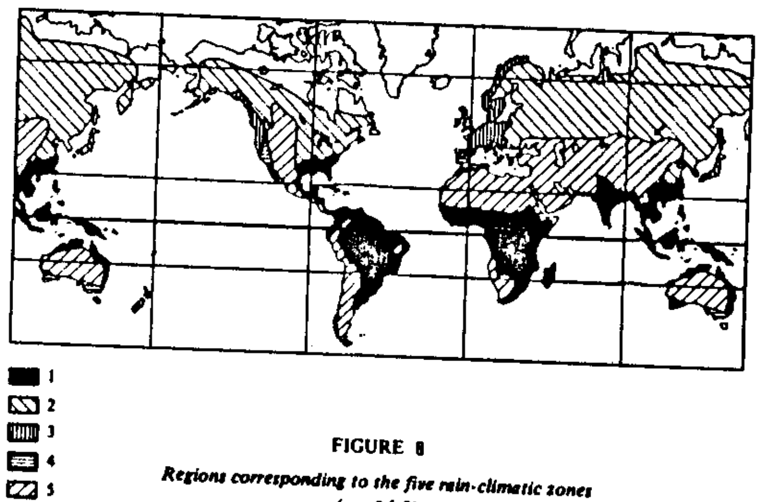

FIGURE 8

Regions corresponding to the five rain-climatic zones
(see § 4.2)

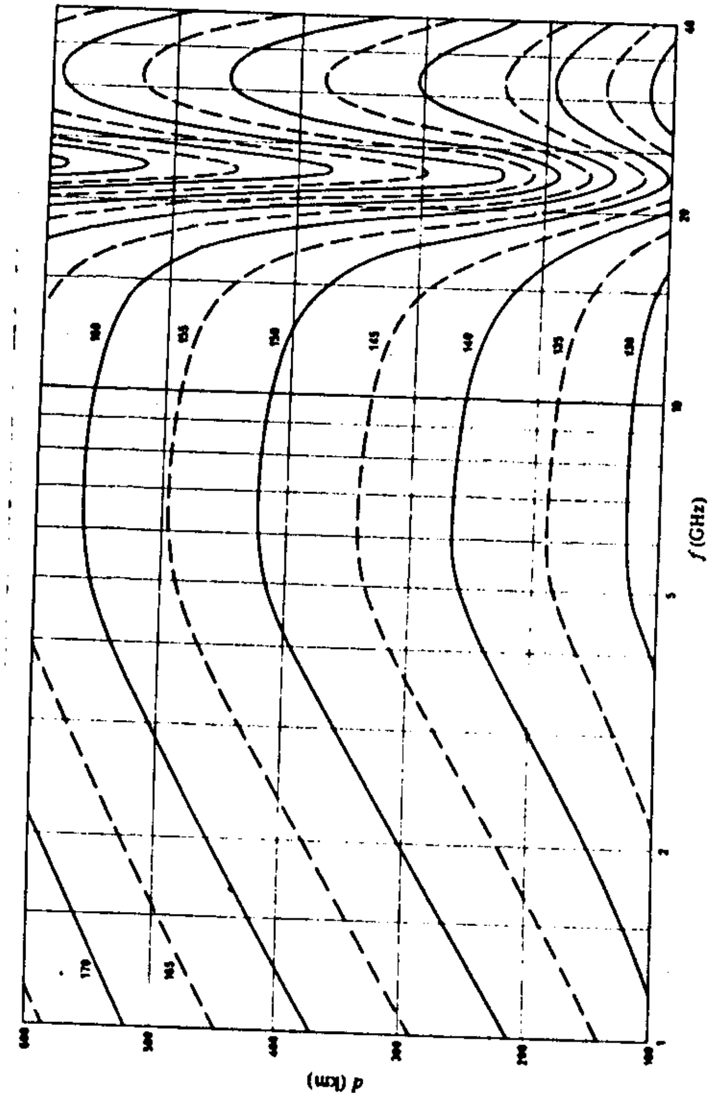

FIGURE 9

Rain-scatter distance as a function of frequency for 0.01% of the time – Rain-Climatic Zone 1

Contours have transmission loss values shown in dB.

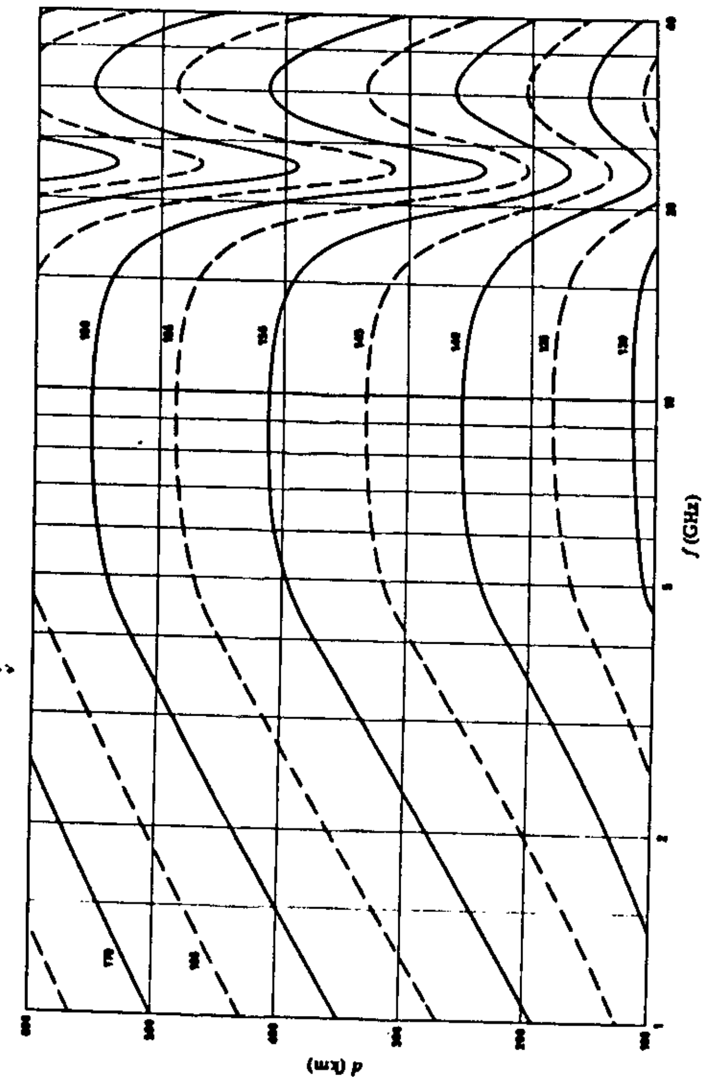

FIGURE 10

Rain-scatter distance as a function of frequency for 0.01% of the time – Rain-Climatic Zone 2

Contours have transmission loss values shown in dB.

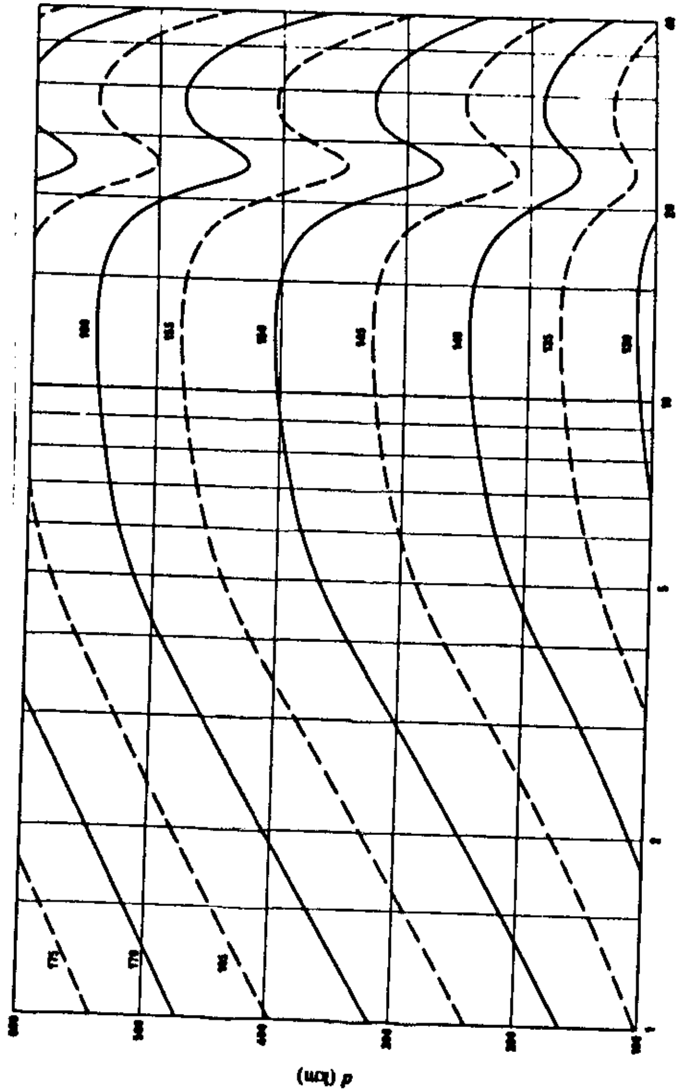

FIGURE 11

Rain-scatter distance as a function of frequency for 0.01% of the time – Rain-Climatic Zone 3

Contours have transmission loss values shown in dB.

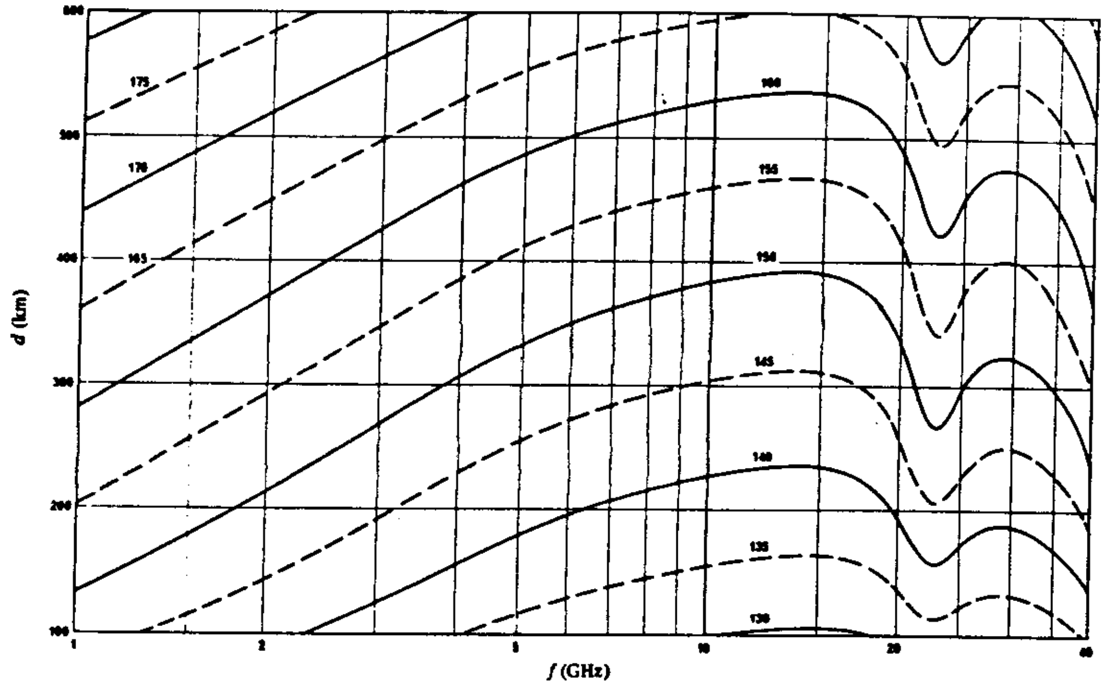

FIGURE 12

Rain-scatter distance as a function of frequency for 0.01 % of the time – Rain-Climatic Zone 4

Contours have transmission loss values shown in dB.

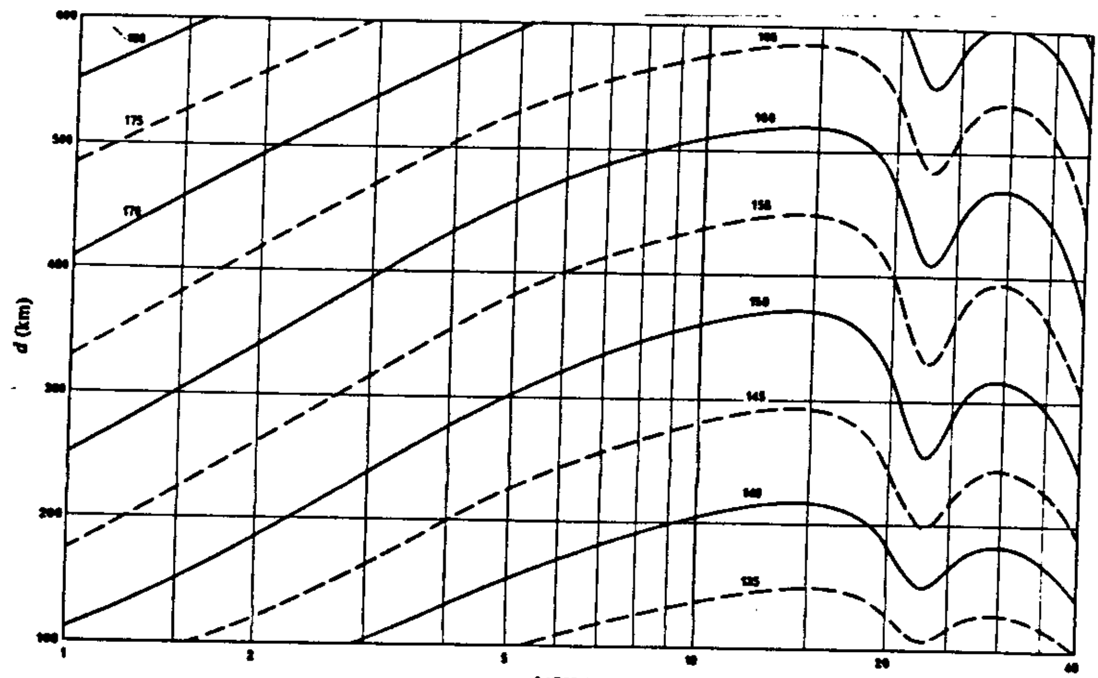

FIGURE 13

Rain-scatter distance as a function of frequency for 0.01 % of the time – Rain-Climatic Zone 5

Contours have transmission loss values shown in dB.

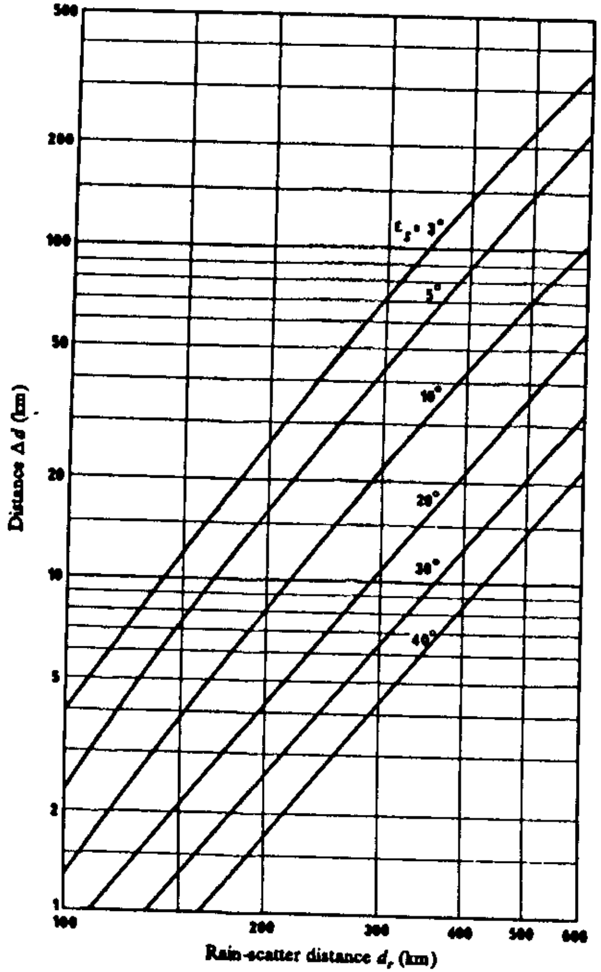

FIGURE 14

Distance Δd as a function of rain-scatter distance d_r and earth station antenna main beam elevation angle ε_s

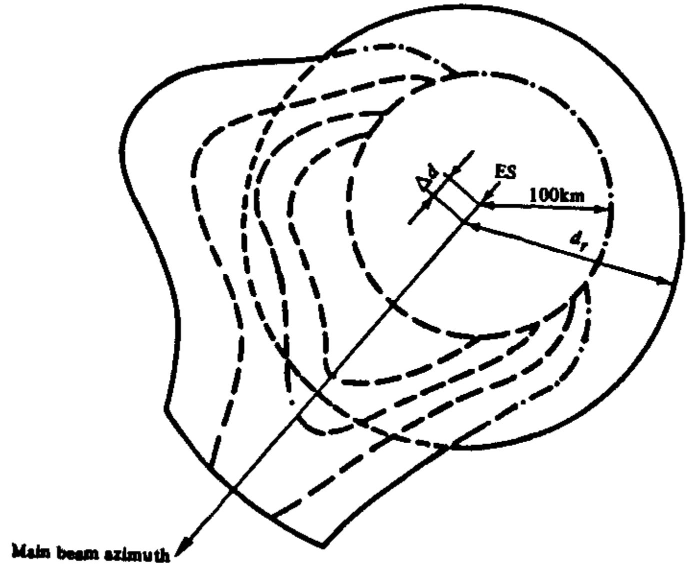

FIGURE 15

Example of a coordination contour

ES: Earth station

——— Coordination contour

–·–·–·– Contour for propagation mode (1)

- - - - - - Contour for propagation mode (2)

— — — — Auxiliary contours for propagation mode (1)

Note: 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.

ANNEX I

Determination and Use of Auxiliary Contours

1. *Introduction*

For great circle propagation mechanisms mode (1) auxiliary contours are of great value in eliminating certain existing or planned terrestrial stations falling within the coordination area without recourse to precise and arduous calculations. The work of both the earth station administration and the affected administrations is therefore eased during subsequent negotiations if these auxiliary contours are supplied.

2. *Determination of the auxiliary contours*

Two types of contours may be determined, depending on whether the earth station is used for transmission or reception.

2.1 *Transmitting earth station*

From equation (2) one may isolate the terms $G_r - P_r(p)$ and define an interference sensitivity factor S (dBW) of the interfered-with terrestrial stations:

$$S = G_r - P_r(p) \quad (32)$$

Table I shows values of this factor for various types of terrestrial stations.

The coordination contour is associated with a (maximum) sensitivity factor S and labelled with its value.

The auxiliary contours are determined in the same way as the corresponding coordination contour for propagation mode (1), but using terrestrial station interference sensitivity factor S values (dBW) which are 5, 10, 15, 20 dB, etc. lower than the value (given in Table I) corresponding to the coordination contour.

2.2 *Receiving earth station*

From equation (2) one may, likewise, isolate the terms $P_{t'} + G_{t'}$ and define the equivalent isotropically radiated power E (dBW) of the interfering terrestrial stations:

$$E = P_{t'} + G_{t'} \quad (33)$$

values for which are listed in Table II.

The coordination contour is associated with a maximum value for E and labelled with this value.

The auxiliary contours are determined in the same way as the corresponding coordination contour for propagation mode (1), but using terrestrial station e.i.r.p. values E (dBW) which are 5, 10, 15, 20 dB, etc. lower than the value (given in Table II) corresponding to the coordination contour.

3. *Use of auxiliary contours*

The auxiliary contours, the coordination contour for great circle propagation mode (1) and the coordination contour for rain-scatter mode (2) are all plotted on the same diagram for a given shared band. An illustrative example is given in Fig. 15.

For each terrestrial station situated within the coordination area, a two stage procedure may be applied, one for the great circle propagation mechanism and the other for scattering from hydrometeors.

3.1 *Great circle propagation mechanisms mode (1)*

If a transmitting terrestrial station is outside the coordination area corresponding to mode (1), it need not be considered further with respect to mode (1).

For each transmitting terrestrial station situated within the coordination area corresponding to mode (1), the e.i.r.p. value in the direction of the earth station is determined. If this value is less than the value associated with the nearest contour defining an area outside of which the station is situated, the station may be considered not to cause more than a permissible level of interference and therefore may be eliminated from further consideration with respect to mode (1).

For each receiving terrestrial station, the analogous procedure may be applied using the interference sensitivity factor instead of the e.i.r.p. value.

3.2 *Elimination of a terrestrial station and rain-scatter propagation mechanism mode (2)*

Terrestrial stations eliminated by the above procedure from further consideration with regard to propagation mode (1) need, nevertheless, be further considered with regard to propagation mode (2) when they lie within the rain-scatter coordination area.

ANNEX II

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 φ between the antenna main beam axis and the horizon direction under consideration. Therefore, knowledge of the angle φ is required for each azimuth.

The elevation ε_s and azimuth α_s of geostationary satellites as seen from an earth station at a latitude ζ are uniquely related. Fig. II-1 shows the possible location arcs of geostationary satellites in a rectangular elevation/azimuth plot, each arc corresponding to an earth station latitude.

Specific relative satellite longitudes may not be known beforehand, but even when they are, the possibility of the addition of a new satellite or the repositioning of an existing one suggests that all or a portion of the applicable arc be considered to hold satellites.

2. *Graphical method for the determination of* $\varphi(\alpha)$

With the correct arc or segment of arc chosen and suitably marked in Fig. II-1, the horizon profile $\varepsilon(\alpha)$ is added to the plot of Fig. II-1, as shown in Fig. II-2, where an example is given for an earth station located at 45° N latitude for a satellite expected to be located somewhere between relative longitudes of 10° E and 45° W.

For each point on the local horizon $\varepsilon(\alpha)$ the smallest distance to the arc is determined and measured on the elevation scale. The example of Fig. II-2 shows the determination of the off-beam angle φ at an azimuth α (= 210°) with a horizontal elevation ε (= 4°). The measurement of φ yields a value of 26°.

When this is done for all azimuths (in suitable increments, e.g. 5°), a relationship $\varphi(\alpha)$ results.

3. *Numerical method for the determination of* $\varphi(\alpha)$

For this purpose the following equations may be used:

$$\psi = \arccos(\cos\zeta \cdot \cos\delta) \qquad (34)$$

$$\alpha_s' = \arccos(\tan\zeta \cdot \cot\psi) \qquad (35)$$

$\alpha_s = \alpha_s' + 180°$ for earth stations located in the northern hemisphere and satellites located west of the earth station (36a)

$\alpha_s = 180° - \alpha_s'$ for earth stations located in the northern hemisphere and satellites located east of the earth station (36b)

$\alpha_s = 360° - \alpha_s'$ for earth stations located in the southern hemisphere and satellites located west of the earth station (36c)

$\alpha_s = \alpha_s'$ for earth stations located in the southern hemisphere and satellites located east of the earth station (36d)

$$\varepsilon_s = \arctan\left(\frac{K - \cos\psi}{\sin\psi}\right) - \psi \qquad (37)$$

$$\varphi(\alpha) = \arccos[\cos\varepsilon \cdot \cos\varepsilon_s \cdot \cos(\alpha - \alpha_s) + \sin\varepsilon \cdot \sin\varepsilon_s] \qquad (38)$$

where:

- ζ: latitude of earth station;
- δ: difference in longitude between the satellite and the earth station;
- ψ: great circle arc between the earth station and the sub-satellite point;
- α_s: satellite azimuth as seen from the earth station;
- ε_s: satellite elevation angle as seen from the earth station;
- α: azimuth of the pertinent direction;
- ε: elevation angle of the horizon in the pertinent azimuth α;
- $\varphi(\alpha)$: angle between the main beam axis and the horizon direction corresponding to the pertinent azimuth α;
- K: orbit radius/earth radius, assumed to be 6.62.

All arcs mentioned above are in degrees.

4. *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 100, the following equation should be used:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for } 0 < \varphi < \varphi_m \qquad (39a)$$

$$G(\varphi) = G_1 \quad \text{for } \varphi_m \leq \varphi < \varphi_r \qquad (39b)$$

$$G(\varphi) = 32 - 25 \log \varphi \quad \text{for } \varphi_r \leq \varphi < 48° \qquad (39c)$$

$$G(\varphi) = -10 \quad \text{for } 48° \leq \varphi \leq 180° \qquad (39d)$$

where:

- D: antenna diameter
- λ: wavelength

} expressed in the same unit

G_1: gain of the first sidelobe $= 2 + 15 \log \frac{D}{\lambda}$

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

$$\varphi_r = 15.85 \left(\frac{D}{\lambda}\right)^{-0.6} \text{ (degrees)}$$

When it is not possible, for antennae with $\frac{D}{\lambda}$ of less than 100, to use the above reference antenna pattern and when neither measured data nor a relevant CCIR Recommendation accepted by the administrations concerned can be used instead, administrations may use the reference diagram as described below:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for } 0 < \varphi < \varphi_m \qquad (40a)$$

$$G(\varphi) = G_1 \quad \text{for } \varphi_m \leq \varphi < 100\frac{\lambda}{D} \qquad (40b)$$

$$G(\varphi) = 52 - 10 \log \frac{D}{\lambda} - 25 \log \varphi \quad \text{for } 100\frac{\lambda}{D} \leq \varphi < 48° \qquad (40c)$$

$$G(\varphi) = 10 - 10 \log \frac{D}{\lambda} \quad \text{for } 48° \leq \varphi \leq 180° \qquad (40d)$$

where:

- D: antenna diameter
- λ: wavelength

} expressed in the same unit

G_1: gain of the first sidelobe $= 2 + 15 \log \frac{D}{\lambda}$

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

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

In cases where $\frac{D}{\lambda}$ is not given, it may be estimated from the expression $20 \log \frac{D}{\lambda} \approx G_{max} - 7.7$, where G_{max} is the main lobe antenna gain in dB.

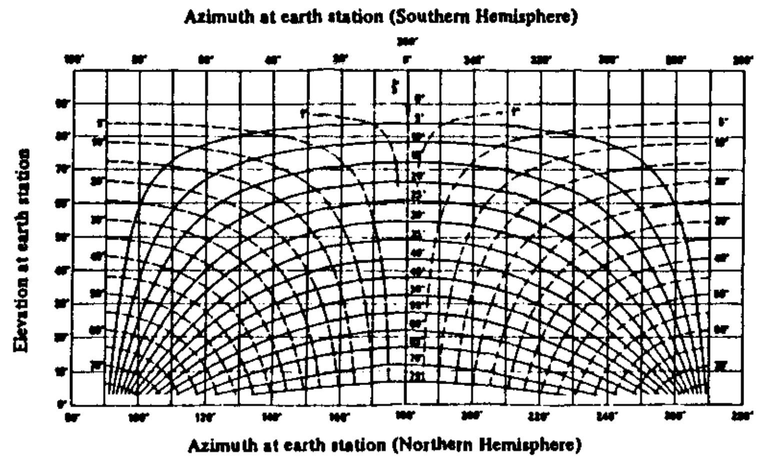

FIGURE II-1

Position arcs of geostationary satellites

——— Arc of geostationary-satellite orbit visible from earth station at terrestrial latitude ζ

Difference in longitude between earth station and the sub-satellite point:

- - - - - - - Satellite longitude E of earth station longitude

-·-·-·-·- Satellite longitude W of earth station longitude

—·—·—· Satellite longitude equal to the earth station longitude

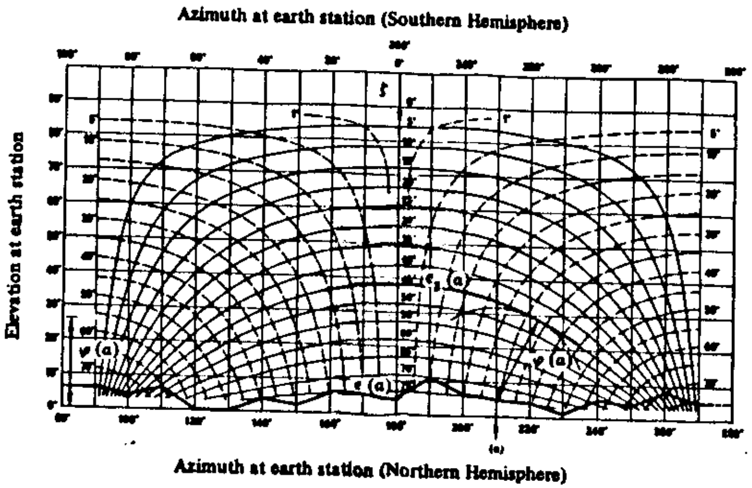

FIGURE II-2

Example of derivation of ψ

——— Arc of geostationary-satellite orbit visible from earth station at terrestrial latitude ζ

········· Horizon profile ε(α)

ψ Difference in longitude between earth station and the sub-satellite point:

------- Satellite longitude E of earth station longitude

-·-·-·- Satellite longitude W of earth station longitude

-··-··- Satellite longitude equal to the earth station longitude

ANNEX III

Graphical Method for the Determination of Coordination Distance for Mixed Paths

1. *Two zones*

The procedure to be followed in the case of a mixed path involving two zones is illustrated by the example shown in Fig. III-1 (a). The earth station is situated in Zone A at a distance of 75 km from Zone B. The graphical

presentation described below is particularly useful where more than one boundary between zones may be involved, as in this example.

In the example given below, the coordination loss is assumed to be 180 dB, the frequency 20 GHz, and the percentage of time 0.01%. The procedure is as follows:

1.1 determine the distance entirely in Zone A that would give the coordination loss. Mark this distance (in this case it is 160 km) from the origin along the abscissa axis of linear graph paper as indicated by the point A (Fig. III-1 (b));

1.2 determine the distance entirely in Zone B that would give the same coordination loss. Mark this distance (in this case it is 530 km) from the origin along the ordinate axis of the chart as indicated by the point B;

1.3 draw a straight line between points A and B representing these distances from the origin;

1.4 starting from the origin, the distance of 75 km from the earth station to Zone B is set off along the abscissa axis of the chart as indicated by the point A_1;

1.5 starting from point A_1 the Zone B path length of 150 km is then set off parallel to the ordinate axis of the chart as indicated by the point B_1;

1.6 the further distance in the next Zone A region is then measured parallel to the abscissa axis from the point B_1 to the point of intersection of the mixed path curve as indicated by X. In Fig. III-1 (b), this distance is 40 km;

1.7 the coordination distance is the sum of distances $0A_1$, A_1B_1 and B_1X and is equal to:

$$75 + 150 + 40 = 265 \text{ km}$$

2. *Three zones*

In some special cases, the mixed path involves all three radio-climatic Zones A, B and C. A solution to this problem can be found in adding a third dimension to the procedure to be followed for mixed paths involving only two zones. Theoretically, it means that the third coordinate has to be determined for a point having coordinates corresponding to the known distances in the first two zones and lying in a plane defined by three points on the axes X, Y and Z, corresponding to distances in Zones A, B and C, respectively, that would give the required basic transmission loss.

In practice, the procedure can be reduced to a simple graphical method shown in Fig. III-2(a) assuming for example a coordination loss (L_1) of 180 dB at a frequency of 20 GHz. It is required to find the coordination distance from the earth station in the direction given in Fig. III-2(a). Here an earth station is situated in Zone A at a distance of 75 km in a given azimuthal direction from Zone B. In the same azimuthal direction Zone B is 150 km long and followed by an unknown portion in Zone C (Fig. III-2(a)).

In this case, the procedure to be applied should be as follows (Fig. III-2(b)):

2.1 repeat the same procedure as for mixed paths involving only two zones, given in steps 1.1 to 1.5 above, and continue as follows:

2.2 from the point B_1 draw a line parallel to the line AB to intersect the abscissa axis as indicated by the point D;

2.3 determine the distance, entirely in Zone C, that would give the coordination loss. Mark this distance (in this case it is 350 km) from the origin along the ordinate axis of the chart as indicated by the length 0C. Draw a straight line between points C and A;

2.4 at the point D draw a line parallel to the ordinate axis to intersect the line CA as indicated by X;

2.5 the distance between the points D and X, which is the unknown distance in Zone C, is found to be 85 km;

2.6 the coordination distance is then the sum of the distances $0A_1$, A_1B_1, and DX and in this example is equal to:

$$75 + 150 + 85 = 310 \text{ km}$$

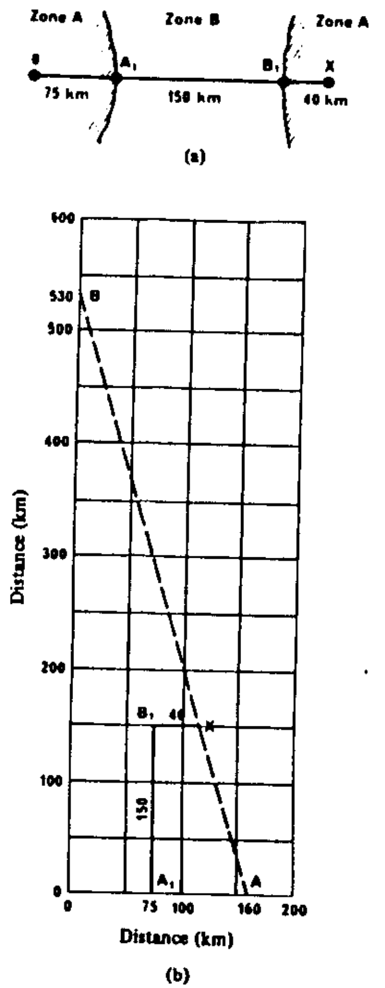

FIGURE III-1

Example of determination of coordination distance for mixed paths involving Zones A and B

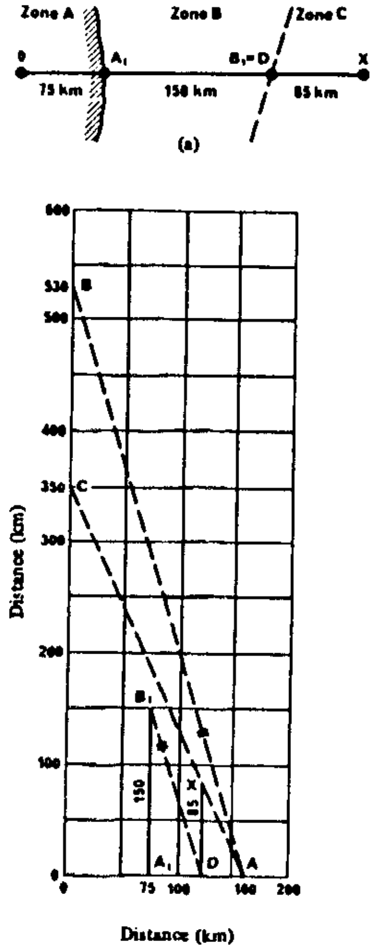

FIGURE III-2

Example of determination of coordination distance for mixed paths involving Zones A, B and C

APPENDIX 29

Method of Calculation for Determining if Coordination is Required Between Geostationary-Satellite Networks Sharing the Same Frequency Bands

1. *Introduction*

The method of calculation for determining if coordination is required under provision No. **1060** is based on the concept that the noise temperature of a system subject to interference increases as the level of the interfering emission increases. It can, therefore, be applied irrespective of the modulation characteristics of these satellite networks, and of the precise frequencies used.

In this method, the apparent increase in the equivalent satellite link noise temperature resulting from an interfering emission of a given system is calculated (see § 2 below) and the ratio of this increase to the equivalent satellite link noise temperature, expressed as a percentage, is compared to a threshold value (see § 3 below).

2. *Calculation of the apparent increase in equivalent noise temperature of the satellite link subject to an interfering emission*

Two possible cases are considered:

Case I: wanted and interfering networks share one or more frequency bands, each in the same direction of transmission;

Case II: wanted and interfering networks share one or more frequency bands, each in opposite directions of transmission (bidirectional use).

These two cases cover all relative satellite positions from closely-spaced to near-antipodal positions.

2.1 *Parameters*

Let A be a satellite link of network R associated with satellite S and A′ be a satellite link of network R′ associated with satellite S′. The symbols relating to satellite link A′ bear primes, those relating to satellite link A do not bear primes.

The parameters are defined as follows (for satellite link A):

T: the equivalent satellite link noise temperature, referred to the output of the receiving antenna of the earth station (K);

T_s: the receiving system noise temperature of the space station, referred to the output of the receiving antenna of the space station (K);

T_e: the receiving system noise temperature of the earth station, referred to the output of the receiving antenna of the earth station (K);

ΔT_s: apparent increase in the receiving system noise temperature of the satellite S, caused by an interfering emission, referred to the output of the receiving antenna of this satellite (K);

ΔT_e: apparent increase in the receiving system noise temperature of the earth station e_R, caused by an interfering emission, referred to the output of the receiving antenna of this station (K);

p_s: maximum power density per Hz delivered to the antenna of satellite S (averaged over the worst 4 kHz band for a carrier frequency below 15 GHz or over the worst 1 MHz band above 15 GHz) (W/Hz);

$g_3(\eta)$: transmitting antenna gain of satellite S in the direction η (numerical power ratio);

η_A: direction, from satellite S, of the receiving earth station e_R of satellite link A;

$\eta_{e'}$: direction, from satellite S, of the receiving earth station e'_R of satellite link A′;

Note: The product $p_s\ g_3(\eta_{e'})$ is the maximum e.i.r.p. per Hz of satellite S in the direction of the receiving earth station e'_R of satellite link A′.

$\eta_{s'}$: direction, from satellite S, of satellite S′;

p_e: maximum power density per Hz delivered to the antenna of the transmitting earth station e_T (averaged over the worst 4 kHz band for a carrier frequency below 15 GHz or over the worst 1 MHz band above 15 GHz) (W/Hz);

$g_2(\delta)$: receiving antenna gain of satellite S in the direction δ (numerical power ratio);

δ_A: direction, from satellite S, of the transmitting earth station e_T of satellite link A;

$\delta_{e'}$: direction, from satellite S, of the transmitting earth station e'_T of satellite link A′;

$\delta_{s'}$: direction, from satellite S, of satellite S′;

θ_t: topocentric angular separation in degrees between the two satellites[1], taking the longitudinal station-keeping tolerances into account;

Note: Only the topocentric angle θ_t should be used in dealing with Case I.

[1] A method for calculation of the topocentric angular separation is given in Annex I.

θ_g : geocentric angular separation in degrees between the two satellites, taking the longitudinal station-keeping tolerances into account;

Note: Only the geocentric angle θ_g should be used in dealing with Case II.

$g_1(\theta_t)$: transmitting antenna gain of the earth station e_T in the direction of satellite S′ (numerical power ratio);

$g_4(\theta_t)$: receiving antenna gain of the earth station e_R in the direction of satellite S′ (numerical power ratio);

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

l_d : free-space transmission loss[1] on the down-link (numerical power ratio), evaluated from satellite S to the receiving earth station e_R for satellite link A;

Note: The free-space transmission loss on any down-link evaluated from the satellites S or S′ to the receiving earth stations e_R or e'_R is considered to be equal to l_d.

l_u : free-space transmission loss[1] on the up-link (numerical power ratio), evaluated from the earth station e_T, to satellite S for satellite link A;

Note: The free-space loss on any up-link evaluated from the earth stations e_T or e'_T to the satellite S or S′ is considered to be equal to l_u.

l_t : free-space transmission loss[1] on the inter-satellite link (numerical power ratio), evaluated from satellite S′ to satellite S;

[1] A method for calculation . the free-space transmission loss is given in Annex II.

γ : transmission gain of a specific satellite link subject to interference evaluated from the output of the receiving antenna of satellite S to the output of the receiving antenna of the earth station e_R (numerical power ratio, usually less than 1).

2.2 *General method*

In the following equations, the frequency to be used for the calculation of l_d, l_u, and l_t is the average frequency of the band common to both networks in the direction considered. If, in a given direction, there is no overlap of the assigned frequency bands of the two networks, the corresponding value (ΔT_s or ΔT_e) is taken to be equal to zero. For cases where the Appendix 3 data have not been published, the assigned frequency band for that network shall be considered as being the frequency range as provided for in Appendix 4.

2.2.1 *Case I – Wanted and interfering networks sharing the same frequency band in the same direction of transmission*

The gains $g_1(\theta_t)$ and $g_4(\theta_t)$ are those of the earth stations concerned. When neither measured data nor a relevant CCIR Recommendation accepted by the administrations concerned are available the radiation patterns set out in Annex III should be used.

2.2.1.1 *Simple frequency-changing transponder on board the satellite*

The parameters ΔT_s and ΔT_e are given by the following equations:

$$\Delta T_s = \frac{p'_e \, g'_1(\theta_t) \, g_2(\delta_{e'})}{k l_u} \qquad (1)$$

$$\Delta T_e = \frac{p'_s \, g'_3(\eta_e) \, g_4(\theta_t)}{k l_d} \qquad (2)$$

The symbol ΔT will be used to denote the apparent increase in the equivalent noise temperature for the entire satellite link referred to the output of the receiving antenna of the receiving earth station e_R due to the interfering emission from link A'.

This increase is the result of the interfering emissions entering at both the satellite and the earth station receiver of link A and can accordingly be expressed as:

$$\Delta T = \gamma \Delta T_s + \Delta T_e \qquad (3)$$

Hence,

$$\Delta T = \gamma \frac{p'_e \, g'_1(\theta_t) \, g_2(\delta_{e'})}{k l_u} + \frac{p'_s \, g'_3(\eta_e) \, g_4(\theta_t)}{k l_d} \qquad (4)$$

An example calculation for the application of the method of this Appendix in Case I is given in Annex IV.

In the same way, the increase $\Delta T'$ in the equivalent noise temperature for the entire satellite link, referred to the output of the receiving antenna of the receiving earth station e'_R, under the effect of the interference caused by satellite link A, is given by the following equations:

$$\Delta T'_{s'} = \frac{p_e \, g_1(\theta_t) \, g'_2(\delta_e)}{k l_u} \qquad (5)$$

$$\Delta T'_{e'} = \frac{p_s \, g_3(\eta_{e'}) \, g'_4(\theta_t)}{k l_d} \qquad (6)$$

$$\Delta T' = \gamma' \frac{p_e \, g_1(\theta_t) \, g'_2(\delta_e)}{k l_u} + \frac{p_s \, g_3(\eta_{e'}) \, g'_4(\theta_t)}{k l_d} \qquad (7)$$

2.2.1.2 *Cases requiring independent treatment of the up-link and the down-link*

If there is a change of modulation in the satellite or if the transmission originates on board the satellite, then the apparent increase in the noise temperature must be related to the total receiving system noise temperature of the specific link being examined (the space station or the earth station, whichever is applicable). In this case, the equivalent noise temperature of the entire satellite link and the transmission gain are not used and equations (1) and (2) above are used separately as required (see § 2.3).

2.2.2 *Case II – Wanted and interfering networks sharing the same frequency band in opposite directions of transmission (bidirectional use)*

The calculation method below only applies to interfering emissions between satellites.

Interference between earth stations using the same frequency band in opposite directions of transmission (bidirectional use) is to be dealt with by coordination procedures analogous to those used for coordination between earth and terrestrial stations.

All the equations relating to Case II shall use the geocentric angle θ_g.

2.2.2.1 *Simple frequency-changing transponder on board the satellite*

The noise temperature increase ΔT_s referred to the output of the receiving antenna of the satellite of link A is given by:

$$\Delta T_s = \frac{p'_s \, g'_3(\eta_s) \, g_2(\delta_{s'})}{k l_s} \qquad (8)$$

The apparent increase in equivalent link noise temperature is then given by:

$$\Delta T = \gamma \Delta T_s \tag{9}$$

The increase $\Delta T'$ in the equivalent noise temperature of the link A' caused by interfering emissions from the satellite associated with the link A is given by:

$$\Delta T' = \gamma' \Delta T'_s = \frac{\gamma' p_s g_3(\eta_{r'}) g'_2(\delta_s)}{k l_s} \tag{10}$$

2.2.2.2 *Cases requiring independent treatment of the up-link and down-link*

In this case equation (8) is used directly with T_s to obtain the percentage increase. The increase $\Delta T'_s$ in the noise temperature of link A' caused by interfering emissions from the satellite associated with link A is obtained in a similar manner.

2.2.3 *Consideration of polarization isolation*

The polarization isolation factor described in this paragraph shall be considered only if the administration responsible for each network has consented to such a course and has notified its polarization or published it for coordination under No. 1060. In this case, the apparent increase in the equivalent satellite link noise temperature shall be determined by the following expressions:

Case I $\quad \Delta T = \dfrac{\gamma \Delta T_s}{Y_u} + \dfrac{\Delta T_e}{Y_d}$

Case II $\quad \Delta T = \dfrac{\gamma \Delta T_s}{Y_{u}}$

where the values of ΔT_s and ΔT_e are those given in § 2.2.1 and § 2.2.2 and the values of the factors of polarization isolation Y_u, Y_d and Y_u are those given in the table below.

Polarization		Factor of polarization isolation (numerical ratio) Y
network R	network R'	
LHC	RHC	4
LHC	L	1.4
RHC	L	1.4
LHC	LHC	1
RHC	RHC	1
L	L	1

where: LHC = left-hand circular (anti-clockwise)
RHC = right-hand circular (clockwise)
L = linear

2.3 *Determination of the satellite links to be considered in calculating the increase in equivalent satellite link noise temperature (Case I only)*

The greatest increase in equivalent satellite link noise temperature caused to any link of another satellite network, existing or planned, by interfering emissions of the proposed satellite network must be determined.

The most unfavourably sited transmitting earth station of the interfering satellite network should be determined for each satellite receiving antenna of the network subject to interference by superimposing the "Earth-to-space" service areas of the interfering network on the space station receiving antenna gain contours plotted on a map of the Earth's surface. The most unfavourably sited transmitting earth station is the one in the direction of which the satellite receiving antenna gain of the network subject to interference is the greatest.

The most unfavourably sited receiving earth station of the network subject to interference should be determined in an analogous manner for each "space-to-Earth" service area of that network. The most unfavourably sited receiving earth station is the one in the direction of which the satellite transmitting antenna gain of the interfering network is the greatest.

2.4 *Use of information furnished under Appendix 4*

When an administration elects to use information furnished under Appendix 4 with the calculation procedures of § 2.2.1.1 and § 2.2.2.1 in order to formulate comments to the advance publication of a new network, the calculations need to be made for both sets of values of γ and T furnished. The greater of the two values of $\Delta T/T$ resulting from these calculations is the one to be used.

3. *Comparison between calculated percentage increase in noise temperature and the threshold value*

3.1 *Simple frequency-changing transponder on board the satellite*

The calculated values of the $\frac{\Delta T}{T}$ and $\frac{\Delta T'}{T'}$, expressed as percentages, shall be compared with the threshold value of 4%.

- If the calculated value of $\frac{\Delta T}{T}$, expressed as a percentage, due to any interfering emission from satellite link A' to satellite link A, is no greater than the threshold value, coordination is not required with respect to interference from link A' to link A.

- If the calculated value of $\frac{\Delta T}{T}$, expressed as a percentage, is greater than the threshold value, coordination is required.

The comparison of $\frac{\Delta T'}{T'}$, with the threshold value, expressed as a percentage, shall be carried out in a similar manner.

3.2 *Cases requiring independent treatment of the up-link and the down-link*

a) In the case of interference into only one link, the up-link or the down-link, the value $\Delta T_e/T_e$ or $\Delta T_s/T_s$, expressed as a percentage, shall be compared with the threshold value of 4%.

b) In the case of interference into both the up-link and the down-link, between which there is a change of modulation on board the satellite, the values of $\Delta T_e/T_e$ and $\Delta T_s/T_s$, expressed as a percentage, shall each be compared with the threshold value of 4%.

When none of the calculated values due to any interfering emission from satellite link A' to satellite link A is greater than the threshold value, coordination is not required with respect to interference from link A' to link A.

When at least one of the calculated values exceeds the threshold value, coordination is required.

The comparison of $\frac{\Delta T_{e'}}{T_{e'}}$ or $\frac{\Delta T_{s'}}{T_{s'}}$, expressed as a percentage, with the threshold value shall be carried out in a similar manner.

4. *Consideration of narrow-band carriers*

The method of calculation described in this Appendix may underestimate the interference from slow swept TV carriers into certain narrow-band (single channel per carrier, SCPC) carriers.

In order to facilitate coordination between the satellite systems and to reduce the number of administrations involved in this procedure, the administrations whose SCPC assignments are either recorded in the Master Register or are under coordination may inform an administration notifying its new assignment of the radio frequency channels used in their systems for SCPC transmission, so that the notifying administration may be able to avoid using these channels for FM-TV transmissions.

Conversely, administrations introducing new systems using SCPC transmissions may seek appropriate information from other administrations on their FM-TV transmissions.

ANNEX I

Calculation of the Topocentric Angular Separation Between Two Geostationary Satellites

The topocentric angular separation θ_t between two geostationary satellites from a given earth station can be determined by using the equation:

$$\theta_t = \arc\cos\left(\frac{d_1^2 + d_2^2 - \left(84\,332 \sin\frac{\theta_g}{2}\right)^2}{2\,d_1 \cdot d_2}\right)$$

where d_1 and d_2 are the distances, in km, from the earth station to the two satellites respectively, and evaluated as d by the method described in Annex II, and θ_g is as defined in § 2.1.

ANNEX II

Calculation of the Free-Space Transmission Loss

The free-space transmission loss L can be determined by using the following equation:

$$L = 20\,(\log f + \log d) + 32.45 \qquad \text{(dB)}$$

where:

f: frequency (MHz);

d: distance (km).

a) The distance d between an earth station and a geostationary satellite is given by the equation:

$$d = 42\,644\sqrt{1 - 0.2954\cos\psi} \qquad \text{(km)}$$

where:

$$\cos\psi = \cos\zeta \times \cos\beta$$

where:

ζ: latitude of the earth station;

β: difference in longitude between the satellite and the earth station.

Note: If $\cos\psi < 0.151$, the satellite is below the horizontal plane.

b) The distance d_s between two geostationary satellites is determined as follows:

$$d_s = 84\,332 \sin\frac{\theta_g}{2} \qquad \text{(km)}$$

where:

θ_g: geocentric angular separation as defined in § 2.1.

ANNEX III

Radiation Patterns for Earth Station Antennae to Be Used When They Are Not Published

When neither measured data nor relevant CCIR Recommendations accepted by the administrations concerned are available then administrations should use the reference patterns as described below (dB):

a) for values of $\frac{D}{\lambda} \geq 100$* (maximum gain $\geq$ 48 dB approx.):

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for } 0 < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \quad \text{for } \varphi_m \leq \varphi < \varphi_r$$

$$G(\varphi) = 32 - 25 \log \varphi \quad \text{for } \varphi_r \leq \varphi < 48°$$

$$G(\varphi) = -10 \quad \text{for } 48° \leq \varphi \leq 180°$$

where:

D = antenna diameter } expressed in the same unit
λ = wavelength }

φ = off-axis angle of the antenna, in degrees, equal to θ_t or θ_R as applicable

G_1 = gain of the first sidelobe = $2 + 15 \log \frac{D}{\lambda}$

$$\varphi_m = \frac{20\lambda}{D}\sqrt{G_{max} - G_1} \quad \text{(degrees)}$$

$$\varphi_r = 15.85\left(\frac{D}{\lambda}\right)^{-0.6} \quad \text{(degrees)}$$

b) for values of $\frac{D}{\lambda} < 100$* (maximum gain < 48 dB approx.):

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for } 0 < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \quad \text{for } \varphi_m \leq \varphi < 100\frac{\lambda}{D}$$

$$G(\varphi) = 52 - 10 \log \frac{D}{\lambda} - 25 \log \varphi \quad \text{for } 100\frac{\lambda}{D} \leq \varphi < 48°$$

$$G(\varphi) = 10 - 10 \log \frac{D}{\lambda} \quad \text{for } 48° \leq \varphi \leq 180°$$

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

---

* In cases where $\frac{D}{\lambda}$ is not given, it may be estimated from the expression $20 \log \frac{D}{\lambda} \approx G_{max} - 7.7$, where G_{max} is the main lobe antenna gain in dB.

ANNEX IV

Example of an Application of Appendix 29

1. *General*

In this example of Case I (see § 2.2.1), two identical satellite networks each with a simple frequency-changing transponder and a global coverage antenna are assumed.

All topocentric angles θ_t are assumed to be equal to 5°.

For this angular separation and for an earth station antenna with $\frac{D}{\lambda}$ greater than 100, the reference radiation pattern ($32 - 25 \log \theta_t$) gives a gain of 14.5 dB in the direction of the satellite of the other network.

The input data are furnished in § 2 below and are expressed in dB values except for the parameters T and θ_t. In § 3 the calculations are performed in dB.

It may be noted that since both satellites use global beams there is practically no antenna discrimination between wanted and unwanted signals at the satellite, and that this constitutes a worst case.

2. *Input data*

The values of the network parameters given in the table below are derived from those published in accordance with Appendix 3 or 4.

	Symbol *	Value	Unit
Up-link at 6 175 MHz	P'_e $G'_1(\theta_t)$ $G_2(\delta_{e'})$ L_u	−37 14.5 15.5 200	dB (W/Hz) dB dB dB
Down-link at 3 950 MHz	P'_s $G'_3(\eta_e)$ $G_4(\theta_t)$ L_d	−57 15.5 14.5 196	dB (W/Hz) dB dB dB
	$10 \log \gamma$ T θ_t	−15 105 5	dB K degrees

3. *Calculation of* $\frac{\Delta T}{T}$

From equation (1)

$$10 \log \Delta T_s = P'_e + G'_1(\theta_t) + G_2(\delta_{e'}) + 228.6 - L_u$$
$$= -37 + 14.5 + 15.5 + 228.6 - 200 = 21.6 \text{ dBK}$$

Therefore,

$$\Delta T_s = 145 \text{ K}$$

From equation (2)

$$10 \log \Delta T_e = P'_s + G'_3(\eta_e) + G_4(\theta_t) + 228.6 - L_d$$
$$= -57 + 15.5 + 14.5 + 228.6 - 196 = 5.6 \text{ dBK}$$

Therefore,

$$\Delta T_e = 3.6 \text{ K}$$

* All capital symbols, except T, refer to parameters given in logarithmic units.

From equation (3)

$$\Delta T = \gamma \Delta T_s + \Delta T_e$$
$$= 0.032 \times 145 + 3.6 = 8.2 \text{ K}$$

Thus

$$\frac{\Delta T}{T} \times 100 = \frac{8.2 \times 100}{105} = 7.8\%$$

4. *Conclusion*

In the example shown, the percentage increase in equivalent satellite link noise temperature is 7.8%. Since it exceeds the threshold value of 4%, coordination between the two networks is required.